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Aircraft Design Optimisation
Conceptual Evaluation of a Three-lifting Surface Turbo-fan Airliner

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To my mother and my father,

Áurea and Fernando

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SUMMARY

Today's high competitiveness in the airline industry urges for the development of even more efficient transport aircraft. In many cases lower operating costs are the key to survival. Although the introduction of emerging advanced technologies has shown improvements both in safety levels and performance, with the associated reductions in costs, the search for more economical aircraft must also take into consideration changes in current design practice. The study of novel configurations is a contribution to this view.

In this research project, advantage was taken from multidisciplinary synergism to design and optimise conventional and three-surface configuration commercial aircraft, to satisfy the same mission and operational requirements. An integrated conceptual design synthesis approach was employed where typical aeronautical disciplines, as well their complex interrelations, were taken into account. All these considerations, together with both cruise and field performance, and static stability and control requirements, resulted in different baseline configurations of the two concepts, although sharing the same fuselage and the same technology standard, but with different Maximum Take-off Weights (MTOW), lifting surfaces, turbo-fan engine sizes, and economics. After coupling the design synthesis program to a gradient based numerical minimization routine, optimisation of these designs was performed for minimum Direct Operating Costs (DOC) and minimum MTOW, and their performance and economics were compared on an equal basis. Trade-off studies were conducted on all aircraft for 1000 through 3000 NM design mission ranges while keeping the same fuselage size, lifting surface planform shapes and same static longitudinal stability margin (inherently stable designs), as obtained for the respective datum designs (Range = 1250 NM).

Thus, using the same comprehensive design tool, built on the same primary assumptions, and using the same analytical methods and principles which include many real life considerations, a systematic and consistent study of both design concepts was conducted. The potential merits of a realistic three-surface transport design were clearly established, when comparison was made with an equivalent mission conventional twin turbo-fan airliner. Within the usual limitations of any initial conceptual design study, it appears that the concept of the three-lifting surface transport can effectively improve in terms of performance and direct operating costs, when compared to conventional aircraft designed for the same operational environment and mission profiles, and may show a promising future.

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NOTATION

A	lifting surface aspect ratio
A_1	compressibility drag parameter in the drag divergence Mach number correlation
A_2	compressibility drag parameter in the drag divergence Mach number correlation
$a=\frac{dC_L}{d\alpha}$	lift curve slope
a_{ij}	coefficients of the stability and control matching real linear equations derived for the computation of the canard and tail volume coefficients
b	lifting surface span
b_i	coefficients of the stability and control matching real linear equations derived for the computation of the canard and tail volume coefficients
C	production cost or force parallel to the fuselage longitudinal reference axis
CEF	cost escalation factor
C_D	aerodynamic drag coefficient
C_{D_c}	compressibility drag coefficient
C_{D_f}	parasite drag coefficient due to trailing edge flaps
C_{D_M}	drag rise coefficient due to Mach number
C_{D_i}	induced or vortex drag coefficient
C_{D_p}	parasite drag coefficient
$C_{D_{p0_c}}$	canard free aircraft parasite drag coefficient
$C_{D_{p0_w}}$	wing free aircraft parasite drag coefficient
C_{D_r}	lifting surface profile drag correction term
C_f	turbulent flat plate skin friction coefficient
C_L	aerodynamic lift coefficient

C_m	pitching moment coefficient
$C_{m_{\delta_{c_L}}}=a_{c_L}\overline{V}_c\tau_c$	canardvator power, at landing conditions in ground effect
$C_{m_{\delta_{e_L}}}=a_{t_L}\overline{V}_t\eta_t\tau_e$	elevator power, at landing conditions in ground effect
C_1 and C_2	terms in the canard lift curve slope equation
$\overline{c}$	lifting surface mean aerodynamic chord
c_{c_r}	canard root chord at fuselage centreline
c_{vt_r}	vertical tail root chord
e	lifting surface Oswald efficiency factor
F_n	single engine thrust
F_{OO_c}	canard loading parameter
F_{Re}	Reynolds number correction factor
g	acceleration due to gravity
h_{loc}	horizontal tail location on vertical tail as a percentage of the vertical tail span
h_n	maximum fuselage nose depth
IR	annual average inflaction rate
I_{YY}	aircraft moment of inertia in pitch
i	lifting surface incidence angle relative to the fuselage longitudinal reference line
K	component aerodynamic form factor
K_y	aircraft pitch radius of gyration
L	lift force
$l_{c_{cg}}$	canard moment arm referred to the aircraft c.g.
$l_{c_{cg_c}}$	distance of canard centre of gravity from fuselage nose apex
$l_{c_{\bar{c}/4}}$	canard moment arm referred to the wing mean aerodynamic quarter chord point

$l_{\bar{c}_{c_{c/4}}}$	distance of the canard mean aerodynamic quarter chord point from fuselage nose apex
$l_{\bar{c}_{ht_{c/4}}}$	distance of the horizontal tail mean aerodynamic quarter chord point from the fuselage nose apex
$l_{c_{r_{c/4}}}$	distance of canard centreline quarter chord point from fuselage nose apex
l_{fus}	fuselage length
$l_{t_{cg}}$	tailplane moment arm referred to the aircraft c.g.
$l_{t_{\bar{c}/4}}$	tailplane moment arm referred to the wing mean aerodynamic quarter chord point
$l_{w_{r_{c/4}}}$	distance of wing root quarter chord point from fuselage nose apex
M	Mach number or pitching moment
M_D	drag divergence Mach number
N	engine rotor speed or normal force
P	total air pressure
P_{ca}	percent corrected engine airflow
Q_p	aircraft production quantity
$q=\frac{1}{2}\varrho V^2$	air stream flow dynamic pressure
RC	rate of climb
Re	Reynolds number
Re_1	Reynolds number per unit length
RS	sink rate
r_n	fuselage nose fineness ratio
S	lifting surface planform area or body wetted area (fuselage or nacelle)
SC_{FAX} or SC_{FAC}	supercritical aerofoil parameter used to shift the drag divergence Mach number

$\frac{S_c}{S_w}$	canard to wing area ratio
SFC	engine specific fuel consumption
SF_n	specific engine thrust
S_K	correction factors in the canard weight estimating relationship
$SM=\frac{dC_m}{dC_L}$	longitudinal static margin
s_f	wing or canard efficiency correction factor due to change in spanwise lift caused by flap deflection
T	total air temperature or total thrust
t/c	lifting surface average thickness to chord ratio
U_{LF}	aircraft ultimate load factor
V	air velocity or aircraft speed
V_s	aircraft stall speed
$\overline{V}$	tail or canard volume coefficient
W	weight
W_a	engine air weight flow rate
W_{ca}	corrected air mass flow rate
W_0	aircraft gross weight or aircraft maximum take-off weight (no distinction is made in the present study)
$\frac{W}{S}$	aircraft take-off wing loading
$w_{f_{\bullet c}}$	fuselage width at the canard intersection
X_{LF}	normal load factor
$\overline{X}_{c_{\bar{c}}}$	longitudinal distance of the canard mean aerodynamic chord leading edge point from canard centreline apex
$\overline{X}_{ht_{\bar{c}}}$	longitudinal distance of the horizontal tail mean aerodynamic chord leading edge point from the tailplane centreline apex

$\overline{X}_{w_{\bar{c}}}$	longitudinal distance of the wing mean aerodynamic chord leading edge point from wing centreline apex
x	longitudinal distance measured from the fuselage nose apex to some particular point, e.g., aircraft c.g., aircraft aerodynamic centre or lifting surface aerodynamic centre
$\overline{x}$	location defined as a fraction of the wing mean aerodynamic chord from its leading edge
$\overline{x}_{p_{\min}}$	wing minimum pressure point in fraction of wing chord
$\overline{Y}_{\bar{c}_c}$	spanwise distance of canard mean aerodynamic chord from fuselage centreline
z	vertical distance measured from the aircraft c.g. to the aircraft or lifting surface aerodynamic centre
α	lifting surface angle of attack
α_0	wing zero-lift angle of attack
α_{0_c}	canard zero-lift angle of attack
γ	flight path angle
Δ	distance range or increment
δ	canard or elevator deflection angle or the total atmospheric pressure ratio to that at sea level static conditions
δ_{c0}	canardvator deflection angle at overall zero lift
δ_{e0}	elevator deflection angle at overall zero lift
ε	wing downwash angle at the horizontal tail
η	lifting surface efficiency defined as the ratio of the dynamic pressure experienced by the surface to that of the undisturbed free air stream
θ	total temperature ratio to that at sea level static conditions
$\dot{\theta}$	aircraft pitch rate
$\ddot{\theta}$	aircraft angular pitch acceleration
Λ	angle of sweep
$\Lambda_{p_{\min}}$	sweep angle at the wing minimum pressure points

λ	taper ratio
μ	dry runway coefficient of rolling friction
ϱ	air density
σ	empirical flap efficiency factor obtained as a function of flap deflection or air density ratio
τ	control effectiveness
ν	kinematic viscosity of air

Subscrips

a	available
ac	aircraft aerodynamic centre
aft	rearward
app	approach
c	canard or canardvator
cg	centre of gravity
cl	climb
cr	cruise
$c/4$	quarter chord point
$\bar{c}/4$	mean aerodynamic quarter chord point
dir	direct
e	elevator
FN	normal force
f	rolling friction
$flap$	flaps
fus	fuselage
fwd	forward
ht	horizontal tail
i	ith component

$jinc$	jet inclination at horizontal tail
L	landing flare
le	leading edge
lg	landing gear
max	maximum
min	minimum
n	engine inlet
nac	engine nacelle
np	neutral point
Re	Reynolds number
r	lift-off rotation, or root or radius of the assumed rotation circular arc path
ref	reference
sl	sea level International Standard Atmosphere (ISA) conditions
sls or 0	sea level static conditions
t	horizontal tail or lifting surface tip or take-off condition
te	trailing edge
th	engine thrust
$trans$	lift-off transition
$t0$	take-off condition
vt	vertical tail
w	wing
wet	wetted

...many things are obvious once someone has pointed them out,...

Professor E.M.L.Beale in "Introduction to Optimisation"

1 Introduction

1.1 Scope of the Study

The underlying reason for this doctoral research investigation stems from the fact that whilst many recent studies attempt to bring some light on the pros and cons of three-lifting surface aircraft concepts versus conventional tail-aft designs by studying different lifting surface arrangements, they do not produce practical realistic results other than some insight into the problem. A more pragmatic approach is needed and a tentative treatment of the problem is described in this thesis.

To succeed, a real world commercial aircraft has to comply with a set of requirements ranging from its ability to perform safely and efficiently a given mission or missions dictated by the market, its growth potential and operating flexibility to accommodate new markets, if necessary capitalizing on new technologies in order to ensure a long and economically competitive life, and conform with the regulations set by the airworthiness regulatory bodies. Under these premises in order to evaluate more effectively the differences posed by both concepts it seems appropriate and opportune to perform parametric and design optimisation preliminary studies on the two configurations. While using the same assumptions, technology levels and ground rules, both concepts are designed to meet a given set of mission and operational requirements, optimised by the same criteria, and their performance and economics compared on an equal basis.

Typical and established engineering methods used in conceptual preliminary design are utilized for the design synthesis which is coupled to a numerical minimization technique capable of finding the combination of significant design variables which optimise an appropriate performance index.

1.2 Research Objectives

The main research objectives were:

1. The development and validation of a computer technique for the conceptual design and optimisation of commercial jet-transport aircraft with respect to suitable functions of merit.

2. The evaluation of the potential advantages of the three-lifting surface configuration aircraft when compared to conventional tail-aft transport designs optimised for the same mission while satisfying the same set of performance constraints.

3. To achieve a better understanding on the complex coupling of the several relevant disciplines which are traditionally considered during the conceptual phase of jet transport vehicle configuration design.

1.3 Structure of the Thesis

This thesis comprises two distinct parts, the main text and the appendices.

The main text is made up of seven separate sections:

1. Chapter 1 introduces the subject of the present research work, explains the reasons for undertaking it and the objectives.

2. Chapter 2 presents a survey on previously published literature in the field and shows the significance of this work.

3. Chapter 3 defines the design criteria, methodology used and describes the conceptual design and analysis tools required for the development of the work with the modifications carried out and assumptions made to adequately model the three-lifting surface concept.

4. Chapter 4 formulates the design optimisation problem, introduces the reader to the numerical minimization technique employed and describes its operation with the design synthesis.

5. Chapter 5 reports the case study undertaken through several steps. Starting from the establishment of a hypothetical mission specification, it describes the initial parametric analysis, the development of the baseline aircraft for both concepts, their optimisation with respect to minimum Direct Operating Costs (DOC) and minimum Maximum Take-off Weight (MTOW), and the conducting of range trade-off studies to determine their relative merits. Results obtained are described and documented. Conclusions arrived at are included, and comments on the operation of the optimiser-design synthesis given.

6. Chapter 6 presents a general assessment of the work with a discussion on the methods used and results obtained. Suggestions for future work are given.

7. Finally Chapter 7 draws the main conclusions from the work.

Each chapter is 'self-contained' showing at its end the respective list of references.

All the eight appendices, placed after the main text, contain detailed information such as theoretical derivations, equations used, computer listings, results and figures required to justify and support the main text.

2 Literature Review

2.1 Aircraft Design and Optimisation

2.1.1 Aircraft Conceptual Design

Significant advances have been achieved in computerised aircraft conceptual and preliminary design. The continuing development of the related techniques and computer based systems reveals the lively interest that exists in the field and is well documented in the existing extensive literature. This remarkable progress, driven by the need of efficient means for rapidly assessing new aerospace systems, kept pace with the fast growing development of the digital computers since the early sixties. A historical account of the progress made so far is briefly given in the following pages.

Until about 1960 conceptual aircraft design studies were usually performed by highly competent and experienced designers[1,2] using relatively simple methods based on systematic graphical techniques. These techniques embodying empirical statistically derived correlations of data from recent past designs included the use of special purpose slide rules, nomographs and overlay methods allowing for an initial rapid evaluation and parametric analysis of new aircraft concepts. Although these ingenious techniques provided a very limited view of the design problem they did develop an intuitive feeling for the sensitivity of a particular configuration to the principal design variables and constraints.

The introduction of the high-speed digital computers offered the aircraft designer a powerful framework enabling a virtually unlimited number of design variables to be changed while searching for the best configuration to meet a given need, that is, the space of design variables could be more exhaustively explored in contrast with the two, three variables a time allowed by the former graphical parametric techniques.

Initially, the computer was used to run self-contained disciplinary analysis programs developed by departmental specialists who were responsible for their accuracy and up-to-date capability. However to carry out the design, interchange of design information and personal contacts between these disciplines are essential and were very frequently done in a highly interactive, sequencing and cyclic manner as the design progressed. This process proved quite inefficient and error prone as the complexity of the vehicle increased, and bigger design staffs were required[3]. The increase in complexity and sophistication of modern advanced aerospace vehicles and the iterative nature of the design process entailed longer and longer design cycles therefore increasing costs and the risk of introducing obsolete products in the market. In addition, competitive pressures at the preliminary design level leading to proposal submission fostered requirements for higher speed of response and accuracy. Both these attributes enhance analytical capability for broad and exhaustive parametric evaluations and trade-off studies. These are essential steps for thoroughly learning about the design and improving or optimising it thus enhancing both the confidence in the solutions found, and the company competitive postures. Automating the design process by integrating all the pertinent disciplines into design synthesis programs offered a solution to the problems and needs just mentioned. Therefore, analysis programs or modules were integrated by commonality of input and output keeping disciplinary responsibility for each module.

Development of design synthesis programs indeed improved the quality of the designs and also allowed for expanded design options while retaining the same cycle time, thus lowering the risk associated with product development[4]. Design information became more consistent, more credible, thorough enough and systematically organized and very importantly was available early in the design process improving decision making capability. It is worth noting that decisions taken at these early design stages have enormous cost implications at the later stages of the development process and during aircraft operation, yet the resources and money expended during the initial phases are usually relatively small[5]. About 70 to 80% of the total program cost is determined by the time the aeroplane concept is formulated[6]. Design innovation gained as well, although indirectly through reduced evaluation time.

2.1.2 Computerized Tools

To adequately explore the many design approaches suggested during the early definition of aerospace vehicle concepts and to select those that show significant promise for further study, most companies, agencies and some Universities have developed their computerized tools for conceptual and preliminary design. A representative list of these former and contemporary programs is given with their acronyms and originators:

- SYNAC - General Dynamics[7]
- CADE - McDonnell Douglas Corp.[8]
- CPDS - Boeing Co.[9,10]
- ASSET - Lockheed California Co.[4]
- CAP - North American Rockwell Corp.[4]
- ASAP - Vought[11]
- ACSYNT - NASA Ames[5,15]
- TRANSYN - NASA Ames[12]
- IPAD - NASA Langley[13,3]
- ODIN - NASA Langley[14]
- MVO - Royal Aerospace Establishment[16]
- VDEP - NASA Langley[17]
- GASP - NASA Ames[18]
- CDS - Rockwell International[19]
- CAPDA - Technische Universitat-Berlin[20,21]
- ADAS - Delft University of Technology[22,23]
- AAA - University of Kansas[24]
- RDS - Conceptual Research Corp.[25]

Most cover the initial concept and preliminary phases, others such as the NASA IPAD system[13,3] tend to cover the total process including the detail design and manufacturing phases. However, more emphasis is here given to conceptual design tools for the present work is concerned with the concept feasibility study phase. The general arrangement adopted by most of these programs is similar, being the differences settled by the way the several modules are interconnected, the level of the detail and the emphasis on particular aircraft types.

ACSYNT appears the most sophisticated of all since its development started earlier in the mid sixties and it has been continuously pursued since then[26,27]. This program offers multi-level design synthesis and analysis including very sophisticated structural and aerodynamic analysis codes. As a result a great amount of detailed design information is generated allowing for much more accurate insight and assessment of the actual aircraft at the preliminary design phase. It now features good graphical capabilities with an appropriately developed conceptual aircraft computer-aided drafting system (CAD) for the interactive and automatic generation of aircraft geometries.

CAPDA and ADAS are well developed computerized transport aircraft design systems which provide configuration design synthesis and analysis, parametric and sensitivity studies, multivariate optimisation and trade-off studies as well as multi-level analysis capabilities. Both programs are coupled with computer-aided drafting systems (CAD). These programs and AAA were developed in a university environment and their improvement and updating is a continuing process.

2.1.3 Numerical Optimisation Techniques

The importance of conducting sensitivity and trade-off studies is stressed during all design activities since it represents the traditional means to get a sound insight into the design and to find the 'best' combination of aircraft design parameters that meet given system requirements. This process, called optimisation, can be automated though it is usually augmented by manual trade-offs. Automated methods for aircraft configuration design optimisation are a natural extension of past parametric methods. Both approaches rely on the designer's experience and intuition for a first guess and both use iterative methods to improve this guess.

Optimisation, as it stands today, is a lively branch of applied mathematics particularly associated with operational research which, in turn, is concerned with decision making. Creating a new product involves making many decisions, which suggests that designing is viewed as a decision making process. Decision making has sometimes to be based on subjective and vague considerations where the experience and creativity of the designer are essential in making proper decisions, bringing new challenges and opportunities for innovations which may influence the success of the new aircraft. Nevertheless, instinct and intuition alone are not always a satisfactory way of making decisions, particularly when the quality of a solution to a practical complex problem involving a great many factors and constraints which strongly interact and entails considerable financial risk, such as happens in aircraft design. Once a mathematical model of the problem, here represented by an integrated vehicle synthesis program which may simulate many alternative designs within its limitations, is established, the 'best' or 'optimum' design can be identified with the aid of mathematical programming methods. 'Optimum' designs should be interpreted as such with regard to a chosen performance criterion, within the tolerance of the mathematical model describing it, and the subjective judgement of the designer.

2.1.3.1 Multivariate Optimisation

Recognizing the potential offered by numerical optimisation techniques, Boeing Company developed a general-purpose optimisation program called AESOP, 'Automated

Engineering and Scientific Optimization Program', starting in 1965 under the direction of D. S. Hague[28,29]. This optimiser can drive up to 100 design variables, and an unlimited number of constraints may be employed through a penalty function. It has nine search strategies, which may be used singly or in combination, for sequentially solving a design problem. The employment of so many optimisation methods emphasizes the strong influence the characteristics of the design synthesis process may have on the suitable choice of the numerical technique[9,30]. This program was widely applied to performance optimisation problems and to multidisciplinary design problems including hypersonic transports and the US space shuttle[9]. Silver and Ashley[30] present an excellent discussion on the methods used and problems encountered with their application, and also include a well annotated list of references.

In the same line of reasoning, the Royal Aerospace Establishment (RAE), in Britain, centered its attention on the development of computerized numerical optimisation techniques[31], combined with aircraft design synthesis[32,33]. The first version of the Multi-Variate Optimisation (MVO) program was developed for civil transports[32,33,34,35] and subsequent parallel work culminated in the development of a program for military aircraft[36,37]. Throughout this development the programs were continuously improved by the introduction of more accurate design relationships and restructured into a modular form. The original optimisation driver[31] was successively replaced by more sophisticated versions[38,39] and is the later numerical algorithm used in the present investigation.

Kirkpatrick and Larcombe[40] described the initial development of the MVO design optimisation program, presented and discussed some of the related experience gained and showed some example applications on rapidly assessing the effect on the optimum design of changes in the specified performance or of advances in aerodynamic, structural or engine technology. They also illustrated, based on ref. 41, how the 'full' benefits could be obtained from an advance in technology and concluded "the benefits obtained by a complete reoptimisation of the aircraft design are 'much greater' than those obtained by using the advance to alter just one or two of the aircraft design characteristics". Also, based on refs. 42 and 43, they showed the advantages of using a compound optimisation function instead of a single objective criterion. This compound optimisation function consists of a weighted figure of merit combining two or more aircraft parameters and it is used to improve the aircraft performance in one respect while not greatly degrading it in another. The technique may be used, in particular, in commercial transports, for example to enhance passenger comfort, stretch potential or operational flexibility at a minimum economic penalty.

While describing the analysis methods employed in the automated synthesis, Kirkpatrick[40] observed that "the mass estimation must be as accurate as possible, but it is also essential when an optimisation procedure is being used that the partial derivatives of the various component masses with respect to each design variable should reflect the true situation as accurately as possible". This point was also addressed by Vanderplaats[15] when he remarked that it is very important to make the discipline modules as accurate as possible which is a fundamental concern in achieving a reliable design tool since the automated optimisation process tends to capitalize on any weakness in the analytical model and produce unrealistic designs or even diverge. Ensuring the accuracy and reliability of the discipline information can provide valuable design information on which to guide and base research and development decisions.

Brian Edwards[44] described some techniques for using MVO programs and how the optimisation method could be used to explore the aircraft design model and cultivate an insight into its characteristics. He stressed the importance of these tools in producing systematic sets of comprehensive consistent data from which a thorough understanding of the interaction between the contending effects within the model can be gained.

Research initiated at RAE has been pursued, extended and complemented by work done in the College of Aeronautics (CoA) at Cranfield, at Loughborough University, and British Aerospace.

To provide a suite of combat aircraft design synthesis modules[45], other MVO programs were developed at the CoA covering Canard Delta[46] and Advanced Short Take-off and Vertical Landing[47] (ASTOVL) configurations; and a similar program for Unmanned Aerial Vehicle[48] synthesis and optimisation was produced where the optimisation drivers were supplied by RAE.

At Loughborough University interest was directed towards the application of MVO methods to evaluate optimum short-haul flight profiles for turbopropeller aircraft[49]. This work was subsequently extended through the integration of the separate aspects of preliminary design optimisation and flight profile optimisation leading to the development of a program called CASTOR (Commuter Aircraft Synthesis and Trajectory Optimisation Routine)[50] for the design/analysis and optimisation of twin-turboprop commuter aircraft of the conventional layout, flying multistage missions. This strategy helps the selection of the best available or projected design for a particular airline route-structure or permits the design of the 'best' solution tailored to that route-structure. More recently[51,52], this program was modified to account for turbo-fan engine data, fuselage pressurization, introduction of composite materials, changes in aircraft operational procedures and updated cost, allowing for the synthesis of optimum regional fan-jet transport aircraft. This later version of the Loughborough MVO program features a very versatile capability for rapidly performing parameter sensitivity and trade-off studies with the incorporation of the newly developed Peri-optimum subprogram which conducts a series of single passes through the synthesis model and automatically generates plots of the design surface around the optimum design point for chosen parameters. The programs were developed in support of industrial design studies performed by the project design team at Short Brothers (Belfast) Plc. and benefited from the close industrial collaboration that existed.

RAE multivariate techniques have been applied as well at British Aerospace in the development of MVO design synthesis/optimisation programs as described by Chacksfield[53] and more recently by Cousin and Metcalfe[54] with the TASOP (Transport Aircraft Synthesis and Optimisation Program) program which features high standard coding, structure, documentation and maintenance procedures enhancing its flexibility and response in terms of applicability to a wide variety of aircraft projects and design problems with improved quality and reliability.

Another interesting effort is represented by OPDOT[55] (Optimum Preliminary Design of Transports) program developed by Sliwa and Arbuckle, which integrates a constrained non-linear programming technique with a transport aircraft preliminary design routine. The program was written to expeditiously obtain answers for a study of the impact of active controls upon transport aircraft[56]. Using the same tool, other studies on medium-range transports followed. These included the evaluation of the influence of selecting different performance indices and constraints on the design[57], and the conceptual study and optimisation of a statically stable, subsonic, canard-configured transport aircraft[58]. The later one was the first reported comprehensive design study of a subsonic, medium-range canard-configured transport aircraft.

Continuing interest on the initial design/optimisation of transport aircraft is shown by the development of similar computerised tools and their application in France and in the old U.S.S.R. as described in references 59 and 60.

2.1.3.2 Selection of Figures of Merit and Multiobjective Functions

The difficulty presented in selecting the appropriate figure of the merit in aeroplane configuration design and its importance have already been stressed and exemplified in many of the above reported investigations. A good illustration of its effect on aircraft optimum configurations is also presented and discussed by Jensen and al.[61] who determined optimum designs of commercial and military cargo transports for seven different performance indices. They concluded that designs for minimum gross weight and D.O.C. show the smallest penalties relative to optimum solutions of the other figures of merit and that 'compromise' designs can be obtained by means of weighted combinations of performance indices.

However, by studying three different classes of subsonic commercial aircraft (short, medium and medium-to-long range) optimised for several different objective functions, Johnson[62] concluded that the optimum configuration is strongly influenced by the prevailing economic conditions which also determine how much technology can be included on the aircraft. So, by optimising an aircraft for minimum gross weight and for minimum D.O.C. may result in quite different configurations as was shown by the effect of increasing the fuel price which, in this case, plays a much more important role in determining D.O.C. and therefore in defining its related configuration. Jacobson and Murphy[63] also illustrated this point of view and emphasized how deeply a change from the present low fuel cost to a high fuel cost environment could affect aircraft design and the airline's competitive position. Thus, Jensen's conclusion on minimum gross weight and D.O.C. designs will hold and should be interpreted in the light of the particular economical environment assumed in their study.

When using multiobjective functions, the relative influences of each individual performance index are significant for the designer. Investigation on the use of multiobjective optimisation methods for conceptual transport aircraft design where conflicting figures of merit are simultaneously considered and effectively combined was undertaken by Dovi and Wrenn[64]. Later, by combining different figures of merit into a multiobjective function with the weighting of individual functions varied parametrically to obtain a series of multiobjective optimal solutions, Malone and Mason[65] showed the evolution of optimum designs from one objective function to another. This evolution provides insight into the importance of each figure of merit to alternate mission tailoring, structural trade-offs and considerations of growth, flexibility and adaptability potential. Additionally a more thorough understanding of the effects of the proper choice of the performance index can be gained.

2.1.4 Systematic Decomposition and Sensitivity Analysis of Complex Coupled Systems

As the design evolves into more detail and refinement, better geometrical representation of the configuration is required together with more accurate disciplinary analysis methods. This starts from the integration of a very flexible CAD design system in the concept design/optimisation program, if not already implemented for which CAAD[66] was the first computerized example, and the inclusion of more sophisticated analysis methods such as Computational Fluid Dynamics (CFD)[67] and Finite Element Methods (FEM)[68]. With the integration of the NLRAERO panel code[69,70] and a FE-analysis program[71] respectively for aerodynamic and structural design and analysis, ADAS system is now becoming a very powerful, sophisticated and complex multi-level design environment for aircraft preliminary design optimisation.

However, due to the optimisation methodology used, this kind of sequential system while growing in complexity tends to obscure the conflicting trends and trade-offs which guide the design towards improvement, without providing visibility of the mutual influences among the diverse engineering and economic disciplines. Additionally it becomes computationally costly and less accurate as the finite differencing needed to generate the system sensitivity derivatives are performed on the entire system analysis in the form of total derivatives of the objective function with respect to each of the specified design variables. An alternative to this conventional approach was proposed by Sobieski[72] at NASA Langley Research Centre and it is known as 'optimisation by decomposition'. This method is appropriate for systematic analysis and optimisation of large engineering systems such as aircraft by decomposition of the design process into a set of smaller, more manageable self-contained subproblems amenable to concurrent analysis. It is intended to particularly fit typical engineering organizations and take advantage of the modern technology of distributed computing and parallel processing. A distinction is made in reference 73 between a top-down hierarchic decomposition in which several levels of subproblems are considered, each depending on the input from a level above as described in ref. 72 and exemplified in ref. 74, and a non-hierarchic decomposition in which the subproblems are all interconnected at the same level[75]. In the hierarchic decomposition, each subproblem contains its own optimisation while in the non-hierarchic decomposition, the optimisation is done at the entire system level, e.g. the system optimisation is treated as a single problem. The later approach is based on sensitivity analysis of a complex, coupled system which concurrently generates partial sensitivity derivatives in each individual discipline fully accounting for the interactions among the parts and the disciplines that govern the design. The system sensitivity design derivatives are computed simultaneously from the partial sensitivity derivatives of its parts for all the design variables of interest and provide a numerically precise and global comprehensive answer which may be used to improve the design by judgemental changes, and/or by formal optimisation. This is in contrast with the former conventional sequential process where the entire design sequence had to be repeated for each design variable perturbation in order to generate information for a finite difference and assess its influence on the design.

Sensitivity analysis offers a practical tool to answer the "what if" questions that arise in design providing visibility of the mutual influences among the engineering specialities, and decomposition into smaller, concurrently executable tasks enables interdisciplinary synergism to be exploited. This method addresses the very important qualitative aspects of the design process, usually dominated by quantitative computable considerations, by supporting human intellect and judgement decisions through sensitivity data which also provide a means of communication between disciplines. Under this scheme, each specialist will know how his decisions will affect other coupled subsystems and the entire system. Thus great emphasis in this method is given to the control of interactions among disciplines and physical subsystems to improve the entire system performance.

These techniques accounting for interdisciplinary coupling have been mostly tested on preliminary and detail design problems[76]. However, references 77 and 78 described the work undertaken at Rockwell towards the application of these techniques to the conceptual design of advanced fighters with emphasis on wing design within an industrial environment. Other example applications, deliberately kept at the conceptual design level, are presented in references 65 and 79 for the design of transport aircraft. The later one focuses on a three-lifting surface transport of the Boeing 777 class designed and optimised for minimum take-off gross weight where the locations and areas of the three lifting surfaces were taken as design variables. A more comprehensive and updated review on the experience obtained from the application of these methodologies is found in reference 80.

The problem of optimal design of aircraft has suggested other alternative approaches.

2.1.5 Genetic Algorithms

For handling problems with discontinuities and local minima, such as the present one, one of the methods that show promise is based on the so-called genetic algorithms[80]. Genetic algorithms[81] are a form of direct random search which simulates the improvement process based on Darwin's evolutionary theory. They start with many possible discrete solutions which are randomly distributed over the design space to create an initial population of designs. Each design member is represented by a bit-string which is a coded listing of the values of the design variables. A measure of fitness is evaluated for each member. The measure of fitness is a function of the degree of satisfaction of the constraints and of the objective function, or functions, whose extremum is sought. Then the members in the population are allowed to evolve through a process of natural selection, mating and crossover of genetic material, and mutation, using probabilistic operations borrowed from evolution theory. In crossover two individuals exchange part of their strings, so two children are generated as combinations of parts of the parents' strings. In mutation, individual bits of the string may be changed. Unlike natural evolution the total number of members in the population is kept constant. The parents are ranked according to the value of their fitness function, the higher the rank of a parent the higher its chance of being selected for reproduction. During the process parents are gradually replaced by better fit children through several generations and, due to the mutations, superior features may occur in some children to initiate a new line of evolution, improving the solution of the optimisation problem until convergence is obtained, or the process is stopped at a given stage of the evolution. A measure of convergence may be obtained from the difference between the fitness of the best member and the average fitness of the population.

These algorithms require only the values of the objective function. Their gradients, first or second derivatives, are not needed, consequently these methods are less susceptible to getting trapped in local extrema as happens with other nonlinear optimisation algorithms. Consequently genetic algorithms are especially effective in locating "interesting" regions within the design space and therefore are more suitable for finding global minima. However, in the neighbourhood of an extremum point they are not as efficient as nonlinear programming methods in finding the exact values of the design variables and the use of a gradient-based search is then recommended[80,81]. Thus application of a hybrid method is favoured.

As described, the process involves not only the survival of the fittest, but the elimination of the weak and it sounds a bit heartless. But optimisation implies discarding many designs, some of them interesting regarding their particular merits, in search of the "fittest", and this one is intended "to survive". This approach is intrinsically suitable to handle multiobjective problems. Reference 82 describes the minimum weight sizing of a business jet aircraft at the conceptual stage using a genetic algorithm. Other applications of these methods on aerospace-related engineering optimisation problems are discussed and illustrated in reference 83.

2.1.6 Knowledge-Based Strategies

Recently another approach to conceptual aircraft design using knowledge based strategies by means of inferential methods is becoming increasingly significant and shows relative success. These methods apply Artificial Intelligence[84] techniques in the development of computer Expert Systems which aim to emulate the problem-solving ability of human experts. These systems are explicitly based on capturing the proper knowledge and coding it into the form of condition-action rules. The rules are program declarative statements which infer a property of an object or of one set of objects from properties of other objects. Selection and execution of the rules are under the control of an "inference engine". Expert Systems adopt a symbolic programming approach which has proved convenient for the deductive reasoning process. However propositions and inference rules in Expert Systems are very often not known with certainty and this fact can pose a limitation in this type of systems. There are other difficulties associated with the development of these systems. They depend not only on the acquisition of adequate expertise but also on their updating and continuous maintenance requirements. Changing knowledge, fixing faults, verification and validation become increasingly difficult[81] and this is a constant concern. One important goal in developing this kind of system is to retain the transparency of design decisions and the flexibility of the classical configuration design process. This approach emphasises interactivity in addition to providing design advice to the user.

At Cranfield, several studies leading to the development of Expert Systems for conceptual design have been performed. These studies started in 1984 with the development of the ADROIT (Aircraft Design by Regulation of Independent Tasks) system[85,86], a prototype program that conceptually designs the wing for high subsonic transport aircraft, which is still under development. A similar system for the design of a transport aircraft fuselage[87] was also developed and, more recently, a program for the overall configuration design of subsonic transport aircraft[88] has been completed. Application of these techniques elsewhere is described in references 89, 90, 91 and 92.

2.1.7 Combined Systems

A trend exists in combining several methods and techniques within one system in order to augment its flexibility in dealing with different problems or apply the most appropriate approach to a given multidisciplinary design optimisation problem. A system for aircraft concept design combining an expert system and a suite of optimisation methods including gradient-based and genetic algorithms is illustrated and problem applications are discussed by Kroo[92]. Another example incorporating similar techniques but developed for "ingenious" jet engine design named EnGENEous[81] is used at General Electric.

2.1.8 The Teaching of Aircraft Project Design Methods

The important educational role provided by these integrated computer aids in teaching aircraft design and optimisation is also widely illustrated throughout the literature[21,22,52,93,94] since Silver[95] first attempted to identify the best in light-aircraft in 1971, at Stanford University, as the topic of his Ph.D. dissertation.

2.2 The Three-lifting Surface Aircraft Concept

2.2.1 Some Practical Examples and Prospects

The concept of a three-lifting surface aircraft although very rarely implemented is not a new one. The Curtiss-Herring No.1 Reims Racer (1908), and the De Havilland Biplane No.2 (1909), illustrated respectively in figures 2.1 and 2.2, were two of the earliest attempts of the type ever flown[96]. A very recent example is the Piaggio P-180 Avanti[97], shown in fig. 2.3, a business class turbo-propeller aircraft intended to offer enhanced comfort and performance as compared to current conventional competing turbo-props.

The aim was to produce an economic/advanced business aircraft. The need for a quiet and comfortable cabin, the use of large extensions of natural laminar flow on the fuselage and lifting surfaces for low drag, and the lowest possible weight target by exploiting interdisciplinary synergism, were the main design drivers. Essentially, its particular layout permits the positioning of the engines and propellers behind the cabin rear pressure bulkhead to minimize engine noise level, thus avoiding the weight penalties associated with the installation of noise insulating materials. Rearward positioning of the wing provides full stand-up headroom in the cabin as well as allowing for a reduced wing-fuselage interference drag which is favoured by an almost mid-wing installation. The relatively high aspect ratio wing and little sweep, $A=12.3$ and $\Lambda=0^\circ$ @ 15% chord, offers an aerodynamically efficient design at subcritical conditions. This feature, combined with a precise contour smoothing and very high quality skin surface finishing, and a cleaner pusher configuration with the propellers located well behind the wing, encourages laminar flow and leads to a high lift-to-drag ratio operation. The wing-mounted engine arrangement provides for a load relief effect and results in a lighter wing structure. Additional structural weight savings are achieved by synergetically combining three major load carrying components, e.g. the wing main spar in the fuselage, forms an integral aluminium alloy fail-safe structural unit with the rear pressure bulkhead and the main landing gear. Owing to the excessive rearward location of the wing, bearing in mind weight, balance, stability and control, the solution of combining a fore-lifting surface together with a conventional tail was adopted. The canard helping the wing for lift generation also ensures aircraft longitudinal trim in favour of a higher trimmed overall lift. For a given longitudinal static stability margin this may also tend to reduce trim drag as usually produced in conventional inherently stable aeroplanes by the required tail down-load. This compromise appears to minimize cruise drag consequently reducing fuel consumption and the amount of fuel to carry for a given mission range. Pitch control is provided by the horizontal tail elevators while the canard auxiliary flaps (single slotted trailing edge flaps) are mechanically coupled with the main wing flaps, both working together as to offset any changes in trim. The end result, when compared to a conventional tail-aft aircraft designed to the same specification and using the same level of technology, would be a lighter aeroplane, probably equipped with less powerful, lighter and more economic engines because of lower maximum take-off weight and drag, thus offering better cruise performance and passenger appeal.

2.2.2 Previous Research

Many authors have recently investigated the advantages of using canards on aircraft configurations. Most of these studies were performed in the sequence of the early seventies energy crisis and subsequent trends in fuel costs whose increase adversely affects airline economics. The aim was to reduce aircraft overall drag to improve performance and decrease operating costs while increasing safety levels.

2.2.2.1 Two-lifting Surface Concepts

Several papers[100-109] dealing with the subject of the minimum induced drag of two-surface aeroplanes, both of the tail aft and of the canard configurations, were based on Prandtl's biplane theory[98] and Munk's stagger theorem[99]. Prandtl calculated the mutually induced drag of a multiplane in potential flow by assuming that the spanwise lift distribution on each surface was elliptical and integrated the product of the downwash and lift across the span. Munk proved that the total induced drag of a multiplane system remains unchanged if the lifting surfaces are displaced (staggered) relative to each other in the direction of flight as long as their spanwise lift distributions are preserved. Thus, the theory rests on the assumption of elliptically loaded lifting surfaces under the mutual influence of their downwash flow fields.

Naylor[100] demonstrated that if the tail of a conventional aeroplane is in the same plane as the wing (zero gap), then the minimum induced drag occurs when the tail load is zero. As for zero gap, Larrabee[101] showed that the induced drag of canard and conventional configurations of equal span ratios is the same if the canard and tail are carrying equal but opposite trim loads. No consideration of longitudinal stability requirements was given in this study. However, McLaughlin[102], in his comprehensive analysis on trimmed drag of conventional and canard aircraft where the effect of gap, span ratio, zero lift moment and static margin were assessed, found that their related static stability margins were considerably different. In fact, the canard design had an unstable static margin of about 0.1, while the conventional showed an excessively stable static margin of about -0.5. This author showed that the cruise drag of practical canard configurations is higher than that for conventional types with similar static margins which is due to the high canard loading that is required for trim. This same conclusion was also obtained by Keith and Selberg[110,111]. After studying conventional subsonic transport aeroplanes, Laitone[103-106] concluded that if the tail is either above or below the plane of the wing (finite gap), then a slightly positive tail load (upload) would produce minimum induced drag which would be virtually the same than that obtained from a zero tail load. The reduction so obtained in induced and compressibility drag for typical aircraft would lead to potential fuel savings amounting to 5%. Shevell's[104] trimmed drag data confirmed these estimates. However, this condition can be attained at only one aft centre of gravity (c.g.) location on a tail-aft design, and cannot be achieved on a pure canard configuration which requires a further forward c.g. location for inherent static longitudinal stability.

Feistel and al[107], while performing wind tunnel experiments on canard-wing arrangements (no fuselage), found a 10% total induced drag reduction when compared with that predicted by the classical Prandtl-Munk theory which was due to favourable canard-wing interference effects. These measurements correlated well with estimates made from a vortex-lattice panel code and were explained and supported analytically by Butler[108] and Kroo[109]. These authors, working independently in an attempt to extend the theory to include more realistic loading distributions, modified Prandtl's biplane induced drag equation to allow for changes in the main wing spanwise lift distribution imparted by the presence of the canard, to minimize the total induced drag. For a typical example, both determined reductions respectively in 6% and 10% of the total induced drag as predicted by the Prandtl-Munk theory which is consistent with the empirical trends found by Feistel.

2.2.2.2 Two- and Three-lifting Surface Concepts

Using the Prandtl-Munk theory, Butler[112] and Kendall[113] compared the induced drag of two-surface and three-surface layouts.

After having studied an advanced fighter type design, Butler concluded that improvements of up to 20% in lift to drag ratio at high lift coefficients are theoretically possible on a three-lifting surface configuration by choosing the lift distribution among the surfaces to reduce total induced drag, while maintaining trimmed conditions at a specified static margin. In addition, since the effects of the downwash of the forward plane on the induced drag are not properly accounted for in the Prandtl-Munk approach, as already referred to above, then there is an additional induced thrust term which can lead to reductions of about 5% over the induced drag predicted by the theory.

Kendall[113,114] showed that minimum induced drag can be achieved at any practical c.g. location on a modern three-surface aeroplane, such as the Piaggio P-180, if the forward and aft trimming surfaces have zero-gap, equal spans and when their opposite trim loads cancel each other. Consequently, in contrast with the limitations presented by the two-surface designs in sustaining minimum induced drag, there is no conflict between the requirements for minimum drag, longitudinal trim and positive static longitudinal stability, thus potential fuel savings relative to conventional and canard types may be expected in all cruise flight conditions. He concluded that the three-surface design can theoretically have a lower cruise trimmed drag than a conventional design which, in turn, is superior to the pure canard type. His results show reasonable agreement with the trends obtained by Butler for low to moderate lift coefficients.

Conventional, canard and three-surface high performance general aviation aircraft were investigated by Rokhsaz and Selberg[115]. A vortex lattice method was used to trim the aircraft and to compute its induced drag while a vortex panel code in combination with a momentum integral boundary layer method was employed to predict inviscid and viscous aerodynamic characteristics. Six and twelve seat configurations were considered. In each case, all aircraft were designed to the same specification with a stable static longitudinal margin of -0.38, assuming common fuselages, wings, vertical tails, engines and internal components. Canard and tailplane surface areas were assumed equal for the canard and conventional concepts, while for the three-surface configuration canard and tail areas were equal to one-half the size assumed in the former cases. Under trim conditions, Kendall's minimum induced drag criteria for the three-surface aircraft, i.e. same span canard and tailplane providing equal and opposite trim loads, was used to obtain the lifting surfaces design cruise incidences. For both payload cases, the conventional designs showed the highest lift to drag ratio followed closely by the three-surface and the canard aircraft. The aerodynamic differences found were not significantly large to support a clear selection on the best layout. However, the canard and three-surface aircraft, if carefully designed, could offer the prospect of a stall- and, hence spin-proof configuration. These authors demonstrated that the Prandtl-Munk theory underestimates the induced drag for the three-surface design which is the result of modifications on the assumed ideal elliptic wing spanwise load distribution due to aerodynamic coupling among the lifting surfaces (outboard shift of the wing's lift distribution due to the downwash directly behind, and upwash outboard of the canard).

Later on, aerodynamic trade-off studies on the six-place configurations were carried out[116] where trimmed lift to drag ratios were analysed over a range of static margins, lifting surface area ratios and aspect ratios. Again, it was concluded that for lower stabilator aspect ratios the conventional aircraft provides the highest lift to drag ratio with the canard and the three-surface about equal where the conventional shows the least induced drag followed by the three-surface and then by the canard configuration. However, the differences are so small that configuration selection should be made in light of other considerations (stability and control, structures, safety, etc.).

A more recent investigation[117], where induced drag predictions obtained from the Prandtl-Munk theory were compared against results produced by a vortex lattice method for non-elliptic (practical) loaded lifting surfaces of the six-place designs, confirmed the conclusions already drawn in the other two studies.

Kroo[118] compared the relative performance of the three layouts (no fuselage considered) optimising the lift distribution of a system of multiple lifting surfaces at low speeds to any combinations of fixed total lift, trim with specified static margin and fixed structural weight. Profile drag and structural weight to resist bending moment are accounted for. His program models lifting surfaces using a discrete vortex Weissinger method with lift-dependent section profile drag. Induced drag estimates are based on Trefftz plane downwash. He concluded that conventional arrangements are generally more efficient than canard designs of identical weight and area. If the section maximum lift coefficient is constant spanwise, tail-aft configurations show greater maximum lift capability than canards of moderate aspect ratio. Relaxing static stability results in canard and conventional designs with similar performances. Three-surface layouts, assuming that the canard and tail have equal span and aspect ratio, achieve minimum drag when their spans are 20% of the wing span. This minimum drag is slightly lower than for the canard and slightly higher than for conventional designs. However, the maximum lift coefficient is obtained for small canard and tail surfaces, thus providing an aerodynamic advantage with regard to the canard design and closely approaching the performance of a tail-aft aircraft. No obvious performance advantage over the conventional type was found for the three-surface concept.

To investigate how non-elliptical load distributions influence the lift, drag and static longitudinal stability of three-surface aircraft, Ostowari and Naik[119] performed a series of wind-tunnel experiments using a typical business jet model. Comparisons were made with canard and conventional configurations. The effects of variations in canard size (although of fixed planform shape), canard and tail incidence angles, stagger and gap were assessed. The main wing and vertical tail remained the same, while the other components were allowed to move or change (fuselage length and canard size). Results showed that the three-surface has better lift and high lift drag characteristics than either the canard or tail-aft configurations, but the cruise drag is the highest. At cruise conditions, induced drag is highest for the canard and lowest for the conventional. A decrease in canard span on the three-surface offers better cruise performance and longitudinal stability characteristics, but has adverse effects on high lift drag. The conventional configuration has better cruise lift to drag ratio while the three-surface showed to be the least efficient. This order is reversed for high lift conditions.

At NASA Langley[120], wind-tunnel tests were also conducted on several advanced unconventional configurations including the types under review and revealed some important design considerations that influence their performance, efficiency and safety. These involved natural laminar flow retention, flow-field interactions among aircraft components, control surface and wing stall behaviour and power effects. Initial results pointed out the importance of recognizing the strong aerodynamic interactions originated from the unconventional placing of lifting and control surfaces as well as from the allocation of the propulsion system. Unconventional aircraft configurations may allow the designer to exploit more effectively the benefits from individual technology advances together with the potential advantages offered by particular arrangements of aircraft components.

In the sequence of the research outlined above and using the ADAS/ NLRAERO system, Middel[69,70] investigated a family of derivative three-surface aircraft configurations, based on the Piaggio P-180 concept, evolving from a near-canard to a near-conventional design. The optimum sizing of lifting surfaces and wing location for minimum cruise trimmed drag was performed together with an assessement of the effect of cruise lift coefficient and c.g. travel on trim drag for a selected configuration. The analysis was limited to subcritical cruise conditions. Simplifying assumptions included were:

- the sum of canard and wing area were held constant ensuring that a given maximum lift coefficient could be attained (same stall speed) if the canard and wing maximum lift coefficient were the same;
- canard and tail volume coefficients referred to the aircraft c.g. were kept identical to ensure a given control pitching moment at low speeds (take-off rotation).

Cruise weight and c.g. location were computed using the semi-empirical methods of ref. 121 with fixed fuel and payload. A Lagrange optimisation technique is employed to optimise the lifting surfaces spanwise lift distribution for minimum drag, based on the Trefftz plane formulation, on every configuration, subject to a given total lift (L=W) and trimmed conditions (C_m=0). So it is assumed that optimum circulation distributions are feasible through appropriate twist and camber of the lifting surfaces. The following conclusions were drawn:

- relaxing static stability requirements, the canard is favoured with regard to minimum cruise drag. The absolute minimum drag is achieved for unstable configurations only.
- the three-surface aircraft may be the best solution if a limited amount of static instability or low stability margin is allowed for.
- for an inherently stable design the conventional type may be the best option.
- for the case where the wing should be located aft of the passenger cabin for comfort, and a positive static margin is required, the three-surface should be considered.
- all stable designs show a tail download.
- changing the configuration from a near-conventional to a near-canard, while preserving the same static margin, increases drag in about 10%. By doing this, canard area increases, at the same time the main wing is moved rearwards with decreasing both wing and tail areas in order to satisfy the above design assumptions. For pitching moment equilibrium the canard lift contribution will increase and consequently its induced drag. Reducing the stability margin by 0.1 yields a drag decrease of about 4%.
- In most cases, the combined load of canard and tail have a positive contribution to the overall lift. This is in contrast with Kendall's[113,114] and Rokhsaz and Selberg's[115] assumption for minimum drag implying that this is achieved for equal and opposite canard and tail trimming loads (these authors, as referred to above, based their research on the assumption that the canard and horizontal tail would only contribute for pitching moment equilibrium). This condition strongly depends on aircraft layout arrangement and c.g. location. On the other hand it was shown that there is a value of the canard area for which the position of the main wing has little effect on the wing lift which suggests that the combined canard and tail lift is nearly constant being their lift differential used for trim.
- Apparently, the configurations having a smaller canard yield not only less drag at the design cruise condition, but also lower drag levels for different c.g.s and lift coefficient.
- Further, Middel concluded that "... one might select a three surface configuration over a conventional because of structural weight savings, despite the higher drag levels at the same weight." Also, "The application of three surface aircraft compared to the conventional aircraft is expected to find limited application unless static margin requirements are relieved. Depending on the level of instability, the three surface configurations might yield lower drag levels than a conventional aircraft."
- Finally, he added "The three surface aircraft principal advantage (minimizing trim drag over a centre of gravity and lift coefficient envelope), allows to yield lower drag levels, depending on the centre of gravity and lift coefficient envelope. It remains to be questioned however, if a conventional aircraft (having a lower drag level at the design centre of gravity and lift coefficient) is outperformed."

Trimming procedures were also investigated. Cruise drag was assessed for trimming with tailplane only, canard only, and both simultaneously. For the baseline (similar to P-180), it was concluded that trimming with the tailplane only is highly penalizing with regard to drag. For extreme forward c.g. and high lift condition a large tail download may be required to obtain a given maximum lift, consequently an excessive angle of attack may lead to canard stall. For all conditions it was found that the best solution in terms of minimum cruise drag is achieved by trimming with the canard and tailplane in combination and that trimmed drag is nearly independent of c.g. location for which the largest feasible shift is possible.

The above conclusions were obtained by assuming constant lifting surfaces planform parameters such as aspect ratio, sweep, taper ratio, and dihedral. However, additional research was conducted on the effects of canard taper and aspect ratio variations. A change in canard taper ratio from 0.2 to 1.0 causes a 1% increase in drag while an increase in aspect ratio from 3 to 10 produces a 2% drag decrease. Providing the c.g. is kept fixed, static margin and the location of the neutral point are very sensitive to changes in canard aspect ratio. In fact, for the same variation in aspect ratio, a typical variation in static margin from 0.0 to 0.25 was found. This suggests that this parameter may be effectively used to fine tune the aircraft static stability margin.

2.2.2.3 Three-lifting Surface Project Designs

The benefits gained in terms of performance, passenger comfort and ride quality are also apparent from the selection of the three-surface concept in the design of commuter and general aviation aeroplanes. This was shown by Roskam in his design studies reported in references 122, 123 and 124. Although the conclusions address specific types of aircraft, they are believed to be of a more general application.

2.2.3 Assessment of the Previous Research

As described above, there has been a vigourous debate within the technical community concerning the suitability of these types of unconventional aircraft in outperforming current conventional designs in use. They range from simple theoretical analytical investigations of a pure aerodynamic nature, where the fuselage was usually neglected and where issues such as longitudinal stability and viscous drag were rarely incorporated, to more complete evaluations including considerations of longitudinal stability and controlability, longitudinal trim, profile drag, aircraft weight, centre of gravity location and shift, and main landing gear location. The first kind, by applying simple methods such as the classical Prandtl-Munk theory and, or their extensions such as those by Laitone, Kroo or Butler to account for the non-elliptical load distribution on the main wing, focused on the minimization of the overall induced drag by systematically studying different lifting surface arrangements with arbitrarily chosen lifting surface areas. Although backed-up by some aerodynamic wind-tunnel experimentations, whose results provided useful scope for assessing the range of validity of theoretical results as obtained from different aerodynamic analysis approaches, mostly for two lifting surface arrangements without fuselage, it was felt that very little empirical information on realistic unusual designs remained to ensure a rapid and reliable means for an unquestionable configuration selection. Thus, this was the reason for pursuing with the second more exhaustive kind of studies such as those by Selberg and Middel. They took into account far more considerations into play and used rather more sophisticated tools such as the aerodynamic vortex lattice and panel analysis methods to reduce the level of uncertanties, likely to occur when dealing with novel configurations from which no empirical data exists, and treated the design problem as a truly multidisciplinary task.

The trends found by Kendall, Rokhsaz and Selberg, and later on obtained from the experiments conducted by Ostowari and Naik, are somewhat misleading. They showed that comparisons between the three concepts is a far more complex problem, and that simplifying assumptions and procedures, usually accepted in the conceptual design of wing-aft tail configurations, are not completely satisfactory when applied on unconventional configurations if an accurate assessment of their relative merits is sought. Bearing in mind Middel's thorough assessment for sizing the lifting surfaces of the generalised designs, a more realistic basis for comparison was achieved. In fact, in his approach, Kendall's conditions for minimum induced drag were relaxed, and the lifting surfaces mutual aerodynamic interferences, together with fuselage effects, were taken into account. These aerodynamic interactions are likely to considerably change the lift distribution on the forward wing of pure canard and three-surface configurations. Considerations of weight and balance, and stability and control were also included by means of maintaining a given stall speed and the same take-off rotation control criterion in his family of designs. Fuselage aerodynamic interaction (fuselage-canard and fuselage-main wing interferences) was determined by Middel of being of the same order as the canard-main wing interference. Its importance on the aircraft overall aerodynamics increases as the canard span tends to be smaller relative to the fuselage diameter. These influences are due not only to the local downwash/upwash effects on the main wing flow field, but also by a greater departure from the assumed elliptical shape of the canard lift distribution for smaller canard span to fuselage diameter ratios. Of course, for smaller wing span to fuselage diameter ratios, the overall aerodynamic efficiency will degrade further.

All these mutual aerodynamic couplings and influences considerably impacts the actual overall lift distribution to maintain pitching moment and weight equilibrium when compared to that of a system of uncoupled lifting surfaces. This also makes current initial profile and induced drag predictions less reliable for unconventional designs, in the absence of appropriate experimental data. Consequently, these aerodynamic effects on the overall lift distribution may change considerably the longitudinal stability behaviour of the complete configuration, as predicted (for example, it is not as simplistic as just adding the isolated fuselage pitching moment derivative with regard to lift to assess the aircraft longitudinal static stability), which brings difficulties in the determination of the neutral point, producing uncertainties on the actual stability margin. An effect of these mutual aerodynamic interferences is the high sensitivity experienced by the static margin to changes in canard aspect ratio, as found by Middel.

On the other hand, as shown in ref. 120 and exemplified in the Piaggio P-180, there are benefits arising from the wise adoption of particular design solutions which may be integrated, synergetically enhancing the overall aerodynamic and structural efficiencies for improved performance and operating costs, while ensuring good flying qualities, operational flexibility and safety.

Hence, to adequately assess and achieve a fair comparison among these different concepts, realistic preliminary design studies should be performed to a given specification under the rules of an airworthiness certification body, adopting an identical technology level and optimised to a given performance index. Uncertainties due to the present lack of appropriate empirical data should be reduced through suitable wind tunnel tests to be conducted on models of the canard and three-surface initial concepts in order to correctly account for practical effects. It is the author's belief that more conclusive results would be obtained in this way even at a conceptual design detail level. This is consistent with Roskam's[96] red, white and blue team approach as the "only way to find out which configuration 'best' meets a given set of design requirements." Following this methodology, Arbuckle and Sliwa[58] conducted optimal conceptual designs of both canard and conventional configurations of a statically stable subsonic medium-range transport. Each configuration was evaluated and optimised on the basis of an economic index of interest to airlines. For the type of aircraft in consideration, his research identified two critical problems for canard configurations, the fore-plane high-lift requirement for trim and the main landing gear longitudinal location. Results suggested that conventional configurations are economically superior to canard configurations for this class of aeroplane, and that a possible alternative could be a three-lifting surface configuration. This solution would allow to solve those design problems while preserving the specific benefits inherent to both configurations.

2.2.4 The Present Research Project

The present investigation adopts this same comprehensive and integrated approach, excluding the experimental tests as proposed above, in evaluating three-surface and conventional jet-transport aircraft designed to the same mission and optimised for minimum Direct Operating Costs (DOC) and minimum Maximum Take-off Weight (MTOW). Although not using the sophisticated aerodynamic tools as utilized by Middel in his studies, a design synthesis program was set up and coupled to a gradient based numerical minimization routine where the typical disciplines of aerodynamics, weights and balance, propulsion, performance and static stability and control as well as economics, at a level adequate to preliminary design work, were taken into account. Three-surface concept design assumptions include balancing the aircraft weight by canard and wing lift, trim and pitch control obtained by simultaneous use of canard and tailplane assuming that both surfaces ensure equal trim/control pitching moment. Inherent longitudinal static stability margin of -0.1 is assumed on every design where the engines are sized for take-off, climb and cruise conditions. The fuselage is fixed by the seat arrangement while the lifting surface areas and planform geometric parameters are allowed to change until the minimum value of the figure of merit is achieved. This is in contrast with the fixed lifting surface planform shapes adopted on other studies. Details of the design synthesis tool and the research methodology pursued are described in Chapters 3 and 5.

Figure 2.4 shows a panelled view of Roskam's[124] promising Advanced Personal Transport and figs. 2.5 and 2.6, reproduced from references 125 and 126, illustrate other visionary future transport designs. All these examples reflect the existing live interest and expectations raised by the potentialities of the concept of the three-lifting surface configuration when applied to transport aircraft.

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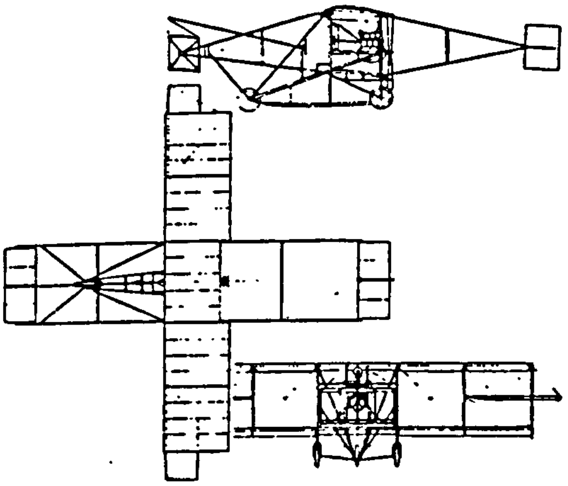

Fig 2.1 - Curtiss Herring No.1 Reims Racer
(from Ref. 96)

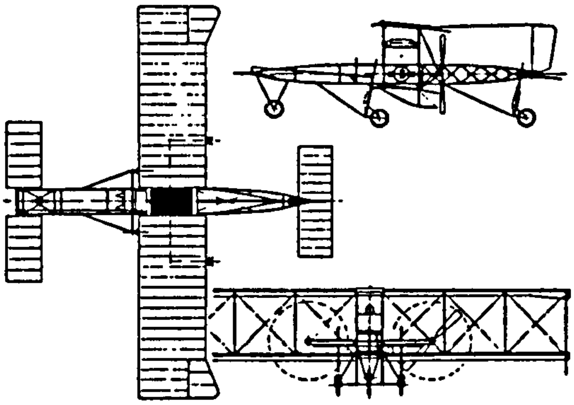

Fig 2.2 - De Havilland Biplane No.2
(from ref. 96)

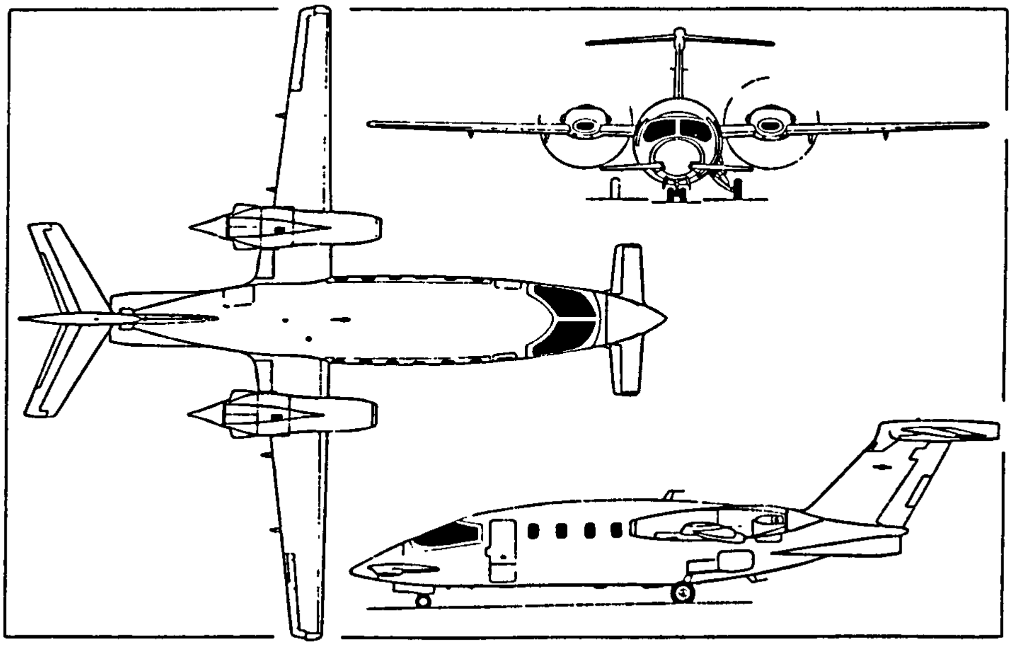

Fig 2.3 - Piaggio P-180 Avanti business transport (from ref. 97)

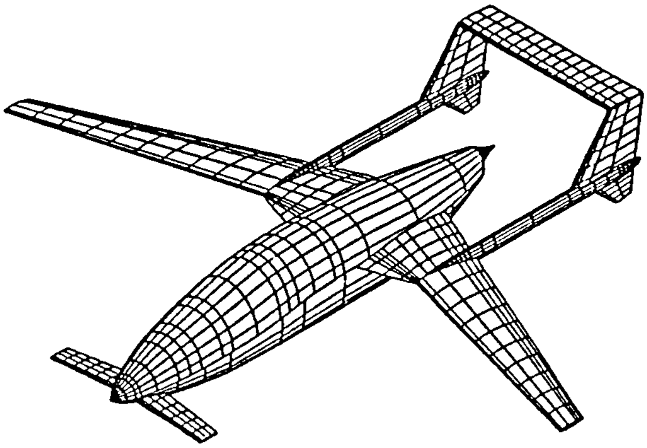

Fig 2.4 - Roskam's Advanced Personal Transport (from ref 124)

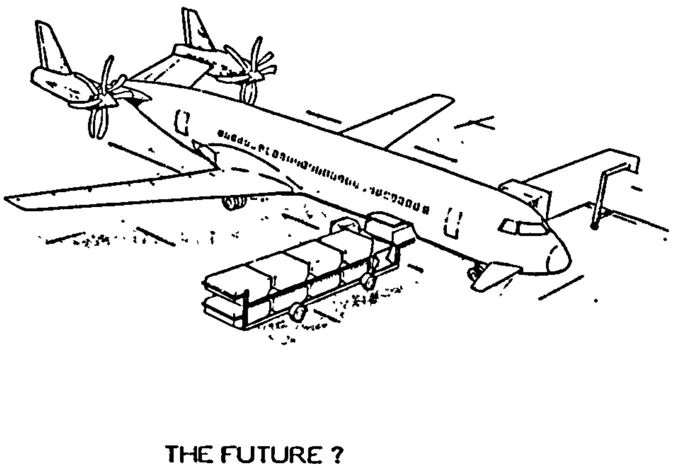

Fig 2.5 - Saab visionary efficient shorthaul aircraft (from ref 125)

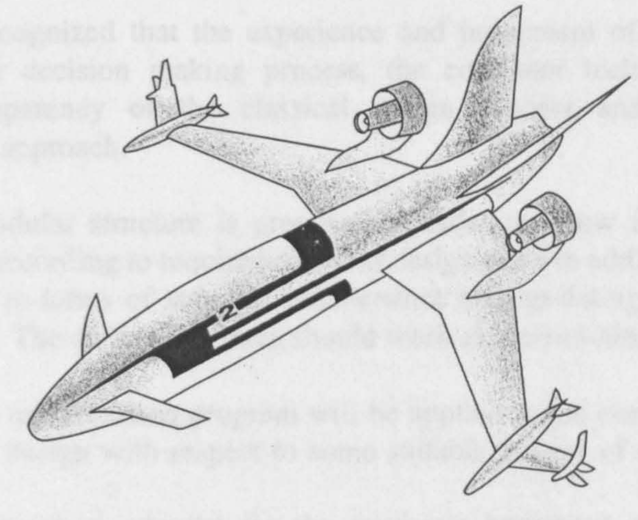

Fig 2.6 - Airbus Industrie's E2 advanced concept, a 220-260 seat, medium/long range transport (from ref 126)

PAGE

NUMBERING

AS ORIGINAL

3 Design Criteria, Methodology and Conceptual Design Tools

3.1 Design System Philosophy, Concept and Structure

The objective of the conceptual design phase is the search for the most efficient configuration for a given mission specification while satisfying operational, performance and airworthiness requirements. This implies the comprehensive study of several potential configurations which must be consolidated iteratively through successive analysis and compared on the grounds of global characteristics, sensitivity and trade-off studies. The most promising concept is then identified and eventually refined during the preliminary and detailed design phases which may follow.

Since it is recognized that the experience and judgement of the designer plays an essential role in the decision making process, the computer technique must retain the flexibility and transparency of the classical design process and therefore reflect an engineering-oriented approach.

A flexible modular structure is proposed in order to allow for easy control of the computing sequence according to required different design tasks in addition to providing space for future extensions in terms of software maintenance and up-dating, range of applications and other capabilities. The design synthesis should work as a stand-alone program if required.

A constrained minimisation program will be applied to the configuration synthesis in order to optimise the design with respect to some suitable figures of merit.

A general flow chart adopted for the synthesis integrated optimisation system is illustrated in Figure 3.1. As shown, the system will include four main modules:

- the Parametric Analysis module
- the Configuration Concept Design module
- the Engineering/ Economic Evaluation module
- the Optimiser

The Parametric Analysis module relies heavily on statistical methods allowing for a first estimate of aircraft take-off, empty and fuel weights. In addition a design space in terms of the thrust loading versus wing loading plot, where all the mission, performance and airworthiness requirements are met is suggested, providing a consistent and realistic set of input data to the subsequent configuration synthesis/ analysis iterations. Take-off gross weight sensitivity studies with respect to mission, aerodynamic and propulsion parameters are also performed and some indication of the technology levels involved is obtained together with some feeling on the critical parameters which drive the design. A prototype of the module was developed following the preliminary sizing method presented by Roskam in his "Airplane Design" volume, Part I[1], and was shown to be working properly. This module will only need as input a mission specification together with assumptions on some empirical and technology related parameters to produce a preliminary sizing of the required wing and engine(s), in terms of wing area and maximum static thrust, providing the assumptions are sound and attainable.

The Configuration Design module and the Engineering/ Economic Analysis modules can be fairly well represented by the flow chart shown by Howe in his lecture note DES 8108[2,3], and reproduced here as Figure 3.2, the Structure and Aeroelastic modules being excluded in this approach.

The Configuration Design module to define the aircraft geometry and component allocation was devised and initial development undertaken, following mainly Roskam's methodology as shown in "Airplane Design", Part II [1].

The Engineering/ Economic Analysis module was originally intended to include the programs identified in section 3.2.

The program RQPMIN, Recursive Quadratic Programming Minimisation[4], developed by the Royal Aerospace Establishment to solve the nonlinear constrained minimization problem will constitute the optimisation driver.

3.2 Available Disciplinary Analysis Programs

Some analysis programs suitable for initial aircraft design work have been developed, used and up-dated by past M.Sc. and Ph.D. students, in the College of Aeronautics (CoA), and have been shown to produce results within acceptable levels of accuracy for the purpose concerned. Hence, in order not to re-invent or duplicate work, it was initially intended to adapt and integrate these programs into the system under study. These programs were:

- MASS-ESTimation, developed by Sarrazin[5] in 1987;
- DELTADD, initially developed by Frosst[6] in 1981 and Sarrazin[5] and subsequently rewritten and improved by Hartland[7] and Howe;
- FLTANAL, developed by Pasaribu[8] in 1991;
- ACCOST, developed by Pasaribu[8] in 1991;
- MITCHELL, developed by Mitchell[9] and modified for the CoA by Theophilou[10] in 1983.

MASS-ESTimation is a component mass breakdown prediction method based on empirical formulae obtained mainly from CoA lecture notes DES 8515 and 8336[2].

DELTADD is based on the Delta method, an empirical drag build-up estimation technique developed by Lockheed in 1978[11], which is able to predict the total configuration drag polar within a CL range of 0.0 to 0.6 or buffet onset and a speed range of $0.2 < M < 2.0$. This program deals with high lift devices which is an improvement on the original method of ref 11.

FLTANAL is a program written to perform flight mission analysis of subsonic transport aircraft. It calculates fuel weight, time and range covered during the climb, cruise and descent legs of the flight profile as well as the reserve fuel.

ACCOST is another program written for the estimation of subsonic transport aircraft and engine costs and is based on methods presented by Nicolai[12], Roskam[1] and Maddalon[13].

The core of both FLTANAL and ACCOST programs was obtained from the OPDOT program developed by Sliwa and Arbuckle[14] in 1980.

MITCHELL is a program to predict the stability and control characteristics of subsonic aircraft[9], developed at the Royal Aircraft Establishment in 1973. The primary sources of data used in this program were the ESDU data sheets.

3.3 Initial Work

A careful evaluation of the disciplinary analysis tools just mentioned above revealed that considerable software development work would be required in order to adapt, streamline and integrate them into an adequate synthesis program to perform realistic preliminary designs of conventional and unconventional three-surface transports as described in 3.1.

For the purpose, a modified version of the MASS-ESTimation program named MASS program was developed in fortran to replace the existing one in basic in order to make possible easy integration with the remaining routines, all of them written in fortran. MASS program differs from the original one mainly in that it computes the fuel weight needed during the range, hold and diversion legs of the mission profile by using the appropriate Breguet equations while assuming user guessed fuel weight fractions for the remaining mission legs. MASS-EST, as it stands, requires user input proportions for fuel burned up to the start of cruise and during the cruising phase. Although this former program was written for a wide scope of aircraft types, MASS is restricted to initial component mass predictions of subsonic narrow body jet transport aircraft. Future extensions to accommodate new types were made easy by the adoption of a highly modular and structured programming style.

MITCHELL program has benefited from an extensive revision driven by the high frequency that running problems were encountered where many of the results, if any, were doubtful, consequently precluding its intended use within the design synthesis program. These problems were mostly associated with the several syntax errors encoded which have been cleared out improving its acceptability and portability. It is worth mentioning that now the program can run on an IBM PC or other compatible platform. Some minor corrections were made to the logic, for example to the calculation of one of the longitudinal stability derivatives, i.e., the non-dimensional force derivative due to velocity increment along 0Z[9], Zw, as well as to the all-moving tail model algorithm used for the computation of the low speed handling characteristics.

It should be noted that the tools referred to in 3.2 are not design but disciplinary analysis programs whose purpose concerns the estimation of the mass, aerodynamic, flight performance, stability and control characteristics of possible conventional configurations as well as their associated costs, assuming a given engine cycle. They should be adequately interrelated through a Configuration Design module able to systematically change design variables until a solution consistent with the requirements is met. To this end a Configuration module was partially developed as stated before which would potentially lead to a preliminary component sizing and allocation, where considerations of weight and balance, stability and control, field performance and required cruise altitude and range within the FAR Part 25 requirements were taken into account.

The fuselage sizing is relatively straightforward for a given passenger seating and baggage arrangement with allowances for the flight deck, doors, emergency exits, toilets, galleys and cabin crew seats providing no transonic or supersonic area rule is used and it is kept fixed throughout the iterations. Only the lifting surfaces geometries and respective locations are allowed to change while the several design criteria are satisfied along the synthesis process. It may happen that the wing no longer accommodates the mission fuel between the main spars for very long ranges in which case an increment to the wing area is input and the overall process restarted.

By initially locating the centre of gravity corresponding to the operating empty mass at 25% of the wing mean aerodynamic chord (usually at 25-30% MAC[15]), a mass balance routine was devised for the estimation of the most critical fore and aft centre of gravity locations based on two extreme loading conditions with all seats, baggage bins and fuel tanks filled respectively forward and aft that point. The design load condition is estimated as well, assuming the maximum take-off mass .

In face of the elaboration implied in the methods used by the existing modules, it was thought convenient and thus more credible, to incorporate the physics of take-off and landing in special purpose analysis subroutines for the field performance evaluation instead of the more simple empirical correlations suggested by Loftin[16], and already included in the initial Parametric Analysis module.

An initial estimate of the tail sizing was implemented using typical tail volume coefficients taken from actual similar mission aircraft. Subsequent refinement would be achieved by iterating among the mass, balance and stability and control modules in order to satisfy required longitudinal and directional static stability and control criteria consistent with the allowable centre of gravity travel. After the flight performance analysis has been done, including all the mission phases from starting up the engine(s) to shut down, further checks on the maximum take off mass is required by repeating the overall process again and again until convergence, and showing then a consistent set of relevant data which describes the configuration. At this stage a first assessment of the aircraft costs including the Research, Development, Testing and Evaluation (RDT&E) and Operating Costs is possible using ACCOST.

It is well known that significant gains[17] can be achieved by designing aircraft for reduced inherent longitudinal stability or even with some degree of instability which are artificially made stable by the introduction of an appropriate highly reliable and redundant feedback Stability Augmentation System (SAS) which will confer the required de-facto stability and handling qualities. This concept allows for significant reduction of the tail size and surface wetted areas thus directly reducing its associated structural mass, skin friction drag, and consequent fuel mass. The lower stability margin will entail a reduction of the trim drag which is most significant at low speeds with flaps deployed, due to the reduction in the required trim downward tail load, providing higher values for the CLmax, and hence improving the take-off and landing performance. So, more payload can be carried for the same aircraft or performance enhanced by fuel reduction or range increase, driving the operating costs to lower levels. The use of a SAS will incur a corresponding single significant initial cost. When considering big capacity aircraft this is not important compared with their initial price and ready economical advantages associated with its implementation, but the same is not so clear for small ones where its market competitivity may be seriously impaired. Following this reasoning the study will focus on inherently stable commercial aircraft to carry 50 passengers which may correspond to an initial cost of no more than US$20 million. Providing that benefits can be obtained from a similar mission three-surface configuration, this concept could be further explored for this class of aircraft assuming that for a given level of technology the improvement through the introduction of a SAS on conventional configurations is not economically feasible. Of course similar study conclusions could be obtained from the two different configuration aircraft both equipped with a SAS in order to preserve the same basis for comparison.

Using the Parametric Analysis module a preliminary sizing of a subsonic turbo-fan airliner to carry 50 passengers over a range of 1250 NM was performed and has shown that a powerplant consisting of two engines, each one rated to a minimum of about 8000 Lb maximum installed static thrust, would be enough, as described in 5.2 and Appendix C. This level of propulsion power would need to be implemented in the FLTANAL routine since it is not representative of the engines already modelled in the program.

Once the Configuration Design module, the mass balance, the field performance evaluation routines and the propulsion model had been concluded and incorporated into the synthesis procedure, the complete design system would be tested, fine tuned if necessary, and validated against a known similar aircraft, and full integration with the numerical optimisation technique obtained. At this stage it would only allow for the conceptual design and optimisation of conventional tail-aft jet transports and a complete review and modification would be required to include the design criteria, implications and contributions of the additional fore lifting surface, typical of the new concept in consideration, in order to properly account for its multidisciplinary effects on the design.

The integration and adaptation of these separate programs clearly represented a major task.

3.4 Switching to GASP

3.4.1 Introduction

During the time of developing this study the author was fortunate in getting involved on an Unmanned Aerial Vehicle System Research & Development work[18], under an University/ Industry joint project initiated in Portugal, aimed to fulfil the need for a cost-effective system for civil observation and reconnaissance missions. The initial vehicle concept design study leading to the first of a series of configurations studied was performed by the author together with Brederode, his former teacher and Professor of Aerodynamics at the Instituto Superior Tecnico (IST), Lisbon University. To facilitate the initial study, some software tools were acquired including the NASA "General Aviation Synthesis Program" (GASP)[19].

This program developed on a CDC computer was not easily portable to other computer systems requiring conversion to run on the Hewlett Packard 9000, Series 730 workstations in use at the IST. Also several most difficult modifications and validations were needed to properly model and synthesise the type of aerial vehicle envisioned. This requirement represented a very time-consuming task even for an experienced engineer with adequate background and expert knowledge and thus it was not of much practical use, at least for the initial months of the project. Nevertheless the program represented a very powerful and comprehensive tool for the purposes of the present research investigation and a change to it was justifiable under the circunstances explained in section 3.3.

The origins of GASP date back to 1973[20,21], and it was developed for several years by engineers at NASA Ames Research Center to conduct aircraft preliminary designs and rapid parametric studies. The program has been used by several Companies and Universities and is under continuing development.

The program comprises several disciplinary modules conveniently interrelated into a computational flow and integrated in a way to produce consistent results of novel designs that are as accurate as the methods implemented, the assumptions made and the input data used. It includes several design options for the synthesis of a wide variety of aircraft types ranging from small single piston or rotary engine propelled general aviation up to twin turboprop/ turbofan powered corporate or transport type aircraft.

GASP is a useful tool for comparing configurations, assessing aircraft performance and economics, performing trade-off and sensitivity studies, and assessing the impact of advanced technologies on aircraft performance and economics. The original program may be operated either in batch or interactive graphics mode although the version in use only runs in batch mode.

3.4.2 Program Structure

The synthesis program consists of a control module and distinct technology modules representing the six pertinent technical disciplines as represented in figure 3.4. Each of the technology modules is composed of one or more separate computer subroutines and the input data to each module may be either the user input or the output from another module. The integration ensures that the results comprise the effects of the multidisciplinar interrelations maintaining data consistency and method compatibility, and leading to significant reductions in both effort and task flow time with configuration results more free from errors since these are restricted to the input data, provided the methods are satisfactory and reliable.

A brief description of the engineering methods used is now given:

Geometry

The module computes the dimensions of the aircraft components. Typical input consists of the number of passengers to be carried, cabin layout, wing and tail surfaces aspect ratio, taper ratio, sweep, aerofoils thickness ratios, fuselage nose and tail fineness ratios and vertical locations of wing and horizontal tail. The cabin is assumed to be of circular cross section and tail surfaces are initially sized using historical trend equations. Geometric data such as component areas, lengths, angles, etc are obtained and eventually used by other modules.

Aerodynamics

The module computes lift, drag coefficients and lift curve slope. Lift coefficient is obtained as the sum of a term proportional to angle of attack and an increment due to high lift devices. Lift curve slope is a function of aspect ratio, Mach number and sweep, including ground effect. Drag coefficient is determined as the sum of profile drag, increments due to the high lift devices, landing gear and compressibility whenever applicable and the vortex drag, including ground effect. The input consists of the aircraft geometry, flight conditions and related configuration providing, in addition to the above data, the drag polars for cruise, take-off and landing conditions.

Propulsion

As already stated, a large variety of powerplants can be simulated from reciprocating/ rotary engines up to turboprop/ fan engines. The module determines the engine size and performance to satisfy both cruise and take-off requirements. From the specific engine performance data, thrust and fuel flow is computed for any flight condition.

Weight and Balance

Inputs to this module consist of a first estimate of the maximum take-off weight and payload, with details of aircraft geometry and empirical weight trend coefficients. Statistical equations for component weight prediction developed in ref. 22 are used and the wing is located so that the aircraft is in balance for the centre of gravity travel and for a desired value of the static margin. An option to resize the horizontal tail is provided. Although ref. 22 concerns in particular V/STOL type aircraft, the correlations imported to GASP are based on statistical regression analysis performed on data from several types of existing aircraft. The adequacy of their application is controlled by the user by assigning appropriate values to the weight trend coefficients to adapt the basic equations to a particular application.

Mission Performance

Mission segment legs such as taxi, take-off, climb, cruise, descent and landing are analysed and total fuel, including reserves, and range determined. The module provides options for the calculation of engine out, accelerate/ stop distance, best rate of climb, high speed climb and other characteristics. For a required range the aircraft size is approached within a specified range tolerance.

Economics

This module computes flyaway and operating costs. Flyaway cost is obtained by summing estimates of labor, material and purchased equipment costs including overhead, tooling, sales and profit both for the manufacturer and the dealer. Operating costs include fuel, oil, inspection and maintenance, insurance, depreciation, crew costs, taxes, and the direct and indirect operating costs are combined to give the total operating cost as a function of the annual utilization rate.

Figure 3.5 represents the GASP program design procedure.

In view of the changes adopted, the synthesis integrated optimisation system as constructed has evolved as shown on figure 3.3, being the Parametric Analysis module excluded from the optimisation cycle, for simplicity, and the Configuration Design and the Engineering/ Economic Evaluation modules replaced by the GASP program.

3.5 Extensions to the Three-Lifting Surface Configuration

This section describes the modifications implemented in the GASP source code in order to properly simulate the contributions of a canard surface upon the overall vehicle design. As long as the changes are introduced the methods and methodologies incorporated in the original program are reviewed together with descriptions of a few additions included for the sake of completion. For any details not shown in the present text, the reader is referred to ref. 19.

GASP is composed of 65 computer subroutines from which the subset used in this study employs 55 plus a new utility one created by the author and called 'Cramer'. These subroutines are grouped by specialities and are listed in figure 3.6. Figure 3.7 shows an updated listing of the subroutines which may be called by the indicated subroutine.

3.5.1 Design Procedure followed by GASP program

Input data includes the general concept of the aircraft being designed in terms of payload, performance criteria, mission profile, geometric characteristics, technology factors relating to structures and materials, propulsion and aerodynamic concepts together with a first guess of the maximum take-off weight and wing loading and several options controlling the sizing criteria.

The computation as represented in figure 3.5 starts with the calculation of the aircraft geometric parameters needed by the aerodynamics, propulsion, weight and performance modules. An initial evaluation of the flap aerodynamic performance is done. The performance module is used to compute the engine size and the required wing loading to satisfy the specified cruise conditions and the landing and take-off field performance including the airworthiness requirements for take-off, climb and balked landing (the present study considers a vehicle under FAR Part 25 requirements).

Weight and balance computations follow together with the empennage sizing for a required longitudinal static margin and satisfying desired stability and control criteria. At this stage a first configuration is obtained where the main component sizes/ weights and respective allocations are completely defined. The configuration is then subject to a full performance analysis from the taxi up to the descent phase until reaching an altitude of 1500 ft over the destination airport. Take-off engine out and accelerate-stop distance conditions are simulated and the cruise conditions at the specified speed, normal power and best specific range cases are considered. Both take-off and landing field performance are recomputed and mission fuel weight and block time obtained.

A check on range is done and the overall calculation repeated until the maximum tolerance of 1% on the desired value is satisfied. Once this convergence is reached cost computations are performed and a full printout of every important design parameters and results produced.

3.5.2 Changes introduced in GASP code

3.5.2.1 General

The version of the program received, while very complete in its formulation, didn't account in its computations for the influence of the wing pitching moment coefficient. Furthermore the tail sizing criteria using stability and control considerations assumed only the controls free and no option for controls locked was implemented. The present study focuses on an airliner where hydraulic boosted flight controls are anticipated so the latter capability would be useful. Also some influences such as those due to the engine jet efflux inclination on stability and the pitching moment required to rotate the aircraft at lift-off were not accounted for in the stability and control equations. All the above limitations were overcome by implementing the related capabilities in the program as described later. In addition a switch enabling the new developed part of the program was included in the input file to allow for the synthesis of unconventional three-lifting surface configurations.

The general GASP design procedure as implemented and shown in section 3.5.1 is kept unchanged. The consideration of another lifting surface complicates the problem and simplifications were allowed in order to reduce both computational effort and costs during the optimisation runs. The main simplification concerns the design criteria adopted which limits the range of configurations to be studied.

While studying conventional subsonic transport aeroplanes, Laitone[23] concluded that if the tail is out of the wing plane (above or below), then a zero tail load would produce minimum induced drag. However this condition can be achieved at only one aft c.g. location for an inherently longitudinal stable aircraft. This c.g. location should be behind the wing-body aerodynamic centre as to create a couple to balance the nose down zero-lift moment, thus leaving the tail unloaded. A good design should allow for this condition during cruise, for time periods as long as possible, by minimizing the c.g. shift produced by the fuel consumption. For the three-lifting surface concept, it is assumed that the above condition is attained in cruise and the tail is unloaded, i.e., both canard and wing balance the aircraft weight. So, by extrapolating Laitone's conclusion on minimum induced drag in conventional configurations for this case, it implies that for the same overall lift the lifting surface sizes will be minimized. It is usually difficult during the flight to maintain this ideal c.g. location for minimum induced drag. Unless the fuel c.g. is always lying on the aircraft zero-fuel c.g., and other influences such as crew or passenger movement are eliminated, it is unlikely c.g. excursions are avoided during flight. So, trimming and control surfaces are required. One can intuitively suggest that cruise longitudinal trim drag could be minimized when trim conditions, other than the ideal one for conventional configurations, are kept by employing two small trimming surfaces, one of them being a fore-plane, instead of only one large rear horizontal tail, for the same desired minimum static margin. From the above a design criteria for the canard/ tail sizing is devised that assumes both surfaces will provide equal trim/control pitching moments and thus both will contribute to the aircraft longitudinal trim and control. They will perform differentially to achieve the required trim and control pitching moments. Thus it is assumed that the tail will contribute to the trim condition in cruise but will not influence the additional lift required to balance weight. Because of this, it is also assumed that the horizontal tail induced drag is negligible, hence it will not be evaluated in GASP computations. This also applies to the conventional designs. Another simplification is that the canard and wing have the same lift coefficient in cruise, thus assuming identical aerodynamic loadings, i. e., the overall aircraft lift will be proportionally distributed by both surface planform areas. All these assumptions are considered reasonable as a first order approximation as far as the initial design is concerned and should be verified at later stages of the design. As stated above the design approach will reduce the range of the three-lifting surface configurations to those with canard/ wing area ratios, say between 0.145 and 0.175. Pure canard configurations can not be evaluated. So, in addition to complementing the wing for providing lift, the canard will be constrained to ensure that it provides only half the required minimum control power. This may reflect the interdisciplinary complexity of the design procedure implemented since all the lifting surfaces are sized at the same time to satisfy stability and control requirements and also to meet the mission, certification and performance constraints.

3.5.2.2 Specific Changes

3.5.2.2.1 Geometry

As briefly described in section 3.4 and figures 3.6 and 3.7, this module computes the initial main aircraft component sizes, determines their initial allocations and other geometric data needed by the other disciplinary modules. It consists of one subroutine called "SIZE".

The fuselage sizing procedure is unchanged which means that both conventional and unconventional designs will show the same basic fuselage for the same accommodation arrangement, the difference being set by the sizing of an additional foreplane and its allocation relative to the overall configuration layout. From a given canard to wing area ratio and for a specified canard location, "SIZE" will only split the statistical conventional tailplane volume coefficient in two, one for the horizontal tail and one for the canard. Assuming that in level unaccelerated flight conditions the lift contributions from both the canard and wing are proportional to the respective areas, i.e., both the aerodynamic loadings remain the same while the tail is kept unloaded (except for trim purposes), it is possible to perform an initial sizing of the three-lifting surfaces. "SIZE" does not locate the wing for weight balance and stability. This is done later on by the subroutines "WEIGHT" and "TAIL", it only sketchs the configuration for further refinement.

Figure 3.8 shows the canard/ wing location geometry. Equations used are detailed in Appendix B.

3.5.2.2.2 Aerodynamics

The aerodynamic model implemented in GASP was modified to include the contributions from the canard surface. The respective module is made up of the eight subroutines listed in figures 3.6 and 3.7, each one performing a specific function as follows:

CTAER - determines required lift and drag coefficients in cruise flight,
AERO - computes the equivalent flat plate areas, wetted areas and the parasite drag for the basic aircraft in the cruise configuration,
DRAG - computes induced drag coefficient, in ground effect whenever applicable, compressibility drag coefficient and the total aircraft drag coefficient with or without flaps and landing gear deployed,
AEROUT - produces the drag polars both for low and high speed conditions,
CLIFT - determines the wing alone lift coefficient or angle of attack,
FLAPS - estimates aircraft maximum lift coefficient, lift and drag increments for several flap types and settings and flap weights,
EODRAG - evaluates the drag increment due to engine failure,
APPFLP - estimates approach flap deflection.

Significant changes were only introduced in the drag related computations involving subroutines AERO and DRAG. Minor changes relating to the switch of the reference area, originally the gross wing area, to that defined as the sum of the canard and the wing gross areas, used for the new concept, were included in subroutines CTAER and FLAPS.

A brief description of the aerodynamic drag model is given in order to illustrate the approach used in simulating the canard drag contribution. This follows the procedure of GASP.

In the 'clean' configuration, the aircraft aerodynamic drag coefficient may be represented by the sum of parasite drag, lift induced drag and compressibility drag coefficients:

$$C_D=C_{D_p}+C_{D_i}+C_{D_c}$$

or

$$C_D=\Sigma_i C_{D_{p_i}}+C_{D_{p_w}}+C_{D_{p_c}}+C_{D_{i_w}}+C_{D_{i_c}}+C_{D_{c_w}}$$

It will be assumed that the air flow at the canard and wing is not incurring any energy losses due to interference with the fuselage boundary layers or canard wake, in this way showing the same dynamic pressure as that of the undisturbed free stream air. So the related efficiencies are taken as unity. Another simplification concerns the compressibility drag which is assumed as originated only by the wing being the component with the lower drag divergence Mach number.

Detailing the several contributions, drag may be expressed as:

Generalized component parasite drag coefficient, $C_{D_{P_i}}$

$$C_{D_{P_i}} = \frac{K_i C_{f_i} S_i}{S_{ref}} = \frac{K_i C_{f_i} S_i}{S_w} \frac{1}{(1+S_c/S_w)}$$

with $C_{f_i} = C_{f_{Re=10^7}} F_{Re_i}$

where K_i is the ith component aerodynamic form factor,

$C_{f_{Re=10^7}}$ is the Mach number dependent flat plate skin friction coefficient evaluated at a reference Reynolds number of 10^7 and obtained as shown next:

$C_{f_{Re=10^7}}$	M
0.002944 - 0.0001760 M	M < 0.4
0.002990 - 0.0003125 M	0.4 ≤ M ≤ 0.92
0.002700	M > 0.92

$F_{Re_i} = \left(\frac{\log Re_i}{7}\right)^{-2.6}$ is the Reynolds number correction term for the ith component derived from the Prandtl-Schlichting turbulent flat plate skin friction equation. For the purposes of Reynolds number computation, the characteristic length is the body length for fuselages and nacelles and the mean aerodynamic chord for wings and other surfaces,

S_i is the ith component area (fuselage, nacelle, and lifting surfaces wetted areas),

$S_{ref} = S_c + S_w = S_w\left(1 + \frac{S_c}{S_w}\right)$ is the reference area.

Wing and Canard parasite drag coefficient, $C_{D_{P_w}}$ and $C_{D_{P_c}}$

The wing and canard parasite drag contributions are computed in a similar way but are factored by a correction term C_{D_r} to reflect its dependency on the lift coefficient. C_{D_r} represents the ratio of the actual clean wing/ canard profile drag at some lift coefficient to the profile drag of the wing/ canard at the angle of attack for minimum profile drag. Typical values are represented in figure III.1.2 of ref. 19. As stated above, the tailplane will contribute to trim by producing some lift. However, during cruise flight, it may be small. Thus, its induced drag is assumed negligible and tail lift dependent drag contributions will not be predicted in GASP evaluations, for simplicity.

The wing parasite drag coefficient may be written as:

$$C_{D_{P_w}}=\frac{K_w C_{f_w} S_w C_{D_r}}{S_{ref}}=K_w C_{f_w} C_{D_r}\frac{1}{(1+S_c/S_w)}$$

and the canard parasite drag coefficient:

$$C_{D_{P_c}}=\frac{K_c C_{f_c} S_c C_{D_r}}{S_{ref}}=K_c C_{f_c} C_{D_r}\frac{S_c}{S_w}\frac{1}{(1+S_c/S_w)}$$

Since the same aerofoil is chosen both for the canard and wing and that lift coefficient on both surfaces is assumed to be the same for a given flight condition, C_{D_r} will take the same value depending only on the actual lift coefficient.

Induced drag coefficients, $C_{D_{i_w}}$ and $C_{D_{i_c}}$

Wing induced drag coefficient may be written as:

$$C_{D_{i_w}}=\frac{C_L^2}{\pi e_w A_w}\frac{1}{(1+S_c/S_w)}$$

and the canard induced drag coefficient:

$$C_{D_{i_c}}=\frac{C_L^2}{\pi e_c A_c}\frac{S_c}{S_w}\frac{1}{(1+S_c/S_w)}$$

Assumptions made were as already noted above concerning to:

- no losses of dynamic pressure in the inflow air stream and
- same lift coefficient on both surfaces.

The wing Oswald efficiency factor is obtained empirically[19] by:

$$e_w=\frac{1}{1.035+1.19A_w(\frac{C_{D_{P_w}}}{\cos^2\Lambda_{w_{c/4}}}+C_{D_{P0_w}})}$$

where $C_{D_{P_w}}$ is the wing parasite drag coefficient as obtained above,

$C_{D_{P0_w}}=\Sigma_i C_{D_{P_i}}+C_{D_{P_c}}$ is the wing free aircraft parasite drag coefficient,

A_w is the wing aspect ratio,

$\Lambda_{w_{c/4}}$ is the wing quarter chord sweep angle.

and the canard Oswald efficiency factor is determined using the same empirical approach:

$$e_c=\frac{1}{1.035+1.19A_c(\frac{C_{D_{P_c}}}{\cos^2\Lambda_{c_{c/4}}}+C_{D_{P0_c}})}$$

where $C_{D_{P_c}}$ is the canard parasite drag coefficient as obtained above,

$C_{D_{P0_c}}=\Sigma_i C_{D_{P_i}}+C_{D_{P_w}}$ is the canard free aircraft parasite drag coefficient,

A_c is the canard aspect ratio,

$\Lambda_{c_{c/4}}$ is the canard quarter chord sweep angle.

Aircraft compressibility drag coefficient, $C_{D_{c_w}}$

This contribution is represented by:

$$C_{D_{c_w}}=K_w \Delta C_{D_M}$$

where K_w is the wing form factor

and ΔC_{D_M} is given by[19] : $10(M-M_D)^3$ if $M>M_D$ or

0 , otherwise

The drag divergence Mach number, M_D is defined as:

$$M_D=A_1+A_2C_L+0.08SC_{FAX}$$

where SC_{FAX} is the supercritical aerofoil parameter which may be input as SC_{FAC} to shift the drag divergence Mach number of the aerofoil. It may take values ranging from 0 to 1 (figure III.1.3 of ref 19).

A_1 and A_2 are compressibility drag parameters which depend on the wing and aerofoil geometries as well as on the wing pressure distributions.

These compressibility parameters are computed using the following empirically derived expressions:

$$A_1=[1+0.0033(4\Lambda_{p_{\min}}-3\Lambda_{t/c_{Max}})][1-1.4t/c-0.06(1-\bar{x}_{p_{\min}})]-0.0368$$

and

$$A_2=-0.33(0.65-\bar{x}_{p_{\min}})[1+0.0033(4\Lambda_{p_{\min}}-3\Lambda_{t/c_{Max}})]$$

where $\bar{x}_{p_{\min}}$ is the wing minimum pressure point in fraction of wing chord (taken as 0.30),

$\Lambda_{p_{\min}}$ is the sweep angle at the wing minimum pressure points, expressed in degrees,

$\Lambda_{t/c_{Max}}$ is the sweep angle at the wing maximum thickness points, expressed in degrees,

t/c is the wing average thickness to chord ratio computed by equation III.1.2 in ref 19.

The sweep angles are obtained as follows:

$$\Lambda_{P_{\min}}=\arctan[\tan\Lambda_{c/4}-\frac{4(\bar{x}_{P_{\min}}-0.25)(1-\lambda)}{A_w(1+\lambda)}]$$

and

$$\Lambda_{t/c_{Max}}=\arctan[\tan\Lambda_{c/4}-\frac{4(\bar{x}_{t/c_{Max}}-0.25)(1-\lambda)}{A_w(1+\lambda)}]$$

where $\Lambda_{c/4}$ is the wing quarter chord sweep angle,

λ is the wing taper ratio,

$\bar{x}_{t/c_{Max}}$ is the wing maximum thickness point in fraction of wing chord (taken as 0.40 for a supercritical aerofoil).

Equations included in the AERO and DRAG subroutines other than the ones just presented are detailed in Appendix B.

3.5.2.2.3 Propulsion

Although the propulsion model is unchanged, it is worth describing the methodology used and how the module operates. Propulsion system performance is calculated during engine sizing and whenever aircraft performance is evaluated. Engine performance methodology is based on tabulated performance data for specific engine cycles. The active module consists of subroutines related to turbojet/ turbofan engines (figures 3.6 and 3.7) and the routines used with their respective functions are shown next:

ENGSZ	- determines the engine size which is expressed in terms of rated sea level static airflow;
ENGINE	- determines engine performance as a function of the flight altitude, Mach number and engine power setting. Engine performance is described by thrust, airflow, fuel flow, specific thrust, percent corrected airflow and thrust specific fuel consumption;
NACDG	- computes nacelle parasite drag during engine sizing and performance calculations;

ENGDT5 - provides propulsion system performance data for the General Electric CF-34 turbo-fan engine allowing it to be scaled up or down in order to simulate a similar cycle powerplant of arbitrary size.

This engine cycle was selected for the thrust level envisioned in the design study. This same engine powers the Canadair Regional Jet which is a similar capacity transport.

The engine is first sized to match cruise drag with an excess cruise thrust to ensure a specified margin of rate of climb will be available. To satisfy required take off distance, or one engine out requirements on the aircraft rate of climb (FAR-Part 25), an engine resizing is done. Engine nacelle geometry is a function of engine size, therefore it is computed while sizing the engine. During this process, which is iterative, nacelle drag is accounted for as an aerodynamic force rather than a penalty on engine performance (this alternative option is also available in GASP).

The scaling of a particular reference engine to match the required cruise thrust is based on the assumption that at a given Mach number, altitude and engine power setting, the specific thrust,SF_n, the specific fuel consumption,SFC, and the percent corrected airflow,P_{ca}, of the scaled engine are the same as for the unscaled engine. Once ENGSZ establishes the sea level static airflow, the scaled engine performance at the specified operating point follows immediately:

Airflow

$$W_a = W_{a_{sls}} P_{ca} \frac{\delta}{\sqrt{\theta}}$$

Thrust

$$F_n = SF_n W_a$$

Fuel Flow

$$W_F = SFC * F_n$$

where $W_{a_{sls}}$ is the ISA sea level static conditions airflow,

$P_{ca} = \frac{W_{ca}}{W_{a_{sls}}}$ is the percent corrected airflow required to convert the engine corrected airflow to the corresponding rated sea level static airflow,

$W_{ca} = W_a \frac{\sqrt{\theta}}{\delta}$ is the corrected airflow,

SF_n is the specific thrust expressed in $[Lb_{thrust}/Lb_{air}/sec]$,

SFC is the specific fuel consumption expressed in [$Lb_{fuel}/HR/Lb_{thrust}$],

$\delta=\frac{P}{P_0}$ is the total pressure to SLS pressure ratio,

$\theta=\frac{T}{T_0}$ is the total temperature to SLS temperature ratio,

Subscript '0' stands for sea level static conditions.

The engine performance data contained in ENGDT5 consists of corrected thrust, corrected airflow and corrected fuel flow tabulated as functions of engine power setting and flight Mach number. Typically, engine power setting is expressed as either the ratio of turbine inlet temperature to the engine face total temperature (T5/T2) or the percent corrected rotor speed ($N/\sqrt{\theta}/N_{Max}$). The relationships are illustrated sckematically in figure 3.9 where the effect of altitude is contained implicitly in the ratios of total temperature and total pressure to sea level static values of these parameters (θ and δ), in terms of which the "corrected" values of thrust, airflow and fuel flow can be found.

3.5.2.2.4 Weight and Balance

The Weight and Balance module has undergone extensive modifications, namely in subroutines WGHT and TAIL to permit the design and analysis of the new concept. As shown in figures 3.6 and 3.7, it is composed of six subroutines, and the ones used with their purposes follow:

DLOAD	- determines the minimum design speeds and structural load factors in accordance with FAR regulations Parts 23 and 25,
WGHT	- computes the weights of the structural components, flight controls and payload and locates the wing for balance purposes, compromising the CG travel obtained from loading considerations with the allowable limits set out by the stability and control requirements,
TAIL	- determines the sizes of the horizontal and vertical tails based on stability and control considerations,
ENGWGT	- estimates the engine(s) weight(s),
WFIXEU	- determines the weight of the fixed equipment and fixed useful load.

A simplified computational flow for subroutine WGHT is shown in figure 3.10.

The weight of the aircraft structure, flight controls, engines, fixed equipment and useful load are estimated using historical trend equations[19].

Canard structural weight is estimated using the same semi-empirical relationship as developed for the wing from Torenbeek's approach[26] and a regression analysis shown in figure V.1.14[19]. This correlation takes into account the material required to resist the root bending moment due to lift in a specified flight condition and does not include the weight of the high lift devices. Whilst the wing flap weight is computed in subroutine FLAPS, the weight of the canard high lift devices will not be evaluated for simplicity, and because it may be assumed negligible in the present initial design approach.

3.5.2.2.4.1 Aircraft Balance

The wing is initially located based on default historical tail volume coefficients. Following the loading rules and solving the equations for weight moment equilibrium, the aircraft centre of gravity and the related forward and rearward positions are determined. Stability and control (S&C) is evaluated in "TAIL" so that the forward control limit falls at the c.g. at the most forward loading condition. Tail moment arms and areas are then recomputed in order to satisfy the c.g. range as well as other required longitudinal and lateral stability and control requirements. This process is iterated until the tail area converges to an acceptable tolerance which is 0.4 sqft difference in successive horizontal tail areas, in the present case. The code now allows for sizing of the canard by introducing canard parameters in terms of a volume coefficient, as used on conventional layouts, to the three-surface configuration. Basically, the procedure now implemented is the same as originally, the only difference resides on the assumptions made, already mentioned above, and on the additional complexity added due to the wing area variation which happens while refining the canard and the tailplane areas, keeping the canard/ wing area ratio constant throughout a complete design synthesis run.

Assuming there is no cargo compartment in the aircraft, the loading conditions are:

Most Forward Load Condition
- Pilots,
- All seats forward of $c.g._f$ are filled by passengers and respective over-head baggage,
- All fuel tanks forward of $c.g._f$ are full[(1)].

Most Aft Load Condition
- Pilots,
- All seats aft of $c.g._r$ are filled by passengers and respective over-head baggage,
- All fuel tanks aft of $c.g._r$ are full[(1)].

Design Load Condition
- Pilots,
- Maximum number of passengers loaded in forward seats and respective overhead baggage,
- Design fuel load contained in wing and fuselage tanks (if any).

3.5.2.2.4.2 Canard and Tail Sizing

Canard and tail sizing is governed by critical longitudinal and lateral stability and control requirements set up by the regulatory authorities. Methods used in the modified "TAIL" subroutine reflect the FAR requirements and within the program limitations the sizing

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[1] If fuel forward of $c.g._f$ (or aft of $c.g._r$) is less than minimum fuel, here assumed as 20% of wing fuel tank capacity, add fuel to the next most forward (or aft) fuel tank until minimum fuel load is reached.

criteria ensures the following:

Horizontal tail and canard

- meeting a specified longitudinal static margin;
- the ability to trim the aircraft maximum lift coefficient in the landing configuration, in ground effect;
- the ability to rotate the aircraft in the take off configuration.

Vertical tail

- meeting a specified directional static stability requirement;
- the ability to maintain the minimum control speed for twin engine aircraft.

In addition to including the necessary logic for the sizing of the three surfaces in the new configuration, the conventional configuration horizontal tail sizing procedure was replaced by a new one, more structured, providing new options for the controls locked and controls free cases and accounting for the contributions from the wing pitching moment, the thrust jet inclination and the rotational control pitching moments in the stability and control equations.

Longitudinal stability and control (stick-fixed) equations as applied to the three-lifting surface aircraft were derived from basic principles and are shown in Appendix A. The formulation implemented in "TAIL" to size the horizontal tail and the canard is based on these equations and is described below.

3.5.2.2.4.2.1 Conventional Configuration

To satisfy the requirements for longitudinal stability and control listed above the stability equation and the pitching moment equilibrium equation were combined in order to determine the minimum tail volume coefficients to satisfy both cruise stability and landing trim, and cruise stability and lift off rotation. The most critical of the two is taken and the required tailplane area, span and moment arm are computed.

Equations A7 and A4 with appropriate adjustments are used and shown next:

- Cruise Stability

For a required static margin and c.g. range, the aircraft forward c.g. position is determined by evaluating the neutral point and the aft c.g. locations as follows:

$$\bar{x}_{np}=\bar{x}_{cg_{dC_m/dC_L=0}}=\bar{x}_{ac}-\Sigma_i\left(\frac{dC_m}{dC_L}\right)_i-\frac{a_t}{a_w}\bar{V}_t\eta_t\left(1-\frac{d\varepsilon}{d\alpha}\right)$$

$$x_{cg_{aft}}=x_{np}-SM \quad ,$$

thus,

$$\bar{x}_{cg_{fwd}}=\bar{x}_{cg_{aft}}-\Delta\bar{x}_{cg}$$

where,

$\bar{x}_{np}$ is the aircraft neutral point location as fraction of wing mean aerodynamic chord,

$\bar{x}_{ac}$ is the aircraft aerodynamic centre location as fraction of the wing mean aerodynamic chord,

$\Sigma_i(\frac{dC_m}{dC_L})_i=(\frac{dC_m}{dC_L})_{fus}+(\frac{dC_m}{dC_L})_{nac}+(\frac{dC_m}{dC_L})_{th_{dir}}+(\frac{dC_m}{dC_L})_{th_{jinc}}$ is the sum of the fuselage, nacelles and powerplant installation contributions to stability,

a_w and a_t are the wing and tailplane lift curve slopes,

$\bar{V}_t=(\bar{x}_{cg}-\bar{x}_t)\frac{S_t}{S_w}$ is the tail volume coefficient,

$\bar{x}_{cg}$ is the aircraft c.g. location as fraction of the wing mean aerodynamic chord,

$\bar{x}_t$ is the tailplane aerodynamic centre location as fraction of the wing mean aerodynamic chord,

S_t is the tailplane planform area,

S_w is the wing planform area,

$\eta_t=\frac{q_t}{q}$ is the dynamic pressure ratio at the tail to that of the undisturbed free air stream,

$\frac{d\varepsilon}{d\alpha}$ is the rate of change of wing downwash at the horizontal tail with angle of attack,

SM is the specified longitudinal static margin,

$\bar{x}_{cg_{aft}}$ is the rearward location of the c.g. as fraction of the wing mean aerodynamic chord,

$\Delta\bar{x}_{cg}$ is the c.g. range as fraction of the wing mean aerodynamic chord,

$\bar{x}_{cg_{fwd}}$ is the forward c.g. location as fraction of the wing mean aerodynamic chord.

- Landing Flare and Lift-off Rotation

To evaluate the horizontal tail volume coefficient the equation for pitching moment equilibrium is used:

$$C_{m_{cg}}=C_L(\bar{x}_{cg}-\bar{x}_{ac})+\Sigma_i C_{m_i}+a_t\alpha_t\bar{V}_t\eta_t=0$$

resolving for $\bar{V}_t$ it becomes

$$\bar{V}_t=\frac{C_L(\bar{x}_{ac}-\bar{x}_{cg})-\Sigma_i C_{m_i}}{a_t\alpha_t\eta_t}$$

where,

$\Sigma_i C_{m_i}$ is the sum of the various pitching moment contributions,

$\alpha_t=\alpha_w-\varepsilon-i_w+i_t+\tau_e\delta_e$ is the tailplane angle of attack,

α_w is the wing angle of attack,

ε is the wing downwash angle at the horizontal tail,

i_w and i_t are the wing and tailplane incidence angles,

$\tau_e=\dfrac{d\alpha_t}{d\delta_e}$ is the elevator control effectiveness,

δ_e is the elevator deflection.

For the two critical control cases, the tail volume coefficients are obtained by replacing the corresponding parameters, ground effects included, in the above equation as detailed below:

Landing Flare

$$\bar{V}_{t_L}=\frac{C_{L_{\max_L}}(\bar{x}_{ac_L}-\bar{x}_{cg_{fwd}})-(C_{m_{ac}}+C_{m_{flap}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th_{dir}}}+C_{m_{th_{jinc}}})_L}{a_{t_L}\eta_{t_L}(\alpha_{w_L}-\varepsilon_L-i_w+i_t+\tau_e\delta_{e_{\max}})}$$

Lift-off Rotation

$$\bar{V}_{t_r}=\frac{C_{L_r}(\bar{x}_{ac_r}-\bar{x}_{cg_{fwd}})-(C_{m_{ac}}+C_{m_{flap}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th_{dir}}}+C_{m_{th_{jinc}}}+C_{m_{lg}}-C_{m_{I_{YY}}})_r}{a_{t_r}\eta_{t_r}(\alpha_{w_r}-\varepsilon_r-i_w+i_t+\tau_e\delta_{e_{\max}})}$$

where,

$C_{m_{ac}}$ is the wing pitching moment coefficient,

$C_{m_{flap}}$ is the flap pitching moment coefficient,

$C_{m_{fus}}$ is the fuselage pitching moment coefficient,

$C_{m_{nac}}$ is the nacelles pitching moment coefficient,

$C_{m_{th_{dir}}}$ is the propulsion direct thrust pitching moment coefficient,

$C_{m_{th_{jinc}}}$ is the propulsion jet-induced downwash at the tail pitching moment coefficient,

$C_{m_{lg}}$ is the landing gear pitching moment coefficient,

$C_{m_{I_{YY}}}$ is the pitching moment coefficient contribution due to the aircraft inertia resistance to rotation,

L and r subscripts stand for landing flare-out and lift-off rotation.

Using the greatest of the tail volume coefficients obtained, the following geometric data is determined:

Tailplane area, $S_t=\frac{\bar{V}_t S_w \bar{c}_w}{l_{t_{cg}}}$

Tailplane span, $b_t=(A_t S_t)^{1/2}$

Tailplane moment arm, $l_{t_{\bar{c}/4}}=l_{t_{cg}}+(\bar{x}_{\bar{c}/4}-\bar{x}_{cg_{aft}})\bar{c}_w$

where, $l_{t_{cg}}=(x_{cg}-x_t)$ is the tailplane moment arm referred to the aircraft c.g.,

and $l_{t_{\bar{c}/4}}=(x_{\bar{c}/4}-x_t)$ is the tailplane moment arm referred to the wing mean aerodynamic quarter chord point.

3.5.2.2.4.2.2 Three-Surface Configuration

Again, to meet the longitudinal S&C requirements, the stability and the pitching moment equilibrium equations as presented in Appendix A were combined to determine the minimum canard and tail volume coefficients consistent with both cruise stability and landing trim, and cruise stability and lift-off rotation. The most critical of the two volume coefficient combinations is adopted and the canard and tailplane areas, spans and moment arms readily obtained.

Equations A7, A39, A42 and A47 and A48 with appropriate adjustments and arrangements are implemented and presented below:

- Cruise Stability

Similarly to the conventional concept case, the aircraft forward c.g. position is determined by evaluating the neutral point and the aft c.g. positions for a given static margin and c.g. range:

$$\bar{x}_{np}=\bar{x}_{ac}-\Sigma_i\left(\frac{dC_m}{dC_L}\right)_i-\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t\left(1-\frac{d\varepsilon}{d\alpha}\right)$$

thus,

$$\bar{x}_{cg_{fwd}}=\bar{x}_{np}-SM-\Delta\bar{x}_{cg}$$

where, $\Sigma_i\left(\frac{dC_m}{dC_L}\right)_i$ is defined as in the conventional configuration case,

a_c is the canard lift curve slope,

$\bar{V}_c=(\bar{x}_{cg}-\bar{x}_c)\frac{S_c}{S_w}$ is the canard volume coefficient,

$\bar{x}_c$ is the canard aerodynamic centre location as fraction of the wing mean aerodynamic chord,

S_c is the canard planform area.

- Landing Flare and Lift-off Rotation

Equations A39/ A47 and A42/ A48, derived from the equation for pitching moment equilibrium assuming that the fore-plane and the horizontal tail contributions to the overall pitching moment are equal, give the forward c.g. location in terms of the tail and the canard parameters respectively. Both may be written in the following form for the two flying conditions considered:

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2}{C_L}a_t\alpha_t\bar{V}_t\eta_t-\frac{1}{C_L}\Sigma_i C_{m_i}$$

and,

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2}{C_L}a_c\alpha_c\bar{V}_c-\frac{1}{C_L}\Sigma_i C_{m_i}$$

where, $\alpha_t=\alpha_w-\varepsilon-i_w+i_t+\tau_e\delta_e$ is the tailplane angle of attack,

$\alpha_c=\alpha_w-\alpha_{0_c}-i_w+i_c+\tau_c\delta_c$ is the canard angle of attack,

α_{0_c} is the canard zero-lift angle of attack,

i_c is the canard incidence angle,

$\tau_c=\frac{d\alpha_c}{d\delta_c}$ is the canardvator control effectiveness,

δ_c is the canardvator deflection.

Two systems of real linear equations are obtained, concerning the landing flare-out and the nose wheel liftoff rotation situations while ensuring longitudinal static stability in cruise, by combining individually the above stability derived equation with the two later control equations. The canard and tailplane volume coefficients are found through the solution to these systems of equations that are shown next:

Cruise Stability and Landing Flare

$$a_{11_L}\bar{V}_{c_L}+a_{12_L}\bar{V}_{t_L}=b_{1_L}$$

$$a_{21_L}\bar{V}_{c_L}+a_{22_L}\bar{V}_{t_L}=b_{2_L}$$

Replacing for the appropriate parameters that include the ground effects the coefficients of the equations are defined:

$$a_{11_L}=(-\frac{a_c}{a_w})_{cr}$$

$$a_{12_L}=[-\frac{a_t}{a_w}\eta_t(1-\frac{d\varepsilon}{d\alpha})]_{cr}+\frac{2}{C_{L_{\max_L}}}a_{t_L}(\alpha_{w_L}-\varepsilon_L-i_w+i_t+\tau_e\delta_{e_{\max}})\eta_{t_L}$$

$$a_{21_L}=a_{11_L}+\frac{2}{C_{L_{\max_L}}}a_{c_L}(\alpha_{w_L}-\alpha_{0_c}-i_w+i_c+\tau_c\delta_{c_{\max}})$$

$$a_{22_L}=[-\frac{a_t}{a_w}\eta_t(1-\frac{d\varepsilon}{d\alpha})]_{cr}$$

$$b_{1_L}=[-\bar{x}_{ac}+\Sigma_i(\frac{dC_m}{dC_L})_i+SM+\Delta\bar{x}_{cg}]_{cr}+[\bar{x}_{ac_L}-\frac{1}{C_{L_{\max_L}}}\Sigma_i C_{m_{i_L}}]$$

$$b_{2_L}=b_{1_L}$$

where, $\Sigma_i(\frac{dC_m}{dC_L})_{i_{cr}}=[(\frac{dC_m}{dC_L})_{fus}+(\frac{dC_m}{dC_L})_{nac}+(\frac{dC_m}{dC_L})_{th_{dir}}+(\frac{dC_m}{dC_L})_{th_{jinc}}]_{cr}$

$$\Sigma_i C_{m_{i_L}}=(C_{m_{ac}}+C_{m_{flap}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th_{dir}}}+C_{m_{th_{jinc}}})_L$$

Cruise Stability and Lift-off Rotation

$$a_{11_r}\bar{V}_{c_r}+a_{12_r}\bar{V}_{t_r}=b_{1_r}$$

$$a_{21_r}\bar{V}_{c_r}+a_{22_r}\bar{V}_{t_r}=b_{2_r}$$

Identically, using the appropriate parameters that account for the ground effects the coefficients of these equations are:

$$a_{11_r}=a_{11_L}$$

$$a_{12_r}=[-\frac{a_t}{a_w}\eta_t(1-\frac{d\varepsilon}{d\alpha})]_{cr}+\frac{2}{C_{L_r}}a_{t_r}(\alpha_{w_r}-\varepsilon_r-i_w+i_t+\tau_e\delta_{e_{\max}})\eta_{t_r}$$

$$a_{21_r}=a_{11_L}+\frac{2}{C_{L_r}}a_{c_r}(\alpha_{w_r}-\alpha_{0_c}-i_w+i_c+\tau_c\delta_{c_{\max}})$$

$$a_{22_r}=a_{22_L}$$

$$b_{1_r}=[-\bar{x}_{ac}+\Sigma_i(\frac{dC_m}{dC_L})_i+SM+\Delta\bar{x}_{cg}]_{cr}+[\bar{x}_{ac_r}-\frac{1}{C_{L_r}}\Sigma_i C_{m_{i_r}}]$$

$$b_{2_r}=b_{1_r}$$

where, $\Sigma_i C_{m_{i_r}}=(C_{m_{ac}}+C_{m_{flap}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th_{dir}}}+C_{m_{th_{jinc}}}+C_{m_{lg}}-C_{m_{I_{YY}}})_r$

The solutions to these systems of equations are obtained using the Cramer's rule which is implemented in the new "Cramer" subroutine included in the program.

The critical canard and tailplane volume coefficients to consider are those whose sum provides a higher value. Once this is done geometric data such as the canard and tail areas, spans and moment arms are determined:

Tail

Tailplane moment arm, $l_{t_{cg}}=l_{t_{\bar{c}/4}}+(\bar{x}_{cg_{aft}}-\bar{x}_{\bar{c}/4})\bar{c}_w$

Tailplane area, $S_t=\frac{\bar{V}_t S_w \bar{c}_w}{l_{t_{cg}}}$

Tailplane span, $b_t=(A_t S_t)^{1/2}$

Canard

Canard moment arm, $l_{c_{cg}}=l_{c_{\bar{c}/4}}+(\bar{x}_{cg_{aft}}-\bar{x}_{\bar{c}/4})\bar{c}_w$

Canard area, $S_c=\frac{\bar{V}_c S_w \bar{c}_w}{l_{c_{cg}}}$

Canard span, $b_c=(A_c S_c)^{1/2}$

Finally, a first order approximation of the canardvator deflection is given by equation A44 reproduced next:

$$\delta_{c_{\max_L}}=\frac{C_{m_{\delta_{e_L}}}}{C_{m_{\delta_{c_L}}}}(\delta_{e_{\max}}+\frac{\alpha_{t_L}}{\tau_e})-\frac{(\alpha_c-\alpha_{0_c})_L}{\tau_c}$$

where, $C_{m_{\delta_{e_L}}}=a_{t_L}\bar{V}_t\eta_t\tau_e$ is the elevator power, at landing conditions in ground effect,

$C_{m_{\delta_{c_L}}}=a_{c_L}\bar{V}_c\tau_c$ is the canardvator power, at landing conditions in ground effect,

$\alpha_{t_L}=\alpha_{w_L}-\varepsilon_L-i_w+i_t$ is the horizontal tail angle of attack at landing in ground effect,

$\alpha_{c_L}=\alpha_{w_L}-i_w+i_c$ is the canard angle of attack at landing in ground effect.

Most of the canard related aerodynamic derivatives are obtained using the same DATCOM type methods as implemented in GASP and used to estimate the tailplane aerodynamic derivatives[19].

As far as the vertical tail is concerned, GASP original procedure[19] is kept unchanged and is applied to both concepts as it stands.

Equations other than the ones shown above and incorporated in subroutines WGHT and TAIL are detailed in Appendix B.

3.5.2.2.5 Mission Performance

The Mission Performance module requires consideration of propulsion, aerodynamics and weight characteristics so the interaction between the subroutines within the program becomes quite complex. It is composed of thirteen subroutines as shown in figures 3.6 and 3.7 and those actually used with their purpose are listed below:

PERFRM	- defines the mission profile and controls the mission computations,
TAXI	- computes the fuel consumption during ground idle,
TAKOFF	- models the take-off manoeuvre up to a specified altitude,
ACCEL	- models the aircraft rectilinear acceleration at constant altitude between mission segments,
CLIMB	- simulates a constrained climb,
XRANGE	- performs cruise range computation,
DESCND	- computes the descent performance,
DLAND	- models the landing manoeuvre,
DERIV	- determines derivatives and checks constraints for the TAKOFF routine,
ASPEED	- determines speed at specified power for equilibrium horizontal flight,
CEILNG	- computes the engine-out service ceiling or the rate of climb for a specified altitude,
RGBAL	- controls the aircraft resizing process to meet the specified range or endurance within a tolerance of 1%.

To ensure consistency with the new reference area adopted for the simulation of the three-surface aircraft, the module was modified to include minor changes in the subroutines TAKOFF, ACCEL, CLIMB, DESCND, DLAND, DERIV, CEILNG and RGBAL, which are reflected in the equations shown in Appendix B.

As stated previously, the mission performance module is used to determine the engine size and the wing loading necessary to meet the specified performance constraints and to compute the amount of fuel required for the mission.

The mission profile consists basically of 6 segments:

- taxi,
- take-off,
- climb,
- cruise,
- descent,
- landing

where straight level flight acceleration is assumed and computed by ACCEL between take-off and climb and climb and cruise.

3.5.2.2.5.1 Taxi

For an input taxi time and runway altitude, assuming the engines at idle thrust, the TAXI routine returns the corresponding burned fuel weight.

3.5.2.2.5.2 Take-off

TAKOFF computes the take-off field performance assuming a sequence of events starting from the beginning of the take-off run up to a specified height as follows:

- initiate ground roll and accelerate,
- rotate,
- lift-off,
- begin landing gear retraction at 50 ft (retraction time assumed = 7 sec),
- distance to an altitude of 35 ft,
- distance to an altitude of 50 ft,
- begin flap retraction at 400 ft (retraction rate assumed = 3.333 degrees/ sec),
- end of take-off at a specified altitude.

For twin engine aircraft the optional engine-out take-off performance can be evaluated. This consists of a continued take-off to an altitude of 50 ft with a failed engine and an accelerate-stop distance consisting of:

- initiate ground roll and accelerate,
- engine failure,
- remove power,
- apply brakes,
- stop aircraft.

The take-off manoeuvre is analysed at maximum engine thrust by integrating the equations of motion for velocity, flight path angle, distance and altitude, using a time interval of 0.2 sec. After the take-off distance has been obtained, the engine size can be varied to satisfy a required take-off field constraint.

3.5.2.2.5.3 Climb

Three types of climb trajectory can be simulated by CLIMB with either maximum thrust or maximum continuous thrust settings and constrained by the pitch angle and the maximum FAR equivalent airspeed at altitudes below 10 000 ft:

- at maximum rate of climb,
- at maximum allowable operating speed,
- at a specified equivalent airspeed.

A point performance technique at required altitude intervals is used for the climb trajectory computation and the engine can be sized so that the aircraft meets the FAR engine-out climb requirements. As already referred to in the Propulsion section, the engine sizing will also take into consideration that enough thrust is available at cruise conditions to meet a prescribed rate of climb.

3.5.2.2.5.4 Cruise

Cruise performance, range and cruise fuel weight is computed by XRANGE using the Breguet range equations for three fuel capacities and three cruise Mach number conditions:

Fuel Capacities:

- Maximum available fuel weight (minimum payload),
- Minimum available fuel weight (maximum payload)
- Design availabe fuel weight.

Mach Numbers:

- Specified cruise Mach number,
- Normal thrust Mach number,
- Maximum specific range Mach number.

Altitude is assumed fixed, during cruise flight.

3.5.2.2.5.5 Descent and Landing

DESCND computes the descent performance constrained by the cabin de-pressurization rate, the fuselage angle and the maximum FAR equivalent speed under 10 000 ft altitude.

The landing field performance is modelled in DLAND by a sequence of four events:

- a glide approach from 50 ft altitude,
- a circular flare to touchdown at constant load factor and velocity,
- a ground roll delay before braking,
- a braked ground roll with or without application of thrust reversers.

If a specified landing distance constraint is not met an iteration on wing loading is performed until the constraint is satisfied. This involves the recomputation of the geometry, aerodynamics, weights and performance.

3.5.2.2.6 Economics

As shown in figures 3.6 and 3.7, the Economics module is composed of two subroutines performing the following tasks:

GACOST	- computes the engine and the airframe costs as well as the direct operating cost (DOC) of the aircraft,
AFCOST	- computes the Research, Development, Testing and Evaluation (RDT&E) costs, the detailed airframe production costs and the initial aircraft cost.

Once the sizing process is completed, this module is called to evaluate the economic worth of the aircraft. GACOST makes use of the engine and airframe cost estimating relationships (CER) developed by Anderson[27] and the Boeing 1977 DOC methodology[29]. RDT&E costs are estimated using a Rand type of formulation based on the airframe weight and cruise Mach number and the detailed airframe production cost is evaluated based on CERs developed by Beltramo[28] in AFCOST. All these costs are corrected to 1993 using a cost escalation factor (CEF) based on an average annual inflation rate of 8%.

The direct operating cost is defined as the sum of the flight crew salary, fuel and oil costs and taxes, insurance, direct maintenance costs involving both the airframe and engines maintenance, maintenance burden costs and depreciation.

Crew salary is a function of the aircraft maximum take-off weight, cruise speed and trip block time. Annual insurance cost is assumed to be 5% of the initial aircraft cost. Airframe direct maintenance costs are composed of material costs and labour costs, and are functions of the airframe weight, flight time, and labour rate of pay. Engines direct maintenance costs are made up of material and labour costs, and are functions of the engine maximum sea level static thrust, number of engines, flight time, and labour rate. Maintenance burden is assumed to be twice the direct maintenance labour costs. Aircraft depreciation is dependent on its initial purchase cost, the estimated spares factor assumed here as 6% of that cost, the number of years in operation and its residual value.

Changes have only been incorporated in subroutine AFCOST in order to reflect the canard cost in the airframe production costs. The estimating correlation used is the same as used for the wing production cost and is presented in Appendix B.

3.5.2.2.7 Utilities

The last group of subroutines displayed in figure 3.6 consists of a library of numerical methods which may be called by the other subroutines and which typically perform a numerical function. Those used and their role are as follows:

TPALT - computes the atmospheric properties or altitude, whichever is applicable,
OUTPUT - prints the geometric data, weights, aerodynamic, and cost results of the design,
Cramer - computes the solution of a system of real linear equations using the Cramer's rule,
BIV - performs linear interpolation in two independent stored variables,
INTS - performs the numerical integration by finite differences of a system of simultaneous first-order differential equations. These equations are defined in subroutine DERIV.
ITRLN - performs linear interpolation in one independent stored variable,
ITRMHW - finds a zero of a function using the Newton-Raphson method.

These subroutines were employed without modifications except Cramer which was purposely developed to assist the computation of the canard and horizontal tail volume coefficients in the new TAIL routine.

3.6 Limitations of the Design Model

The design model is a mathematical abstraction of the envisioned real system. It contains the underlying physics of the aircraft design, including aerodynamics, weights propulsion, performance, etc. Its accuracy depends on how accurately it models reality. The mathematical model requires inputs from the real world and the results must be continuously compared with real world results, from which appropriate calibration may be provided.

In the initial conceptual design phase, when no information exists other than the mission and technology level requirements and the operational and certification criteria, the best way to proceed is to rely on statisticaly derived data from past experience and on empirical and semi-empirical disciplinary analysis methods to formulate a first approach to the solution. Of course statistical data and empirical analysis methods will only be reliable for some well ordered classes of aircraft and for the more usual conventional tail-aft configurations for which they apply and any extrapolations will incur in some degree of error due to incorrect modelling or insuficiency of data. Overall the results of a design study can only be as accurate as the data and the analysis methods on which it is based.

While it is true that historical data and empirical methods allow the reproduction of existing aircraft at their actual technology level with an acceptable degree of accuracy, they also permit the assessment of the impact produced by the introduction of new technologies, or the adoption of radical different configurations, on the performance and costs of new aircraft after appropriate inputs, modifications and adjustments have been made to the synthesis/analysis procedures. Thus extrapolation from past experience is frequently needed in spite of the risks involved, providing these are carefully and adequately controlled. It seems to be the only reasonable way to study new concepts when no specific detailed data is available.

As referred to in Chapter 2, most of the existing synthesis programs for conceptual design are automated forms of the traditional manual design procedures with more or less flexibility dependent on whether they present high or low degree of modularity, open-ended structure and interactivity with the designer. The usual result of these procedures, whether automated or not, are design concepts that will permit the selection of the few most promising ones for more detailed study rather than a very compreensive and refined good preliminary design. GASP program can be classified as a modular, open-ended, not-interactive synthesis program and represents the mathematical abstraction of the design used in the present work.

Interactivity would be particularly helpful in the development of the baseline design needed to initiate the iterative trial-and-error design procedure by allowing flair and innovation, as well as involving the designer directly with the design process; and afterwards, during the optimisation process as explained later in Section 5.4, and for rapidly performing the trade-off studies shown in Section 5.5. Although interactivity is desirable it would not be achieved unless innovation is allowed by the existing disciplinary analysis modules as well as by the synthesis procedures implemented in GASP. In fact the different modules should be prepared and re-written in such a flexible way as to permit an arbitrary geometry to be analysed, probably generated by a conceptual CAD system as exemplified by CDS[30,31] or a more advanced version of RDS-CAD[32]. The inclusion of more disciplinary modules reflecting different design criteria or new assumptions to cope with creativity would be useful as would an interactive engine with suitable controlers to allow running the analysis modules independently, or in combination as appropriate to the problem to be solved, or to the aims of a particular design investigation. Probably the integration with a commercial relational data-base would enhance the design environment by providing better storage of intermediate and final results with the potential for incorporating a commercially available CAD and Graphical systems.

Fortunately, in contrast with the difficulty presented when handling combat aircraft[33,34,35,36], the geometry of a subsonic transport aircraft can be formulated in terms of relatively straightforward equations from which the computer can derive the baseline design. This is implemented in the GASP geometric module for the conventional transport, and in order to develop the three-surface baseline concept the only change consisted of the addition of a lifting fore-plane together with the definition of its location on the fuselage and the inclusion of the initial tail/canard sizing criteria, as was already shown in Section 3.5. This latter section also reflects the considerable additional changes that were required in the disciplinary modules to produce the needed improvement in terms of innovation and creativity capacity within GASP, although of limited scope. In addition to conventional concepts, the program can now synthesize the three-surface concepts of the particular type already described (with canard/wing area ratios limited to values within 0.145 and 0.175). It will not evolve readily, for example, a canard configuration or other exotic concepts.

With regard to the accuracy of the results, the disciplinary areas where more uncertainties are posed usually correspond to the weights, aerodynamics and cost predictions. This is especially true for GASP. The Propulsion module contains actual tabulated engine performance data for current turbofan engines and the Performance module, which computes the flight profile, mission fuel required, block time, engine size and the wing loading, is quite elaborate and grounded on physical principles. This will produce results as realistic and as accurate are the weight and aerodynamic predictions provided by the respective modules.

Since it was proposed the study of the impact of a configuration change rather than that due to the introduction of new technologies, it was decided to adopt technology levels reflecting the mid-seventies period for which these modules were developed, calibrated and validated. It seems that the important issue here is to compare different concepts using the same assumptions, design criteria and ground rules.

The GASP weight predictions are usually accurate to within 10% for the maximum take-off weight as shown in ref. 21 which is typical of most conceptual design tools[5,37,38], assuming the other discipline modules are providing precise information. Since the canard will complement the wing for lift generation it is assumed that similar structural concepts are adopted for both components, thus justifying the use of the same Torenbeek's semi-empirical weight estimating relationship[26] as utilized for the wing. However the canardvator weight is not computed for simplicity, it being assumed that it is negligible at this initial stage of the design.

An accurate performance assessment requires a good prediction of the aircraft aerodynamic characteristics. GASP Aerodynamics module embodies empirical and statistical aerodynamic analysis methods[19,39] and appears to give acceptable results for conventional designs. This is shown in Appendix G where low speed and high speed drag polars for two different conventional aircraft configurations are compared with those obtained using the CoA DELTADD program. Based on a Lockheed empirical drag build-up estimation technique[11], this program is well known by its good results obtained at the early stages of preliminary design. The version now in use deals with flap systems while the original one did not.

The airlines operating costs are generally divided into Direct Operating Costs (DOC) and Indirect Operating Costs (IOC). DOC broadly comprises the costs associated with flying operations, maintenance and depreciation of flight equipment while IOC include the operator's other costs such as maintenance and depreciation of ground properties and equipment, servicing, administration and sales. Thus aircraft IOC strongly depends on the particular airline organization and managerial policy and is not under the control of the designer. On the other hand, several factors influencing DOC are directly related to the aircraft concept and operational characteristics and as such fall under the designer's control. This makes it a more attractive and convenient criterion for conceptual design economic evaluation. The Economics module as implemented in GASP consists of a systematic statistically based cost estimating procedure based on several sources, as referred to in section 3.5, whose main purpose is to provide a consistent means for comparing the operating economics of competing designs under a standard set of conditions. The corresponding results are useful for establishing first-order trends as required in the initial design stages, and not for comparing absolute levels of DOC with actual operating aircraft. The reasons are that standardized methods do not consider factors such as fleet mix and size, route structure, actual en-route winds, component commonality with other aircraft in the fleet, serviceability, reliability, variations in crew salary, labour rates and fuel costs, all of which will vary from one operator to another and can have a significant impact on costs. To give some idea about the accuracy of such methods, it is worth mentioning that the airframe production costs needed for the evaluation of the aircraft initial cost are computed using the cost estimating relationships developed by Beltramo and al[28] who demonstrated a precision within 4%, for two commercial transport aircraft (F-28 and DC-10-10) assuming a 10% manufacturer's profit, when actual component and system weights were used in the calculations.

Since the primary use of a conceptual design tool is the comparison of configurations resulting from different concepts being evaluated, changes of mission or performance requirements, varying levels of technology, relative trade-offs and trends are more important than the absolute precision of predicting a performance index. Whereas GASP absolute predictive capabilities are expected to be marginal, the accuracy of the relative comparisons of designs is expected to be good.

The above arguments suggest that the methods employed, including the modifications made which incorporate accepted engineering practices, simplifications and assumptions, often needed at the initial preliminary design stages, will ensure acceptable results for conceptual design work providing caution is exercised on their applicability and appropriate empirical correction factors are applied where necessary. Historical data blended with empirical or semi-empirical analysis techniques when adequately applied, and cautiously extrapolated, provide a measure of the feasibility of novel concepts within real world constraints.

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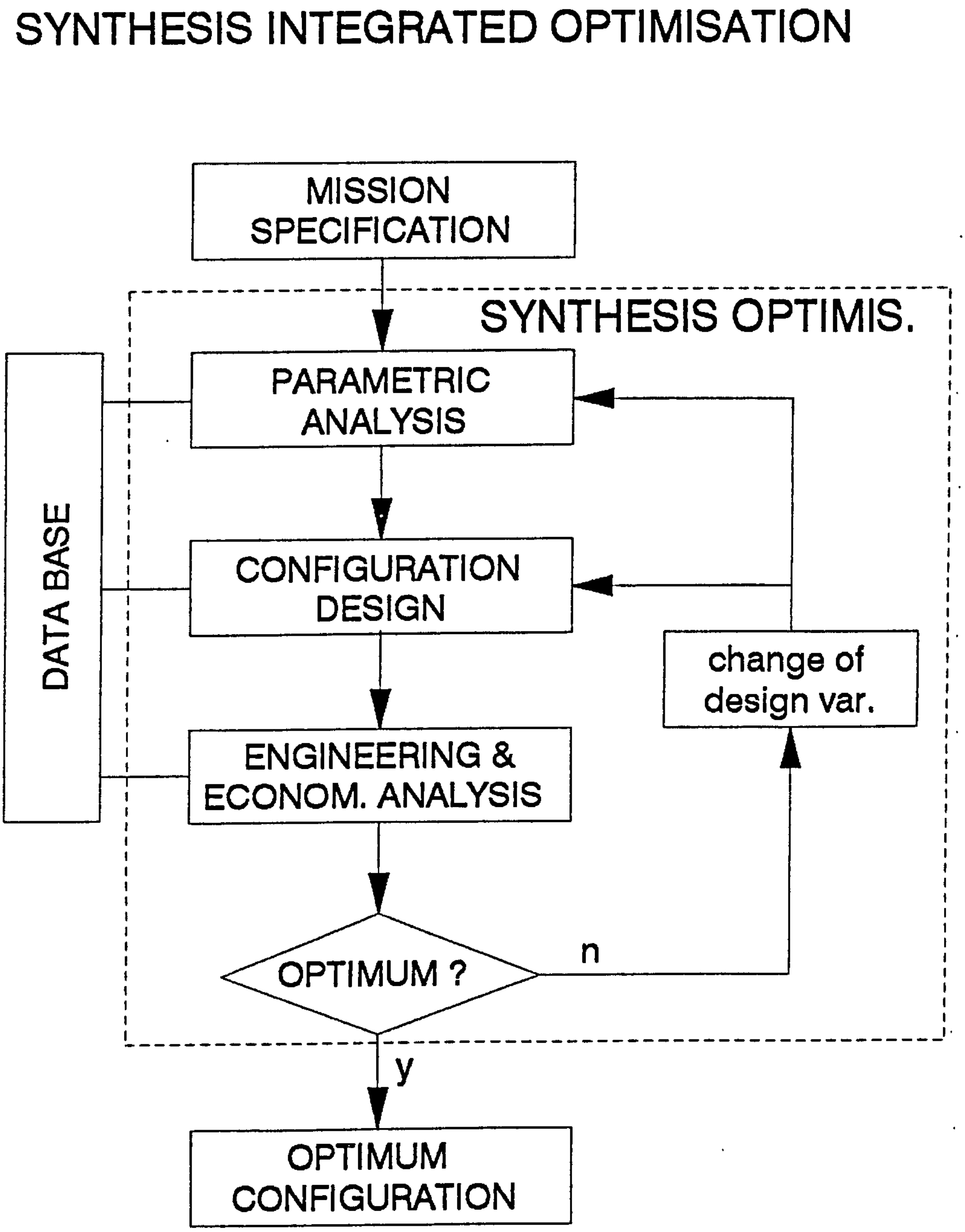


Fig 3.1 - Design Synthesis and Optimisation System Initial Flow-chart

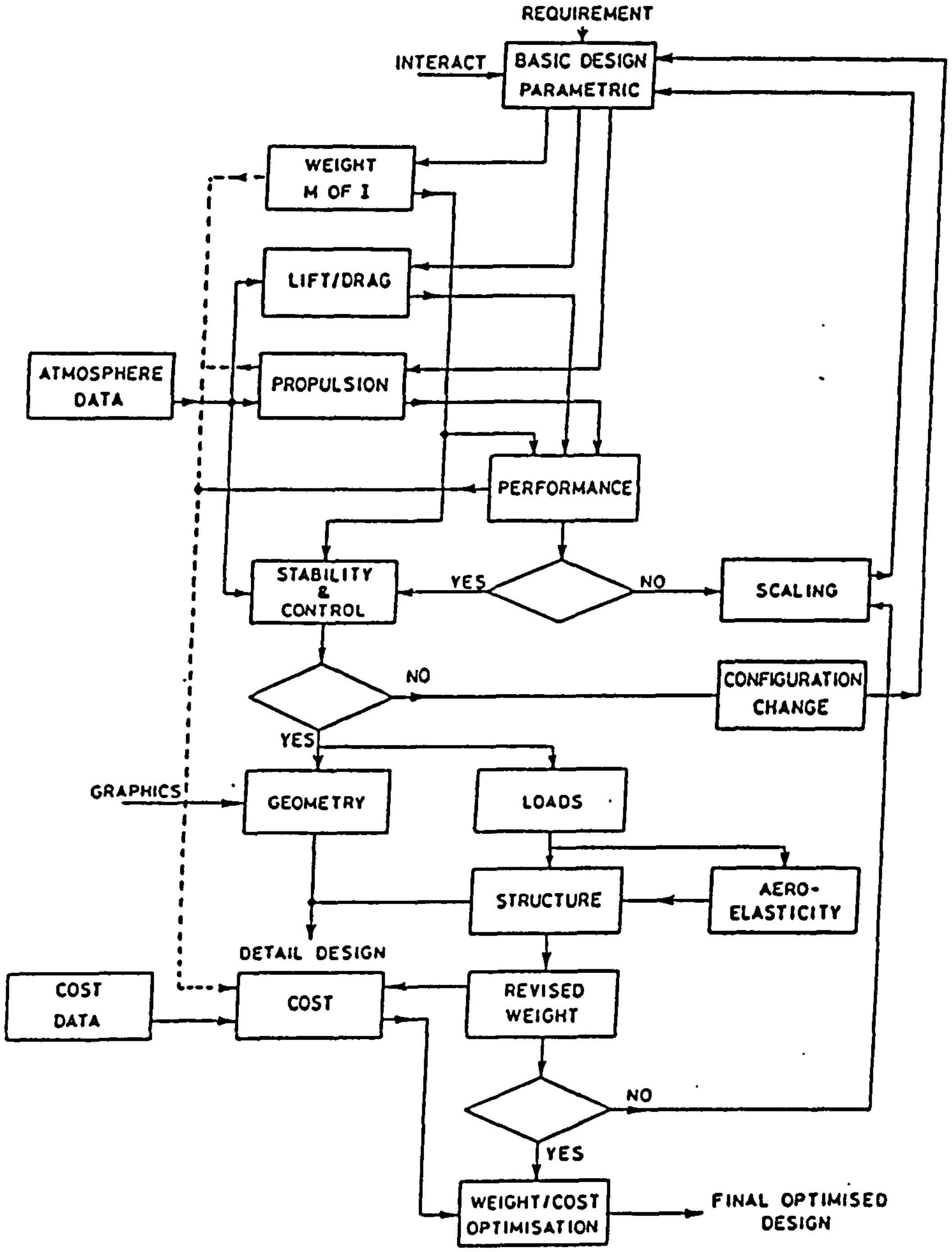


Fig 3.2 - Flow-chart of Project Design Process
(reproduced from reference 3)

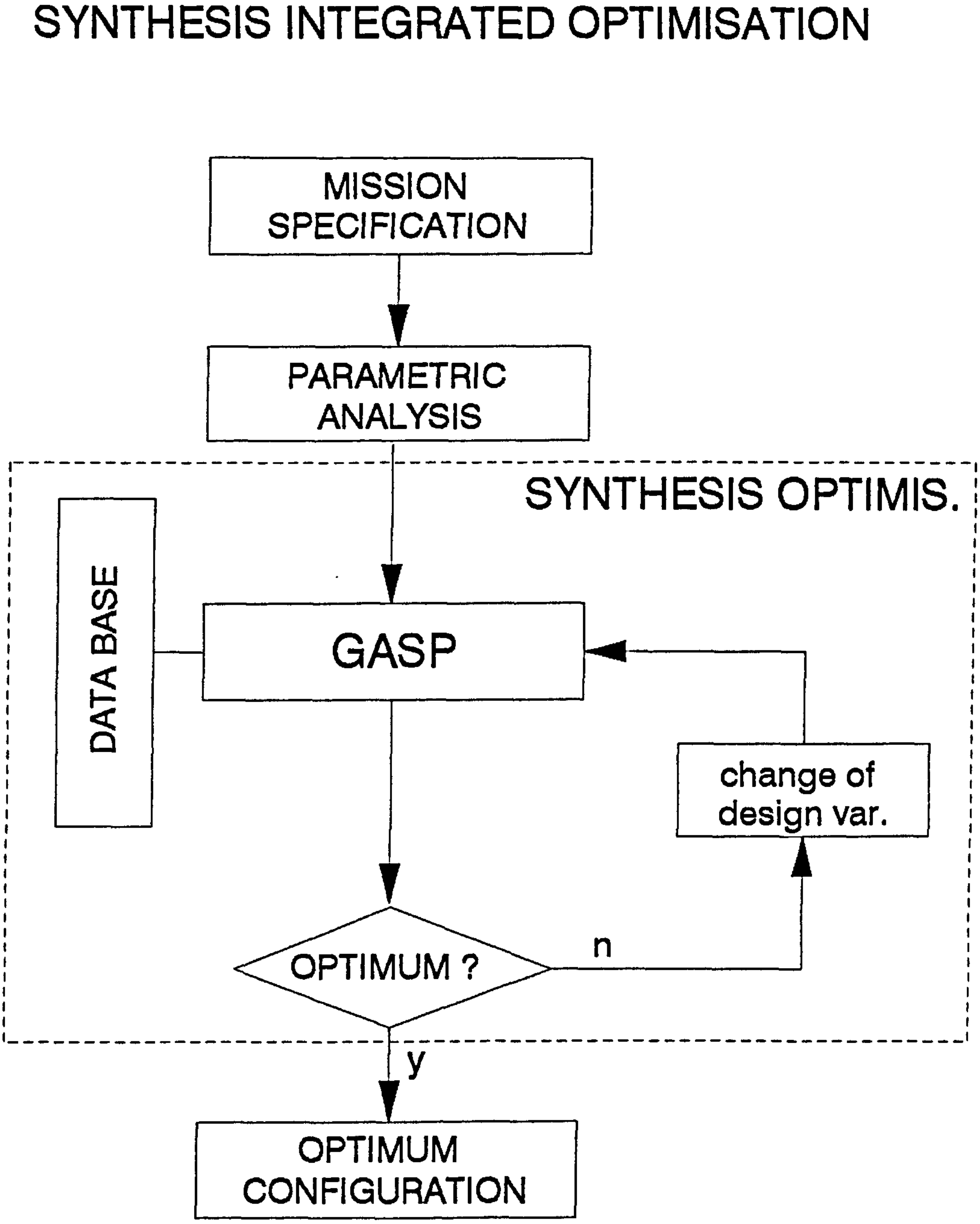


Fig 3.3 - Design Synthesis and Optimisation System Actual Flow-chart

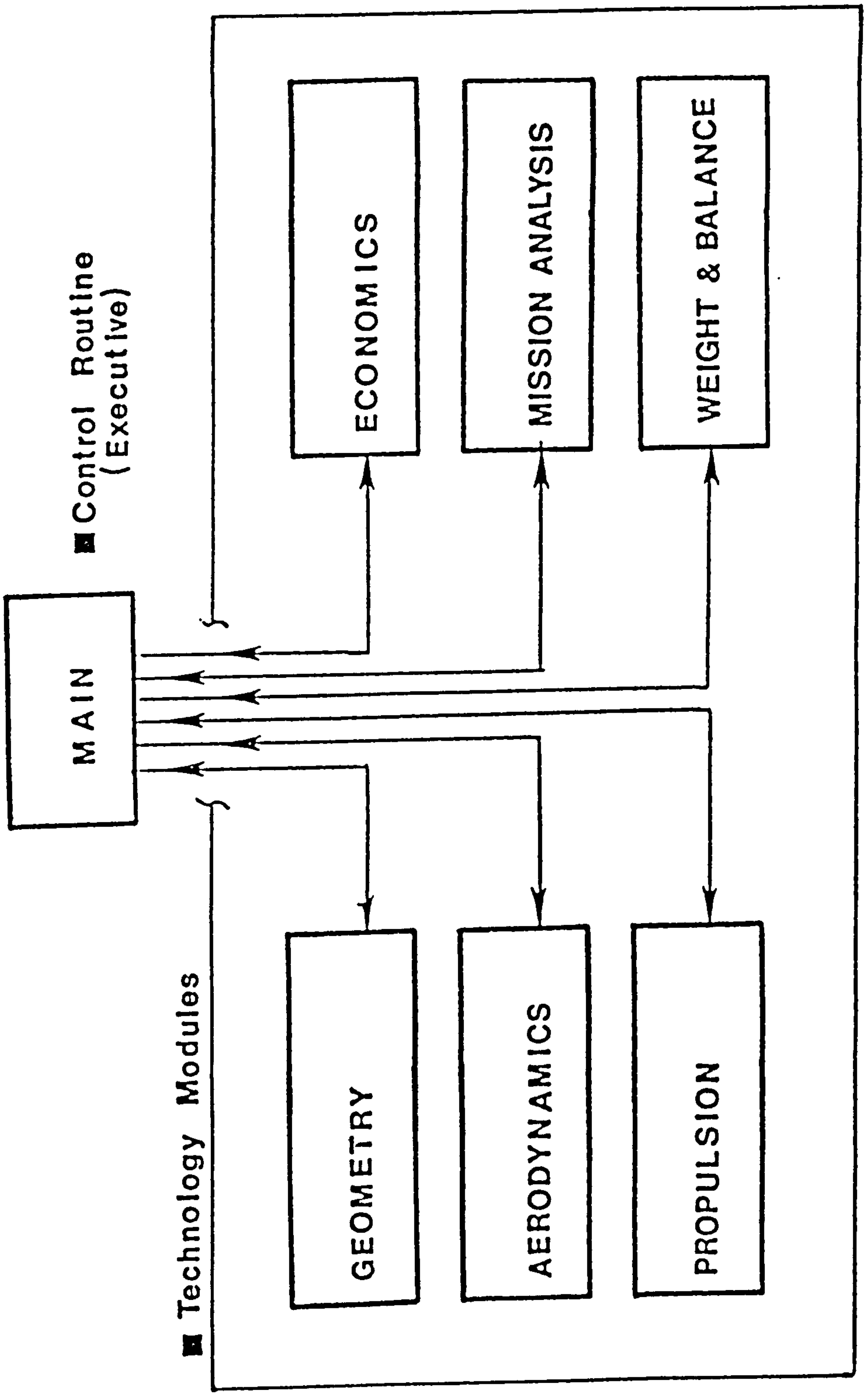


Fig 3.4 - GASP Program Structure
(reproduced from reference 19)

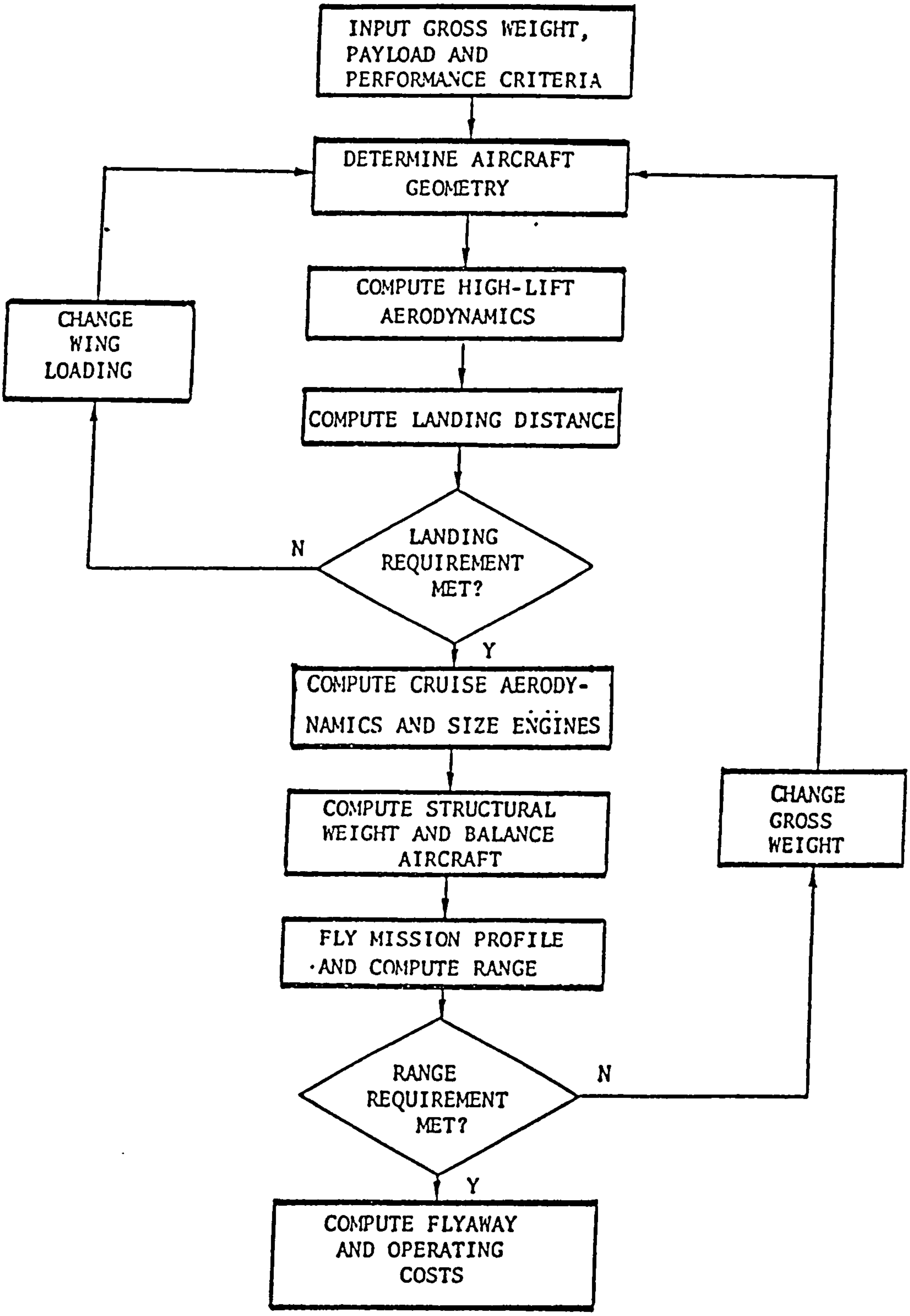


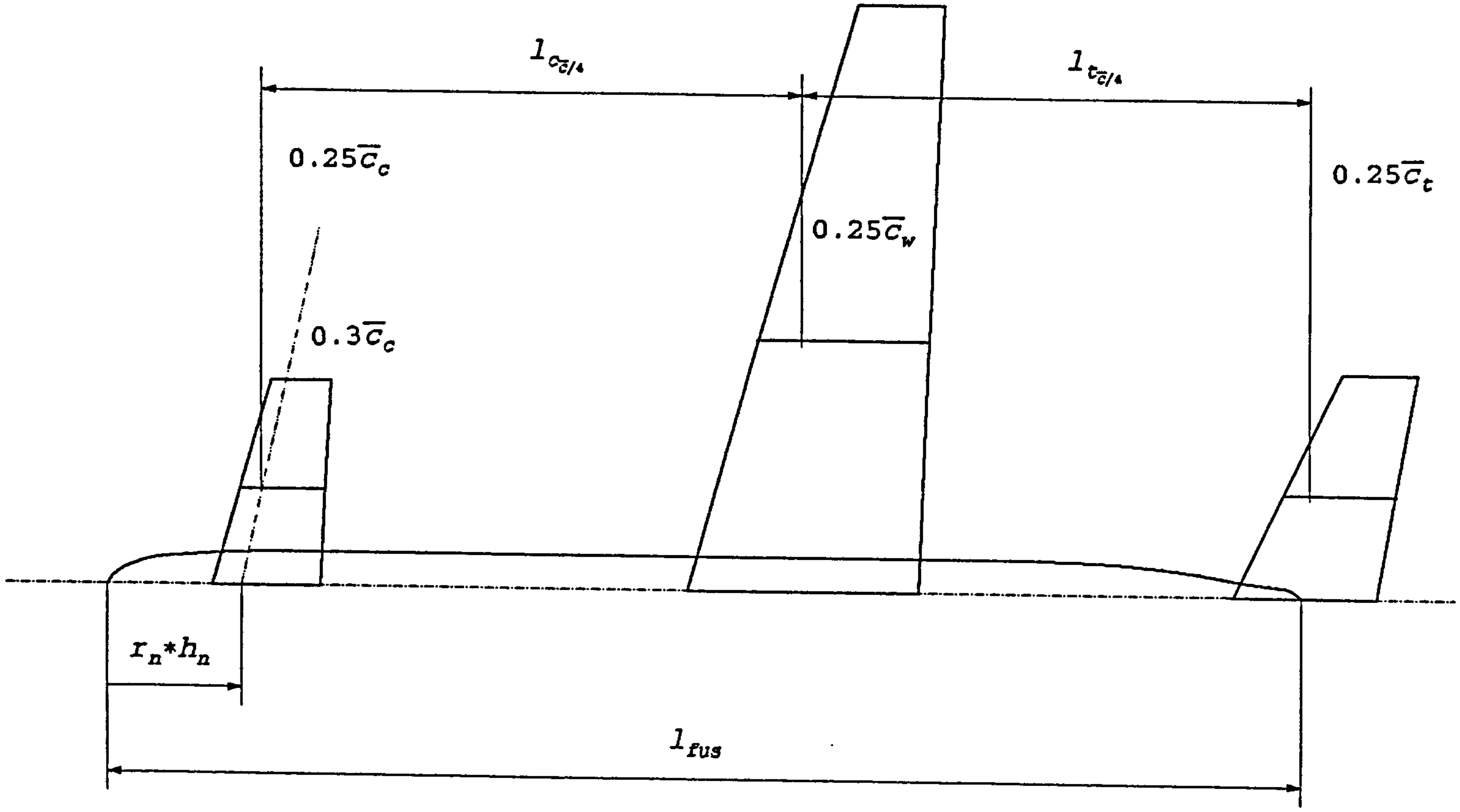
Fig 3.5 - Typical GASP Computational Flow
(reproduced from reference 19)

Purpose	Control	Geometry	Aerodynamics	Propulsion	Weight & Balance	Performance	Economics	Utilities
Program	MAIN							
Subroutines		SIZE	CTAER	ENGINE	DLOAD	PERFRM	GACOST	TPALT
			AERO	ENGSZ	WGHT	TAXI	AFCOST	OUTPUT
			DRAG	ENGDT1	TAIL	TAKOFF		Cramer
			AEROUT	ENGDT2	WFIXEU	CLIMB		BIV
			CLIFT	ENGDT3	WTREAT	ACCEL		INTS
			FLAPS	ENGDT4	ENGWGT	XRANGE		ITRLN
			EODRAG	ENGDT5		TURN		ITRMHW
			APPFLP	ENGDT6		DESCND		MAXMHW
				ENGDT7		DLAND		BISC
				ENGDT8		DERIV		MAPS
				ENGDTT		ASPEED		STORE3
				NACDG		CEILNG		
				HOPWSZ		RGBAL		
				RCWSZ				

Fig 3.6 - GASP Subroutines

Program		Subroutines called
Control	MAIN	SIZE CTAER AEROUT FLAPS ENGSZ WGHT ENGWGT PERFRM XRANGE DLAND RGBAL GACOST OUTPUT MAPS
Subroutines		
Geometry	SIZE	TPALT
Aerodynamics	CTAER	AERO DRAG CLIFT TPALT
	AERO	
	DRAG	ITRLN
	AEROUT	DRAG CLIFT FLAPS
	CLIFT	
	FLAPS	TPALT BIV ITRLN
	EODRAG	
	APPFLP	FLAPS ITRMHW
Propulsion	ENGINE	ENGDT1 ENGDT2 ENGDT3 ENGDT4 ENGDT5 ENGDT6 ENGDT7 ENGDT8 ENGDTT NACDG ITRMHW
	ENGSZ	DRAG EODRAG APPFLP ENGINE ENGWGT PERFRM TURN CEILNG TPALT
	ENGDT1	BIV ITRLN
	ENGDT2	BIV ITRLN
	ENGDT3	BIV ITRLN
	ENGDT4	BIV
	ENGDT5	BIV ITRLN
	ENGDT6	BIV ITRLN
	ENGDT7	BIV
	ENGDT8	BIV ITRLN
	ENGDTT	
	NACDG	
	HOPWSZ	ITRLN
	RCWSZ	BIV ITRLN
Weight & Balance	DLOAD	
	WGHT	CTAER ENGINE ENGSZ DLOAD TAIL WFIXEU WTREAT ENGWGT ASPEED TPALT
	TAIL	CLIFT ENGINE TPALT Cramer BIV ITRLN
	WFIXEU	
	WTREAT	ITRLN
	ENGWGT	ENGINE HOPWSZ RCWSZ
Performance	PERFRM	TAXI TAKOFF CLIMB ACCEL XRANGE TURN DLAND
	TAXI	ENGINE TPALT
	TAKOFF	DRAG CLIFT EODRAG ENGINE DERIV TPALT INTS
	CLIMB	DRAG CLIFT ENGINE TPALT
	ACCEL	CTAER DRAG ENGINE TPALT
	XRANGE	CTAER ENGINE ACCEL DESCND ASPEED TPALT ITRMHW
	TURN	DRAG ENGINE TPALT
	DESCND	DRAG CLIFT ENGINE TPALT ITRMHW
	DLAND	AERO DRAG CLIFT ENGINE TPALT
	DERIV	DRAG CLIFT
	ASPEED	CTAER ENGINE TPALT ITRMHW
	CEILNG	DRAG ENGINE TPALT
	RGBAL	SIZE CTAER AEROUT FLAPS ENGSZ WGHT ENGWGT PERFRM OUTPUT
Economics	GACOST	ENGINE ASPEED AFCOST TPALT
	AFCOST	
Utilities	TPALT	
	OUTPUT	AERO CLIFT WFIXEU TPALT
	Cramer	
	BIV	
	INTS	DERIV
	ITRLN	
	ITRMHW	
	MAXMHW	
	BISC	
	MAPS	
	STORE3	

Fig 3.7 - GASP Program and Subroutines



(Note: see also fig B1)

Fig 3.8 - Initial Canard/ Horizontal Tail Sizing

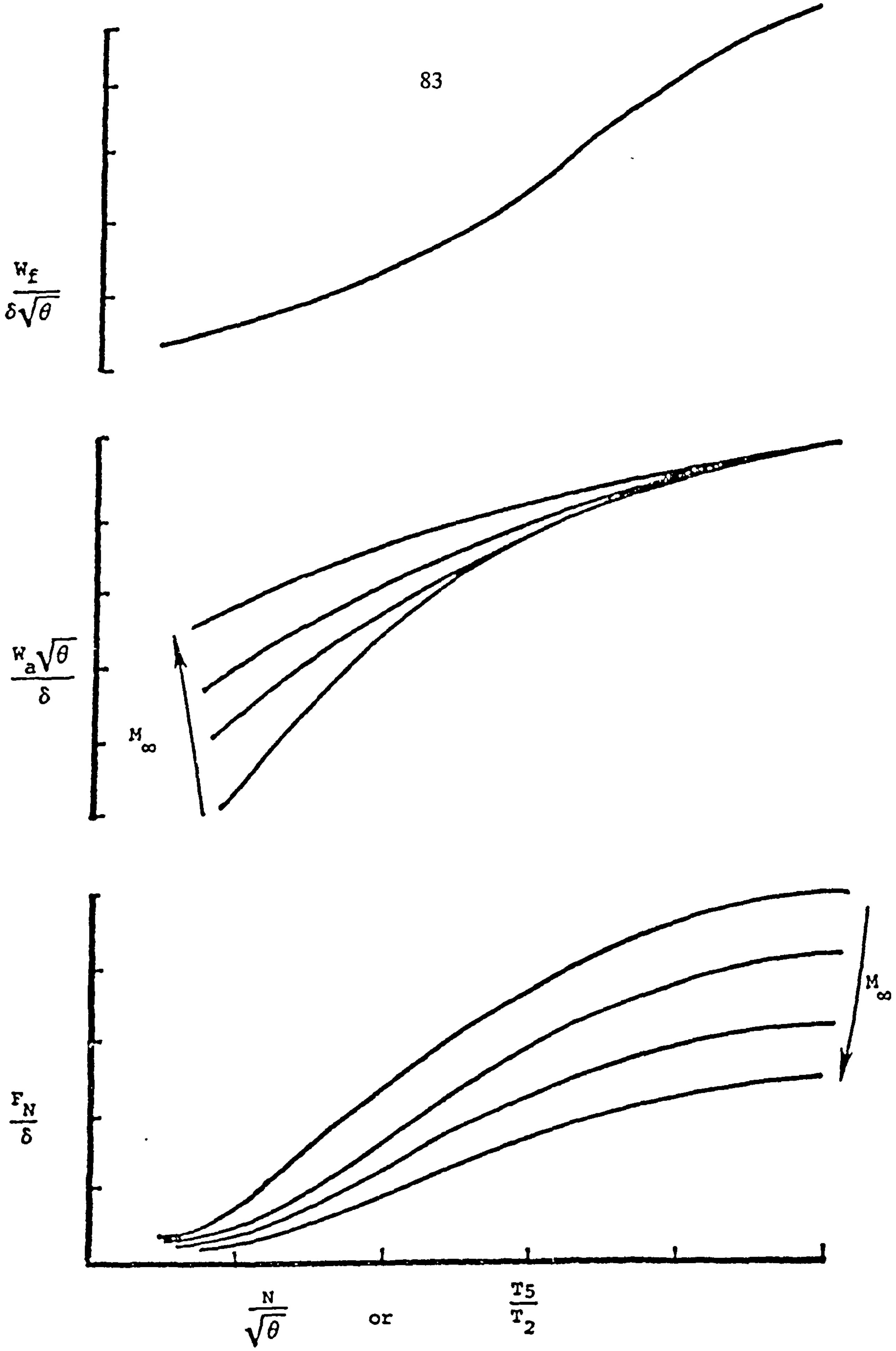


Fig 3.9 - Engine Performance
(reproduced from reference 19)

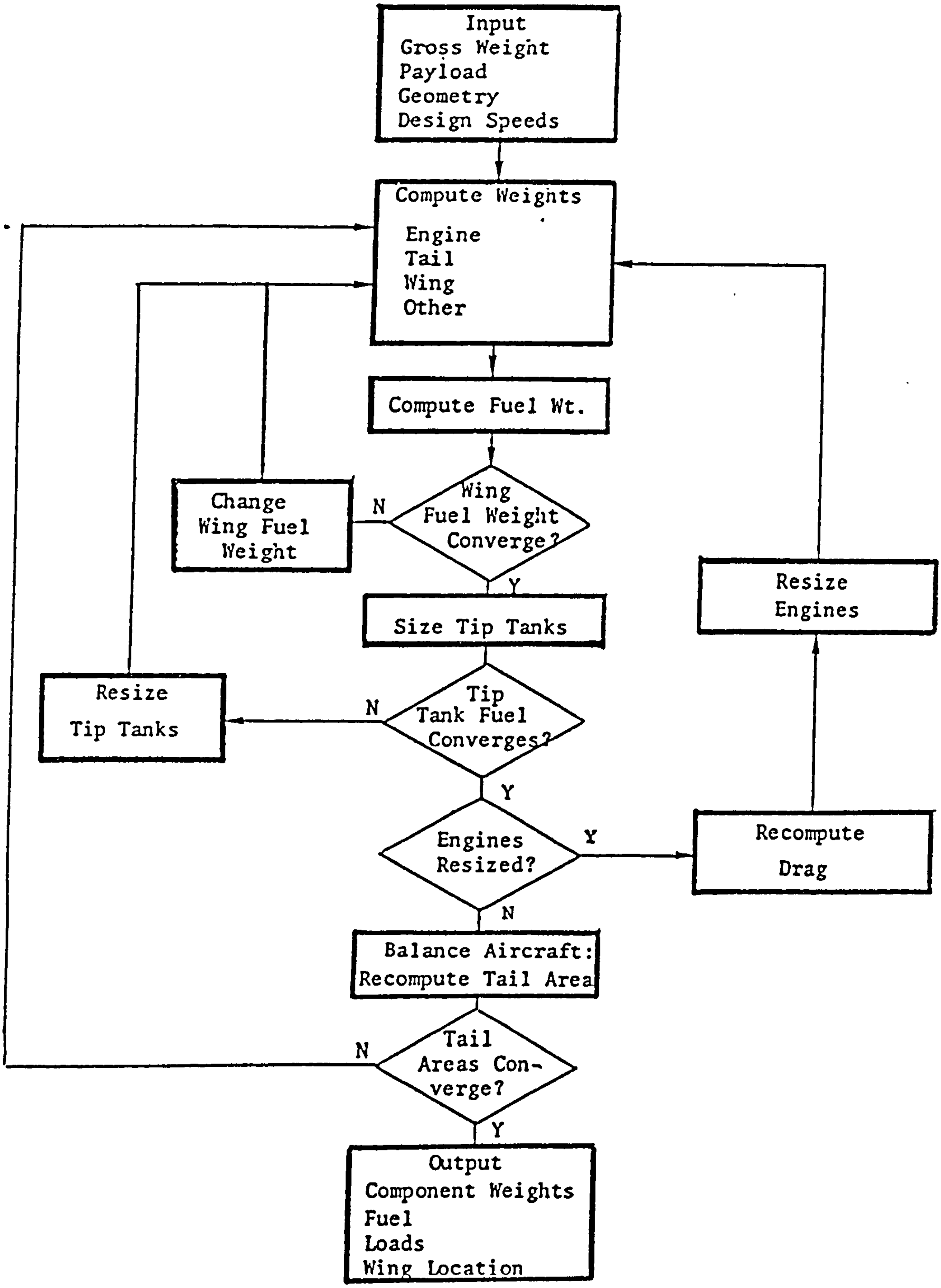


Fig 3.10 - Simplified Flow-chart for Subroutine WGHT
(reproduced from reference 19)

4 Optimisation

4.1 Problem Formulation and Minimization Technique Employed

Optimisation involves finding the best answer to a problem. Once a mathematical model of the problem has been built a suitable numerical method for finding maxima or minima may be applied. Many numerical methods of this kind generally known as mathematical programming techniques were developed in the last forty years. A more general mathematical programming problem may be formally stated as:

minimize $f(x)$

subject to $g_i(x)=0$ $(i = 1 ,\dots, m')$,

and $g_i(x)\leq 0$ $(i = m'+1 ,\dots, m)$,

with $L_j \leq x_j \leq U_j$ $(j = 1 ,\dots, n)$

where $f(x)$ is the objective function,

$g_i(x)$ are the constraint functions,

$x \in R^n$ is a design vector,

x_j are the problem independent variables,

and L_j and U_j are the lower and upper variable limits, respectivelly.

The functions $f(x)$ and $g_i(x)$ may be non-linear and the independent variables are simple lower and upper bounded.

A general purpose non-linear constrained optimisation program named Recursive Quadratic Programming MINimization (RQPMIN), developed at the Royal Aerospace Establishment (R.A.E.)[8] intended, in particular, to perform aircraft design optimisation studies was available in the College of Aeronautics and thus it was used in the present project. As mentioned in chapter 2, the package has been extensively used in other research studies namely at R.A.E.[1], at Loughborough University of Technology[5] and in the CoA[2,3,4] and appears to produce good results.

The program can handle problems with up to 75 constraints and up to 50 variables. It can solve unconstrained optimisation problems as well, however limits on the independent variables must always be specified. It is assumed that the problem functions (objective and constraints) are twice continuously differentiable. If any of the functions are linear the code takes advantage of the fact. However if all the problem functions are linear a dedicated linear programming technique is recommended for computational efficiency. As with any other mathematical programming technique the program may also be used to find the maximum of the objective function by minimising the symmetric of the objective function. The program has modular architecture comprising nearly 90 subroutines and is written in ANSI Standard Fortran 77.

The algorithm of RQPMIN is based on the Lagrange-Newton approach which implies that a stationary point of the Lagrangian function is evaluated by Newton's method[6]. This method differs from other similar methods in that it does not use a penalty function to force global convergence. Skrobanski[7] introduces the new concept of pseudo-feasibility which assumes a trial point is rejected if the square root of the sum of the squares of the constraints is greater than the radius of pseudo-feasibility. This radius, initially defined as a relatively large figure, will only be reduced when necessary. Very often the radius of pseudo-feasibility is kept unchanged throughout the minimization process.

The numerical method is detailed in ref. 7 and ref. 8 describes its application and operation as well as the associated progress reports, diagnostic messages and detailed output.

As illustrated by the problem statement the numerical technique deals with a set of mathematical entities which can be identified as:

External Variables (EV)	- user application initial input or default design variables
Independent Variables (IV)	- external variables at the disposal of the optimisation driver
Dependent Variables (DV)	- variables evaluated as functions of the external and independent variables
Objective Function (OF)	- chosen figure of merit or cost function to be minimized or maximized by the optimiser
Equality Constraint (EC)	- function which must be satisfied by the solution. This constraint remains active throughout the optimisation process.
Inequality Constraint (IC)	- function which must be satisfied by the problem solution. This function will be active whenever it is not met by the solution vector.

4.2 Optimiser-Design Synthesis Operation

In order to set up the design optimisation system, two subroutines, USERF and USERD as well as an input data file, RQPMIN.DAT must be provided by the user. USERF will define the OF, the IVs, the ECs, and the ICs, call the design synthesis program and must return the values of the problem functions at a given point x. USERD will define the analytical derivatives of the problem functions (OF, EC and IC), only possible when explicit dependence of the problem functions on design variables is known, and return the respective values at that point. A dummy USERD should be supplied if all differentiation is to be done by finite differences. RQPMIN.DAT contains the initial values of the IVs, the upper and lower bounds and the scale factors of the IVs, the OFs, the ECs and the ICs. Scale factors are introduced to normalise their values to near unity ensuring a proper operation of the mathematical programming algorithm. Finally a number of command and assignment keywords are included to control the operation and tune the performance of RQPMIN. Examples of these user written subroutines and input files are shown in Appendix E for the optimisation studies done.

RQPMIN starts checking for possible errors in the input file and if everything is fine proceeds with the optimisation. An initialization phase follows during which USERF and thus the GASP synthesis program are called for a number of times similar to the number of independent variables used to evaluate the objective and the constraint functions. The IVs are varied one a time allowing RQPMIN to decide on which initial search direction to head in by the end of this phase. Then a series of feasibility steps may begin where the IVs are automatically changed while the program searchs for a feasible path subject to the constraints in order to start minimizing the objective function. If a feasible path is not found, the program will stop with the message 'no further progress possible' and a new set of initial IVs should be tried by the user. When a feasible path is located, a series of minimization steps is performed until a minimum of the objective function is found, satisfying the constraint functions within the prescribed tolerances and meeting the method convergence criteria.

Three types of convergence may occur:

A - the program has located a point at which the estimated distances to the minimum of the objective function and to the minimum of the sum of the squares of the constraint functions are less than the specified tolerances;

B - the program has located a point at which the estimated distance to the minimum of the sum of the squares of the constraint functions is less than the specified tolerance and a value of the objective function sufficiently smaller than the current value cannot be found;

C - the program has located a point at which the estimated distance to the minimum of the sum of the squares of the constraint functions is less than the specified tolerance and no independent variables exist.

It should be noted that none of the convergence types guarantees that the numerical technique has found a valid solution nor the 'no further progress possible' message means that the run has failed. It is possible that the program stops at a saddle point of the objective function or if this function represents a design surface with many hills and valleys it can suggest that a point in a less deep valley has been found and thus it has converged on a local minimum. To check for these problems the program should be re-started from different initial design points.

During its operation, RQPMIN produces progress reports and warnings which are sent to the user's terminal and an output file. The frequency of the progress reports is controlled by a keyword given in the input file and their context relates to the successive stages of the optimisation process:

- initialization context;
- feasibility step context;

- minimization step context;
- changing to central differences context;
- final call to user routine context.

The output file consists of five sections from which two are optional:

- listing of input file (optional);
- Analysis of input file data and control parameters;
- Starting point;
- Intermediate output (optional);
- final output.

Appendix E shows the RQPMIN.RES output files for the relevant optimisations performed (1st solutions, as defined in section 5.4) where all sections are included except the first optional one. There follows a description of these sections:

Analysis of input file data and control parameters - consists of a list of all the input variables and functions in normalised format, and the RQPMIN control parameters including the default values.

Starting point - lists the initial values of the variables and problem functions in a normalised format.

Intermediate output - lists the best values of the variables and problem functions in a normalised format as found at given stages of the optimisation. The corresponding values of the Lagrange multiplier estimates, the partial derivatives of the Lagrangian function, the norms of the active constraints and the values of the various convergence criteria are also listed. This optional section is included if this information is required by the user and is activated through input control parameters specifying when it should start (iteration number) and its frequency (after how many iterations).

Final output - is similar to the intermediate output and printed when the program stops.

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5 The Case Study

5.1 The Mission Requirement

Chapter 1 introduced the reader to the topic and scope of the present investigation. It is not intended to generate optimum configuration initial designs with the aim of future production and commercialisation in response to an eventual market need or opportunity, to compete with similar type existing aircraft for the same slice of the market, but only to study potential advantages eventually offered by the usually named Three-lifting Surface configuration aircraft. In this view a very simple mission profile for a commercial transport aircraft is sought in order to base the conceptual optimum design of a familiar tail-aft configured design or conventional one and a new unconventional one. This relatively simple flight profile, although already sufficiently elaborate, will not consider any turn manoeuvres nor any air traffic control (ATC) impositions. The standard alternate airport diversion leg or any additional mission alternatives or scenarios usually considered during every serious potential aircraft initial study are not considered as well. This simplification is quite fair for that it seems not to invalidate or compromise the realistic conclusions and trends that were expected to draw.

A Turbo-fan jet transport aircraft to carry economically 50 passengers across a distance of 1250 nautical miles on a regular basis is envisioned. It was designed for a yearly utilization of 3200 hours during an expected life time of 15 years. The mission specification is summarized as follows:

Payload:	50 passengers each one at 175 lbs and 25 lbs of baggage;
Crew:	2 pilots and a cabin attendant each one at 175 lbs and 25 lbs of baggage;
Range:	1250 NM to destination (with 45 minutes of fuel reserves at cruise conditions);
Cruise altitude:	35000 ft for the design range;
Cruise Mach number:	0.8 at cruise altitude;
Climb:	direct to 35000 ft at maximum take-off weight;
Field length:	FAR Part 25 take-off field length of 6000 ft at an altitude of 5000 ft and a 95 degree F day; FAR Part 25 landing field length of 5000 ft at an altitude of 5000 ft and a 95 degree F day. (Landing performance at a landing to maximum take-off weight ratio of 0.94)
Power-plants:	two turbo-fan engines;
Pressurization:	8000 ft cabin at 40000 ft altitude;
Technology level:	conventional (no advanced technologies considered other than wing/canard supercritical aerofoil technology);
Certification Base:	FAR Part 25.

5.2 Parametric Analysis and the Initial Design

An initial parametric analysis has been performed using a Preliminary Sizing (PreSiz) program, purposely developed by the author as mentioned in Chapter 3, in order to select a credible initial design point for the subsequent GASP analysis/ synthesis evaluations. The program is based on Roskam's rapid sizing method as shown in his "Airplane Design"[1], Part I volume. Appendix C presents the input file used together with the results obtained. A brief description of the input design data is enclosed as well. The output file consists of four parts:

- the mission specification which has been analysed;
- the results of the maximum take-off, empty and fuel weight predictions;
- a sensitivity study report of the maximum take-off weight due to variations of payload, empty weight, range, endurance, cruise speed, specific fuel consumption and lift to drag ratio;
- the low speed drag polar estimations for several wing loadings and wing aspect ratios and performance tables to account for fieldlength, FAR climb, cruise speed and direct climb requirements.

Table 5.1 includes a summary of the main results obtained. Figure 5.1 illustrates the design space in terms of a thrust to weight versus wing loading diagram, where the selected initial design point for which all requirements are met is identified, laying on the intersection of the take-off and the landing performance constraints. This plot clearly shows that the design is determined not only by the two fieldlength constraints but also by the FAR Part 25 engine-out missed approach climb requirement. This is in contrast with the most usually considered 2nd segment climb requirement, and by the direct climb to cruise height requirement.

The matching results to note are:

Maximum take-off weight = 44076 lbs
Empty weight = 24698 lbs
Fuel weight = 8558 lbs

Maximum lift coefficients:

Take-off CLmax = 2.45
Landing CLmax = 3.25

Wing aspect ratio = 8.3

Take-off wing loading = 83.75 lb/sqft
Wing area = 526.3 sqft
Take-off thrust to weight ratio = 0.345
Engine maximum static take-off thrust = 7603 lbs

5.3 The Baseline Designs

Having brought the initial guess to the right order, two baseline concepts were evolved using the modified GASP synthesis program.

5.3.1 General Considerations

In order to better understand the implications of adding a foreplane to the aircraft the basic geometry is kept the same. So effects due to configuration changes, e.g., low and high wing, wing mounted and fuselage podded engines, will not be reflected in the results.

Examples of existing aircraft that could approximately meet the present requirement are the VFW-Fokker 28 and the Canadair CL-601 Regional Jet[2]. Both aircraft have a low clean wing, fuselage mounted engines and a T-tail. This is the basic configuration to be adopted in the study. The aft fuselage engine installation is favoured because of the reduction in the risk of ingestion of debris at take-off and taxiing, little asymmetric thrust after engine failure, and a clean wing. Another significant reason is related to avoiding air flow disturbance likely to occur at the engine intakes due to the canard wake and tip vortices in the new configuration, if they are podded on the wing.

The fuselage is to be kept as small and compact as possible within acceptable limits consistent with comfort standards, required performance and operating costs in a way not to affect adversely the aircraft's earning capacity. A cylindrical mid-section is chosen and the general dimensions are determined by the passenger seat layout. Four-abreast seats at a pitch of 31 in and a one aisle arrangement is selected and allowances for the flight deck, passenger doors, one galley, one toilet, nose and tail cones are made.

To achieve high subsonic cruise Mach numbers consistent with low wing and canard weights, supercritical aerofoil technology is adopted with a modest rearward sweep on both lifting surfaces. Powerful double slotted Fowler flaps[3] are initially selected to obtain the high maximum lift coefficients at take-off and landing needed to comply with the field performance requirements, allowing for the expected wing loading.

According to the thrust level required, about 8000 lb per engine, the General Electric CF 34 turbofan cycle, as used currently on the Canadair Regional Jet, is selected and adequately scaled during the GASP runs.

It is assumed the basic airframe is manufactured of conventional aluminium alloy materials, so all the weight trend coefficients employed in the weight prediction correlations will adequately reflect this decision. There is no need to simulating the employment of new advanced materials such as fibre-reinforced plastic composite materials. This remark extends also to any other class of advanced technologies since a comparison of two different configurations, using the same technologies and both designed according to the same ground rules, is what is needed in order to find their relative merits.

In terms of static stability it is required that both concepts have a stable longitudinal static margin of SM = 10% mac and directional stability with the yaw-moment derivative with respect to sideslip of $dC_n/d\beta = 0.002$ per degree.

The direct operating costs are calculated based on the following assumptions:

- Total Research, Development, Testing and Evaluation predicted by a Rand derived formulation (historical average number of prototype aircraft assumed);
- market potential demand of 500 aircraft of the type;
- year of costs calculations = 1993;
- annual average inflation rate of 8%;
- airframe production cost including 10% profit;
- yearly utilization of 3200 hours;
- flight crew and cabin attendants annual gross salary, including pension, overtime, subsidies and travelling computed as functions of take-off gross weight and cruise speed giving values about US$185000 for the captain, 80% of this figure for the 1st officer and 35% for the cabin attendant, which relates roughly to current practice (these are predicted very closely by GASP correlations);
- avionic equipment cost of 4 million US dollars;
- fuel and oil costs at 85 US cents/ US gallon plus taxes worth 4.5% fuel costs;
- insurance of 0.5 % flyaway price per annum;
- maintenance labour cost of US$23 dollars per man-hour;
- maintenance burden at 200% of the direct maintenance labour cost;
- depreciation determined as the total investment, including 6% airframe price on spares, over 15 years to 10% residual value;
- no landing fees nor average net cost of finance considered.

Noise characteristics are of prime importance if restrictions are to be avoided in the use of the aircraft. These shall meet the requirements set in FAR Part 36. These issues are not accounted for in this thesis, the reason being that the most important single factor to reduce the level of noise is the engine bypass ratio which is under the control of the designer. It is influenced not only by its design, but by its installation in a nacelle and by the aircraft design itself giving necessary take-off and landing performances (steepest take-off and approach flight paths, for example). Other measures may be used to reduce noise both at the engine design level and with proper integration with nacelles equipped with acoustic lining and/or splitter plates in the inlet and exhaust[3]. The selected power-plants have a high bypass ratio of 6.3[2], so providing adequate integration with the aircraft is achieved, noise is unlikely to cause any problems and there is already experience with the Canadair Jet with its relatively low noise level[2]. Under these circumstances it is acceptable to neglect noise evaluations at this stage.

5.3.2 GASP Input Data and Baseline Solutions

The parameters composing the GASP input file, organised by their respective disciplinary groups, are listed below with the proposed values for the initial trial configurations, both conventional and unconventional. Additional parameters related to the modifications done in GASP, as described in Chapter 3, are shown in italics and the appropriate program control options are included as well.

Geometry

General data

Engine cycle indicator - General Electric CF 34	5
Conventional (0) or Three-Lifting Surface concept (1) (option)	
take-off gross weight (initial guess) [lb]	44050
take-off wing loading (initial guess) [lb/sqft]	83
number of passengers	50
design cruise Mach number	0.8
design cruise altitude [ft]	35000
number of engines	2

Fuselage data

seats abreast in fuselage	4
seat width [in]	20
number of aisles	1
aisle width [in]	19
seat pitch [in]	31
length of flight deck plus passenger door allowance [ft]	11.22
mean fuselage diameter minus nose cone max. diameter [ft] (≈ windscreen height)	2.47
fuselage nose cone fineness ratio	1
fuselage tail cone fineness ratio (assuming allowances for galley, toilet and rear passenger door)	3.2

Nacelle

nacelle drag assumed as part of aircraft drag (option)	1
length of pylon attachment for fuselage mounted engines [ft]	10

Wing

wing aspect ratio	8.3
wing tip thickness to chord ratio	0.10
wing root thickness to chord ratio	0.13
wing taper ratio	0.20
sweep of wing 1/4 chord [degrees]	14.5
wing incidence to fuselage horizontal datum line [degrees]	2

Canard

canard aspect ratio	*5.5*
canard thickness to chord ratio	*0.10*
canard taper ratio	*0.50*
sweep of canard 1/4 chord [degrees]	*15*
canard incidence to fuselage horizontal datum line [degrees]	*2*

canard to wing area ratio	*0.145*

Horizontal tail

location of tailplane on vertical fin as a fraction of fin span	1
tailplane aspect ratio	4
tailplane thickness to chord ratio	0.10
tailplane taper ratio (initial value)	0.55
sweep of tailplane 1/4 chord [degrees]	27.5

Vertical tail

fin aspect ratio	1
fin thickness to chord ratio	0.12
fin taper ratio	0.70
sweep of fin 1/4 chord [degrees]	50.5

Aerodynamics

number of points in wing/ canard profile drag table	12

values of C_L in wing/canard profile drag table:

-1.0, -0.6, -0.4, -0.2, 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.2

normalized wing/canard profile drag values in wing/canard profile drag table:

2.400, 1.466, 1.221, 1.066, 1.005, 1.000, 1.005, 1.046, 1.138, 1.333, 1.743, 2.718

increment in overall drag coefficient	0.0015
increment in equivalent flat plate area of fuselage [sqft]	0.2
shift in drag divergence Mach number due to supercritical aerofoil design	0.75
increment in wetted area/wing area	0
wing zero lift angle of attack [degrees]	-1.6
program computes increment in drag coefficient due to engine out (option)	-1
maximum clean basic wing lift coefficient at reference conditions[4]	1.2
altitude for Reynolds number calculation (field conditions) [ft]	5000
wing pitching moment coefficient	*-0.06*
canard aerodynamic form factor (control value)	*-1*
canard zero lift angle of attack [degrees]	*-1.0*

Flaps

number of flap segments per wing panel	1
fraction of wing span without flaps due to wing mounted engines	0
double slotted Fowler flaps (selection)	7
take-off flap deflection [degrees]	15
landing flap deflection [degrees]	40
flap chord to wing chord ratio	0.30
flap span to wing span ratio	0.75

Propulsion

engines sized for cruise, take-off and climb (option)	2
FAR Part 25 turbine propulsion sizing requirements (option)	1
engine power setting during take-off, maximum power (option)	5
engine power setting during climb, maximum climb power (option)	7
engine power setting during acceleration, maximum power (option)	5
take-off field altitude [ft]	5000
increment in take-off ambient temperature above ISA standard day [degree F]	36
required rate of climb at cruise conditions [fpm]	50
required take-off distance to 35 ft (not constrained)	99999
engine face sea level static Mach number	0.5
engine face hub/tip ratio	0.437
ratio of cruise weight to maximum take-off gross weight (for engine sizing)	0.97
engine out service ceiling required [ft]	0
input maximum static thrust for one engine (if engine known) [lb]	0
inlet pressure recovery factor	1

Weights

weight trend coefficient of engine installation, fraction of dry engine	0.135
weight trend coefficient of landing gear, fraction of gross weight	0.038
main gear weight fraction of landing gear weight	0.8
weight trend coefficient of engine nacelle, fraction of dry engine	0.338
weight per passenger including luggage [lb]	200
wing/canard strut attachment point, fraction of semi-span (for cantilever wing/canard = 0)	0
incremental control group weight [lb]	0
weight trend coefficient of horizontal tail	0.18
weight trend coefficient of vertical tail	0.22
weight trend coefficient of wing and canard, excluding high lift devices	133.4
location of main gear on wing, fraction of wing semi-span	0.25
engine c.g. fraction of fuselage length (for fuselage mounted engines)	0.75
c.g. of fuselage and contents, fraction of fuselage length	0.45
transport design structural category, FAR Part 25 (used to determine allowable load factors and design speeds)	3
maximum operating design flight speed, structural [mph]	685
weight trend coefficient of fuselage	107
weight trend coefficient of cockpit controls	20
weight trend coefficient of fixed wing controls	0.43
weight of stability augmentation system [lb]	0
engine c.g. in relation to the leading edge of the wing mean aerodynamic chord (mac),as a fraction of mac, for wing mounted engines, positive aft	0
wing/canard c.g. with respect to mac quarter chord point, fraction of mac	0.2
aircraft c.g. with respect to mac quarter chord point, fraction of mac	0
fuselage pressure differential in order to maintain an 8000 ft cabin at 40000 ft altitude [psi]	8.2
location of engines on wing (on fuselage = 0)	0

weight trend coefficient for fuel system	0.02
fraction of total theoretical wing volume used for wing fuel	0.43
program computes fwd and aft c.g. limits and sizes canard and, or horizontal and vertical tail for stability and control	2
incremental structural weight [lb]	0
dry weight of one engine, function of engine size [lb]	0
engine specific weight [lb/lb$_{Thrust}$]	0.16
weight of one nacelle, function of engine size [lb]	0
nacelle weight to nacelle surface area ratio [lb/sqft]	2.287
weight of one pylon, function of engine size [lb]	0
factor for turbofan engine pylon weight	0.7
nacelle length to diameter ratio	3

Stability and Control (Canard and/or Tail Sizing)

controls free (0) or controls locked (1) (option)	*1*
pitching moment coefficient about centre of gravity due to all engines during landing (direct thrust effect only)	0
aircraft static margin, fraction of mac	0.1
elevator chord to horizontal tail chord ratio	0.35
maximum up elevator deflection, negative for trailing edge up (degrees)	-25
tailplane incidence angle relative to fuselage horizontal datum line (degrees)	0
vertical position of thrust line relative to c.g., positive for thrust below c.g.	0
distance of main wheel contact point aft of mac leading edge, fraction of mac	0.52
low wing position on fuselage	0
required directional stability of aircraft, function of take-off gross weight and wing span [degree^{-1}]	0.002
rudder chord to vertical tail chord	0.30
ratio of minimum control speed to stall speed in take-off configuration	0.99
maximum rudder deflection [degrees]	25
canardvator chord to canard chord ratio	*0.35*
jet-flow inclination contribution to the aircraft longitudinal static stability	*0.03*

Performance

Taxi

time spent taxiing before take-off and after landing [hr]	0.1666

Take-off

program computes full mission (option)	1
program computes engine-out and acceleration/ stop distance (option)	0
maximum allowable fuselage floor angle [degrees]	15
altitude at start of mission [ft]	5000
maximum load factor during take-off rotation	1.1
estimate of time required to rotate aircraft during take-off [sec]	3.5
increment of engine failure decision speed above stall [kt]	5

increment of take-off rotation speed above engine failure decision speed [kt]	5
ratio of allowable lift-off speed to stall speed	1.1
coefficient of rolling friction	0.02
coefficient of braking friction	0.4
increment in take-off ambient temperature above ISA standard day [degree F]	36
terminal altitude for take-off segment [ft]	500

Climb

climb at maximum rate of climb (option)	1
altitude increment during climb [ft]	1000

Cruise

cruise flown at speed at normal rated cruise power, for cost and range calculation (option)	1
hold wing loading fixed during range balance (option)	0
required fuel reserve, fraction of 45 min	1
required design range [NM]	1250
off-design mission altitude [ft]	25000
off-design specified Mach number	0.5
maximum take-off gross weight scale factor for range balance iterations (default function of gross weight and range)	0.80

Landing

landing weight as a fraction of gross weight (option)	2
increment in landing ambient temperature above ISA standard day (degree F)	36
time delay for brake and reverse thrust application during landing (sec)	1
wing height above ground during ground run (ft)	5.5
required landing distance (not constrained)	99999
altitude of landing field (ft)	5000
ratio of landing weight to maximum take-off gross weight	0.94
ratio of approach speed to stall speed	1.3
maximum allowable rate of sink during approach [ft/min]	1000
ratio of reverse thrust to idle thrust during landing	0
ratio of touchdown speed to stall speed	1.15
obstacle height (ft)	50
landing touchdown sink rate (ft/sec)	3
landing flare load factor	1.2

Costs

additional equipment cost as a function of base cost (option)	1
year of cost calculation	1993
cost of avionic equipment (million US$)	4
aircraft utilization per year (hr/annum)	3200
fuel cost (US$/US gallon)	0.85

insurance as a fraction of flyaway price per annum	0.005
maintenance burden factor	2
aircraft residual value as a fraction of initial value	0.10
aircraft depreciation period [years]	15
production quantity	500
maintenance labour cost (US$/man-hour)	23
annual average inflation rate	0.08

It is worth noting that the canard related parameters are only used if the unconventional concept design synthesis option is used.

The above GASP input data list was employed on both the concept baseline designs and for the optimisations. However some small changes were required. These were concerned with the concept option actually taken, the three-surface configuration initial lifting surface loading required to obtain the same result as found for the conventional aircraft in the baseline design case, and with the convergence adjustable weight scale factor which is arbitrarily changed to approximate the configuration design range closer to the required range. The latter may be changed for other reasons to be explained in section 5.4.

Appendix D includes the detailed GASP results for the two baseline configurations while table 5.1 summarizes the main results obtained including those found during the initial parametric analysis. Figures 5.2 and 5.3 show the airliner three view sketches corresponding, respectively, to the classical and to the three-surface designs. The sketches were produced using Raymer's RDS-Student CAD program[5].

5.4 The Optimised Designs

5.4.1 General Considerations

The search for the best feasible design must be based on a quantifiable criterion, single or compounded, usually called the figure of merit. The performance index, the cost function or the objective function describing the design problem lend themselves to quantification. In commercial aviation the most commonly used are the Direct Operating Costs (DOC) at the design range or the Maximum Take-off Weight (MTOW). For the airlines the former forms a more relevant criterion since it reflects the aircraft economic potential[8,9]. Both objective functions are used in the present study.

5.4.2 Setting up the Tool

The optimisation technique has three main functions:

- Receive the results from the synthesis evaluation and interpret the data in the light of the previous design iterations;
- Decide which design variables should be perturbed, how large the perturbations should be, and repeat the design synthesis with the new design variables;

- Find whether the chosen perturbations succeed in moving towards the optimum solution, and repeat the iterations until the optimisation of the objective function has been achieved or the search has proved to be fruitless.

As described in Chapter 4 and shown in Appendix E, the user written subroutines USERF and USERD, and the RQPMIN.DAT file were developed following the recommendations set in ref. 6. This reference should be consulted for any details not presented here. USERF assigns the design independent variables, calls the design synthesis program, and defines the objective and the selected constraint functions.

The independent variables chosen for the optimisations, both for the conventional and the three-surface configurations, are listed below where the additional variables related with the latter one are in italics (the adopted variable lower and upper bounds as shown in the RQPMIN.DAT input file are also included):

wing loading [lb/sqft]	[80,105]
wing aspect ratio	[8,10]
wing quarter chord sweep angle [degrees]	[11,35]
wing taper ratio	[0.16,0.31]
horizontal tail aspect ratio	[3.8,4.3]
horizontal tail quarter chord sweep angle [degrees]	[20,35]
vertical tail aspect ratio	[0.8,1.2]
vertical tail quarter chord sweep angle [degrees]	[40,53]
canard aspect ratio	*[4,8]*
canard quarter chord sweep angle [degrees]	*[10,35]*
canard taper ratio	*[0.16,0.7]*
canard incidence angle [degrees]	*[0,3]*
canard over wing area ratio	*[0.145,0.175]*
engine c.g. location as a fraction of fuselage length	*[0.75,0.85]*

The constraint functions reflect the low speed field performances and cruise performance boundary limits of the design space in the form of inequalities. These functions and their extreme values are:

FAR Part 25 take-off distance [ft]	(maximum value = 6000)
FAR Part 25 landing distance [ft]	(maximum value = 5000)
approach speed [knots], EAS	(maximum value = 125)
cruise Mach number	(minimum value = 0.76, maximum value = 0.86)

The objective function, either DOC or MTOW, is defined according to the criterion the design is to be optimised for.

Since no analytical derivatives exist for the problem functions, that is the objective and constraint functions with respect to the design variables, a void USERD subroutine is included and the driver will evaluate them by finite differences whenever necessary.

The starting point, or initial estimate of the solution, for all the optimisations performed and defined in the optimiser input file, corresponds to that of the baseline configurations. These are feasible designs satisfying all the constraints as obtained with GASP when working as a stand-alone program, and described in the previous section.

5.4.3 Optimisation Results

Several local "optimum" solutions were obtained either for minimum DOC and minimum MTOW for both concepts. Generally speaking convergence of the numerical algorithm was achieved within 6% and 4% of the lowest obtained figure of merit, respectively, for the conventional and for the three-surface configurations. Most convergences were of the B type, although many A type were obtained while optimising the three-surface design for minimum weight. No C type convergence occurred.

For all the cases considered figure E1, in Appendix E, summarises the "best" solutions obtained at this stage and calls them 1st solutions. Listings of the next closest to the "best" are included as well, and are named 2nd and 3rd solutions. In addition to the values corresponding to the initial and the convergence point design variables and respective functions, objective and constraints, information on the convergence type, CPU time and number of function evaluations (nfe) per run is given. (nfe) corresponds to the number of times the GASP program was called by RQPMIN. Several "optimum" solutions achieved show the complex nature of the design surface, which is typical of complex practical engineering systems design problems where multiple local optimum solutions are usually found. This may be an advantage since it allows the designer additional freedom to select the most suitable solution among many other "good" solutions. This behaviour was previously explained in Chapter 4 when the convergence criteria were introduced. However a recommendation was then given for checking purposes to re-start the optimisation from a different starting point. It was found during the initial trial runs, after setting up the system, that the convergence of the numerical method was very sensitive to the slightest change in the initial design variables, and on their lower and upper bounds. To keep the starting point virtually unchanged in terms of the RQPMIN interface, it was decided to change, in successive optimisation runs, the weight scale factor in the GASP input file which controls the precision in the synthesis range-balance iterations. Effectively this produces slightly different results from the design program and acts as if the optimisation actually started from a different starting point. This was the procedure used for checking the optimum design point result and search for better results.

Detailed GASP result listings of the two optimised configurations, both for minimum DOC and minimum MTOW, are also included in Appendix E, while table 5.1 presents a summary of their main characteristics together with the initial parametric analysis results and the baseline designs data. Figures 5.4, 5.5, 5.6 and 5.7 show the airliner three view sketches corresponding to the four optimised designs. A comparison of the cruise drag polars obtained for the baseline and minimum DOC datum designs is illustrated in fig 5.13.

5.4.4 Method Idiosyncrasy and Graphical Displays

Optimum results were obtained only with difficulty. The reasons as understood by the author were due to several factors, some of them may be attributed to:

- the complexity of the engineering design model itself, in particular where the three surface design case is concerned. When trying to match the three lifting surfaces sizing with the required stability and control requirements, for some combinations of the design variables, the process diverged and as a result the solution was lost.

- numerical difficulties associated with the mathematical technique itself. While trying to find or adjust the direction of a feasible path, for instance, during the evaluation of function derivatives at a point where the design surface has sharp ridges or saddle points, it was found that it produced wrong perturbations on the design variables used in the next iteration.

- inability of the minimization package to identify bad moves, and thus in discarding wrong steps in the light of sudden surges of the figure of merit. A 'memory' capability, if implemented, would significantly improve the performance of the mathematical programming method by reducing markedly the number of iterations to convergence and computation time.

- difficulties associated with meeting the method convergence criteria which are intimately related with the characteristics of the design surface topology. Proper tolerances to the problem functions had to be carefully chosen in a way so as not to compromise meaningful results or making convergence impossible. There were cases where the program converged on a solution by numerically violating one of the constraints (for example, all the three optimum local solutions as determined for the minimum MTOW three-surface configurations, as shown in Appendix E, fig E1). Doubts on the proper operation of RQPMIN arose. In one case, it happened however that a particular design point had been previously assessed by the optimiser during the process of minimization without satisfying the convergence criteria. Later, convergence was achieved on the very same design point, which suggested that the minimum solution of the objective function had been determined, with a probably very tight tolerance. Although, in view of the accuracy of a design synthesis model for initial preliminary studies, the tolerance used and the magnitude of the constraint violation were considered of no significance for practical purposes, and the result acceptable.

5.4.5 A Quest for Transparency and Efficiency in the Design Optimisation Process

An appropriate graphics capability would be useful to allow the user to monitor the optimisation progress and stop it when no improvement on the performance index is experienced. Histories of the objective function, constraint functions and design variables are a convenient way of learning more about the design problem, draw conclusions and help the designer's decision making. To illustrate some advantages of using graphical displays and the insights gained concerning the problem behaviour, together with the particular behaviour of RQPMIN, some comments are appropriate on to the historical diagrams contained in Appendix F. For illustrative purposes this Appendix shows the convergence histories of the problem functions and design variables for the direct operating costs optimisation cases (first solutions) performed on both configurations.

In the case of the conventional configuration, figure F1, and in spite of the apparent randomness or noise in the engineering processes, the numerical method is seen to fail to convergence for three times before actually stopping on the method "optimum" solution. If a close analysis on the progress of the objective and constraint functions, as well as on the design variables controlled by the algorithm is exercised, it will be concluded that iteration number 487 corresponds virtually to the same point as the final convergence. Deliberately stopping the process at that point or on iterations numbers 386, 577 and 718 solutions very close to the optimum design solution would be determined, since they tend to stabilize after those points before the occurrence of sudden large excursions whose probable explanation is given above. Other comments can be drawn in particular to the evolution of the MTOW. In fact, the history of the objective function diagram shows a very close reduction trend on the MTOW, although this is more prone to wild variations in contrast to the small randomness experienced by the DOC function. This behaviour may be explained in part if not a great difference exists on the best solution when the optimisation is performed with regard to the minimum MTOW. The constraint history diagrams show that none of them were violated, so they remained inactive during the complete run and could be ignored. Thus this particular problem could be treated such as any simpler unconstrained problem, reducing the computational effort and time. Looking at the design variables' evolution, it can be noticed that the wing loading increases until reaching iteration number 216 after which it remains almost constant on its upper bound up to when convergence is achieved. It means that this variable could have been assigned a fixed value at that point, reducing the number of design variables to be optimised. This action would help problem simplification, and speed up the design optimisation process without affecting its result, and with minimum computational costs.

Similar considerations can be expressed by looking at the historical diagrams related to the optimisation of the three-surface concept with respect to minimum DOC, as shown on figure F2. The objective function and the MTOW curves display very similar reduction trend patterns, reinforcing the same feeling that no major difference would be produced by choosing any performance index between the two. The constraints' histories suggest that cruise Mach number could be ignored since it does not influence the optimisation process. The FAR Part 25 take-off distance requirement is the critical one and both the landing distance and the approach speed are very close to their imposed limit boundaries. A close look at the design variables suggests that the wing quarter chord sweep could have been ignored since it stabilizes on about the same value after iteration number 336 as was assumed for its starting value. After iteration number 386 the optimisation could be stopped. All the function and variable values seemed to converge and stabilize very closely to the "optimum" converged point until an abrupt departure occurred at iteration number 415, violating all the three critical constraints, and leading to another subsidence towards stable values at about iteration number 561. At this point the program could again be stopped before the mathematical convergence criteria were satisfied.

The difficulty associated with the selection of the tolerances on the objective and constraint functions required by the convergence criteria, and referred to above, was detected while optimising the three-surface concept to minimum MTOW. This case, corresponding to the last column of table 5.1, is not illustrated by historical diagrams. Here the system converged at iteration number 1348 on a solution, violating the take-off distance constraint. This solution had virtually occurred previously at iteration number 1000 without satisfying the convergence criteria. This fact may suggest that the convergence is not easily satisfied due to a very small tolerance imposed on the problem functions. On the other hand it appears that there is some inconsistency in the coding of the convergence criteria, since convergence actually occurred while violating one of the constraints. It is the author's opinion that theoretically convergence shouldn't have occurred because, numerically speaking, the solution is unfeasible.

An interactive design optimisation capability, such as exemplified by IDESIGN software[7], would considerably improve the visibility of the design optimisation process. Owing to increased transparency, design contending effects become more clear, improving the designer's understanding as well as his learning process. This helps the user to refine the problem formulation and to accelerate the optimum design. Additionally, any potential numerical difficulties in the optimising algorithm may be identified.

5.4.6 Reflection on the Performance Index and Optimum Results

The considerations made above concerning the adoption of the performance index, DOC or MTOW, can be substantiated by the results on table 5.1 where the conventional design optimised for both figures of merit show the same DOC while the respective MTOWs are close within 0.15%. However for the unconventional case, the DOCs are within 1.1% and the MTOW results differ by 1.2%. It is the author's opinion that the latter differences may turn out to be irrelevant if a better local result could be achieved for the three-surface aircraft optimised for minimum weight. It should be noted that in this particular case the minimum weight came up slightly higher then the weight obtained for the minimum DOC optimisation, reflecting the local nature of the optimum results rather than the desired global or absolute optimum.

The results obtained at this stage enable one to say that optimisations performed for minimum DOC or minimum MTOW produce approximately the same optimum design solutions for each concept (assuming the design range of 1250 NM and the adopted economic assumptions).

5.5 Range Trade-off Studies

To assess the relative worth of the several designs obtained thus far, a series of range trade-off studies was conducted for design ranges, ranging from 1000 to 3000 nautical miles at 250 NM intervals.

These studies were performed using GASP program with input files related to the baseline and to the optimised configuration solutions, the only difference being the required design range. The aircraft families so obtained maintain the same take-off wing loading and the same overall geometry as the datum aircraft (Range=1250 NM), thus, for the particular case in consideration the transports look alike apart for the lifting surface areas which increase with weight. No restrictions were imposed on the take-off and landing field lengths. Tables 5.2, 5.3, 5.4, 5.5, 5.6 and 5.7 include the main characteristics of these designs.

Plots of DOC and MTOW versus range were prepared for both the conventional and the three-lifting surface configurations (baseline and optimised designs) related to the conventional datum and are shown for each case on figures 5.8.1, 5.8.2, 5.9.1, 5.9.2, 5.10.1 and 5.10.2. Benefits on DOC and MTOW of the unconventional design with respect to the corresponding classical one are shown on figures 5.8.3, 5.9.3 and 5.10.3.

DOC and MTOW range trade-offs for the configurations optimised for minimum DOC are presented in figures 5.11.1 and 5.11.2 and compared to the baseline design curves. All results are normalised to those of the baseline conventional datum design. Benefits on DOC and MTOW of the minimum DOC configurations with regard to the conventional and to the three-surface baseline designs are shown respectively on figures 5.11.3 and 5.11.4. The same for the minimum MTOW configurations is illustrated in figures 5.12.1 and 5.12.2, 5.12.3 and 5.12.4, respectively.

5.5.1 Baseline Designs

As stated above, the wing loading on both baseline configurations was kept unchanged, W/S = 83 lb/sqft, while generating the aircraft families to meet the required design ranges. Taking into account the particular range in consideration all designs satisfy all the other initial requirement constraints with the exception of the three-surface aircraft synthesised for a design range of 3000 NM, which marginally exceeds the FAR Part 25 Take-off field length by 1.05% (= 6062.9 ft).

Figure 5.8.1 shows that the conventional designs offer a minimum DOC for a design range of 1500 NM which increases parabolically for both lower and higher ranges. The three-surface design shows a similar trend with a minimum DOC at a design range of 1750 NM, corresponding to a DOC saving of 5.5% with regard to that of the same range conventional design (fig 5.8.3). This graph, fig 5.8.1, shows that whilst the three-surface design DOC is more sensitive at shorter ranges than the conventional one, it offers clear advantage for higher ranges since its DOC curve shows smaller differences with regard to range than that of the conventional design. Ultimately, at a range of 3000 NM, the three-surface baseline offers a saving in DOC of about 7.9% as seen on figure 5.8.3 which turns out to correspond roughly to an annual saving of nearly US$315000, assuming the cost assumptions employed are accepted. Figure 5.8.3 shows that, for the baseline designs, DOC benefit can be obtained from the operation of a three-surface configuration which increases linearly from a minimum of 4.1% at a design range of 1000 NM up to nearly 8% at 3000 NM range. With regard to the M.T.O.W for all ranges considered the unconventional design MTOW is lower than that for its conventional counterpart as seen on figure 5.8.2. Comparing both concepts with the conventional baseline datum (R = 1250 NM), MTOW growths of 40.3% and 30.2% respectively for the conventional and for the three-surface designs at a design range of 3000 NM are visualized. Roughly speaking and in a similar manner as for the DOC, it can be said that the difference in weight increase with range results in a weight reduction of about 7.2% being achieved for the three-surface at the upper extreme design range simulated. At the datum range its weight benefit is about 4.5%.

5.5.2 DOC and MTOW Optimised Designs

The search for the best compromise consistent with the initial mission specification, satisfying field and cruise performance, stability and control requirements and also meeting the FAR regulations while minimizing the DOC or the MTOW, would probably entail a change in wing loading on every case driven by RQPMIN. In fact, for the design datum range (R=1250 NM), tables 5.4 through 5.7 show that the minimum DOC or minimum MTOW is achieved by an increase of the wing loading corresponding to a decrease in the aircraft lifting surface areas and respective weights, at an expense of the aircraft field performance.

Tables 5.4 and 5.6, for the conventional optimised designs, show that the "optimal" corresponds to a wing loading of 105 lb/sqft which is the upper limit imposed on this design variable, as indicated in section 5.4. This limit was chosen for empirical reasons assuming it represents already a relatively high value for practical purposes when compared to that adopted on equivalent type aircraft (Ex.: Fokker F28 W/S = 85.88 lb/sqft; Canadair RJ 100 W/S = 80.82 lb/sqft and RJ 100 ER W/S = 86.87 lb/sqft).

Tables 5.5 and 5.7 related to the three-surface optimisation show that the "optimal" is constrained by the FAR take-off field length without approaching the upper wing loading bound. When conducting the range trade-off studies the field length constraints were relaxed, i.e. unconstrained, since they do not seem to change the objective of the research in a meaningful manner. This led to easing and speeding up the several design synthesis runs. In this way it is shown in the same tables, that for ranges above the specification range all the unconventional designs violate the take-off field length while the conventional designs only violate it for ranges equal or above 2250 NM. The maximum violation occurs for the three-surface optimised for minimum MTOW at a design range of 3000 NM with a take-off field length of 6660.8 ft which corresponds to 11% above the specification value. Having in mind the required range, this difference may turn to be insignificant in practical terms.

Regarding the optimised designs trade-offs, figures 5.9 and 5.10 deserve the same qualitative considerations as developed above for the baseline studies shown on figure 5.8. The effect of the range trade-offs performed with the MTOW optimised designs on the DOC, figure 5.10.1 may seem strange. Recalling that the three-surface DOC curve grows faster for lower ranges than happens for the conventional counterpart, it is not surprising that the two curves may intercept for some particular designs. For this design case DOC penalties are experienced by the unconventional designs (fig 5.10.3). According to the curves on figures 5.9 and 5.10, the conventional optimised design has a minimum DOC occurring between the design ranges of 1500 and 1750 NM, while for the three-surface it happens at a range of 1750 NM, as for the baseline. In agreement with these trends, a maximum of 3.5% DOC benefit is obtained by the three-surface design with respect to the DOC optimised classical concept at a design range of 3000 NM. This roughly corresponds to an annual saving per aircraft of US$134000, assuming the cost assumptions made are realistic. For the DOC optimised configurations range trade-offs, an almost linear growth on DOC benefit is offered by the three-surface concept from 0.4% (1000 NM range) up to 3.5% (3000 NM range). For the MTOW, the three-surface optimised designs show weight advantages with respect to the conventional optimised configurations for all ranges considered, 3.45% average weight benefit for the DOC optimised range trade-off designs and 2.43% average weight benefit for the MTOW optimised range trade-off designs, as shown respectively on figures 5.9.2, 5.9.3 and 5.10.2, 5.10.3.

5.5.3 Optimised versus Baseline Designs

Figures 5.11 and 5.12 provide a convenient way of comparing the optimised designs with the corresponding design range baselines and to assess both the inherent potential benefits offered by the drastic configuration change due to the inclusion of a fore-plane as well as the power of the mathematical programming techniques.

In fact, a first inspection of figures 5.11.1 and 5.12.1, show that a most significant contribution to the overall gain comes from the simple switch of the baseline conventional configuration to an equivalent three-lifting surface one in contrast with the result obtained from its optimisation. This is illustrated by the wide spacing displayed by the two baseline designs range trade-off curves, while maintaining the same take-off wing loading. The one for the baseline unconventional design almost mixes up with the corresponding optimised designs curves. Considering the conventional datum design (R=1250 NM) as a base for comparison, the corresponding three-surface baseline shows a benefit in DOC of 4.7% (fig 5.8.3) while the DOC optimised designs, tail-aft and three-surface show respectively 6.1% and 6.4% DOC advantage (fig 5.11.3). This means that, for the design range concerned, performing a DOC optimisation on the classical baseline design will give only an advantage of about 1.4% in relation to the three-surface baseline (not optimised). On the other hand, if the three-surface baseline is optimised for DOC this advantage would turn to be about 1.7%. For the datum range, and assuming the cost figures as reasonable predictions, it can be said that the three-surface baseline will show annual DOC benefits per aircraft of nearly US$172100 while its optimised version will represent a saving of about US$233900 with respect to the tail-aft baseline configuration. The optimised conventional one presents an intermediate annual saving, for this study (DOC optimisation) of about US$224650. When performing MTOW optimisations, the optimised three-surface transport does not show the "best" DOC result as the latter case. This is claimed by the minimum weight conventional configuration (fig 5.12.1). The reason is probably because the MTOW minimization runs conducted on the three-surface design were unable to locate a better minimum MTOW solution, as explained before at the end of section 5.4.

At increasing design range, DOC benefits claimed by the three-surface designs are more noticeable since this concept is less sensitive in terms of DOC for higher ranges than the tail-aft concept, as shown before. Thus at a design range of 3000 NM, taking the conventional baseline design at this range as a base for comparison, the corresponding three-surface baseline shows a benefit in DOC of 7.9% (fig 5.8.3), as referred to above, while the DOC optimised designs, tail-aft and unconventional one show respectively 7.6% and 10.9% DOC advantage (fig 5.11.3). These figures mean that for the design range considered, performing a DOC optimisation on the classical baseline design gives a penalty of about 0.3% with respect to the three-surface baseline (not optimised). On the other hand if the three-surface baseline is optimised for DOC the advantage would be increased to 2.9%. In fact a three-surface airliner optimised for minimum DOC and to fly a distance of 3000 NM would represent roughly an annual saving of about US$432000 per aircraft when compared to the initial baseline conventional design for the same range, assuming the cost assumptions and utilization rate employed are close to reality. It is interesting to see that for design ranges at, or above, 2750 NM the conventional aircraft optimised both for minimum DOC and minimum MTOW experiences higher DOC than the corresponding design range three-surface baseline designs as shown on figures 5.11.1, 5.11.4, 5.12.1 and 5.12.4.

Regarding the MTOW, the three-surface baseline airliner generally offers weight advantages with respect to the conventional optimised configurations at design ranges above the datum range as observed on figures 5.11.2, 5.11.4, 5.12.2 and 5.12.4. For all design ranges considered, the optimised unconventional transports display the lowest MTOW, 8% weight saving at 1250 NM design range and 8.9% weight saving at 3000 NM design range when compared to the same range tail-aft baseline concept (figs. 5.11.2 and 5.11.3). With respect to the three-surface baseline concept these weight savings are respectively 3.7% and 1.8% (figs. 5.11.2 and 5.11.4). These gains were taken from the minimum DOC unconventional solutions since these were the best solutions found for this configuration based on the minimum DOC rather than on minimum weight, as noted above and referred to in section 5.4.

5.6 Concluding Remarks

It was shown that DOC and MTOW benefits are evident when switching from a conventional tail-aft configuration to a same mission equivalent three-surface aircraft design, assuming the same wing loading is kept on both concepts. Further more it was found that DOC benefits increase linearly with design ranges which nearly double from a range of 1000 NM up to 3000 NM. Although MTOW increases with design range, weight savings are also experienced. These increase from 4.2% at 1000 NM range, up to 7.2% MTOW saving at 3000 NM design range.

When optimising the above designs it is observed that improvement on the figures of merit is obtained, but a major general gain, comparable to that obtained from the optimised tail-aft configuration, is produced simply by the adoption of the concept under study. It is interesting to note that the canard equipped version is less cost sensitive at longer ranges than the equivalent classical concept. It may be observed that the marginal gains determined by the conventional one, optimised for medium haul, are offset and turn to be cost penalties with regard to the three-surface baseline design for long ranges (equal to or above 2750 NM). On the other hand, while optimising the three-surface concept, sensible gains both on DOC and MTOW are demonstrated with respect to its baseline design for all design ranges analysed, and have greater impact on cost savings achieved for higher ranges (figs. 5.11.1 and 5.11.4). Annual economies in DOC per airliner amounting to roughly US$233900 at 1250 NM design range and US$432000 at 3000 NM design range with regard to the classical baseline concept are possible, providing the cost assumptions used in the studies are credible.

From the design study results, within the usual limitations of any initial conceptual design study but in the present case including many real life considerations that quantitatively are important ingredients for any realistic study, it appears that little doubt exists on the inherent achievable benefits when replacing a conventional design by an equivalent mission twin turbo-fan airliner of the three-lifting surface type.

It is worth noting that the conclusions here are based on a more complex approach than used by others and reported in Chapter 2. It is the author belief that within the time constraints of the present research, a comprehensive, consistent and systematic design study has been conducted on the topic, and the results are of a conclusive nature regarding the merits of such a potential unusual commercial turbofan airliner.

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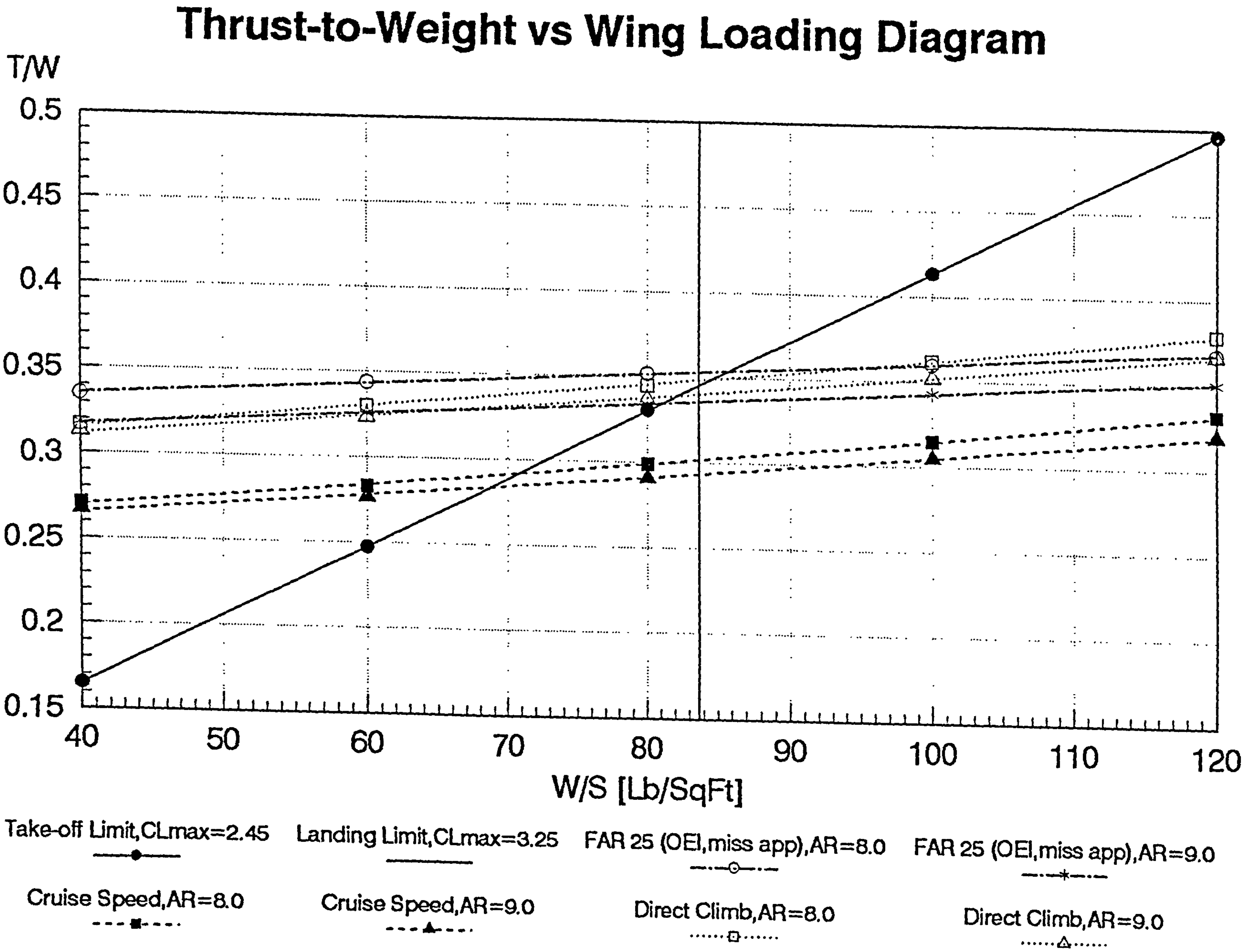

Fig 5.1 - Design Constraint Diagram

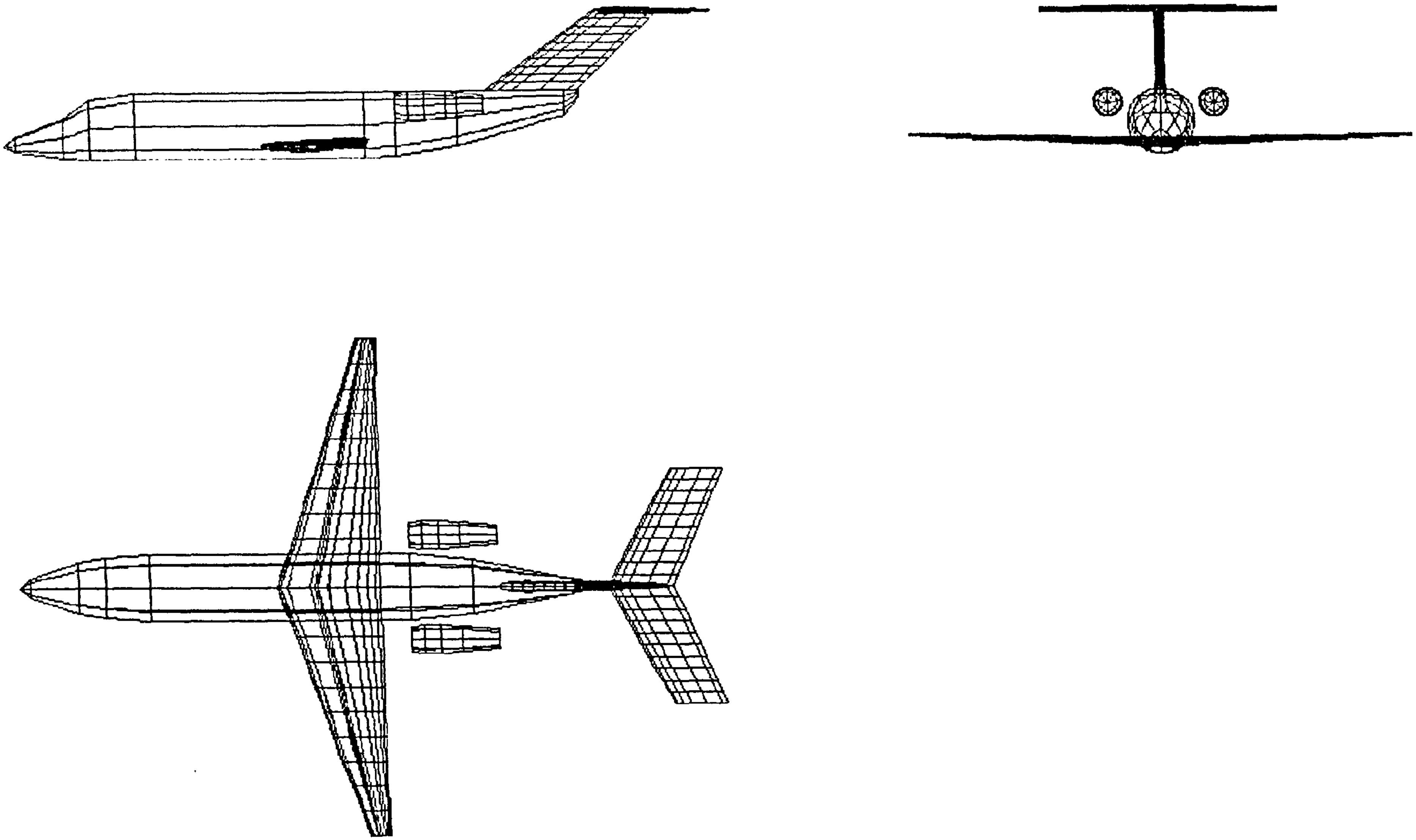

Fig 5.2 - Conventional Baseline Configuration

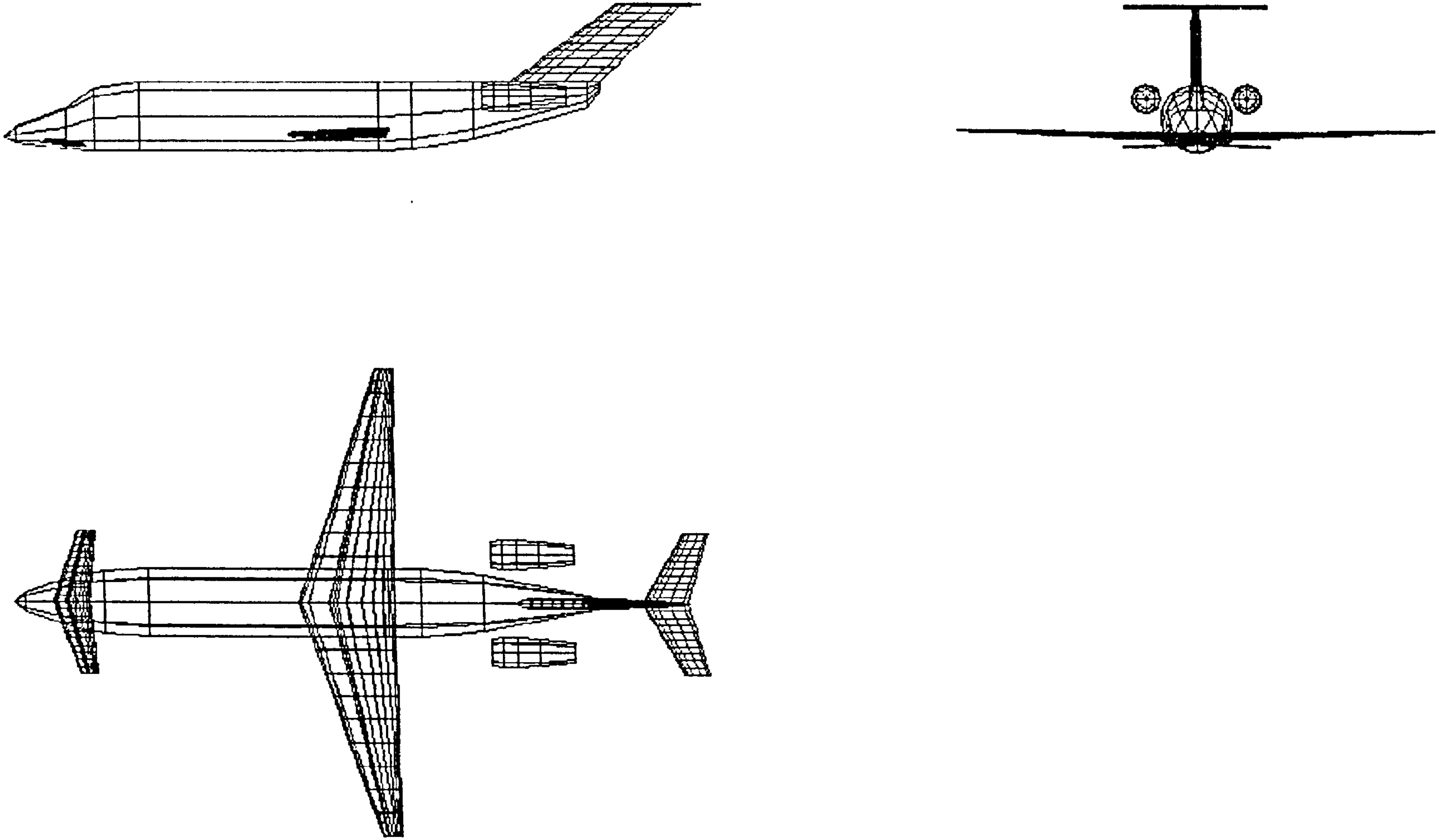

Fig 5.3 - Three-Lifting Surface Baseline Configuration

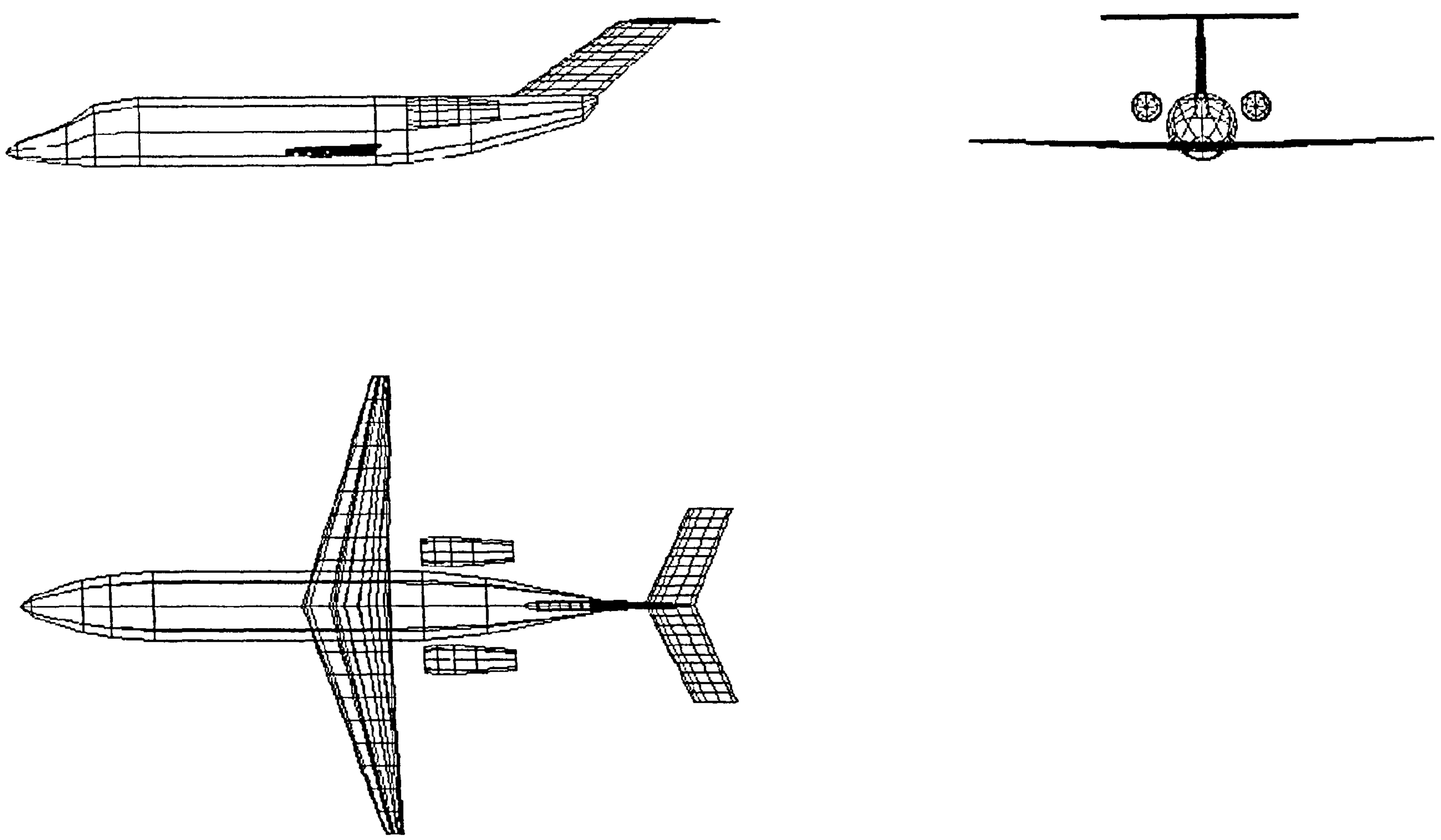

Fig 5.4 - Conventional Configuration optimised for minimum D.O.C.

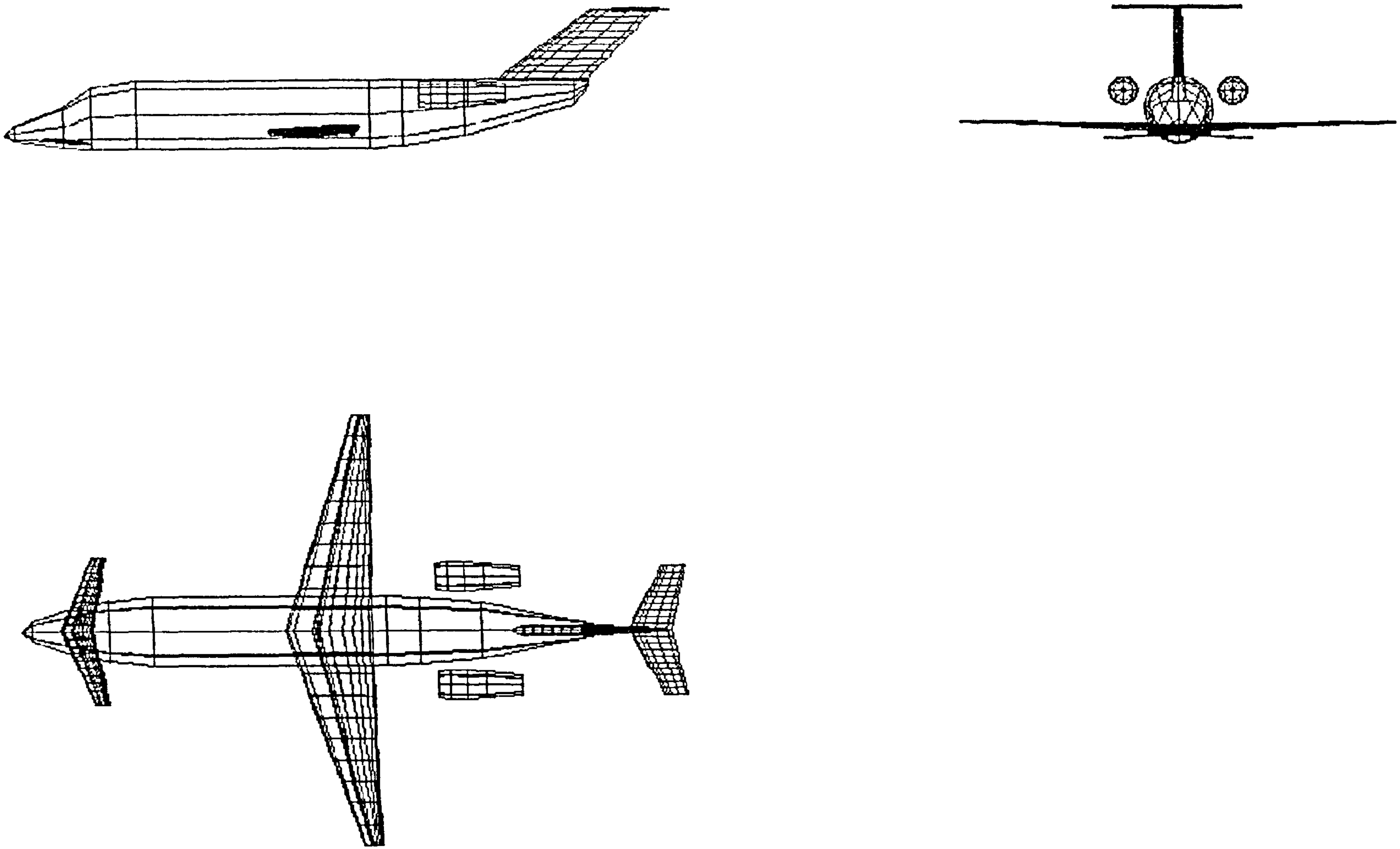

Fig 5.5 - Three-Lifting Surface Configuration optimised for minimum D.O.C.

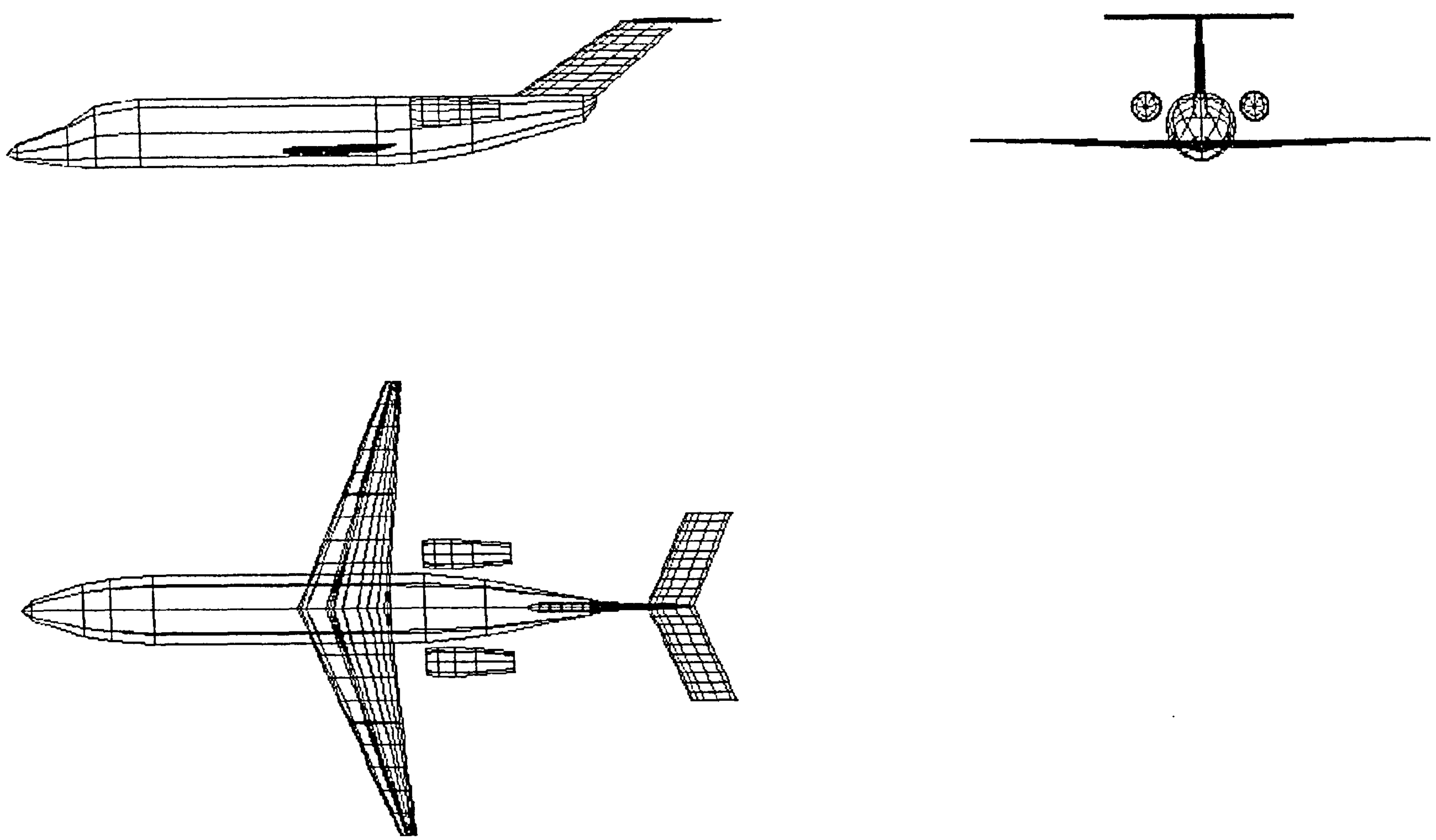

Fig 5.6 - Conventional Configuration optimised for minimum M.T.O.W.

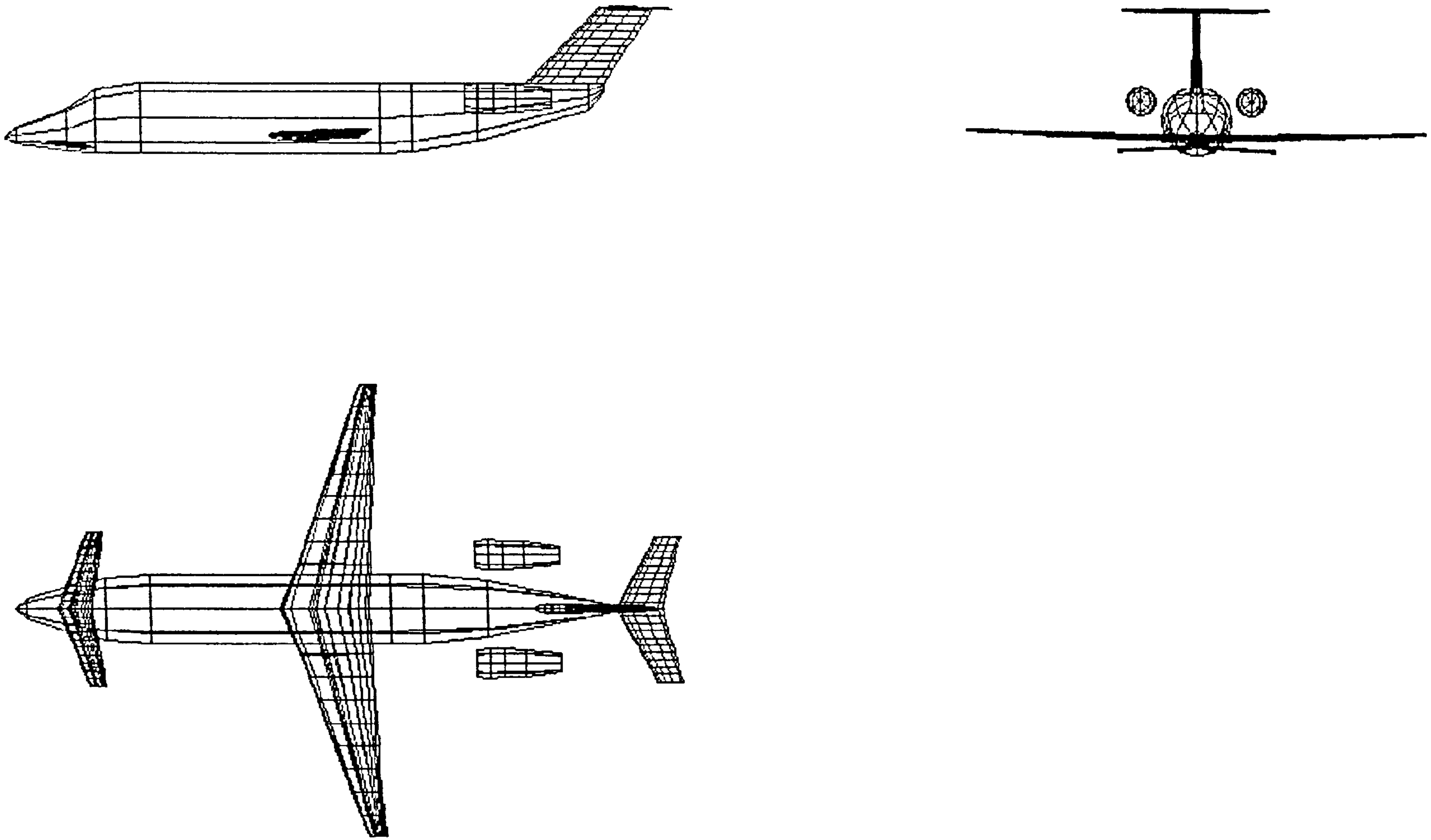

Fig 5.7 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.

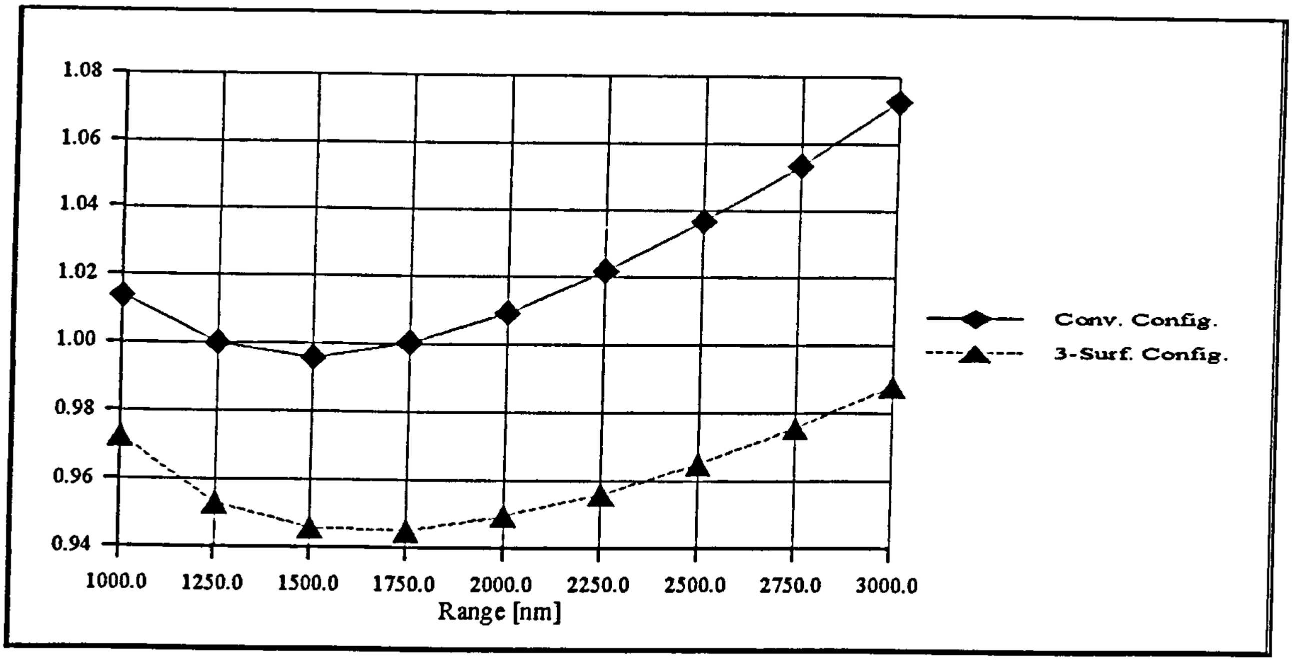

Fig 5.8.1 - Direct Operating Costs - Range Trade-off for the Baseline Configurations

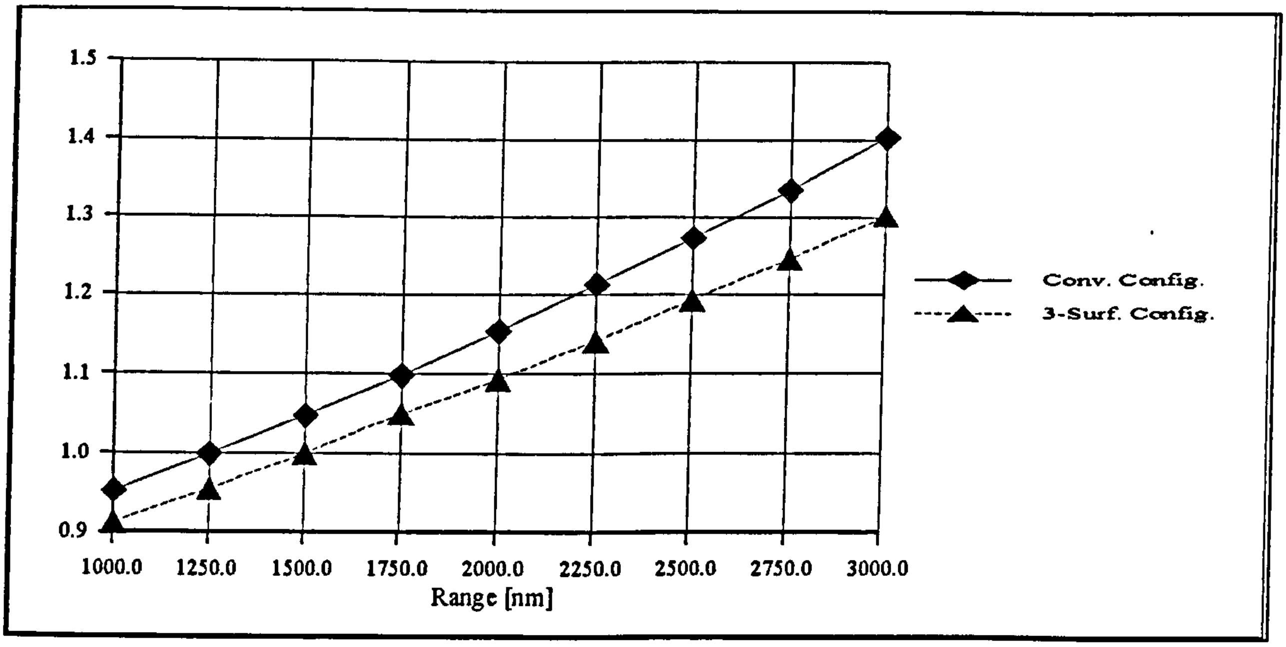

Fig 5.8.2 - Maximum Take-off Weight - Range Trade-off for the Baseline Configurations

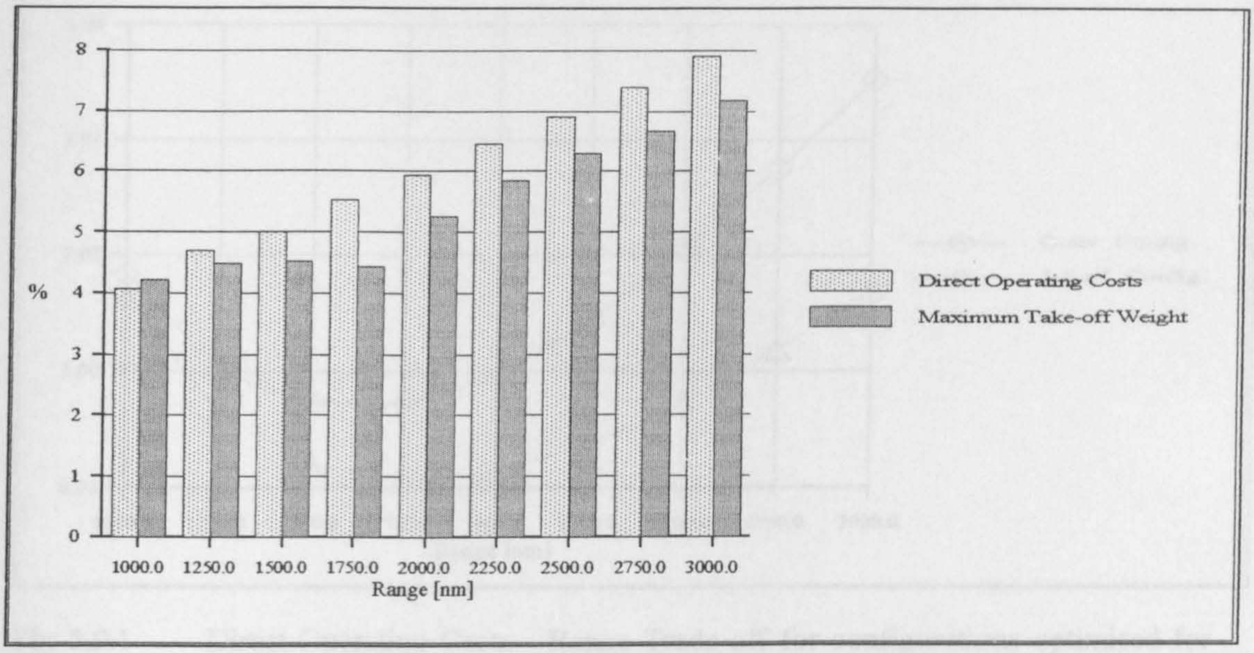

Fig 5.8.3 - Three-Surface versus Conventional Configurations Benefits (Baseline Designs)

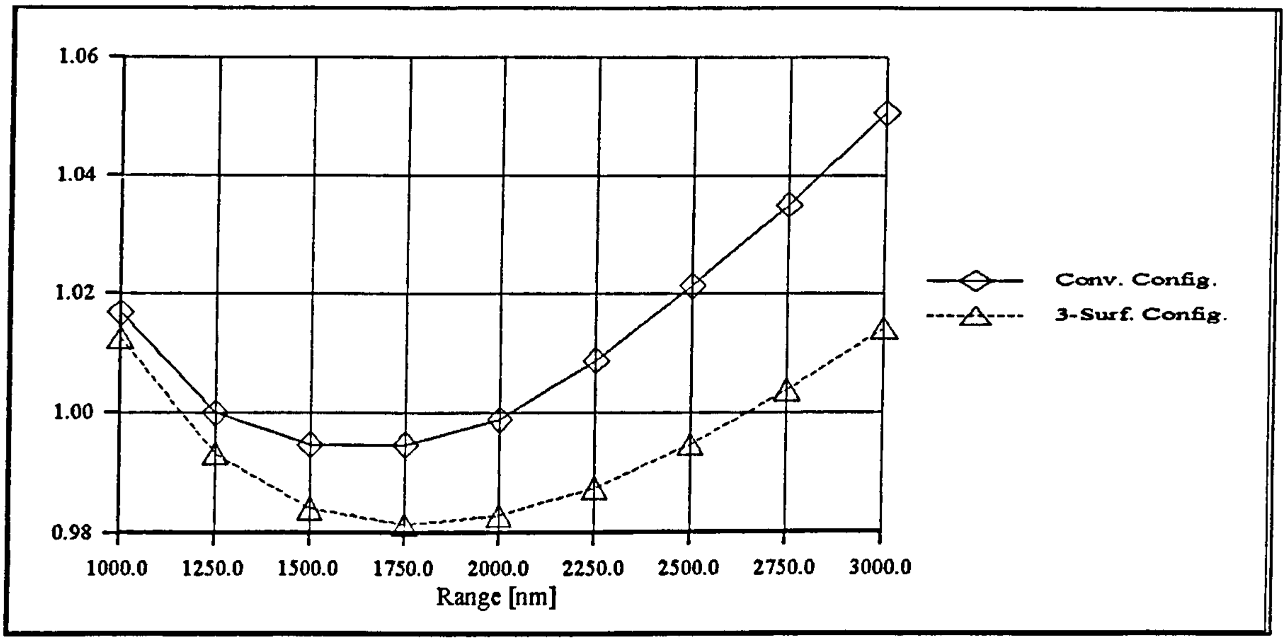

Fig 5.9.1 - Direct Operating Costs - Range Trade-off for configurations optimised for minimum D.O.C.

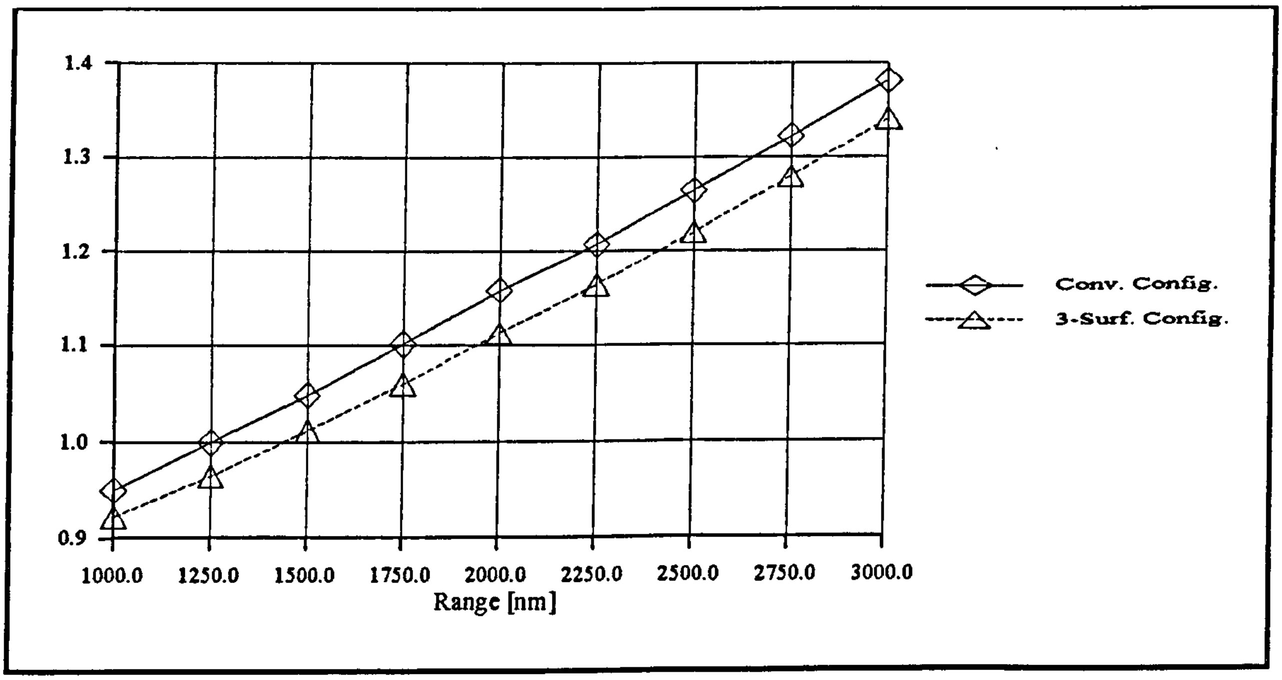

Fig 5.9.2 - Maximum Take-off Weight - Range Trade-off for configurations optimised for minimum D.O.C.

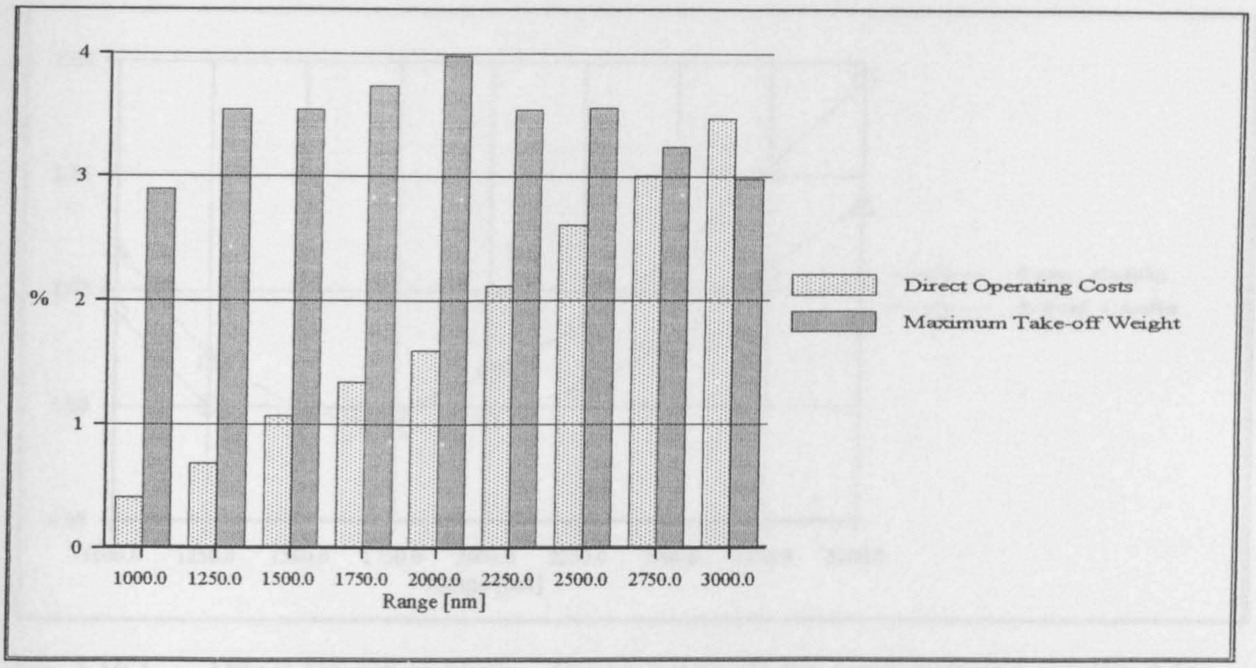

Fig 5.9.3 - Three-Surface versus Conventional Configurations Benefits (Configurations optimised for minimum D.O.C.)

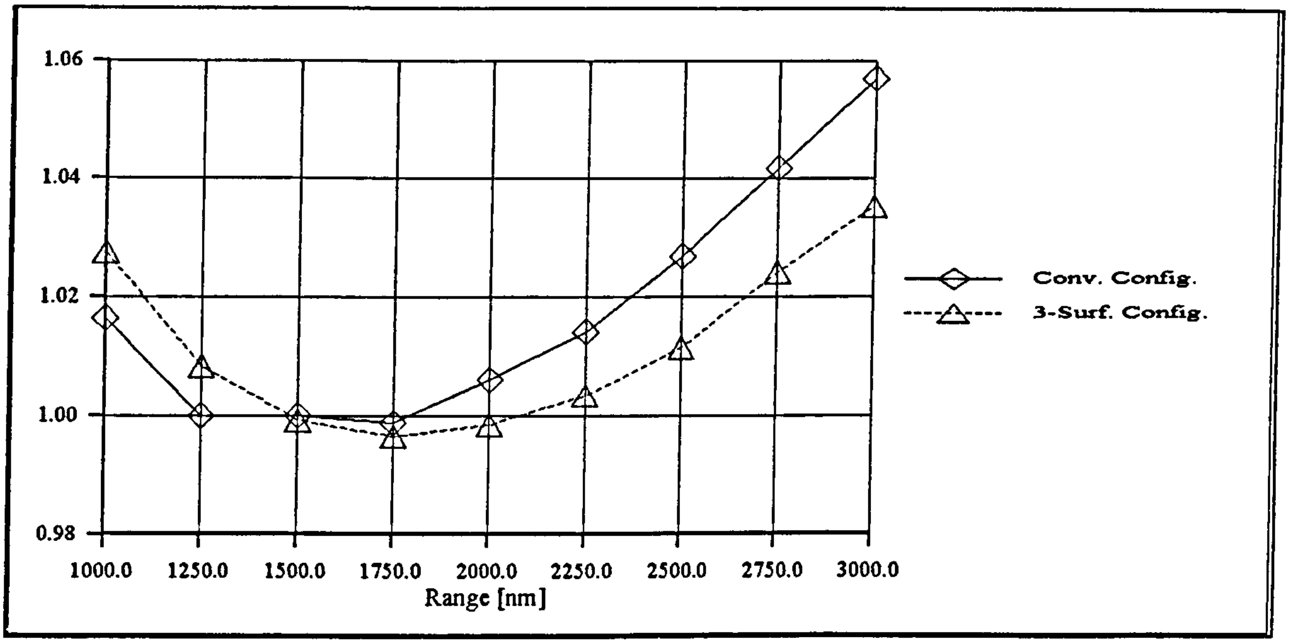

Fig 5.10.1 - Direct Operating Costs - Range Trade-off for configurations optimised for minimum Max. Take-off Weight

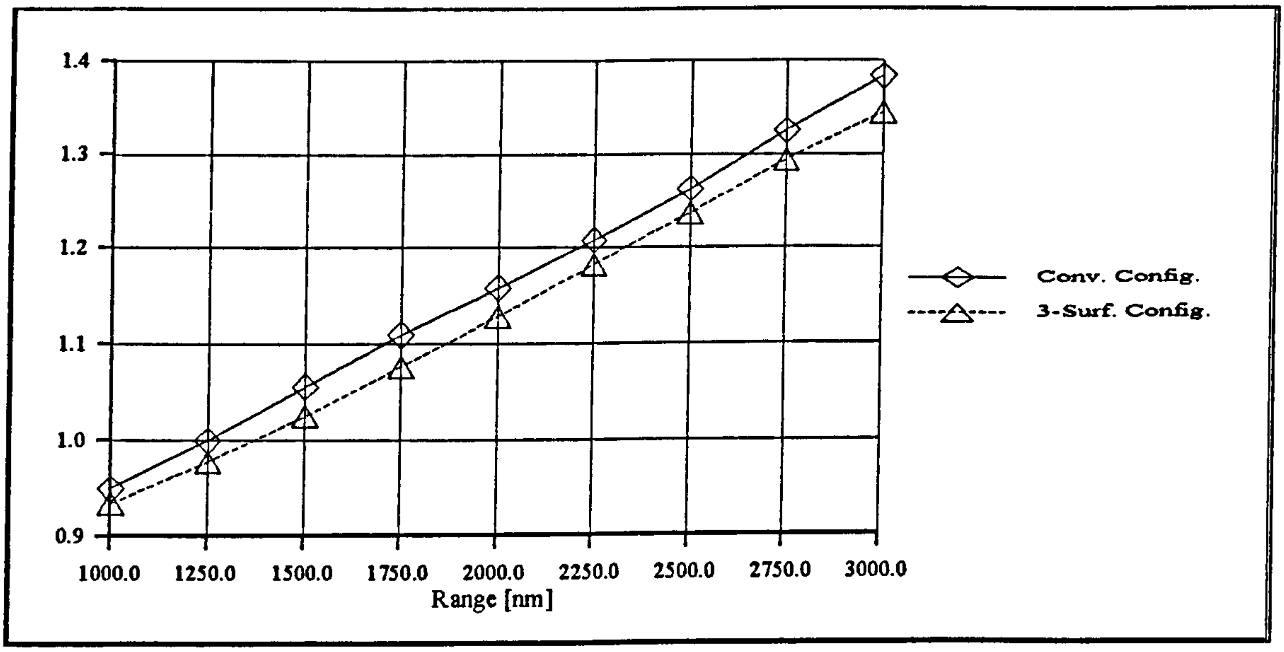

Fig 5.10.2 - Maximum Take-off Weight - Range Trade-off for configurations optimised for minimum Max. Take-off Weight

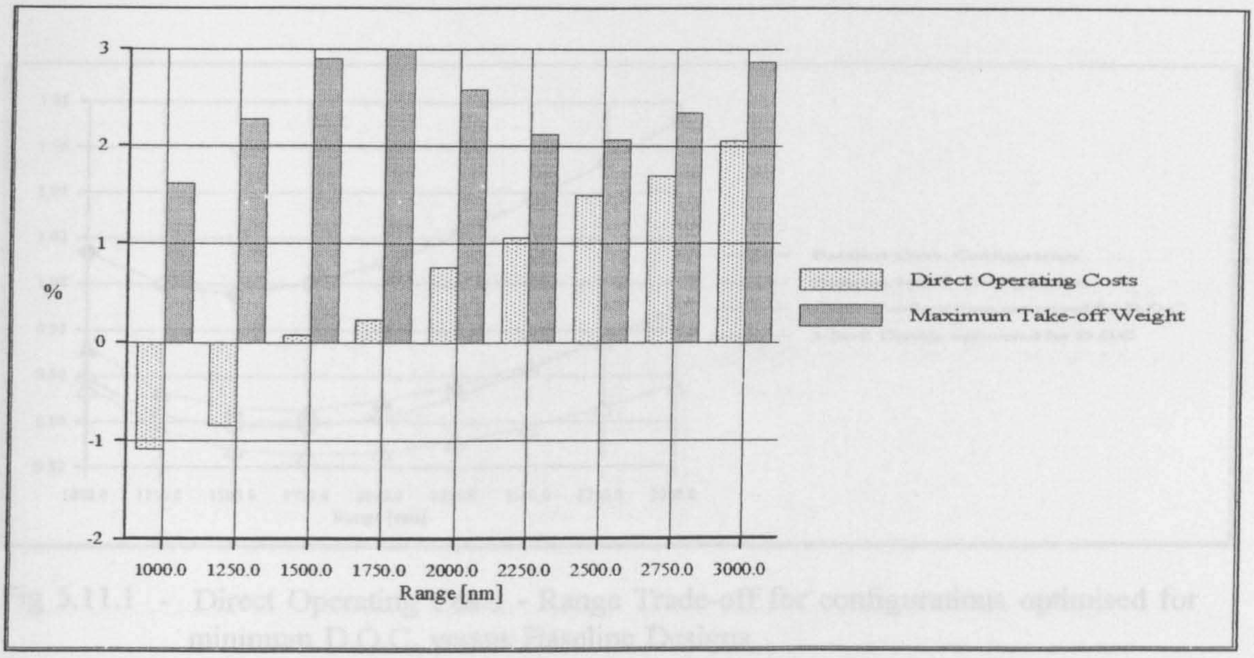

Fig 5.10.3 - Three-Surface versus Conventional Configurations Benefits (Configurations optimised for minimum Max.Take-off Weight)

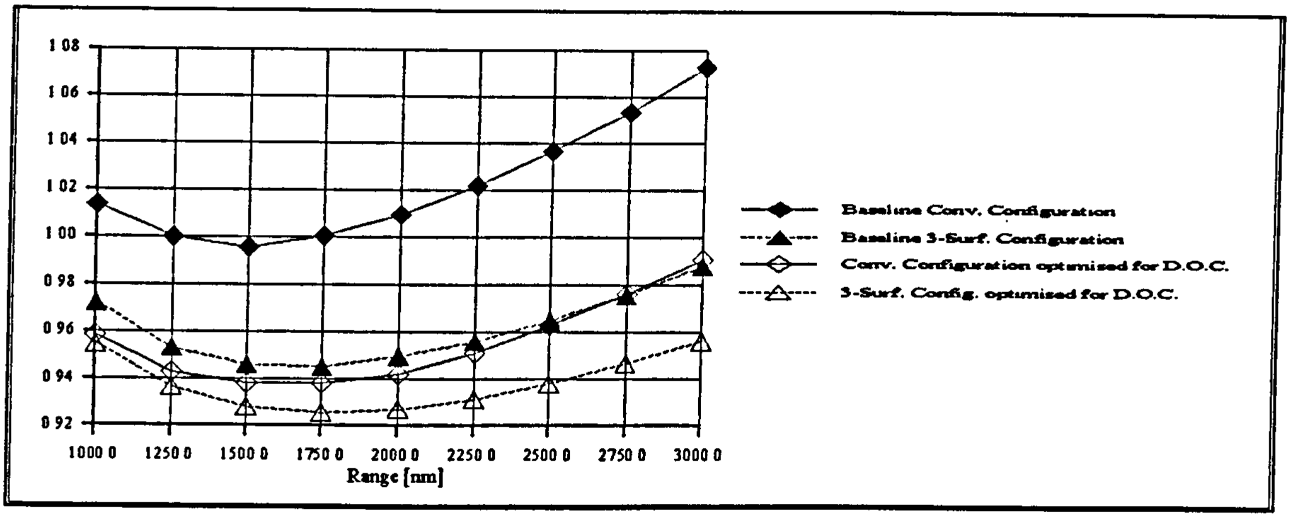

Fig 5.11.1 - Direct Operating Costs - Range Trade-off for configurations optimised for minimum D.O.C. versus Baseline Designs

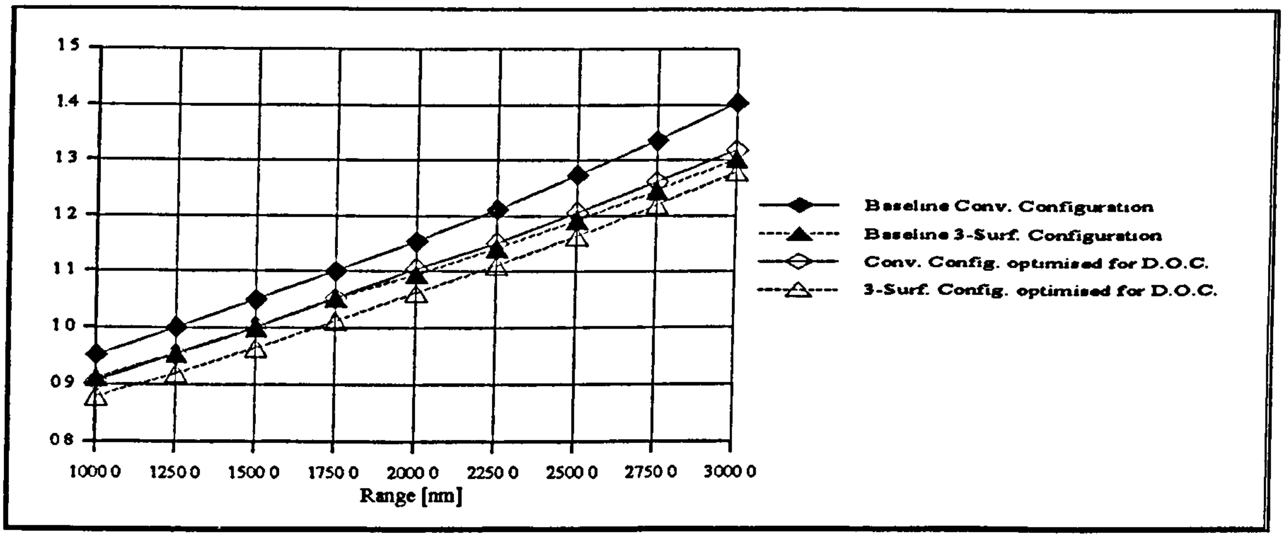

Fig 5.11.2 - Maximum Take-off Weight - Range Trade-off for configurations optimised for minimum D.O.C. versus Baseline Designs

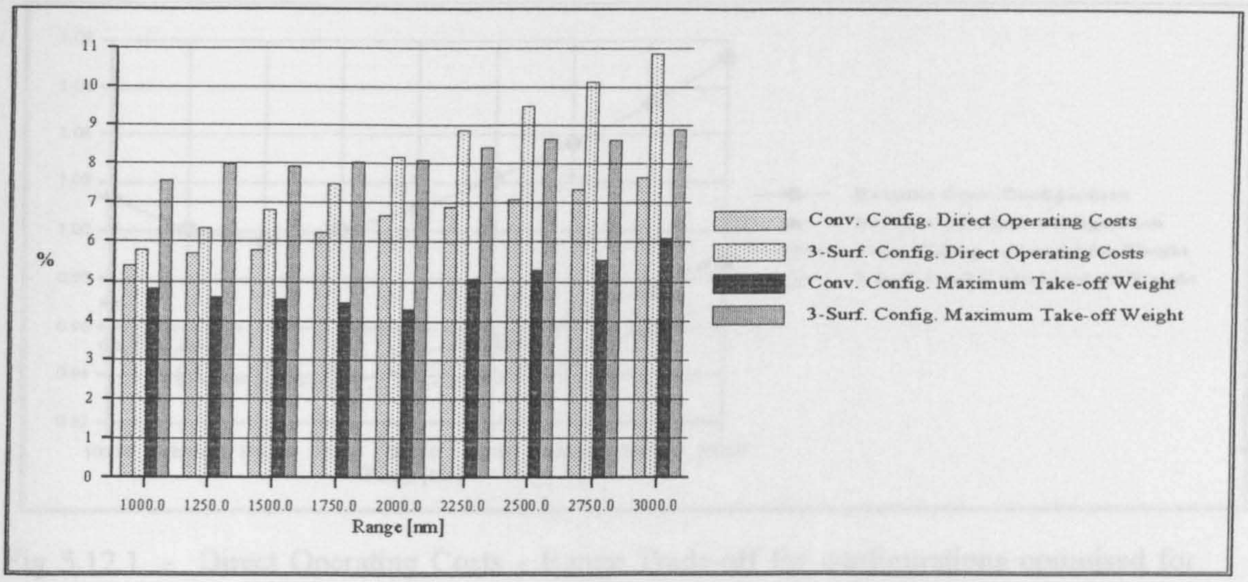

Fig 5.11.3 - Benefits of Configurations optimised for minimum D.O.C. with regard to the Conventional Baseline Design

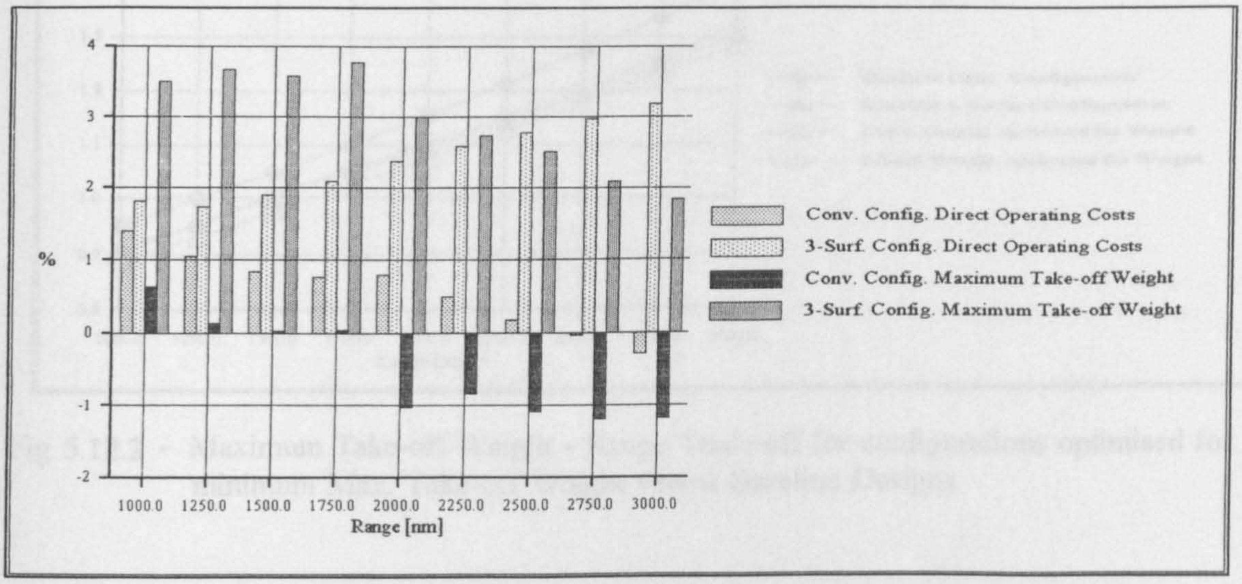

Fig 5.11.4 - Benefits of Configurations optimised for minimum D.O.C. with regard to the Three-Surface Baseline Design

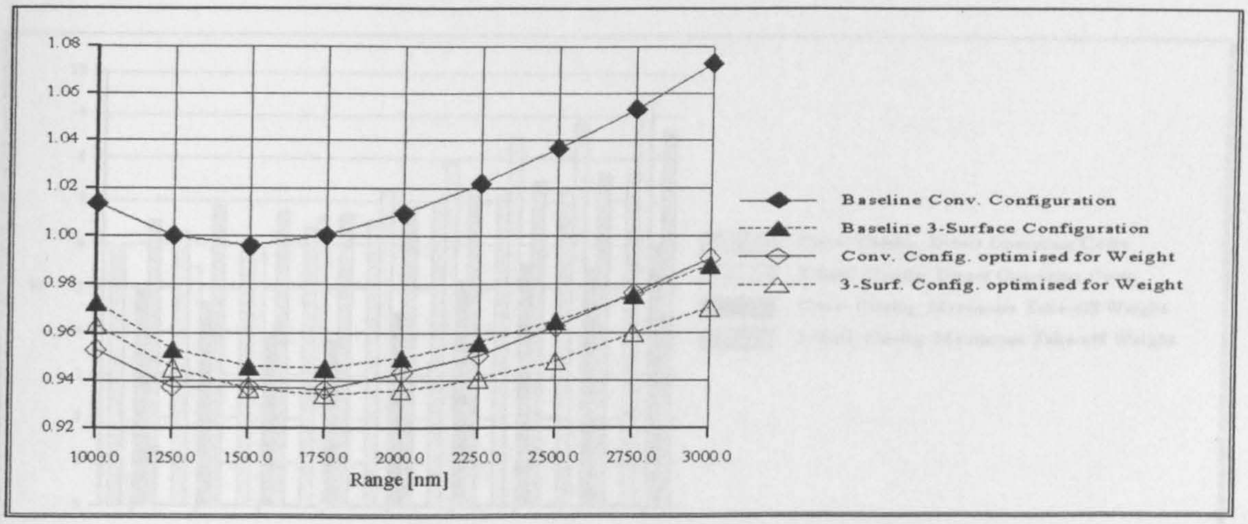

Fig 5.12.1 - Direct Operating Costs - Range Trade-off for configurations optimised for minimum Max. Take-off Weight versus Baseline Designs

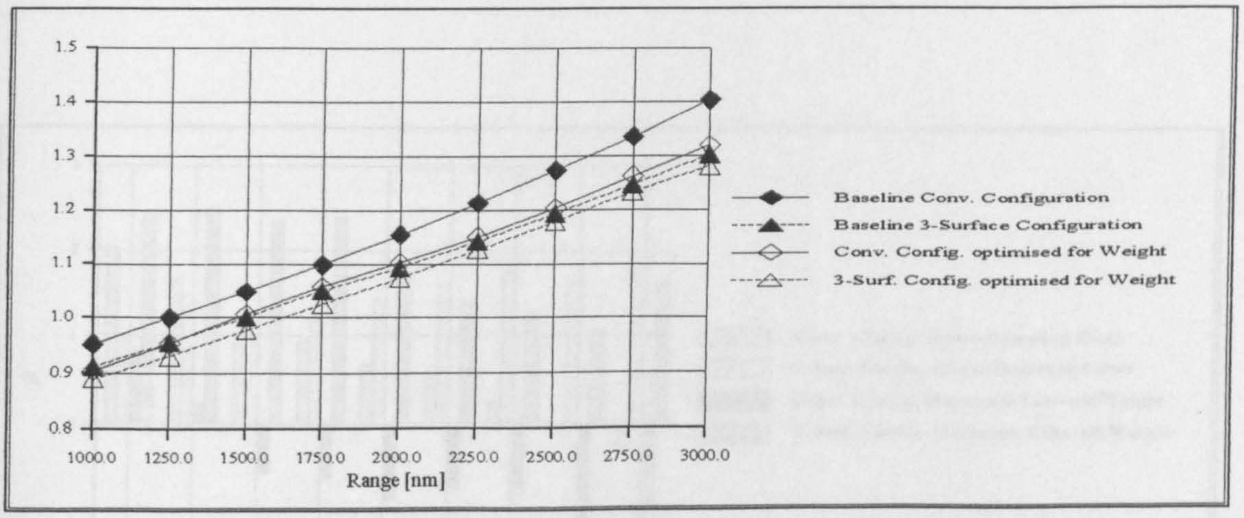

Fig 5.12.2 - Maximum Take-off Weight - Range Trade-off for configurations optimised for minimum Max. Take-off Weight versus Baseline Designs

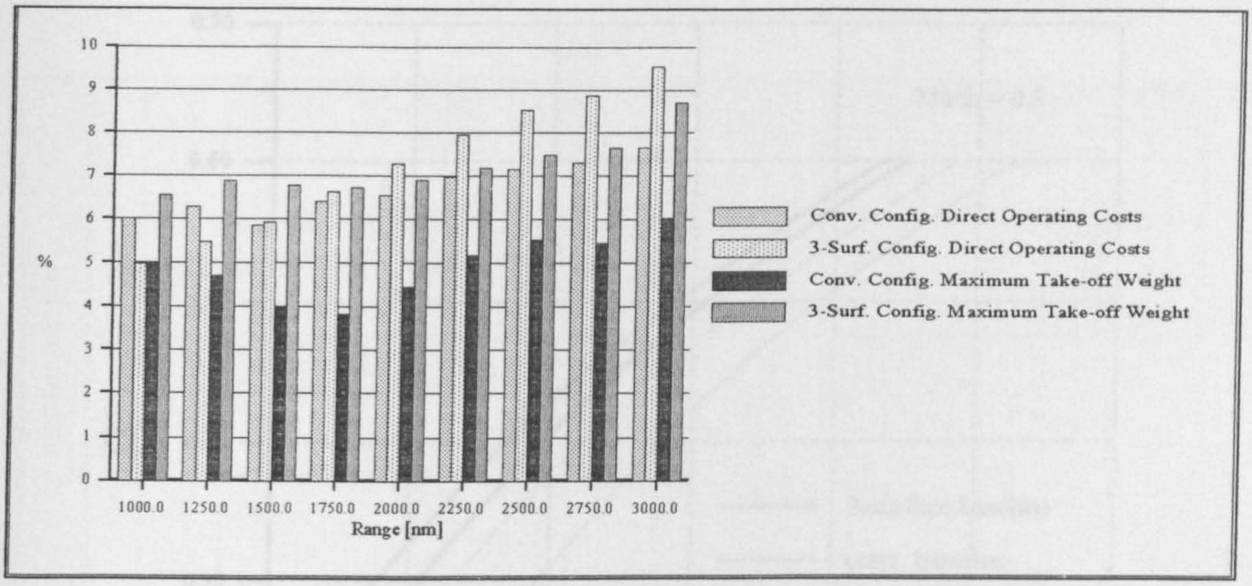

Fig 5.12.3 - Benefits of Configurations optimised for minimum Max. Take-off Weight with regard to the Conventional Baseline Design

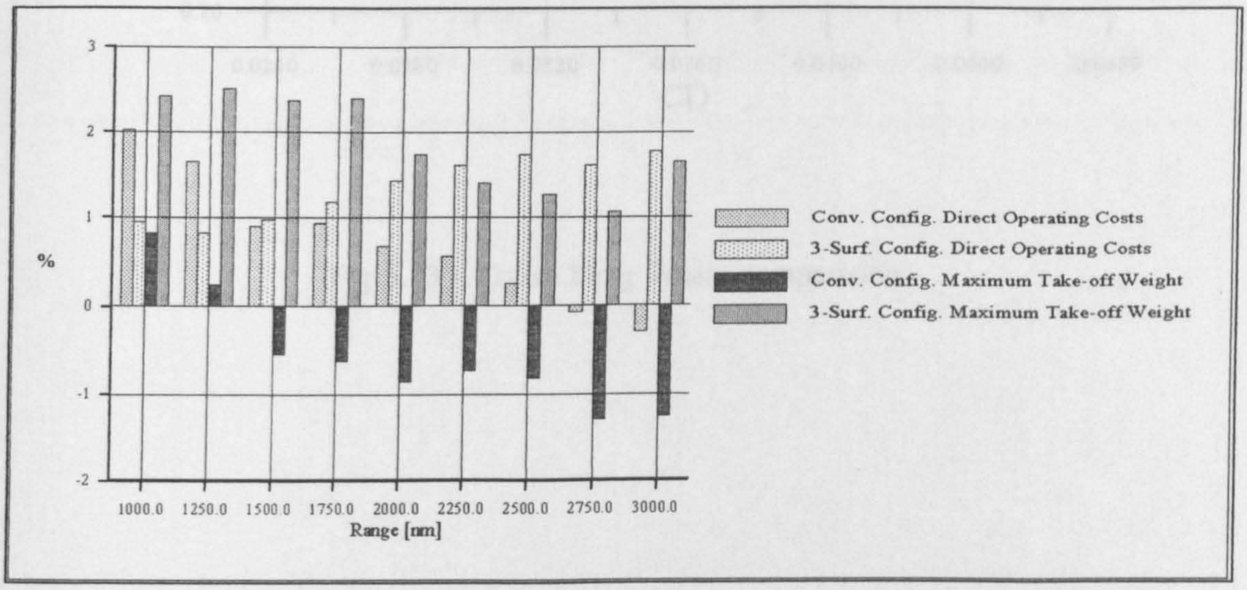

Fig 5.12.4 - Benefits of Configurations optimised for minimum Max. Take-off Weight with regard to the Three-Surface Baseline Design

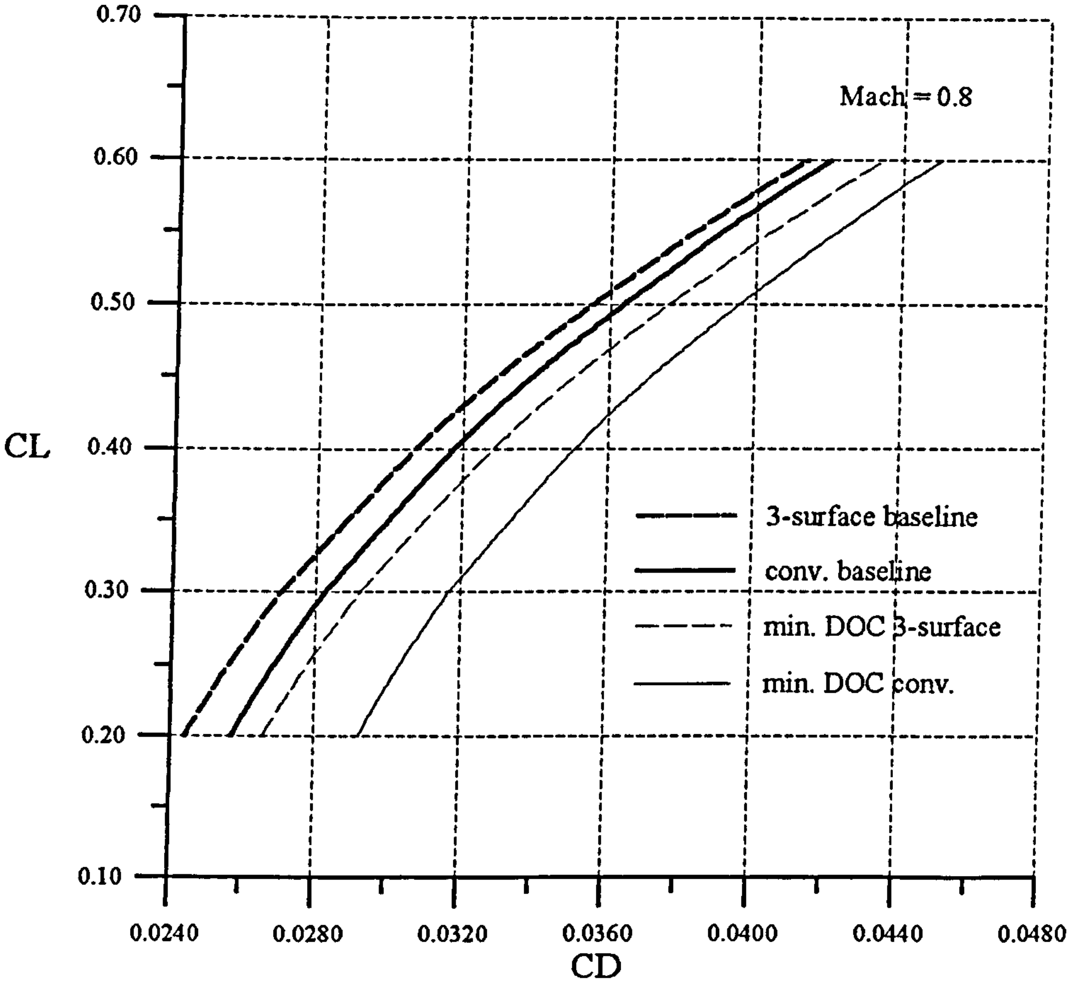

Fig 5.13 - Cruise Drag Polars comparision

		PreSiz	GASP		RQPMIN+GASP			
			Baselines		Min. D.O.C.		Min. M.T.O.W.	
			Conv.	3-Surf.	Conv.	3-Surf.	Conv.	3-Surf.
M.T.O.W.	LB	44076	47873	45726	45707	44050	45639	44576
E.W.	LB	24698	27385	25899	25554	24612	25540	25170
Fuel Weight	LB	8558	9389	8747	9074	8372	9020	8340
Engine Max. St. T/O Thrust	LB	7603	9920	9291	9756	8899	9785	8842
T/O Wing Loading	PSF	83.75	83.00	83.00	105.00	93.00	105.00	90.80
T/O Thrust to Weight Ratio		0.345	0.414	0.406	0.427	0.404	0.429	0.397
Cruise Mach No.		0.80	0.79	0.81	0.83	0.80	0.84	0.79
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		11.00	11.98	12.24	11.72	12.26	11.68	12.50
T/O CLmax		2.450	2.466	2.156	2.503	2.136	2.432	2.119
Landing CLmax		3.250	3.264	2.845	3.296	2.811	3.187	2.783
FAR 25 T/O Field Length	FT	6000.0	4638.0	5360.5	5475.7	5994.8	5598.1	6004.9
FAR 25 Land. Field Length	FT	5000.0	4016.8	4496.0	4807.5	4965.6	4940.5	4911.8
Wing Area	SQFT	526.29	576.78	481.05	435.30	409.06	434.67	419.08
Wing Aspect Ratio		8.30	8.30	8.30	8.88	8.40	8.72	8.84
Wing 1/4 Chord Sweep	DEG		14.50	14.50	14.88	14.51	18.57	16.12
Canard Area	SQFT			69.75		64.77		71.91
Canard Aspect Ratio				5.50		6.10		6.01
Canard 1/4 Chord Sweep	DEG			15.00		20.55		18.24
Canard to Wing Area Ratio				0.1450		0.1583		0.1716
Mission Range	NM	1250.00	1250.14	1250.43	1262.25	1239.81	1249.73	1238.91
Aircraft Price	US$		18.2E+06	17.6E+06	17.5E+06	17.0E+06	17.6E+06	17.2E+06
D.O.C./N Mile	US$/NM		2.79	2.66	2.62	2.61	2.62	2.64

Table 5.1 - Summary of Main Results

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	549.29	576.78	604.39	633.91	665.74	699.58	734.44	770.16	809.30
Wing Aspect Ratio		8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30
Wing 1/4 Chord Sweep	DEG	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Engine Max. St. T/O Thrust	LB	9709	9920	10134	10363	10612	10878	11153	11436	11748
M.T.O.W.	LB	45591	47873	50164	52614	55257	58065	60959	63923	67172
O.E.W.	LB	27740	28484	29197	29980	30878	31831	32812	33815	34914
E.W.	LB	26647	27385	28092	28869	29760	30707	31681	32677	33769
Fuel Weight	LB	7851	9389	10967	12634	14379	16234	18147	20108	22257
T/O Wing Loading	PSF	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
T/O Thrust to Weight Ratio		0.426	0.414	0.404	0.394	0.384	0.375	0.366	0.358	0.350
Cruise Mach No.		0.80	0.79	0.79	0.78	0.78	0.77	0.76	0.76	0.75
Cruise Speed (TAS)	KT	462.4	458.8	455.5	451.1	447.6	444.1	440.7	437.5	434.1
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		11.67	11.98	12.27	12.57	12.87	13.17	13.46	13.75	14.03
Approach Speed (EAS)	KT	109.3	109.1	109.0	108.9	108.8	108.8	108.8	108.7	108.7
Approach Speed (TAS)	KT	121.9	121.8	121.6	121.5	121.4	121.4	121.4	121.3	121.3
T/O Stall Speed (TAS)	KT	107.5	107.5	107.5	107.5	107.5	107.4	107.4	107.4	107.4
Landing Stall Speed (TAS)	KT	93.6	93.4	93.3	93.2	93.2	93.1	93.1	93.1	93.1
T/O Flap (angle/CLmax)	DEG/	15./2.466	15./2.466	15./2.467	15./2.467	15./2.468	15./2.468	15./2.469	15./2.469	15./2.47
Landing Flap (angle/CLmax)	DEG/	40./3.257	40./3.264	40./3.271	40./3.279	40./3.283	40./3.285	40./3.286	40./3.287	40./3.289
FAR 25 T/O Field Length	FT	4539.4	4638.0	4707.3	4798.6	4901.5	4972.5	5070.9	5140.9	5239.4
FAR 25 Land. Field Length	FT	4028.3	4016.8	4005.9	3994.9	3987.0	3982.4	3978.2	3974.9	3970.1
Mission Range	NM	999.64	1250.14	1499.38	1749.46	1998.84	2251.78	2499.16	2740.01	2991.25
Block Fuel	LB	6023	7515	9046	10675	12378	14203	16069	17966	20075
Block Time	HR	2.478	3.044	3.613	4.201	4.790	5.395	5.997	6.593	7.221
Aircraft Price	US$	17.9E+06	18.2E+06	18.5E+06	18.8E+06	19.1E+06	19.5E+06	19.9E+06	20.3E+06	20.7E+06
D.O.C./Flight	US$/Flight	2827.95	3488.65	4166.35	4883.72	5630.33	6421.80	7231.04	8054.38	8954.73
D.O.C./N Mile	US$/NM	2.83	2.79	2.78	2.79	2.82	2.85	2.89	2.94	2.99

Table 5.2 - Conventional Baseline Configuration Range Trade-off (Datum aircraft - Range=1250 N Mile)

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	459.48	481.05	503.88	529.03	551.01	575.44	601.11	627.65	656.26
Wing Aspect Ratio		8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30
Wing 1/4 Chord Sweep	DEG	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Canard Area	SQFT	66.63	69.75	73.06	76.71	79.90	83.44	87.16	91.01	95.16
Canard Aspect Ratio		5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Canard 1/4 Chord Sweep	DEG	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Canard to Wing Area Ratio		0.1450	0.1450	0.1450	0.1450	0.1450	0.1450	0.1450	0.1450	0.1450
Engine Max. St. T/O Thrust	LB	9041	9291	9557	9852	9923	10140	10370	10609	10860
M.T.O.W.	LB	43669	45726	47897	50282	52351	54666	57120	59662	62349
O.E.W.	LB	26348	26979	27677	28451	29020	29742	30510	31308	32157
E.W.	LB	25274	25899	26591	27359	27924	28641	29403	30195	31038
Fuel Weight	LB	7321	8747	10220	11831	13331	14923	16609	18354	20192
T/O Wing Loading	PSF	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
T/O Canard Loading	PSF	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
T/O Thrust to Weight Ratio		0.414	0.406	0.399	0.392	0.379	0.371	0.363	0.356	0.348
Cruise Mach No.		0.81	0.81	0.81	0.81	0.80	0.79	0.79	0.79	0.78
Cruise Speed (TAS)	KT	466.4	466.7	467.2	467.0	460.6	458.5	456.4	454.4	452.3
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		12.02	12.24	12.47	12.72	13.09	13.37	13.64	13.92	14.19
Approach Speed (EAS)	KT	117.0	116.9	116.8	116.6	116.5	116.4	116.4	116.4	116.3
Approach Speed (TAS)	KT	130.6	130.5	130.3	130.2	130.0	129.9	129.9	129.9	129.8
T/O Stall Speed (TAS)	KT	116.5	117.4	118.2	118.9	119.7	120.2	120.6	121.0	121.2
Landing Stall Speed (TAS) .	KT	101.5	102.2	102.9	103.3	103.9	104.3	104.7	105.0	105.2
T/O Flap (angle/CLmax)	DEG/	15./2.155	15./2.156	15./2.156	15./2.157	15./2.158	15./2.158	15./2.159	15./2.16	15./2.16
Landing Flap (angle/CLmax)	DEG/	40./2.839	40./2.845	40./2.851	40./2.858	40./2.863	40./2.868	40./2.869	40./2.87	40./2.872
FAR 25 T/O Field Length	FT	5280.8	5360.5	5441.1	5505.5	5658.3	5747.5	5855.4	5954.3	6062.9
FAR 25 Land. Field Length	FT	4506.2	4496.0	4485.3	4474.3	4460.2	4450.9	4447.4	4444.4	4438.3
Mission Range	NM	1000.20	1250.43	1494.02	1751.02	2008.36	2252.37	2501.73	2747.19	2995.65
Block Fuel	LB	5592	6965	8390	9960	11440	12994	14648	16342	18135
Block Time	HR	2.467	3.004	3.525	4.078	4.691	5 245	5.816	6.382	6.961
Aircraft Price	US$	17.3E+06	17.6E+06	17.9E+06	18.3E+06	18.4E+06	18.7E+06	19.0E+06	19.4E+06	19.7E+06
D.O.C./Flight	US$/Flight	2714.28	3326.02	3943.71	4619.85	5321.85	6009.79	6737.13	7479.25	8259.99
D.O.C./N Mile	US$/NM	2.71	2.66	2.64	2.64	2.65	2.67	2.69	2.72	2.76

Table 5.3 - Three-Surface Baseline Configuration Range Trade-off (Datum Aircraft - Range=1250 N Mile)

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	413.31	435.30	456.00	478.68	503.65	524.96	549.90	574.98	600.79
Wing Aspect Ratio		8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88
Wing 1/4 Chord Sweep	DEG	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88
Engine Max. St. T/O Thrust	LB	9457	9756	10029	10332	10664	10700	10937	11176	11424
M.T.O.W.	LB	43397	45707	47880	50261	52883	55120	57740	60373	63083
O.E.W.	LB	25856	26632	27344	28125	28968	29691	30543	31362	32200
E.W.	LB	24783	25554	26260	27034	27870	28590	29436	30250	31081
Fuel Weight	LB	7541	9074	10536	12136	13916	15429	17197	19010	20883
T/O Wing Loading	PSF	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
T/O Thrust to Weight Ratio		0.436	0.427	0.419	0.411	0.403	0.388	0.379	0.370	0.362
Cruise Mach No.		0.83	0.83	0.83	0.83	0.83	0.81	0.81	0.80	0.79
Cruise Speed (TAS)	KT	477.3	479.3	476.7	476.6	477.0	469.1	465.1	461.5	457.4
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		11.47	11.72	11.92	12.15	12.39	12.83	13.12	13.41	13.68
Approach Speed (EAS)	KT	122.3	122.2	122.0	121.9	121.7	121.6	121.5	121.4	121.4
Approach Speed (TAS)	KT	136.5	136.3	136.2	136.0	135.8	135.7	135.6	135.5	135.5
T/O Stall Speed (TAS)	KT	120.0	120.0	120.0	120.0	119.9	119.9	119.9	119.9	119.9
Landing Stall Speed (TAS)	KT	104.7	104.7	104.5	104.3	104.2	104.1	104.0	104.0	103.9
T/O Flap (angle/CLmax)	DEG/	15./2.501	15./2.503	15./2.504	15./2.505	15./2.505	15./2.506	15./2.507	15./2.507	15./2.508
Landing Flap (angle/CLmax)	DEG/	40./3.288	40./3.296	40./3.303	40./3.31	40./3.318	40./3.325	40./3.333	40./3.336	40./3.337
FAR 25 T/O Field Length	FT	5383.8	5475.7	5543.9	5612.4	5706.5	5867.2	5974.4	6076.5	6188.1
FAR 25 Land. Field Length	FT	4819.9	4807.5	4795.9	4784.1	4771.9	4757.0	4744.1	4737.1	4732.2
Mission Range	NM	999.91	1262.25	1490.90	1737.17	1997.76	2248.64	2497.06	2748.95	2994.48
Block Fuel	LB	5717	7186	8601	10156	11873	13378	15090	16879	18711
Block Time	HR	2.408	2.950	3.445	3.964	4.510	5.118	5.694	6.284	6.874
Aircraft Price	US$	17.2E+06	17.5E+06	17.8E+06	18.2E+06	18.6E+06	18.8E+06	19.2E+06	19.5E+06	19.8E+06
D.O.C./Flight	US$/Flight	2675.84	3307.73	3902.71	4548.69	5251.71	5969.32	6713.30	7487.52	8279.82
D.O.C./N Mile	US$/NM	2.68	2.62	2.62	2.62	2.63	2.66	2.69	2.72	2.77

Table 5.4 - Minimum D.O.C. Conventional Configuration Range Trade-off (Datum aircraft - Range=1250 N Mile)

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	391.21	409.06	428.72	449.25	471.60	493.79	517.05	542.30	568.11
Wing Aspect Ratio		8.40	8.40	8.40	8.40	8.40	8.40	8.40	8 40	8.40
Wing 1/4 Chord Sweep	DEG	14.51	14.51	14.51	14.51	14.51	14.51	14.51	14.51	14.51
Canard Area	SQFT	61.93	64.77	67.87	71.12	74.65	78.17	81.85	85.85	89.93
Canard Aspect Ratio		6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10
Canard 1/4 Chord Sweep	DEG	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55
Canard to Wing Area Ratio		0.1583	0.1583	0.1583	0.1583	0.1583	0.1583	0.1583	0.1583	0.1583
Engine Max. St. T/O Thrust	LB	8656	8899	9171	9451	9754	10057	10375	10718	11069
M.T.O.W.	LB	42141	44050	46186	48385	50779	53170	55685	58414	61204
O E.W.	LB	25080	25678	26346	27038	27796	28551	30510	30216	31106
E.W.	LB	24020	24612	25275	25961	26712	27461	29403	29113	29995
Fuel Weight	LB	7060	8372	9840	11347	12983	14618	16609	18198	20098
T/O Wing Loading	PSF	93.0	93.0	93.0	93.0	93.0	93.0	93 0	93.0	93.0
T/O Canard Loading	PSF	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0
T/O Thrust to Weight Ratio		0.411	0.404	0.397	0.391	0.384	0.378	0.373	0.367	0.362
Cruise Mach No.		0.79	0.80	0.80	0.80	0.80	0.80	0.81	0.81	0.81
Cruise Speed (TAS)	KT	458.1	459.3	459.8	461.1	462.6	464.0	465.4	466.9	468.4
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		12.06	12.26	12.50	12.71	12.94	13.15	13.35	13.57	13.77
Approach Speed (EAS)	KT	124.6	124.5	124.3	124.2	124.0	123.9	123 8	123.7	123.7
Approach Speed (TAS)	KT	139.0	138.9	138.7	138.6	138.4	138.2	138.1	138.1	138.1
T/O Stall Speed (TAS)	KT	128.1	128.9	129.7	130.4	131.0	131.4	131.8	132.2	132.4
Landing Stall Speed (TAS)	KT	111.8	112.3	113.0	113.4	113.8	114.1	114.4	114.6	114.9
T/O Flap (angle/CLmax)	DEG/	15./2.136	15./2.136	15./2.137	15./2.138	15./2.139	15./2.139	15./2.14	15./2.141	15./2.141
Landing Flap (angle/CLmax)	DEG/	40./2.806	40./2.811	40./2.818	40./2.824	40./2 831	40./2.838	40./2.843	40./2.844	40./2.846
FAR 25 T/O Field Length	FT	5935.4	5994.8	6075.0	6155.0	6232.7	6320.9	6386.2	6458.5	6548.6
FAR 25 Land. Field Length	FT	4977.3	4965.6	4955.3	4942.9	4929.9	4918.7	4910.5	4907.3	4904.4
Mission Range	NM	1000.25	1239.81	1495.17	1741.10	1998.94	2247.47	2492.61	2746.16	2991.22
Block Fuel	LB	5401	6675	8104	9534	11111	12696	14353	16144	17974
Block Time	HR	2.500	3.018	3.572	4.099	4.647	5.173	5.688	6.216	6.723
Aircraft Price	US$	16.7E+06	17.0E+06	17.3E+06	17.6E+06	18.0E+06	18.3E+06	18.7E+06	19.1E+06	19.7E+06
D.O.C./Flight	US$/Flight	2665.74	3239.85	3873.02	4497.98	5171.95	5841.37	6524.81	7253.99	7985.00
D.O.C./N Mile	US$/NM	2.67	2.61	2.59	2.58	2.59	2.60	2.62	2.64	2.67

Table 5.5 - Minimum D.O.C. Three-Surface Configuration Range Trade-off (Datum aircraft - Range=1250 N Mile)

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	412.49	434.67	458.64	481.85	502.87	524.43	548.47	575.61	601.25
Wing Aspect Ratio		8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72
Wing 1/4 Chord Sweep	DEG	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57
Engine Max. St. T/O Thrust	LB	9482	9785	10107	10419	10514	10720	10951	11213	11462
M.T.O.W.	LB	43309	45639	48155	50592	52799	55063	57587	60437	63128
O.E.W.	LB	25739	26619	27520	28297	28947	29661	30497	31383	32212
E.W.	LB	24667	25540	26434	27205	27851	28560	29390	30269	31093
Fuel Weight	LB	7570	9020	10635	12294	13852	15402	17090	19054	20916
T/O Wing Loading	PSF	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
T/O Thrust to Weight Ratio		0.438	0.429	0.42	0.412	0.398	0.389	0.38	0.371	0.363
Cruise Mach No.		0.83	0.84	0.83	0.83	0.82	0.81	0.81	0.80	0.79
Cruise Speed (TAS)	KT	480.8	482.4	480.1	480.6	473.2	469.6	465.7	461.8	457.9
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		11.43	11.68	11.92	12.15	12.53	12.80	13.08	13.38	13.65
Approach Speed (EAS)	KT	124.4	124.2	124.1	123.9	123.8	123.7	123.7	123.7	123.6
Approach Speed (TAS)	KT	138.8	138.6	138.4	138.3	138.1	138.0	138.0	138.0	138.0
T/O Stall Speed (TAS)	KT	121.8	121.7	121.7	121.7	121.7	121.7	121.7	121.6	121.6
Landing Stall Speed (TAS)	KT	106.5	106.3	106.2	106.1	105.9	105.9	105.9	105.9	105.8
T/O Flap (angle/CLmax)	DEG/	15./2.431	15./2.432	15./2.433	15./2.433	15./2.434	15./2.434	15./2.435	15./2.436	15./2.436
Landing Flap (angle/CLmax)	DEG/	40./3.179	40./3.187	40./3.195	40./3.203	40./3.21	40./3.213	40./3.214	40./3.216	40./3.217
FAR 25 T/O Field Length	FT	5521.2	5598.1	5678.1	5753.1	5900.5	6012.1	6111.9	6236.3	6357.2
FAR 25 Land. Field Length	FT	4953.7	4940.5	4926.4	4914.1	4899.1	4891.4	4886.0	4880.3	4875.5
Mission Range	NM	1005.04	1249.73	1498.98	1753.78	2007.15	2239.11	2481.40	2748.56	2993.71
Block Fuel	LB	5735	7137	8680	10278	11835	13330	14994	16902	18736
Block Time	HR	2.404	2.907	3.441	3.971	4.563	5.092	5.653	6.279	6.865
Aircraft Price	US$	17.1E+06	17.6E+06	18.0E+06	18.3E+06	18.5E+06	18.8E+06	19.1E+06	19.5E+06	19.8E+06
D.O.C./Flight	US$/Flight	2672.41	3269.62	3920.66	4582.31	5282.69	5941.08	6665.42	7488.66	8278.03
D.O.C./N Mile	US$/NM	2.66	2.62	2.62	2.61	2.63	2.65	2.69	2.73	2.77

Table 5.6 - Minimum Max. Take-off Weight Conventional Configuration Range Trade-off (Datum aircraft - Range=1250 N Mile)

Range Case	NM	1000	1250	1500	1750	2000	2250	2500	2750	3000
Fuselage Length	FT	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25	79.25
Wing Area	SQFT	400.71	419.08	439.70	461.48	483.68	506.55	530.01	555.00	576.41
Wing Aspect Ratio		8.84	8.84	8.84	8.84	8.84	8.84	8.84	8.84	8.84
Wing 1/4 Chord Sweep	DEG	16.12	16.12	16.12	16.12	16.12	16.12	16.12	16.12	16.12
Canard Area	SQFT	68.76	71.91	75.45	79.19	83.00	86.92	90.95	95.24	98.91
Canard Aspect Ratio		6.01	6.01	6.01	6.01	6.01	6.01	6.01	6.01	6.01
Canard 1/4 Chord Sweep	DEG	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24
Canard to Wing Area Ratio		0.1716	0.1716	0.1716	0.1716	0.1716	0.1716	0.1716	0.1716	0.1716
Engine Max. St. T/O Thrust	LB	8598	8842	9113	9400	9693	9997	10307	10459	10667
M.T.O.W.	LB	42608	44576	46759	49074	51438	53895	56399	59022	61318
O.E.W.	LB	25597	26236	26950	27709	28488	29296	30124	30900	31622
E.W.	LB	24536	25170	25878	26631	27403	28205	29027	29798	30515
Fuel Weight	LB	7011	8340	9809	11365	12951	14599	16275	18122	19696
T/O Wing Loading	PSF	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8
T/O Canard Loading	PSF	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8
T/O Thrust to Weight Ratio		0.404	0.397	0.390	0.383	0.377	0.371	0.365	0.354	0.348
Cruise Mach No.		0.79	0.79	0.79	0.80	0.80	0.80	0.80	0.79	0.79
Cruise Speed (TAS)	KT	456.1	457.2	458.4	459.8	461.2	462.7	463.2	458.0	456.1
Cruise Height	FT	35000	35000	35000	35000	35000	35000	35000	35000	35000
Cruise L/D		12.28	12.50	12.72	12.95	13.16	13.38	13.60	13.97	14.22
Approach Speed (EAS)	KT	123.7	123.6	123.5	123.3	123.2	123.1	122.9	122.9	122.9
Approach Speed (TAS)	KT	138.0	137.9	137.7	137.6	137.4	137.3	137.2	137.1	137.1
T/O Stall Speed (TAS)	KT	124.1	124.7	125.2	125.6	125.9	126.2	126.4	126.8	126.9
Landing Stall Speed (TAS)	KT	108.4	108.8	109.2	109.4	109.6	109.7	109.7	110.1	110.2
T/O Flap (angle/CLmax)	DEG/	15./2.118	15./2.119	15./2.12	15./2.121	15./2.121	15./2.122	15./2.123	15./2.123	15./2.124
Landing Flap (angle/CLmax)	DEG/	40./2.777	40./2.783	40./2.79	40./2.796	40./2.802	40./2.808	40./2.815	40./2.817	40./2.818
FAR 25 T/O Field Length	FT	5917.7	6004.9	6082.8	6156.1	6235.3	6324.3	6392.0	6567.6	6660.8
FAR 25 Land. Field Length	FT	4921.3	4911.8	4899.5	4888.1	4877.2	4868.0	4857.7	4848.1	4845.2
Mission Range	NM	997.59	1238.91	1493.03	1749.03	1997.71	2244.05	2485.24	2770.17	2990.79
Block Fuel	LB	5379	6658	8085	9575	11102	12690	14308	16142	17682
Block Time	HR	2.505	3.032	3.580	4.131	4.661	5.183	5.700	6.384	6.895
Aircraft Price	US$	16.9E+06	17.2E+06	17.5E+06	17.8E+06	18.2E+06	18.6E+06	18.9E+06	19.2E+06	19.5E+06
D.O.C./Flight	US$/Flight	2681.99	3267.41	3902.10	4559.29	5218.33	5890.85	6576.83	7422.18	8099.91
D.O.C./N Mile	US$/NM	2.69	2.64	2.61	2.61	2.61	2.63	2.65	2.68	2.71

Table 5.7 - Minimum Max. Take-off Weight Three-Surface Configuration Range Trade-off (Datum aircraft - Range=1250 N Mile)

6 Discussion and Recommendations

6.1 Aircraft Conceptual Design Tools and Optimisation

In order to support the establishment of a strategy for carrying out the present investigation, a survey of past work on computerized aircraft design synthesis methods was initially done, as shown in section 2.1. A design synthesis tool was needed where many attributes learned from past systems such as flexibility, modularity, adaptability, open-ended structure and well commented coding should be considered. The tool should provide a fast and credible means for systematically assessing new designs of the transport class which in turn should provide consistent results for conventional and equivalent three-surface configurations in order to meet the same initial mission specification, and amenable to comparison. Additionally, the system should be coupled to an available numerical minimization technique, the RAE RQPMIN code, capable of driving the design synthesis in order to find the particular design solution which, while meeting the mission specification and satisfying the airworthiness requirements and performance constraints, should offer the lowest value of the cost function. In this case, either DOC or MTOW for both the envisioned aircraft concepts.

Development of an initial design synthesis tool was planned to incorporate existing CoA disciplinary analysis programs. An overall assessment of the suitability of these tools for the present investigation was made, indicating that considerable development work should be pursued in order to complete the system. This would involve compatibilization among the several codes, development of additional programs to account for features and design needs not accounted for in the existing codes, their adaptation, streamlining, integration, and appropriate modification to allow for the design of the three-surface configuration. These requirements were partially complied with the development of a preliminary parametric analysis module called PREliminary SIZing (PRESIZ), a MASS estimation program for narrow body jet transport aircraft and the correction of the MITCHELL code for the evaluation of the stability and control characteristics of rigid aeroplanes. However, this work was abandoned as the opportunity for using the NASA GASP synthesis program came along. This comprehensive, and already considerably detailed code, proved to be adequate for the present research, for which appropriate modifications were carried out to extend its capability to the conceptual design of three-surface aircraft configurations. These consisted mainly in the development of appropriate routines for the sizing of the three lifting surfaces taking into account aircraft weight and balance, and longitudinal static stability and control considerations. A complete revision of the program, including its several disciplinary modules, was performed as needed to ensure consistency in the calculations and achieve full integration with RQPMIN.

As described in Chapter 3, this program represents the mathematical model of a real system, in particular an aircraft system placed in its real environment. Thus, it represents a very complex situation. In analysing any real system, the engineer has to make many concessions to reality by means of an approximate, although meaningful, abstract representation. Since, what is actually analysed is not the real system, but only an abstraction of it, caution must be exercised on the results obtained against the limitations of the model approach. These limitations and the model accuracy were broadly described in section 3.6, however some particular aspects deserve further comment.

6.2 The Three-surface Transport Model and Design Philosophy

In section 3.6, the Aerodynamics, Weights, and Economics modules were identified as representing critical disciplinary areas likely to produce inaccuracies in the design solutions. The methods used with appropriate empirical calibration factors were shown to give reasonable results when applied to conventional configurations (the conventional design aerodynamic predictions reinforced by the satisfactory dynamic stability and control characteristics analysed with Mitchell code, and shown in Appendix G, illustrate this view). However, the same GASP methods were extended to include the design and evaluation of three-surface configurations. Canard profile and induced drag estimates were included, however the tailplane induced drag and lifting surfaces mutual interference effects were excluded. A wing efficiency term, $\eta_w = q_w/q_\infty$, could be included to reflect some loss of the air flow dynamic pressure likely to occur on the wing due to flow interactions with both the fuselage boundary layer and the canard wake. However, for a long-coupled canard (stagger≈400% mac), and relatively small canard to wing span ratios ($b_c/b_w \approx 0.31 \sim 0.34$), helped by a convenient canard anhedral (not considered in the computations) to increase their relative gap, it was assumed reasonable to consider this effect negligible, i.e., $\eta_w=1$, since only a relatively small inward portion of the wing span would be affected. Fuselage interference effects were included in the evaluation of the overall aircraft profile drag in the form of an arbitrarily assumed overall drag increment of 15 drag counts (this is listed in GASP input data, Chapter 5); this increment is also used in the evaluation of the canard and wing Oswald span efficiency factors, thus reflecting an additional influence on the lifting surfaces spanwise lift distributions. This same interference drag increment was also applied in the evaluation of the conventional designs.

In their approach to evaluate the aerodynamics of their canard configured transport, Arbuckle and Sliwa[1] included the Prandtl-Munk induced drag interference terms, but reduced the computed induced drag by 10% in face of empirical evidence provided by Feistal[2] and theoretically demonstrated by Butler[3] and Kroo[4]. However, the Prandtl-Munk theory, as indicated by previous studies and reported in section 2.2, see Rokhsaz and Selberg[5] for example, underestimates induced drag on three-surface arrangements. Besides, the theory assumes elliptically loaded lifting surfaces and no fuselage. The more comprehensive studies conducted by Middel[6] showed the complexity of the problem when practical issues are accounted for in designing real aircraft. He stressed the important influence the fuselage has on the overall lift distribution with implications on the actual lifting surfaces lift fractions, producing uncertainties in the estimation of the proper location of the neutral point, as computed when using, for example, the present approach in the absence of adequate empirical correction factors. It is then necessary to employ more sophisticated techniques such as aerodynamic panel methods as utilised by Middel, or to run wind tunnel tests using models of the configurations just synthesized to check, modify or, and validate the aerodynamic predictions obtained by the modified GASP aerodynamic methods for three-surface concepts. Unless proper validation is done to the methodology employed in GASP, three-suface aircraft aerodynamic predictions will remain suspect.

However, for long canard-wing staggers of about 400% mac which is the case in the current research, the "roll-up" effect of the foreplane flow onto the wing does not influence interference drag by more than a few percent[1], but fuselage interference effects on both canard and wing lift distributions (both longitudinal and spanwise), and resulting induced drag are deemed to be important and should be determined more accurately to refine and check the present results. Probably for the three-surface configuration, GASP aerodynamic predictions may represent the most significant weakness of the model, since a poor representation of these characteristics might compromise the designs obtained by posing doubts on the predicted performance and, consequently, on the estimated direct operating costs. As well known, these are very sensitive to airlines.

For the moment, it shall be assumed that, by appropriate wing twist and lifting surfaces-fuselage intersection fairings, both lift and drag characteristics as computed are actually achievable and acceptable as a first guess.

Low speed high lift conditions impose a relatively high canard maximum lift coefficient (maximum canard lift coefficient for the three-surface designs range from CL_{max}= 2.8 ~ 2.85 as shown in Appendix D and E, figs D2, D4.1, E8, E15, and E17.1). This certainly will add in cost, weight and drag penalties. Canard structural weight and drag are computed accounting only for the lift fraction carried by the foreplane. At least a double slotted Fowler flap as employed in the main wing is needed on the canard to achieve this level of high lift. Additionally, this flap has to provide adequate pitch control in assisting the tail elevator for trim. Thus a complex and costly canard flap system is antecipated, where the corresponding RDE&T costs will play a significant part. For a first evaluation, the canard high lift and control actuation systems were not considered in the component weight predictions nor the associated development, manufacturing and maintenance costs estimated by the Economics module. Both these contributions should be quantified in the future on more detailed studies.

The three-surface configuration design philosophy, lies on the assumption that longitudinal equilibrium is achieved by two equal trimming pitching moment contributions each one provided by the canard and the tail, where the canard will also produce additional lift to assist the wing. So, the horizontal tail will only contribute in part to pitching moment equilibrium, whilst the canard will additionaly share with the wing the lift required to balance the aircraft weight. This criteria is only a simplification of the actual trim problem because such aeroplanes are redundant in terms of ways of generating moments and forces to satisfy trim conditions. What happens is that, within aerodynamic limits, three independent lift forces may be generated. To maintain level trimmed flight, two conditions must be satisfied which are the equilibrium of forces (L=W), and the overall pitching moment must equal zero (Cm=0). Since the number of unknowns exceeds the number of equilibrium equations, an unlimited combination of longitudinal load distributions is possible to satisfy the trim condition which makes the system statically indeterminate. This situation offers the designer flexibility, not present in conventional nor in pure canard designs, to select the longitudinal lift distribution which minimizes (or maximizes) a given performance index. In cruise conditions a performance index to minimize could be trim drag.

One of the lessons learned from past studies, Kendall[7] and Middel[6], was the potential offered by the three-surface configuration in yielding minimum trim drag at all centre of gravity locations. This is attractive for general aviation and transport aeroplanes but some type of longitudinal lift distribution optimisation is required. So, an appropriate automatic flight control system should be designed to control the incidence of both the canard and horizontal tail, or the deflections of their trailing edge control surfaces, or both in combination, in a way to minimize trim drag at arbitrary cg locations, during cruise and at any high lift mode. Costs associated with this particular flight control system should also be considered in future more detailed studies.

Regarding the present work and the figures of merit used, optimisation of the longitudinal load distribution for minimum drag could be indirectly achieved by relieving the arbitrary imposition of 0 degree setting angle of the horizontal tail, i.e., assuming this parameter is an additional design variable and allowing RQPMIN to find the incidences of the three lifting surfaces (canard, wing, and horizontal tail) while searching for the "best" aircraft. However, this would entail some changes in the synthesis aerodynamic model, at least in making allowances for induced drag on the tailplane, since the probably reasonable assumption made of neglecting this contribution may not hold. This approach would probably give better results than those obtained, although no other empirical calibration would be possible. Problems with the operation of the nonlinear programming package, and reported in Chapter 5, suggested the use of a reduced number of design variables as well as of constraint functions as possible and, at the same time, consistent with the desire of not excessively compromising the answers of the present investigation. Increasing the number of design variables would add in the multi-dimensionality of the design space, thus increasing its complexity. Constraining it further would make the numerical technique to find a feasible optimum solution more difficult. Thus, in face of problems encountered in driving the designs with the current design variables and constraint functions, it was decided to limit any potential problems to the present level and not running into difficulties of loosing convergence, or of longer computer run times with their associated increased costs.

The specification of constant cruise altitude in the Performance module is somewhat restrictive, since it might play a significant part in the optimisation of any real aircraft, most importantly when the consideration of long design ranges is involved. However, this simplification was felt justified at this stage.

6.3 Multidisciplinary Synergism and Results

The Design Study

As noted above, the three-surface designs in the present work, assume both the canard and wing will produce the lift required to balance the aircraft weight. Thus, it differs from Kendall's[7] analysis where the canard and tail only trim the aircraft for different centre of gravity locations to achieve minimum induced trim drag conditions. This author, as well as Rokhsaz and Selberg[5], assume that all their three configurations (i.e, conventional, canard and three-surface) use the same wing, all aircraft have the same weight and do not account for any configuration synergism in the sense of taking advantage of the canard lifting capability other than that required to satisfy trim. By doing so, a smaller wing could be selected while maintaining the same wing loading even for the same aircraft weight. This was accomplished in the present approach. The equivalent three-surface baseline aircraft was derived while keeping constant the same lifting surfaces aerodynamic loading as selected for the conventional baseline, excluding that of the horizontal tail. It is worth noting that it is possible to have a c.g. location for which the trim surface load becomes zero and the lift/weight couple is enough to balance the zero-lift moment. Since this is negative for most practical configurations, the centre of gravity for this particular condition shall lie behind the wing-body aerodynamic centre[7]. Within the assumptions made, the tail may only take a limited amount of negative load to generate its share in pitching moment to offset any changes in trim. This results in a smaller size tailplane, due to the useful positive canard trim load, and in a smaller wing which is complemented by the canard lift potential. Moreover, when comparing with equivalent conventional designs at high lift conditions, requiring the same maximum lift coefficient to satisfy field performance constraints, and with similar inherently stable static stability margins, the wing and canard together no longer need to supply the required increased maximum lift to balance the higher tail trimming download, potentially yielding a lower induced drag. This will further results in reduction of the required wing size.

Previous research[8,9] indicated that three-surface designs can have improved high lift performance, however to also achieve efficient performance in cruise, a compromise should be worked out. An approach to this compromise was to adopt the criterion of equal canard and tail control powers for sizing purposes. For practical designs, this condition poses limits on the feasibility of the canard to wing area ratio. In the present case, where a fuselage length related to a typical 50 passenger transport with the same specified interior layout is considered, this area ratio will be bound between 0.145 and 0.175. The design strategy presented, then allows for the sizing of the canard and tail to provide the required stability and control characteristics and for possible reduction (optimisation) of the relative sizes of both the wing and horizontal tail when compared with an equivalent conventional configuration. It implies, however, the addition of a relatively small foreplane. Since all the horizontal lifting surfaces will be of a smaller size, scope for structurally lighter and more efficient components exists, thus decreasing the aircraft empty weight. For a given mission and design range, a lower empty weight combined with a good aerodynamic design may result in drag savings leading to the selection of less powerful, smaller and probably more economic engines. These will further contribute for lower drag levels and decrease of the design fuel weight. Small engines will also improve engine-out conditions. This may result in smaller fin and rudder, with the associated drag and weight savings, in favour of a better lift to drag ratio. Block fuel may even decrease for the same level of engine fuel specific consumption. It seems that the use of a canard provides a reasonable mean to achieve an improved overall aerodynamic load distribution over the aircraft configuration yielding a structurally more efficient solution. Owing to a more uniform distributed load, structural weight relief may also be encouraged in the fuselage, especially for aft engine mounted configuration types with high fuselage fineness ratios, such as exemplified by the McDonnell Douglas MD 90[10]. This weight relief effect can also be considered in further detailed studies. However, increases in the field length of the three-surface designs are identified. These are mainly due to wing geometric constraints which affect flap size, thus decreasing the available maximum lift coefficient. For the same flap type and the same flap to wing span ratio, as used for the equivalent conventional designs, reduction in wing size entails a smaller wing high lift device being applied. All these effects influence the overall design towards a reduced MTOW, better cruise performance, although compromised by field length requirements, and operational profitability to the airliner through reduced direct operating costs.

While keeping the aircraft wing loading constant, replacement of the conventional baseline by an equivalent three-surface configuration is viewed as a powerful way to improve it, through multidisciplinar synergism as just described. The improvement approximates that obtained by optimising the baseline designs (figs 5.11 and 5.12). It is seen that all three-surface designs show higher cruise lift to drag ratios, thus offering better aerodynamic efficiency, than their equivalent conventional counterparts (table 5.1). Range trade-off studies indicated that all designs benefited from better cruise lift to drag ratios for increased design ranges as well as from longer cruise stage legs. However, three-surface designs are slightly better with the advantage of being less cost sensitive at longer ranges than the equivalent classical designs (figs 5.11, 5.12;tables 5.2 through 5.7). Within the economic assumptions made, a DOC benefit of about 4.7% for the three-surface baseline datum design (Range=1250 NM) was found, which increases linearly up to 7.9% at a design range of 3000 NM. On the other hand, when the designs were optimised for minimum DOC, the tail-aft and the three-surface concepts offered respectively a 6.1% and 6.4% DOC advantage at 1250 NM design range, and 7.6% and 10.9% at 3000 NM range. Additionally, the three-surface designs showed weight savings with regard to all the conventional designs, including the optimised ones, at design ranges above 1250 NM (figs 5.11 and 5.12). For all design ranges considered, an average weight saving of 3.45% was identified for the three-surface designs with respect to their equivalent conventional designs, where all the configurations were optimised for DOC. Similar trends were found for minimum MTOW optimisation cases. Whichever the performance index used, DOC or MTOW, no significant differences where found on the optimum designs generated. This may be due to the prevailing cost scenario as assumed. Should the economic environment change, probably the optimum designs would be different[11,12].

All designs driven by the mathematical constrained minimization technique experienced an increase in wing loading. This suggests a reduction in the wetted area of the lifting surfaces leading to lower aircraft total drag (fig 6.1) and weight levels, as well as improvement of the ride quality characteristics, hence in passenger comfort standards. Minimum DOC designs (for Range=1250 NM) experienced drag reductions of about 16.6% for the conventional design, and 7.9% for the three-surface respectively with regard to the corresponding baseline configurations. With respect to the conventional baseline, the three-surface baseline overall drag reduced in 7.7%, while that of the optimised one was 15% lower. However, the resulting engine thrust levels on the optimised conventional designs didn't decrease so much as it happened on the optimised three-surface configurations. In fact, the optimised tail-aft designs show higher take-off sea level static thrust to weight ratios than their related baseline design (3.1% more was found on the minimum DOC conventional datum design), whilst the reverse is true for the optimised three-surface designs which show a relative decrease in this ratio (table 5.1 and fig 6.2). This is due to the reduction in cruise lift to drag ratios experienced by the conventional optimised designs, while the three-surface optimised configurations offer an improved aerodynamic efficiency (table 5.1).

Figures 7.3 through 7.5 show the impact of the design range on the aircraft Operating Empty to Maximum Take off Weight (OEW/MTOW) ratios. This ratio decreases with increased range in virtue of the increased amount of fuel required to satisfy it, but also gives an indication on how efficient the design is to accomplish its mission. For small ranges its sensitivity also increases with trip length variations which reflects the difficulty associated with the design of successful short-haul aircraft[13]. Fig 6.3 shows the reductions in this ratio when the three-surface concept is adopted instead of the conventional one (baselines). Further decrease on the optimised designs OEW/MTOW ratio is also experienced for all ranges. However, a slight improvement is observed on the DOC optimised three-surface ratios, which increases with range, when compared with their equivalent optimised conventional designs. Fig 6.5 shows the OEW/MTOW ratios pertaining to the optimised design studies. The curves of both conventional design optimisations, (DOC and MTOW), match. This reinforces the feeling that both DOC and MTOW optimisations virtually give identical answers for the present case. However, the minimum MTOW three-surface configuration designs show higher values for the OEW/MTOW ratios which are close to the corresponding values of their baselines (fig 6.4). This illustrates the local nature of the optimum results, as obtained by RQPMIN, rather than the desired global optimum. This particularity represents a limitation of the gradient-based minimization techniques. It is recalled that the minimum weight for this configuration, which was the best achieved from all the weight optimisations performed, came up slightly higher than that obtained from the minimum DOC optimisation (section 5.4).

The above differences, attributes, and trends may also suggest the three-surface transport aircraft offers a greater stretch potential.

As seen, there is an intimate coupling among every engineering discipline, and their interrelating influences shall be adequately modelled for any comprehensive and useful assessment. Methods and techniques used for the conceptual designs were considered adequate for the purposes of the present work, however validation is required to ascertain the limitations of the aerodynamic model applied on three-surface configurations. The use of optimisation techniques in the initial project design work which guide the configuration towards the optimum was seen to be highly beneficial. The results of the present study are regarded more conclusive in nature than those obtained by others on this type of aircraft (three-surface transports), as surveyed in section 2.2. The results are based on a comprehensive model where many real life considerations, operational and practical constraints are incorporated. Because of the strong influence these considerations have on any realistic design project, they cannot be excluded if a practical and satisfactory solution is sought. As in any preliminary study, there are however limitations which are inherent to the model used, as described above. These will only be minimized by more detailed studies. Nevertheless, owing to the considerable completeness employed in the approach, practical potential merits of a three-surface transport were quantified and were clearly shown when it was compared with an equivalent mission conventional turbofan powered airliner.

Other Advantages of the Concept of Three-surface Aircraft

Another advantage offered by the three-surface against the pure canard configuration relates the main landing gear location which, for this case, works out in a favourable manner similar to that in conventional designs. Additionally, nose gear collapse may be minimized in the case of canard stall after landing touch down by preserving the remaining elevator pitch control authority. Manoeuvrability at stall might be enhanced when compared to canard and conventional aircraft. Assuming the canard stalls first, which should be ensured by careful design, both the tailplane elevator and the ailerons provide control at stall conditions. On pure canard arrangements a complete loss of pitch control will occur, whilst on conventional designs elevator control is still preserved but loss of lateral control can be experienced although it may be limited, provided an appropriate inboard spanwise location of the stall initiation is ensured.

All these advantages, combined with the prospects of maintaining minimum trimmed drag at all centre of gravity locations with an appropriate flight control system, better cruise lift to drag ratios and the potential for synergetically achieving savings in weight, contributing to reduced direct operating costs as quantified and shown in Chapter 5, make the three-surface concept an attractive choice to the airline transport industry. Although these cost benefits seem apparently very small, they may turn to be meaningful for an airline in the long run. It appears there is a justifiable and well founded interest on the application of the three-surface concept to transport aircraft.

RQPMIN - Constrained Optimisation Numerical Technique

Problems with the operation of the optimisation technique (RQPMIN) were identified and commented in section 5.4. These suggest some improvement can be made in the future. It is worth mention that some results uncovered an ill-conditioning condition affecting the method covergence criteria. Thus, a revision of the related coding is suggested. The implementation of a user-friendly interactivity through graphical displays, to adequately monitoring the convergence process, as referred to in the same section, would improve design visibility. This enhancement would help the users in understanding which parameters drive the design, refining the problem formulation and accelerating the optimum design process. It would also enable one to easily identify any potential problems in the mathematical programming algorithm, if it is the case.

New Technologies

The designs were based on the assumption of employing available and proven technology. Concerning the applicability of new technological advances a word of caution must be said. Its criterious use, with emphasis on reliable, safe and affordable technologies, would probably produce benefits. However it is restricted by adequate balance between increases in acquisition costs and decreases in direct operating costs, these in turn are highly dependent on the prevailing operating economic conditions[11,12].

Additional Work Done

Validation of the GASP design synthesis program was demonstrated for two actual conventional aircraft, the Canadair Regional Jet 100 and the Learjet 35A. The calculated MTOWs are within 7% of those of the real aircraft, using similar requirements, geometric parameters and wing loadings. Results are shown in Appendix I, and confirm its adequacy for the initial conceptual design work.

The above discussion on the GASP model for the design synthesis of three-surface transport aircraft highlighted an eventual defficiency in the aerodynamic modelling of the fuselage/canard interference due to the absence of actual empirical evidence which shall be assessed in future more detailed studies. On the other hand, interdisciplinary synergism suggests that potential structural weight savings are likely to be encouraged in the fuselage. It is also recognised that the fuselage weight estimating relationship employed, although quite elaborated, since it also depends on its weight including the contents, empennage and engine weights and their variations during the design synthesis, probably will not predict, with the desired accuracy, the fuselage weight of unusual aircraft as it does for a conventional one. The reason being that it was developed based on a statistically derived correlation of actual conventional aircraft. Three-surface aircraft fuselage weights as computed are thought to be conservative. In trying to control these uncertainties, an inexpensive way will be by performing a sensitivity analysis on the minimum DOC conventional aircraft to incremental changes, say ±10% of fuselage weight and drag. Appendix J presents the results of such a study. It was shown that benefits arise from reducing both fuselage structural mass and drag. This is especially important of fuselage mass due to the large impact its changes have on range performance. Fuselage mass decrease also improves the aircraft economic worth by additionally increasing its cargo payload potential. The results indicate a very low sensitivity to drag variations. It may be reasonable to assume that a similar fuselage weight and drag sensitivity hold for the three-surface configuration transport. This fact will increase the confidence on the GASP performance and economics by minimising the impact of drag uncertainties in the final design. Because fuselage mass, as predicted for the unusual configuration, may be on the conservative side, the benefits indicated may improve with regard to the results obtained. As already suggested above, this should be confirmed in future work.

The GASP drag, mass and cost equations were reviewed to identify any discontinuities which might cause the difficulties experienced during the optimisation process. It was observed that these discontinuities were unlikely for the aircraft sizes studied, thus they would not explain the optimisation "jumps". Additionally a more detailed analysis of the convergence history diagrams of figure F1, in Appendix F, was performed. The analysis suggested that the large divergent excursions encountered during the process of minimisation may be produced by the numerical technique itself. This happens after RQPMIN experiences difficulty in improving the objective function, probably because of the particular nature of the design surface, in combination with the difficulty in satisfying the method convergence criteria. The latter one may be related with very small tolerances imposed on the problem functions. Instead of stopping, the process suddenly diverges, possibly to re-initiate a new minimisation. This work is described in Appendix K.

6.4 Suggestions for Future Work

From the foregoing, the following suggestions are made for further research work:

- Perform aerodynamic analytical studies, employing more sophisticated analytical tools, and, or wind tunnel experiments, using geometric models based on the three-surface aircraft configurations as obtained in the present study. Results should be utilised to provide empirical evidence for confirming, or calibrating the GASP aerodynamic model in order to produce more credible predictions for this concept.

- Design of a special flap control system suitable for the three-surface aircraft, and estimation of aerodynamic, weight and costs information to feedback in the iterative synthesis evaluation process. The respective actuation system weight and associated costs should be predicted as well. This is useful for checking the error incurred in the current design evaluation.

- Evaluate the costs associated with a special purpose longitudinal lift distribution optimisation flight control system and analyse its impact on the present results.

- Evaluate the potential for fuselage weight savings in case of canard application on high fineness ratio fuselages of transport aircraft.

- Modify the MITCHELL Stability and Control program to perform handling quality evaluations on three-surface aircraft.

- Revise the RQPMIN numerical technique in the light of suggestions made in the previous section, and enhance it with the addition of a flexible interactive capability.

- After adequate empirical calibration of GASP aerodynamic model, and appropriate improvement of RQPMIN have been made, optimisation of the baseline designs should be performed with the canard, wing and tail incidence setting angles as additional design variables to allow for the longitudinal load distribution optimisation. Other design variables could be employed as, for example, the longitudinal stability static margin to assess its impact on the overall optimum designs. Results should be compared with the present ones.

- Overall improvement of the design synthesis program with the incorporation of more accurate and updated analysis methods, with provision for increased design options and flexibility. The integration of a dynamic stability and control analysis module would be useful for future research. The implementation of an interactive operating mode would be desirable.

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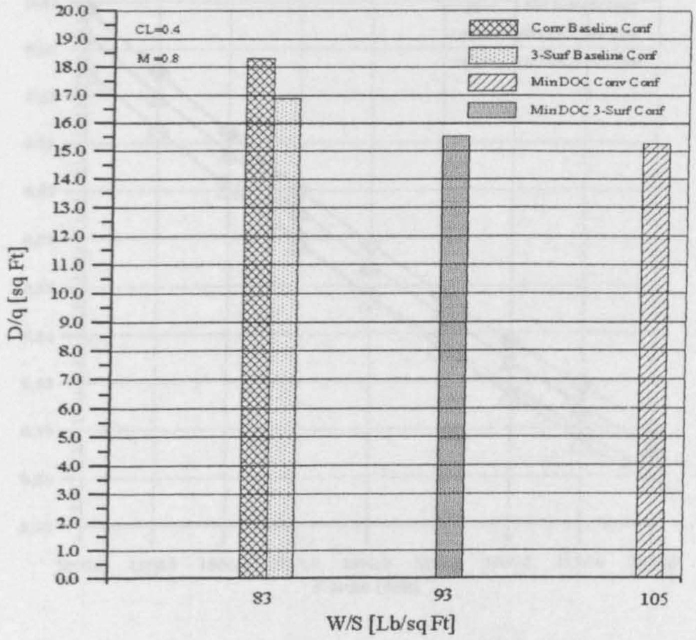

Fig 6.1 - Baseline and Min DOC Datum Designs Drag Levels

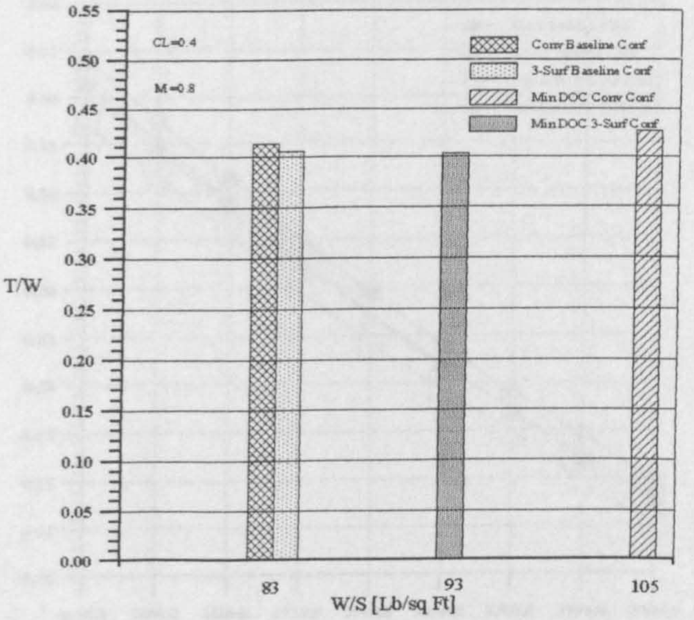

Fig 6.2 - Baseline and Min DOC Datum Designs Thrust to Weight Ratios

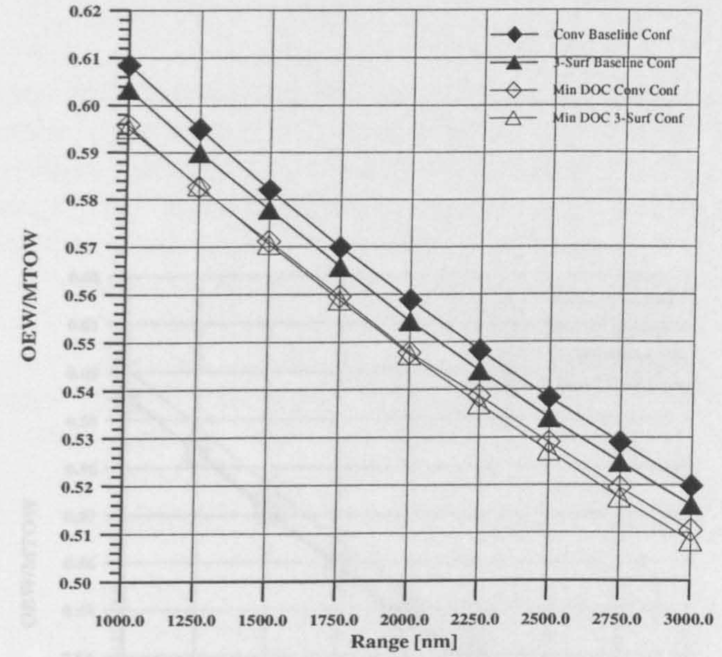

Fig 6.3 - OEW/MTOW Ratios - Range Trade-off for Min DOC Configurations versus Baseline Designs

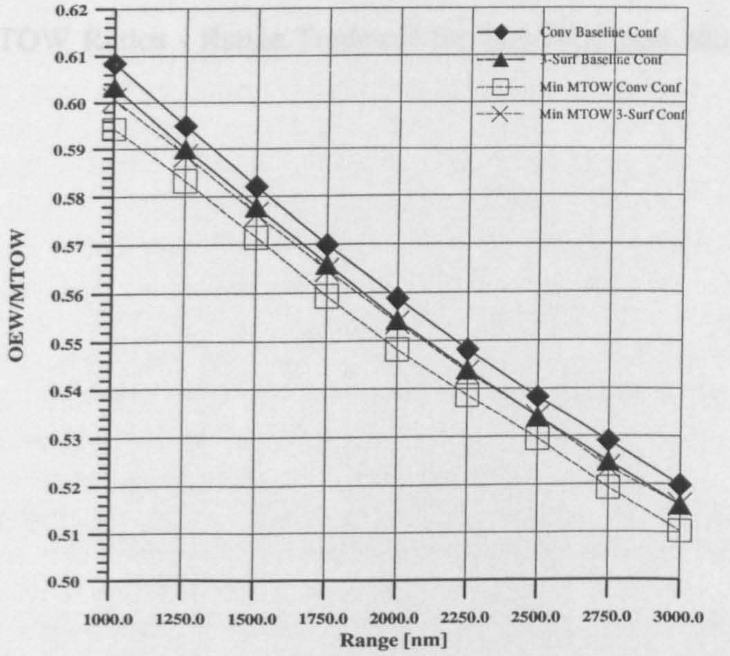

Fig 6.4 - OEW/MTOW Ratios - Range Trade-off for Min MTOW Configurations versus Baseline Designs

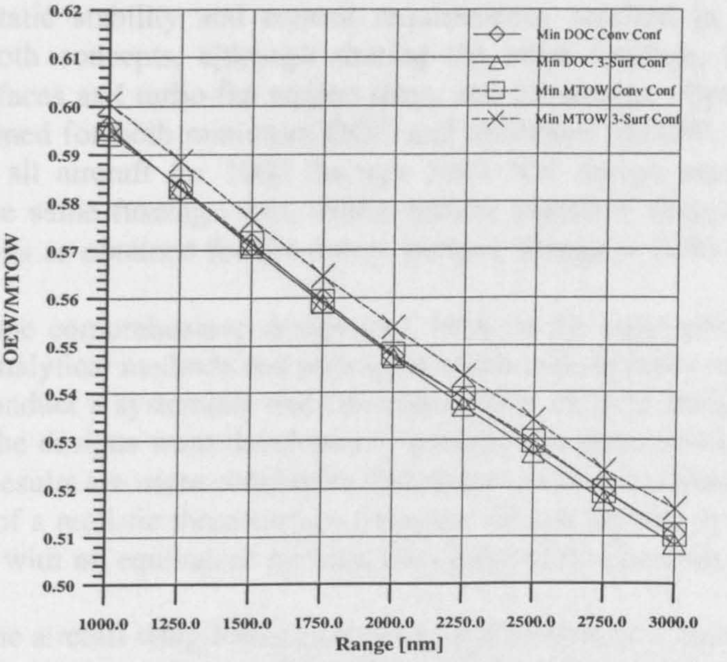

Fig 6.5 - OEW/MTOW Ratios - Range Trade-off for Min DOC and Min MTOW Designs

7 Conclusions

In this research project, advantage was taken from aerodynamic and structural aspects to design and optimise conventional and three-surface configuration transport aircraft to satisfy the same mission requirement. An integrated conceptual design synthesis approach was employed where typical aeronautical disciplines, as well their complex interrelations, were taken into account. All these considerations, together with both cruise and field performance, and static stability and control requirements, resulted in different baseline configurations of both concepts, although sharing the same fuselage, but with different MTOWs, lifting surfaces and turbo-fan engine sizes, and economics. Optimisation of these designs were performed for both minimum DOC and minimum MTOW. Trade-off studies were conducted on all aircraft for 1000 through 3000 NM design mission ranges while keeping invariant the same fuselage size, lifting surface planform shapes and longitudinal static stability margins as obtained for the datum designs (Range = 1250 NM).

Using the same comprehensive design tool, built on the same primary assumptions, and using the same analytical methods and principles which include many real life constraints, it was possible to conduct a systematic and consistent study on both design concepts (same technology level). The designs were developed to perform the same mission, and compared on an equal basis. Results are more conclusive than those previously obtained by others, and the potential merits of a realistic three-surface transport aircraft are clearly established when comparison is made with an equivalent mission conventional jet transport.

By keeping the aircraft wing loading constant, replacement of a conventional baseline aircraft by an equivalent three-surface configuration was demonstrated to be a powerful design strategy to improve it, through multidisciplinar synergism. The improvement obtained almost mixes up with that obtained by optimising the baseline designs. All three-surface designs exhibited higher cruise lift to drag ratios, thus offering better aerodynamic efficiency than their equivalent conventional designs. Range trade-off studies indicated that all designs benefited from better cruise lift to drag ratios for increased design ranges as well as from longer cruise stage legs. However, three-surface designs are slightly better with the advantage of being less cost sensitive at longer ranges than the equivalent classical designs. Within the economic assumptions made, a DOC benefit of about 4.7% for the three-surface baseline datum design (Range=1250 NM) with respect to the conventional one was found, which increased linearly up to nearly 8% at a design range of 3000 NM. When optimised for minimum DOC, the conventional and the three-surface concepts offered a 6.1% and 6.4% DOC advantage at a 1250 NM range, respectively, and 7.6% and 10.9% at 3000 NM range. Additionally, the three-surface designs revealed weight savings with regard to all the conventional designs, including the optimised ones at design ranges above 1250 NM. For all design ranges, an average saving in weight of 3.45% was identified for the unusual designs with respect to their equivalent conventional designs, where all the configurations were optimised for DOC. Similar trends were found for minimum MTOW optimisation cases. For the figures of merit used in the optimisations, DOC or MTOW, no significant differences were found on the optimum designs generated. This may be attributed to the prevailing particular economic conditions.

All designs driven by the minimization numerical technique experienced an increase in wing loading. This produced a reduction in the wetted area of the lifting surfaces yielding both lower aircraft drag and weight. This would result in better ride quality characteristics, and comfort. However, the resulting engine thrust of the optimised conventional designs didn't experience as much a reduction as in the optimised three-surface configurations. Effectively, the optimised classical designs showed higher thrust to weight ratios than the respective baseline design, whilst the reverse was found for the optimised three-surface designs. These presented lower thrust to weight ratios than its baseline. The relatively high engine thrust of the optimised conventional designs is related to the degradation in cruise lift to drag ratios these aircraft experience, while the three-surface optimised configurations offered an improved aerodynamic efficiency. These attributes may also suggest that three-surface transports offer a greater stretch potential than the equivalent conventional aircraft.

It appears that the concept of a three-surface transport can effectively improve in terms of performance and costs when compared to conventional and canard configured aircraft designed for the same operational environment and mission profiles whose benefits tend to increase with increased design range by wisely exploiting and compromising the particular advantages offered by these two configurations. However, an overall criticism is that very little test data exists to confirm the potential drag savings predicted for the three-surface concept. Thus, more detailed studies, both analytical and experimental, on the three-surface should be done in the future as suggested in Chapter 6, for checking and validation purposes.

The importance of optimisation techniques coupled with a multidisciplinary approach for the design of real systems has again been demonstrated with the present design study. It is in complete agreement with Sobieski and Chopra[1] in their introductory note to the "Journal of Aircraft" special section on "Multidisciplinary Optimisation of Aeronautical Systems", where they anticipated that optimisation will be the primary tool to employ when designers face the question: *"How to decide what to change, and to what extent to change it, when everything influences everything else."*

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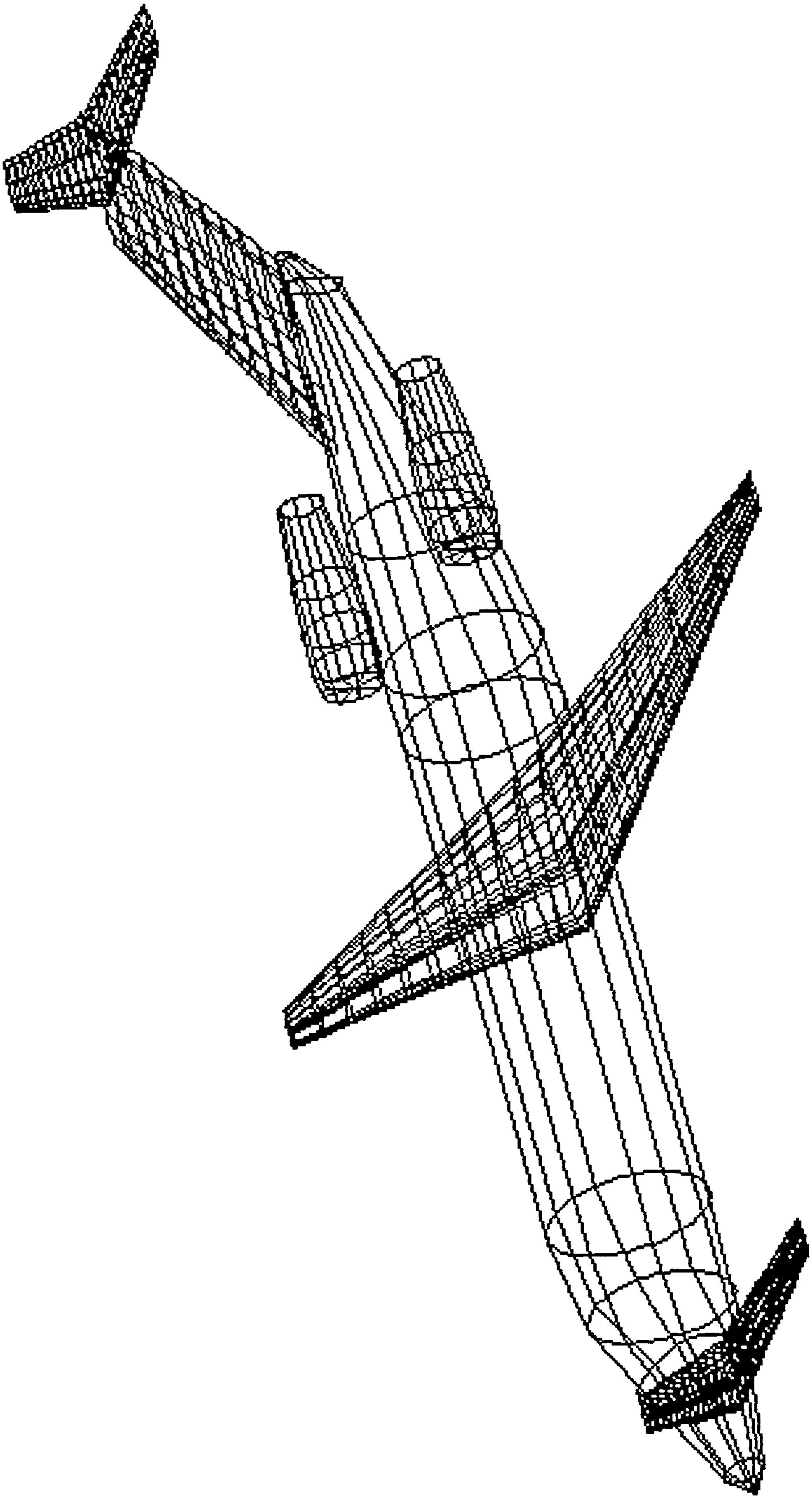

Fig 7.2 - Min DOC Three-lifting Surface Turbo-fan Transport

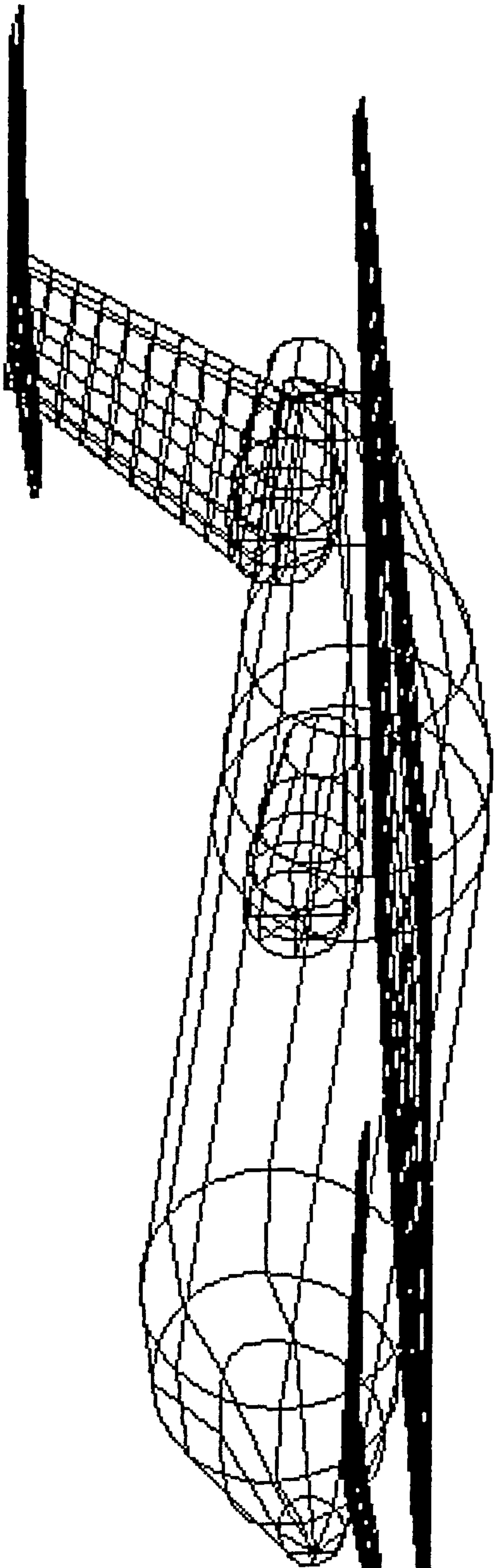

Fig 7.1 - Min DOC Three-lifting Surface Turbo-fan Transport

APPENDIX A

Longitudinal Stability and Control Considerations (stick-fixed) Applied to the Three-Lifting Surface Concept

Introduction

In this Appendix, the longitudinal static stability and control (stick fixed) equations for the three-surface concept are theoretically derived from basic principles. These equations form the basis of the procedure implemented in subroutine TAIL to size the horizontal tailplane and the canard, as shown in section 3.5.2.2 under "Aircraft Balance".

Longitudinal Stability and Control Considerations (stick-fixed) Applied to the Three-Lifting Surface Concept

A.1 Static Longitudinal Stability

Static longitudinal equilibrium of an aircraft may be studied by referring to the equation of moments about the YY axis passing through the centre of gravity. These moments and their variations with respect to the aircraft lift coefficient are considered.

The simplified case of a gliding (power-off), controls locked, flight condition is first analysed.

A.1.1 Pitching Moment Equilibrium and Static Stability Equations

From figure A.1, the equation of moment equilibrium may be written as:

$$M_{cg}=N(x_{cg}-x_{ac})+Cz_a+M_{ac}+M_{fus}+M_{nac}+N_c(x_{cg}-x_c)+C_cz_c+M_{ac_c}+ \\ +N_t(x_{cg}-x_t)+C_tz_t+M_{ac_t}$$

(A1)

The angle of attack, α *, usually is very small and so are the wing drag related contribution at low lift coefficients and the canard and tail pitching moment and drag contributions to the overall pitching moment. This allows writing equation (A1) in a more familiar and simplified form by neglecting these influences:*

$$M_{cg}=L(x_{cg}-x_{ac})+M_{ac}+M_{fus}+M_{nac}+L_c(x_{cg}-x_c)+L_t(x_{cg}-x_t)$$

(A2)

Dividing through by $qS_w\bar{c}$ *,the coefficient form of equation (A2) may be written:*

$$C_{m_{cg}}=C_L(\bar{x}_{cg}-\bar{x}_{ac})\eta_w+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{L_c}\bar{V}_c\eta_c+C_{L_t}\bar{V}_t\eta_t$$

(A3)

where

q *is the undisturbed flow dynamic pressure,*

S_w *is the wing reference area,*

$\bar{c}$ is the wing mean aerodynamic chord,

$\bar{x}=\frac{x}{\bar{c}}$ are the distances as fractions of the wing mean aerodynamic chord,

$\eta_w=\frac{q_w}{q}$ is the dynamic pressure ratio at the wing to that of the undisturbed free air stream,

$\eta_c=\frac{q_c}{q}$ is the dynamic pressure ratio at the canard to that of the undisturbed free air stream,

$\eta_t=\frac{q_t}{q}$ is the dynamic pressure ratio at the tail to that of the undisturbed free air stream,

$\bar{V}_c=(\bar{x}_{cg}-\bar{x}_c)\frac{S_c}{S_w}$ is the canard volume coefficient,

$\bar{V}_t=(\bar{x}_{cg}-\bar{x}_t)\frac{S_t}{S_w}$ is the tail volume coefficient,

Since the canard is placed near the fuselage nose, it is assumed that no energy losses due to fuselage boundary layer interactions will be incurred by the air surrounding this lifting surface. Thereby, it may be assumed that $\eta_c=1$. However, the same can not be said for the wing due to those flow interactions with the fuselage boundary layer and with the canard induced wake. Nevertheless, it will be assumed that the canard has a small span when compared with that of the wing and, in this way, affecting only a relatively small inner portion of the wing span. Therefore, it may be reasonable to consider the wing efficiency as unity, $\eta_w=1$. Another simplification concerns the canard downwash/upwash effects on the wing which will be assumed to be minimized through an appropriate wing twist, and for this reason will not be considered in the analysis.

Remembering that:

$C_{L_c}=(dC_{L_c}/d\alpha_c)\,(\alpha_c-\alpha_{0c})=a_c(\alpha_c-\alpha_{0c})$ for a cambered canard,

where α_{0c} is the canard zero-lift angle of attack,

$C_{L_t}=(dC_{L_t}/d\alpha_t)\,\alpha_t=a_t\alpha_t$ using a symmetric aerofoil in the horizontal tail, and that

$(dC_L/d\alpha)=a_w$

for a long coupled canard configuration, which is the case under consideration, the influence of the wing upwash on the canard may be assumed negligible, i.e., $\varepsilon_u=0$ *, then,*

$$\alpha_c=(\alpha_w-i_w+i_c)=(\alpha_0+\frac{1}{a_w}C_L-i_w+i_c)$$

$$\alpha_t=(\alpha_w-\varepsilon-i_w+i_t)=[\alpha_0+\frac{1}{a_w}C_L(1-\frac{d\varepsilon}{d\alpha})-i_w+i_t]$$

where

α_w *and* i_w *are the wing angles of attack and incidence, respectively,*

α_0 *is the wing zero-lift angle of attack,*

a_w , a_c *and* a_t *are the wing, canard and tail lift curve slopes,*

i_c *and* i_t *are the canard and tail incidence setting angles and*

ε *is the wing downwash angle at the tail.*

Equation (A3) may now read:

$$C_{m_{cg}}=C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+a_c(\alpha_c-\alpha_{0c})\bar{V}_c+a_t\alpha_t\bar{V}_t\eta_t \qquad (A4)$$

or

$$C_{m_{cg}}=C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+\frac{a_c}{a_w}C_L\bar{V}_c+a_c(\alpha_0-\alpha_{0c}-i_w+i_c)\bar{V}_c+$$
$$+\frac{a_t}{a_w}C_L\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})+a_t(\alpha_0-i_w+i_t)\bar{V}_t\eta_t \qquad (A5)$$

Equations (A1) through (A5) are the equilibrium equations in pitch for gliding flight, power-off, stick fixed, which must sum up to $C_{m_{cg}}=0$ *for equilibrium.*

The pitching moment coefficient is a function of the lift coefficient and for longitudinal static stability to be achieved the derivative dC_m/dC_L *should be negative.*

Differentiating equation (A5) with respect to C_L, the stability equation for this flight condition is obtained:

$$\frac{dC_m}{dC_L}=(\overline{x}_{cg}-\overline{x}_{ac})+(\frac{dC_m}{dC_L})_{fus}+(\frac{dC_m}{dC_L})_{nac}+\frac{a_c}{a_w}\overline{V}_c+\frac{a_t}{a_w}\overline{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})$$

(A6)

where $\frac{dC_{m_{ac}}}{dC_L}=0$ by definition of the aerodynamic centre.

A.1.2 Neutral Point (stick-fixed)

The stick-fixed neutral point, x_{np}, is the c.g. position for which the aircraft becomes neutrally stable, i.e., $dC_m/dC_L=0$. The neutral point establishes an absolute rear limit on the permissible c.g. travel if a stable aircraft with irreversible controls is desired.

Equating equation (A6) to zero, the aircraft neutral point may be determined:

$$\overline{x}_{np}=\overline{x}_{cg_{dC_m/dC_L=0}}=\overline{x}_{ac}-(\frac{dC_m}{dC_L})_{fus}-(\frac{dC_m}{dC_L})_{nac}-\frac{a_c}{a_w}\overline{V}_c-\frac{a_t}{a_w}\overline{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})$$

(A7)

Once the neutral point is known, the stability at any other c.g. position may be evaluated from:

$$\frac{dC_m}{dC_L}=\overline{x}_{cg}-\overline{x}_{np}$$

(A8)

A.1.3 Thrust Effects on Stability

For jet-powered aircraft three major contributions to equilibrium and longitudinal static stability are due to the powerplant installation:

. the direct thrust,
. the normal forces at the diffuser inlet, if any, and
. the jet-induced downwash at the horizontal tail.

In most cases the thrust, T, is nearly independent of speed and may be assumed constant. For unaccelerate flight, its contribution *is:*

$$\left(\frac{dC_m}{dC_L}\right)_{th}=\frac{T}{W}\frac{z_{th}}{\bar{c}} \tag{A9}$$

where T *is the total thrust,*
W *is the aircraft weight,*
z_{th} *is the distance above or below the c.g. (positive if thrust line below c.g.).*

The contribution from the direct normal force on the intake inlets can be evaluated from intake airflow momentum considerations:

$$\left(\frac{dC_m}{dC_L}\right)_{F_N}=\frac{W_a}{g}\frac{1-\frac{d\varepsilon}{d\alpha}}{a_w}\frac{x_{cg}-x_n}{\bar{c}}\frac{0.05}{\varrho S_w v} \tag{A10}$$

where W_a *is the weight of the air taken by the engines,*
ε *is the downwash angle at the inlets for engines installed on the rear fuselage (which is the case),*
x_n *is the distance from nose to the inlet locations,*
v *is the air velocity at the inlets.*

The contribution from the jet-induced downwash at the horizontal tail need be considered for those installations where the jet stream passes under or over the horizontal tail surface. The change in pitching moment coefficient due to the change in flow inclination at the horizontal tail is given by:

$$\Delta C_m=a_t\bar{V}_t\eta_t\Delta\alpha_t \tag{A11}$$

The change in angle of attack of the tail due to the downwash must be determined at each value of the lift coefficient and plotted against C_L*. It may be predicted using the methods presented in NACA WR-L-213,in e.g. Perkins and Hage*[A1]*. Finally, a plot of* C_m *vs* C_L *may be constructed.*

For the purposes of this study and having in mind that the engines are located aft on the fuselage at about the same vertical location as the aircraft cg, for every configurations analysed, it will be assumed the overall effect from the power units will be destabilizing and approximately $(dC_m/dC_L)_{th}\approx 0.03$*, the* main contribution being due to the flow inclination at the tail. Flight test data may consubstantiate this assumption (see Perkins and Hage[A1], *for example).*

A.1.4 Centre of Gravity Rear Location

In order that the aircraft possess stick-fixed longitudinal stability, the most rear location for the c.g. may be determined by using equations (A7) and (A8) for a given static stability margin including the contribution from the power effects. Since these represent a destabilising term, as explained above, the power-off neutral point will shift forward roughly 3 percent of the mean aerodynamic chord as experience suggests.

A.2 Control Theory

Control moments on three-surface aircraft may be produced by changing the lift on the horizontal tail and canard. This can be accomplished by deflecting the elevator and the canardvator or changing the incidence of the tail and canard if all-moving surfaces are used.

A.2.1 Longitudinal Control Power

The magnitudes of the moment coefficients obtained per degree deflection of the elevator and the canardvator are called the control powers, and both may be evaluated analytically from equation (A4) by differentiating $C_{m_{cg}}$ *with respect to elevator deflection,* δ_e *and to canardvator deflection,* δ_c *. It shall be assumed that the control deflections are positive downward.*

The elevator power is:

$$C_{m_{\delta_e}}=\frac{dC_m}{d\delta_e}=a_t\bar{V}_t\eta_t\frac{d\alpha_t}{d\delta_e}=a_t\bar{V}_t\eta_t\tau_e$$

(A12)

and, similarly, the canardvator power is:

$$C_{m_{\delta_c}}=\frac{dC_m}{d\delta_c}=a_c\bar{V}_c\frac{d\alpha_c}{d\delta_c}=a_c\bar{V}_c\tau_c$$

(A13)

where the control effectivenesses τ_e *and* τ_c *are functions of the ratio of the elevator or canardvator area to the whole horizontal tail or canard area, respectively. An empirically determined curve for the control effectiveness versus the area ratio is given in figure 5.33 of Perkins and Hage*[A1].

A.2.2 Control Surface Deflections versus Equilibrium Lift Coefficient

The elevator and canardvator deflections required for equilibrium may be determined analytically from a knowledge of the pitching moment curve slope, dC_m/dC_L *and the control powers,*

$C_{m_{\delta_e}}$ *, and* $C_{m_{\delta_c}}$.

Including now the influence of the control deflections, equation (A4) may be written:

$$C_{m_{cg}}=C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+a_c(\alpha_c-\alpha_{0c}+\tau_c\delta_c)\bar{V}_c+a_t(\alpha_t+\tau_e\delta_e)\bar{V}_t\eta_t \tag{A14}$$

Note that the control of the equilibrium lift coefficient is effected solely through the influence of the terms $\tau_e\delta_e$ *and* $\tau_c\delta_c$.

The control angles required for equilibrium lift coefficient may be expressed by:

$$\delta_e=\delta_{e0}+\frac{d\delta_e}{dC_L}C_L \tag{A15}$$

and

$$\delta_c=\delta_{c0}+\frac{d\delta_c}{dC_L}C_L \tag{A16}$$

where δ_{e0} *and* δ_{c0} *are the elevator and the canardvator angles at the overall zero lift.*

Assuming that both contributions to the pitching moment coefficient are identical in magnitude it may be convenient to write:

$$a_c(\alpha_c-\alpha_{0c}+\tau_c\delta_c)\bar{V}_c=a_t(\alpha_t+\tau_e\delta_e)\bar{V}_t\eta_t$$

(A17)

and resolving for δ_c :

$$\delta_c=\frac{a_t}{a_c}\frac{\bar{V}_t}{\bar{V}_c}\frac{\eta_t}{\tau_c}(\alpha_t+\tau_e\delta_e)-\frac{(\alpha_c-\alpha_{0c})}{\tau_c}$$

(A18)

which replaced in equation (A14) and equating it to zero, for moment equilibrium, the corresponding elevator deflection may be expressed as:

$$\delta_e=-\frac{1}{2C_{m_{\delta_e}}}[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+2a_t\alpha_t\bar{V}_t\eta_t]$$

(A19)

or

$$\delta_e=-\frac{1}{2C_{m_{\delta_e}}}[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}]-\frac{C_L}{a_w\tau_e}(1-\frac{d\varepsilon}{d\alpha})-\frac{\alpha_0-i_w+i_t}{\tau_e}$$

(A20)

Differentiating equation (A19) with respect to C_L, the rate of change of elevator angle with equilibrium lift coefficient may be obtained:

$$\frac{d\delta_e}{dC_L}=-\frac{1}{2C_{m_{\delta_e}}}[(\bar{x}_{cg}-\bar{x}_{ac})+(\frac{dC_m}{dC_L})_{fus}+(\frac{dC_m}{dC_L})_{nac}+2\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})]$$

(A21)

or

$$\frac{d\delta_e}{dC_L}=-\frac{1}{2C_{m_{\delta_e}}}[(\bar{x}_{cg}-\bar{x}_{ac})+(\frac{dC_m}{dC_L})_{fus}+(\frac{dC_m}{dC_L})_{nac}]-\frac{1}{a_w\tau_e}(1-\frac{d\varepsilon}{d\alpha})$$

(A22)

where the elevator power, $C_{m_{\delta_e}}$ was defined in equation (A12).

Equation (A15) may now take the form:

$$\delta_e=\delta_{e0}-\frac{C_L}{2C_{m_{\delta_e}}}\left[(\bar{x}_{cg}-\bar{x}_{ac})+\left(\frac{dC_m}{dC_L}\right)_{fus}+\left(\frac{dC_m}{dC_L}\right)_{nac}+2\frac{a_t}{a_w}\bar{V}_t\eta_t\left(1-\frac{d\varepsilon}{d\alpha}\right)\right]$$

(A23)

δ_{e0} may be evaluated from equation (A19) or (A20) for $C_L=0$, as follows, and assuming that at zero-lift the contribution from the fuselage and nacelles are negligible:

$$\delta_{e0}=-\frac{C_{m_{ac}}}{2C_{m_{\delta_e}}}-\frac{\alpha_0-i_w+i_t}{\tau_e}$$

(A24)

the elevator angle required to vary the equilibrium lift coefficient therefore varies inversely with the elevator power $C_{m_{\delta_e}}$.

A similar treatment for the canardvator deflection will follow.

So, replacing in equation (A18) δ_e, from equation (A19), it may be written as:

$$\delta_c=-\frac{1}{2C_{m_{\delta_c}}}\left[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+2a_c(\alpha_c-\alpha_{0c})\bar{V}_c\right]$$

(A25)

or

$$\delta_c=-\frac{1}{2C_{m_{\delta_c}}}\left[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}\right]-\frac{C_L}{a_w\tau_c}-\frac{\alpha_0-\alpha_{0c}-i_w+i_c}{\tau_c}$$

(A26)

Differentiating equation (A25) with respect to C_L, it may be written:

$$\frac{d\delta_c}{dC_L}=-\frac{1}{2C_{m_{\delta_c}}}\left[(\bar{x}_{cg}-\bar{x}_{ac})+\left(\frac{dC_m}{dC_L}\right)_{fus}+\left(\frac{dC_m}{dC_L}\right)_{nac}+2\frac{a_c}{a_w}\bar{V}_c\right]$$

(A27)

or

$$\frac{d\delta_c}{dC_L}=-\frac{1}{2C_{m_{\delta_c}}}\left[(\bar{x}_{cg}-\bar{x}_{ac})+\left(\frac{dC_m}{dC_L}\right)_{fus}+\left(\frac{dC_m}{dC_L}\right)_{nac}\right]-\frac{1}{a_w\tau_c}$$

(A28)

and equation (A16) may take the form:

$$\delta_c=\delta_{c0}-\frac{C_L}{2C_{m_{\delta_c}}}\left[(\bar{x}_{cg}-\bar{x}_{ac})+\left(\frac{dC_m}{dC_L}\right)_{fus}+\left(\frac{dC_m}{dC_L}\right)_{nac}+2\frac{a_c}{a_w}\bar{V}_c\right]$$

(A29)

where $\boldsymbol{\delta_{c0}}$ *can be evaluated from equation (A25) or (A26) for* $\boldsymbol{C_L=0}$*, with the assumption that* $C_{m_{fus}}=C_{m_{nac}}=0$:

$$\delta_{c0}=-\frac{C_{m_{ac}}}{2C_{m_{\delta_c}}}-\frac{\alpha_0-\alpha_{0c}-i_w+i_c}{\tau_c}$$

(A30)

A.3 Centre of Gravity Forward Location

Evaluation of the most forward c.g. available results from the requirement that the elevator and the canardvator possess enough control authority in all flight conditions within the flight envelope, in order to bring the aircraft into equilibrium at the maximum lift coefficient, to rotate it during take-off, flaring-out on landing and yet preserve a safe margin for manoeuvring. An analysis will be carried out for free flight out of ground effect and for flight in ground effect such as during landing flare and take-off.

A.3.1 Free Flight

The maximum permissible forward c.g. for this condition will be that for which maximum up elevator and maximum down canardvator will just balance out the maximum lift coefficient.

Equations (A23) and (A29) may be used to obtain $\boldsymbol{\delta_e}$ *and* $\boldsymbol{\delta_c}$ *as functions of* $\boldsymbol{(dC_m/dC_L)}$ *in order to find the* $\boldsymbol{(dC_m/dC_L)_{Limit}}$.

Then, from equation (A23), it can be written:

$$\delta_e=\delta_{e0}-\frac{C_L}{2C_{m_{\delta_e}}}[(\frac{dC_m}{dC_L})-\frac{a_c}{a_w}\bar{V}_c+\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})] \tag{A31}$$

and from equation (A29),

$$\delta_c=\delta_{c0}-\frac{C_L}{2C_{m_{\delta_c}}}[(\frac{dC_m}{dC_L})+\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})] \tag{A32}$$

Expressions for the limiting stability may be found analytically by substituting $C_{L_{max}}$ *,* $\delta_{e_{max}}$ *and* $\delta_{c_{max}}$ *, respectively in equations (A31) and (A32), and solving for* $(dC_m/dC_L)_{max}$*.*

Then,

$$(\frac{dC_m}{dC_L})_{max}=\frac{2C_{m_{\delta_e}}}{C_{L_{max}}}(\delta_{e0}-\delta_{e_{max}})+\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha}) \tag{A33}$$

and

$$(\frac{dC_m}{dC_L})_{max}=\frac{2C_{m_{\delta_c}}}{C_{L_{max}}}(\delta_{c0}-\delta_{c_{max}})-\frac{a_c}{a_w}\bar{V}_c+\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha}) \tag{A34}$$

From these two relations an expression may be obtained relating the maximum canardvator deflection to the maximum elevator deflection in order to balance the maximum lift coefficient:

$$\delta_{c_{max}}=\delta_{c0}-\frac{C_{L_{max}}}{C_{m_{\delta_c}}}[\frac{C_{m_{\delta_e}}}{C_{L_{max}}}(\delta_{e0}-\delta_{e_{max}})+\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})] \tag{A35}$$

and for any equilibrium lift coefficient the following expression may be useful:

$$\delta_c=\delta_{c0}-\frac{C_L}{C_{m_{\delta_c}}}[\frac{C_{m_{\delta_e}}}{C_L}(\delta_{e0}-\delta_e)+\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})] \tag{A36}$$

another relation but in terms of (dC_m/dC_L) may be obtained by combining equations (A23) and (A29):

$$\delta_c=\delta_{c0}-\frac{C_{m_{\delta_e}}}{C_{m_{\delta_c}}}(\delta_{e0}-\delta_e)\frac{(\frac{dC_m}{dC_L})+\frac{a_c}{a_w}\bar{V}_c-\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})}{(\frac{dC_m}{dC_L})-\frac{a_c}{a_w}\bar{V}_c+\frac{a_t}{a_w}\bar{V}_t\eta_t(1-\frac{d\varepsilon}{d\alpha})} \qquad (A37)$$

Aircraft are usually more stable with power-off than they are with high power. So the critical forward location of the c.g. will be for power-off and equations (A33) and (A34) will indicate how far forward the c.g. may be moved from the power-off neutral point. The maximum allowable stability, i.e., the most forward permissible c.g. location, varies directly with the elevator power, $C_{m_{\delta_e}}$ *and with the canardvator power,* $C_{m_{\delta_c}}$ *and inversely with the aircraft maximum lift coefficient. If a large c.g. range is needed according to the loading schedules, the aircraft must present large horizontal tail and canard, both of high aspect ratio and long arms to the c.g.. So, the horizontal tail and canard sizes are greatly determined by the extent of the aircraft c.g. range.*

A.3.2 Landing Flare

The proximity of the ground changes the lifting surfaces induced flow field in terms of downwash reduction. This reduction in downwash entails an increase of the tail angle of attack which means that to trim out the same aircraft lift coefficient, the elevator and the canardvator will require greater deflections than those that would be required when out of the ground influence. On the other hand, the downwash reduction increases the slope of the lifting surfaces lift curves. These effects mean that the most forward location, as determined from equations (A33) or (A34), will shift rearward and to relocate it to the same point, in other words, to trim out the maximum lift coefficient, in the presence of the ground, the control deflection increases shall be determined. If not practical, the c.g. forward location should me moved rearwards becoming a more critical situation, and a compromise should be achieved.

Aircraft stability is also affected by the ground effect the main contribution coming from the reduction in wing downwash at the tail. Since ε *is reduced for a given* C_L, $d\varepsilon/d\alpha$ *will be reduced as well increasing in this way the tail contribution to stability, i.e., moving the neutral point rearwards. As this effect is stabilising it will pose no problem.*

The most forward c.g. for trimming out $C_{L_{max}}$ in the ground effect may be obtained from the equilibrium equation and including the pitching moment contribution from the engines idle thrust:

Equation (A19) may be written as:

$$\delta_e=-\frac{1}{2C_{m_{\delta_e}}}[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}+2a_t(\alpha_w-\varepsilon-i_w+i_t)\bar{V}_t\eta_t] \tag{A38}$$

Rearranging this equation and replacing δ_e and C_L for $\delta_{e_{max}}$ and $C_{L_{max}}$, respectively, assuming all other variables corresponding to those at $C_{L_{max}}$ (landing configuration) and in the ground effect, the $\bar{x}_{cg_{fwd}}$ will become:

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_e}}}{C_{L_{max}}}[\delta_{e_{max}}+\frac{\alpha_w-\varepsilon-i_w+i_t}{\tau_e}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}}{2C_{m_{\delta_e}}}] \tag{A39}$$

or

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_e}}}{C_{L_{max}}}[\delta_{e_{max}}+\frac{C_{L_{max}}}{a_w\tau_e}(1-\frac{d\varepsilon}{d\alpha})+\frac{\alpha_0-i_w+i_t}{\tau_e}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}}{2C_{m_{\delta_e}}}] \tag{A40}$$

similarly, from equation (A25):

$$\delta_c=-\frac{1}{2C_{m_{\delta_c}}}[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}+2a_c(\alpha_w-\alpha_{0c}-i_w+i_c)\bar{V}_c] \tag{A41}$$

and rearranging:

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_c}}}{C_{L_{max}}}[\delta_{c_{max}}+\frac{\alpha_w-\alpha_{0c}-i_w+i_c}{\tau_c}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}}{2C_{m_{\delta_c}}}] \tag{A42}$$

or

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_c}}}{C_{L_{max}}}\left[\delta_{c_{max}}+\frac{C_{L_{max}}}{a_w\tau_c}+\frac{\alpha_0-\alpha_{0c}-i_w+i_c}{\tau_c}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}}{2C_{m_{\delta_c}}}\right] \tag{A43}$$

combining equations (A39) and (A42), a simple relation for $\delta_{c_{max}}$ may be found:

$$\delta_{c_{max}}=\frac{C_{m_{\delta_e}}}{C_{m_{\delta_c}}}\left(\delta_{e_{max}}+\frac{\alpha_t}{\tau_e}\right)-\frac{(\alpha_c-\alpha_{0c})}{\tau_c} \tag{A44}$$

Equation (A44) may be derived directly from the design criterium represented by equation (A17).

the following may also be useful:

$$\delta_c=\frac{C_{m_{\delta_e}}}{C_{m_{\delta_c}}}\left(\delta_e+\frac{\alpha_t}{\tau_e}\right)-\frac{(\alpha_c-\alpha_{0c})}{\tau_c} \tag{A45}$$

Both equations (A39) and (A42) will give the limiting forward c.g. location for any condition of flight, including flight in ground effect. Information on the change of the variables in (A39),(A40),(A42) through (A45) due to this effect may be found with the methods suggested by Perkins and Hage[A1]*, for example.*

A.3.3 Take-off Rotation

For a tricycle-gear aircraft the longitudinal controls must be powerful enough to rotate the nose at 80 to 85% of the take-off speed with the most forward c.g..

Again, for rotation analysis, the equilibrium equation will be used, including, as it was the case for the landing flare, the pitching moment contribution from thrust (here, maximum thrust) in ground effect, but adding the contributions from the landing gear and from the control pitching moment in order to overcome the aircraft inertial resistance to pitch. From this description it appears that a more severe situation than that for the landing is found with regard to the design of the canard and the elevator. This explains why sometimes the elevator is sized by take-off rotation requirements.

Then, equation (A19) may be written as

$$\delta_e=-\frac{1}{2C_{m_{\delta_e}}}[C_L(\bar{x}_{cg}-\bar{x}_{ac})+C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}+C_{m_{lg}}-C_{m_{I_{YY}}}+ \\ +2a_t(\alpha_w-\varepsilon-i_w+i_t)\bar{V}_t\eta_t]$$

(A46)

rearranging and assuming that all other variables correspond to those at the lift-off rotation (take-off configuration), then $\bar{x}_{cg_{fwd}}$ *becomes:*

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_e}}}{C_{L_r}}[\delta_{e_r}+\frac{\alpha_w-\varepsilon-i_w+i_t}{\tau_e}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}+C_{m_{lg}}-C_{m_{I_{YY}}}}{2C_{m_{\delta_e}}}]$$

(A47)

and similarly with regard to the canard:

$$\bar{x}_{cg_{fwd}}=\bar{x}_{ac}-\frac{2C_{m_{\delta_c}}}{C_{L_r}}[\delta_{c_r}+\frac{\alpha_w-\alpha_{0c}-i_w+i_c}{\tau_c}+\frac{C_{m_{ac}}+C_{m_{fus}}+C_{m_{nac}}+C_{m_{th}}+C_{m_{lg}}-C_{m_{I_{YY}}}}{2C_{m_{\delta_c}}}]$$

(A48)

A.3.3.1 Pitching Moment Contribution Due to Landing Gear

It is assumed that the nose gear is resting without carrying any weight and that the main gear supports the difference between the maximum take-off weight and the lift generated at the rotation initiation. This contribution is compounded by a normal force term and a rolling friction term as follows:

$$C_{m_{lg}}=C_{m_{lg_{FN}}}+C_{m_{lg_f}}$$

(A49)

$$C_{m_{lg}}=\frac{W-L}{qS_w}[(\bar{x}_{cg}-\bar{x}_{lg})-\mu\frac{z_{lg}}{\bar{c}}]$$

(A50)

where W is the maximum aircraft take-off weight,
L is the total lift at the start of rotation,
$\overline{x}_{lg}$ is the distance of the main landing gear from the nose as a fraction of the mean aerodynamic chord,
z_{lg} is the c.g. height above the ground,
μ is the rolling friction coefficient (usually taken as =0.03).

A.3.3.2 Control Pitching Moment Contribution to Induce the Overall Aircraft Pitching Acceleration.

The pitching moment coefficient due to the aircraft inertial resistance to rotation is given as follows:

$$C_{m_{I_{YY}}}=\frac{I_{YY}\ddot{\theta}}{qS_w\bar{c}}\qquad\text{(A51)}$$

where I_{YY} is the aircraft moment of inertia about the YY axis,
$\ddot{\theta}$ is the aircraft angular pitch acceleration.

Assuming that the rotation follows a circular arc path of radius r at constant pitch rate, $\dot{\theta}=const$, the pitch acceleration $\ddot{\theta}$ may be expressed as:

$$\ddot{\theta}=\frac{V_{trans}^2}{r}\qquad\text{(A52)}$$

with V_{trans} as the transition speed.

From

$$L=W\frac{V_{trans}^2}{{V_{S_{to}}}^2}\frac{C_{L_{trans}}}{C_{L_{max}}}=W+\frac{W}{g}\frac{V_{trans}^2}{r}\qquad\text{(A53)}$$

where $\frac{W}{g}\frac{V_{trans}^2}{r}$ is the centrifugal force, it comes

$$\frac{V_{trans}^2}{r}=\left(\frac{V_{trans}^2}{{V_{S_{t0}}}^2}\frac{C_{L_{trans}}}{C_{L_{max}}}-1\right)g \tag{A54}$$

now equation (A51) may read:

$$C_{m_{I_{YY}}}^{\bullet}=\frac{I_{YY}}{qS_w\bar{C}}\frac{V_{trans}^2}{r}=\frac{I_{YY}}{qS_w\bar{C}}\left(\frac{V_{trans}^2}{{V_{S_{t0}}}^2}\frac{C_{l_{trans}}}{C_{L_{max}}}-1\right)g \tag{A55}$$

where

$$\frac{C_{L_{trans}}}{C_{L_{max}}}\simeq 0.8\sim 0.9$$

and

$$V_{trans}\simeq 0.85V_{t0}=0.85*1.2V_{S_{t0}}$$

To overcome this inertial moment coefficient the control contribution to the overall pitching moment coefficient will be equal to $-C_{m_{I_{YY}}}$.

References

A1. Perkins,C.D.;Hage,R.E.
Airplane Performance Stability and Control
ed. John Wiley & Sons, Inc., 1949

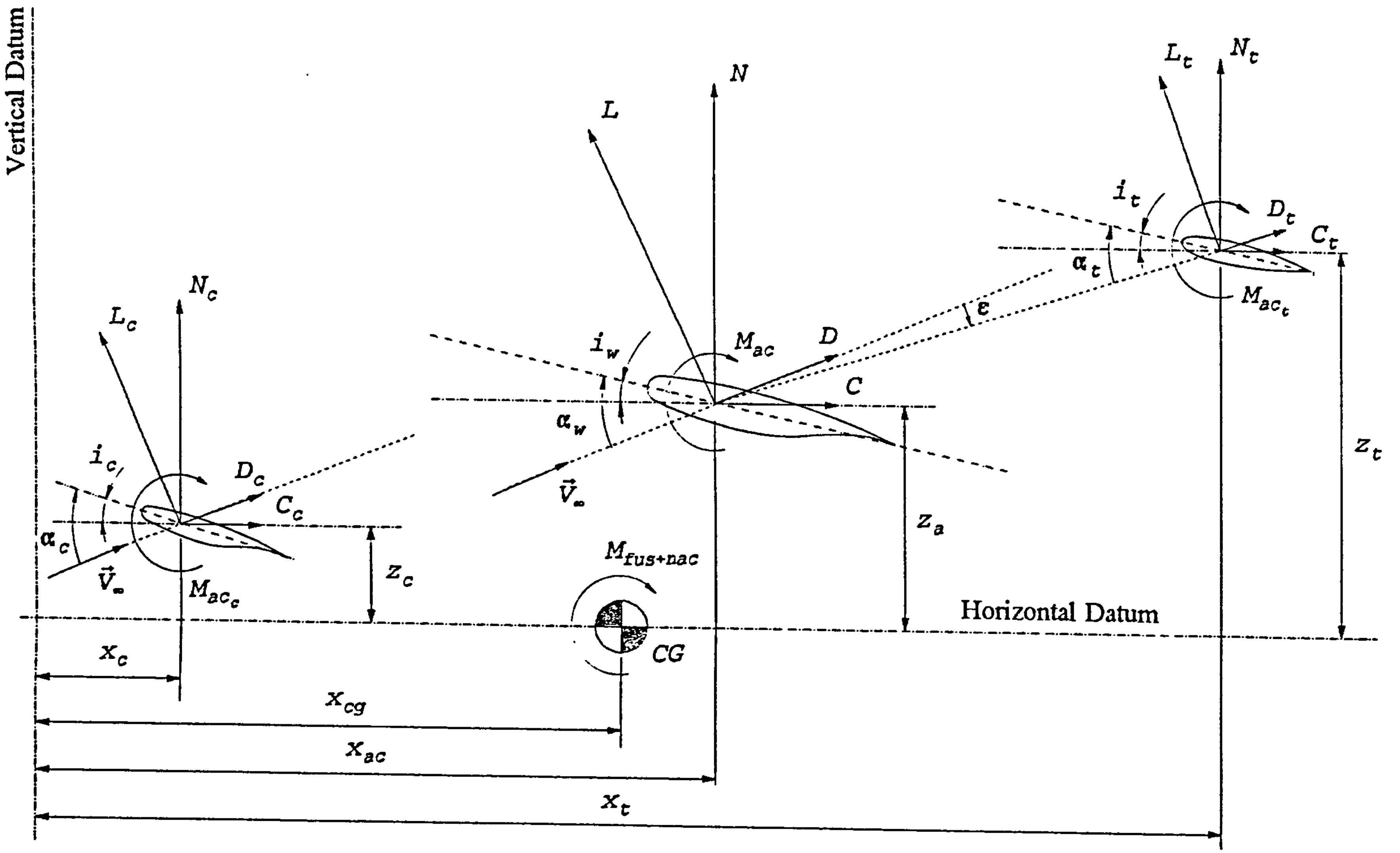

Fig A1 - Forces and Moments Scheme

APPENDIX B

Equations Implemented in GASP-3S
(Three-lifting Surface Concept)

Introduction

GASP code was modified and extended to include the design synthesis of three-surface aircraft. The procedure was described in Chapter 3, and the required equations presented. However, additional formulae was included to ensure computational consistency. This is listed in the present Appendix.

Note to figure B1: To initialise the synthesis, the GEOMETRY module assumes that the horizontal tail apex is coincident with the vertical tail leading edge. This is consistent with the relationship provided in the present Appendix. Subsequent refinement of the surface sizes assumes the root chord of the tailplane trailing edge lying on the fin trailing edge.

Equations Implemented in GASP-3S

B.1 Geometry

Wing

Wing area, $S_w=\frac{W_0}{(\frac{W}{S})}\frac{1}{(1+(\frac{S_c}{S_w}))}$

where $\frac{W}{S}=\frac{W_0}{(S_c+S_w)}=\frac{W_{0c}}{S_c}=\frac{W_{0w}}{S_w}$ *is the wing or canard loading.*

Canard

canard area, $S_c=S_w(\frac{S_c}{S_w})$

canard span, $b_c=(A_cS_c)^{\frac{1}{2}}$

canard chord at fuselage centreline, $c_{c_r}=2\frac{S_c}{b_c(1+\lambda_c)}$

canard mean aerodynamic chord, $\overline{c}_c=\frac{2}{3}c_{c_r}(1+\frac{\lambda_c^2}{1+\lambda_c})$

canard leading edge sweep angle, $\Lambda_{c_{le}}=\arctan(\frac{1-\lambda_c}{A_c(1+\lambda_c)}+\tan\Lambda_{c_{c/4}})$

canard trailing edge sweep angle, $\Lambda_{c_{te}}=\arctan(\frac{3(\lambda_c-1)}{A_c(1+\lambda_c)}+\tan\Lambda_{c_{c/4}})$

distance of the horizontal tail mean aerodynamic quarter chord point from the fuselage nose apex, see figure B1:

$$l_{\overline{c}_{ht_{c/4}}}=l_{fus}-c_{vt_r}+(b_{vt}h_{loc}\tan\Lambda_{vt_{le}})+\overline{X}_{ht_{\overline{c}}}+0.25\overline{c}_{ht}$$

distance of the canard mean aerodynamic quarter chord point from fuselage nose apex. It is assumed the canard main spar located at 30% chord attached to the front fuselage pressure bulkhead main frame and passing through a centreline point at a distance from nose apex defined as the product of the maximum nose depth by the nose fineness ratio, see figure B1:

$$l_{\bar{c}_{c c/4}}=(r_n h_n)-0.3c_{c_r}+\bar{X}_{c_{\bar{c}}}+0.25\bar{c}_c$$

with $\bar{X}_{c_{\bar{c}}}=\frac{b_c}{2}\tan\Lambda_{c_{le}}\frac{1+2\lambda_c}{3(1+\lambda_c)}$

canard moment arm,

$$l_{c_{\bar{c}/4}}=l_{\bar{c}_{ht c/4}}-l_{\bar{c}_{c c/4}}-l_{ht_{\bar{c}/4}}$$

where $l_{ht_{\bar{c}/4}}$ *and* $l_{c_{\bar{c}/4}}$ *are respectively the tailplane and canard moment arms referred to the wing mean aerodynamic quarter chord point rather than to the aircraft aft centre of gravity point as later considered on the stability evaluations and subsequent refinements.*

canard volume coefficient, $\bar{V}_c=\frac{l_{c_{\bar{c}/4}}}{\bar{c}_w}\frac{S_c}{S_w}$

Tailplane

horizontal tail volume coefficient, $\bar{V}_{ht}=\frac{l_{ht_{\bar{c}/4}}}{\bar{c}_w}\frac{S_{ht}}{S_w}$

B.2 Aerodynamics

Canard aerodynamic form factor, $K_c=1.03[2+4(\frac{t}{c})_c+240(\frac{t}{c})^4_c]$

Canard Reynolds number, $Re_c=Re_1\bar{c}_c$

where $Re_1=(\frac{V}{\nu})_{cr}$ *is the Reynolds number per foot at cruise conditions*

Canard Reynolds number correction factor, $F_{Re_c}=(\frac{\log Re_c}{7})^{-2.6}$

Canard parasite drag coefficient, $C_{D_{Pc}}=K_c C_{f_{Re=10^7}} F_{Re_c} C_{D_r}\frac{S_c}{S_w}\frac{1}{1+S_c/S_w}$

Canard wetted area, $S_{wet_c}=2S_c-3\bar{c}_c w_{f_{\bullet c}}\frac{1+\lambda_c}{\lambda_c^2+\lambda_c+1}[1+\frac{w_{f_{\bullet c}}}{2b_c}(\lambda_c-1)]$

where $w_{f_{\bullet c}}$ *is the fuselage width at the canard intersection.*

In low speed flight conditions, the aircraft aerodynamic drag coefficient is represented by:

$$C_D=\Sigma_i C_{D_{p_i}}+C_{D_{p_w}}+C_{D_{p_c}}+C_{D_{i_w}}+C_{D_{i_c}}+\Delta C_{D_f}$$

The first term may include now the landing gear parasite drag coefficient when appropriate and,

where, ΔC_{D_f} *is the parasite drag increment due to trailing edge flaps,*

$C_{D_{i_w}}=\frac{(C_L-\sigma\Delta C_L)^2}{\pi e_w A_w s_f}\frac{1}{1+S_c/S_w}$ *is the wing induced drag coefficient,*

$C_{D_{i_c}}=\frac{(C_L-\sigma\Delta C_L)^2}{\pi e_c A_c s_f}\frac{S_c}{S_w}\frac{1}{1+S_c/S_w}$ *is the canard induced drag coefficient,*

ΔC_L *is the lift increment due to flaps,*

σ *is an empirical flap efficiency factor obtained as a function of flap deflection,*

s_f *is a wing or canard efficiency correction factor due to change in spanwise lift caused by flap deflection.*

Canard lift curve slope:

$$a_c=\frac{\pi A_c}{1+\sqrt{1+C_1C_2}}$$

where, $C_1=(\frac{A_c}{2\cos\Lambda_{c_{c/4}}})^2$

and $C_2=1-(M*\cos\Lambda_{c_{c/4}})^2$

B.3 Weight and Balance

Canard Weight:

$$W_c=S_{K_{cw}}S_{K_{NO}}S_{K_{EPOS_c}}S_{K_{GEAR_c}}F_{OO_c}\frac{b_c^{1.049}(1+\lambda_c)^{0.4}}{(\frac{t}{c})_{c_r}^{0.4}\cos^{1.535}\Lambda_{c_{c/2}}}*10^{-5}$$

where

$S_{K_{cw}}=133.4$ *is the canard weight trend factor (it takes the same value as the wing weight trend factor,* $S_{K_{ww}}$ *)*

$S_{K_{NO}}=1+\frac{2.5}{\sqrt{\frac{b_c}{\cos\Lambda_{c_{c/2}}}}}$ *is the correction factor for the non-optimum material,*

$S_{K_{EPOS_c}}=1.05$ *is the correction factor for high-subsonic jet aircraft with no canard mounted engines,*

$S_{K_{GEAR_c}}=0.95$ *is the correction factor for landing gear not mounted on canard,*

$F_{OO_c}=[S_{K_{STR}}U_{LF}[S_c(\frac{W_0}{S_c+S_w})-0.8W_{c_1}]]^{0.757}$ *is the canard loading parameter,*

$S_{K_{STR}}=1$ *is the reduction in bending moment factor for braced canard,*

U_{LF} *is the ultimate design load factor determined in subroutine DLOAD,*

W_0 *is the design maximum take-off weight,*

W_{c_1} *is the canard weight,*

b_c *is the canard span,*

λ_c *is the canard taper ratio,*

$(t/c)_{c_r}$ *is the canard root thickness ratio,*

$\Lambda_{c_{c/2}} = \arctan(\tan\Lambda_{c_{c/4}} - \frac{1-\lambda_c}{A_c(1+\lambda_c)})$ *is the canard half chord sweep angle.*

Assuming the canard centre of gravity is located 8% aft of the canard mean aerodynamic quarter chord point, its distance from the fuselage nose apex may be expressed by:

$$l_{c_{cg_c}} = l_{w_{r_{c/4}}} - 0.25c_{w_r} + \bar{X}_{w_{\bar{c}}} + 0.25\bar{c}_w - l_{c_{\bar{c}/4}} + 0.08\bar{c}_c$$

Spanwise distance of canard mean aerodynamic chord from fuselage centreline:

$$\bar{Y}_{\bar{c}_c} = \frac{b_c(1+2\lambda_c)}{6(1+\lambda_c)}$$

Distance of canard centreline quarter chord point from fuselage nose apex:

$$l_{c_{r_{c/4}}} = (r_n h_n) - 0.05c_{c_r}$$

canard tip chord:

$$c_{c_t} = \lambda_c c_{c_r}$$

Propulsion Installation pitching moment coefficients due to jet inclination at the tail:

- at landing conditions

$$C_{m_{thjinc_L}} = (\frac{dC_m}{dC_L})_{thjinc} C_{L_{max_L}}$$

- at take-off rotation conditions

$$C_{m_{thjinc_r}} = (\frac{dC_m}{dC_L})_{thjinc} C_{L_r}$$

where $(\frac{dC_m}{dC_L})_{thjinc} = 0.03$ *, as assumed in Appendix A, is the jet-flow inclination contribution to the aircraft longitudinal static stability.*

Aircraft moment of inertia about the YY axis:

$$I_{YY}=\frac{W_0}{g}(K_y)^2$$

where, K_y is the aircraft pitch radius of gyration as obtained through the empirical linear regression of figure V.1.11[19],

and g is the acceleration due to gravity.

Lift force at nose wheel liftoff rotation:

$$L=C_{L_r}qS_w(1+\frac{S_c}{S_w})$$

where, $C_{L_r}=\frac{1}{2}\varrho_r(0.85V_s)_r^2$ is the lift coefficient at nose wheel liftoff conditions,

ϱ_r is the air density at the field height,

V_s is the aircraft stall speed at the take-off configuration.

B.4 Performance

Stall speed at sea level International Standard Atmospheric (ISA) conditions:

$$V_{s_{sl}}=\sqrt{\frac{2W_0}{\varrho_0 C_{L_{max}}S_w(1+\frac{S_c}{S_w})}}$$

Take-off speed:

$$V_t=r_{V_t}V_{s_{sl}}\frac{1}{\sqrt{\sigma}}$$

where $r_{V_t}=\frac{V_t}{V_{s_{sl}}}$ is the ratio of the take-off speed to the stall speed at sea level ISA conditions,

$\sigma=\frac{\varrho}{\varrho_0}$ the ratio of the actual air density at the runway altitude to that at sea level ISA conditions.

Take-off lift coefficient:

$$C_{L_t}=\frac{2W_0}{\varrho V_t^2 S_w(1+\frac{S_c}{S_w})}$$

Take-off thrust required:

$$T_{rq}=qS_w(1+\frac{S_c}{S_w})C_D V_t$$

Take-off horizontal acceleration:

$$(\frac{dV}{dt})_t=\frac{g}{W}[T_a\cos\alpha_t-qS_w(1+\frac{S_c}{S_w})C_D-\mu(W-qS_w(1+\frac{S_c}{S_w})C_L-T_a\sin\alpha_t)-W\sin\gamma]$$

where T_a *is the available* Thrust,

μ *is the ground rolling coefficient of friction,*

γ *is the flight path angle.*

Horizontal flight acceleration:

$$(\frac{dV}{dt})=\frac{g}{W}[T-0.7PM^2S_w(1+\frac{S_c}{S_w})C_D]$$

where P *is the absolute air pressure at flight altitude,*

M *is the momentary flight Mach number.*

Minimum climb speed:

$$V_{cl}=1.1\sqrt{\frac{2W}{S_w(1+\frac{S_c}{S_w})\varrho C_{L_{\max}}}}$$

Where 1.1 *represents a margin above the stall speed.*

Climb lift coefficient:

$$C_L=\frac{W\cos\gamma}{qS_w(1+\frac{S_c}{S_w})}$$

Rate of climb:

$$RC=\frac{V[T_a-qS_w(1+\frac{S_c}{S_w})C_D]}{W}$$

Wing loading:

$$\frac{W}{S}=\frac{W}{S_w(1+\frac{S_c}{S_w})}$$

Sink rate:

$$RS=\frac{V_{app}[qS_w(1+\frac{S_c}{S_w})C_D-T_{idle}]}{W}$$

where $V_{app}=1.3V_{s_L}$ *is the approach speed,*

V_{s_L} *is the landing stall speed,*

T_{idle} *is the idle thrust.*

Normal load factor increment due to lift and thrust:

$$X_{LF}=\frac{[qS_w(1+\frac{S_c}{S_w})C_L+T_a\sin\alpha]}{W\cos\gamma}$$

Variations of the above equations are used throughout the Mission Performance module, where necessary, for the computation of some of the as shown implicit parameters and thus they are not reproduced.

B.5 Economics

Canard production cost:

$$C_c=1730W_c^{0.766}(Q_p)^{-0.218}CEF$$

where W_c *is the canard weight as determined above,*

Q_p *is the estimated aircraft production quantity,*

$CEF=(1+IR)^{(year-1975)}$ *is the cost escalation factor,*

IR *is the annual average inflation rate,*

year is the actual year of the calculation.

This cost estimating relationship is the same as used for the wing and includes both production cost and an assumed aircraft manufacturer's profit of 10%.

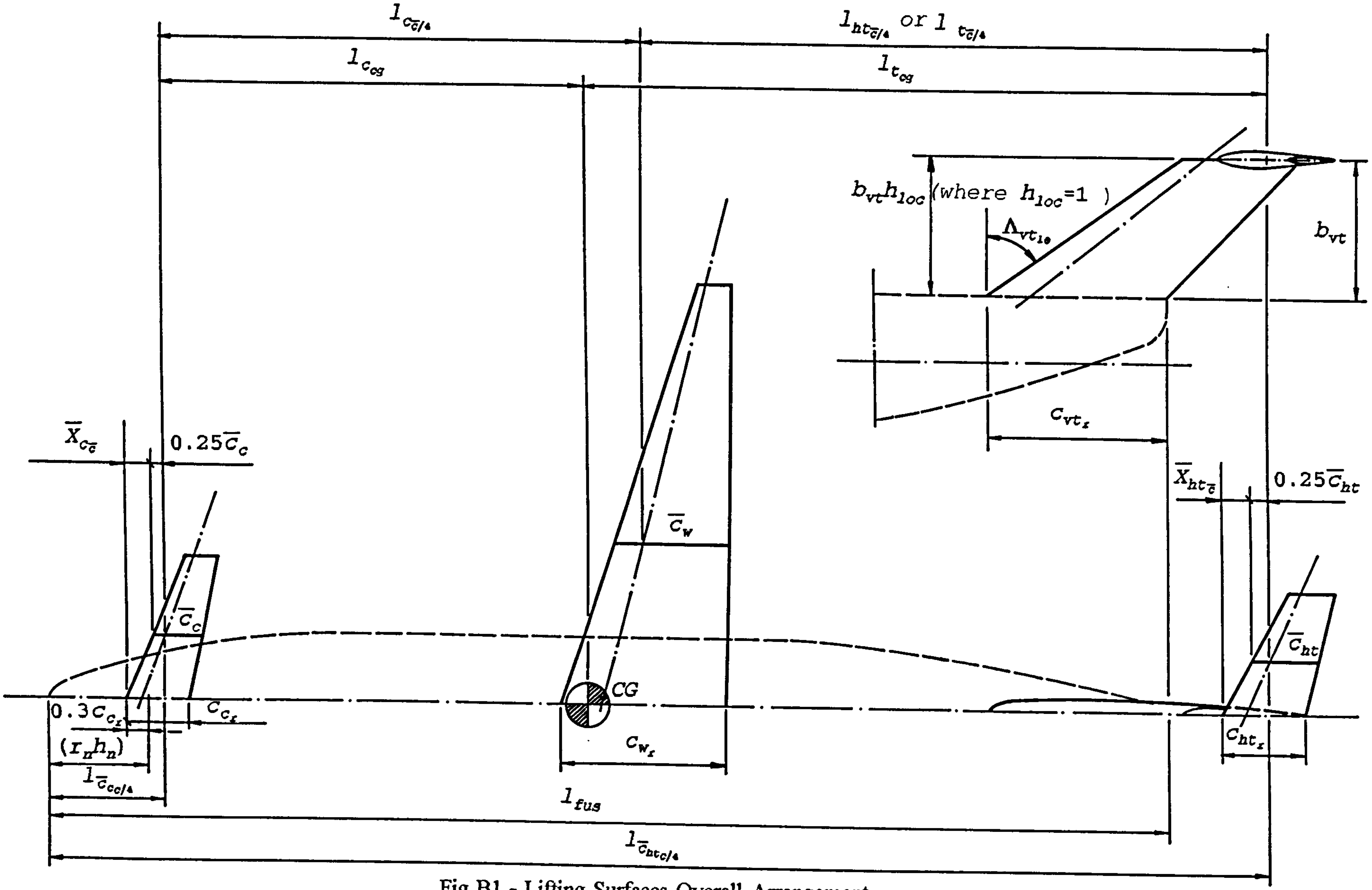

Fig B1 - Lifting Surfaces Overall Arrangement

APPENDIX C

Parametric Analysis - Aircraft Initial Sizing

Introduction

Following the preliminary sizing method presented by Roskam[5.1], a Parametric Analysis module named "PRESIZ" was developed. This module relies on historical data and allows for the estimation of aircraft take-off, empty and fuel weights. Results allow for establishing a take-off Thrust to Weight versus Wing Loading plot. This diagram represents a constrained solution space where all the mission, performance and airworthiness requirements are satisfied. Take-off gross weight sensitivity studies with respect to mission, aerodynamic and propulsion parameters are also evaluated. A mission specification, together with some assumptions on empirical and technology related parameters, are all required as input to run the program.

This Appendix encloses the PRESIZ input file (fig C2), and the output listing (fig C3) required to create the design diagram shown in fig 5.1. This Thrust to Weight vs Wing Loading plot was used to select the starting design point for the more elaborate GASP evaluations that followed. A key is also provided in fig C1 to describe what the data in the input file is.

Note: ref 5.1 refers to ref 1 of Chapter 5, Vol Part I.

PreSiz Input File Data (description)

Passenger no.;passenger weight[lb];baggage weight[lb];
flight crew no.;cabin crew no.;crew weight [lb];crew baggage weight[lb];
range[NM];loiter time[hr];distance to alternate[NM];
cruise Mach no.;cruise altitude[ft];
FAR 25 take-off field length[ft];field altitude[ft];day temperature[degree F];
FAR 25 landing field length[ft];
Landing weight to maximum take-off weight ratio;

- mission weight fuel fractions:
engine start & warm-up;taxi;take-off;climb;descent;landing,taxi and shut down;

cruise lift to drag ratio;engine cruise specific fuel consumption[lb/lb/hr];loiter lift to drag ratio;engine loiter specific fuel consumption[lb/lb/hr];
average climb speed[kt];average climb rate[ft/min];cruise altitude sonic speed[kt];trapped fuel and oil weight as a fraction of the maximum take-off weight;reserve fuel to used fuel weight ratio(usually representing 45 min of flight at cruise conditions);A and B regression line constants of equation 2.16 which relates the aircraft empty weight to the maximum take-off weight, taken from table 2.15 for the appropriate aircraft category (in ref. 5.1);

CLmax array dimension (N) at take-off configuration;wing loading array dimension (M) at take-off configuration;
air pressure ratio at take-off field altitude;
CLmax array at take-off configuration (N values);
wing loading array at take-off configuration (M values)[lb/sqft];

CLmax array dimension (K) at landing configuration;
air density at sea level standard conditions [slugs/cuft];
CLmax array at landing configuration (K values);

a and b regression line coefficients for equation 3.21 which relates the equivalent parasite area to the aircraft wetted area and assuming an equivalent skin friction coefficient of cf=0.003. These coefficients are taken from table 3.4 of ref.(5.1);c and d regression line coefficients for equation 3.22 which relates the wetted area to the aircraft maximum take-off weight. The coefficients are taken from table 3.5 of ref.(5.1) for the category of aircraft into consideration;

lowest wing aspect ratio to consider;clean configuration Oswald efficiency factor;
additional zero-lift drag coefficient due to take-off flaps; take-off configuration Oswald efficiency factor;
additional zero-lift drag coefficient due to landing flaps; landing configuration Oswald efficiency factor;
additional zero-lift drag coefficient due to landing gear;
number of engines;

clean configuration CLmax;take-off CLmax;landing CLmax;
Mach drag divergency compressibility drag increment;air density at cruise altitude [slugs/cuft];rate of climb capability at cruise altitude [ft/min];
Initial guess for the maximum take-off weight [lb]

Fig C1 - PreSiz Input Data List

```
  50      175.     25.
   2        1     175.     25.
1250.        .0       .0
    .8  35000.
6000.    5000.     95.
5000.
    .94
8000.
    .9983    .9983   .9983   .9742   .9806  1.
  11.        .5    12.7     .4
 315.    2220.    576.3     .005     .27     .0833  1.0383

   5        5
    .8320
   1.2      1.6     2.0     2.4     2.8
  40.      60.     80.    100.    120.

   7
  23.78E-04
   1.6      1.9     2.2     2.5     2.8     3.1     3.4

  -2.5229   1.       .0199   .7531
   6.        .85
    .015     .80
    .065     .75
    .020

   2
   1.3      2.45     3.25

    .0007   7.365E-04     500.


  50000.
```

Fig C2 - PreSiz Input.dat File

```
                 TRANSPORT AIRCRAFT MISSION SPECIFICATION

PAYLOAD:          NUMBER OF PASSENGERS    =     50
                  PASSENGER WEIGHT        =    175.0  LBS
                  HAND BAGGAGE WEIGHT     =     25.0  LBS

CREW:             FLIGHT DECK             =      2
                  CABIN                   =      1
                  CREW WEIGHT             =    175.0  LBS
                  HAND BAGGAGE WEIGHT     =     25.0  LBS

RANGE:            DISTANCE TO DESTINATION =   1250.0  NM
                  HOLDING TIME            =       .0  HOURS
                  DISTANCE TO ALTERNATE   =       .0  NM

CRUISE ALTITUDE                           =  35000.0  FT

CRUISE MACH NO. @ 35000.0  FT             =        .80

CLIMB:  DIRECT TO 35000.0  FT @ MAX TAKE-OFF WEIGHT

FIELD LENGTH:     TAKE-OFF                =   6000.0  FT
                  LANDING                 =   5000.0  FT
                  FIELD ALTITUDE          =   5000.0  FT
                  FIELD TEMPERATURE       =     95.0  F

POWER-PLANTS:       2  TURBO-FANS

CERTIFICATION BASE:    FAR 25
```

Fig C3 - PreSiz Output.dat File

```
  I. TAKE-OFF GROSS WEIGHT, EMPTY WEIGHT AND FUEL WEIGHT


TAKE-OFF GROSS WEIGHT, WTO  =      44076.48  LBS

EMPTY WEIGHT, WE            =      24698.35  LBS

FUEL WEIGHT, WF             =       8557.75  LBS


 II. SENSITIVITIES OF AEROPLANE TAKE-OFF GROSS WEIGHT


GROWTH FACTOR DUE TO PAYLOAD =                       3.8291   LBS/LB

GROWTH FACTOR DUE TO EMPTY WEIGHT =                  1.8529   LBS/LB

GROWTH FACTOR DUE TO RANGE =                        17.9014   LBS/NM

GROWTH FACTOR DUE TO ENDURANCE =                  5718.7880   LBS/HR

GROWTH FACTOR DUE TO SPEED =                       -48.5353   LBS/KT

******  RANGE CASE ******

GROWTH FACTOR DUE TO SPECIFIC FUEL CONSUMPTION = 44753.4400  LBS/(LBS/HR LB)

GROWTH FACTOR DUE TO LIFT-TO-DRAG RATIO =        -2034.2470   LBS
```

Fig C3 - PreSiz Output.dat File (continued)

```
III. SIZING TO PERFORMANCE


   1. ESTIMATING DRAG POLARS AT LOW SPEED

    WTO        W/S(TO)        S        SWET        F        CDO
   [LBS]        [PSF]       [FT2]      [FT2]     [FT2]

 44076.480    80.000      550.956   3291.942    9.875     .0179


    ASPECT RATIO (ASSUMED),  AR  =    8.00

                                                          2
    LOW SPEED, CLEAN    :   CD =    .0179    +   .0468  CL
                                                          2
    TAKE-OFF, GEAR UP   :   CD =    .0329    +   .0497  CL
                                                          2
    TAKE-OFF, GEAR DOWN:    CD =    .0529    +   .0497  CL
                                                          2
    LANDING, GEAR UP    :   CD =    .0829    +   .0531  CL
                                                          2
    LANDING, GEAR DOWN :    CD =    .1029    +   .0531  CL


    ASPECT RATIO (ASSUMED),  AR  =    9.00

                                                          2
    LOW SPEED, CLEAN    :   CD =    .0179    +   .0416  CL
                                                          2
    TAKE-OFF, GEAR UP   :   CD =    .0329    +   .0442  CL
                                                          2
    TAKE-OFF, GEAR DOWN:    CD =    .0529    +   .0442  CL
                                                          2
    LANDING, GEAR UP    :   CD =    .0829    +   .0472  CL
                                                          2
    LANDING, GEAR DOWN :    CD =    .1029    +   .0472  CL
```

Fig C3 - PreSiz Output.dat File (continued)

```
   WTO          W/S(TO)         S           SWET          F          CDO
  [LBS]          [PSF]        [FT2]        [FT2]        [FT2]

44076.480      100.000       440.765     3291.942      9.875       .0224


  ASPECT RATIO (ASSUMED),   AR   =    8.00

                                                          2
  LOW SPEED, CLEAN     :   CD =     .0224    +   .0468  CL
                                                          2
  TAKE-OFF, GEAR UP    :   CD =     .0374    +   .0497  CL
                                                          2
  TAKE-OFF, GEAR DOWN:     CD =     .0574    +   .0497  CL
                                                          2
  LANDING, GEAR UP     :   CD =     .0874    +   .0531  CL
                                                          2
  LANDING, GEAR DOWN :     CD =     .1074    +   .0531  CL


  ASPECT RATIO (ASSUMED),   AR   =    9.00

                                                          2
  LOW SPEED, CLEAN     :   CD =     .0224    +   .0416  CL
                                                          2
  TAKE-OFF, GEAR UP    :   CD =     .0374    +   .0442  CL
                                                          2
  TAKE-OFF, GEAR DOWN:     CD =     .0574    +   .0442  CL
                                                          2
  LANDING, GEAR UP     :   CD =     .0874    +   .0472  CL
                                                          2
  LANDING, GEAR DOWN :     CD =     .1074    +   .0472  CL
```

Fig C3 - PreSiz Output.dat File (continued)

```
3. SIZING TO TAKE-OFF DISTANCE REQUIREMENTS


*** SUMMARY OF MINIMUM VALUES FOR T/W(TO) ***


CLMAX (TO) =            1.200     1.600     2.000     2.400     2.800

   W/S(TO)
   [PSF]

   40.00                 .337      .252      .202      .168      .144

   60.00                 .505      .379      .303      .252      .216

   80.00                 .673      .505      .404      .337      .288

  100.00                 .841      .631      .505      .421      .361

  120.00                1.010      .757      .606      .505      .433


4. SIZING TO LANDING DISTANCE REQUIREMENTS


     CLMAX(L)        W/S(TO)
                      [PSF]

      1.600           41.186

      1.900           48.908

      2.200           56.630

      2.500           64.353

      2.800           72.075

      3.100           79.797

      3.400           87.520
```

Fig C3 - PreSiz Output.dat File (continued)

```
5. SIZING TO CLIMB REQUIREMENTS  (FAA)


NUMBER  OF  ENGINES,          NENG    =   2

CL MAX (CLEAN)  (ASSUMED),  CLMAX     =   1.300

CL MAX (TO)     (ASSUMED),  CLMAXTO   =   2.450

CL MAX (L)      (ASSUMED),  CLMAXL    =   3.250


LANDING CLIMB REQ.                 TAKE-OFF CLIMB REQ. (OEI)
- FAR 25.121 (OEI)                - FAR 25.121 - 2ND SEGMENT

ASPECT RATIO =  8.0

W/S (TO)       T/W(TO)             W/S (TO)       T/W(TO)
 [PSF]                              [PSF]


 40.000         .335                40.000         .307
 60.000         .344                60.000         .313
 80.000         .352                80.000         .320
100.000         .360               100.000         .327
120.000         .368               120.000         .333


ASPECT RATIO =  9.0

W/S (TO)       T/W(TO)             W/S (TO)       T/W(TO)
 [PSF]                              [PSF]


 40.000         .318                40.000         .283
 60.000         .326                60.000         .290
 80.000         .334                80.000         .296
100.000         .343               100.000         .303
120.000         .351               120.000         .310
```

Fig C3 - PreSiz Output.dat File (continued)

```
  6. SIZING TO CRUISE SPEED REQUIREMENTS


   *** SUMMARY OF MINIMUM VALUES FOR T/W(TO) ***

COMPRESSIBILITY DRAG INCREMENT (ASSUMED) =    7.00  DRAG COUNTS

ASPECT RATIO =         6.0   7.0   8.0   9.0   10.0  11.0  12.0

      W/S(TO)
       [PSF]

       40.00           .283  .276  .271  .267  .263  .261  .259

       60.00           .302  .291  .283  .277  .272  .268  .265

       80.00           .323  .309  .299  .291  .284  .279  .274

      100.00           .346  .328  .315  .305  .297  .290  .285

      120.00           .369  .348  .332  .320  .311  .303  .296


  7. SIZING TO DIRECT CLIMB REQUIREMENTS


   *** SUMMARY OF MINIMUM VALUES FOR T/W(TO) ***


CLIMB RATE AT 35000 FT SERVICE CEILING (ASSUMED) =  500.00  FPM

ASPECT RATIO =         6.0   7.0   8.0   9.0   10.0  11.0  12.0

      W/S(TO)
       [PSF]

       40.00           .329  .323  .317  .313  .310  .307  .305

       60.00           .348  .338  .330  .324  .319  .315  .312

       80.00           .370  .356  .345  .337  .331  .325  .321

      100.00           .392  .375  .362  .352  .344  .337  .331

      120.00           .415  .395  .379  .367  .357  .349  .342
```

Fig C3 - PreSiz Output.dat File (concluded)

APPENDIX D

The Baseline Designs

Introduction

This Appendix encloses the GASP output listings containing the detailed results for the conventional and the three-surface baseline designs. The parameters composing the GASP input files, organised by their respective disciplinary groups, were repeated on the first page of the output print-outs. These are listed in section 5.3 with the proposed values for the initial trial configurations, both conventional and unconventional. A complete list of GASP input variable names is given in Appendix H. The low speed and cruise drag polars related to the conventional and the three-surface baseline designs are illustrated respectively in figs. D.3 and D.4. Table 5.1, included in the main text, summarizes the main results obtained. Figures 5.2 and 5.3 show the three view sketches of the classical and the three-surface baseline airliners which are based on the present results.

Note: The research was conducted on the CoA SUN Spark stations, where Range Trade-off studies were done up to a maximum design range of 2000 NM. However, it was thought useful to extend the investigation to higher ranges. This was later accomplished using a Hewlett Packard 9000 platform, at IST. Because the numerical results for the same run cases were found slightly different, due to differences in the FORTRAN compilers employed, a new set of results were obtained by repeating all the design synthesis and design optimisation computer work. So, numerical consistency is preserved in the results. All output listings herein, as well as those included in Appendix E, were obtained on a HP workstation.

```
 0                      50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - CONVENTIONAL CONFIG.
                                     ENGINE CYCLE IS G. E.  CF-34
                                         INPUT DATA FOLLOW
                                        *******************
 0
 0 CONFIG  WG      =  44050.          *****GEOMETRY*****
           WGS     =  83.000          KWRITE  =      2      FUSEL  SAB    =      4.                ELODN   =   1.000
           PAX     =     50.          IGEAR   =      0             WS     =  20.000                ELODT   =   3.200
           EMCRU   =    .800          KCONFG  =      0             AS     =      1.                BMLOD   =  14.500
           HNCRU   =  35000.          KTIPX   =      0             WAS    =  19.000       NACELLE  KNAC    =       1
                                      ENP     =     2.             PS     =    31.0                ELN     =    .000
                                      NTYE    =      7             ELPC   =  11.220                DBARN   =    .000
           Kanard  =       0          KPLOT   =      1             HCK    =   2.470                ELRW    =  10.000

 0   WING  TCT     =    .100    HORIZ VBARHX  =  .0000      VERT   VBARVX =   .0000       Canard   TCcan   =    .100
           TCR     =    .130    TAIL  TCHT    =   .100      TAIL   TCVT   =    .120                ARcan   =   5.500
           AR      =   8.300          ARHT    =  4.000             ARVT   =   1.000                SLMcan  =    .500
           SLM     =    .200          SLMH    =   .550             SLMV   =    .700                DwpqCa  =  15.000
           DLMC4   =  14.500          DWPQCH  = 27.500             DWPQCV =  50.500                EYEcan  =   2.000
           EYEW    =   2.000          COELTH  =   .000             BOELTV =    .000                SWcOSW  =    .150
                                      SAH     =  1.000
 0
 0         CKW     =  -1.000          ***AERODYNAMICS***
           CKF     =  -1.000          CKHT    =  -1.000            GRFE   =    .000                DCDSE   = -1.0000
           CKN     =  -1.000          CKTP    =  -1.000            SCFAC  =    .750                CKWc    =  -1.000
           CKVT    =  -1.000          DELCD   =  .00150            DLSWSW =    .000                cmacw   =   -.060
                                      DELFE   =    .200            ALPHLO =  -1.600                alzerc  =  -1.000

 0         KWCD    =      12
           ACLS    =  -1.000  -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
           ACDCDR  =   2.400  1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

 0                                   *HIGH LIFT DEVICES*
 0         RCLMAX  =   1.200    FLAPS JFLTYP  =      7      LED  CLEOC  =    .000
           ALTFLP  =   5000.          DFLPTO  = 15.000           DELLED =    .000
           FLAPN   =      1.          DFLPLD  = 40.000           DCLMLE =    .930
           WCFLAP  =  -1.000          CFOC    =   .300           DELLEO =  45.000
           BENGOB  =    .000          BTEOB   =   .750
                                      DCLMTE  =   .000
                                      DCDOTE  =   .000
                                      DELTEO  =   .000

 0                                   ****PROPULSION****
 0         JENGSZ  =       2          HPORT   =  5000.          RCCRU  =  50.000                 RWCRTX  =    .970
           IPART   =       1          TDELTO  =    36.          XTORQ  =  99999.                 HSCREQ  =      0.
           KODETO  =       5          KODECL  =      7          SMlD   =    .500                 THIN    =      0.
           KODETR  =       5          KODEAC  =      5          HBTP   =    .437                 PR      =   1.000

 0                                   *****WEIGHTS*****
 0         SKPEI   =   .1350          SKY     =  .1800          SKB    = 107.000                 SKFS    =   .0200
           SKLG    =   .0380          SKZ     =  .2200          SKCC   =  20.000                 SKWF    =   .4300
           SKMG    =   .8000          SKTL    = 1.0000          SKFW   =   .4300                 SKFT    =   .9790
           SKPES   =   .3380          SKWW    = 133.400         SKSAS  =    .000                 SKWTP   =  1.8900
           WPLX    =      .0          YMG     =  .2500          EGMRGN =   .0000                 LCWING  =       2
           WPEX    =      .0          RELP    =  .7500          CPMRGN =   .2000
           WFUL    =      .0          RELR    =  .4500          STMRGN =   .0000                 LDCKMX  =   8.000
           UWPAX   =   200.0          CATD    =     3.          DELP   =   8.200                 ATMXQC  =   3.160
           STRUT   =   .0000          VMLFSL  =  685.0          YP     =   .0000                 DELWST  =      .0
           DELWFC  =      .0
 0 ENGINE  WENG    =      .0          WNAC    =     .0          WPYLON =      .0
           SWSLS   =    .160          UWNAC   =  2.287          FPYL   =    .700                 XLQDE   =   3.000

 0                                  *STABILITY AND CONTROL*
 0         KSFixd  =       1          STATIC  =   .100          ZCG    = 999.000                 CNPAC   =   .0020
           CMFLPL  = 999.000          CHALF   = 999.000         TP     =      .0                 ARVTE   =  -1.000
           CMFLPT  = 999.000          CHDEL   = 999.000         CXA    =    .520                 RV      =    .300
                                      RH      =   .350          DCMCLP =9999.000                 TAUV    = 999.000
           CMPLD   =    .000          DEMAX   =  -25.0          HWING  =      0.                 RVMCS   =    .990
                                      EYET    =     .0          dcmcpi =    .030                 DRMAX   =    25.0
                                      TAUH    = 999.000         rc     =    .350

 0,                                   ***PERFORMANCE***
 0   TAXI  DELTT   =    .167          XLFMAX  =  1.100          DVR    =   5.000                 TDELTX  =  36.000
       TO  IFLY    =       1          DELTVR  =  3.500          UM     =    .020                 HTMAX   = 500.000
           THEMAX  =  15.000          DV1     =  5.000          MUB    =    .400                 NFAIL   =       0
           HOO     =   5000.          VRAT    =   1.10          WTMISN =      0.

 0  CLIMB  ICLM    =       1   CRUISE CRMACH  =   .000          FRESF  =   1.000                 FACW1   =    .800
           DELH    =   1000.          CRALT   =     0.          RCRRQ  =  1250.0                 ISWING  =       0
           VCLMB   =      .0          ICRUS   =      1          OFALT  =  25000.                 OFEM    =    .500
 0   LAND  IWLD    =       2          XLDGRQ  = 99999.          VRATT  =   1.300                 HAPP    =     50.
           TDELLD  =    36.0          ALTLND  =  5000.          RSMX   =   1000.                 SINKTD  =     3.0
           TDELAY  =     1.0          WLPCT   =  .9400          TROTID =    .000                 XLFMX   =   1.200
           HTG     =     5.5          TIDLE   =     .0          VTDRAT =     1.1

 0                                   ******COST******
 0         NCADE   =       1          HIR     =   .005          RI     =    .300                 CMV     =    .800
           CLIAB   =  1993.0          TR      =  2.000          OHR    = 500.000                 CCRW    =      0.
           HRI     =4000000.          PRV     =   .100          CRWOH  =  23.000                 UCSENG  =    .000
           CMF     =      .2          DYR     =   15.0          CINP   =      0.                 UCSPP   =    .000
           TBO     =  3200.0          SRPM    =     .0          CP     =      0.                 ALR     =   3.400
           FCSP    =    .850

 1
 0+++++ H.TAIL C.L. CHORD MUST =    8.502 TO BE LOCATED AT SPECIFIED POSITION ON VERTICAL+++++
  +++++ H.TAIL TAPER CHANGED TO    .8214
```

Fig. D1 - Conventional Baseline Configuration GASP output file

```
**************************************************************************************************

 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1   .0223   .5848
  GROSS WGT, GROSS WGT MINUS1      47873.0    48147.5


0  *******************************************************************************************
0                         FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)     ,    DELTA CD
                      CLMAX     VSTALL,KTS  FLAP ANGLE   LE ANGLE    DELTA CL    ------ --

 FLAPS UP          1.2932       148.7         .0          .0        .0000       .0000
 T.O. CONFIG       2.4660       107.5       15.0          .0       1.1629       .0432
 LDG. CONFIG       3.2639        93.4       40.0          .0       1.9705       .1924

0                        DOUBLE SLOTTED FOWLER FLAPS
                         OPT ANGLE    DELCL AT OPT   DELCD AT OPT    AREA(FT2)     WEIGHT(LB)

 FLAPS                     30.0         2.2500          .1500         120.6          697.3
0  *******************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.476   LIFT= 46436.8   L/D=  13.055   ALTITUDE= 35000.0   MACH=   .8000

1                                       ENGINE SIZING DATA FOLLOW
                                        ***************************
0VSTLKT=  99.6 KTS EAS   VRAT= 1.100 CLTO= 2.0380
      VEND =  237.6 KNOTS EAS
0
 ROTATION (TIME=   23.1 AND TAS=   122.2 EAS=   109.6)
 LIFTOFF (TIME=   25.0 DIST=   2951.1 TAS=   129.8 EAS=   116.4)
 DISTANCE TO 35 FT.=  4176.5   TAS=   144.9 EAS=   129.9 V35/VS=  1.3035
 GEAR RETRACTION STARTED AT   31.2 SEC,COMPLETE AT   38.2 SEC
 FLAP RETRACTION STARTED AT   41.3 SEC,COMPLETE AT   45.8 SEC
0VSTLKT=  99.6 KTS EAS   VRAT= 1.100 CLTO= 2.0380
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  205.2 KNOTS EAS
 ENGINE FAILURE (TIME=   21.8 AND TAS=   116.6 EAS=   104.6)
0
 ROTATION (TIME=   25.0 AND TAS=   122.2 EAS=   109.6)
 LIFTOFF (TIME=   27.8 DIST=   3518.5 TAS=   125.8 EAS=   112.8)
 DISTANCE TO 35 FT.=  4913.6   TAS=   127.7 EAS=   114.5 V35/VS=  1.1489


     ACCELERATE - STOP DISTANCE =     5192.0 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      4913.6 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      4176.5 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     4803.0 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     4397.4 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .012 HRS   FUEL USED=       73. LBS   WEIGHT=   47800. LBS   ALT.=     5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                                VS              V      GRAD      R/C   REQ.R/C
   CONFIGURATION                                   ALT (FT)   KEAS    V/VS    KTAS    (PCT)    (FPM)    (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT    5000.     99.8  1.1403  126.8    2.517   323.01     1.00  1.904  8.721
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT             5250.     99.8  1.2000  134.0    4.244   575.44   325.40  1.719 10.524
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT           6500.    137.2  1.2500  195.7    5.256  1041.15   237.69   .838 14.118
   APPROACH FLAPS -ONE ENG OUT                      5000.     95.3  1.4116  150.0    4.813   730.41   318.72  1.362 11.498
   LANDING FLAPS - ALL ENGINES                      5000.     86.7  1.3000  125.7   14.150  1799.64   406.99  1.939  7.204

     APPROACH FLAP SETTING = 19.8 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 24584.5 FT.
         BEST RATE OF CLIMB SPEED   =    271.1 KTAS
         ENGINE-OUT RATE OF CLIMB   =      49.6 FPM
         WEIGHT AT ALTITUDE         = 45958.1 LBS
0                         ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE              1522.4
   NACELLE WEIGHT/ENGINE              342.4
   PYLON WEIGHT/ENGINE                178.8
      PROP OR QFAN             .0
      GEARBOX                  .0
      SHROUD                   .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.99
   NACELLE LENGTH(FT)              11.96

0VSTLKT=  99.6 KTS EAS   VRAT= 1.100 CLTO= 2.0380
      VEND =  237.1 KNOTS EAS
0
 ROTATION (TIME=   22.1 AND TAS=   122.2 EAS=   109.6)
 LIFTOFF (TIME=   24.0 DIST=   2844.6 TAS=   130.4 EAS=   117.0)
 DISTANCE TO 35 FT.=  4042.7   TAS=   146.0 EAS=   130.9 V35/VS=  1.3137
 GEAR RETRACTION STARTED AT   30.0 SEC,COMPLETE AT   37.0 SEC
 FLAP RETRACTION STARTED AT   40.1 SEC,COMPLETE AT   44.6 SEC
0VSTLKT=  99.6 KTS EAS   VRAT= 1.100 CLTO= 2.0380
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  197.2 KNOTS EAS
 ENGINE FAILURE (TIME=   20.8 AND TAS=   116.6 EAS=   104.6)
0
 ROTATION (TIME=   23.8 AND TAS=   122.2 EAS=   109.6)
 LIFTOFF (TIME=   26.4 DIST=   3328.7 TAS=   125.9 EAS=   113.0)
 DISTANCE TO 35 FT.=  4670.0   TAS=   128.4 EAS=   115.1 V35/VS=  1.1555
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
     ACCELERATE - STOP DISTANCE =    5094.3 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     4670.0 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     4042.7 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =    4649.1 FEET
 ALL ENGINE DISTANCE TO 50 FT. =    4266.5 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .012 HRS   FUEL USED=      74. LBS   WEIGHT=   47799. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                         VS            V      GRAD      R/C   REQ.R/C
   CONFIGURATION                               ALT (FT)  KEAS   V/VS   KTAS   (PCT)    (FPM)    (FPM)    CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.   99.8 1.1403  126.8   2.864   367.58     1.00  1.904  8.536
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.   99.8 1.2000  134.0   4.576   620.48   325.40  1.719 10.251
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  137.2 1.2500  195.7   5.398  1069.14   237.69   .838 13.392
   APPROACH FLAPS -ONE ENG OUT                   5000.   95.3 1.4116  150.0   5.109   775.33   318.72  1.362 11.140
   LANDING FLAPS - ALL ENGINES                   5000.   86.7 1.3000  125.7  15.280  1943.37   406.99  1.939  7.171

     APPROACH FLAP SETTING = 19.8 DEG.

                          *

     +++ ENGINE-OUT SERVICE CEILING = 25133.1 FT.
         BEST RATE OF CLIMB SPEED   =   269.8 KTAS
         ENGINE-OUT RATE OF CLIMB   =    49.8 FPM
         WEIGHT AT ALTITUDE         = 45958.1 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    389.02

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    389.02

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   9920.1 LBS
**********************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE              1587.2
   NACELLE WEIGHT/ENGINE              342.4
   PYLON WEIGHT/ENGINE                183.3
      PROP OR QFAN            .0
      GEARBOX                 .0
      SHROUD                  .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.99
   NACELLE LENGTH(FT)              11.96
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

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0*****************************************************************************************************
                  ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

              MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
              WT           CG        WT          CG         WT          CG

A/C OWE    28484.05      44.05    28484.05     44.05    28484.05      44.05
PAX         6120.00                2040.00               8500.00
BAGGAGE         .00      56.36     1500.00     56.36     1500.00      56.36
WING FUEL   1877.79      44.22     1877.79     44.22     9388.94      44.22
TIP FUEL        .00        .00         .00       .00         .00        .00
FUS FUEL        .00      44.22         .00     44.22         .00      44.22
TOTAL      36481.84      41.71    33901.84     44.85    47872.99      43.15

0                 ---TAIL SIZING SUMMARY---

        Static Longitudinal Stability, Stick-fixed, considered


0                      WING                    CANARD          TAIL         DOWN    FLAP
CONDITION  ALPHA     CL     CLA     CMac   ALPHA    CLA     CLA    EFF.     WASH    CM

 CRUISE    1.5712  .3710  .1170 -.0600  .0000  .0000  .0762 1.0000
 LIFTOFF   2.0000 1.4720  .0618 -.0600  .0000  .0000  .0635 1.0000  .3767 -.1031
 LANDING  13.7607 3.2639  .0842 -.0600  .0000  .0000  .0635 1.0000 2.5920 -.2000

0           --FUSELAGE-- ---NACELLE--        -------POWER-------         L.GEAR ROT.POWER
CONDITION   DCM     CM     DCM     CM  DCMdth DCMfinc CMdth  CMfinc    CT      CM      CM

 CRUISE     .3054          .1052         .0000  .0300                .0000
 LIFTOFF    .5781  .0000  .1052  .0000                 .0000  .0442  .0000 -.3641 4.6176
 LANDING    .4244  .4202  .1052  .1041                 .0000  .0979

0     ELEVATOR PARAMETERS
          CMDELTE(CONTROL POWER)        =  -.06308            WING DE/DALPHA =    .37673
          TAUH(EFFECTIVENESS)           =   .48250
          DEMAX(MAX.ELEVATOR DEFLEC.)   =-25.00000


0                                  FRACTION     STATION          HORIZONTAL TAIL SIZES
                                     MAC      (DATUM NOSE)
      NEUTRAL POINT                 .6452       46.270           STATIC STABILITY AND LANDING TRIM    215.1616
      STATIC MARGIN                 .1000                        STATIC STABILITY AND LIFTOFF ROT.    270.2973
      AFT CG LIMIT(STABILITY)       .5452       45.313
      CG RANGE(LOADING)             .3280                        REQUIRED TAIL SIZE                   270.2973
      FWD CG LIMIT(CONTROL)         .2172       42.243           TAIL ARM(ELTH)                        44.8583

0     VERTICAL TAIL AREA =  117.2811 FOR DIRECTIONAL STABILITY OF      .00200
0     RUDDER POWER AT MAX.DEFL.=   .0178 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4461
0     VERTICAL TAIL AREA=  121.9062 FOR MINIMUM CONTROL SPEED =     98.62 KTS
0     REQUIRED VERTICAL TAIL AREA =  121.9062  TAIL ARM(ELTV) =   33.5393

**************************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.476   LIFT= 46436.8   L/D=  11.906   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25        H-TAIL VOL. ARM         =   44.86        C.G.LOCATION OF PROPULSION=   59.43
 WING 1/4C LOC.ON C.L.=   38.79        H-TAIL C.G.LOCATION     =   87.79        C.G.OF REMAINING WEIGHT   =   35.66
 MAC 1/4C LOCATION     =   42.27        H-TAIL MAC FROM C.L.    =    7.95
 MAC DIST.FROM C.L.    =   13.45        H-TAIL LOCAT ON VERT.=       1.00
 WING C.G.LOCATION     =   44.18        V-TAIL VOL. ARM         =   33.54
 TIP TANKS C.G.LOCATE =      .00        V-TAIL C.G.LOCATION     =   76.70        DIST.L.E.VERT.TO L.E.HORZ.=     .07
0                       WING        H-TAIL      V-TAIL

  AREA                576.783     270.297     121.906
  SPAN                 69.190      32.881      11.041
  ASPECT RATIO          8.300       4.000       1.000
  TAPER RATIO            .200        .821        .700
  1/4C. SWEEP          14.500      27.500      50.500
  L.E. SWEEP           18.723      28.593      52.459
  C.L. CHORD           13.894       9.026      12.990
  MEAN CHORD            9.571       8.247      11.156
  TIP CHORD             2.779       7.414       9.093
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
0                                            MISSION PERFORMANCE DATA FOLLOWS
                                             ********************************
0   TAXI AT IDLE THRUST

                    FUEL                          FUEL
  TIME    RANGE     USED    WEIGHT    ALT.        FLOW
  (HRS)   (NM)      (LBS)   (LBS)     (FT)      (LB/HR)

   .000       0.       0.   47873.    5000.      907.
   .167       0.     151.   47722.    5000.      907.
0VSTLKT=  99.5 KTS EAS   VRAT= 1.100 CLTO= 2.0380
     VEND =   236.9 KNOTS EAS
0           (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                     FUEL                                                                                                     FUEL    FUS.
   TIME    DIST.     USED    WEIGHT    ALT.      TAS     EAS   MACH  ACCEL     CL      CD   ALPHA GAMMA     ROC   LOAD THRUST    FLOW   ANGLE
  (SEC)   (FEET)    (LBS)    (LBS)     (FT)     (KTS)   (KTS)   NO. (FPS2)                  (DEG) (DEG)    (FPM)  FACT  (LBS)  (LB/HR) (DEG)

     .0       .0    151.0  47722.   5000.0      .0      .0  .000  11.21 1.4701  .1193  2.00    .00        .0   .00  17594.   6266.    .00
    1.0      5.6    152.8  47720.   5000.0     6.6     5.9  .010  11.06 1.4701  .1193  2.00    .00        .0   .00  17379.   6266.    .00
    2.0     22.3    154.5  47718.   5000.0    13.1    11.8  .019  10.91 1.4701  .1193  2.00    .00        .0   .00  17168.   6266.    .00
    3.0     49.9    156.3  47717.   5000.0    19.6    17.6  .029  10.75 1.4702  .1193  2.00    .00        .0   .00  16960.   6267.    .00
    4.0     88.3    158.0  47715.   5000.0    25.9    23.2  .038  10.59 1.4702  .1193  2.00    .00        .0   .00  16757.   6269.    .00
    5.0    137.3    159.7  47713.   5000.0    32.1    28.8  .048  10.42 1.4703  .1193  2.00    .00        .0   .00  16556.   6271.    .00
    6.0    196.8    161.5  47712.   5000.0    38.3    34.3  .057  10.24 1.4704  .1193  2.00    .00        .0   .00  16360.   6273.    .00
    7.0    266.6    163.2  47710.   5000.0    44.3    39.8  .066  10.07 1.4705  .1193  2.00    .00        .0   .00  16166.   6275.    .00
    8.0    346.4    165.0  47708.   5000.0    50.2    45.1  .075   9.89 1.4707  .1193  2.00    .00        .0   .00  15976.   6277.    .00
    9.0    436.2    166.7  47706.   5000.0    56.1    50.3  .083   9.70 1.4708  .1193  2.00    .00        .0   .00  15789.   6280.    .00
   10.0    535.7    168.5  47705.   5000.0    61.8    55.4  .092   9.51 1.4710  .1193  2.00    .00        .0   .00  15606.   6282.    .00
   11.0    644.8    170.2  47703.   5000.0    67.4    60.4  .100   9.32 1.4712  .1193  2.00    .00        .0   .00  15427.   6285.    .00
   12.0    763.2    171.9  47701.   5000.0    72.9    65.4  .108   9.16 1.4714  .1194  2.00    .00        .0   .00  15290.   6288.    .00
   13.0    890.9    173.7  47699.   5000.0    78.3    70.2  .116   8.99 1.4716  .1194  2.00    .00        .0   .00  15157.   6292.    .00
   14.0   1027.5    175.4  47698.   5000.0    83.5    75.0  .124   8.82 1.4718  .1194  2.00    .00        .0   .00  15026.   6295.    .00
   15.0   1173.0    177.2  47696.   5000.0    88.7    79.6  .132   8.65 1.4720  .1194  2.00    .00        .0   .00  14897.   6299.    .00
   16.0   1327.2    178.9  47694.   5000.0    93.8    84.2  .139   8.48 1.4723  .1194  2.00    .00        .0   .00  14771.   6302.    .00
   17.0   1489.9    180.7  47692.   5000.0    98.8    88.7  .147   8.30 1.4725  .1194  2.00    .00        .0   .00  14648.   6306.    .00
   18.0   1661.0    182.4  47691.   5000.0   103.7    93.0  .154   8.13 1.4728  .1195  2.00    .00        .0   .00  14527.   6310.    .00
   19.0   1840.2    184.2  47689.   5000.0   108.5    97.3  .161   7.95 1.4730  .1195  2.00    .00        .0   .00  14409.   6314.    .00
   20.0   2027.3    186.0  47687.   5000.0   113.2   101.5  .168   7.77 1.4733  .1195  2.00    .00        .0   .00  14293.   6318.    .00
   21.0   2222.3    187.7  47685.   5000.0   117.7   105.6  .175   7.60 1.4736  .1195  2.00    .00        .0   .00  14180.   6323.    .00
   22.0   2425.0    189.5  47684.   5000.0   122.2   109.6  .181   7.42 1.4738  .1195  2.00    .00        .0   .00  14069.   6327.    .00
0
 ROTATION (TIME=   22.0 AND TAS=   122.0 EAS=   109.5)
   23.0   2635.0    191.2  47682.   5000.0   126.5   113.5  .188   7.11 1.6085  .1302  3.64    .00        .0   .85  13962.   6331.   1.64
 LIFTOFF (TIME=   23.8 DIST=   2808.2 TAS=   129.8 EAS=   116.5)
   24.0   2852.2    193.0  47680.   5000.0   130.6   117.2  .194   6.70 1.7774  .1448  5.78    .00        .5  1.01  13860.   6335.   3.79
   25.0   3076.2    194.7  47678.   5000.7   134.5   120.6  .200   6.10 1.8187  .1502  6.28    .50     117.8  1.10  13764.   6339.   4.78
   26.0   3306.2    196.5  47677.   5004.3   137.9   123.7  .205   5.44 1.7350  .1519  5.08   1.27     310.2  1.09  13699.   6342.   4.36
   27.0   3541.7    198.3  47675.   5011.0   141.0   126.4  .209   4.74 1.6727  .1569  4.28   2.03     506.3  1.10  13642.   6345.   4.31
   28.0   3781.8    200.0  47673.   5021.1   143.6   128.8  .213   4.13 1.6113  .1581  3.58   2.78     704.8  1.10  13591.   6346.   4.36
   29.0   4026.0    201.8  47671.   5034.6   145.9   130.8  .217   3.63 1.5576  .1561  2.98   3.50     903.2  1.09  13546.   6347.   4.48
 DISTANCE TO 35 FT.=  4033.0    TAS=   146.0 EAS=   130.9 V35/VS=  1.3158
   30.0   4273.7    203.6  47669.   5051.3   148.0   132.6  .220   3.16 1.5220  .1538  2.58   4.22    1102.7  1.10  13505.   6347.   4.80
 GEAR RETRACTION STARTED AT   29.9 SEC,COMPLETE AT   36.9 SEC
   31.0   4524.3    205.3  47668.   5071.3   149.8   134.2  .222   2.82 1.4873  .1467  2.18   4.92    1301.4  1.10  13467.   6346.   5.10
   32.0   4777.5    207.1  47666.   5094.7   151.4   135.6  .225   2.52 1.4530  .1393  1.78   5.62    1500.8  1.10  13432.   6345.   5.40
   33.0   5033.0    208.8  47664.   5121.3   152.8   136.8  .227   2.21 1.4274  .1329  1.48   6.30    1699.7  1.10  13400.   6343.   5.79
   34.0   5290.4    210.6  47662.   5151.3   154.0   137.9  .229   1.92 1.4018  .1268  1.18   6.98    1895.9  1.09  13370.   6340.   6.16
   35.0   5549.3    212.4  47661.   5184.5   155.1   138.7  .230   1.61 1.3848  .1217   .98   7.65    2092.7  1.10  13343.   6337.   6.64
   36.0   5809.5    214.1  47659.   5221.0   156.0   139.4  .232   1.32 1.3677  .1166   .78   8.33    2288.4  1.09  13319.   6333.   7.11
   37.0   6070.5    215.9  47657.   5260.8   156.7   140.0  .233   1.02 1.3591  .1126   .68   8.99    2481.3  1.10  13296.   6328.   7.67
   38.0   6332.1    217.6  47655.   5303.7   157.2   140.4  .234    .65 1.3506  .1117   .58   9.65    2670.4  1.10  13277.   6322.   8.23
   39.0   6593.8    219.4  47654.   5349.7   157.5   140.5  .234    .29 1.3420  .1108   .48  10.30    2854.5  1.10  13261.   6316.   8.79
   40.0   6855.3    221.1  47652.   5398.8   157.6   140.5  .234   -.01 1.3162  .1082   .18  10.96    3035.9  1.08  13248.   6309.   9.14
 FLAP RETRACTION STARTED AT   40.0 SEC,COMPLETE AT   44.5 SEC
   41.0   7116.5    222.9  47650.   5449.7   157.6   140.4  .234    .10 1.1325  .1059   .98  10.87    3011.0   .93  13235.   6302.   9.85
   42.0   7378.3    224.6  47648.   5498.4   157.7   140.4  .235    .08 1.0718  .1220  3.28  10.12    2808.6   .89  13222.   6295.  11.41
0VSTLKT=  99.5 KTS EAS   VRAT= 1.100 CLTO= 2.0380
0 ENGINE OUT PERFORMANCE FOLLOWS
     VEND =   199.7 KNOTS EAS
0           (TEMP.=  537. DEG:STD.+36.)
.0   TAKEOFF  (ELEVATION=  5000. FT)

                     FUEL                                                                                                     FUEL    FUS.
   TIME    DIST.     USED    WEIGHT    ALT.      TAS     EAS   MACH  ACCEL     CL      CD   ALPHA GAMMA     ROC   LOAD THRUST    FLOW   ANGLE
  (SEC)   (FEET)    (LBS)    (LBS)     (FT)     (KTS)   (KTS)   NO. (FPS2)                  (DEG) (DEG)    (FPM)  FACT  (LBS)  (LB/HR) (DEG)

     .0       .0    151.0  47722.   5000.0      .0      .0  .000  11.21 1.4701  .1193  2.00    .00        .0   .00  17594.   6266.    .00
    1.0      5.6    152.8  47720.   5000.0     6.6     5.9  .010  11.06 1.4701  .1193  2.00    .00        .0   .00  17379.   6266.    .00
    2.0     22.3    154.5  47718.   5000.0    13.1    11.8  .019  10.91 1.4701  .1193  2.00    .00        .0   .00  17168.   6266.    .00
    3.0     49.9    156.3  47717.   5000.0    19.6    17.6  .029  10.75 1.4702  .1193  2.00    .00        .0   .00  16960.   6267.    .00
    4.0     88.3    158.0  47715.   5000.0    25.9    23.2  .038  10.59 1.4702  .1193  2.00    .00        .0   .00  16757.   6269.    .00
    5.0    137.3    159.7  47713.   5000.0    32.1    28.8  .048  10.42 1.4703  .1193  2.00    .00        .0   .00  16556.   6271.    .00
    6.0    196.8    161.5  47712.   5000.0    38.3    34.3  .057  10.24 1.4704  .1193  2.00    .00        .0   .00  16360.   6273.    .00
    7.0    266.6    163.2  47710.   5000.0    44.3    39.8  .066  10.07 1.4705  .1193  2.00    .00        .0   .00  16166.   6275.    .00
    8.0    346.4    165.0  47708.   5000.0    50.2    45.1  .075   9.89 1.4707  .1193  2.00    .00        .0   .00  15976.   6277.    .00
    9.0    436.2    166.7  47706.   5000.0    56.1    50.3  .083   9.70 1.4708  .1193  2.00    .00        .0   .00  15789.   6280.    .00
   10.0    535.7    168.5  47705.   5000.0    61.8    55.4  .092   9.51 1.4710  .1193  2.00    .00        .0   .00  15606.   6282.    .00
   11.0    644.8    170.2  47703.   5000.0    67.4    60.4  .100   9.32 1.4712  .1193  2.00    .00        .0   .00  15427.   6285.    .00
   12.0    763.2    171.9  47701.   5000.0    72.9    65.4  .108   9.16 1.4714  .1194  2.00    .00        .0   .00  15290.   6288.    .00
   13.0    890.9    173.7  47699.   5000.0    78.3    70.2  .116   8.99 1.4716  .1194  2.00    .00        .0   .00  15157.   6292.    .00
   14.0   1027.5    175.4  47698.   5000.0    83.5    75.0  .124   8.82 1.4718  .1194  2.00    .00        .0   .00  15026.   6295.    .00
   15.0   1173.0    177.2  47696.   5000.0    88.7    79.6  .132   8.65 1.4720  .1194  2.00    .00        .0   .00  14897.   6299.    .00
   16.0   1327.2    178.9  47694.   5000.0    93.8    84.2  .139   8.48 1.4723  .1194  2.00    .00        .0   .00  14771.   6302.    .00
   17.0   1489.9    180.7  47692.   5000.0    98.8    88.7  .147   8.30 1.4725  .1194  2.00    .00        .0   .00  14648.   6306.    .00
   18.0   1661.0    182.4  47691.   5000.0   103.7    93.0  .154   8.13 1.4728  .1195  2.00    .00        .0   .00  14527.   6310.    .00
   19.0   1840.2    184.2  47689.   5000.0   108.5    97.3  .161   7.95 1.4730  .1195  2.00    .00        .0   .00  14409.   6314.    .00
   20.0   2027.3    186.0  47687.   5000.0   113.2   101.5  .168   7.77 1.4733  .1195  2.00    .00        .0   .00  14293.   6318.    .00
 ENGINE FAILURE (TIME=   20.7 AND TAS=   116.5 EAS=   104.5)
   21.0   2222.3    187.5  47685.   5000.0   117.5   105.4  .174   2.69 1.4736  .1284  2.00    .00        .0   .00   7093.   3161.    .00
   22.0   2422.0    188.4  47685.   5000.0   119.0   106.8  .177   2.65 1.4737  .1280  2.00    .00        .0   .00   7074.   3162.    .00
   23.0   2624.4    189.3  47684.   5000.0   120.6   108.2  .179   2.60 1.4738  .1276  2.00    .00        .0   .00   7055.   3163.    .00
   24.0   2829.3    190.2  47683.   5000.0   122.1   109.6  .181   2.55 1.4739  .1273  2.00    .00        .0   .00   7036.   3163.    .00
0
 ROTATION (TIME=   23.9 AND TAS=   122.0 EAS=   109.5)
   25.0   3036.8    191.0  47682.   5000.0   123.6   110.9  .183   2.38 1.6112  .1379  3.68    .00        .0   .81   7017.   3164.   1.68
   26.0   3246.7    191.9  47681.   5000.0   124.9   112.1  .185   2.15 1.7724  .1516  5.73    .00        .0   .92   7001.   3165.   3.73
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

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 LIFTOFF (TIME=   26.6 DIST=   3373.7 TAS=   125.7 EAS=   112.7)
   27.0  3458.8    192.8  47680.  5000.0  126.1  113.2  .187    1.88 1.9234  .1654  7.74    .03      6.0  1.02   6986.    3165.  5.76
   28.0  3672.7    193.7  47679.  5000.8  127.1  114.1  .189    1.42 2.0021  .1755  8.74    .45    102.3  1.08   6973.    3166.  7.19
   29.0  3888.0    194.6  47678.  5004.0  127.8  114.6  .190     .69 2.0101  .1887  8.54   1.27    287.5  1.10   6965.    3166.  7.81
   30.0  4103.9    195.4  47678.  5010.3  128.0  114.8  .190     .01 1.9695  .2009  7.84   2.09    473.9  1.08   6962.    3166.  7.93
   31.0  4319.8    196.3  47677.  5018.9  128.0  114.8  .190     .00 1.8278  .1932  6.14   2.34    530.5  1.00   6961.    3165.  6.48
   32.0  4535.8    197.2  47676.  5027.6  128.0  114.7  .190    -.01 1.8089  .1967  5.94   2.26    510.7   .99   6960.    3164.  6.19
 DISTANCE TO 35 FT.=  4727.8    TAS=   128.0 EAS=   114.7 V35/VS=  1.1534
   33.0  4751.7    198.1  47675.  5035.9  128.0  114.7  .190     .00 1.8075  .1999  5.94   2.14    483.4   .99   6958.    3164.  6.07
   34.0  4967.7    199.0  47674.  5043.8  128.0  114.7  .190     .00 1.8150  .2032  6.04   2.04    461.8   .99   6957.    3163.  6.08
   35.0  5183.8    199.8  47673.  5051.3  128.0  114.7  .190    -.01 1.8230  .2057  6.14   1.97    445.9  1.00   6956.    3163.  6.11


     ACCELERATE - STOP DISTANCE =     5078.4 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=     4727.8 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =     4033.0 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =    4638.0 FEET
  ALL ENGINE DISTANCE TO 50 FT. =    4256.3 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=   .178 HRS   FUEL USED=     225. LBS   WEIGHT=  47648. LBS   ALT.=    5500. FT.


    ACCELERATE TO MACH NO. = .396

 0                   FUEL                                                    FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    THRUST   FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

    .178      .00   224.7  47648.    5500.    152.    140.  .235  .708  13522.    6202.
    .186     1.77   277.5  47596.    5500.    257.    237.  .396  .806  11555.    6380.

   END OF ACCELERATION SEGMENT
   TIME=  .186 HRS   FUEL USED=   277.5 LBS   WEIGHT=  47596. LBS   RANGE=    2. NM
 0   CLIMB TO   35000. FT. AT MAXIMUM RATE OF CLIMB
 0                   FUEL                                                                         FUS.                          FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH     CL      CD    ALPHA GAMMA ANGLE     R/C    THRUST    FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV                    (DEG) (DEG) (DEG)   (FPM)    (LBS)  (LB/HR)

    .186       2.     277.   47596.   5500.    241.    222.  .371  .801  .4882  .0361  3.90  8.16 10.06    3468.   10244.    5613.
    .189       2.     291.   47582.   6000.    242.    222.  .374  .800  .4907  .0362  3.92  7.61  9.53    3251.   10147.    5559.
    .194       4.     319.   47554.   7000.    245.    221.  .379  .800  .4958  .0365  3.97  7.44  9.40    3210.    9946.    5447.
    .199       5.     348.   47525.   8000.    247.    219.  .383  .799  .5038  .0369  4.05  7.34  9.39    3191.    9756.    5334.
    .204       6.     376.   47497.   9000.    248.    217.  .387  .798  .5121  .0373  4.14  7.13  9.27    3125.    9566.    5221.
    .210       7.     403.   47470.  10000.    258.    222.  .404  .801  .4895  .0361  3.85  5.67  7.52    2587.    9249.    5117.
    .216       9.     436.   47437.  11000.    261.    221.  .410  .800  .4939  .0364  3.89  6.76  8.65    3113.    9059.    5002.
    .221      10.     463.   47410.  12000.    264.    220.  .416  .799  .4998  .0367  3.95  6.17  8.11    2869.    8870.    4889.
    .227      12.     492.   47381.  13000.    266.    218.  .421  .799  .5059  .0370  4.00  5.98  7.98    2810.    8684.    4780.
    .233      14.     520.   47353.  14000.    269.    217.  .427  .798  .5122  .0373  4.06  5.78  7.84    2742.    8498.    4673.
    .239      15.     548.   47325.  15000.    272.    216.  .435  .798  .5145  .0374  4.07  5.41  7.48    2605.    8302.    4569.
    .246      17.     578.   47295.  16000.    277.    217.  .444  .798  .5138  .0374  4.04  5.06  7.10    2477.    8078.    4457.
    .252      19.     608.   47265.  17000.    280.    215.  .450  .797  .5205  .0378  4.10  5.08  7.18    2511.    7878.    4343.
    .259      21.     636.   47237.  18000.    283.    214.  .456  .796  .5276  .0382  4.17  4.86  7.03    2427.    7681.    4232.
    .266      23.     665.   47208.  19000.    285.    212.  .462  .795  .5348  .0385  4.23  4.65  6.88    2344.    7487.    4123.
    .273      25.     695.   47178.  20000.    288.    211.  .469  .794  .5421  .0389  4.29  4.44  6.73    2261.    7296.    4016.
    .280      27.     724.   47149.  21000.    291.    209.  .475  .793  .5495  .0394  4.36  4.23  6.59    2177.    7109.    3912.
    .288      29.     754.   47119.  22000.    294.    208.  .482  .792  .5569  .0398  4.42  4.03  6.45    2094.    6924.    3809.
    .296      31.     785.   47088.  23000.    298.    207.  .490  .792  .5625  .0401  4.46  3.77  6.23    1984.    6739.    3710.
    .304      34.     816.   47057.  24000.    304.    207.  .502  .792  .5590  .0399  4.39  3.32  5.71    1782.    6527.    3623.
    .314      37.     850.   47023.  25000.    306.    206.  .508  .791  .5683  .0404  4.47  3.41  5.88    1845.    6338.    3533.
    .323      39.     882.   46991.  26000.    309.    204.  .515  .790  .5780  .0410  4.56  3.20  5.76    1751.    6153.    3443.
    .332      42.     914.   46959.  27000.    312.    202.  .523  .789  .5860  .0415  4.62  2.96  5.58    1636.    5968.    3356.
    .343      45.     949.   46924.  28000.    316.    201.  .532  .788  .5920  .0418  4.65  2.72  5.38    1522.    5786.    3271.
    .353      49.     984.   46889.  29000.    320.    200.  .540  .787  .5991  .0423  4.70  2.55  5.25    1441.    5608.    3187.
    .365      53.    1021.   46852.  30000.    325.    199.  .551  .787  .6029  .0425  4.71  2.29  5.00    1317.    5431.    3106.
    .378      57.    1061.   46812.  31000.    328.    198.  .559  .786  .6120  .0431  4.77  2.15  4.92    1249.    5226.    3000.
    .391      61.    1101.   46772.  32000.    336.    199.  .575  .786  .6061  .0427  4.66  1.71  4.37    1017.    5010.    2905.
    .407      67.    1148.   46725.  33000.    354.    205.  .607  .791  .5680  .0404  4.15  1.15  3.30     720.    4776.    2829.
    .431      75.    1214.   46659.  34000.    362.    206.  .625  .792  .5615  .0400  4.02  1.23  3.25     790.    4607.    2740.
    .452      83.    1272.   46601.  35000.    370.    207.  .641  .792  .5578  .0398  3.92  1.08  3.00     709.    4438.    2655.
 0   END OF CLIMB TO   35000. FT
  TIME=   .452 HRS   FUEL USED=     1272. LBS   WEIGHT=   46601. LBS   RANGE=     83. NM

 0ALTITUDE=     35000. FT   TAS=      458.77 KTS   MACH NO=       .7949


    ACCELERATE TO MACH NO. = .800

 0                   FUEL                                                    FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    THRUST   FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

    .452    82.51  1271.6  46601.   35000.    370.    207.  .641  .792    4737.    3020.
    .503   104.91  1436.3  46437.   35000.    461.    258.  .800  .816    4846.    3167.

   END OF ACCELERATION SEGMENT
   TIME=  .503 HRS   FUEL USED=  1436.3 LBS   WEIGHT=  46437. LBS   RANGE=  105. NM
 ***SPECIFIED MACH NUMBER CONDITION CAN NOT BE PERFORMED AT NORMAL RATED POWER CONDITION***


    ACCELERATE TO MACH NO. = .795

 0                   FUEL                                                    FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    THRUST   FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

    .452    82.51  1271.6  46601.   35000.    370.    207.  .641  .792    4737.    3020.
    .501   104.12  1430.9  46442.   35000.    458.    256.  .795  .815    4842.    3163.

   END OF ACCELERATION SEGMENT
   TIME=  .501 HRS   FUEL USED=  1430.9 LBS   WEIGHT=  46442. LBS   RANGE=  104. NM
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Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

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      ACCELERATE TO MACH NO. = .739

 0                      FUEL                                                               FUEL
    TIME    RANGE      USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    THRUST     FLOW
   (HRS)   (NM)       (LBS)    (LBS)      (FT)   (KTS)  (KTS)     NO.   DIV      (LBS)   (LB/HR)

    .452    82.51   1271.6   46601.   35000.    370.    207.   .641  .792    4737.     3020.
    .480    94.53   1363.6   46509.   35000.    426.    238.   .739  .808    4792.     3107.

   END OF ACCELERATION SEGMENT
   TIME=  .480 HRS   FUEL USED=  1363.6 LBS   WEIGHT=  46509. LBS   RANGE=   95. NM


 0                                           DESIGN CASE
                                             CRUISE PERFORMANCE SUMMARY
                                                        FOR
                                             ****** MAXIMUM FUEL ******
                                             FUEL AVAILABLE=  10835.
 0                                  AT                      AT                      AT
                              SPECIFIED SPEED         NORMAL POWER           BEST SPEC. RANGE
                              START    END           START    END            START    END
                              CRUISE   CRUISE        CRUISE   CRUISE         CRUISE   CRUISE
                              -------  -------       -------  -------        -------  -------
    TIME           HRS.        .000     .000          .501    3.272           .480    3.951
    RANGE          N.MI         0.       0.           104.    1375.            95.    1575.
    FUEL USED      LBS.         0.       0.          1431.    8193.          1364.    9094.
    WEIGHT         LBS.         0.       0.         46442.   39680.         46509.   38779.
    ALTITUDE       FT.          0.       0.         35000.   35000.         35000.   35000.
    TAS            KTS.         .0       .0          458.8    458.8          426.8    426.8
    EAS            KTS.         .0       .0          255.7    255.7          237.8    237.8
    MACH NO.                  .0000    .0000         .7949    .7949          .7395    .7395
    DIV. MACH                 .0000    .0000         .8159    .8237          .8088    .8174
    ANGLE ATTACK DEG.          .000     .000         1.535     .985          2.252    1.612
    FUSE. ANGLE  DEG.          .000     .000         -.465   -1.015           .252    -.388
    CL                        .0000    .0000         .3645    .3006          .4219    .3517
    L/D                        .000     .000        11.980   10.622         12.754   11.597
    FUEL FLOW      LB/HR        .0       .0         2518.4   2368.7         2321.5   2140.1
    BREG. FACTOR N.MI.          0.       0.          8465.    7690.          8555.    7738.
    SPEC. RANGE    NM/LB     .00000   .00000        .18216   .19368         .18383   .19941


 0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
            (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
 0                      FUEL                                                                                  FUS.                            FUEL
    TIME    RANGE      USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    CL       CD    ALPHA GAMMA ANGLE     R/S    THRUST      FLOW
   (HRS)   (NM)       (LBS)    (LBS)      (FT)   (KTS)  (KTS)     NO.   DIV                   (DEG) (DEG) (DEG)    (FPM)    (LBS)    (LB/HR)

   3.284   1381.    8215.   39658.   35000.    459.    256.   .795  .823  .3084  .0289  1.05 -1.65 -2.60    1339.    2574.     1764.  R
   3.297   1387.    8239.   39634.   34000.    461.    262.   .795  .825  .2941  .0285   .93 -1.60 -2.67    1306.    2727.     1871.  R
   3.310   1393.    8265.   39608.   33000.    463.    268.   .795  .826  .2805  .0281   .81 -1.55 -2.74    1271.    2888.     1984.  R
   3.324   1399.    8293.   39580.   32000.    465.    275.   .795  .828  .2677  .0277   .70 -1.51 -2.81    1241.    3054.     2100.  R
   3.338   1406.    8324.   39549.   31000.    467.    281.   .795  .829  .2555  .0274   .60 -1.46 -2.87    1209.    3228.     2223.  R
   3.352   1412.    8357.   39516.   30000.    469.    288.   .795  .831  .2440  .0271   .50 -1.42 -2.92    1180.    3406.     2350.  R
   3.366   1419.    8393.   39480.   29000.    471.    294.   .795  .832  .2331  .0268   .40 -1.38 -2.98    1153.    3590.     2482.  R
   3.381   1426.    8432.   39441.   28000.    473.    301.   .795  .833  .2227  .0266   .32 -1.35 -3.03    1127.    3781.     2619.  R
   3.396   1433.    8474.   39399.   27000.    475.    308.   .795  .834  .2129  .0264   .23 -1.31 -3.08    1100.    3981.     2763.  R
   3.412   1441.    8519.   39354.   26000.    477.    314.   .795  .836  .2035  .0262   .15 -1.28 -3.13    1077.    4200.     2918.  R
   3.427   1448.    8568.   39305.   25000.    479.    321.   .795  .837  .1946  .0260   .07 -1.24 -3.17    1053.    4412.     3073.  R
   3.443   1456.    8620.   39253.   24000.    481.    328.   .795  .838  .1862  .0258   .00 -1.21 -3.21    1032.    4631.     3234.  R
   3.460   1464.    8676.   39197.   23000.    483.    335.   .795  .839  .1782  .0257  -.07 -1.18 -3.25    1011.    4858.     3401.  R
   3.477   1472.    8734.   39139.   22000.    477.    337.   .782  .839  .1762  .0256  -.06 -1.17 -3.24     992.    4903.     3451.  R
   3.494   1480.    8794.   39079.   21000.    472.    339.   .770  .839  .1739  .0256  -.06 -1.16 -3.23     972.    4967.     3513.  R
   3.499   1482.    8798.   39075.   20000.    391.    286.   .636  .831  .2429  .0271   .81 -4.81 -6.00    3329.    1059.      762.  A
   3.504   1484.    8802.   39071.   19000.    387.    288.   .627  .831  .2402  .0270   .80 -4.80 -6.00    3285.    1104.      798.  A
   3.509   1486.    8806.   39067.   18000.    383.    289.   .617  .831  .2375  .0269   .79 -4.79 -6.00    3240.    1150.      835.  A
   3.514   1488.    8811.   39062.   17000.    378.    291.   .608  .832  .2349  .0269   .78 -4.78 -6.00    3196.    1199.      873.  A
   3.520   1490.    8816.   39057.   16000.    374.    293.   .599  .832  .2322  .0268   .76 -4.76 -6.00    3153.    1248.      913.  A
   3.525   1492.    8821.   39052.   15000.    370.    294.   .591  .832  .2295  .0267   .75 -4.75 -6.00    3110.    1300.      954.  A
   3.530   1494.    8826.   39047.   14000.    367.    296.   .583  .833  .2269  .0267   .73 -4.73 -6.00    3067.    1353.      997.  A
   3.536   1496.    8832.   39041.   13000.    363.    298.   .574  .833  .2242  .0266   .72 -4.72 -6.00    3025.    1408.     1041.  A
   3.542   1498.    8838.   39035.   12000.    359.    299.   .567  .833  .2215  .0266   .70 -4.70 -6.00    2984.    1465.     1088.  A
   3.547   1500.    8844.   39029.   11000.    356.    301.   .559  .834  .2189  .0265   .68 -4.68 -6.00    2944.    1523.     1135.  A
   3.557   1503.    8853.   39021.   10000.    291.    250.   .455  .822  .3180  .0292  1.88 -3.48 -3.60    1789.    1203.      866.  S
   3.566   1505.    8861.   39012.    9000.    286.    250.   .446  .822  .3180  .0292  1.89 -3.42 -3.53    1731.    1244.      898.  S
   3.576   1508.    8870.   39003.    8000.    282.    250.   .438  .822  .3179  .0292  1.90 -3.36 -3.46    1674.    1286.      931.  S
   3.586   1511.    8880.   38993.    7000.    277.    250.   .430  .822  .3179  .0292  1.91 -3.29 -3.39    1617.    1330.      965.  S
   3.597   1514.    8891.   38982.    6000.    273.    250.   .422  .822  .3178  .0292  1.92 -3.23 -3.31    1561.    1375.     1000.  S
   3.608   1517.    8903.   38971.    5000.    269.    250.   .414  .822  .3177  .0292  1.93 -3.16 -3.23    1505.    1421.     1037.  S
   3.620   1520.    8915.   38958.    4000.    265.    250.   .406  .822  .3176  .0292  1.94 -3.09 -3.16    1450.    1469.     1075.  S
   3.632   1523.    8928.   38945.    3000.    261.    250.   .399  .822  .3175  .0292  1.94 -3.02 -3.08    1396.    1518.     1115.  S
   3.644   1526.    8943.   38930.    2000.    257.    250.   .391  .822  .3174  .0292  1.95 -2.95 -3.00    1341.    1569.     1155.  S
   3.650   1528.    8950.   38923.    1500.    255.    250.   .388  .822  .3173  .0292  1.95 -2.91 -2.95    1314.    1595.     1176.  S
 0   END OF DSCNT TO     1500. FT
  TIME=  3.650 HRS   FUEL USED=      8950. LBS   WEIGHT=    38923. LBS   RANGE=    1528. NM

 0       RESERVE FUEL(LBS)          0.               1889.               1741.
           (   45.0 MIN.)

    ****************************************************************************************************

     ACCELERATE TO MACH NO. = .800

 0                      FUEL                                                               FUEL
    TIME    RANGE      USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    THRUST     FLOW
   (HRS)   (NM)       (LBS)    (LBS)      (FT)   (KTS)  (KTS)     NO.   DIV      (LBS)   (LB/HR)

    .452    82.51   1271.6   46601.   35000.    370.    207.   .641  .792    4737.     3020.
    .503   104.91   1436.3   46437.   35000.    461.    258.   .800  .816    4846.     3167.

   END OF ACCELERATION SEGMENT
   TIME=  .503 HRS   FUEL USED=  1436.3 LBS   WEIGHT=  46437. LBS   RANGE=  105. NM
 ***SPECIFIED MACH NUMBER CONDITION CAN NOT BE PERFORMED AT NORMAL RATED POWER CONDITION***
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

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     ACCELERATE TO MACH NO. = .795

 0                    FUEL                                                                 FUEL
   TIME     RANGE     USED     WEIGHT     ALT.      TAS     EAS      MACH   MACH    THRUST     FLOW
   (HRS)    (NM)      (LBS)    (LBS)      (FT)    (KTS)   (KTS)      NO.    DIV     (LBS)    (LB/HR)

    .452     82.51   1271.6   46601.   35000.     370.     207.   .641   .792    4737.     3020.
    .501    104.12   1430.9   46442.   35000.     458.     256.   .795   .815    4842.     3163.

   END OF ACCELERATION SEGMENT
   TIME=  .501 HRS   FUEL USED=  1430.9 LBS   WEIGHT=  46442. LBS   RANGE=  104. NM

     ACCELERATE TO MACH NO. = .739

 0                    FUEL                                                                 FUEL
   TIME     RANGE     USED     WEIGHT     ALT.      TAS     EAS      MACH   MACH    THRUST     FLOW
   (HRS)    (NM)      (LBS)    (LBS)      (FT)    (KTS)   (KTS)      NO.    DIV     (LBS)    (LB/HR)

    .452     82.51   1271.6   46601.   35000.     370.     207.   .641   .792    4737.     3020.
    .480     94.53   1363.6   46509.   35000.     426.     238.   .739   .808    4792.     3107.

   END OF ACCELERATION SEGMENT
   TIME=  .480 HRS   FUEL USED=  1363.6 LBS   WEIGHT=  46509. LBS   RANGE=   95. NM


 0                                         DESIGN CASE
                                           CRUISE PERFORMANCE SUMMARY
                                                      FOR
                                           ***** DESIGN PAYLOAD *****
                                           **** MAXIMUM PAYLOAD *****
                                           FUEL AVAILABLE=   9389.
 0                              AT                    AT                    AT
                          SPECIFIED SPEED       NORMAL POWER        BEST SPEC. RANGE
                          START     END         START     END         START     END
                          CRUISE   CRUISE       CRUISE   CRUISE       CRUISE   CRUISE
                          -------  -------      -------  -------      -------  -------
   TIME         HRS.        .000      .000         .501    2.664         .480    3.280
   RANGE        N.MI          0.        0.         104.    1097.          95.    1289.
   FUEL USED    LBS.          0.        0.        1431.    6746.        1364.    7648.
   WEIGHT       LBS.          0.        0.       46442.   41127.       46509.   40225.
   ALTITUDE     FT.           0.        0.       35000.   35000.       35000.   35000.
   TAS          KTS.          .0        .0        458.8    458.8        426.8    426.8
   EAS          KTS.          .0        .0        255.7    255.7        237.8    237.8
   MACH NO.                .0000     .0000        .7949    .7949        .7395    .7395
   DIV. MACH               .0000     .0000        .8159    .8223        .8088    .8158
   ANGLE ATTACK DEG.        .000      .000        1.535    1.082        2.252    1.731
   FUSE. ANGLE  DEG.        .000      .000        -.465    -.918         .252    -.269
   CL                      .0000     .0000        .3645    .3119        .4219    .3649
   L/D                      .000      .000       11.980   10.888       12.754   11.846
   FUEL FLOW    LB/HR         .0        .0       2518.4   2400.5       2321.5   2173.0
   BREG. FACTOR N.MI.         0.        0.        8465.    7865.        8555.    7905.
   SPEC. RANGE  NM/LB     .00000    .00000       .18216   .19111       .18383   .19640


 0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
              (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
 0                    FUEL                                                                                     FUS.                         FUEL
   TIME     RANGE     USED     WEIGHT     ALT.      TAS     EAS      MACH   MACH     CL       CD     ALPHA GAMMA ANGLE      R/S     THRUST     FLOW
   (HRS)    (NM)      (LBS)    (LBS)      (FT)    (KTS)   (KTS)      NO.    DIV                      (DEG) (DEG) (DEG)    (FPM)     (LBS)    (LB/HR)

   2.677    1102.     6768.   41105.   35000.     459.     256.   .795   .821   .3196   .0292   1.15 -1.65 -2.50    1339.     2578.     1766.   R
   2.690    1108.     6792.   41081.   34000.     461.     262.   .795   .823   .3048   .0288   1.02 -1.60 -2.58    1306.     2730.     1872.   R
   2.703    1114.     6818.   41055.   33000.     463.     268.   .795   .825   .2907   .0284    .90 -1.55 -2.65    1271.     2891.     1985.   R
   2.716    1120.     6846.   41027.   32000.     465.     275.   .795   .827   .2774   .0280    .79 -1.51 -2.72    1241.     3056.     2101.   R
   2.730    1127.     6877.   40996.   31000.     467.     281.   .795   .828   .2648   .0276    .68 -1.46 -2.79    1209.     3229.     2224.   R
   2.744    1134.     6910.   40963.   30000.     469.     288.   .795   .830   .2529   .0273    .58 -1.42 -2.85    1180.     3407.     2350.   R
   2.758    1140.     6946.   40927.   29000.     471.     294.   .795   .831   .2416   .0270    .48 -1.38 -2.91    1153.     3590.     2482.   R
   2.773    1147.     6985.   40888.   28000.     473.     301.   .795   .832   .2309   .0268    .39 -1.35 -2.96    1127.     3781.     2619.   R
   2.788    1155.     7027.   40847.   27000.     475.     308.   .795   .834   .2207   .0265    .30 -1.31 -3.01    1100.     3980.     2762.   R
   2.804    1162.     7072.   40801.   26000.     477.     314.   .795   .835   .2110   .0263    .21 -1.28 -3.06    1077.     4198.     2918.   R
   2.820    1170.     7120.   40753.   25000.     479.     321.   .795   .836   .2018   .0261    .14 -1.24 -3.11    1053.     4409.     3072.   R
   2.836    1177.     7173.   40701.   24000.     481.     328.   .795   .837   .1930   .0260    .06 -1.21 -3.15    1032.     4627.     3232.   R
   2.852    1185.     7229.   40645.   23000.     483.     335.   .795   .838   .1847   .0258   -.01 -1.18 -3.19    1011.     4854.     3399.   R
   2.869    1193.     7287.   40586.   22000.     477.     337.   .782   .838   .1825   .0258   -.01 -1.17 -3.18     992.     4902.     3451.   R
   2.886    1201.     7347.   40526.   21000.     472.     339.   .770   .838   .1802   .0257   -.01 -1.16 -3.17     972.     4966.     3513.   R
   2.891    1204.     7362.   40511.   20000.     489.     357.   .795   .841   .1618   .0254   -.21 -3.79 -6.00    3277.     3686.     3022.   A
   2.896    1206.     7366.   40507.   19000.     392.     292.   .635   .831   .2425   .0271    .81 -4.81 -6.00    3335.     1104.      798.   A
   2.901    1208.     7370.   40503.   18000.     388.     293.   .626   .831   .2398   .0270    .80 -4.80 -6.00    3290.     1150.      835.   A
   2.907    1210.     7375.   40498.   17000.     383.     295.   .616   .831   .2372   .0269    .79 -4.79 -6.00    3246.     1199.      873.   A
   2.912    1212.     7380.   40493.   16000.     379.     296.   .607   .832   .2345   .0269    .78 -4.78 -6.00    3202.     1248.      913.   A
   2.917    1214.     7385.   40488.   15000.     375.     298.   .599   .832   .2319   .0268    .76 -4.76 -6.00    3159.     1300.      954.   A
   2.922    1216.     7390.   40483.   14000.     371.     300.   .590   .832   .2293   .0267    .75 -4.75 -6.00    3116.     1353.      997.   A
   2.928    1218.     7396.   40477.   13000.     368.     301.   .582   .833   .2266   .0267    .73 -4.73 -6.00    3074.     1408.     1041.   A
   2.933    1220.     7402.   40471.   12000.     364.     303.   .574   .833   .2240   .0266    .71 -4.71 -6.00    3032.     1465.     1088.   A
   2.939    1222.     7408.   40465.   11000.     360.     305.   .566   .833   .2213   .0266    .70 -4.70 -6.00    2991.     1523.     1135.   A
   2.948    1224.     7416.   40457.   10000.     291.     250.   .455   .820   .3298   .0296   2.01 -3.42 -3.42    1759.     1203.      866.   S
   2.958    1227.     7425.   40448.    9000.     286.     250.   .446   .820   .3297   .0296   2.02 -3.36 -3.35    1703.     1244.      898.   S
   2.968    1230.     7434.   40439.    8000.     282.     250.   .438   .820   .3296   .0296   2.03 -3.31 -3.28    1647.     1286.      931.   S
   2.979    1233.     7444.   40429.    7000.     277.     250.   .430   .820   .3296   .0296   2.04 -3.24 -3.21    1592.     1330.      965.   S
   2.990    1236.     7455.   40418.    6000.     273.     250.   .422   .820   .3295   .0296   2.05 -3.18 -3.13    1538.     1375.     1000.   S
   3.001    1239.     7467.   40406.    5000.     269.     250.   .414   .820   .3294   .0296   2.06 -3.12 -3.06    1483.     1421.     1037.   S
   3.012    1242.     7479.   40394.    4000.     265.     250.   .406   .820   .3293   .0296   2.07 -3.05 -2.98    1430.     1469.     1075.   S
   3.025    1245.     7493.   40380.    3000.     261.     250.   .399   .820   .3292   .0296   2.07 -2.98 -2.91    1377.     1518.     1115.   S
   3.037    1248.     7508.   40366.    2000.     257.     250.   .391   .820   .3291   .0296   2.08 -2.91 -2.83    1324.     1569.     1155.   S
   3.044    1250.     7515.   40358.    1500.     255.     250.   .388   .820   .3290   .0296   2.08 -2.87 -2.79    1298.     1595.     1176.   S
 0   END OF DSCNT TO     1500. FT
  TIME=  3.044 HRS   FUEL USED=    7515. LBS   WEIGHT=   40358. LBS   RANGE=   1250. NM

 0      RESERVE FUEL(LBS)        0.                  1889.                1741.
          (   45.0 MIN.)

    ****************************************************************************
 0      RANGE = 1250.    BLOCK TIME= 3.044    USED FOR DESIGN RANGE AND COST

    ****************************************************************************
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
0  *************************************************************************************************
0              TEMP.=  537. DEG:STD.+36.
      LANDING ELEVATION= 5000. FT.
      LANDING WING LOADING=  78.02 PSF.
      LANDING WEIGHT =    45001. LBS.

      LANDING DISTANCE FROM 50. FT.=   2410. FT.

      F.A.R. FACTORED FIELD LENGTH =   4017. FT.
0                     APPROACH              TRANSITION              DELAY                 ROLL
0                  DIST=        615.   DIST=        179.   DIST=         182.   DIST=       1434.
                   R/S=        1000.   XLFMX=      1.200   TDELAY=       1.00   MUB=        .4000
                   VAPEAS=    109.13   SINKTD=     3.000   TIDLE=        645.   TR/TIDLE=   .0000
                   VAPTAS=    121.77   VSTEAS=     83.95   VTDTAS=     107.72   ABAR(G)=    .3590
                   THETA=       4.65   CLMX=      3.2639
                   THRUST=     2700.   HFLAR=       20.9
*****************************************************************************************************
0                RANGE OR ENDURANCE ITERATION SUMMARY

                             GROSS      RANGE(NMI) OR
                ITERATION   WEIGHT(LB)   ENDURANCE(HR)

                    0        44050.00       816.875
                    1        55062.50      1980.942
                    2        48147.52      1277.911
                    3        47872.99      1250.136
                   REQUIRED RG. OR END. = 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.476   LIFT= 46436.8   L/D=  11.906   ALTITUDE= 35000.0   MACH=   .8000

0  GROSS WEIGHT =    47873.        PASSENGERS =  50. PLUS CREW

0  FUSELAGE       LENGTH              (ELF)          79.25   FT
                  WIDTH               (SWF)           9.25   FT
                  WETTED AREA         (SF)           1910.   SQFT
                  DELTA P             (DELP)          8.20   PSI

0  WING           ASPECT RATIO        (AR)            8.30
                  AREA                (SW)           576.8   SQFT
                  SPAN                (B)             69.2   FT
                  GEOM. MEAN CHORD    (CBARW)         9.57   FT
                  QUARTER CHORD SWEEP(DLMC4)          14.5   DEG
                  TAPER RATIO         (SLM)           .200
                  ROOT THICKNESS      (TCR)           .130
                  TIP THICKNESS       (TCT)           .100
                  WING LOADING        (WGS)           83.0   PSF
                  WING FUEL VOLUME    (VFW)         1620.4   GAL

0  HOR. TAIL      ASPECT RATIO        (ARHT)          4.00
                  AREA                (SHT)          270.3   SQFT
                  SPAN                (BHT)          32.88   FT
                  MEAN CHORD          (CBARHT)        8.25   FT
                  THICKNESS/CHORD     (TCHT)          .100
                  MOMENT ARM          (ELTH)          44.9   FT
                  VOLUME COEFF.       (VBARH)        2.196

0  VERT. TAIL     ASPECT RATIO        (ARVT)          1.00
                  AREA                (SVT)          121.9   SQFT
                  SPAN                (BVT)          11.04   FT
                  MEAN CHORD          (CBARVT)       11.16   FT
                  THICKNESS/CHORD     (TCVT)          .120
                  MOMENT ARM          (ELTV)          33.5   FT
                  VOLUME COEFF.       (VBARV)         .102

0  ENG.NACELLES   LENGTH              (ELN)          11.96   FT
                  MEAN DIAMETER       (DBARN)         3.99   FT
                  NUMBER ENGINES      (ENP)            2.0
                  WETTED AREA         (SN)          299.40   SQFT

                  LOCATION                         ON FUSELAGE

0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
   ULT. LF =  5.70   MAN. LF =  2.50   GUST LF =  3.80

0  PROPULSION GROUP
      PRIMARY ENGINES           (WEP)       3174.
      PRIMARY ENGINE INSTL.     (WPEI)       429.
      FUEL SYSTEM               (WFSS)       188.
      TOTAL PROP.GROUP WT.      (WP)        3791.
0  STRUCTURES GROUP
      WING                      (WW)        5378.
      HOR. TAIL                 (WHT)        950.
      VERT. TAIL                (WVT)        544.
      FUSELAGE                  (WB)        6038.   (INCL.     .0 LBS A.T.W.)
      LANDING GEAR              (WLG)       1819.
      PRIMARY ENG. SECTION      (WPES)      1051.
      GROUP WEIGHT INC.         (DELWST)       0.
      TOTAL STRUC.GROUP WT.     (WST)      15779.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS          (WCC)         98.
      FIXED WING CONTROLS       (WCFW)       983.
      SAS                       (WSAS)         0.
      GROUP WEIGHT INC.         (DELWFC)       0.
      TOTAL CONTROL WT.         (WFC)       1081.
0  WT. OF FIXED EQUIPMENT       (WFE)       6734.

   WEIGHT EMPTY                 (WE)       27385.

   FIXED USEFUL LOAD            (WFUL)      1099. (INC. CREW )

   OPERATING WEIGHT EMPTY       (OWE)      28484.

0  PAYLOAD                      (WPL)      10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

   FUEL                         (WFA)       9389. (WFW= 9389.) (WFTP=    0.)

   GROSS WEIGHT                 (WG)       47873.
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
0         FIXED EQUIP GROUP                      FIXED USEFUL LOAD
0     WAPU               372.27         WCREW ( 2.)          340.00
      WINSTR             261.68         WSTU  ( 1.)          130.00
      WHYD               399.15         WCBAG                110.00
      WELEC              970.00         WUF                  144.10
      WAV                500.00         WOIL                 131.14
      WFUR              3410.00         WSRV                 116.00
      WAC                477.91         WH2O                  53.00
      WAI                323.00         WEMER                 40.00
      WAUXG               20.00         WCATER                35.00

      WFE               6734.01         WFUL                1099.24

 0  DESIGN MACH =  .800          DESIGN ALTITUDE =  35000.          DESIGN Q (PSF) =224.03
 0  DESIGN RE.NUM. PER FT.    = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274
 0  AERODYNAMIC DATA

 0                          FLATPLATE              WETTED
    DRAG BREAKDOWN          AREA(SQFT)     CDO     AREA(SQFT)
 0        WING                3.7482     .00650      910.28
          FUSELAGE            5.4592     .00946     1910.38
          VERT.TAIL            .7493     .00130      243.81
          HOR. TAIL           1.6685     .00289      540.59
          ENGINE NAC.         1.2061     .00209      299.40
          TIP TANKS            .0000     .00000         .00
          INCREMENTAL          .8652     .00150         .00
 0            TOTAL          13.6964     .02375     3904.47

             MEAN SKIN FRICTION COEF.=  .003508


 0  AERODYNAMIC COEFF.
        A1                                           .8006
        A2                                          -.1227
        A3                                           .0386
        A4=.75X(T/C)                                 .0909
        A5=CDO--                                     .0152
        A6                                          2.3717
        A7=1/(PI.SEE.AR)                             .0481
        3-D LIFT SLOPE AT CRUISE MACH    (CLALPH)   6.7033    PER RADIAN
        OSWALD FACTOR                    (SEE)       .7980
 0  CRUISE CD =  .0237 +   .0481 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
 0  RETRACTABLE LANDING GEAR CD INC.= .02700


 0 CRUISE DRAG
 0CL=    .2000
             MACH      CD     L/D   CLALPH   ALPHA
           .50000  .02570  7.7818  5.3413    .5454
           .55000  .02570  7.7818  5.4739    .4934
           .60000  .02570  7.7818  5.6323    .4345
           .65000  .02570  7.7818  5.8228    .3680
           .70000  .02570  7.7818  6.0544    .2927
           .75000  .02570  7.7818  6.3408    .2072
           .80000  .02570  7.7818  6.7033    .1095
           .85000  .02577  7.7604  7.1781   -.0036
 0CL=    .3000
             MACH      CD     L/D   CLALPH   ALPHA
           .50000  .02824 10.6242  5.3413   1.6181
           .55000  .02824 10.6242  5.4739   1.5401
           .60000  .02824 10.6242  5.6323   1.4518
           .65000  .02824 10.6242  5.8228   1.3520
           .70000  .02824 10.6242  6.0544   1.2390
           .75000  .02824 10.6242  6.3408   1.1108
           .80000  .02824 10.6242  6.7033    .9642
           .85000  .02871 10.4502  7.1781    .7946
 0CL=    .4000
             MACH      CD     L/D   CLALPH   ALPHA
           .50000  .03173 12.6045  5.3413   2.6907
           .55000  .03173 12.6045  5.4739   2.5868
           .60000  .03173 12.6045  5.6323   2.4691
           .65000  .03173 12.6045  5.8228   2.3360
           .70000  .03173 12.6045  6.0544   2.1854
           .75000  .03173 12.6045  6.3408   2.0144
           .80000  .03173 12.6045  6.7033   1.8189
           .85000  .03322 12.0399  7.1781   1.5928
 0CL=    .5000
             MACH      CD     L/D   CLALPH   ALPHA
           .50000  .03636 13.7517  5.3413   3.7634
           .55000  .03636 13.7517  5.4739   3.6335
           .60000  .03636 13.7517  5.6323   3.4863
           .65000  .03636 13.7517  5.8228   3.3200
           .70000  .03636 13.7517  6.0544   3.1317
           .75000  .03636 13.7517  6.3408   2.9180
           .80000  .03636 13.7517  6.7033   2.6737
           .85000  .03977 12.5714  7.1781   2.3910
 0CL=    .6000
             MACH      CD     L/D   CLALPH   ALPHA
           .50000  .04194 14.3045  5.3413   4.8361
           .55000  .04194 14.3045  5.4739   4.6802
           .60000  .04194 14.3045  5.6323   4.5036
           .65000  .04194 14.3045  5.8228   4.3039
           .70000  .04194 14.3045  6.0544   4.0781
           .75000  .04194 14.3045  6.3408   3.8216
           .80000  .04200 14.2849  6.7033   3.5284
           .85000  .04848 12.3759  7.1781   3.1892
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                        FLAPS UP                                 TAKEOFF                            LANDING
    ALPHA        CL        CD        L/D        CL        CD        L/D        CL        CD        L/D
  -2.00000   -.03398    .02390  -1.42164   1.12894    .09199  12.27200   1.93656    .25363   7.63548
    .00000    .13592    .02465   5.51486   1.29884    .10647  12.19921   2.10646    .27263   7.72653
   2.00000    .30582    .02841  10.76268   1.46874    .12512  11.73825   2.27636    .29737   7.65506
   4.00000    .47571    .03515  13.53470   1.63863    .14913  10.98798   2.44626    .32602   7.50338
   6.00000    .64561    .04496  14.35835   1.80853    .17597  10.27770   2.61615    .35792   7.30934
   8.00000    .81551    .05808  14.04126   1.97843    .20563   9.62109   2.78605    .39306   7.08805
  10.00000    .98541    .07505  13.13038   2.14833    .23813   9.02151   2.95595    .43145   6.85116
  12.00000   1.15530    .09764  11.83206   2.31822    .27346   8.47725   3.12585    .47309   6.60735
  13.62379   1.29324    .11824  10.93707   2.45616    .30423   8.07335   3.26378    .50928   6.40868
  13.62379   1.29324    .11824  10.93707   2.45616    .30423   8.07335   3.26378    .50928   6.40868

0                       DFLAP=       .00          DFLAP=     15.00          DFLAP=     40.00
0                       CLMAX=   1.29324          CLMAX=   2.46601          CLMAX=   3.26389

0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
     FLAP DEFL.     CLMAX     CL         CD        L/D
       10.000      2.10997
                               .78264    .06760  11.57796
                               .95254    .07898  12.06072
                              1.12244    .09396  11.94634
                              1.29233    .11339  11.39711
                              1.46223    .13765  10.62254
                              1.63213    .16472   9.90860
                              1.80203    .19459   9.26083
                              1.97192    .22726   8.67711
                              2.10997    .25586   8.24644
                              2.10997    .25586   8.24644
       20.000      2.71356
                              1.38623    .11999  11.55260
                              1.55613    .13640  11.40830
                              1.72603    .15788  10.93243
                              1.89592    .18335  10.34037
                              2.06582    .21168   9.75906
                              2.23572    .24287   9.20528
                              2.40562    .27692   8.68689
                              2.57551    .31384   8.20654
                              2.71356    .34593   7.84415
                              2.71356    .34593   7.84415
       30.000      3.06861
                              1.74128    .17737   9.81722
                              1.91118    .19541   9.78051
                              2.08108    .21931   9.48918
                              2.25098    .24640   9.13541
                              2.42087    .27646   8.75671
                              2.59077    .30948   8.37125
                              2.76067    .34548   7.99088
                              2.93057    .38444   7.62300
                              3.06861    .41828   7.33629
                              3.06861    .41828   7.33629




0ALTITUDE=      35000. FT    TAS=      462.89 KTS    MACH NO=       .8021


0                                RDT&E AND AIRFRAME PRODUCTION COSTS
                                                (1993. DOLLARS)
0                            TOTAL RDT&E COSTS             1083.3055 MILLION
0                                         AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                                 500. AIRCRAFT
                                                  WEIGHT(LB)    COST($)     COST($/LB)
           STRUCTURE(  4350934.$)
                                   WING                  5378.    1285076.      238.97
                                   EMPENNAGE             1493.     506664.      339.29
                                   FUSELAGE              6038.    1672142.      276.95
                                   LANDING GEAR          1819.     321079.      176.50
                                   NACELLES              1051.     565972.      538.32
           PROPULSION INSTAL(      182642.$)
                                   ENGINE INSTALLAT.      429.     156026.      364.08
                                   FUEL SYSTEM            188.      26616.      141.74
           SYSTEMS(  2721797.$)
                                   FLIGHT CONTROLS       1081.     507345.      469.41
                                   HYDRAULIC              399.      49720.      124.57
                                   ELECTRICAL             970.     464214.      478.57
                                   AIR CONDITIONING       478.     256070.      535.82
                                   ANTI-ICING             323.     170111.      526.66
                                   AUX. POWER UNIT        372.     207143.      556.42
                                   FURNISHINGS           3410.     796443.      233.56
                                   INSTRUMENTS            262.     217047.      829.44
                                   AVIONICS INSTALL.      250.      49032.      196.13
                                   AUX. ITEMS              20.       4671.      233.56
          INTEGRATION(  1813843.$)
0                                    AIRFRAME TOTALS    23960.    9069216.      378.51
0                                    ENGINES                      2957537.
                                     PROPELLER                          0.
                                     AVIONICS                     4000000.
                                     A/C COST(NO RD)             16026753.
                                     R&D PER A/C                  2166611.
                                     TOTAL A/C COST              18193364.

0                  ENGINES      NUMBER =     2.  TYPE=     7

0 EMPTY WEIGHT= 27385.     AIRFRAME WEIGHT= 24210.     WEIGHT OF 1 ENGINE=  1587.     CRUISE SPEED= 463. KTS
0 THRUST/ENGINE=   9920.
0 TOTAL AIRCRAFT COST= 18193364.     AIRFRAME COST= 15235827.     COST OF 1 ENGINE=  1478769.     COST OF 1 PROP.=         0.
```

Fig. D1 - Conventional Baseline Configuration GASP output file (continued)

```
0                               --- COST DATA ---
                             GASP SHORTHAUL METHOD
0           DESIGN MISSION
0               OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0  ******************************************************************************************************
0                   RANGE=    1250. N.M.    BLOCK FUEL=    7515. LBS    BLOCK TIME=  3.0436 HRS.
0   UTILIZATION                          3200.
 FLYING OPERATIONS
    FLIGHT CREW                        380.452
    FUEL,OIL,AND TAXES( .850$/G)       998.247
    INSURANCE                           86.521
 DIRECT MAINTENANCE
    AIRFRAME                           181.888
    ENGINE                             292.913
 MAINTENANCE BURD.                     385.784
 DEPRECIATION                         1162.847

    TOTAL DOC ($/TRIP)                3488.654
              ($/B.HR.)               1146.219
              ($/N.MI.)                  2.791
```

Fig. D1 - Conventional Baseline Configuration GASP output file (concluded)

```
                          50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - THREE-SURF. CONFIG.
0                                    ENGINE CYCLE IS G. E.  CF-34
                                         INPUT DATA FOLLOW
                                        ********************

0                                       *****GEOMETRY*****
0 CONFIG  WG      =   44050.          KWRITE  =        2       FUSEL  SAB     =       4.            ELODN   =    1.000
          WGS     =   86.600          IGEAR   =        0              WS      =   20.000            ELODT   =    3.200
          PAX     =      50.          KCONFG  =        0              AS      =       1.            BMLOD   =   14.500
          EMCRU   =     .800          KTIPX   =        0              WAS     =   19.000   NACELLE  KNAC    =        1
          HNCRU   =   35000.          ENP     =       2.              PS      =     31.0            ELN     =     .000
                                      NTYE    =        7              ELPC    =   11.220            DBARN   =     .000
          Kanard  =        1          KPLOT   =        1              HCK     =    2.470            ELRW    =   10.000

0   WING  TCT     =     .100   HORIZ  VBARHX  =    .0000       VERT   VBARVX  =    .0000   Canard   TCcan   =     .100
          TCR     =     .130   TAIL   TCHT    =     .100       TAIL   TCVT    =     .120            ARcan   =    5.500
          AR      =    8.300          ARHT    =    4.000              ARVT    =    1.000            SLMcan  =     .500
          SLM     =     .200          SLMH    =     .550              SLMV    =     .700            DwpqCa  =   15.000
          DLMC4   =   14.500          DWPQCH  =   27.500              DWPQCV  =   50.500            EYEcan  =    2.000
          EYEW    =    2.000          COELTH  =     .000              BOELTV  =     .000            SWcOSW  =     .145
                                      SAH     =    1.000

0                                      ***AERODYNAMICS***
0         CKW     =   -1.000          CKHT    =   -1.000              GRFE    =     .000            DCDSE   = -1.0000
          CKF     =   -1.000          CKTP    =   -1.000              SCFAC   =     .750            CKWc    =   -1.000
          CKN     =   -1.000          DELCD   =   .00150              DLSWSW  =     .000            cmacw   =    -.060
          CKVT    =   -1.000          DELFE   =     .200              ALPHL0  =   -1.600            alzerc  =   -1.000

0         KWCD    =       12
          ACLS    =   -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR  =    2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                      *HIGH LIFT DEVICES*
0         RCLMAX  =    1.200   FLAPS  JFLTYP  =        7       LED    CLEOC   =     .000
          ALTFLP  =    5000.          DFLPTO  =   15.000              DELLED  =     .000
          FLAPN   =       1.          DFLPLD  =   40.000              DCLMLE  =     .930
          WCFLAP  =   -1.000          CFOC    =     .300              DELLEO  =   45.000
          BENGOB  =     .000          BTEOB   =     .750
                                      DCLMTE  =     .000
                                      DCDOTE  =     .000
                                      DELTEO  =     .000

0                                      ****PROPULSION****
0         JENGSZ  =        2          HPORT   =    5000.              RCCRU   =   50.000            RWCRTX  =     .970
          IPART   =        1          TDELTO  =      36.              XTORQ   =   99999.            HSCREQ  =       0.
          KODETO  =        5          KODECL  =        7              SM1D    =     .500            THIN    =       0.
          KODETR  =        5          KODEAC  =        5              HBTP    =     .437            PR      =    1.000

0                                      *****WEIGHTS*****
0         SKPEI   =    .1350          SKY     =    .1800              SKB     =  107.000            SKFS    =    .0200
          SKLG    =    .0380          SKZ     =    .2200              SKCC    =   20.000            SKWF    =    .4300
          SKMG    =    .8000          SKTL    =   1.0000              SKFW    =    .4300            SKFT    =    .9790
          SKPES   =    .3380          SKWW    =  133.400              SKSAS   =     .000            SKWTP   =   1.8900
          WPLX    =       .0          YMG     =    .2500              EGMRGN  =    .0000            LCWING  =        2
          WFEX    =       .0          RELP    =    .8500              CPMRGN  =    .2000
          WFUL    =       .0          RELR    =    .4500              STMRGN  =    .0000            LDCKMX  =    8.000
          UWPAX   =    200.0          CATD    =       3.              DELP    =    8.200            ATMXQC  =    3.160
          STRUT   =    .0000          VMLFSL  =    685.0              YP      =    .0000            DELWST  =       .0
          DELWFC  =       .0
0 ENGINE  WENG    =       .0          WNAC    =       .0              WPYLON  =       .0
          SWSLS   =     .160          UWNAC   =    2.287              FPYL    =     .700            XLQDE   =    3.000

0                                    *STABILITY AND CONTROL*
0         KSFixd  =        1          STATIC  =     .100              ZCG     =  999.000            CNPAC   =    .0020
          CMFLPL  =  999.000          CHALF   =  999.000              TP      =       .0            ARVTE   =   -1.000
          CMFLPT  =  999.000          CHDEL   =  999.000              CXA     =     .520            RV      =     .300
                                      RH      =     .350              DCMCLP  = 9999.000            TAUV    =  999.000
          CMPLD   =     .000          DEMAX   =    -25.0              HWING   =       0.            RVMCS   =     .990
                                      EYET    =       .0              dcmcpi  =     .030            DRMAX   =     25.0
                                      TAUH    =  999.000              rc      =     .350

0,                                     ***PERFORMANCE***
0   TAXI  DELTT   =     .167          XLFMAX  =    1.100              DVR     =    5.000            TDELTX  =   36.000
      TO  IFLY    =        1          DELTVR  =    3.500              UM      =     .020            HTMAX   =  500.000
          THEMAX  =   15.000          DV1     =    5.000              MUB     =     .400            NFAIL   =        0
          HOO     =    5000.          VRAT    =     1.10              WTMISN  =       0.

0  CLIMB  ICLM    =        1  CRUISE  CRMACH  =     .000              FRESF   =    1.000            FACW1   =     .958
          DELH    =    1000.          CRALT   =       0.              RCRRQ   =   1250.0            ISWING  =        0
          VCLMB   =       .0          ICRUS   =        1              OFALT   =   25000.            OFEM    =     .500
0   LAND  IWLD    =        2          XLDGRQ  =   99999.              VRATT   =    1.300            HAPP    =      50.
          TDELLD  =     36.0          ALTLND  =    5000.              RSMX    =    1000.            SINKTD  =      3.0
          TDELAY  =      1.0          WLPCT   =    .9400              TROTID  =     .000            XLFMX   =    1.200
          HTG     =      5.5          TIDLE   =       .0              VTDRAT  =      1.1

0                                      ******COST******
0         NCADE   =        1          HIR     =     .005              RI      =     .300            CMV     =     .800
          CLIAB   =   1993.0          TR      =    2.000              OHR     =  500.000            CCRW    =       0.
          HRI     = 4000000.          PRV     =     .100              CRWOH   =   23.000            UCSENG  =     .000
          CMF     =       .2          DYR     =     15.0              CINP    =       0.            UCSPP   =     .000
          TBO     =   3200.0          SRPM    =       .0              CP      =       0.            ALR     =    3.400
          FCSF    =     .850
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file

```
*****************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1   .0216  -.1414
  GROSS WGT, GROSS WGT MINUS1      45725.7     45981.2

0   ******************************************************************************************
0                        FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                      CLMAX     VSTALL,KTS  FLAP ANGLE   LE ANGLE    DELTA CL    DELTA CD

 FLAPS UP            1.1337       161.7         .0          .0        .0000       .0000
 T.O. CONFIG         2.1556       117.4        15.0         .0       1.0109       .0374
 LDG. CONFIG         2.8448       102.2        40.0         .0       1.7103       .1664

0                       DOUBLE SLOTTED FOWLER FLAPS
                       OPT ANGLE    DELCL AT OPT   DELCD AT OPT    AREA(FT2)     WEIGHT(LB)

 FLAPS                   30.0         2.2500          .1500          94.7          647.9
0   ******************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.610   LIFT= 44353.9   L/D=  13.324   ALTITUDE= 35000.0   MACH=   .8000

1                                   ENGINE SIZING DATA FOLLOW
                                   **************************
0VSTLKT= 108.9 KTS EAS   VRAT= 1.100 CLTO= 1.7815
     VEND =  249.4 KNOTS EAS
0
 ROTATION (TIME=   26.6 AND TAS=   132.5 EAS=   118.9)
 LIFTOFF (TIME=   28.8 DIST=   3740.4 TAS=   140.1 EAS=   125.6)
 DISTANCE TO 35 FT.=  5024.4   TAS=   152.3 EAS=   136.6 V35/VS=  1.2545
 GEAR RETRACTION STARTED AT    34.9 SEC,COMPLETE AT    41.9 SEC
 FLAP RETRACTION STARTED AT    45.1 SEC,COMPLETE AT    49.6 SEC
0VSTLKT= 108.9 KTS EAS   VRAT= 1.100 CLTO= 1.7815
0 ENGINE OUT PERFORMANCE FOLLOWS
     VEND =  206.3 KNOTS EAS
 ENGINE FAILURE (TIME=   25.1 AND TAS=   126.9 EAS=   113.9)
0
 ROTATION (TIME=   29.8 AND TAS=   132.5 EAS=   118.9)
 LIFTOFF (TIME=   33.0 DIST=   4660.7 TAS=   135.0 EAS=   121.1)
 DISTANCE TO 35 FT.=  6785.6   TAS=   135.5 EAS=   121.5 V35/VS=  1.1161


     ACCELERATE - STOP DISTANCE =      6142.7 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      6785.6 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     5024.4 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     5778.0 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5258.3 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .013 HRS   FUEL USED=      74. LBS   WEIGHT=   45651. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                       VS             V      GRAD      R/C    REQ.R/C
   CONFIGURATION                               ALT (FT)   KEAS    V/VS   KTAS    (PCT)     (FPM)     (FPM)     CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  109.0  1.1285  137.1    2.152    298.69      1.00  1.700  8.829
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  109.0  1.2000  146.4    4.208    623.31    355.51  1.503 11.051
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  149.6  1.2500  213.3    4.762   1028.04    259.05   .736 14.216
   APPROACH FLAPS -ONE ENG OUT                   5000.  104.3  1.3510  157.0    4.481    712.18    333.74  1.296 11.570
   LANDING FLAPS - ALL ENGINES                   5000.   94.9  1.3000  137.5   12.955   1802.77    445.30  1.690  7.145

     APPROACH FLAP SETTING = 19.7 DEG.



     +++ ENGINE-OUT SERVICE CEILING = 23163.7 FT.
         BEST RATE OF CLIMB SPEED   =   273.9 KTAS
         ENGINE-OUT RATE OF CLIMB   =    50.0 FPM
         WEIGHT AT ALTITUDE         = 43896.6 LBS

0                       ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE           1426.2
   NACELLE WEIGHT/ENGINE           320.7
   PYLON WEIGHT/ENGINE             170.4
      PROP OR QFAN           .0
      GEARBOX                .0
      SHROUD                 .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.86
   NACELLE LENGTH(FT)              11.58

0VSTLKT= 108.9 KTS EAS   VRAT= 1.100 CLTO= 1.7815
     VEND =  247.8 KNOTS EAS
0
 ROTATION (TIME=   25.4 AND TAS=   132.5 EAS=   118.9)
 LIFTOFF (TIME=   27.6 DIST=   3594.6 TAS=   140.6 EAS=   126.1)
 DISTANCE TO 35 FT.=  4856.6   TAS=   153.5 EAS=   137.7 V35/VS=  1.2646
 GEAR RETRACTION STARTED AT    33.6 SEC,COMPLETE AT    40.6 SEC
 FLAP RETRACTION STARTED AT    43.7 SEC,COMPLETE AT    48.2 SEC
0VSTLKT= 108.9 KTS EAS   VRAT= 1.100 CLTO= 1.7815
0 ENGINE OUT PERFORMANCE FOLLOWS
     VEND =  201.5 KNOTS EAS
 ENGINE FAILURE (TIME=   24.0 AND TAS=   126.9 EAS=   113.9)
0
 ROTATION (TIME=   28.2 AND TAS=   132.5 EAS=   118.9)
 LIFTOFF (TIME=   31.4 DIST=   4425.7 TAS=   135.3 EAS=   121.4)
 DISTANCE TO 35 FT.=  6243.5   TAS=   136.1 EAS=   122.0 V35/VS=  1.1208
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
     ACCELERATE - STOP DISTANCE =     6011.0 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      6243.5 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      4856.6 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =      5585.0 FEET
 ALL ENGINE DISTANCE TO 50 FT. =      5091.6 FEET
0    AT END OF TAKEOFF PHASE
 TIME=   .013 HRS   FUEL USED=       75. LBS   WEIGHT=   45651. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS               V       GRAD      R/C    REQ.R/C
   CONFIGURATION                              ALT (FT)   KEAS    V/VS    KTAS    (PCT)    (FPM)     (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.   109.0  1.1285   137.1    2.462   341.71      1.00  1.700  8.631
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT           5250.   109.0  1.2000   146.4    4.495   665.81    355.51  1.503 10.727
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT         6500.   149.6  1.2500   213.3    4.809  1038.06    259.05   .736 13.358
   APPROACH FLAPS -ONE ENG OUT                    5000.   104.3  1.3510   157.0    4.739   753.13    333.74  1.296 11.186
   LANDING FLAPS - ALL ENGINES                    5000.    94.9  1.3000   137.5   14.020  1950.93    445.30  1.690  7.108

     APPROACH FLAP SETTING = 19.7 DEG.

                       .

     +++ ENGINE-OUT SERVICE CEILING = 23690.8 FT.
         BEST RATE OF CLIMB SPEED   =    272.4 KTAS
         ENGINE-OUT RATE OF CLIMB   =     50.0 FPM
         WEIGHT AT ALTITUDE         = 43896.6 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=     364.33

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    364.33

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   9290.5 LBS
*********************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE            1486.5
   NACELLE WEIGHT/ENGINE            320.7
   PYLON WEIGHT/ENGINE              174.7
      PROP OR QFAN            .0
      GEARBOX                 .0
      SHROUD                  .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.86
   NACELLE LENGTH(FT)              11.58

0********************************************************************************************************************
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Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
                        ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                 MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
                  WT         CG          WT         CG          WT         CG

   A/C OWE    26978.51     44.01     26978.51     44.01     26978.51     44.01
   PAX         6120.00                2040.00                8500.00
   BAGGAGE         .00     56.36      1500.00     56.36      1500.00     56.36
   WING FUEL   1645.98     45.14      8229.90     45.14      8229.90     45.14
   TIP FUEL        .00       .00          .00       .00          .00       .00
   FUS FUEL        .00     45.14          .00     45.14       517.27     45.14
   TOTAL      34744.48     41.61     38748.40     44.95     45725.67     43.26
0                        ---TAIL SIZING SUMMARY---

         Static Longitudinal Stability, Stick-fixed, considered


0                    WING                  CANARD           TAIL         DOWN   FLAP
 CONDITION  ALPHA    CL     CLA    CMac  ALPHA   CLA    CLA   EFF.     WASH   CM

  CRUISE   1.7088  .3871  .1170 -.0600 2.7088  .0984  .0762 1.0000
  LIFTOFF  2.0000 1.3256  .0657 -.0600 3.0000  .0755  .0636 1.0000  .3679 -.1031
  LANDING 11.8265 2.8448  .0845 -.060012.8265  .0755  .0636 1.0000 2.1752 -.2000

0            --FUSELAGE-- ---NACELLE--          ------POWER-------         L.GEAR ROT.POWER
 CONDITION   DCM    CM     DCM    CM  DCMdth DCMfinc CMdth  CMfinc   CT     CM     CM

  CRUISE    .4488          .1831         .0000  .0300                .0000
  LIFTOFF   .7988  .0000  .1831  .0000                 .0000  .0398  .0000 -.6104 4.8510
  LANDING   .6215  .5160  .1831  .1520                 .0000  .0853

0      CANARD PARAMETERS
           CMDELTC(CONTROL POWER)        =  -.02252
           TAUc(EFFECTIVENESS)           =   .48250
           DcMAX(MAX.CANARDVATOR DEFLEC)= 37.78492

0      ELEVATOR PARAMETERS
           CMDELTE(CONTROL POWER)        =  -.02759            WING DE/DALPHA =    .36786
           TAUH(EFFECTIVENESS)           =   .48250
           DEMAX(MAX.ELEVATOR DEFLEC.)   =-25.00000


0                              FRACTION    STATION         CANARD AND HORIZONTAL TAIL SIZES
                                 MAC     (DATUM NOSE)                                               CANARD        HOR.TAIL


      NEUTRAL POINT              .4780      45.887         STATIC STABILITY AND LANDING TRIM
      STATIC MARGIN              .1000                     STATIC STABILITY AND LIFTOFF ROT.
      AFT CG LIMIT(STABILITY)    .3780      45.013
      CG RANGE(LOADING)          .3820                     REQUIRED SIZES                           69.7529       90.5412
      FWD CG LIMIT(CONTROL)     -.0041      41.674         CANARD AND TAIL ARMS (ELcan,ELTH)        36.1202       42.8884
0     VERTICAL TAIL AREA =  107.6360 FOR DIRECTIONAL STABILITY OF     .00200
0     RUDDER POWER AT MAX.DEFL.=   .0178 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4461
0     VERTICAL TAIL AREA=   92.5623 FOR MINIMUM CONTROL SPEED =    107.75 KTS
0     REQUIRED VERTICAL TAIL AREA =  107.6360  TAIL ARM(ELTV) =   32.1851
*************************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.610   LIFT= 44353.9   L/D=  12.641   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25       H-TAIL VOL. ARM       =   42.89       C.G.LOCATION OF PROPULSION=   67.36
 WING 1/4C LOC.ON C.L.=   40.65       H-TAIL C.G.LOCATION   =   87.11       C.G.OF REMAINING WEIGHT   =   35.66
 MAC 1/4C LOCATION     =   43.83       H-TAIL MAC FROM C.L. =    4.30
 MAC DIST.FROM C.L.    =   12.29       H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   45.58       V-TAIL VOL. ARM       =   32.19
 TIP TANKS C.G.LOCATE =      .00       V-TAIL C.G.LOCATION   =   76.85       DIST.L.E.VERT.TO L.E.HORZ.=    2.41

 CANARD 1/4C LOC. ON C.L. =    6.54
 CANARD MAC DIST.FROM C.L.=    4.35
 CANARD VOLUME ARM        =   36.12
 CANARD C.G. LOCATION     =    8.00

0                    WING        CANARD       H-TAIL      V-TAIL

   AREA            481.052       69.753       90.541     107.636
   SPAN             63.188       19.587       19.031      10.375
   ASPECT RATIO      8.300        5.500        4.000       1.000
   TAPER RATIO        .200         .500         .550        .700
   1/4C. SWEEP      14.500       15.000       27.500      50.500
   L.E. SWEEP       18.723       18.188       30.674      52.459
   C.L. CHORD       12.688        4.748        6.139      12.206
   MEAN CHORD        8.741        3.693        4.891      10.482
   TIP CHORD         2.538        2.374        3.376       8.544
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
0                                        MISSION PERFORMANCE DATA FOLLOWS
                                         ********************************
0    TAXI AT IDLE THRUST

                      FUEL                           FUEL
   TIME    RANGE      USED     WEIGHT     ALT.       FLOW
   (HRS)   (NM)      (LBS)     (LBS)      (FT)     (LB/HR)

   .000       0.        0.    45726.     5000.      849.
   .167       0.      141.    45584.     5000.      849.
0VSTLKT= 106.4 KTS EAS   VRAT= 1.100 CLTO= 1.7815
      VEND =  246.7 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                      FUEL                                                                                                       FUEL    FUS.
   TIME    DIST.      USED     WEIGHT     ALT.      TAS      EAS   MACH  ACCEL       CL        CD  ALPHA GAMMA       ROC   LOAD THRUST    FLOW  ANGLE
   (SEC)  (FEET)     (LBS)     (LBS)      (FT)    (KTS)    (KTS)    NO. (FPS2)                     (DEG) (DEG)     (FPM)   FACT  (LBS) (LB/HR) (DEG)

      .0      .0     141.4    45584.    5000.0       .0       .0   .000  10.98 1.3233  .1329  2.00   .00        .0    .00 16478.    5868.   .00
     1.0     5.5     143.1    45583.    5000.0      6.5      5.8   .010  10.84 1.3233  .1329  2.00   .00        .0    .00 16280.    5868.   .00
     2.0    21.8     144.7    45581.    5000.0     12.9     11.5   .019  10.69 1.3233  .1329  2.00   .00        .0    .00 16087.    5869.   .00
     3.0    48.9     146.3    45579.    5000.0     19.2     17.2   .028  10.53 1.3234  .1329  2.00   .00        .0    .00 15896.    5870.   .00
     4.0    86.5     148.0    45578.    5000.0     25.4     22.8   .038  10.37 1.3234  .1329  2.00   .00        .0    .00 15709.    5871.   .00
     5.0   134.5     149.6    45576.    5000.0     31.5     28.2   .047  10.20 1.3235  .1329  2.00   .00        .0    .00 15525.    5873.   .00
     6.0   192.8     151.2    45574.    5000.0     37.5     33.6   .056  10.03 1.3236  .1330  2.00   .00        .0    .00 15345.    5874.   .00
     7.0   261.1     152.9    45573.    5000.0     43.4     38.9   .064   9.85 1.3237  .1330  2.00   .00        .0    .00 15168.    5876.   .00
     8.0   339.3     154.5    45571.    5000.0     49.2     44.1   .073   9.66 1.3239  .1330  2.00   .00        .0    .00 14993.    5878.   .00
     9.0   427.2     156.1    45570.    5000.0     54.9     49.2   .081   9.48 1.3240  .1330  2.00   .00        .0    .00 14822.    5881.   .00
    10.0   524.6     157.8    45568.    5000.0     60.5     54.2   .090   9.29 1.3242  .1330  2.00   .00        .0    .00 14655.    5883.   .00
    11.0   631.3     159.4    45566.    5000.0     65.9     59.1   .098   9.09 1.3244  .1330  2.00   .00        .0    .00 14491.    5886.   .00
    12.0   747.2     161.0    45565.    5000.0     71.3     63.9   .106   8.92 1.3246  .1331  2.00   .00        .0    .00 14357.    5888.   .00
    13.0   872.0     162.7    45563.    5000.0     76.5     68.6   .114   8.74 1.3248  .1331  2.00   .00        .0    .00 14235.    5891.   .00
    14.0  1005.6     164.3    45561.    5000.0     81.7     73.3   .121   8.57 1.3250  .1331  2.00   .00        .0    .00 14116.    5894.   .00
    15.0  1147.8     165.9    45560.    5000.0     86.7     77.8   .129   8.39 1.3252  .1331  2.00   .00        .0    .00 13999.    5898.   .00
    16.0  1298.5     167.6    45558.    5000.0     91.6     82.2   .136   8.21 1.3254  .1332  2.00   .00        .0    .00 13885.    5901.   .00
    17.0  1457.3     169.2    45556.    5000.0     96.5     86.5   .143   8.03 1.3256  .1332  2.00   .00        .0    .00 13773.    5904.   .00
    18.0  1624.3     170.9    45555.    5000.0    101.2     90.8   .150   7.84 1.3259  .1332  2.00   .00        .0    .00 13663.    5908.   .00
    19.0  1799.1     172.5    45553.    5000.0    105.8     94.9   .157   7.66 1.3261  .1332  2.00   .00        .0    .00 13557.    5911.   .00
    20.0  1981.6     174.1    45551.    5000.0    110.3     99.0   .164   7.48 1.3264  .1333  2.00   .00        .0    .00 13452.    5915.   .00
    21.0  2171.6     175.8    45550.    5000.0    114.7    102.9   .170   7.29 1.3266  .1333  2.00   .00        .0    .00 13350.    5919.   .00
    22.0  2369.0     177.4    45548.    5000.0    119.0    106.7   .177   7.11 1.3269  .1333  2.00   .00        .0    .00 13251.    5922.   .00
    23.0  2573.5     179.1    45547.    5000.0    123.2    110.5   .183   6.93 1.3272  .1333  2.00   .00        .0    .00 13154.    5926.   .00
    24.0  2784.9     180.7    45545.    5000.0    127.2    114.1   .189   6.74 1.3274  .1334  2.00   .00        .0    .00 13059.    5930.   .00
0
 ROTATION (TIME=    24.6 AND TAS=    129.8 EAS=    116.4)
    25.0  3003.2     182.4  45543.  5000.0  131.2  117.7  .195      6.53 1.3485  .1357  2.24   .00        .0    .76 12967.    5934.   .24
    26.0  3228.0     184.0  45542.  5000.0  134.9  121.1  .200      6.07 1.4782  .1530  3.79   .00        .0    .89 12881.    5937.  1.79
 LIFTOFF (TIME=    26.8 DIST=    3412.2 TAS=    137.7 EAS=    123.6)
    27.0  3458.8     185.7  45540.  5000.0  138.4  124.2  .205      5.50 1.6159  .1738  5.48   .01       3.4   1.03 12822.    5941.  3.50
    28.0  3695.2     187.3  45538.  5001.0  141.5  126.9  .210      4.89 1.6424  .1781  5.78   .59     146.5   1.09 12769.    5944.  4.37
    29.0  3936.6     189.0  45537.  5005.1  144.3  129.4  .214      4.50 1.5828  .1688  4.98  1.32     336.9   1.09 12721.    5946.  4.30
    30.0  4182.3     190.6  45535.  5012.3  146.8  131.7  .218      4.11 1.5318  .1611  4.38  2.04     530.1   1.09 12675.    5948.  4.42
    31.0  4432.1     192.3  45533.  5022.7  149.2  133.8  .221      3.73 1.4856  .1543  3.88  2.74     723.0   1.09 12633.    5949.  4.62
 DISTANCE TO 35 FT.=  4661.3    TAS=    151.1 EAS=    135.5 V35/VS=  1.2731
    32.0  4685.5     193.9  45532.  5036.4  151.3  135.6  .225      3.33 1.4487  .1490  3.48  3.45     921.4   1.10 12594.    5950.  4.93
    33.0  4942.1     195.6  45530.  5053.4  153.2  137.3  .227      2.95 1.4132  .1441  3.08  4.14    1119.3   1.10 12558.    5950.  5.22
 GEAR RETRACTION STARTED AT    32.8 SEC,COMPLETE AT    39.8 SEC
    34.0  5201.5     197.2  45528.  5073.7  154.9  138.8  .230      2.67 1.3872  .1365  2.78  4.81    1316.4   1.10 12525.    5949.  5.59
    35.0  5463.3     198.9  45527.  5097.3  156.4  140.1  .232      2.37 1.3615  .1300  2.48  5.48    1514.6   1.10 12494.    5948.  5.97
    36.0  5727.2     200.5  45525.  5124.2  157.7  141.2  .234      2.09 1.3359  .1238  2.18  6.14    1710.2   1.10 12465.    5946.  6.33
    37.0  5992.9     202.2  45523.  5154.3  158.9  142.2  .236      1.80 1.3189  .1185  1.98  6.80    1907.4   1.10 12438.    5943.  6.79
    38.0  6260.0     203.8  45522.  5187.8  159.9  143.0  .238      1.52 1.3018  .1133  1.78  7.45    2102.1   1.10 12414.    5940.  7.24
    39.0  6528.4     205.5  45520.  5224.4  160.7  143.7  .239      1.26 1.2847  .1081  1.58  8.10    2294.6   1.10 12391.    5936.  7.68
    40.0  6797.5     207.1  45518.  5264.3  161.4  144.2  .240       .97 1.2762  .1045  1.48  8.75    2487.6   1.10 12371.    5931.  8.23
    41.0  7067.1     208.8  45517.  5307.3  161.9  144.6  .241       .61 1.2676  .1036  1.38  9.39    2676.8   1.10 12353.    5926.  8.77
    42.0  7336.9     210.4  45515.  5353.5  162.2  144.7  .241       .27 1.2591  .1027  1.28 10.02    2859.2   1.09 12339.    5920.  9.30
    43.0  7606.5     212.1  45514.  5402.6  162.2  144.7  .241      -.01 1.2333  .1000   .98 10.64    3036.1   1.07 12327.    5914.  9.62
 FLAP RETRACTION STARTED AT    42.9 SEC,COMPLETE AT    47.4 SEC
    44.0  7875.7     213.7  45512.  5453.5  162.3  144.5  .241      -.01 1.0873  .1008  2.03 10.60    3025.7    .95 12315.    5907. 10.64
    45.0  8145.3     215.4  45510.  5502.7  162.3  144.4  .241      -.01 1.0133  .1121  3.78 10.03    2863.4    .89 12304.    5901. 11.81
0VSTLKT= 106.4 KTS EAS   VRAT= 1.100 CLTO= 1.7815
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  202.0 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                      FUEL                                                                                                       FUEL    FUS.
   TIME    DIST.      USED     WEIGHT     ALT.      TAS      EAS   MACH  ACCEL       CL        CD  ALPHA GAMMA       ROC   LOAD THRUST    FLOW  ANGLE
   (SEC)  (FEET)     (LBS)     (LBS)      (FT)    (KTS)    (KTS)    NO. (FPS2)                     (DEG) (DEG)     (FPM)   FACT  (LBS) (LB/HR) (DEG)

      .0      .0     141.4    45584.    5000.0       .0       .0   .000  10.98 1.3233  .1329  2.00   .00        .0    .00 16478.    5868.   .00
     1.0     5.5     143.1    45583.    5000.0      6.5      5.8   .010  10.84 1.3233  .1329  2.00   .00        .0    .00 16280.    5868.   .00
     2.0    21.8     144.7    45581.    5000.0     12.9     11.5   .019  10.69 1.3233  .1329  2.00   .00        .0    .00 16087.    5869.   .00
     3.0    48.9     146.3    45579.    5000.0     19.2     17.2   .028  10.53 1.3234  .1329  2.00   .00        .0    .00 15896.    5870.   .00
     4.0    86.5     148.0    45578.    5000.0     25.4     22.8   .038  10.37 1.3234  .1329  2.00   .00        .0    .00 15709.    5871.   .00
     5.0   134.5     149.6    45576.    5000.0     31.5     28.2   .047  10.20 1.3235  .1329  2.00   .00        .0    .00 15525.    5873.   .00
     6.0   192.8     151.2    45574.    5000.0     37.5     33.6   .056  10.03 1.3236  .1330  2.00   .00        .0    .00 15345.    5874.   .00
     7.0   261.1     152.9    45573.    5000.0     43.4     38.9   .064   9.85 1.3237  .1330  2.00   .00        .0    .00 15168.    5876.   .00
     8.0   339.3     154.5    45571.    5000.0     49.2     44.1   .073   9.66 1.3239  .1330  2.00   .00        .0    .00 14993.    5878.   .00
     9.0   427.2     156.1    45570.    5000.0     54.9     49.2   .081   9.48 1.3240  .1330  2.00   .00        .0    .00 14822.    5881.   .00
    10.0   524.6     157.8    45568.    5000.0     60.5     54.2   .090   9.29 1.3242  .1330  2.00   .00        .0    .00 14655.    5883.   .00
    11.0   631.3     159.4    45566.    5000.0     65.9     59.1   .098   9.09 1.3244  .1330  2.00   .00        .0    .00 14491.    5886.   .00
    12.0   747.2     161.0    45565.    5000.0     71.3     63.9   .106   8.92 1.3246  .1331  2.00   .00        .0    .00 14357.    5888.   .00
    13.0   872.0     162.7    45563.    5000.0     76.5     68.6   .114   8.74 1.3248  .1331  2.00   .00        .0    .00 14235.    5891.   .00
    14.0  1005.6     164.3    45561.    5000.0     81.7     73.3   .121   8.57 1.3250  .1331  2.00   .00        .0    .00 14116.    5894.   .00
    15.0  1147.8     165.9    45560.    5000.0     86.7     77.8   .129   8.39 1.3252  .1331  2.00   .00        .0    .00 13999.    5898.   .00
    16.0  1298.5     167.6    45558.    5000.0     91.6     82.2   .136   8.21 1.3254  .1332  2.00   .00        .0    .00 13885.    5901.   .00
    17.0  1457.3     169.2    45556.    5000.0     96.5     86.5   .143   8.03 1.3256  .1332  2.00   .00        .0    .00 13773.    5904.   .00
    18.0  1624.3     170.9    45555.    5000.0    101.2     90.8   .150   7.84 1.3259  .1332  2.00   .00        .0    .00 13663.    5908.   .00
    19.0  1799.1     172.5    45553.    5000.0    105.8     94.9   .157   7.66 1.3261  .1332  2.00   .00        .0    .00 13557.    5911.   .00
    20.0  1981.6     174.1    45551.    5000.0    110.3     99.0   .164   7.48 1.3264  .1333  2.00   .00        .0    .00 13452.    5915.   .00
    21.0  2171.6     175.8    45550.    5000.0    114.7    102.9   .170   7.29 1.3266  .1333  2.00   .00        .0    .00 13350.    5919.   .00
    22.0  2369.0     177.4    45548.    5000.0    119.0    106.7   .177   7.11 1.3269  .1333  2.00   .00        .0    .00 13251.    5922.   .00
    23.0  2573.5     179.1    45547.    5000.0    123.2    110.5   .183   6.93 1.3272  .1333  2.00   .00        .0    .00 13154.    5926.   .00
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
 ENGINE FAILURE (TIME=    23.3 AND TAS=    124.2 EAS=    111.4)
    24.0  2784.4    180.2  45545.  5000.0  125.8  112.9  .187     2.04 1.3274   .1419  2.00     .00         .0   .00    6546.    2964.    .00
    25.0  2997.9    181.1  45545.  5000.0  127.0  113.9  .189     2.00 1.3275   .1417  2.00     .00         .0   .00    6532.    2965.    .00
    26.0  3213.4    181.9  45544.  5000.0  128.2  115.0  .190     1.96 1.3275   .1414  2.00     .00         .0   .00    6518.    2965.    .00
    27.0  3430.9    182.7  45543.  5000.0  129.3  116.0  .192     1.91 1.3276   .1412  2.00     .00         .0   .00    6505.    2966.    .00
0
 ROTATION (TIME=    27.4 AND TAS=    129.8 EAS=    116.4)
    28.0  3650.3    183.5  45542.  5000.0  130.5  117.0  .194     1.78 1.3831   .1474  2.65     .00         .0   .78    6492.    2967.    .65
    29.0  3871.5    184.4  45541.  5000.0  131.4  117.9  .195     1.45 1.5128   .1655  4.22     .00         .0   .87    6481.    2967.   2.22
    30.0  4094.1    185.2  45541.  5000.0  132.2  118.6  .196     1.10 1.6425   .1853  5.83     .00         .0   .95    6472.    2967.   3.83
 LIFTOFF (TIME=    30.4 DIST=    4183.5 TAS=    132.4 EAS=    118.8)
    31.0  4317.9    186.0  45540.  5000.1  132.7  119.1  .197      .68 1.7590   .2047  7.32     .08       17.9  1.03    6466.    2968.   5.40
    32.0  4542.3    186.8  45539.  5001.1  133.0  119.3  .197      .36 1.7815   .2086  7.55     .47      111.7  1.05    6462.    2968.   6.02
    33.0  4767.1    187.6  45538.  5003.8  133.2  119.4  .198      .10 1.7815   .2087  7.42     .92      217.1  1.06    6460.    2968.   6.34
    34.0  4992.0    188.5  45537.  5008.3  133.2  119.5  .198      .02 1.7411   .2018  6.86    1.30      306.4  1.03    6460.    2967.   6.16
    35.0  5216.8    189.3  45536.  5013.8  133.2  119.5  .198      .00 1.7156   .1976  6.56    1.48      347.5  1.02    6459.    2967.   6.04
    36.0  5441.7    190.1  45536.  5019.7  133.2  119.4  .198      .02 1.6967   .1944  6.36    1.55      364.1  1.00    6458.    2967.   5.91
    37.0  5666.6    190.9  45535.  5025.8  133.2  119.4  .198      .01 1.6948   .1941  6.36    1.57      370.6  1.00    6457.    2966.   5.94
    38.0  5891.4    191.8  45534.  5032.1  133.2  119.4  .198      .00 1.6933   .1939  6.36    1.59      375.0  1.00    6457.    2966.   5.95
 DISTANCE TO 35 FT.=  5997.1    TAS=    133.2 EAS=    119.4 V35/VS=  1.1223
    39.0  6116.3    192.6  45533.  5038.3  133.2  119.4  .198      .00 1.6923   .1937  6.36    1.60      377.8  1.00    6456.    2965.   5.97
    40.0  6341.2    193.4  45532.  5044.6  133.2  119.4  .198      .00 1.6916   .1936  6.36    1.61      379.3  1.00    6455.    2965.   5.97
    41.0  6566.1    194.2  45531.  5051.0  133.2  119.4  .198      .00 1.6912   .1936  6.36    1.61      379.9  1.00    6454.    2964.   5.98


      ACCELERATE - STOP DISTANCE =     5869.4 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=      5997.1 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =      4661.3 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =      5360.5 FEET
  ALL ENGINE DISTANCE TO 50 FT. =      4893.9 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=   .179 HRS   FUEL USED=      215. LBS   WEIGHT=   45510. LBS   ALT.=      5500. FT.


    ACCELERATE TO MACH NO. = .412

 0                 FUEL                                                              FUEL
   TIME    RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST     FLOW
   (HRS)   (NM)    (LBS)   (LBS)     (FT)    (KTS)  (KTS)   NO.   DIV    (LBS)    (LB/HR)

   .179      .00   215.3  45510.    5500.    157.   144.  .241  .722  12587.     5815.
   .188     2.03   270.1  45455.    5500.    268.   247.  .412  .812  10638.     5985.

   END OF ACCELERATION SEGMENT
   TIME=  .188 HRS   FUEL USED=   270.1 LBS   WEIGHT=  45455. LBS   RANGE=     2. NM
 0   CLIMB TO    35000. FT. AT MAXIMUM RATE OF CLIMB
 0                 FUEL                                                                                    FUS.                          FUEL
   TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH    CL       CD    ALPHA GAMMA ANGLE     R/C    THRUST     FLOW
   (HRS)   (NM)    (LBS) ·  (LBS)     (FT)    (KTS)  (KTS)   NO.   DIV                    (DEG) (DEG) (DEG)    (FPM)    (LBS)    (LB/HR)

    .188       2.     270.  45455.    5500.    245.    226.  .377  .803  .4725  .0342  3.71  7.93  9.63    3424.    9523.     5262.
    .191       3.     283.  45443.    6000.    246.    225.  .380  .803  .4761  .0343  3.75  7.49  9.23    3250.    9439.     5211.
    .196       4.     310.  45416.    7000.    249.    224.  .385  .802  .4797  .0345  3.78  7.14  8.92    3138.    9247.     5107.
    .201       5.     337.  45389.    8000.    251.    223.  .390  .802  .4871  .0349  3.85  7.10  8.95    3141.    9069.     5001.
    .206       7.     363.  45362.    9000.    260.    228.  .406  .804  .4669  .0338  3.60  5.70  7.29    2620.    8779.     4899.
    .213       8.     394.  45331.   10000.    263.    226.  .412  .803  .4715  .0341  3.64  6.39  8.03    2966.    8603.     4790.
    .218      10.     421.  45304.   11000.    266.    225.  .417  .803  .4767  .0344  3.69  6.57  8.25    3078.    8427.     4684.
    .224      11.     447.  45279.   12000.    268.    223.  .423  .802  .4828  .0347  3.74  5.99  7.73    2836.    8253.     4580.
    .230      13.     474.  .45252.   13000.    271.    222.  .429  .801  .4886  .0350  3.80  5.79  7.59    2769.    8079.     4478.
    .236      14.     501.  45225.   14000.    274.    221.  .435  .801  .4946  .0353  3.85  5.59  7.44    2702.    7907.     4379.
    .242      16.     528.  45198.   15000.    276.    219.  .441  .800  .5003  .0356  3.90  5.38  7.28    2626.    7734.     4283.
    .248      18.     555.  45171.   16000.    282.    221.  .452  .801  .4957  .0353  3.83  4.77  6.59    2377.    7518.     4182.
    .255      20.     584.  45141.   17000.    285.    219.  .458  .800  .5020  .0357  3.88  4.91  6.80    2474.    7332.     4076.
    .262      22.     612.  45114.   18000.    288.    218.  .464  .799  .5087  .0360  3.94  4.70  6.64    2391.    7149.     3972.
    .269      24.     639.  45086.   19000.    291.    216.  .471  .798  .5155  .0364  4.00  4.49  6.49    2308.    6969.     3871.
    .276      26.     667.  45058.   20000.    294.    215.  .477  .797  .5224  .0368  4.06  4.29  6.35    2225.    6792.     3771.
    .284      28.     695.  45030.   21000.    297.    213.  .484  .796  .5294  .0372  4.12  4.09  6.21    2142.    6617.     3674.
    .291      30.     724.  45002.   22000.    300.    212.  .491  .795  .5364  .0376  4.18  3.89  6.07    2059.    6446.     3578.
    .299      33.     753.  44973.   23000.    303.    210.  .498  .795  .5436  .0380  4.24  3.69  5.93    1976.    6277.     3484.
    .308      35.     782.  44943.   24000.    310.    212.  .512  .795  .5369  .0376  4.13  3.12  5.25    1711.    6078.     3404.
    .318      38.     816.  44910.   25000.    313.    210.  .519  .794  .5457  .0381  4.20  3.28  5.49    1815.    5902.     3319.
    .327      41.     846.  44880.   26000.    316.    208.  .526  .793  .5549  .0387  4.28  3.08  5.36    1721.    5729.     3236.
    .336      44.     877.  44848.   27000.    318.    206.  .533  .792  .5642  .0392  4.36  2.89  5.25    1627.    5561.     3153.
    .347      47.     910.  44816.   28000.    321.    204.  .540  .791  .5736  .0398  4.43  2.70  5.13    1534.    5395.     3072.
    .358      51.     943.  44783.   29000.    325.    203.  .548  .790  .5818  .0403  4.49  2.48  4.98    1427.    5231.     2993.
    .369      55.     978.  44748.   30000.    329.    201.  .557  .789  .5897  .0408  4.55  2.29  4.84    1332.    5071.     2915.
    .382      59.    1014.  44711.   31000.    358.    216.  .610  .798  .5147  .0364  3.60  1.08  2.68     682.    4791.     2862.
    .406      67.    1084.  44641.   32000.    361.    213.  .617  .797  .5256  .0370  3.69  1.77  3.45    1126.    4628.     2763.
    .421      73.    1125.  44600.   33000.    364.    211.  .624  .795  .5370  .0376  3.78  1.59  3.37    1021.    4468.     2667.
    .437      79.    1169.  44557.   34000.    366.    209.  .632  .794  .5486  .0383  3.87  1.42  3.28     918.    4313.     2574.
    .455      85.    1216.  44510.   35000.    374.    209.  .648  .794  .5460  .0381  3.78  1.07  2.85     711.    4159.     2491.
 0   END OF CLIMB TO    35000. FT
  TIME=    .455 HRS   FUEL USED=     1216. LBS   WEIGHT=   44510. LBS   RANGE=      85. NM

 0ALTITUDE=      35000. FT   TAS=      466.70 KTS   MACH NO=       .8087


   ACCELERATE TO MACH NO. = .800

 0                FUEL                                                              FUEL
  TIME    RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST     FLOW
  (HRS)   (NM)    (LBS)   (LBS)     (FT)    (KTS)  (KTS)   NO.   DIV    (LBS)    (LB/HR)

  .456   85.41  1215.5  44510.  35000.    374.   209.  .648  .794   4440.     2834.
  .503  106.41  1360.0  44366.  35000.    461.   258.  .800  .816   4537.     2964.

  END OF ACCELERATION SEGMENT
  TIME=  .503 HRS   FUEL USED=  1360.0 LBS   WEIGHT=  44366. LBS   RANGE=  106. NM


   ACCELERATE TO MACH NO. = .809

 0                FUEL                                                              FUEL
  TIME    RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST     FLOW
  (HRS)   (NM)    (LBS)   (LBS)     (FT)    (KTS)  (KTS)   NO.   DIV    (LBS)    (LB/HR)

  .456   85.41  1215.5  44510.  35000.    374.   209.  .648  .794   4440.     2834.
  .508  108.87  1375.5  44350.  35000.    466.   260.  .809  .818   4550.     2976.
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
   END OF ACCELERATION SEGMENT
   TIME=  .508 HRS   FUEL USED=  1375.5 LBS   WEIGHT=  44350. LBS   RANGE=  109. NM

    ACCELERATE TO MACH NO. = .826

 0                   FUEL                                                                FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH     THRUST     FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)    (KTS)  (KTS)     NO.   DIV      (LBS)   (LB/HR)

    .456   85.41   1215.5  44510.   35000.    374.    209.  .648  .794    4440.     2834.
    .514  111.71   1393.3  44332.   35000.    476.    266.  .826  .819    4563.     2990.

   END OF ACCELERATION SEGMENT
   TIME=  .514 HRS   FUEL USED=  1393.3 LBS   WEIGHT=  44332. LBS   RANGE=  112. NM


 0                                      DESIGN CASE
                                        CRUISE PERFORMANCE SUMMARY
                                                FOR
                                        ***** DESIGN PAYLOAD *****
                                        **** MAXIMUM PAYLOAD *****
                                        ****** MAXIMUM FUEL ******
                                        FUEL AVAILABLE=   8747.
 0                             AT                      AT                     AT
                         SPECIFIED SPEED         NORMAL POWER          BEST SPEC. RANGE
                         START     END           START    END           START    END
                         CRUISE    CRUISE        CRUISE   CRUISE        CRUISE   CRUISE
                         -------   -------       -------  -------       -------  -------
   TIME          HRS.       .503     2.966         .508    2.615          .514    2.819
   RANGE         N.MI       106.     1243.         109.    1092.          112.    1211.
   FUEL USED     LBS.      1360.     6989.        1376.    6250.         1393.    6912.
   WEIGHT        LBS.     44366.    38736.       44350.   39475.        44332.   38814.
   ALTITUDE      FT.      35000.    35000.       35000.   35000.        35000.   35000.
   TAS           KTS.      461.7     461.7        466.7    466.7         476.7    476.7
   EAS           KTS.      257.3     257.3        260.1    260.1         265.7    265.7
   MACH NO.                .8000     .8000        .8087    .8087         .8260    .8260
   DIV. MACH               .8171     .8227        .8180    .8241         .8199    .8250
   ANGLE ATTACK DEG.       1.478     1.087        1.378     .963         1.189     .842
   FUSE. ANGLE  DEG.       -.522     -.913        -.622   -1.037         -.811   -1.158
   CL                      .3601     .3144        .3522    .3031         .3375    .2955
   L/D                    12.367    11.429       12.242   11.187        11.989   11.043
   FUEL FLOW     LB/HR    2343.9    2232.6       2375.0   2256.7        2447.5   2345.2
   BREG. FACTOR N.MI.      8745.     8016.        8721.    8169.         8640.    7895.
   SPEC. RANGE  NM/LB     .19697    .20680       .19651   .20681        .19477   .20327


 0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
             (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
 0                   FUEL                                                                              FUS.                              FUEL
   TIME    RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    CL       CD     ALPHA GAMMA ANGLE      R/S    THRUST      FLOW
   (HRS)   (NM)     (LBS)    (LBS)     (FT)    (KTS)  (KTS)     NO.   DIV                    (DEG) (DEG) (DEG)     (FPM)   (LBS)     (LB/HR)

   2.628   1098.    6271.   39455.   35000.    467.    261.  .809  .823  .3105   .0272   1.03 -1.62 -2.60    1339.    2344.     1638.  R
   2.640   1104.    6293.   39433.   34000.    469.    267.  .809  .825  .2961   .0268    .90 -1.57 -2.67    1306.    2483.     1737.  R
   2.653   1110.    6317.   39409.   33000.    471.    273.  .809  .827  .2824   .0264    .79 -1.53 -2.74    1271.    2629.     1841.  R
   2.667   1117.    6343.   39382.   32000.    473.    279.  .809  .828  .2695   .0260    .68 -1.48 -2.80    1241.    2779.     1949.  R
   2.681   1123.    6372.   39354.   31000.    475.    286.  .809  .830  .2573   .0256    .58 -1.44 -2.86    1209.    2936.     2062.  R
   2.695   1130.    6402.   39323.   30000.    477.    293.  .809  .831  .2457   .0253    .48 -1.40 -2.92    1180.    3097.     2179.  R
   2.709   1137.    6436.   39290.   29000.    479.    299.  .809  .832  .2347   .0251    .38 -1.36 -2.98    1153.    3263.     2300.  R
   2.724   1144.    6472.   39254.   28000.    481.    306.  .809  .834  .2243   .0248    .30 -1.32 -3.03    1127.    3435.     2427.  R
   2.739   1151.    6510.   39215.   27000.    483.    313.  .809  .835  .2144   .0246    .21 -1.29 -3.07    1100.    3616.     2560.  R
   2.755   1159.    6552.   39173.   26000.    485.    320.  .809  .836  .2050   .0244    .13 -1.25 -3.12    1077.    3816.     2704.  R
   2.771   1166.    6597.   39128.   25000.    487.    327.  .809  .837  .1961   .0242    .06 -1.22 -3.16    1053.    4008.     2847.  R
   2.787   1174.    6646.   39080.   24000.    489.    334.  .809  .838  .1876   .0240   -.01 -1.19 -3.21    1032.    4206.     2995.  R
   2.803   1182.    6697.   39028.   23000.    491.    341.  .809  .839  .1795   .0239   -.08 -1.16 -3.25    1011.    4411.     3149.  R
   2.820   1191.    6752.   38974.   22000.    489.    346.  .802  .840  .1748   .0238   -.11 -1.15 -3.25     992.    4527.     3246.  R
   2.837   1199.    6809.   38917.   21000.    483.    347.  .789  .840  .1727   .0237   -.11 -1.14 -3.24     972.    4586.     3303.  R
   2.842   1201.    6812.   38913.   20000.    408.    299.  .664  .833  .2325   .0250    .66 -4.66 -6.00    3368.    1005.      725.  A
   2.847   1203.    6816.   38910.   19000.    404.    300.  .654  .833  .2299   .0249    .66 -4.66 -6.00    3324.    1048.      759.  A
   2.852   1205.    6820.   38905.   18000.    400.    302.  .645  .833  .2273   .0249    .65 -4.65 -6.00    3281.    1092.      794.  A
   2.857   1207.    6824.   38901.   17000.    395.    304.  .635  .834  .2247   .0248    .63 -4.63 -6.00    3238.    1138.      831.  A
   2.863   1209.    6829.   38897.   16000.    391.    306.  .626  .834  .2221   .0248    .62 -4.62 -6.00    3195.    1185.      869.  A
   2.868   1211.    6834.   38892.   15000.    387.    307.  .617  .834  .2195   .0247    .61 -4.61 -6.00    3153.    1234.      908.  A
   2.873   1213.    6839.   38887.   14000.    383.    309.  .608  .835  .2170   .0246    .60 -4.60 -6.00    3111.    1285.      949.  A
   2.879   1215.    6844.   38881.   13000.    379.    311.  .600  .835  .2144   .0246    .58 -4.58 -6.00    3070.    1337.      991.  A
   2.884   1217.    6850.   38876.   12000.    375.    313.  .592  .835  .2118   .0245    .57 -4.57 -6.00    3029.    1390.     1035.  A
   2.890   1219.    6856.   38870.   11000.    372.    315.  .584  .836  .2092   .0245    .55 -4.55 -6.00    2989.    1446.     1080.  A
   2.900   1222.    6864.   38861.   10000.    291.    250.  .455  .821  .3318   .0279   2.03 -3.15 -3.13    1621.    1127.      811.  S
   2.911   1225.    6873.   38852.    9000.    286.    250.  .446  .821  .3317   .0279   2.04 -3.10 -3.06    1568.    1165.      841.  S
   2.922   1229.    6883.   38843.    8000.    282.    250.  .438  .821  .3317   .0279   2.05 -3.04 -2.99    1515.    1205.      872.  S
   2.933   1232.    6893.   38833.    7000.    277.    250.  .430  .821  .3316   .0279   2.06 -2.98 -2.92    1463.    1245.      904.  S
   2.945   1235.    6904.   38821.    6000.    273.    250.  .422  .821  .3315   .0279   2.07 -2.92 -2.85    1411.    1287.      937.  S
   2.957   1238.    6916.   38810.    5000.    269.    250.  .414  .821  .3314   .0279   2.08 -2.85 -2.77    1359.    1331.      971.  S
   2.970   1242.    6929.   38797.    4000.    265.    250.  .406  .821  .3313   .0279   2.09 -2.79 -2.70    1308.    1375.     1007.  S
   2.983   1245.    6943.   38783.    3000.    261.    250.  .399  .821  .3312   .0279   2.10 -2.72 -2.62    1257.    1422.     1044.  S
   2.997   1249.    6958.   38768.    2000.    257.    250.  .391  .821  .3311   .0279   2.10 -2.65 -2.55    1207.    1469.     1082.  S
   3.004   1250.    6965.   38760.    1500.    255.    250.  .388  .821  .3310   .0279   2.11 -2.62 -2.51    1182.    1493.     1101.  S
 0   END OF DSCNT TO     1500. FT
  TIME=  3.004 HRS   FUEL USED=      6965. LBS   WEIGHT=   38760. LBS   RANGE=   1250. NM

 0      RESERVE FUEL(LBS)     1758.              1781.              1836.
          (   45.0 MIN.)

    *****************************************************************************
 0      RANGE = 1250.     BLOCK TIME= 3.004    USED FOR DESIGN RANGE AND COST

    *****************************************************************************
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
0  *********************************************************************************************
0             TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  78.04 PSF.
     LANDING WEIGHT =    42982. LBS.

     LANDING DISTANCE FROM 50. FT.=   2698. FT.

     F.A.R. FACTORED FIELD LENGTH =   4496. FT.
0                         APPROACH             TRANSITION             DELAY               ROLL
0                    DIST=        659.    DIST=        192.    DIST=        195.    DIST=       1651.
                     R/S=        1000.    XLFMX=      1.200    TDELAY=      1.00    MUB=        .4000
                     VAPEAS=    116.91    SINKTD=     3.000    TIDLE=       606.    TR/TIDLE=   .0000
                     VAPTAS=    130.45    VSTEAS=     89.93    VTDTAS=    115.40    ABAR(G)=    .3577
                     THETA=       4.34    CLMX=      2.8448
                     THRUST=     2838.    HFLAR=       20.9
****************************************************************************************************
0                RANGE OR ENDURANCE ITERATION SUMMARY

                             GROSS       RANGE(NMI) OR
                 ITERATION   WEIGHT(LB)   ENDURANCE(HR)

                     0        44050.00      1073.205
                     1        45981.21      1276.961
                     2        45725.67      1250.429
                     REQUIRED RG. OR END. = 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=    1.610   LIFT= 44353.9   L/D=  12.641   ALTITUDE= 35000.0   MACH=   .8000

0  GROSS WEIGHT =   45726.        PASSENGERS =  50. PLUS CREW

0  FUSELAGE       LENGTH            (ELF)            79.25   FT
                  WIDTH             (SWF)             9.25   FT
                  WETTED AREA       (SF)             1910.   SQFT
                  DELTA P           (DELP)            8.20   PSI

0  WING           ASPECT RATIO      (AR)              8.30
                  AREA              (SW)             481.1   SQFT
                  SPAN              (B)               63.2   FT
                  GEOM. MEAN CHORD  (CBARW)           8.74   FT
                  QUARTER CHORD SWEEP(DLMC4)          14.5   DEG
                  TAPER RATIO       (SLM)             .200
                  ROOT THICKNESS    (TCR)             .130
                  TIP THICKNESS     (TCT)             .100
                  WING LOADING      (WGS)             83.0   PSF
                  WING FUEL VOLUME  (VFW)           1230.7   GAL

0  CANARD         ASPECT RATIO      (ARcan)           5.50
                  AREA              (SWc)             69.8   SQFT
                  SPAN              (Bcan)            19.6   FT
                  GEOM. MEAN CHORD  (CBARc)           3.69   FT
                  QUARTER CHORD SWEEP(DwpqCa)         15.0   DEG
                  TAPER RATIO       (SLMcan)          .500
                  THICKNESS/CHORD   (TCcan)           .100
                  MOMENT ARM        (ELcan)           36.1   FT
                  VOLUME COEFF.     (VBARc)           .599
                  CANARD LOADING    (WGS)             83.0   PSF

0  HOR. TAIL      ASPECT RATIO      (ARHT)            4.00
                  AREA              (SHT)             90.5   SQFT
                  SPAN              (BHT)            19.03   FT
                  MEAN CHORD        (CBARHT)          4.89   FT
                  THICKNESS/CHORD   (TCHT)            .100
                  MOMENT ARM        (ELTH)            42.9   FT
                  VOLUME COEFF.     (VBARH)           .923

0  VERT. TAIL     ASPECT RATIO      (ARVT)            1.00
                  AREA              (SVT)            107.6   SQFT
                  SPAN              (BVT)            10.37   FT
                  MEAN CHORD        (CBARVT)         10.48   FT
                  THICKNESS/CHORD   (TCVT)            .120
                  MOMENT ARM        (ELTV)            32.2   FT
                  VOLUME COEFF.     (VBARV)           .114

0  ENG.NACELLES   LENGTH            (ELN)            11.58   FT
                  MEAN DIAMETER     (DBARN)           3.86   FT
                  NUMBER ENGINES    (ENP)              2.0
                  WETTED AREA       (SN)            280.49   SQFT

                  LOCATION                         ON FUSELAGE


0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
   ULT. LF =  5.64   MAN. LF =  2.50   GUST LF =  3.76

0  PROPULSION GROUP
      PRIMARY ENGINES          (WEP)       2973.
      PRIMARY ENGINE INSTL.    (WPEI)       401.
      FUEL SYSTEM              (WFSS)       175.
      TOTAL PROP.GROUP WT.     (WP)        3549.
0  STRUCTURES GROUP
      WING                     (WW)        4792.
      CANARD                   (WWc)        372.
      HOR. TAIL                (WHT)        459.
      VERT. TAIL               (WVT)        425.
      FUSELAGE                 (WB)        5980.   (INCL.      .0 LBS A.T.W.)
      LANDING GEAR             (WLG)       1738.
      PRIMARY ENG. SECTION     (WPES)       991.
      GROUP WEIGHT INC.        (DELWST)       0.
      TOTAL STRUC.GROUP WT.    (WST)      14757.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS         (WCC)         96.
      FIXED WING CONTROLS      (WCFW)       892.
      SAS                      (WSAS)         0.
      GROUP WEIGHT INC.        (DELWFC)       0.
      TOTAL CONTROL WT.        (WFC)        988.
0  WT. OF FIXED EQUIPMENT      (WFE)       6605.
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
   WEIGHT EMPTY               (WE)      25899.

   FIXED USEFUL LOAD          (WFUL)     1080. (INC. CREW )

   OPERATING WEIGHT EMPTY     (OWE)     26979.

0  PAYLOAD                    (WPL)     10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

   FUEL                       (WFA)      8747. (WFW= 8230.) (WFTP=    0.)

   GROSS WEIGHT               (WG)      45726.


0         FIXED EQUIP GROUP                     FIXED USEFUL LOAD
0    WAPU                 372.27       WCREW ( 2.)          340.00
     WINSTR               241.36       WSTU  ( 1.)          130.00
     WHYD                 376.77       WCBAG                110.00
     WELEC                970.00       WUF                  131.60
     WAV                  500.00       WOIL                 124.34
     WFUR                3410.00       WSRV                 116.00
     WAC                  477.91       WH2O                  53.00
     WAI                  236.26       WEMER                 40.00
     WAUXG                 20.00       WCATER                35.00

     WFE                 6604.57       WFUL                1079.94

0  DESIGN MACH =  .800          DESIGN ALTITUDE =  35000.          DESIGN Q (PSF) =224.03
0  DESIGN RE.NUM. PER FT.    = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274

0  AERODYNAMIC DATA

0                          FLATPLATE              WETTED
   DRAG BREAKDOWN         AREA(SQFT)     CDO     AREA(SQFT)
0       WING                 3.1680    .00575       741.11
        CANARD                .5046    .00092        62.03
        FUSELAGE             5.4592    .00991      1910.38
        VERT.TAIL             .6680    .00121       215.27
        HOR. TAIL             .6074    .00110       181.08
        ENGINE NAC.          1.1846    .00215       280.49
        TIP TANKS             .0000    .00000          .00
        INCREMENTAL           .8262    .00150          .00
0           TOTAL           12.4180    .02255      3390.37

            MEAN SKIN FRICTION COEF.=  .003663


0  AERODYNAMIC COEFF.                           AIRCRAFT           WING                         CANARD
                                      (except Wing and Canard)
       A1                                                          .8013                         .8306
       A2                                                         -.1227                        -.1225
       A3                                                          .0383                         .0286
       A4=.75X(T/C)                                                .0906                         .0750
       A5=CDO--                                      .0135
       A6                                                         2.4035                        2.6403
       A7=1/(PI.SEE.AR)                                            .0476                         .0677
       3-D LIFT SLOPE AT CRUISE MACH     (CLALPH)                 6.7033 PER RAD.    (CLALFc)   5.6370 PER RAD.
       OSWALD FACTOR                     (SEE)                     .8063             (SEEcan)    .8555

0  CRUISE CD =  .0224 +   .0501 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
0  RETRACTABLE LANDING GEAR CD INC.= .02727


0 CRUISE DRAG
0CL=    .2000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .02439  8.1991  5.3413   .5454
         .55000  .02439  8.1991  5.4739   .4934
         .60000  .02439  8.1991  5.6323   .4345
         .65000  .02439  8.1991  5.8228   .3680
         .70000  .02439  8.1991  6.0544   .2927
         .75000  .02439  8.1991  6.3408   .2072
         .80000  .02439  8.1991  6.7033   .1095
         .85000  .02445  8.1786  7.1781  -.0036
0CL=    .3000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .02704 11.0967  5.3413  1.6181
         .55000  .02704 11.0967  5.4739  1.5401
         .60000  .02704 11.0967  5.6323  1.4518
         .65000  .02704 11.0967  5.8228  1.3520
         .70000  .02704 11.0967  6.0544  1.2390
         .75000  .02704 11.0967  6.3408  1.1108
         .80000  .02704 11.0967  6.7033   .9642
         .85000  .02747 10.9209  7.1781   .7946
0CL=    .4000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .03068 13.0381  5.3413  2.6907
         .55000  .03068 13.0381  5.4739  2.5868
         .60000  .03068 13.0381  5.6323  2.4691
         .65000  .03068 13.0381  5.8228  2.3360
         .70000  .03068 13.0381  6.0544  2.1854
         .75000  .03068 13.0381  6.3408  2.0144
         .80000  .03068 13.0381  6.7033  1.8189
         .85000  .03209 12.4646  7.1781  1.5928
0CL=    .5000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .03550 14.0862  5.3413  3.7634
         .55000  .03550 14.0862  5.4739  3.6335
         .60000  .03550 14.0862  5.6323  3.4863
         .65000  .03550 14.0862  5.8228  3.3200
         .70000  .03550 14.0862  6.0544  3.1317
         .75000  .03550 14.0862  6.3408  2.9180
         .80000  .03550 14.0862  6.7033  2.6737
         .85000  .03878 12.8948  7.1781  2.3910
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
0CL=   .6000
              MACH      CD    L/D    CLALPH   ALPHA
            .50000  .04131 14.5229  5.3413  4.8361
            .55000  .04131 14.5229  5.4739  4.6802
            .60000  .04131 14.5229  5.6323  4.5036
            .65000  .04131 14.5229  5.8228  4.3039
            .70000  .04131 14.5229  6.0544  4.0781
            .75000  .04131 14.5229  6.3408  3.8216
            .80000  .04136 14.5056  6.7033  3.5284
            .85000  .04764 12.5937  7.1781  3.1892

 0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                          FLAPS UP                                TAKEOFF                               LANDING
       ALPHA       CL        CD         L/D         CL         CD        L/D         CL          CD        L/D
    -2.00000   -.03398   .02252 -1.50915    .97692    .07894 12.37531  1.67631    .21771   7.69977
      .00000    .13592   .02329  5.83516  1.14682    .09190 12.47889  1.84620    .23452   7.87222
     2.00000    .30582   .02722 11.23516  1.31672    .10881 12.10151  2.01610    .25600   7.87536
     4.00000    .47571   .03423 13.89603  1.48661    .13092 11.35516  2.18600    .28361   7.70777
     6.00000    .64561   .04446 14.52199  1.65651    .15716 10.54028  2.35590    .31460   7.48851
     8.00000    .81551   .05811 14.03343  1.82641    .18635  9.80085  2.52579    .34898   7.23771
    10.00000    .98541   .07577 13.00598  1.99631    .21850  9.13658  2.69569    .38674   6.97038
    11.74615   1.13374   .09606 11.80203  2.14464    .24897  8.61393  2.84402    .42247   6.73193
    11.74615   1.13374   .09606 11.80203  2.14464    .24897  8.61393  2.84402    .42247   6.73193
    11.74615   1.13374   .09606 11.80203  2.14464    .24897  8.61393  2.84402    .42247   6.73193

0                         DFLAP=       .00          DFLAP=    15.00          DFLAP=    40.00
0                         CLMAX=  1.13374           CLMAX=  2.15556           CLMAX=  2.84477

0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
    FLAP DEFL.     CLMAX     CL         CD        L/D
      10.000     1.84325
                            .67479    .05879 11.47713
                            .84469    .06905 12.23225
                           1.01458    .08276 12.25894
                           1.18448    .10052 11.78341
                           1.35438    .12407 10.91610
                           1.52428    .15087 10.10297
                           1.69417    .18060  9.38088
                           1.84325    .20909  8.81572
                           1.84325    .20909  8.81572
                           1.84325    .20909  8.81572
      20.000     2.36712
                           1.19866    .10262 11.68087
                           1.36856    .11707 11.68978
                           1.53845    .13554 11.35063
                           1.70835    .16015 10.66751
                           1.87825    .18773 10.00486
                           2.04815    .21830  9.38208
                           2.21804    .25186  8.80677
                           2.36712    .28375  8.34217
                           2.36712    .28375  8.34217
                           2.36712    .28375  8.34217
      30.000     2.67528
                           1.50682    .15172  9.93159
                           1.67672    .16776  9.99465
                           1.84661    .18843  9.80007
                           2.01651    .21453  9.39946
                           2.18641    .24373  8.97045
                           2.35631    .27603  8.53646
                           2.52620    .31142  8.11199
                           2.67528    .34501  7.75410
                           2.67528    .34501  7.75410
                           2.67528    .34501  7.75410


0ALTITUDE=      35000. FT    TAS=      471.16 KTS    MACH NO=       .8164


0                               RDT&E AND AIRFRAME PRODUCTION COSTS
                                            (1993. DOLLARS)
0                          TOTAL RDT&E COSTS          1056.8395 MILLION
0                                     AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                         500. AIRCRAFT
                                              WEIGHT(LB)      COST($)      COST($/LB)
          STRUCTURE(  4191369.$)
                               WING                   4792.     1176474.       245.50
                               CANARD                  372.      166251.       446.33
                               EMPENNAGE               884.      339096.       383.57
                               FUSELAGE               5980.     1659884.       277.57
                               LANDING GEAR           1738.      308815.       177.73
                               NACELLES                991.      540848.       545.84
          PROPULSION INSTAL(   170920.$)
                               ENGINE INSTALLAT.       401.      146124.       364.08
                               FUEL SYSTEM             175.       24796.       141.74
          SYSTEMS(  2612710.$)
                               FLIGHT CONTROLS         988.      463585.       469.41
                               HYDRAULIC               377.       46933.       124.57
                               ELECTRICAL              970.      464214.       478.57
                               AIR CONDITIONING        478.      256070.       535.82
                               ANTI-ICING              236.      124429.       526.66
                               AUX. POWER UNIT         372.      207143.       556.42
                               FURNISHINGS            3410.      796443.       233.56
                               INSTRUMENTS             241.      200191.       829.44
                               AVIONICS INSTALL.       250.       49032.       196.13
                               AUX. ITEMS               20.        4671.       233.56
          INTEGRATION(  1743750.$)
0                                AIRFRAME TOTALS     22676.     8718749.       384.50
0                                ENGINES                        2757603.
                                 PROPELLER                            0.
                                 AVIONICS                       4000000.
                                 A/C COST(NO RD)               15476352.
                                 R&D PER A/C                    2113679.
                                 TOTAL A/C COST                17590030.

0                    ENGINES       NUMBER =      2.  TYPE=      7

0 EMPTY WEIGHT= 25899.     AIRFRAME WEIGHT= 22926.     WEIGHT OF 1 ENGINE=  1486.     CRUISE SPEED= 471. KTS
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (continued)

```
0 THRUST/ENGINE=   9291.
0 TOTAL AIRCRAFT COST= 17590030.    AIRFRAME COST= 14832428.    COST OF 1 ENGINE=  1378802.    COST OF 1 PROP.=       0.

0                           --- COST DATA ---
                           GASP SHORTHAUL METHOD
0          DESIGN MISSION
0              OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0 **************************************************************************************************
0                   RANGE=    1250. N.M.    BLOCK FUEL=    6965. LBS    BLOCK TIME=  3.0039 HRS.
0   UTILIZATION                       3200.
 FLYING OPERATIONS
    FLIGHT CREW                     375.489
    FUEL,OIL,AND TAXES( .850$/G)    925.232
    INSURANCE                        82.561
 DIRECT MAINTENANCE
    AIRFRAME                        172.472
    ENGINE                          286.704
 MAINTENANCE BURD.                  373.948
 DEPRECIATION                      1109.617

    TOTAL DOC ($/TRIP)             3326.023
              ($/B.HR.)            1107.231
              ($/N.MI.)               2.660
```

Fig. D2 - Three-Lifting Surface Baseline Configuration GASP output file (concluded)

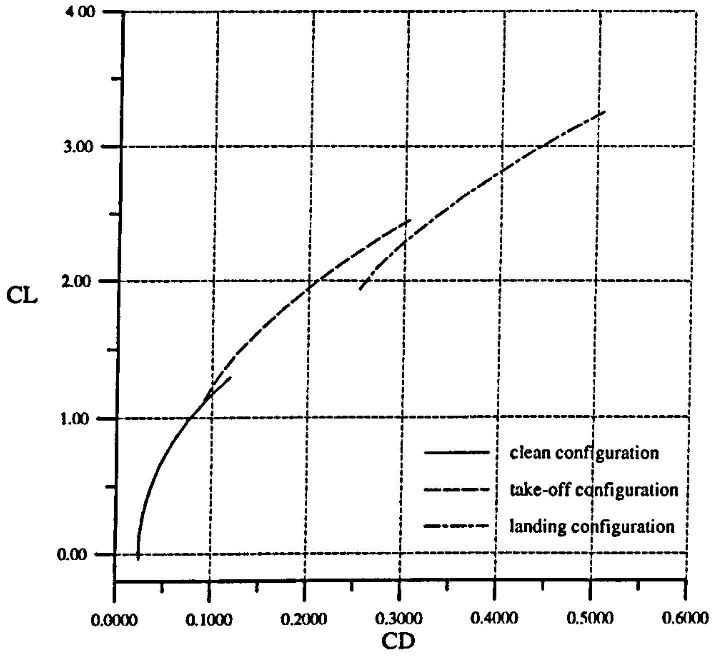

Fig. D3.1 - Conventional baseline concept low speed drag polars

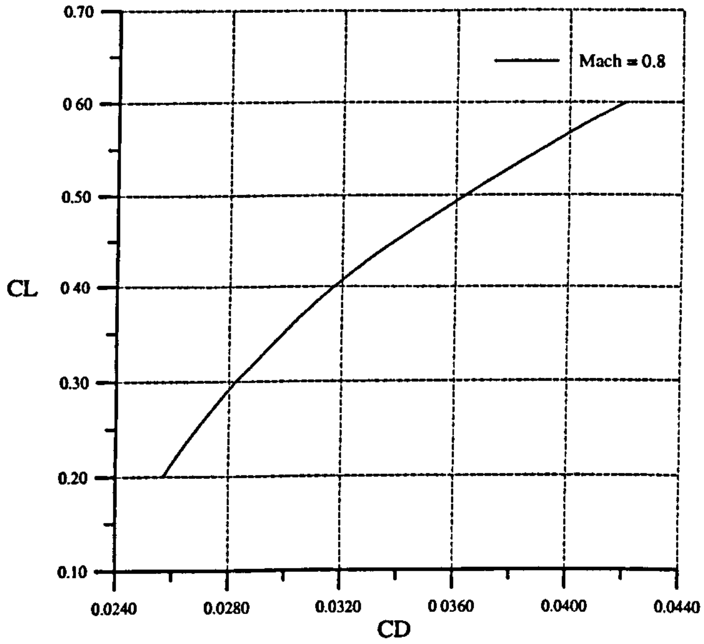

Fig. D3.2 - Conventional baseline concept Cruise drag polar

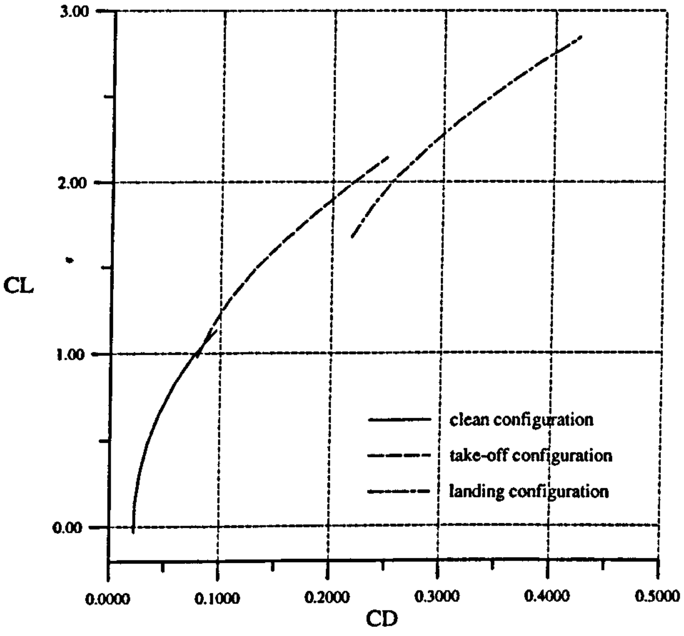

Fig. D4.1 - Three-lifting Surface baseline concept low speed drag polars

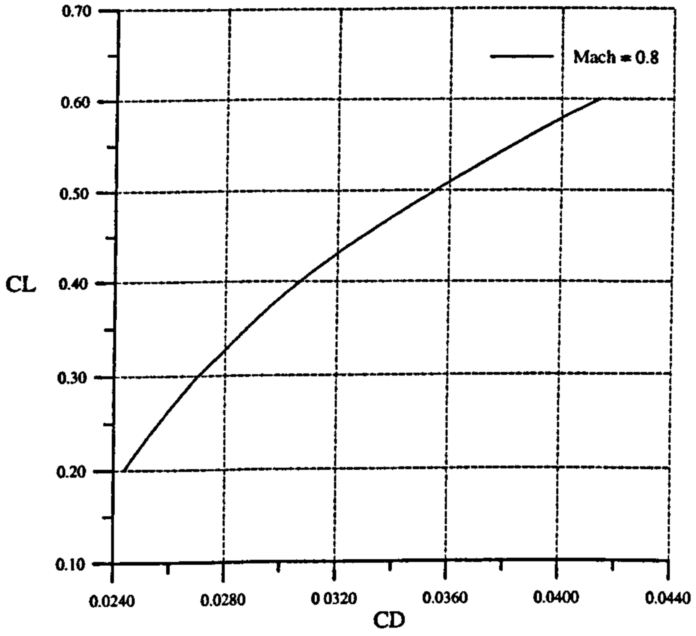

Fig. D4.2 - Three-lifting Surface baseline concept Cruise drag polar

APPENDIX E

The Optimised Designs

Introduction

Information related to the relevant optimisation work performed is included in the present Appendix.

Several local "optimum" solutions were obtained either for minimum DOC and minimum MTOW for both concepts. Fig E1 summarises the "best" solutions achieved and calls them 1st solutions. Listings of the next closest to the "best" are included as well, and are named 2nd and 3rd solutions. In addition to the values corresponding to the initial and the convergence point design variables and respective objective and constraint functions, information on the convergence type, CPU time and number of function evaluations (nfe) per run is given.

Figures E2 through E8, and E9 through E15 group the USERF and USERD RQPMIN user-defined subroutines, the optimiser RQPMIN.DAT input and RQPMIN.RES output files, and the GASP output listings corresponding to both concepts optimisation solutions, regarding respectively the minimum DOC, and the minimum MTOW cases. Figures E16 and E17 illustrate the low speed and cruise drag polars related to the conventional and the three-surface minimum DOC designs.

The user written subroutines USERF and USERD, and the RQPMIN.DAT file were written following the recommendations of ref. E1. This reference should be consulted for details not shown here. USERF assigns the design independent variables, calls the design synthesis program and defines the objective and the selected constraint functions. The independent variables chosen for the optimisations, both for the conventional and the three-surface configurations, were listed in section 5.4.2 together with their lower and upper bounds. Their assignment, as shown in figs E2 and E9, is done using the respective variable names as recognized by GASP program, and listed in Apendix H. The synthesis program is called by the name of its "MAIN" program (figs 3.6 and 3.7). However, the selected objective and the constraint functions were defined by employing the names used by GASP OUTPUT subroutine (figs 3.6 and 3.7). Before printing the results, this subroutine renames the most relevant data and incorporates them in an array called DATOUT(i). The objective and the constraint functions were defined in section 5.4.2, nevertheless, they are reproduced here for the sake of clarity:

Direct Operating Cost optimisation cases (fig E2)

Objective Function:
DATOUT(133) - Direct Operating Cost [US$/NM]

Maximum Take-off Weight optimisation cases (fig E9)

Objective Function:
DATOUT(5) - Maximum Take-off Weight [Lb]

The constraint functions, reflecting the low speed field performances and cruise performance boundary limits, are expressed in the form of inequalities. The assignment of these functions is done in terms of their residuals with regard to the mission requirements (most taken as extreme values, where the cruise Mach number was allowed to vary between M=0.76 and M=0.86). The same constraint functions were used in all optimisation cases (figs E2 and E9):

Constraint Functions:
DATOUT(92) - FAR Part 25 take-off distance [ft], (maximum value = 6000)
DATOUT(49) - FAR Part 25 landing distance [ft], (maximum value = 5000)
DATOUT(51) - approach speed [knots], EAS, (maximum value = 125)
DATOUT(109) - cruise Mach number, (min value = 0.76, max value = 0.86)

The starting point, or initial estimate of the solution, for all the optimisations performed and defined in the RQPMIN.DAT input file, corresponds to that of the baseline configurations. These are feasible designs, satisfying all the constraints, as obtained with GASP when working as a stand-alone program.

The optimisation of Three-surface configurations requires, in the present research, more design variables than the conventional aircraft. The variables allowed to be optimised are controlled in the RQPMIN.DAT file through a variable status definition controller (4th caracter place of a variable definition record) which is set accordingly (figs E3, E6, E10, and E13).

No analytical derivatives exist for the problem functions. An empty USERD subroutine was included and the driver evaluated the objective and constraint functions derivatives with respect to the design variables, by finite differences when necessary.

During its operation, RQPMIN produces progress reports and warnings which are sent to the user's terminal and to an output file (RQPMIN.RES). The frequency of the progress reports is controlled by a keyword given in the input file and their context relates to the successive stages of the optimisation process. A description of these reports was given in section 4.2.

Detailed GASP result listings of the two optimised configurations both for minimum DOC (figs E5 and E8), and minimum MTOW (figs E12 and E15), are included. The low speed and cruise drag polars related to the minimum DOC conventional and the three-surface designs are illustrated respectively in figs. E16 and E17.

In the main text, table 5.1 presents a summary of their main characteristics together with the initial parametric analysis results and the baseline designs data. Figures 5.4, 5.5, 5.6 and 5.7 show the airliner three view sketches corresponding to the four optimised designs.

References:

E1 Skrobanski,J.J.
User Guide for RQPMIN (A Program for Constrained Optimisation)
TM Aero 2059, Royal Aircraft Establishment, Farnborough, Hants, 1986

Relevant Design Optimisation Results

Direct Operating Costs Minimization (D.O.C.)

Conventional Configuration

1st Solution

```
Convergence type :   B
cpu time :          53:36.58


Initial Point

icallf =    0    nfe =    0              weight [Lb]   = 47880.4336

Merit Function
d.o.c. [$/NM]                                          =    2.7904

Independent Variables
wing loading   [lb/sqft]                               =     83.000
wing aspect ratio                                      =      8.300
wing quarter chord sweep angle [degrees]               =     14.500
wing taper ratio                                       =       .200
horizontal tail aspect ratio                           =      4.000
horizontal tail quarter chord sweep angle [degrees]    =     27.500
vertical tail aspect ratio                             =      1.000
vertical tail quarter chord sweep angle [degrees]      =     50.500

Constraint Functions
FAR 25 take-off distance [ft]                          =   4633.977
FAR 25 landing distance [ft]                           =   4016.758
approach speed [knots],EAS                             =    109.133
cruise Mach number                                     =       .795


Convergence Point

icallf =    3    nfe =  759              weight [Lb]   = 45706.8047

Merit Function
d.o.c. [$/NM]                                          =    2.6205

Independent Variables
wing loading   [lb/sqft]                               =    105.000
wing aspect ratio                                      =      8.879
wing quarter chord sweep angle [degrees]               =     14.878
wing taper ratio                                       =       .198
horizontal tail aspect ratio                           =      4.153
horizontal tail quarter chord sweep angle [degrees]    =     25.253
vertical tail aspect ratio                             =      1.012
vertical tail quarter chord sweep angle [degrees]      =     52.725

Constraint Functions
FAR 25 take-off distance [ft]                          =   5475.669
FAR 25 landing distance [ft]                           =   4807.549
approach speed [knots],EAS                             =    122.153
cruise Mach number                                     =       .830
```

Fig E1 - Relevant Design Optimisation Solutions

```
2nd Solution

Convergence type :   B
cpu time :          42:05.58


Initial Point

icallf =    0    nfe =    0             weight [Lb]   = 47899.9258

Merit Function
d.o.c. [$/NM]                                         =    2.7902

Independent Variables
wing loading    [lb/sqft]                             =      83.000
wing aspect ratio                                     =       8.300
wing quarter chord sweep angle [degrees]              =      14.500
wing taper ratio                                      =        .200
horizontal tail aspect ratio                          =       4.000
horizontal tail quarter chord sweep angle [degrees]   =      27.500
vertical tail aspect ratio                            =       1.000
vertical tail quarter chord sweep angle [degrees]     =      50.500

Constraint Functions
FAR 25 take-off distance [ft]                         =    4637.342
FAR 25 landing distance [ft]                          =    4016.663
approach speed [knots],EAS                            =     109.132
cruise Mach number                                    =        .795


Convergence Point

icallf =    3    nfe =  606             weight [Lb]   = 45594.4063

Merit Function
d.o.c. [$/NM]                                         =    2.6259

Independent Variables
wing loading    [lb/sqft]                             =     105.000
wing aspect ratio                                     =       8.240
wing quarter chord sweep angle [degrees]              =      12.193
wing taper ratio                                      =        .165
horizontal tail aspect ratio                          =       3.922
horizontal tail quarter chord sweep angle [degrees]   =      20.951
vertical tail aspect ratio                            =       1.165
vertical tail quarter chord sweep angle [degrees]     =      50.762

Constraint Functions
FAR 25 take-off distance [ft]                         =    5412.435
FAR 25 landing distance [ft]                          =    4779.025
approach speed [knots],EAS                            =     121.689
cruise Mach number                                    =        .828
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

Three-Surface Configuration

```
1st Solution

Convergence type :   B
cpu time :          37:49.32

Initial Point

icallf =    0    nfe =    0                weight [Lb]  = 46598.3594

Merit Function
d.o.c. [$/NM]                                           =    2.7339

Independent Variables
wing loading   [lb/sqft]                                =     70.378
wing aspect ratio                                       =      8.300
wing quarter chord sweep angle [degrees]                =     14.500
wing taper ratio                                        =       .200
canard aspect ratio                                     =      5.500
canard quarter chord sweep angle [degrees]              =     15.000
canard taper ratio                                      =       .500
canard incidence angle [degrees]                        =      2.000
horizontal tail aspect ratio                            =      4.000
horizontal tail quarter chord sweep angle [degrees]     =     27.500
vertical tail aspect ratio                              =      1.000
vertical tail quarter chord sweep angle [degrees]       =     50.500
canard over wing area ratio                             =       .145
engine c.g. location as a fraction of fuselage length   =       .750

Constraint Functions
FAR 25 take-off distance [ft]                           =   4668.619
FAR 25 landing distance [ft]                            =   3943.402
approach speed [knots],EAS                              =    107.597
cruise Mach number                                      =       .793


Convergence Point

icallf =    3    nfe =  619                weight [Lb]  = 44050.0000

Merit Function
d.o.c. [$/NM]                                           =    2.6132

Independent Variables
wing loading   [lb/sqft]                                =     92.966
wing aspect ratio                                       =      8.397
wing quarter chord sweep angle [degrees]                =     14.508
wing taper ratio                                        =       .202
canard aspect ratio                                     =      6.097
canard quarter chord sweep angle [degrees]              =     20.545
canard taper ratio                                      =       .503
canard incidence angle [degrees]                        =      2.033
horizontal tail aspect ratio                            =      3.908
horizontal tail quarter chord sweep angle [degrees]     =     24.435
vertical tail aspect ratio                              =       .894
vertical tail quarter chord sweep angle [degrees]       =     50.097
canard over wing area ratio                             =       .158
engine c.g. location as a fraction of fuselage length   =       .758

Constraint Functions
FAR 25 take-off distance [ft]                           =   5994.771
FAR 25 landing distance [ft]                            =   4965.626
approach speed [knots],EAS                              =    124.453
cruise Mach number                                      =       .796
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

```
2nd Solution

Convergence type :   B
cpu time :          38:51.2


Initial Point

icallf =    0    nfe =    0                weight [Lb]  = 46594.3008

Merit Function
d.o.c. [$/NM]                                              =    2.7354

Independent Variables
wing loading   [lb/sqft]                                   =     70.379
wing aspect ratio                                          =      8.300
wing quarter chord sweep angle [degrees]                   =     14.500
wing taper ratio                                           =       .200
canard aspect ratio                                        =      5.500
canard quarter chord sweep angle [degrees]                 =     15.000
canard taper ratio                                         =       .500
canard incidence angle [degrees]                           =      2.000
horizontal tail aspect ratio                               =      4.000
horizontal tail quarter chord sweep angle [degrees]        =     27.500
vertical tail aspect ratio                                 =      1.000
vertical tail quarter chord sweep angle [degrees]          =     50.500
canard over wing area ratio                                =       .145
engine c.g. location as a fraction of fuselage length      =       .750

Constraint Functions
FAR 25 take-off distance [ft]                              =   4668.039
FAR 25 landing distance [ft]                               =   3943.466
approach speed [knots],EAS                                 =    107.598
cruise Mach number                                         =       .793


Convergence Point

icallf =    3    nfe =  503                weight [Lb]  = 45354.3438

Merit Function
d.o.c. [$/NM]                                              =    2.6564

Independent Variables
wing loading   [lb/sqft]                                   =     83.813
wing aspect ratio                                          =      8.535
wing quarter chord sweep angle [degrees]                   =     17.395
wing taper ratio                                           =       .200
canard aspect ratio                                        =      6.118
canard quarter chord sweep angle [degrees]                 =     16.717
canard taper ratio                                         =       .503
canard incidence angle [degrees]                           =      2.060
horizontal tail aspect ratio                               =      4.173
horizontal tail quarter chord sweep angle [degrees]        =     28.664
vertical tail aspect ratio                                 =      1.056
vertical tail quarter chord sweep angle [degrees]          =     52.969
canard over wing area ratio                                =       .158
engine c.g. location as a fraction of fuselage length      =       .849

Constraint Functions
FAR 25 take-off distance [ft]                              =   5607.999
FAR 25 landing distance [ft]                               =   4642.339
approach speed [knots],EAS                                 =    119.277
cruise Mach number                                         =       .799
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

Maximum Take-off Weight Minimization

Conventional Configuration

```
 1st solution

 Convergence type :   B
 cpu time :          1:30:27.13


 Initial Point

 icallf =    0    nfe =    0              d.o.c. [$/NM]   = 2.7901

 Merit Function
 weight     [Lb]                                          =  47875.8320

 Independent Variables
 wing loading   [lb/sqft]                                 =     83.000
 wing aspect ratio                                        =      8.300
 wing quarter chord sweep angle [degrees]                 =     14.500
 wing taper ratio                                         =       .200
 horizontal tail aspect ratio                             =      4.000
 horizontal tail quarter chord sweep angle [degrees]      =     27.500
 vertical tail aspect ratio                               =      1.000
 vertical tail quarter chord sweep angle [degrees]        =     50.500

 Constraint Functions
 FAR 25 take-off distance [ft]                            =   4638.922
 FAR 25 landing distance [ft]                             =   4016.783
 approach speed [knots],EAS                               =    109.133
 cruise Mach number                                       =       .795


Convergence Point

icallf =    3    nfe = 1163              d.o.c. [$/NM]   = 2.6163

Merit Function
weight     [Lb]                                          =  45638.7422

Independent Variables
wing loading   [lb/sqft]                                 =    104.995
wing aspect ratio                                        =      8.717
wing quarter chord sweep angle [degrees]                 =     18.569
wing taper ratio                                         =       .170
horizontal tail aspect ratio                             =      4.036
horizontal tail quarter chord sweep angle [degrees]      =     23.943
vertical tail aspect ratio                               =      1.041
vertical tail quarter chord sweep angle [degrees]        =     52.626

Constraint Functions
FAR 25 take-off distance [ft]                            =   5598.113
FAR 25 landing distance [ft]                             =   4940.534
approach speed [knots],EAS                               =    124.209
cruise Mach number                                       =       .836
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

```
2nd Solution

Convergence type :   B
cpu time :         1:39:51.80


Initial Point

icallf =    0    nfe =    0             d.o.c. [$/NM]  = 2.7906

Merit Function
weight     [Lb]                                         =   47872.9883

Independent Variables
wgs   [lb/sqft]                                         =     83.000
wing aspect ratio                                       =      8.300
wing quarter chord sweep angle [degrees]                =     14.500
wing taper ratio                                        =       .200
horizontal tail aspect ratio                            =      4.000
horizontal tail quarter chord sweep angle [degrees]     =     27.500
vertical tail aspect ratio                              =      1.000
vertical tail quarter chord sweep angle [degrees]       =     50.500

Constraint Functions
FAR 25 take-off distance [ft]                           =   4637.960
FAR 25 landing distance [ft]                            =   4016.793
approach speed [knots],EAS                              =    109.133
cruise Mach number                                      =       .795


Convergence Point

icallf =    3    nfe = 1178             d.o.c. [$/NM]  = 2.6338

Merit Function
weight     [Lb]                                         =   45792.0430

Independent Variables
wing loading   [lb/sqft]                                =    104.970
wing aspect ratio                                       =      9.173
wing quarter chord sweep angle [degrees]                =     15.494
wing taper ratio                                        =       .185
horizontal tail aspect ratio                            =      4.083
horizontal tail quarter chord sweep angle [degrees]     =     28.425
vertical tail aspect ratio                              =      1.136
vertical tail quarter chord sweep angle [degrees]       =     45.386

Constraint Functions
FAR 25 take-off distance [ft]                           =   5481.575
FAR 25 landing distance [ft]                            =   4798.645
approach speed [knots],EAS                              =    122.029
cruise Mach number                                      =       .829
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

Three-Surface Configuration

```
 1st Solution

 Convergence type :   B
 cpu time :        1:39:57.20


 Initial Point

 icallf =    0    nfe =    0            d.o.c. [$/NM]  = 2.7356

 Merit Function
 weight     [Lb]                                       =   46568.8633

 Independent Variables
 wing loading   [lb/sqft]                              =     70.386
 wing aspect ratio                                     =      8.300
 wing quarter chord sweep angle [degrees]              =     14.500
 wing taper ratio                                      =       .200
 canard aspect ratio                                   =      5.500
 canard quarter chord sweep angle [degrees]            =     15.000
 canard taper ratio                                    =       .500
 canard incidence angle [degrees]                      =      2.000
 horizontal tail aspect ratio                          =      4.000
 horizontal tail quarter chord sweep angle [degrees]   =     27.500
 vertical tail aspect ratio                            =      1.000
 vertical tail quarter chord sweep angle [degrees]     =     50.500
 canard over wing area ratio                           =       .145
 engine c.g. location as a fraction of fuselage length =       .750

 Constraint Functions
 FAR 25 take-off distance [ft]                         =   4666.837
 FAR 25 landing distance [ft]                          =   3943.893
 approach speed [knots],EAS                            =    107.605
 cruise Mach number                                    =       .793


 Convergence Point

 icallf =    3    nfe = 1348            d.o.c. [$/NM]  = 2.6373

 Merit Function
 weight     [Lb]                                       =   44575.9922

 Independent Variables
 wing loading   [lb/sqft]                              =     90.788
 wing aspect ratio                                     =      8.841
 wing quarter chord sweep angle [degrees]              =     16.116
 wing taper ratio                                      =       .183
 canard aspect ratio                                   =      6.005
 canard quarter chord sweep angle [degrees]            =     18.238
 canard taper ratio                                    =       .496
 canard incidence angle [degrees]                      =      2.028
 horizontal tail aspect ratio                          =      3.983
 horizontal tail quarter chord sweep angle [degrees]   =     26.344
 vertical tail aspect ratio                            =      1.142
 vertical tail quarter chord sweep angle [degrees]     =     40.000
 canard over wing area ratio                           =       .172
 engine c.g. location as a fraction of fuselage length =       .811

 Constraint Functions
 FAR 25 take-off distance [ft]                         =   6004.885
 FAR 25 landing distance [ft]                          =   4911.794
 approach speed [knots],EAS                            =    123.602
 cruise Mach number                                    =       .792
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

```
2nd Solution

Convergence type :   A
cpu time :          19:05.65


Initial Point

icallf =    0    nfe =    0            d.o.c. [$/NM]  = 2.7356

Merit Function
weight     [Lb]                                        =   46569.1445

Independent Variables
wing loading   [lb/sqft]                               =     70.386
wing aspect ratio                                      =      8.300
wing quarter chord sweep angle [degrees]               =     14.500
wing taper ratio                                       =       .200
canard aspect ratio                                    =      5.500
canard quarter chord sweep angle [degrees]             =     15.000
canard taper ratio                                     =       .500
canard incidence angle [degrees]                       =      2.000
horizontal tail aspect ratio                           =      4.000
horizontal tail quarter chord sweep angle [degrees]    =     27.500
vertical tail aspect ratio                             =      1.000
vertical tail quarter chord sweep angle [degrees]      =     50.500
canard over wing area ratio                            =       .145
engine c.g. location as a fraction of fuselage length  =       .750

Constraint Functions
FAR 25 take-off distance [ft]                          =   4666.874
FAR 25 landing distance [ft]                           =   3943.885
approach speed [knots],EAS                             =    107.605
cruise Mach number                                     =       .793


Convergence Point

icallf =    3    nfe =  255            d.o.c. [$/NM]  = 2.6164

Merit Function
weight     [Lb]                                        =   44580.5117

Independent Variables
wing loading   [lb/sqft]                               =     92.180
wing aspect ratio                                      =      9.331
wing quarter chord sweep angle [degrees]               =     18.556
wing taper ratio                                       =       .160
canard aspect ratio                                    =      6.694
canard quarter chord sweep angle [degrees]             =     15.930
canard taper ratio                                     =       .552
canard incidence angle [degrees]                       =      2.146
horizontal tail aspect ratio                           =      3.975
horizontal tail quarter chord sweep angle [degrees]    =     33.387
vertical tail aspect ratio                             =      1.058
vertical tail quarter chord sweep angle [degrees]      =     46.045
canard over wing area ratio                            =       .148
engine c.g. location as a fraction of fuselage length  =       .825

Constraint Functions
FAR 25 take-off distance [ft]                          =   6023.916
FAR 25 landing distance [ft]                           =   4934.055
approach speed [knots],EAS                             =    123.992
cruise Mach number                                     =       .798
```

Fig E1 - Relevant Design Optimisation Solutions (continued)

```
3rd Solution

Convergence type :   A
cpu time :          37:39.55


Initial Point

icallf =    0    nfe =    0              d.o.c. [$/NM]  = 2.7354

Merit Function
weight     [Lb]                                          =   46594.3008

Independent Variables
wing loading    [lb/sqft]                                =      70.379
wing aspect ratio                                        =       8.300
wing quarter chord sweep angle [degrees]                 =      14.500
wing taper ratio                                         =        .200
canard aspect ratio                                      =       5.500
canard quarter chord sweep angle [degrees]               =      15.000
canard taper ratio                                       =        .500
canard incidence angle [degrees]                         =       2.000
horizontal tail aspect ratio                             =       4.000
horizontal tail quarter chord sweep angle [degrees]      =      27.500
vertical tail aspect ratio                               =       1.000
vertical tail quarter chord sweep angle [degrees]        =      50.500
canard over wing area ratio                              =        .145
engine c.g. location as a fraction of fuselage length    =        .750

Constraint Functions
FAR 25 take-off distance [ft]                            =    4668.039
FAR 25 landing distance [ft]                             =    3943.466
approach speed [knots],EAS                               =     107.598
cruise Mach number                                       =        .793


Convergence Point

icallf =    3    nfe =  474              d.o.c. [$/NM]  = 2.6132

Merit Function
weight     [Lb]                                          =   44585.0195

Independent Variables
wing loading    [lb/sqft]                                =      91.003
wing aspect ratio                                        =       8.917
wing quarter chord sweep angle [degrees]                 =      19.818
wing taper ratio                                         =        .198
canard aspect ratio                                      =       6.224
canard quarter chord sweep angle [degrees]               =      16.453
canard taper ratio                                       =        .519
canard incidence angle [degrees]                         =       2.230
horizontal tail aspect ratio                             =       3.835
horizontal tail quarter chord sweep angle [degrees]      =      23.007
vertical tail aspect ratio                               =       1.200
vertical tail quarter chord sweep angle [degrees]        =      49.247
canard over wing area ratio                              =        .147
engine c.g. location as a fraction of fuselage length    =        .822

Constraint Functions
FAR 25 take-off distance [ft]                            =    6023.080
FAR 25 landing distance [ft]                             =    4978.010
approach speed [knots],EAS                               =     124.623
cruise Mach number                                       =        .803
```

Fig E1 - Relevant Design Optimisation Solutions (concluded)

```
c
c
c                          SUBROUTINES USERF & USERD
c
c                                     BY
c
c                                  J.NUNES
c
c                                    1993
c
c                          College of Aeronautics
c
c                      CRANFIELD INSTITUTE OF TECHNOLOGY
c

      SUBROUTINE USERF(x,func,iocode,nprob,icallf,nfe)

      integer iocode(76)
      real x(50),func(76)

C     Variable declarations:
      ..............
      ..............

C     Common Block declarations:
      ..............
      ..............

C     Assignment of the Independent Variable values:

      WGS    = X(1)
      AR     = X(2)
      DLMC4  = X(3)
      SLM    = X(4)
      ARHT   = X(5)
      DWPQCH = X(6)
      ARVT   = X(7)
      DWPQCV = X(8)
      ARcan  = X(9)
      DwpqCa = X(10)
      SLMcan = X(11)
      EYEcan = X(12)
      SWcOSW = X(13)
      RELP   = X(14)

C     Execution of the Design Synthesis subroutine.

      CALL MAIN(icallf,nfe)

C     Objective Function:

      FUNC(1) = DATOUT(133)

C     Inequality Constraints:

      FUNC(2) = 6000. - DATOUT(92)
      FUNC(3) = 5000. - DATOUT(49)
      FUNC(4) = 125. - DATOUT(51)
      FUNC(5) = DATOUT(109) - .76
      FUNC(6) = .86 - DATOUT(109)

      DO I=2,6
      FUNC(I) = -FUNC(I)
```

Fig E2 - USERF.F and USERD.F subroutines used for the Direct Operating Cost optimisation cases

```
      END DO

      RETURN
      END


      SUBROUTINE USERD(x,gradcd,iocode,nprob)

      integer iocode(76)
      real x(50),gradcd(50)

      WRITE(2,100)
100   FORMAT(  'SUBROUTINE USERD CALLED, NO DERIVATIVES AVAILABLE')
      END
```

Fig E2 - USERF.F and USERD.F subroutines used for the Direct Operating Cost optimisation cases (concluded)

```
*....data for 50 Pax turbofan airliner

VARIABLES
01 1  95.0             83.000             80.000       105.000
02 1   9.0              8.300              8.000        10.000
03 1  23.0             14.500             11.000        35.000
04 1    .235             .200               .160          .310
05 1   4.0              4.000              3.800         4.300
06 1  27.5             27.500             20.000        35.000
07 1   1.0              1.000               .800         1.200
08 1  46.5             50.500             40.000        53.000
09 0   6.0              5.500              4.000         8.000
10 0  23.0             15.000             10.000        35.000
11 0    .43              .500               .160          .700
12 0   1.5              2.000               .000         3.000
13 0    .15              .15                .145          .175
14 0    .8               .75                .75           .85
FUNCTIONS
01 00 00    3.0          1
02 -1 00 6000.0
03 -1 00 5000.0
04 -1 00  120.0
05 -1 00     .8
06 -1 00     .8
CONTROLS
XTOLU = .0001
XTOLV = .0001
OFROM = 1
OFREQ = 10
RFREQ = 50
NFEMAX = 20000
RUN
END
```

Fig E3 - RQPMIN.DAT file for the Conventional D.O.C. optimisation case

```
1Program  RQPMIN  Version 1.0  for VAX

 ANALYSIS OF  INPUT FILE DATA  AND  CONTROL PARAMETERS

 Input file: rqpmin.dat
 Output file: rqpmin.res


 Variable data
 -------------

 Number of variables =    14

 Index      Status        Scale            Starting value        Lower bound          Upper bound
    1          1       .9500000E+02         .8736842E+00        .8421053E+00         .1105263E+01
    2          1       .9000000E+01         .9222223E+00        .8888889E+00         .1111111E+01
    3          1       .2300000E+02         .6304348E+00        .4782609E+00         .1521739E+01
    4          1       .2350000E+00         .8510638E+00        .6808510E+00         .1319149E+01
    5          1       .4000000E+01         .1000000E+01        .9500000E+00         .1075000E+01
    6          1       .2750000E+02         .1000000E+01        .7272727E+00         .1272727E+01
    7          1       .1000000E+01         .1000000E+01        .8000000E+00         .1200000E+01
    8          1       .4650000E+02         .1086022E+01        .8602151E+00         .1139785E+01
    9          0       .6000000E+01         .9166667E+00        .6666667E+00         .1333333E+01
   10          0       .2300000E+02         .6521739E+00        .4347826E+00         .1521739E+01
   11          0       .4300000E+00         .1162791E+01        .3720930E+00         .1627907E+01
   12          0       .1500000E+01         .1333333E+01        .0000000E+00         .2000000E+01
   13          0       .1500000E+00         .1000000E+01        .9666666E+00         .1166667E+01
   14          0       .8000000E+00         .9375000E+00        .9375000E+00         .1062500E+01

 Problem function data
 ---------------------

 Number of constraints =    5

 Index    Status     Type         Scale                 Index    Status     Type        Scale
    1        0         0      .3000000E+01                 2        -1         0      .6000000E+04
    3       -1         0      .5000000E+04                 4        -1         0      .1200000E+03
    5       -1         0      .8000000E+00                 6        -1         0      .8000000E+00

 objective is function     1                     problem number =     1


 Control parameters
 ------------------

 nfemax = 20000      nimax  =  1000      nsmax  =    20
 nsetc  =     4      nsetcf =     8      nsetv  =     4     nsetvf =     8
 ofreq  =    10      ofrom  =     1      rfreq  =    50     rfrom  =     1

 centrl = F     fdset  = F     norep  = F     cheats = T     fast   = T     quasi  = T
 fixrp  = F     timid  = F     monitr = F     nofrec = F     yesbc  = F     shrnk  = T     project = T

 xtol   =   .1000000E-05     xtolu  =   .1000000E-03     xtolv  =   .1000000E-03     gtol   =   .1000000E-02
 rtol   =   .1000000E+00     omegar =   .1000000E+00     rpmax  =   .2000000E+00
 umin   =   .1000000E-05     vminf  =   .1000000E-02     vminc  =   .1000000E-05     ctol   =   .1000000E-02
 umax   =   .1000000E+00     vmax   =   .1000000E+00     omega  =   .1000000E+00     mu     =   .1000000E-03
 bdtol  =   .1000000E+00     lmtol  =   .1000000E+00     mtol   =   .5000000E+00     cmax   =   .1000000E-01
 subtol =   .1000000E-02     qrtol  =   .1000000E+02     bfstol =   .1000000E-05     diftol =   .5000000E-03
 ztol   =   .1000000E-29

 End of input data
 -----------------
1Program  RQPMIN  Version 1.0  for VAX

 STARTING POINT


 free variables
 --------------

  1   .8736842E+00  2   .9222223E+00  3   .6304348E+00  4   .8510638E+00  5   .1000000E+01  6   .1000000E+01  7   .1000000E+01
  8   .1086022E+01

 objective function
 ------------------

 f(x) =   .9301342E+00

 inactive inequality constraints
 -------------------------------

  2  -.2276705E+00  3  -.1966485E+00  4  -.1322241E+00  5  -.4364401E-01  6  -.8135602E-01
1Program  RQPMIN  Version 1.0  for VAX                      16-Feb-94

 end of iteration number     1
 ----------------------------

 end of a successful minimization step
 one or more variables fixed on their bounds
 number of calls made to user function so far =    18
```

Fig E4 - RQPMIN.RES file for the Conventional D.O.C. optimisation case

```
 free variables
 --------------

  1   .8736842E+00  2   .9311035E+00  3   .6295375E+00  4   .8493608E+00  5   .1001428E+01  6   .9994873E+00  7   .1001758E+01

 variables fixed at or near their upper bounds
 ---------------------------------------------

  8   .1139785E+0_

 objective function
 ------------------

 f(x) =   .9276107E+00

 inactive inequality constraints
 -------------------------------

  2  -.2278682E+00  3  -.1980603E+00  4  -.1332310E+00  5  -.4598059E-01  6  -.7901944E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  1  -.1035213E+01  2   .4851818E-01  3   .1358986E-01  4   .2229214E-01  5   .4729032E+00  6   .6914138E-02  7  -.2348423E-01
  8   .8585452E+00

 convergence criteria
 --------------------

 pdatum =   .9276107E+00     ldatum =   .9276107E+00     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .6999969E+00     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .1035213E+01
 nde    =     0      ndef =     2      ndec =     0      ncalls =     4      nfuncs =     2
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number    11
 ----------------------------

 end of a successful minimization step
 one or more variables fixed on their bounds
 number of calls made to user function so far =   249

 free variables
 --------------

  5   .1003972E+01  2   .9842719E+00  3   .6453965E+00  4   .8434670E+00  7   .9974220E+00  6   .9884853E+00

 variables fixed at or near their upper bounds
 ---------------------------------------------

  8   .1139785E+01  1   .1105263E+01

 objective function
 ------------------

 f(x) =   .8741906E+00

 inactive inequality constraints
 -------------------------------

  2  -.8674577E-01  3  -.3816914E-01  4  -.2350896E-01  5  -.8725725E-01  6  -.3774278E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  5   .6669760E-01  2   .2850890E+00  3   .1919269E+00  4  -.2670288E-01  7  -.1195669E+00  6   .3973841E+00  8  -.2726912E+00
  1   .2765655E-01

 convergence criteria
 --------------------

 pdatum =   .8741906E+00     ldatum =   .8741906E+00     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .5421638E+00     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .3973841E+00
 nde    =     0      ndef =    24      ndec =     2      ncalls =    51      nfuncs =    25
1Program  RQPMIN  Version 1.0  for VAX                      16-Feb-94

 end of iteration number    19
 ----------------------------

 CONVERGENCE DETECTED  [ Code B ]     after   760 calls to user routine
```

Fig E4 - RQPMIN.RES file for the Conventional D.O.C. optimisation case (continued)

```
free variables
--------------

 5   .1038232E+01  2   .9865924E+00  3   .6468687E+00  4   .8411893E+00  7   .1011612E+01  6   .9182850E+00  8   .1133873E+01
 1   .1105263E+01

objective function
------------------

f(x) =   .8734975E+00

inactive inequality constraints
-------------------------------

 2  -.8738843E-01  3  -.3849024E-01  4  -.2372239E-01  5  -.8806892E-01  6  -.3693111E-01

Partial derivatives of Lagrangian function
------------------------------------------

 5   .3544688E+00  2   .9655952E-02  3  -.1156330E+00  4   .2655983E+00  7   .4523992E-01  6   .1238584E+00  8  -.8141994E-01
 1   .2880096E+00

convergence criteria
--------------------

pdatum =   .8734975E+00     ldatum =   .8734975E+00     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .3544688E+00     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .3544688E+00
nde    =     0      ndef =    24      ndec =    32      ncalls =   112      nfuncs =    56
```

Fig E4 - RQPMIN.RES file for the Conventional D.O.C. optimisation case (concluded)

```
                       50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - CONVENTIONAL CONFIG.
0                                   ENGINE CYCLE IS G. E.  CF-34
                                         INPUT DATA FOLLOW
                                        ********************

0
0 CONFIG  WG      =   44050.          *****GEOMETRY*****
                                      KWRITE  =        2       FUSEL  SAB     =       4.              ELODN    =    1.000
          WGS     =  105.000          IGEAR   =        0              WS      =   20.000              ELODT    =    3.200
          PAX     =      50.          KCONFG  =        0              AS      =       1.              BMLOD    =   14.500
          EMCRU   =     .800          KTIPX   =        0              WAS     =   19.000     NACELLE  KNAC     =        1
          HNCRU   =   35000.          ENP     =       2.              PS      =     31.0              ELN      =   11.848
                                      NTYE    =        7              ELPC    =   11.220              DBARN    =    3.949
          Kanard  =        0          KPLOT   =        1              HCK     =    2.470              ELRW     =   10.000

0    WING TCT     =     .100   HORIZ  VBARHX  =    .0000       VERT   VBARVX  =    .0000     Canard   TCcan    =     .100
          TCR     =     .130   TAIL   TCHT    =     .100       TAIL   TCVT    =     .120              ARcan    =    5.500
          AR      =    8.879          ARHT    =    4.153              ARVT    =    1.012              SLMcan   =     .500
          SLM     =     .198          SLMH    =     .887              SLMV    =     .700              DwpqCa   =   15.000
          DLMC4   =   14.878          DWPQCH  =   25.253              DWPQCV  =   52.725              EYEcan   =    2.000
          EYEW    =    2.000          COELTH  =     .000              BOELTV  =     .000              SWcOSW   =     .150
                                      SAH     =    1.000

0           *                        ***AERODYNAMICS***
0         CKW     =   -1.000          CKHT    =   -1.000              GRFE    =     .000              DCDSE    = -1.0000
          CKF     =   -1.000          CKTP    =   -1.000              SCFAC   =     .750              CKWc     =    2.497
          CKN     =   -1.000          DELCD   =   .00150              DLSWSW  =     .000              cmacw    =    -.060
          CKVT    =   -1.000          DELFE   =     .200              ALPHL0  =   -1.600              alzerc   =   -1.000

0         KWCD    =       12
          ACLS    =   -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR  =    2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                    *HIGH LIFT DEVICES*
0         RCLMAX  =    1.200   FLAPS  JFLTYP  =        7       LED    CLEOC   =     .000
          ALTFLP  =    5000.          DFLPTO  =   15.000              DELLED  =     .000
          FLAPN   =       1.          DFLPLD  =   40.000              DCLMLE  =     .930
          WCFLAP  =   -1.000          CFOC    =     .300              DELLEO  =   45.000
          BENGOB  =     .000          BTEOB   =     .750
                                      DCLMTE  =     .000
                                      DCDOTE  =     .000
                                      DELTEO  =     .000

0                                    ****PROPULSION****
0         JENGSZ  =        2          HPORT   =    5000.              RCCRU   =   50.000              RWCRTX   =     .970
          IPART   =        1          TDELTO  =      36.              XTORQ   =   99999.              HSCREQ   =       0.
          KODETO  =        5          KODECL  =        7              SM1D    =     .500              THIN     =       0.
          KODETR  =        5          KODEAC  =        5              HBTP    =     .437              PR       =    1.000

0                                    *****WEIGHTS*****
0         SKPEI   =    .1350          SKY     =    .1800              SKB     =  107.000              SKFS     =    .0200
          SKLG    =    .0380          SKZ     =    .2200              SKCC    =   20.000              SKWF     =    .4300
          SKMG    =    .8000          SKTL    =   1.0000              SKFW    =    .4300              SKFT     =    .9790
          SKPES   =    .3380          SKWW    =  133.400              SKSAS   =     .000              SKWTP    =   1.8900
          WPLX    =       .0          YMG     =    .2500              EGMRGN  =    .0000              LCWING   =        2
          WFEX    =       .0          RELP    =    .7500              CPMRGN  =    .2000
          WFUL    =   1078.3          RELR    =    .4500              STMRGN  =    .0000              LDCKMX   =    8.000
          UWPAX   =    200.0          CATD    =       3.              DELP    =    8.200              ATMXQC   =    3.160
          STRUT   =    .0000          VMLFSL  =    685.0              YP      =    .0000              DELWST   =       .0
          DELWFC  =       .0
0 ENGINE  WENG    =       .0          WNAC    =       .0              WPYLON  =       .0
          SWSLS   =     .160          UWNAC   =    2.287              FPYL    =     .700              XLQDE    =    3.000

0                                   *STABILITY AND CONTROL*
0         KSFixd  =        1          STATIC  =     .100              ZCG     =    5.500              CNPAC    =    .0020
          CMFLPL  =  999.000          CHALF   =  999.000              TP      =       .0              ARVTE    =   -1.000
          CMFLPT  =  999.000          CHDEL   =  999.000              CXA     =     .520              RV       =     .300
                                      RH      =     .350              DCMCLP  =     .000              TAUV     =  999.000
          CMPLD   =     .000          DEMAX   =    -25.0              HWING   =       0.              RVMCS    =     .990
                                      EYET    =       .0              dcmcpi  =     .030              DRMAX    =     25.0
                                      TAUH    =  999.000              rc      =     .350

0,                                   ***PERFORMANCE***
0    TAXI DELTT   =     .167          XLFMAX  =    1.100              DVR     =    5.000              TDELTX   =   36.000
       TO IFLY    =        1          DELTVR  =    3.500              UM      =     .020              HTMAX    =  500.000
          THEMAX  =   15.000          DV1     =    5.000              MUB     =     .400              NFAIL    =        0
          HOO     =    5000.          VRAT    =     1.10              WTMISN  =       0.

0   CLIMB ICLM    =        1   CRUISE CRMACH  =     .800              FRESF   =    1.000              FACW1    =     .920
          DELH    =    1000.          CRALT   =   35000.              RCRRQ   =   1250.0              ISWING   =        0
          VCLMB   =       .0          ICRUS   =        1              OFALT   =   25000.              OFEM     =     .500
0    LAND IWLD    =        2          XLDGRQ  =   99999.              VRATT   =    1.300              HAPP     =      50.
          TDELLD  =     36.0          ALTLND  =    5000.              RSMX    =    1000.              SINKTD   =      3.0
          TDELAY  =      1.0          WLPCT   =    .9400              TROTID  =     .000              XLFMX    =    1.200
          HTG     =      5.5          TIDLE   =       .0              VTDRAT  =      1.1

0                                    ******COST******
0         NCADE   =        1          HIR     =     .005              RI      =     .300              CMV      =     .800
          CLIAB   =   1993.0          TR      =    2.000              OHR     =  500.000              CCRW     =       0.
          HRI      =4000000.          PRV     =     .100              CRWOH   =   23.000              UCSENG   =     .000
          CMP     =       .2          DYR     =     15.0              CINP    =       0.              UCSPP    =     .000
          TBO     =   3200.0          SRPM    =       .0              CP      =       0.              ALR      =    1.120
          FCSP    =     .850
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution

```
**********************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1   .1790  -.1365
  GROSS WGT, GROSS WGT MINUS1      45706.8     47880.4

0  ******************************************************************************************
0                    FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                   CLMAX      VSTALL,KTS  FLAP ANGLE   LE ANGLE     DELTA CL     DELTA CD

 FLAPS UP          1.3173       165.5          .0          .0         .0000        .0000
 T.O. CONFIG       2.5033       120.0        15.0          .0        1.1756        .0429
 LDG. CONFIG       3.2957       104.7        40.0          .0        1.9834        .1911

0                   DOUBLE SLOTTED FOWLER FLAPS
                   OPT ANGLE    DELCL AT OPT  DELCD AT OPT    AREA(FT2)      WEIGHT(LB)

 FLAPS                30.0         2.2500         .1500          90.1          644.3
0  ******************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.215   LIFT= 44335.6   L/D=  12.669   ALTITUDE= 35000.0   MACH=   .8000

1                                     ENGINE SIZING DATA FOLLOW
                                      **************************
0VSTLKT= 111.2 KTS EAS   VRAT= 1.100 CLTO= 2.0688
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   25.3 AND TAS=   135.1 EAS=   121.2)
 LIFTOFF (TIME=   27.4 DIST=   3604.2 TAS=   143.5 EAS=   128.8)
 DISTANCE TO 35 FT.=  4944.7   TAS=   158.2 EAS=   141.9 V35/VS=  1.2753
 GEAR RETRACTION STARTED AT   33.5 SEC,COMPLETE AT   40.5 SEC
 FLAP RETRACTION STARTED AT   43.7 SEC,COMPLETE AT   48.2 SEC
0VSTLKT= 111.2 KTS EAS   VRAT= 1.100 CLTO= 2.0688
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  212.7 KNOTS EAS
 ENGINE FAILURE (TIME=   23.9 AND TAS=   129.6 EAS=   116.2)
0
 ROTATION (TIME=   27.6 AND TAS=   135.1 EAS=   121.2)
 LIFTOFF (TIME=   30.6 DIST=   4319.6 TAS=   138.8 EAS=   124.5)
 DISTANCE TO 35 FT.=  5991.1   TAS=   140.6 EAS=   126.1 V35/VS=  1.1333


     ACCELERATE - STOP DISTANCE =     6227.4 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      5991.1 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      4944.7 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =      5686.3 FEET
 ALL ENGINE DISTANCE TO 50 FT. =      5187.3 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .013 HRS   FUEL USED=       76. LBS   WEIGHT=   45631. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                         VS            V      GRAD      R/C   REQ.R/C
   CONFIGURATION                               ALT (FT)  KEAS   V/VS   KTAS   (PCT)    (FPM)    (FPM)    CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT 5000.  111.4  1.1257  139.8   1.968   278.43     1.00  1.984  8.247
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  111.4  1.2000  149.6   4.140   626.56   363.26  1.745 10.297
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  152.9  1.2500  218.1   4.668  1030.29   264.86   .853 13.118
   APPROACH FLAPS -ONE ENG OUT                   5000.  106.7  1.3997  166.5   4.681   788.47   353.74  1.398 11.218
   LANDING FLAPS - ALL ENGINES                   5000.   97.1  1.3000  140.7  13.961  1987.52   455.55  1.957  7.042

     APPROACH FLAP SETTING = 19.8 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 22097.6 FT.
         BEST RATE OF CLIMB SPEED    =    276.2 KTAS
         ENGINE-OUT RATE OF CLIMB    =     49.6 FPM
         WEIGHT AT ALTITUDE          = 43878.5 LBS

0                      ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE              1496.0
   NACELLE WEIGHT/ENGINE              336.4
   PYLON WEIGHT/ENGINE                176.5
      PROP OR QFAN           .0
      GEARBOX                .0
      SHROUD                 .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.95
   NACELLE LENGTH(FT)              11.86


0VSTLKT= 111.2 KTS EAS   VRAT= 1.100 CLTO= 2.0688
      VEND =  249.8 KNOTS EAS
0
 ROTATION (TIME=   24.1 AND TAS=   135.1 EAS=   121.2)
 LIFTOFF (TIME=   26.2 DIST=   3451.2 TAS=   143.9 EAS=   129.1)
 DISTANCE TO 35 FT.=  4789.4   TAS=   159.5 EAS=   143.0 V35/VS=  1.2860
 GEAR RETRACTION STARTED AT   32.3 SEC,COMPLETE AT   39.3 SEC
 FLAP RETRACTION STARTED AT   42.4 SEC,COMPLETE AT   46.9 SEC
0VSTLKT= 111.2 KTS EAS   VRAT= 1.100 CLTO= 2.0688
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  207.3 KNOTS EAS
 ENGINE FAILURE (TIME=   22.8 AND TAS=   129.6 EAS=   116.2)
0
 ROTATION (TIME=   26.0 AND TAS=   135.1 EAS=   121.2)
 LIFTOFF (TIME=   29.0 DIST=   4078.5 TAS=   139.1 EAS=   124.8)
 DISTANCE TO 35 FT.=  5580.5   TAS=   141.2 EAS=   126.6 V35/VS=  1.1378
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
      ACCELERATE - STOP DISTANCE =    6101.6 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     5580.5 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     4789.4 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     5507.8 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5034.4 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .012 HRS   FUEL USED=      77. LBS   WEIGHT=   45630. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                             VS               V      GRAD       R/C    REQ.R/C
   CONFIGURATION                                  ALT (FT)  KEAS    V/VS    KTAS    (PCT)     (FPM)     (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT   5000.   111.4  1.1257  139.8    2.312    326.96      1.00  1.984  8.068
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT           5250.   111.4  1.2000  149.6    4.457    674.55    363.26  1.745 10.004
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT         6500.   152.9  1.2500  218.1    4.726   1043.12    264.86   .853 12.348
   APPROACH FLAPS -ONE ENG OUT                    5000.   106.7  1.3997  166.5    4.946    833.20    353.74  1.398 10.823
   LANDING FLAPS - ALL ENGINES                    5000.    97.1  1.3000  140.7   15.101   2149.73    455.55  1.957  7.001

     APPROACH FLAP SETTING = 19.8 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 22627.0 FT.
         BEST RATE OF CLIMB SPEED    =   277.6 KTAS
         ENGINE-OUT RATE OF CLIMB    =    50.0 FPM
         WEIGHT AT ALTITUDE          = 43878.5 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    382.59

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    382.59

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   9756.0 LBS
**************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE             1561.0
   NACELLE WEIGHT/ENGINE             336.4
   PYLON WEIGHT/ENGINE               181.1
      PROP OR QFAN           .0
      GEARBOX                .0
      SHROUD                 .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.95
   NACELLE LENGTH(FT)              11.86

0**************************************************************************************************************
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
                    ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

             MOST FWD LOAD            MOST AFT LOAD            DESIGN LOAD
              WT          CG           WT          CG           WT          CG

 A/C OWE    26632.33    43.75     26632.33    43.75      26632.33    43.75
 PAX         6120.00               2040.00                8500.00
 BAGGAGE         .00    56.36      1500.00    56.36       1500.00    56.36
 WING FUEL   1370.17    44.55      6850.87    44.55       6850.87    44.55
 TIP FUEL        .00      .00          .00      .00           .00      .00
 FUS FUEL        .00    44.55          .00    44.55       2223.61    44.55
 TOTAL      34122.50    41.32     37023.20    44.65      45706.80    43.00

0                    ---TAIL SIZING SUMMARY---

         Static Longitudinal Stability, Stick-fixed, considered


0                   WING                  CANARD         TAIL         DOWN   FLAP
 CONDITION  ALPHA    CL     CLA     CMac  ALPHA   CLA    CLA   EFF.   WASH   CM

  CRUISE   2.3333  .4694  .1193 -.0600  .0000  .0000  .0792 1.0000
  LIFTOFF  2.0000 1.4887  .0665 -.0600  .0000  .0000  .0653 1.0000  .3417 -.1031
  LANDING 13.7355 3.2957  .0856 -.0600  .0000  .0000  .0653 1.0000 2.3468 -.2000

0         --FUSELAGE-- ---NACELLE--         -------POWER-------          L.GEAR ROT.POWER
 CONDITION  DCM    CM     DCM    CM  DCMdth DCMfinc CMdth  CMfinc   CT     CM      CM

  CRUISE   .5211         .1250         .0000  .0300                .0000
  LIFTOFF  .9347  .0000  .1250  .0000                .0000  .0447  .0000 -.7071 5.5738
  LANDING  .7267  .7297  .1250  .1255                .0000  .0989

0      ELEVATOR PARAMETERS
           CMDELTE(CONTROL POWER)        = -.06425            WING DE/DALPHA =   .34172
           TAUH(EFFECTIVENESS)           =  .48250
           DEMAX(MAX.ELEVATOR DEFLEC.)   =-25.00000


0                                  FRACTION    STATION          HORIZONTAL TAIL SIZES
                                     MAC     (DATUM NOSE)
      NEUTRAL POINT                 .4650      45.211          STATIC STABILITY AND LANDING TRIM    161.6600
      STATIC MARGIN                 .1000                      STATIC STABILITY AND LIFTOFF ROT.    165.0607
      AFT CG LIMIT(STABILITY)       .3650      44.406
      CG RANGE(LOADING)             .4130                      REQUIRED TAIL SIZE                   165.0607
      FWD CG LIMIT(CONTROL)        -.0481      41.069          TAIL ARM(ELTH)                        44.1978

0     VERTICAL TAIL AREA =   99.7735 FOR DIRECTIONAL STABILITY OF      .00200
0     RUDDER POWER AT MAX.DEFL.=   .0180 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4491
0     VERTICAL TAIL AREA=   89.6395 FOR MINIMUM CONTROL SPEED =    110.10 KTS
0     REQUIRED VERTICAL TAIL AREA =   99.7735  TAIL ARM(ELTV) =   33.1082

************************************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.215   LIFT= 44335.6   L/D=  12.153   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25        H-TAIL VOL. ARM        =   44.20        C.G.LOCATION OF PROPULSION=   59.43
 WING 1/4C LOC.ON C.L.=   40.38        H-TAIL C.G.LOCATION    =   88.29        C.G.OF REMAINING WEIGHT   =   35.66
 MAC 1/4C LOCATION     =   43.59        H-TAIL MAC FROM C.L. =    6.41
 MAC DIST.FROM C.L.    =   12.07        H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   45.20        V-TAIL VOL. ARM        =   33.11
 TIP TANKS C.G.LOCATE =      .00        V-TAIL C.G.LOCATION    =   77.50        DIST.L.E.VERT.TO L.E.HORZ.=    1.50
0                         WING        H-TAIL       V-TAIL

   AREA                 435.303      165.061       99.774
   SPAN                  62.171       26.182       10.046
   ASPECT RATIO           8.879        4.153        1.012
   TAPER RATIO             .198         .887         .700
   1/4C. SWEEP           14.878       25.253       52.725
   L.E. SWEEP            18.835       25.924       54.483
   C.L. CHORD            11.692        6.682       11.684
   MEAN CHORD             8.049        6.312       10.034
   TIP CHORD              2.311        5.927        8.179
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
0                                  MISSION PERFORMANCE DATA FOLLOWS
                                   ********************************
0   TAXI AT IDLE THRUST

                    FUEL                              FUEL
  TIME    RANGE     USED     WEIGHT     ALT.          FLOW
  (HRS)   (NM)      (LBS)    (LBS)      (FT)        (LB/HR)

   .000       0.        0.   45707.     5000.        892.
   .167       0.      149.   45558.     5000.        892.
0VSTLKT= 111.0 KTS EAS   VRAT= 1.100 CLTO= 2.0688
      VEND =  250.0 KNOTS EAS
0           (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                    FUEL                                                                                                               FUEL    FUS.
   TIME    DIST.    USED    WEIGHT     ALT.      TAS      EAS   MACH  ACCEL      CL       CD  ALPHA GAMMA       ROC    LOAD THRUST    FLOW    ANGLE
  (SEC)   (FEET)   (LBS)     (LBS)     (FT)     (KTS)    (KTS)   NO.  (FPS2)                  (DEG) (DEG)     (FPM)    FACT  (LBS)  (LB/HR)  (DEG)

     .0       .0   148.5   45558.   5000.0       .0       .0  .000  11.57 1.4863  .1309  2.00   .00        .0    .00  17303.    6162.    .00
    1.0      5.8   150.2   45557.   5000.0      6.8      6.1  .010  11.41 1.4863  .1309  2.00   .00        .0    .00  17085.    6162.    .00
    2.0     23.0   152.0   45555.   5000.0     13.5     12.2  .020  11.25 1.4864  .1309  2.00   .00        .0    .00  16871.    6163.    .00
    3.0     51.5   153.7   45553.   5000.0     20.2     18.1  .030  11.08 1.4864  .1309  2.00   .00        .0    .00  16660.    6164.    .00
    4.0     91.1   155.4   45551.   5000.0     26.7     24.0  .040  10.91 1.4865  .1309  2.00   .00        .0    .00  16454.    6165.    .00
    5.0    141.6   157.1   45550.   5000.0     33.1     29.7  .049  10.74 1.4866  .1309  2.00   .00        .0    .00  16251.    6167.    .00
    6.0    203.0   158.8   45548.   5000.0     39.5     35.4  .059  10.56 1.4867  .1309  2.00   .00        .0    .00  16052.    6169.    .00
    7.0    274.9   160.5   45546.   5000.0     45.7     41.0  .068  10.37 1.4868  .1310  2.00   .00        .0    .00  15855.    6172.    .00
    8.0    357.2   162.2   45545.   5000.0     51.8     46.5  .077  10.19 1.4870  .1310  2.00   .00        .0    .00  15662.    6174.    .00
    9.0    449.8   164.0   45543.   5000.0     57.8     51.8  .086  10.00 1.4872  .1310  2.00   .00        .0    .00  15473.    6176.    .00
   10.0    552.4   165.7   45541.   5000.0     63.7     57.1  .095   9.81 1.4873  .1310  2.00   .00        .0    .00  15288.    6179.    .00
   11.0    664.9   167.4   45539.   5000.0     69.5     62.3  .103   9.63 1.4875  .1310  2.00   .00        .0    .00  15120.    6182.    .00
   12.0    787.0   169.1   45538.   5000.0     75.1     67.4  .112   9.46 1.4877  .1310  2.00   .00        .0    .00  14982.    6186.    .00
   13.0    918.6   170.8   45536.   5000.0     80.7     72.4  .120   9.29 1.4880  .1310  2.00   .00        .0    .00  14847.    6189.    .00
   14.0   1059.5   172.5   45534.   5000.0     86.2     77.3  .128   9.12 1.4882  .1311  2.00   .00        .0    .00  14713.    6193.    .00
   15.0   1209.6   174.3   45532.   5000.0     91.5     82.1  .136   8.94 1.4885  .1311  2.00   .00        .0    .00  14583.    6196.    .00
   16.0   1368.6   176.0   45531.   5000.0     96.8     86.8  .144   8.77 1.4887  .1311  2.00   .00        .0    .00  14455.    6200.    .00
   17.0   1536.5   177.7   45529.   5000.0    102.0     91.5  .151   8.59 1.4890  .1311  2.00   .00        .0    .00  14329.    6204.    .00
   18.0   1713.0   179.4   45527.   5000.0    107.0     96.0  .159   8.42 1.4893  .1311  2.00   .00        .0    .00  14206.    6209.    .00
   19.0   1897.9   181.2   45526.   5000.0    112.0    100.4  .166   8.24 1.4895  .1312  2.00   .00        .0    .00  14086.    6213.    .00
   20.0   2091.1   182.9   45524.   5000.0    116.8    104.8  .173   8.06 1.4898  .1312  2.00   .00        .0    .00  13968.    6217.    .00
   21.0   2292.4   184.6   45522.   5000.0    121.6    109.1  .180   7.89 1.4901  .1312  2.00   .00        .0    .00  13852.    6222.    .00
   22.0   2501.7   186.3   45520.   5000.0    126.2    113.2  .187   7.71 1.4904  .1312  2.00   .00        .0    .00  13739.    6226.    .00
   23.0   2718.7   188.1   45519.   5000.0    130.7    117.3  .194   7.53 1.4907  .1313  2.00   .00        .0    .00  13628.    6231.    .00
   24.0   2943.2   189.8   45517.   5000.0    135.2    121.2  .201   7.36 1.4911  .1313  2.00   .00        .0    .00  13523.    6235.    .00
0
 ROTATION (TIME=   23.9 AND TAS=   134.9 EAS=   121.0)
   25.0  3175.1   191.5  45515.  5000.0  139.5  125.1  .207     7.06 1.6315  .1429  3.67   .00        .0    .83  13446.    6240.   1.67
   26.0  3414.1   193.3  45513.  5000.0  143.5  128.8  .213     6.69 1.7966  .1577  5.70   .00        .0    .97  13373.    6244.   3.70
 LIFTOFF (TIME=   26.0 DIST=  3414.1 TAS=   143.5 EAS=   128.8)
   27.0  3659.9   195.0  45512.  5000.4  147.4  132.2  .219     6.14 1.9022  .1687  7.02   .30      77.0   1.09  13304.    6249.   5.31
   28.0  3911.8   196.7  45510.  5003.3  150.9  135.3  .224     5.52 1.8264  .1699  5.92  1.01     270.4   1.10  13241.    6252.   4.93
   29.0  4169.1   198.5  45508.  5009.4  153.9  138.1  .229     4.83 1.7658  .1760  5.12  1.71     465.5   1.10  13184.    6255.   4.83
   30.0  4431.3   200.2  45507.  5018.8  156.7  140.5  .233     4.25 1.7041  .1781  4.42  2.39     661.8   1.10  13133.    6257.   4.81
   31.0  4697.6   202.0  45505.  5031.5  159.0  142.6  .236     3.74 1.6583  .1776  3.92  3.07     862.4   1.10  13087.    6258.   4.98
 DISTANCE TO 35 FT.=  4761.5   TAS=   159.6 EAS=   143.1 V35/VS=  1.2883
   32.0  4967.6   203.7  45503.  5047.5  161.2  144.5  .239     3.31 1.6135  .1741  3.42  3.73    1063.0   1.10  13046.    6258.   5.15
 GEAR RETRACTION STARTED AT   32.1 SEC,COMPLETE AT   39.1 SEC
   33.0  5240.7   205.4  45501.  5066.9  163.0  146.1  .242     3.00 1.5783  .1667  3.02  4.38    1261.9   1.10  13007.    6258.   5.40
   34.0  5516.6   207.2  45500.  5089.6  164.8  147.6  .245     2.74 1.5435  .1580  2.62  5.02    1461.3   1.09  12971.    6257.   5.64
   35.0  5795.0   208.9  45498.  5115.6  166.3  148.9  .247     2.47 1.5176  .1504  2.32  5.65    1659.7   1.10  12937.    6255.   5.97
   36.0  6075.6   210.6  45496.  5144.9  167.7  150.1  .249     2.23 1.4916  .1427  2.02  6.28    1858.0   1.09  12906.    6253.   6.29
   37.0  6358.1   212.4  45494.  5177.5  169.0  151.2  .251     1.97 1.4743  .1362  1.82  6.89    2054.8   1.10  12875.    6250.   6.71
   38.0  6642.2   214.1  45493.  5213.4  170.1  152.1  .253     1.73 1.4569  .1297  1.62  7.51    2252.7   1.10  12847.    6247.   7.13
   39.0  6927.7   215.8  45491.  5252.6  171.1  152.9  .254     1.49 1.4395  .1232  1.42  8.12    2449.7   1.10  12821.    6243.   7.54
   40.0  7214.3   217.6  45489.  5295.1  171.9  153.5  .255     1.17 1.4221  .1207  1.22  8.73    2644.1   1.09  12797.    6238.   7.95
   41.0  7501.6   219.3  45487.  5340.7  172.5  154.0  .256      .83 1.4134  .1198  1.12  9.33    2833.2   1.10  12776.    6232.   8.44
   42.0  7789.2   221.0  45486.  5389.5  172.9  154.2  .257      .50 1.4047  .1189  1.02  9.93    3021.1   1.09  12757.    6226.   8.94
 FLAP RETRACTION STARTED AT   42.2 SEC,COMPLETE AT   46.7 SEC
   43.0  8076.9   222.8  45484.  5441.1  173.2  154.3  .257      .35 1.2501  .1173  1.62 10.25    3122.8    .98  12741.    6219.   9.87
   44.0  8365.0   224.5  45482.  5492.3  173.4  154.4  .258      .27 1.1465  .1293  3.42  9.83    3001.0    .91  12726.    6212.  11.25
0VSTLKT= 111.0 KTS EAS   VRAT= 1.100 CLTO= 2.0688
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  207.1 KNOTS EAS
0           (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                    FUEL                                                                                                               FUEL    FUS.
   TIME    DIST.    USED    WEIGHT     ALT.      TAS      EAS   MACH  ACCEL      CL       CD  ALPHA GAMMA       ROC    LOAD THRUST    FLOW    ANGLE
  (SEC)   (FEET)   (LBS)     (LBS)     (FT)     (KTS)    (KTS)   NO.  (FPS2)                  (DEG) (DEG)     (FPM)    FACT  (LBS)  (LB/HR)  (DEG)

     .0       .0   148.5   45558.   5000.0       .0       .0  .000  11.57 1.4863  .1309  2.00   .00        .0    .00  17303.    6162.    .00
    1.0      5.8   150.2   45557.   5000.0      6.8      6.1  .010  11.41 1.4863  .1309  2.00   .00        .0    .00  17085.    6162.    .00
    2.0     23.0   152.0   45555.   5000.0     13.5     12.2  .020  11.25 1.4864  .1309  2.00   .00        .0    .00  16871.    6163.    .00
    3.0     51.5   153.7   45553.   5000.0     20.2     18.1  .030  11.08 1.4864  .1309  2.00   .00        .0    .00  16660.    6164.    .00
    4.0     91.1   155.4   45551.   5000.0     26.7     24.0  .040  10.91 1.4865  .1309  2.00   .00        .0    .00  16454.    6165.    .00
    5.0    141.6   157.1   45550.   5000.0     33.1     29.7  .049  10.74 1.4866  .1309  2.00   .00        .0    .00  16251.    6167.    .00
    6.0    203.0   158.8   45548.   5000.0     39.5     35.4  .059  10.56 1.4867  .1309  2.00   .00        .0    .00  16052.    6169.    .00
    7.0    274.9   160.5   45546.   5000.0     45.7     41.0  .068  10.37 1.4868  .1310  2.00   .00        .0    .00  15855.    6172.    .00
    8.0    357.2   162.2   45545.   5000.0     51.8     46.5  .077  10.19 1.4870  .1310  2.00   .00        .0    .00  15662.    6174.    .00
    9.0    449.8   164.0   45543.   5000.0     57.8     51.8  .086  10.00 1.4872  .1310  2.00   .00        .0    .00  15473.    6176.    .00
   10.0    552.4   165.7   45541.   5000.0     63.7     57.1  .095   9.81 1.4873  .1310  2.00   .00        .0    .00  15288.    6179.    .00
   11.0    664.9   167.4   45539.   5000.0     69.5     62.3  .103   9.63 1.4875  .1310  2.00   .00        .0    .00  15120.    6182.    .00
   12.0    787.0   169.1   45538.   5000.0     75.1     67.4  .112   9.46 1.4877  .1310  2.00   .00        .0    .00  14982.    6186.    .00
   13.0    918.6   170.8   45536.   5000.0     80.7     72.4  .120   9.29 1.4880  .1310  2.00   .00        .0    .00  14847.    6189.    .00
   14.0   1059.5   172.5   45534.   5000.0     86.2     77.3  .128   9.12 1.4882  .1311  2.00   .00        .0    .00  14713.    6193.    .00
   15.0   1209.6   174.3   45532.   5000.0     91.5     82.1  .136   8.94 1.4885  .1311  2.00   .00        .0    .00  14583.    6196.    .00
   16.0   1368.6   176.0   45531.   5000.0     96.8     86.8  .144   8.77 1.4887  .1311  2.00   .00        .0    .00  14455.    6200.    .00
   17.0   1536.5   177.7   45529.   5000.0    102.0     91.5  .151   8.59 1.4890  .1311  2.00   .00        .0    .00  14329.    6204.    .00
   18.0   1713.0   179.4   45527.   5000.0    107.0     96.0  .159   8.42 1.4893  .1311  2.00   .00        .0    .00  14206.    6209.    .00
   19.0   1897.9   181.2   45526.   5000.0    112.0    100.4  .166   8.24 1.4895  .1312  2.00   .00        .0    .00  14086.    6213.    .00
   20.0   2091.1   182.9   45524.   5000.0    116.8    104.8  .173   8.06 1.4898  .1312  2.00   .00        .0    .00  13968.    6217.    .00
   21.0   2292.4   184.6   45522.   5000.0    121.6    109.1  .180   7.89 1.4901  .1312  2.00   .00        .0    .00  13852.    6222.    .00
   22.0   2501.7   186.3   45520.   5000.0    126.2    113.2  .187   7.71 1.4904  .1312  2.00   .00        .0    .00  13739.    6226.    .00
ENGINE FAILURE (TIME=    22.7 AND TAS=   129.4 EAS=   116.0)
   23.0   2718.7   187.9   45519.   5000.0    130.5    117.1  .194   2.59 1.4907  .1407  2.00   .00        .0    .00   6817.    3115.    .00
   24.0   2940.2   188.8   45518.   5000.0    132.0    118.4  .196   2.55 1.4909  .1403  2.00   .00        .0    .00   6799.    3116.    .00
   25.0   3164.4   189.6   45517.   5000.0    133.5    119.7  .198   2.50 1.4910  .1400  2.00   .00        .0    .00   6781.    3117.    .00
   26.0   3391.0   190.5   45516.   5000.0    134.9    121.1  .200   2.46 1.4911  .1397  2.00   .00        .0    .00   6763.    3117.    .00
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
0
 ROTATION (TIME=   26.0 AND TAS=   134.9 EAS=   121.0)
   27.0  3620.2   191.4  45515.  5000.0  136.4  122.3  .202   2.29 1.6236  .1504  3.58   .00      .0   .79   6751.    3118.  1.58
   28.0  3851.6   192.2  45515.  5000.0  137.7  123.5  .204   2.06 1.7886  .1649  5.61   .00      .0   .89   6739.    3119.  3.61
   29.0  4085.1   193.1  45514.  5000.0  138.8  124.5  .206   1.81 1.9537  .1807  7.72   .00      .0   .99   6729.    3120.  5.72
 LIFTOFF (TIME=   29.0 DIST=   4085.1 TAS=   138.8 EAS=   124.5)
   30.0  4320.3   194.0  45513.  5000.4  139.8  125.4  .208   1.42 2.0574  .1924  9.06   .26    64.2  1.06   6720.    3120.  7.31
   31.0  4557.0   194.8  45512.  5002.6  140.5  126.0  .209    .88 2.0688  .2032  8.96   .85   211.0  1.08   6714.    3120.  7.81
   32.0  4794.5   195.7  45511.  5007.5  140.8  126.3  .209    .22 2.0688  .2197  8.73  1.51   374.7  1.09   6710.    3120.  8.23
   33.0  5032.2   196.6  45510.  5014.9  140.8  126.3  .209   -.01 1.9508  .2172  7.29  1.97   491.1  1.02   6709.    3120.  7.26
   34.0  5269.9   197.4  45509.  5023.2  140.8  126.3  .209    .01 1.8889  .2159  6.59  1.99   495.1   .99   6708.    3119.  6.57
   35.0  5507.6   198.3  45509.  5031.3  140.8  126.3  .209   -.01 1.8873  .2199  6.59  1.90   472.9   .99   6707.    3118.  6.49
 DISTANCE TO 35 FT.=  5620.7   TAS=   140.8 EAS=   126.3 V35/VS=  1.1370
   36.0  5745.3   199.2  45508.  5039.0  140.8  126.3  .209    .01 1.8863  .2221  6.59  1.80   449.2   .99   6706.    3118.  6.39
   37.0  5983.0   200.0  45507.  5046.3  140.8  126.2  .209    .00 1.8944  .2249  6.69  1.73   430.8   .99   6705.    3117.  6.42


      ACCELERATE - STOP DISTANCE =    6086.0 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     5620.7 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     4761.5 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =    5475.7 FEET
 ALL ENGINE DISTANCE TO 50 FT. =    5004.8 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .179 HRS   FUEL USED=     225. LBS   WEIGHT=  45482. LBS   ALT.=    5500. FT.

    ACCELERATE TO MACH NO. = .418

0                FUEL                                                           FUEL
  TIME   RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST    FLOW
  (HRS)  (NM)    (LBS)   (LBS)     (FT)   (KTS)  (KTS)    NO.   DIV    (LBS)   (LB/HR)

  .179     .00   224.8  45482.   5500.   167.   154.  .258  .702  13019.    6122.
  .187    1.88   276.8  45430.   5500.   271.   250.  .418  .800  11135.    6286.

  END OF ACCELERATION SEGMENT
  TIME=  .187 HRS   FUEL USED=   276.8 LBS   WEIGHT=  45430. LBS   RANGE=     2. NM
0   CLIMB TO   35000. FT. AT MAXIMUM RATE OF CLIMB
0               FUEL                                                                                 FUS.                       FUEL
  TIME   RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH    CL      CD    ALPHA GAMMA ANGLE    R/C    THRUST    FLOW
  (HRS)  (NM)    (LBS)   (LBS)     (FT)   (KTS)  (KTS)    NO.   DIV                  (DEG) (DEG) (DEG)   (FPM)   (LBS)   (LB/HR)

   .187      2.    277.  45430.   5500.   251.   232.  .387  .792  .5680  .0433  4.67  8.18 10.85   3622.    9887.    5534.
   .189      2.    289.  45417.   6000.   252.   231.  .389  .791  .5726  .0435  4.72  7.73 10.45   3440.    9800.    5481.
   .194      4.    316.  45391.   7000.   261.   235.  .404  .794  .5520  .0423  4.46  6.34  8.80   2923.    9505.    5373.
   .200      5.    347.  45360.   8000.   265.   235.  .411  .794  .5533  .0424  4.46  6.85  9.31   3199.    9307.    5254.
   .205      7.    374.  45333.   9000.   267.   234.  .417  .793  .5593  .0427  4.51  6.78  9.29   3197.    9123.    5139.
   .210      8.    401.  45306.  10000.   270.   232.  .423  .792  .5656  .0431  4.57  6.57  9.14   3129.    8940.    5026.
   .216      9.    428.  45279.  11000.   273.   231.  .428  .791  .5716  .0435  4.62  6.77  9.39   3259.    8758.    4917.
   .221     11.    453.  45254.  12000.   275.   230.  .434  .790  .5788  .0438  4.69  6.15  8.83   2988.    8576.    4810.
   .226     12.    480.  45227.  13000.   278.   228.  .440  .790  .5856  .0442  4.74  5.94  8.68   2916.    8396.    4705.
   .232     14.    506.  45200.  14000.   281.   227.  .447  .789  .5908  .0445  4.79  5.67  8.45   2816.    8212.    4603.
   .238     15.    534.  45173.  15000.   285.   226.  .455  .789  .5945  .0447  4.81  5.39  8.20   2714.    8025.    4505.
   .244     17.    561.  45145.  16000.   291.   227.  .466  .789  .5900  .0445  4.73  4.88  7.61   2510.    7810.    4406.
   .251     19.    591.  45116.  17000.   294.   226.  .473  .788  .5959  .0448  4.77  4.96  7.74   2579.    7614.    4296.
   .257     21.    618.  45088.  18000.   298.   225.  .481  .788  .6004  .0451  4.80  4.67  7.47   2460.    7416.    4189.
   .264     23.    647.  45060.  19000.   302.   225.  .489  .787  .6040  .0453  4.81  4.42  7.23   2358.    7221.    4085.
   .271     25.    676.  45031.  20000.   306.   223.  .497  .787  .6097  .0457  4.85  4.26  7.11   2299.    7033.    3983.
   .278     27.    705.  45002.  21000.   309.   222.  .505  .786  .6164  .0461  4.90  4.06  6.96   2220.    6851.    3882.
   .286     30.    734.  44973.  22000.   313.   221.  .513  .785  .6224  .0465  4.94  3.83  6.77   2118.    6670.    3784.
   .294     32.    763.  44943.  23000.   316.   220.  .520  .784  .6306  .0470  5.00  3.68  6.68   2056.    6496.    3686.
   .302     35.    793.  44913.  24000.   321.   219.  .530  .784  .6342  .0473  5.00  3.36  6.37   1906.    6317.    3594.
   .310     38.    825.  44882.  25000.   328.   220.  .544  .784  .6288  .0469  4.90  2.94  5.84   1701.    6112.    3513.
   .320     41.    859.  44848.  26000.   331.   218.  .551  .783  .6390  .0476  4.98  3.05  6.04   1785.    5934.    3425.
   .330     44.    891.  44816.  27000.   334.   216.  .559  .782  .6497  .0483  5.06  2.85  5.91   1682.    5760.    3339.
   .340     47.    924.  44782.  28000.   365.   232.  .613  .792  .5646  .0430  4.01  1.33  3.33    855.    5479.    3308.
   .359     54.    989.  44718.  29000.   368.   230.  .621  .791  .5734  .0436  4.06  2.24  4.30   1458.    5338.    3225.
   .370     58.   1026.  44681.  30000.   371.   228.  .630  .790  .5830  .0441  4.12  2.09  4.21   1374.    5198.    3143.
   .383     63.   1064.  44643.  31000.   376.   226.  .640  .789  .5908  .0445  4.16  1.86  4.02   1238.    5022.    3040.
   .396     68.   1105.  44602.  32000.   380.   225.  .650  .788  .5984  .0450  4.19  1.68  3.87   1126.    4851.    2939.
   .411     74.   1148.  44559.  33000.   385.   224.  .662  .787  .6040  .0453  4.19  1.46  3.65    996.    4683.    2843.
   .428     80.   1196.  44511.  34000.   391.   223.  .675  .787  .6077  .0456  4.17  1.26  3.43    873.    4519.    2750.
   .447     88.   1248.  44458.  35000.   395.   220.  .684  .785  .6201  .0464  4.24  1.20  3.44    837.    4360.    2655.
0   END OF CLIMB TO   35000. FT
 TIME=   .447 HRS   FUEL USED=    1248. LBS   WEIGHT=   44458. LBS   RANGE=     88. NM

0ALTITUDE=     35000. FT   TAS=     479.27 KTS   MACH NO=      .8305

    ACCELERATE TO MACH NO. = .800

0               FUEL                                                           FUEL
  TIME   RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST    FLOW
  (HRS)  (NM)    (LBS)   (LBS)     (FT)   (KTS)  (KTS)    NO.   DIV    (LBS)   (LB/HR)

  .447   87.58  1248.2  44458.  35000.   394.   220.  .684  .785   4680.    3009.
  .480  102.77  1356.2  44351.  35000.   461.   258.  .800  .805   4765.    3114.

  END OF ACCELERATION SEGMENT
  TIME=  .480 HRS   FUEL USED=  1356.2 LBS   WEIGHT=  44351. LBS   RANGE=  103. NM

    ACCELERATE TO MACH NO. = .830

0               FUEL                                                           FUEL
  TIME   RANGE   USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST    FLOW
  (HRS)  (NM)    (LBS)   (LBS)     (FT)   (KTS)  (KTS)    NO.   DIV    (LBS)   (LB/HR)

  .447   87.58  1248.2  44458.  35000.   394.   220.  .684  .785   4680.    3009.
  .491  108.17  1391.8  44315.  35000.   479.   267.  .830  .809   4792.    3149.

  END OF ACCELERATION SEGMENT
  TIME=  .491 HRS   FUEL USED=  1391.8 LBS   WEIGHT=  44315. LBS   RANGE=  108. NM
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Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

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 ACCELERATE TO MACH NO. = .848
                                                                                              FUEL
0                       FUEL                                                                  FLOW
 TIME     RANGE         USED     WEIGHT    ALT.       TAS     EAS      MACH   MACH    THRUST  (LB/HR)
 (HRS)    (NM)         (LBS)     (LBS)     (FT)      (KTS)   (KTS)     NO.    DIV      (LBS)

  .447     87.58      1248.2    44458.    35000.     394.    220.     .684   .785    4680.    3009.
  .497    110.86      1409.2    44297.    35000.     489.    273.     .848   .811    4794.    3171.

 END OF ACCELERATION SEGMENT
 TIME=   .497 HRS    FUEL USED=   1409.2 LBS    WEIGHT=   44297. LBS    RANGE=   111. NM


0                                             DESIGN CASE
                                              CRUISE PERFORMANCE SUMMARY
                                                          FOR
                                              ***** DESIGN PAYLOAD *****
                                              **** MAXIMUM PAYLOAD *****
                                              ****** MAXIMUM FUEL ******
                                              FUEL AVAILABLE=    9074.
                                                          AT                           AT
0                                  AT               NORMAL POWER              BEST SPEC. RANGE
                            SPECIFIED SPEED       START      END              START      END
                            START     END         CRUISE     CRUISE           CRUISE     CRUISE
                            CRUISE    CRUISE      -------    -------          -------    -------
                            -------   -------
  TIME             HRS.       .480     3.035        .491      2.564             .497      2.712
  RANGE            N.MI       103.     1282.        108.      1101.             111.      1195.
  FUEL USED        LBS.      1356.     7274.       1392.      6431.            1409.      7091.
  WEIGHT           LBS.     44351.    38433.      44315.     39276.           44297.     38616.
  ALTITUDE         FT.      35000.    35000.      35000.     35000.           35000.     35000.
  TAS              KTS.      461.7     461.7       479.3      479.3            489.3      489.3
  EAS              KTS.      257.3     257.3       267.1      267.1            272.7      272.7
  MACH NO.                   .8000     .8000       .8305      .8305            .8478      .8478
  DIV. MACH                  .8055     .8130       .8096      .8171            .8117      .8181
  ANGLE ATTACK     DEG.      2.217     1.707       1.797      1.304            1.575      1.168
  FUSE. ANGLE      DEG.       .217     -.293       -.203      -.696            -.425      -.832
  CL                         .4554     .3947       .4223      .3610            .4051      .3531
  L/D                       12.155    11.314      11.721     10.776           11.195     10.469
  FUEL FLOW        LB/HR    2400.7    2237.5      2516.6     2351.4           2644.7     2489.3
  BREG. FACTOR     N.MI.     8535.     7935.       8445.      8011.            8200.      7595.
  SPEC. RANGE      NM/LB    .19231    .20634      .19044     .20382           .18500     .19655


0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
              (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
                                                                                                   FUS.                            FUEL
0                       FUEL                                                                       ALPHA GAMMA ANGLE      R/S     THRUST     FLOW
 TIME     RANGE         USED     WEIGHT    ALT.      TAS     EAS     MACH   MACH    CL       CD     (DEG) (DEG) (DEG)     (FPM)     (LBS)   (LB/HR)
 (HRS)    (NM)         (LBS)     (LBS)     (FT)     (KTS)   (KTS)    NO.    DIV

 2.576    1107.        6453.    39254.    35000.    479.    268.    .830   .816   .3705   .0337   1.38 -1.58 -2.20    1339.     2491.     1763.  R
 2.589    1113.        6477.    39230.    34000.    481.    274.    .830   .818   .3533   .0331   1.24 -1.53 -2.29    1306.     2625.     1863.  R
 2.602    1120.        6503.    39204.    33000.    484.    280.    .830   .820   .3370   .0325   1.11 -1.49 -2.37    1271.     2768.     1968.  R
 2.615    1126.        6530.    39176.    32000.    486.    287.    .830   .822   .3216   .0320    .99 -1.44 -2.46    1241.     2914.     2078.  R
 2.629    1133.        6561.    39146.    31000.    488.    294.    .830   .824   .3070   .0316    .87 -1.40 -2.53    1209.     3069.     2194.  R
 2.643    1140.        6593.    39113.    30000.    490.    300.    .830   .825   .2931   .0312    .76 -1.36 -2.60    1180.     3228.     2314.  R
 2.658    1147.        6629.    39078.    29000.    492.    307.    .830   .827   .2800   .0308    .65 -1.32 -2.67    1153.     3393.     2439.  R
 2.673    1154.        6667.    39040.    28000.    494.    314.    .830   .829   .2675   .0305    .55 -1.29 -2.74    1127.     3566.     2570.  R
 2.688    1162.        6708.    38999.    27000.    496.    321.    .830   .830   .2557   .0302    .46 -1.25 -2.79    1100.     3764.     2715.  R
 2.703    1170.        6752.    38955.    26000.    498.    328.    .830   .831   .2445   .0299    .37 -1.22 -2.85    1077.     3947.     2856.  R
 2.719    1178.        6800.    38907.    25000.    500.    336.    .830   .833   .2338   .0296    .28 -1.19 -2.91    1053.     4138.     3003.  R
 2.735    1186.        6850.    38856.    24000.    502.    343.    .830   .834   .2237   .0294    .20 -1.16 -2.96    1032.     4334.     3155.  R
 2.752    1194.        6905.    38802.    23000.    505.    350.    .830   .835   .2141   .0292    .12 -1.13 -3.01    1011.     4537.     3313.  R
 2.768    1203.        6963.    38744.    22000.    503.    355.    .825   .836   .2078   .0291    .09 -1.11 -3.03     992.     4670.     3425.  R
 2.786    1211.        7022.    38684.    21000.    497.    357.    .812   .836   .2051   .0290    .09 -1.10 -3.01     972.     4730.     3484.  R
 2.790    1213.        7026.    38681.    20000.    427.    312.    .694   .829   .2677   .0305    .90 -4.90 -6.00    3699.     1079.      781.  A
 2.795    1215.        7030.    38677.    19000.    422.    314.    .684   .829   .2645   .0304    .89 -4.89 -6.00    3652.     1125.      817.  A
 2.799    1217.        7034.    38673.    18000.    418.    316.    .674   .829   .2614   .0303    .88 -4.88 -6.00    3606.     1172.      855.  A
 2.804    1219.        7038.    38669.    17000.    413.    318.    .664   .830   .2583   .0302    .87 -4.87 -6.00    3560.     1222.      895.  A
 2.809    1221.        7042.    38664.    16000.    409.    320.    .655   .830   .2552   .0301    .86 -4.86 -6.00    3514.     1272.      935.  A
 2.814    1223.        7047.    38660.    15000.    405.    322.    .646   .830   .2521   .0301    .85 -4.85 -6.00    3469.     1325.      978.  A
 2.818    1225.        7052.    38655.    14000.    401.    323.    .637   .831   .2491   .0300    .83 -4.83 -6.00    3424.     1379.     1021.  A
 2.823    1227.        7057.    38650.    13000.    397.    325.    .628   .831   .2460   .0299    .82 -4.82 -6.00    3379.     1435.     1067.  A
 2.828    1229.        7063.    38644.    12000.    393.    327.    .620   .832   .2430   .0298    .80 -4.80 -6.00    3335.     1493.     1114.  A
 2.833    1230.        7069.    38638.    11000.    389.    329.    .611   .832   .2400   .0298    .78 -4.78 -6.00    3291.     1552.     1163.  A
 2.844    1234.        7078.    38629.    10000.    291.    250.    .455   .810   .4171   .0355   2.89 -3.10 -2.21    1595.     1183.      851.  S
 2.855    1237.        7087.    38620.     9000.    286.    250.    .446   .810   .4170   .0354   2.91 -3.04 -2.13    1540.     1224.      883.  S
 2.866    1240.        7097.    38609.     8000.    282.    250.    .438   .810   .4169   .0354   2.92 -2.98 -2.06    1486.     1265.      915.  S
 2.878    1243.        7108.    38598.     7000.    277.    250.    .430   .810   .4168   .0354   2.93 -2.92 -1.98    1433.     1308.      949.  S
 2.890    1246.        7120.    38586.     6000.    273.    250.    .422   .810   .4167   .0354   2.95 -2.85 -1.91    1379.     1352.      984.  S
 2.902    1250.        7133.    38574.     5000.    269.    250.    .414   .810   .4166   .0354   2.96 -2.79 -1.83    1327.     1397.     1020.  S
 2.915    1253.        7147.    38560.     4000.    265.    250.    .406   .810   .4164   .0354   2.97 -2.72 -1.75    1274.     1444.     1057.  S
 2.929    1257.        7162.    38545.     3000.    261.    250.    .399   .810   .4163   .0354   2.98 -2.64 -1.67    1222.     1493.     1096.  S
 2.943    1260.        7178.    38529.     2000.    257.    250.    .391   .810   .4161   .0354   2.99 -2.57 -1.58    1171.     1543.     1136.  S
 2.950    1262.        7186.    38520.     1500.    255.    250.    .388   .810   .4159   .0354   2.99 -2.53 -1.54    1145.     1568.     1157.  S
0  END OF DSCNT TO     1500. FT
 TIME=  2.950 HRS   FUEL USED=     7186. LBS   WEIGHT=    38520. LBS   RANGE=    1262. NM

0      RESERVE FUEL(LBS)     1801.                1887.                 1984.
         (   45.0 MIN.)

   ***********************************************************************************
0      RANGE = 1262.    BLOCK TIME= 2.950    USED FOR DESIGN RANGE AND COST
   ***********************************************************************************
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Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
0  ************************************************************************************
0            TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  98.70 PSF.
     LANDING WEIGHT =    42964. LBS.

     LANDING DISTANCE FROM 50. FT.=   2885. FT.

     F.A.R. FACTORED FIELD LENGTH =   4808. FT.
0                    APPROACH             TRANSITION            DELAY                 ROLL
0                 DIST=        689.    DIST=        201.    DIST=        204.    DIST=        1791.
                  R/S=        1000.    XLFMX=      1.200    TDELAY=      1.00    MUB=         .4000
                  VAPEAS=    122.15    SINKTD=     3.000    TIDLE=       638.    TR/TIDLE=    .0000
                  VAPTAS=    136.30    VSTEAS=     93.96    VTDTAS=    120.57    ABAR(G)=     .3600
                  THETA=       4.15    CLMX=      3.2957
                  THRUST=     3055.    HFLAR=       20.9
0  ************************************************************************************
*******************************************************************************************
0              RANGE OR ENDURANCE ITERATION SUMMARY

                           GROSS      RANGE(NMI) OR
               ITERATION  WEIGHT(LB)  ENDURANCE(HR)

                   0       44050.00     1079.430
                   1       47880.43     1473.778
                   2       45706.80     1262.253
                   REQUIRED RG. OR END. = 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.215   LIFT= 44335.6   L/D=  12.153   ALTITUDE= 35000.0   MACH=   .8000

0  GROSS WEIGHT =   45707.        PASSENGERS =  50. PLUS CREW

0  FUSELAGE       LENGTH              (ELF)           79.25   FT
                  WIDTH               (SWF)            9.25   FT
                  WETTED AREA         (SF)            1910.   SQFT
                  DELTA P             (DELP)           8.20   PSI

0  WING           ASPECT RATIO        (AR)             8.88
                  AREA                (SW)            435.3   SQFT
                  SPAN                (B)              62.2   FT
                  GEOM. MEAN CHORD    (CBARW)          8.05   FT
                  QUARTER CHORD SWEEP(DLMC4)           14.9   DEG
                  TAPER RATIO         (SLM)            .198
                  ROOT THICKNESS      (TCR)            .130
                  TIP THICKNESS       (TCT)            .100
                  WING LOADING        (WGS)           105.0   PSF
                  WING FUEL VOLUME    (VFW)          1024.5   GAL

0  HOR. TAIL      ASPECT RATIO        (ARHT)           4.15
                  AREA                (SHT)           165.1   SQFT
                  SPAN                (BHT)           26.18   FT
                  MEAN CHORD          (CBARHT)         6.31   FT
                  THICKNESS/CHORD     (TCHT)           .100
                  MOMENT ARM          (ELTH)           44.2   FT
                  VOLUME COEFF.       (VBARH)         2.082

0  VERT. TAIL     ASPECT RATIO        (ARVT)           1.01
                  AREA                (SVT)            99.8   SQFT
                  SPAN                (BVT)           10.05   FT
                  MEAN CHORD          (CBARVT)        10.03   FT
                  THICKNESS/CHORD     (TCVT)           .120
                  MOMENT ARM          (ELTV)           33.1   FT
                  VOLUME COEFF.       (VBARV)          .122

0  ENG.NACELLES   LENGTH              (ELN)           11.86   FT
                  MEAN DIAMETER       (DBARN)          3.95   FT
                  NUMBER ENGINES      (ENP)             2.0
                  WETTED AREA         (SN)           294.21   SQFT

                  LOCATION                          ON FUSELAGE

0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
   ULT. LF =  4.98   MAN. LF =  2.50   GUST LF =  3.32

0  PROPULSION GROUP
      PRIMARY ENGINES           (WEP)       3122.
      PRIMARY ENGINE INSTL.     (WPEI)       421.
      FUEL SYSTEM               (WFSS)       181.
      TOTAL PROP.GROUP WT.      (WP)        3725.
0  STRUCTURES GROUP
      WING                      (WW)        4386.
      HOR. TAIL                 (WHT)        743.
      VERT. TAIL                (WVT)        452.
      FUSELAGE                  (WB)        6008.   (INCL.      .0 LBS A.T.W.)
      LANDING GEAR              (WLG)       1737.
      PRIMARY ENG. SECTION      (WPES)      1035.
      GROUP WEIGHT INC.         (DELWST)       0.
      TOTAL STRUC.GROUP WT.     (WST)      14361.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS          (WCC)         96.
      FIXED WING CONTROLS       (WCFW)       800.
      SAS                       (WSAS)         0.
      GROUP WEIGHT INC.         (DELWFC)       0.
      TOTAL CONTROL WT.         (WFC)        896.
0  WT. OF FIXED EQUIPMENT       (WFE)       6573.

   WEIGHT EMPTY                 (WE)       25554.

   FIXED USEFUL LOAD            (WFUL)      1079. (INC. CREW )

   OPERATING WEIGHT EMPTY       (OWE)      26632.
0  PAYLOAD                      (WPL)      10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

   FUEL                         (WFA)       9074. (WFW= 6851.) (WFTP=    0.)

   GROSS WEIGHT                 (WG)       45707.
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
0            FIXED EQUIP GROUP                       FIXED USEFUL LOAD
0   WAPU                 372.27          WCREW ( 2.)           340.00
    WINSTR               238.60          WSTU  ( 1.)           130.00
    WHYD                 367.47          WCBAG                 110.00
    WELEC                970.00          WUF                   125.18
    WAV                  500.00          WOIL                  129.37
    WFUR                3410.00          WSRV                  116.00
    WAC                  477.91          WH2O                   53.00
    WAI                  216.32          WEMER                  40.00
    WAUXG                 20.00          WCATER                 35.00

    WFE                 6572.56          WFUL                 1078.55

0  DESIGN MACH =  .800          DESIGN ALTITUDE =  35000.          DESIGN Q (PSF) =224.03
0  DESIGN RE.NUM. PER FT.   = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274

0  AERODYNAMIC DATA

0                            FLATPLATE              WETTED
   DRAG BREAKDOWN            AREA(SQFT)     CDO     AREA(SQFT)
0       WING                   2.9044     .00667      667.21
        FUSELAGE               5.4592     .01254     1910.38
        VERT.TAIL               .6234     .00143      199.55
        HOR. TAIL              1.0629     .00244      330.12
        ENGINE NAC.            1.1868     .00273      294.21
        TIP TANKS               .0000     .00000         .00
        INCREMENTAL             .6530     .00150         .00
0           TOTAL             11.8896     .02731     3401.47

           MEAN SKIN FRICTION COEF.=  .003495


0  AERODYNAMIC COEFF.
       A1                                                .8014
       A2                                               -.1227
       A3                                                .0383
       A4=.75X(T/C)                                      .0906
       A5=CDO--                                          .0179
       A6                                               2.4351
       A7=1/(PI.SEE.AR)                                  .0466
       3-D LIFT SLOPE AT CRUISE MACH        (CLALPH)    6.8371    PER RADIAN
       OSWALD FACTOR                        (SEE)        .7694

0  CRUISE CD =  .0273 +   .0466 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
0  RETRACTABLE LANDING GEAR CD INC.= .03450


0 CRUISE DRAG
0CL=     .2000
             MACH      CD     L/D    CLALPH    ALPHA
           .50000  .02921  6.8468  5.4228    .5132
           .55000  .02921  6.8468  5.5598    .4611
           .60000  .02921  6.8468  5.7237    .4021
           .65000  .02921  6.8468  5.9210    .3353
           .70000  .02921  6.8468  6.1613    .2598
           .75000  .02921  6.8468  6.4591    .1741
           .80000  .02921  6.8468  6.8371    .0760
           .85000  .02927  6.8330  7.3339   -.0375
0CL=     .3000
             MACH      CD     L/D    CLALPH    ALPHA
           .50000  .03168  9.4706  5.4228   1.5697
           .55000  .03168  9.4706  5.5598   1.4916
           .60000  .03168  9.4706  5.7237   1.4031
           .65000  .03168  9.4706  5.9210   1.3030
           .70000  .03168  9.4706  6.1613   1.1898
           .75000  .03168  9.4706  6.4591   1.0611
           .80000  .03168  9.4706  6.8371    .9140
           .85000  .03211  9.3443  7.3339    .7437
0CL=     .4000
             MACH      CD     L/D    CLALPH    ALPHA
           .50000  .03508 11.4040  5.4228   2.6263
           .55000  .03508 11.4040  5.5598   2.5221
           .60000  .03508 11.4040  5.7237   2.4041
           .65000  .03508 11.4040  5.9210   2.2707
           .70000  .03508 11.4040  6.1613   2.1197
           .75000  .03508 11.4040  6.4591   1.9482
           .80000  .03508 11.4040  6.8371   1.7521
           .85000  .03647 10.9673  7.3339   1.5250
0CL=     .5000
             MACH      CD     L/D    CLALPH    ALPHA
           .50000  .03958 12.6339  5.4228   3.6829
           .55000  .03958 12.6339  5.5598   3.5527
           .60000  .03958 12.6339  5.7237   3.4052
           .65000  .03958 12.6339  5.9210   3.2384
           .70000  .03958 12.6339  6.1613   3.0496
           .75000  .03958 12.6339  6.4591   2.8352
           .80000  .03958 12.6339  6.8371   2.5901
           .85000  .04283 11.6741  7.3339   2.3062
0CL=     .6000
             MACH      CD     L/D    CLALPH    ALPHA
           .50000  .04501 13.3309  5.4228   4.7395
           .55000  .04501 13.3309  5.5598   4.5832
           .60000  .04501 13.3309  5.7237   4.4062
           .65000  .04501 13.3309  5.9210   4.2060
           .70000  .04501 13.3309  6.1613   3.9795
           .75000  .04501 13.3309  6.4591   3.7223
           .80000  .04506 13.3167  6.8371   3.4281
           .85000  .05130 11.6963  7.3339   3.0875
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
   0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                            FLAPS UP                     TAKEOFF                   LANDING
            ALPHA      CL        CD      L/D        CL        CD      L/D        CL        CD      L/D
          -2.00000  -.03445    .02747 -1.25382  1.14118    .09514 11.99513  1.94895    .25534  7.63264
            .00000   .13778    .02821  4.88401  1.31340    .10966 11.97737  2.12118    .27430  7.73315
           2.00000   .31001    .03198  9.69522  1.48563    .12856 11.55621  2.29340    .29919  7.66541
           4.00000   .48223    .03871 12.45812  1.65786    .15268 10.85840  2.46563    .32786  7.52029
           6.00000   .65446    .04855 13.48126  1.83008    .17962 10.18846  2.63786    .35977  7.33203
           8.00000   .82669    .06174 13.38901  2.00231    .20939  9.56272  2.81008    .39491  7.11571
          10.00000   .99891    .07875 12.68468  2.17454    .24197  8.98674  2.98231    .43329  6.88300
          12.00000  1.17114    .10175 11.51049  2.34676    .27738  8.46056  3.15453    .47489  6.64262
          13.63969  1.31729    .12345 10.67105  2.49291    .30963  8.05116  3.29573    .51142  6.44433
          13.63969  1.31729    .12345 10.67105  2.49291    .30963  8.05116  3.29573    .51142  6.44433

   0                           DFLAP=       .00          DFLAP=    15.00          DFLAP=    40.00
   0                           CLMAX=  1.31729           CLMAX=  2.50326          CLMAX=  3.29573

   0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
        FLAP DEFL.     CLMAX    CL       CD      L/D
           10.000     2.13428
                                 .78750   .07073 11.13381
                                 .95973   .08206 11.69606
                                1.13196   .09703 11.66553
                                1.30418   .11666 11.17959
                                1.47641   .14100 10.47092
                                1.64863   .16814  9.80534
                                1.82086   .19806  9.19329
                                1.99309   .23078  8.63616
                                2.13428   .25969  8.21853
                                2.13428   .25969  8.21853
           20.000     2.74181
                                1.39503   .12267 11.37225
                                1.56726   .13905 11.27104
                                1.73948   .16069 10.82487
                                1.91171   .18621 10.26625
                                2.08393   .21458  9.71159
                                2.25616   .24580  9.17880
                                2.42839   .27987  8.67684
                                2.60061   .31679  8.20931
                                2.74181   .34918  7.85211
                                2.74181   .34918  7.85211
           30.000     3.09918
                                1.75240   .17966  9.75411
                                1.92462   .19762  9.73889
                                2.09685   .22170  9.45784
                                2.26908   .24883  9.11902
                                2.44130   .27891  8.75303
                                2.61353   .31195  8.37814
                                2.78576   .34794  8.00644
                                2.95798   .38689  7.64556
                                3.09918   .42103  7.36100
                                3.09918   .42103  7.36100


 0ALTITUDE=     35000. FT   TAS=     482.40 KTS   MACH NO=      .8359


 0                                    RDT&E AND AIRFRAME PRODUCTION COSTS
                                                  (1993. DOLLARS)
 0                               TOTAL RDT&E COSTS           1068.2820 MILLION
 0                                           AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                                    500. AIRCRAFT
                                                          WEIGHT(LB)     COST($)     COST($/LB)
            STRUCTURE(  4060151.$)
                                   WING                       4386.    1099279.       250.64
                                   EMPENNAGE                  1195.     427073.       357.47
                                   FUSELAGE                   6008.    1665887.       277.26
                                   LANDING GEAR               1737.     308707.       177.74
                                   NACELLES                   1035.     559205.       540.31
            PROPULSION INSTAL(     179169.$)
                                   ENGINE INSTALLAT.           421.     153445.       364.08
                                   FUEL SYSTEM                 181.      25724.       141.74
            SYSTEMS(  2555619.$)
                                   FLIGHT CONTROLS             896.     420442.       469.41
                                   HYDRAULIC                   367.      45774.       124.57
                                   ELECTRICAL                  970.     464214.       478.57
                                   AIR CONDITIONING            478.     256070.       535.82
                                   ANTI-ICING                  216.     113925.       526.66
                                   AUX. POWER UNIT             372.     207143.       556.42
                                   FURNISHINGS                3410.     796443.       233.56
                                   INSTRUMENTS                 239.     197905.       829.44
                                   AVIONICS INSTALL.           250.      49032.       196.13
                                   AUX. ITEMS                   20.       4671.       233.56
            INTEGRATION(  1698735.$)
 0                                   AIRFRAME TOTALS      22182.    8493674.       382.91
 0                                   ENGINES                        2905339.
                                     PROPELLER                            0.
                                     AVIONICS                       4000000.
                                     A/C COST(NO RD)               15399012.
                                     R&D PER A/C                    2136564.
                                     TOTAL A/C COST                17535576.

 0                  ENGINES      NUMBER =     2.  TYPE=     7

 0 EMPTY WEIGHT= 25554.     AIRFRAME WEIGHT= 22432.     WEIGHT OF 1 ENGINE=  1561.     CRUISE SPEED= 482. KTS
 0 THRUST/ENGINE=   9756.
 0 TOTAL AIRCRAFT COST= 17535576.     AIRFRAME COST= 14630238.     COST OF 1 ENGINE=  1452669.     COST OF 1 PROP.=        0.
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (continued)

```
0                              --- COST DATA ---
                            GASP SHORTHAUL METHOD
0          DESIGN MISSION
0              OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0  **************************************************************************************************
0                   RANGE=    1262. N.M.     BLOCK FUEL=     7186. LBS     BLOCK TIME=  2.9504 HRS.
0   UTILIZATION                        3200.
 FLYING OPERATIONS
    FLIGHT CREW                      368.800
    FUEL,OIL,AND TAXES( .850$/G)     954.597
    INSURANCE                         80.839
 DIRECT MAINTENANCE
    AIRFRAME                         167.142
    ENGINE                           284.465
 MAINTENANCE BURD.                   365.406
 DEPRECIATION                       1086.476

    TOTAL DOC ($/TRIP)              3307.725
              ($/B.HR.)             1121.111
              ($/N.MI.)                2.620
               •
```

Fig E5 - Conventional Configuration optimised for minimum D.O.C. - GASP solution (concluded)

```
*....data for 50 Pax turbofan airliner

VARIABLES
01 1  95.0           86.750          80.000      105.000
02 1   9.0            8.300           8.000       10.000
03 1  23.0           14.500          11.000       35.000
04 1    .235           .200            .160         .310
05 1   4.0            4.000           3.800        4.300
06 1  27.5           27.500          20.000       35.000
07 1   1.0            1.000            .800        1.200
08 1  46.5           50.500          40.000       53.000
09 1   6.0            5.500           4.000        8.000
10 1  23.0           15.000          10.000       35.000
11 1    .43            .500            .160         .700
12 1   1.5            2.000            .000        3.000
13 1    .15            .15             .145         .175
14 1    .8             .75             .75          .85
FUNCTIONS
01 00 00    3.0        1
02 -1 00 6000.0
03 -1 00 5000.0
04 -1 00  120.0
05 -1 00     .8
06 -1 00     .8
CONTROLS
XTOLU = .0001
XTOLV = .0001
OFROM = 1
OFREQ = 10
RFREQ = 50
NFEMAX = 20000
RUN
END
```

Fig E6 - RQPMIN.DAT file for the Three-Lifting Surface D.O.C. optimisation case

```
1Program  RQPMIN  Version 1.0  for VAX

 ANALYSIS OF  INPUT FILE DATA  AND  CONTROL PARAMETERS

 Input file: rqpmin.dat
 Output file: rqpmin.res


 Variable data
 -------------

 Number of variables =    14

 Index      Status        Scale           Starting value        Lower bound         Upper bound
     1          1      .9500000E+02        .9131579E+00        .8421053E+00        .1105263E+01
     2          1      .9000000E+01        .9222223E+00        .8888889E+00        .1111111E+01
     3          1      .2300000E+02        .6304348E+00        .4782609E+00        .1521739E+01
     4          1      .2350000E+00        .8510638E+00        .6808510E+00        .1319149E+01
     5          1      .4000000E+01        .1000000E+01        .9500000E+00        .1075000E+01
     6          1      .2750000E+02        .1000000E+01        .7272727E+00        .1272727E+01
     7          1      .1000000E+01        .1000000E+01        .8000000E+00        .1200000E+01
     8          1      .4650000E+02        .1086022E+01        .8602151E+00        .1139785E+01
     9          1      .6000000E+01        .9166667E+00        .6666667E+00        .1333333E+01
    10          1      .2300000E+02        .6521739E+00        .4347826E+00        .1521739E+01
    11          1      .4300000E+00        .1162791E+01        .3720930E+00        .1627907E+01
    12          1      .1500000E+01        .1333333E+01        .0000000E+00        .2000000E+01
    13          1      .1500000E+00        .1000000E+01        .9666666E+00        .1166667E+01
    14          1      .8000000E+00        .9375000E+00        .9375000E+00        .1062500E+01

 Problem function data
 ---------------------

 Number of constraints =     5

 Index     Status      Type          Scale                Index     Status      Type         Scale
    1         0          0       .3000000E+01                2         -1         0       .6000000E+04
    3        -1          0       .5000000E+04                4         -1         0       .1200000E+03
    5        -1          0       .8000000E+00                6         -1         0       .8000000E+00

 objective is function     1                   problem number =     1

 Control parameters
 ------------------

 nfemax = 20000      nimax  =  1000      nsmax  =    20
 nsetc  =     4      nsetcf =     8      nsetv  =     4      nsetvf =     8
 ofreq  =    10      ofrom  =     1      rfreq  =    50      rfrom  =     1

 centrl = F      fdset  = F      norep  = F      cheats = T      fast   = T      quasi  = T
 fixrp  = F      timid  = F      monitr = F      nofrec = F      yesbc  = F      shrnk  = T      projct = T

 xtol   =   .1000000E-05     xtolu  =   .1000000E-03     xtolv  =   .1000000E-03     gtol   =   .1000000E-02
 rtol   =   .1000000E+00     omegar =   .1000000E+00     rpmax  =   .2000000E+00
 umin   =   .1000000E-05     vminf  =   .1000000E-02     vminc  =   .1000000E-05     ctol   =   .1000000E-02
 umax   =   .1000000E+00     vmax   =   .1000000E+00     omega  =   .1000000E+00     mu     =   .1000000E-03
 bdtol  =   .1000000E+00     lmtol  =   .1000000E+00     mtol   =   .5000000E+00     cmax   =   .1000000E-01
 subtol =   .1000000E-02     qrtol  =   .1000000E+02     bfstol =   .1000000E-05     diftol =   .5000000E-03
 ztol   =   .1000000E-29

 End of input data
 -----------------
1Program  RQPMIN  Version 1.0  for VAX

 STARTING POINT



 free variables
 --------------

  1  .9131579E+00  2  .9222223E+00  3  .6304348E+00  4  .8510638E+00  5  .1000000E+01  6  .1000000E+01  7  .1000000E+01
  8  .1086022E+01  9  .9166667E+00 10  .6521739E+00 11  .1162791E+01 12  .1333333E+01 13  .1000000E+01 14  .9375000E+00

 objective function
 ------------------

 f(x) =   .9113006E+00

 inactive inequality constraints
 -------------------------------

  2  -.2218968E+00  3  -.2113195E+00  4  -.1450278E+00  5  -.4114293E-01  6  -.8385710E-01
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number     1
 ----------------------------

 end of a successful minimization step
 number of calls made to user function so far =     60
```

Fig E7 - RQPMIN.RES file for the Three-Lifting Surface D.O.C. optimisation case

```
 free variables
 --------------

  1   .9056399E+00  2   .9381056E+00  3   .6405770E+00  4   .8631462E+00  5   .1012208E+01  6   .1013268E+01  7   .1013431E+01
  8   .1096338E+01  9   .9415752E+00 10   .6654051E+00 11   .1176070E+01 12   .1343306E+01 13   .1013591E+01 14   .9520572E+00

 objective function
 ------------------

 f(x) =   .9111835E+00

 inactive inequality constraints
 -------------------------------

  2  -.2080367E+00  3  -.2018121E+00  4  -.1381598E+00  5  -.3883965E-01  6  -.8616038E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  1   .5422831E+00  2   .5409718E+00  3   .4446506E+00  4  -.5501509E+00  5   .7889270E+00  6   .5812645E+00  7   .4202127E+00
  8   .4251003E+00  9   .4136562E+00 10  -.8766651E+00 11  -.5730391E+00 12   .8237361E+00 13   .1140833E+00 14   .6594657E+00

 convergence criteria
 --------------------

 pdatum =   .9111835E+00     ldatum =   .9111835E+00     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .3181815E+01     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .8766651E+00
 nde    =      0     ndef =      4     ndec =      0     ncalls =      8     nfuncs =      4
1Program  RQPMIN  Version 1.0  for VAX                   16-Feb-94

 end of iteration number    11
 ----------------------------

 end of a successful minimization step
 number of calls made to user function so far =   415

 free variables
 --------------

  1   .1088571E+01 14   .9481185E+00  3   .6307811E+00  4   .8588357E+00  5   .9769369E+00  6   .8885419E+00  7   .8941292E+00
  8   .1077350E+01  9   .1016114E+01 10   .8932611E+00 11   .1168866E+01 12   .1355567E+01 13   .1055593E+01  2   .9329544E+00

 objective function
 ------------------

 f(x) =   .8704389E+00

 inactive inequality constraints
 -------------------------------

  2  -.8533529E-03  3  -.8119043E-02  4  -.5353101E-02  5  -.4506424E-01  6  -.7993579E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  1  -.2833009E+00 14  -.7754564E-01  3   .3156066E+00  4   .1972914E-01  5   .5561113E-01  6   .9113549E-01  7  -.4224777E+00
  8  -.6240606E-01  9  -.6906986E+00 10   .9131431E-01 11   .5384684E+00 12   .6685852E+00 13  -.5574226E+00  2  -.1536608E+00

 convergence criteria
 --------------------

 pdatum =   .8704389E+00     ldatum =   .8704389E+00     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .4304282E+01     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .6906986E+00
 nde    =      0     ndef =     14     ndec =      7     ncalls =     44     nfuncs =     23
1Program  RQPMIN  Version 1.0  for VAX                   16-Feb-94

 end of iteration number    13
 ----------------------------

 CONVERGENCE DETECTED  [ Code 8 ]     after   620 calls to user routine
```

Fig E7 - RQPMIN.RES file for the Three-Lifting Surface D.O.C. optimisation case (continued)

```
free variables
--------------

 1   .1088571E+01 14   .9481185E+00  3   .6307811E+00  4   .8588357E+00  5   .9769369E+00  6   .8885419E+00  7   .8941292E+00
 8   .1077350E+01  9   .1016114E+01 10   .8932611E+00 11   .1168866E+01 12   .1355567E+01 13   .1055593E+01  2   .9329544E+00

objective function
------------------

f(x) =   .8710610E+00

inactive inequality constraints
-------------------------------

 2  -.8714193E-03  3  -.6874707E-02  4  -.4561170E-02  5  -.4492499E-01  6  -.8007504E-01

Partial derivatives of Lagrangian function
------------------------------------------

 1  -.2833009E+00 14  -.7754564E-01  3   .3156066E+00  4   .1972914E-01  5   .5561113E-01  6   .9113549E-01  7  -.4224777E+00
 8  -.6240606E-01  9  -.6906986E+00 10   .9131431E-01 11   .5384684E+00 12   .6685852E+00 13  -.5574226E+00  2  -.1536608E+00

convergence criteria
--------------------

pdatum =   .8704389E+00     ldatum =   .8704389E+00     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .6906986E+00     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .6906986E+00
nde    =     0      ndef =     14      ndec =     14      ncalls =    60      nfuncs =     32
```

Fig E7 - RQPMIN.RES file for the Three-Lifting Surface D.O.C. optimisation case (concluded)

```
                                 50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - THREE-SURF. CONFIG.
0                                               ENGINE CYCLE IS G. E.  CF-34
                                                    INPUT DATA FOLLOW
                                                   *******************

0                                                 *****GEOMETRY*****
0 CONFIG  WG      =  44050.            KWRITE  =       2      FUSEL  SAB     =      4.                ELODN   =   1.000
          WGS     = 103.414            IGEAR   =       0             WS      =  20.000                ELODT   =   3.200
          PAX     =     50.            KCONFG  =       0             AS      =      1.                BMLOD   =  14.500
          EMCRU   =    .800            KTIPX   =       0             WAS     =  19.000      NACELLE   KNAC    =       1
          HNCRU   =  35000.            ENP     =      2.             PS      =    31.0                ELN     =  11.330
                                       NTYE    =       7             ELPC    =  11.220                DBARN   =   3.777
          Kanard  =       1            KPLOT   =       1             HCK     =   2.470                ELRW    =  10.000

0   WING  TCT     =    .100     HORIZ  VBARHX  =   .0000      VERT   VBARVX  =   .0000      Canard    TCcan   =    .100
          TCR     =    .130     TAIL   TCHT    =    .100      TAIL   TCVT    =    .120                ARcan   =   6.097
          AR      =   8.397            ARHT    =   3.908             ARVT    =    .894                SlMcan  =    .503
          SLM     =    .202            SLMH    =    .550             SLMV    =    .700                DwpqCe  =  20.545
          DLMC4   =  14.508            DWPQCH  =  24.435             DWPQCV  =  50.097                EYEcan  =   2.033
          EYEW    =   2.000            COELTH  =    .000             BOELTV  =    .000                SWcOSW  =    .158
                                       SAH     =   1.000

0                                                ***AERODYNAMICS***
0         CKW     =  -1.000            CKHT    =  -1.000             GRFE    =    .000                DCDSE   = -1.0000
          CKF     =  -1.000            CKTP    =  -1.000             SCFAC   =    .750                CKWc    =   2.497
          CKN     =  -1.000            DELCD   =  .00150             DLSWSW  =    .000                cmacw   =   -.060
          CKVT    =  -1.000            DELFE   =    .200             ALPHLO  =  -1.600                alzero  =  -1.000

0         KWCD    =      12
          ACLS    =  -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR  =   2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                                *HIGH LIFT DEVICES*
0         RCLMAX  =   1.200     FLAPS  JFLTYP  =       7      LED    CLEOC   =    .000
          ALTFLP  =   5000.            DFLPTO  =  15.000             DELLED  =    .000
          FLAPN   =      1.            DFLPLD  =  40.000             DCLMLE  =    .930
          WCFLAP  =  -1.000            CFOC    =    .300             DELLEO  =  45.000
          BENGOB  =    .000            BTEOB   =    .750
                                       DCLMTE  =    .000
                                       DCDOTE  =    .000
                                       DELTEO  =    .000

0                                                ****PROPULSION****
0         JENGSZ  =       2            HPORT   =   5000.             RCCRU   =  50.000                RWCRTX  =    .970
          IPART   =       1            TDELTO  =     36.             XTORQ   =  99999.                HSCREQ  =      0.
          KODETO  =       5            KODECL  =       7             SM1D    =    .500                THIN    =      0.
          KODETR  =       5            KODEAC  =       5             HBTP    =    .437                PR      =   1.000

0                                                *****WEIGHTS*****
0         SKPEI   =   .1350            SKY     =   .1800             SKB     = 107.000                SKPS    =   .0200
          SKLG    =   .0380            SKZ     =   .2200             SKCC    =  20.000                SKWF    =   .4300
          SKMG    =   .8000            SKTL    =  1.0000             SKFW    =   .4300                SKPT    =   .9790
          SKPES   =   .3380            SKWW    = 133.400             SKSAS   =    .000                SKWTP   =  1.8900
          WPLX    =      .0            YMG     =   .2500             EGMRGN  =   .0000                LCWING  =       2
          WPEX    =      .0            RELP    =   .7585             CPMRGN  =   .2000
          WPUL    =  1065.5            RELR    =   .4500             STMRGN  =   .0000                LDCKMX  =   8.000
          UWPAX   =   200.0            CATD    =      3.             DELP    =   8.200                ATMXQC  =   3.160
          STRUT   =   .0000            VMLFSL  =   685.0             YP      =   .0000                DELWST  =      .0
          DELWPC  =      .0
0 ENGINE  WENG    =      .0            WNAC    =      .0             WPYLON  =      .0
          SWSLS   =    .160            UWNAC   =   2.287             FPYL    =    .700                XLQDE   =   3.000

0                                                *STABILITY AND CONTROL*
0         KSFixd  =       1            STATIC  =    .100             ZCG     =   5.500                CNPAC   =   .0020
          CMFLPL  = 999.000            CHALF   = 999.000             TP      =      .0                ARVTE   =  -1.000
          CMFLPT  = 999.000            CHDEL   = 999.000             CXA     =    .520                RV      =    .300
                                       RH      =    .350             DCMCLP  =    .000                TAUV    = 999.000
          CMPLD   =    .000            DEMAX   =   -25.0             HWING   =      0.                RVMCS   =    .990
                                       EYET    =      .0             dcmcpi  =    .030                DRMAX   =    25.0
                                       TAUH    = 999.000             rc      =    .350

0,                                               ***PERFORMANCE***
0   TAXI  DELTT   =    .167            XLFMAX  =   1.100             DVR     =   5.000                TDELTX  =  36.000
      TO  IFLY    =       1            DELTVR  =   3.500             UM      =    .020                HTMAX   = 500.000
          THEMAX  =  15.000            DV1     =   5.000             MUB     =    .400                NFAIL   =       0
          H00     =   5000.            VRAT    =    1.10             WTMISN  =      0.

0  CLIMB  ICLM    =       1     CRUISE CRMACH  =    .800             FRESF   =   1.000                FACW1   =    .985
          DELH    =   1000.            CRALT   =  35000.             RCRRQ   =  1250.0                ISWING  =       0
          VCLMB   =      .0            ICRUS   =       1             OFALT   =  25000.                OFEM    =    .500
0   LAND  IWLD    =       2            XLDGRQ  =  99999.             VRATT   =   1.300                HAPP    =     50.
          TDELLD  =    36.0            ALTLND  =   5000.             RSMX    =   1000.                SINKTD  =     3.0
          TDELAY  =     1.0            WLPCT   =   .9400             TROTID  =    .000                XLFMX   =   1.200
          HTG     =     5.5            TIDLE   =      .0             VTDRAT  =     1.1

0                                                ******COST******
0         NCADE   =       1            HIR     =    .005             RI      =    .300                CMV     =    .800
          CLIAB   =  1993.0            TR      =   2.000             OHR     = 500.000                CCRW    =      0.
          HRI     =4000000.            PRV     =    .100             CRWOH   =  23.000                UCSENG  =    .000
          CMF     =      .2            DYR     =    15.0             CINP    =      0.                UCSPP   =    .000
          TBO     =  3200.0            SRPM    =      .0             CP      =      0.                ALR     =   1.120
          FCSF    =    .850
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution

```
0   **********************************************************************************************
0                        FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                      CLMAX      VSTALL,KTS  FLAP ANGLE   LE ANGLE     DELTA CL     DELTA CD

 FLAPS UP             1.1248       177.4          .0           .0         .0000       .0000
 T.O. CONFIG          2.1363       128.9        15.0           .0         .9974       .0366
 LDG. CONFIG          2.8112       112.3        40.0           .0        1.6844       .1630

0                       DOUBLE SLOTTED FOWLER FLAPS
                       OPT ANGLE     DELCL AT OPT   DELCD AT OPT     AREA(FT2)      WEIGHT(LB)

 FLAPS                   30.0          2.2500          .1500            74.2           607.4
0   **********************************************************************************************
0   **********************************************************************************************
0             TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  97.21 PSF.
     LANDING WEIGHT =     41407. LBS.

     LANDING DISTANCE FROM 50. FT.=   3097. FT.

     F.A.R. FACTORED FIELD LENGTH =   5161. FT.
0                       APPROACH              TRANSITION              DELAY                   ROLL
0                   DIST=       740.    DIST=        216.     DIST=        219.     DIST=       1922.
                    R/S=       1000.    XLFMX=      1.200     TDELAY=      1.00     MUB=        .4000
                    VAPEAS=   131.26    SINKTD=     3.000     TIDLE=         0.     TR/TIDLE=   .0000
                    VAPTAS=   146.46    VSTEAS=    100.97     VTDTAS=    129.56     ABAR(G)=    .3874
                    THETA=      3.86    CLMX=      2.8112
                    THRUST=    3172.    HFLAR=       20.9
0   **********************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=    2.218    LIFT= 42728.5    L/D=  13.405    ALTITUDE= 35000.0    MACH=    .8000

1                                        ENGINE SIZING DATA FOLLOW
                                         **************************
0VSTLKT= 119.5 KTS EAS   VRAT= 1.100 CLTO= 1.7655
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   29.7 AND TAS=   144.3 EAS=   129.5)
 LIFTOFF (TIME=   32.2 DIST=   4583.0 TAS=   152.4 EAS=   136.7)
 DISTANCE TO 35 FT.=  5963.2    TAS=   163.6 EAS=   146.7 V35/VS=  1.2274
 GEAR RETRACTION STARTED AT   38.3 SEC,COMPLETE AT   45.3 SEC
 FLAP RETRACTION STARTED AT   48.5 SEC,COMPLETE AT   53.0 SEC
0VSTLKT= 119.5 KTS EAS   VRAT= 1.100 CLTO= 1.7655
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  216.4 KNOTS EAS
 ENGINE FAILURE (TIME=   28.2 AND TAS=   138.8 EAS=   124.5)
0
 ROTATION (TIME=   33.7 AND TAS=   144.3 EAS=   129.5)
 LIFTOFF (TIME=   37.0 DIST=   5726.4 TAS=   146.5 EAS=   131.4)
 DISTANCE TO 35 FT.=  9180.4    TAS=   147.1 EAS=   131.9 V35/VS=  1.1040


     ACCELERATE - STOP DISTANCE =     7327.3 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      9180.4 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5963.2 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6857.7 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     6215.2 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .014 HRS   FUEL USED=      76. LBS   WEIGHT=   43974. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                         VS              V      GRAD       R/C    REQ.R/C
   CONFIGURATION                               ALT (FT)   KEAS    V/VS   KTAS    (PCT)     (FPM)     (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT 5000.   119.6  1.1170  149.0    1.291    194.71      1.00  1.719  8.404
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT         5250.   119.6  1.2000  160.7    3.722    605.15    390.24  1.489 10.862
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT       6500.   163.8  1.2500  233.7    4.009    948.18    283.80   .732 13.577
   APPROACH FLAPS -ONE ENG OUT                  5000.   114.6  1.3464  172.0    3.951    687.82    365.63  1.289 11.323
   LANDING FLAPS - ALL ENGINES                  5000.   104.3  1.3000  151.2   12.031   1840.36    489.51  1.670  7.002

     APPROACH FLAP SETTING = 19.7 DEG.



     +++ ENGINE-OUT SERVICE CEILING = 20789.0 FT.
         BEST RATE OF CLIMB SPEED   =   275.2 KTAS
         ENGINE-OUT RATE OF CLIMB   =    49.8 FPM
         WEIGHT AT ALTITUDE         = 42288.0 LBS

0                         ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0VSTLKT= 119.5 KTS EAS   VRAT= 1.100 CLTO= 1.7655
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   28.3 AND TAS=   144.3 EAS=   129.5)
 LIFTOFF (TIME=   30.8 DIST=   4389.6 TAS=   152.8 EAS=   137.1)
 DISTANCE TO 35 FT.=  5763.6    TAS=   164.9 EAS=   147.8 V35/VS=  1.2372
 GEAR RETRACTION STARTED AT   36.8 SEC,COMPLETE AT   43.8 SEC
 FLAP RETRACTION STARTED AT   47.0 SEC,COMPLETE AT   51.5 SEC
0VSTLKT= 119.5 KTS EAS   VRAT= 1.100 CLTO= 1.7655
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  207.4 KNOTS EAS
 ENGINE FAILURE (TIME=   26.9 AND TAS=   138.8 EAS=   124.5)
0
 ROTATION (TIME=   31.5 AND TAS=   144.3 EAS=   129.5)
 LIFTOFF (TIME=   34.8 DIST=   5342.8 TAS=   146.9 EAS=   131.8)
 DISTANCE TO 35 FT.=  7956.8    TAS=   147.8 EAS=   132.5 V35/VS=  1.1087


     ACCELERATE - STOP DISTANCE =     7160.5 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      7956.8 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5763.6 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6628.1 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     6017.3 FEET
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

```
0   AT END OF TAKEOFF PHASE
 TIME=   .014 HRS   FUEL USED=      77. LBS   WEIGHT=  43973. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;    AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                         VS              V      GRAD      R/C    REQ.R/C
    CONFIGURATION                               ALT (FT)  KEAS    V/VS    KTAS   (PCT)     (FPM)    (FPM)     CL    L/D

    1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  119.6  1.1170  149.0   1.532    230.97      1.00  1.719  8.186
    2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  119.6  1.2000  160.7   3.935    639.79    390.24  1.489 10.482
    FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  163.8  1.2500  233.7   3.954    935.05    283.80   .732 12.656
    APPROACH FLAPS -ONE ENG OUT                   5000.  114.6  1.3232  169.1   4.168    713.25    359.33  1.335 10.859
    LANDING FLAPS - ALL ENGINES                   5000.  104.3  1.3000  151.2  13.054   1996.88    489.51  1.670  6.959

      APPROACH FLAP SETTING = 19.7 DEG.


      +++ ENGINE-OUT SERVICE CEILING = 21343.0 FT.
          BEST RATE OF CLIMB SPEED   =   274.3 KTAS
          ENGINE-OUT RATE OF CLIMB   =    49.7 FPM
          WEIGHT AT ALTITUDE         = 42288.0 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    348.98

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    348.98

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   8899.1 LBS
*****************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE            1423.9
   NACELLE WEIGHT/ENGINE            307.2
   PYLON WEIGHT/ENGINE              169.2
      PROP OR QFAN           .0
      GEARBOX                .0
      SHROUD                 .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.78
   NACELLE LENGTH(FT)              11.33

0****************************************************************************************************
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

```
                         ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                    MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
                     WT          CG         WT          CG         WT          CG

  A/C OWE      25677.90      41.87    25677.90      41.87    25677.90      41.87
  PAX           5440.00                2040.00                8500.00
  BAGGAGE           .00      56.36     1500.00      56.36     1500.00      56.36
  WING FUEL     1278.90      42.37     1278.90      42.37     6394.48      42.37
  TIP FUEL          .00        .00         .00        .00         .00        .00
  FUS FUEL          .00      42.37         .00      42.37     1977.62      42.37
  TOTAL        32396.79      39.69    30496.79      43.02    44050.00      41.45
0                        ---TAIL SIZING SUMMARY---

         Static Longitudinal Stability, Stick-fixed, considered


0                  WING                   CANARD          TAIL        DOWN    FLAP
 CONDITION  ALPHA    CL     CLA     CMac  ALPHA    CLA     CLA   EFF.   WASH    CM

  CRUISE    2.3358  .4623  .1174 -.0600 3.3691  .0990  .0771 1.0000
  LIFTOFF   2.0000 1.3135  .0681 -.0600 3.0333  .0764  .0640 1.0000  .3505 -.1031
  LANDING  11.6750 2.8112  .0849 -.060012.7083  .0765  .0640 1.0000 2.0458 -.2000

0          --FUSELAGE-- ---NACELLE--          ------POWER-------         L.GEAR ROT.POWER
 CONDITION  DCM    CM    DCM    CM  DCMdth DCMfinc CMdth  CMfinc    CT      CM      CM

  CRUISE   .4954         .1487          .0000  .0300               .0000
  LIFTOFF  .8549  .0000  .1487  .0000                .0000  .0394  .0000 -.3882 4.9797
  LANDING  .6855  .5629  .1487  .1221                .0000  .0843

0     CANARD PARAMETERS
          CMDELTC(CONTROL POWER)        =  -.02539
          TAUc(EFFECTIVENESS)           =   .48250
          DcMAX(MAX.CANARDVATOR DEFLEC)= 37.47721

0     ELEVATOR PARAMETERS
          CMDELTE(CONTROL POWER)        =  -.03079           WING DE/DALPHA =   .35046
          TAUH(EFFECTIVENESS)           =   .48250
          DEMAX(MAX.ELEVATOR DEFLEC.)   =-25.00000


0                               FRACTION    STATION          CANARD AND HORIZONTAL TAIL SIZES
                                   MAC    (DATUM NOSE)                                           CANARD        HOR.TAIL


     NEUTRAL POINT                .5812      43.973          STATIC STABILITY AND LANDING TRIM
     STATIC MARGIN                .1000                      STATIC STABILITY AND LIFTOFF ROT.
     AFT CG LIMIT(STABILITY)      .4812      43.172
     CG RANGE(LOADING)            .4164                      REQUIRED SIZES                      64.7705       77.2809
     FWD CG LIMIT(CONTROL)        .0648      39.838          CANARD AND TAIL ARMS (ELcan,ELTH)   32.9524       44.0981

0     VERTICAL TAIL AREA =  100.8787 FOR DIRECTIONAL STABILITY OF      .00200
0     RUDDER POWER AT MAX.DEFL.=   .0168 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4190
0     VERTICAL TAIL AREA=   74.1509 FOR MINIMUM CONTROL SPEED =    118.28 KTS
0     REQUIRED VERTICAL TAIL AREA =  100.8787  TAIL ARM(ELTV) =   34.0464

*********************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.218   LIFT= 42728.5   L/D=  12.793   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25        H-TAIL VOL. ARM       =   44.10        C.G.LOCATION OF PROPULSION=   60.11
 WING 1/4C LOC.ON C.L.=   38.22        H-TAIL C.G.LOCATION   =   85.64        C.G.OF REMAINING WEIGHT   =   35.66
 MAC 1/4C LOCATION     =   41.17        H-TAIL MAC FROM C.L.  =    3.92
 MAC DIST.FROM C.L.    =   11.41        H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   42.77        V-TAIL VOL. ARM       =   34.05
 TIP TANKS C.G.LOCATE =      .00        V-TAIL C.G.LOCATION   =   76.08        DIST.L.E.VERT.TO L.E.HORZ.=    3.01

 CANARD 1/4C LOC. ON C.L. =     6.56
 CANARD MAC DIST.FROM C.L.=     4.42
 CANARD VOLUME ARM        =    32.95
 CANARD C.G. LOCATION     =     8.49

0                        WING        CANARD       H-TAIL      V-TAIL

   AREA                409.061      64.770      77.281     100.879
   SPAN                 58.606      19.872      17.378       9.497
   ASPECT RATIO          8.397       6.097       3.908        .894
   TAPER RATIO            .202        .503        .550        .700
   1/4C. SWEEP          14.508      20.545      24.435      50.097
   L.E. SWEEP           18.668      23.223      27.863      52.314
   C.L. CHORD           11.615       4.338       5.738      12.496
   MEAN CHORD            8.006       3.378       4.572      10.732
   TIP CHORD             2.344       2.181       3.156       8.747
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

```
0                                       MISSION PERFORMANCE DATA FOLLOWS
                                        ********************************
0   TAXI AT IDLE THRUST

                  FUEL                        FUEL
  TIME   RANGE    USED    WEIGHT    ALT.      FLOW
  (HRS)  (NM)     (LBS)   (LBS)     (FT)    (LB/HR)

   .000      0.       0.  44050.    5000.     813.
   .167      0.     135.  43915.    5000.     813.
0VSTLKT= 113.1 KTS EAS   VRAT= 1.100 CLTO= 1.7655
      VEND =   248.2 KNOTS EAS
0            (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                   FUEL                                                                                                                  FUEL    FUS.
  TIME    DIST.    USED    WEIGHT     ALT.      TAS      EAS    MACH  ACCEL      CL        CD  ALPHA GAMMA      ROC    LOAD THRUST      FLOW   ANGLE
  (SEC)   (FEET)   (LBS)   (LBS)      (FT)     (KTS)    (KTS)    NO. (FPS2)                    (DEG) (DEG)     (FPM)   FACT  (LBS)    (LB/HR) (DEG)

     .0       .0   135.5  43915.   5000.0       .0       .0   .000  10.92 1.3108   .1363  2.00    .00          .0    .00  15783.    5621.    .00
    1.0      5.4   137.0  43913.   5000.0      6.4      5.8   .010  10.77 1.3108   .1363  2.00    .00          .0    .00  15596.    5621.    .00
    2.0     21.7   138.6  43911.   5000.0     12.8     11.5   .019  10.63 1.3108   .1363  2.00    .00          .0    .00  15411.    5621.    .00
    3.0     48.6   140.2  43910.   5000.0     19.1     17.1   .028  10.47 1.3109   .1363  2.00    .00          .0    .00  15230.    5622.    .00
    4.0     86.0   141.7  43908.   5000.0     25.2     22.6   .037  10.31 1.3109   .1363  2.00    .00          .0    .00  15051.    5624.    .00
    5.0    133.7   143.3  43907.   5000.0     31.3     28.1   .046  10.15 1.3110   .1364  2.00    .00          .0    .00  14876.    5625.    .00
    6.0    191.7   144.9  43905.   5000.0     37.3     33.4   .055   9.98 1.3111   .1364  2.00    .00          .0    .00  14705.    5627.    .00
    7.0    259.6   146.4  43904.   5000.0     43.2     38.7   .064   9.81 1.3112   .1364  2.00    .00          .0    .00  14535.    5629.    .00
    8.0    337.4   148.0  43902.   5000.0     48.9     43.9   .073   9.63 1.3114   .1364  2.00    .00          .0    .00  14369.    5631.    .00
    9.0    424.9   149.5  43900.   5000.0     54.6     49.0   .081   9.45 1.3115   .1364  2.00    .00          .0    .00  14206.    5633.    .00
   10.0    521.8   151.1  43899.   5000.0     60.2     54.0   .089   9.27 1.3117   .1364  2.00    .00          .0    .00  14046.    5635.    .00
   11.0    628.1   152.7  43897.   5000.0     65.6     58.9   .097   9.08 1.3118   .1364  2.00    .00          .0    .00  13889.    5637.    .00
   12.0    743.4   154.2  43896.   5000.0     71.0     63.7   .105   8.91 1.3120   .1365  2.00    .00          .0    .00  13759.    5640.    .00
   13.0    867.8   155.8  43894.   5000.0     76.2     68.4   .113   8.75 1.3122   .1365  2.00    .00          .0    .00  13642.    5643.    .00
   14.0   1000.9   157.4  43893.   5000.0     81.4     73.0   .121   8.58 1.3124   .1365  2.00    .00          .0    .00  13528.    5646.    .00
   15.0   1142.6   158.9  43891.   5000.0     86.4     77.5   .128   8.41 1.3126   .1365  2.00    .00          .0    .00  13416.    5649.    .00
   16.0   1292.7   160.5  43890.   5000.0     91.4     82.0   .136   8.23 1.3129   .1366  2.00    .00          .0    .00  13306.    5652.    .00
   17.0   1451.1   162.1  43888.   5000.0     96.2     86.3   .143   8.06 1.3131   .1366  2.00    .00          .0    .00  13198.    5655.    .00
   18.0   1617.7   163.7  43886.   5000.0    101.0     90.6   .150   7.89 1.3133   .1366  2.00    .00          .0    .00  13093.    5659.    .00
   19.0   1792.1   165.2  43885.   5000.0    105.6     94.7   .157   7.71 1.3136   .1366  2.00    .00          .0    .00  12990.    5662.    .00
   20.0   1974.3   166.8  43883.   5000.0    110.1     98.8   .163   7.53 1.3139   .1367  2.00    .00          .0    .00  12889.    5666.    .00
   21.0   2164.0   168.4  43882.   5000.0    114.6    102.8   .170   7.36 1.3141   .1367  2.00    .00          .0    .00  12791.    5669.    .00
   22.0   2361.2   170.0  43880.   5000.0    118.9    106.6   .176   7.18 1.3144   .1367  2.00    .00          .0    .00  12695.    5673.    .00
   23.0   2565.5   171.5  43878.   5000.0    123.1    110.4   .183   7.01 1.3146   .1368  2.00    .00          .0    .00  12601.    5676.    .00
   24.0   2776.9   173.1  43877.   5000.0    127.2    114.1   .189   6.83 1.3149   .1368  2.00    .00          .0    .00  12509.    5680.    .00
   25.0   2995.2   174.7  43875.   5000.0    131.2    117.7   .195   6.66 1.3152   .1368  2.00    .00          .0    .00  12420.    5684.    .00
   26.0   3220.1   176.3  43874.   5000.0    135.1    121.2   .201   6.49 1.3155   .1368  2.00    .00          .0    .00  12335.    5688.    .00
0
 ROTATION (TIME=    26.5 AND TAS=    137.2 EAS=     123.1)
   27.0   3451.6   177.8  43872.   5000.0    139.0    124.7   .206   6.28 1.3480   .1405  2.38    .00          .0    .76  12273.    5691.    .38
   28.0   3689.4   179.4  43871.   5000.0    142.6    127.9   .212   5.84 1.4766   .1577  3.90    .00          .0    .88  12214.    5695.   1.90
 LIFTOFF (TIME=    28.8 DIST=    3883.9 TAS=    145.3 EAS=    130.3)
   29.0   3933.0   181.0  43869.   5000.0    145.9    130.9   .217   5.30 1.6132   .1783  5.56    .01         2.1   1.02  12159.    5698.   3.57
   30.0   4182.0   182.6  43867.   5000.9    148.9    133.5   .221   4.67 1.6640   .1865  6.16    .50       131.3   1.10  12111.    5701.   4.66
   31.0   4435.7   184.2  43866.   5004.7    151.5    135.9   .225   4.30 1.6043   .1771  5.36   1.21       323.2   1.09  12066.    5704.   4.56
   32.0   4693.6   185.8  43864.   5011.6    154.0    138.1   .229   3.90 1.5616   .1706  4.86   1.90       517.2   1.10  12025.    5705.   4.76
   33.0   4955.4   187.4  43863.   5021.9    156.2    140.1   .232   3.54 1.5151   .1636  4.36   2.58       713.4   1.10  11986.    5706.   4.94
 DISTANCE TO 35 FT.=  5212.8    TAS=    158.2 EAS=    141.8 V35/VS=  1.2535
   34.0   5220.6   188.9  43861.   5035.4    158.2    141.9   .235   3.17 1.4780   .1581  3.96   3.25       910.0   1.10  11951.    5707.   5.21
   35.0   5488.8   190.5  43860.   5052.2    160.0    143.4   .238   2.79 1.4510   .1543  3.66   3.91      1105.2   1.10  11918.    5707.   5.57
 GEAR RETRACTION STARTED AT    34.9 SEC,COMPLETE AT    41.9 SEC
   36.0   5759.7   192.1  43858.   5072.3    161.6    144.8   .240   2.56 1.4164   .1451  3.26   4.56      1302.5   1.09  11887.    5706.   5.82
   37.0   6032.8   193.7  43856.   5095.6    163.0    146.1   .242   2.27 1.3993   .1390  3.06   5.21      1499.4   1.10  11859.    5705.   6.27
   38.0   6308.0   195.3  43855.   5122.3    164.3    147.1   .244   2.02 1.3736   .1317  2.76   5.86      1699.1   1.10  11832.    5703.   6.62
   39.0   6584.9   196.9  43853.   5152.2    165.5    148.1   .246   1.75 1.3565   .1259  2.56   6.49      1894.9   1.10  11807.    5700.   7.05
   40.0   6863.3   198.4  43852.   5185.5    166.4    148.9   .247   1.50 1.3394   .1202  2.36   7.12      2090.0   1.10  11785.    5697.   7.48
   41.0   7142.7   200.0  43850.   5221.9    167.3    149.6   .249   1.24 1.3309   .1155  2.26   7.74      2283.9   1.10  11763.    5694.   8.00
   42.0   7423.1   201.6  43848.   5261.6    168.0    150.1   .250   1.00 1.3137   .1102  2.06   8.36      2474.6   1.09  11744.    5689.   8.42
   43.0   7703.9   203.2  43847.   5304.4    168.4    150.4   .250    .65 1.3051   .1093  1.96   8.98      2663.2   1.09  11727.    5684.   8.93
   44.0   7985.0   204.8  43845.   5350.4    168.7    150.6   .251    .30 1.3052   .1093  1.96   9.59      2850.0   1.10  11713.    5679.   9.55
   45.0   8265.8   206.3  43844.   5399.4    168.8    150.5   .251    .01 1.2879   .1075  1.76  10.19      3028.1   1.09  11701.    5673.   9.95
 FLAP RETRACTION STARTED AT    45.0 SEC,COMPLETE AT    49.5 SEC
   46.0   8546.4   207.9  43842.   5450.4    168.9    150.4   .251    .01 1.1295   .1061  2.46  10.26      3046.3    .95  11690.    5666.  10.71
   47.0   8827.2   209.5  43841.   5500.1    168.9    150.3   .251   -.01 1.0506   .1173  4.11   9.73      2892.5    .89  11680.    5660.  11.84
0VSTLKT= 113.1 KTS EAS   VRAT= 1.100 CLTO= 1.7655
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =   204.1 KNOTS EAS
0            (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)
                 FUEL                                                                                                                   FUEL    FUS.
  TIME    DIST.   USED    WEIGHT     ALT.      TAS      EAS    MACH  ACCEL      CL       CD  ALPHA GAMMA       ROC   LOAD THRUST      FLOW   ANGLE
  (SEC)   (FEET)  (LBS)   (LBS)      (FT)     (KTS)    (KTS)    NO. (FPS2)                   (DEG) (DEG)      (FPM)  FACT  (LBS)    (LB/HR) (DEG)

     .0       .0  135.5  43915.   5000.0       .0       .0   .000  10.92 1.3108  .1363  2.00    .00           .0    .00  15783.    5621.    .00
    1.0      5.4  137.0  43913.   5000.0      6.4      5.8   .010  10.77 1.3108  .1363  2.00    .00           .0    .00  15596.    5621.    .00
    2.0     21.7  138.6  43911.   5000.0     12.8     11.5   .019  10.63 1.3108  .1363  2.00    .00           .0    .00  15411.    5621.    .00
    3.0     48.6  140.2  43910.   5000.0     19.1     17.1   .028  10.47 1.3109  .1363  2.00    .00           .0    .00  15230.    5622.    .00
    4.0     86.0  141.7  43908.   5000.0     25.2     22.6   .037  10.31 1.3109  .1363  2.00    .00           .0    .00  15051.    5624.    .00
    5.0    133.7  143.3  43907.   5000.0     31.3     28.1   .046  10.15 1.3110  .1364  2.00    .00           .0    .00  14876.    5625.    .00
    6.0    191.7  144.9  43905.   5000.0     37.3     33.4   .055   9.98 1.3111  .1364  2.00    .00           .0    .00  14705.    5627.    .00
    7.0    259.6  146.4  43904.   5000.0     43.2     38.7   .064   9.81 1.3112  .1364  2.00    .00           .0    .00  14535.    5629.    .00
    8.0    337.4  148.0  43902.   5000.0     48.9     43.9   .073   9.63 1.3114  .1364  2.00    .00           .0    .00  14369.    5631.    .00
    9.0    424.9  149.5  43900.   5000.0     54.6     49.0   .081   9.45 1.3115  .1364  2.00    .00           .0    .00  14206.    5633.    .00
   10.0    521.8  151.1  43899.   5000.0     60.2     54.0   .089   9.27 1.3117  .1364  2.00    .00           .0    .00  14046.    5635.    .00
   11.0    628.1  152.7  43897.   5000.0     65.6     58.9   .097   9.08 1.3118  .1364  2.00    .00           .0    .00  13889.    5637.    .00
   12.0    743.4  154.2  43896.   5000.0     71.0     63.7   .105   8.91 1.3120  .1365  2.00    .00           .0    .00  13759.    5640.    .00
   13.0    867.8  155.8  43894.   5000.0     76.2     68.4   .113   8.75 1.3122  .1365  2.00    .00           .0    .00  13642.    5643.    .00
   14.0   1000.9  157.4  43893.   5000.0     81.4     73.0   .121   8.58 1.3124  .1365  2.00    .00           .0    .00  13528.    5646.    .00
   15.0   1142.6  158.9  43891.   5000.0     86.4     77.5   .128   8.41 1.3126  .1365  2.00    .00           .0    .00  13416.    5649.    .00
   16.0   1292.7  160.5  43890.   5000.0     91.4     82.0   .136   8.23 1.3129  .1366  2.00    .00           .0    .00  13306.    5652.    .00
   17.0   1451.1  162.1  43888.   5000.0     96.2     86.3   .143   8.06 1.3131  .1366  2.00    .00           .0    .00  13198.    5655.    .00
   18.0   1617.7  163.7  43886.   5000.0    101.0     90.6   .150   7.89 1.3133  .1366  2.00    .00           .0    .00  13093.    5659.    .00
   19.0   1792.1  165.2  43885.   5000.0    105.6     94.7   .157   7.71 1.3136  .1366  2.00    .00           .0    .00  12990.    5662.    .00
   20.0   1974.3  166.8  43883.   5000.0    110.1     98.8   .163   7.53 1.3139  .1367  2.00    .00           .0    .00  12889.    5666.    .00
   21.0   2164.0  168.4  43882.   5000.0    114.6    102.8   .170   7.36 1.3141  .1367  2.00    .00           .0    .00  12791.    5669.    .00
   22.0   2361.2  170.0  43880.   5000.0    118.9    106.6   .176   7.18 1.3144  .1367  2.00    .00           .0    .00  12695.    5673.    .00
   23.0   2565.5  171.5  43878.   5000.0    123.1    110.4   .183   7.01 1.3146  .1368  2.00    .00           .0    .00  12601.    5676.    .00
   24.0   2776.9  173.1  43877.   5000.0    127.2    114.1   .189   6.83 1.3149  .1368  2.00    .00           .0    .00  12509.    5680.    .00
   25.0   2995.2  174.7  43875.   5000.0    131.2    117.7   .195   6.66 1.3152  .1368  2.00    .00           .0    .00  12420.    5684.    .00
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

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 ENGINE FAILURE (TIME=   25.1 AND TAS=   131.7 EAS=   118.1)
   26.0  3219.0   175.6  43874.  5000.0  133.2  119.5  .198    1.90 1.3154  .1450  2.00   .00       .0   .00   6188.    2843.    .00
   27.0  3444.9   176.4  43874.  5000.0  134.3  120.5  .199    1.86 1.3155  .1448  2.00   .00       .0   .00   6176.    2843.    .00
   28.0  3672.7   177.2  43873.  5000.0  135.4  121.5  .201    1.82 1.3155  .1446  2.00   .00       .0   .00   6165.    2844.    .00
   29.0  3902.4   178.0  43872.  5000.0  136.5  122.5  .203    1.78 1.3156  .1444  2.00   .00       .0   .00   6157.    2844.    .00
0
 ROTATION (TIME=   29.7 AND TAS=   137.2 EAS=   123.1)
   30.0  4133.8   178.8  43871.  5000.0  137.5  123.4  .204    1.73 1.3274  .1455  2.14   .00       .0   .74   6148.    2845.    .14
   31.0  4366.9   179.6  43870.  5000.0  138.5  124.2  .206    1.44 1.4559  .1619  3.66   .00       .0   .82   6140.    2845.   1.66
   32.0  4601.5   180.4  43870.  5000.0  139.3  124.9  .207    1.11 1.5845  .1809  5.21   .00       .0   .91   6134.    2846.   3.21
   33.0  4837.2   181.2  43869.  5000.0  139.8  125.4  .208     .74 1.7130  .2016  6.82   .00       .0  1.00   6130.    2846.   4.82
 LIFTOFF (TIME=   33.0 DIST=   4837.2 TAS=   139.8 EAS=   125.4)
   34.0  5073.6   182.0  43868.  5000.3  140.1  125.7  .208     .44 1.7655  .2106  7.47   .20     49.4  1.03   6127.    2846.   5.67
   35.0  5310.5   182.7  43867.  5001.7  140.3  125.9  .208     .27 1.7655  .2106  7.39   .48    119.0  1.04   6125.    2846.   5.87
   36.0  5547.6   183.5  43867.  5004.3  140.5  126.0  .209     .09 1.7655  .2107  7.31   .78    193.3  1.04   6124.    2846.   6.08
   37.0  5784.9   184.3  43866.  5008.1  140.5  126.0  .209     .02 1.7405  .2065  6.97  1.05    260.7  1.02   6123.    2846.   6.02
   38.0  6022.1   185.1  43865.  5012.8  140.5  126.0  .209     .00 1.7229  .2036  6.77  1.19    294.5  1.01   6123.    2846.   5.96
   39.0  6259.3   185.9  43864.  5017.9  140.5  126.0  .209     .02 1.7040  .2004  6.57  1.25    309.9  1.00   6122.    2845.   5.82
   40.0  6496.5   186.7  43863.  5023.1  140.5  126.0  .209     .02 1.7023  .2001  6.57  1.26    313.5  1.00   6121.    2845.   5.83
   41.0  6733.8   187.5  43863.  5028.3  140.5  126.0  .209     .02 1.7009  .1999  6.57  1.27    314.9  1.00   6121.    2845.   5.84
   42.0  6971.1   188.3  43862.  5033.6  140.5  126.0  .209     .02 1.6999  .1998  6.57  1.27    315.0  1.00   6120.    2844.   5.84
 DISTANCE TO 35 FT.=  7036.4    TAS=   140.5 EAS=   126.0 V35/VS=  1.1140
   43.0  7208.4   189.1  43861.  5038.8  140.5  126.0  .209     .02 1.6992  .1996  6.57  1.27    315.1  1.00   6119.    2844.   5.84
   44.0  7445.7   189.9  43860.  5044.1  140.6  126.0  .209     .02 1.6987  .1996  6.57  1.27    315.4  1.00   6119.    2844.   5.84
   45.0  7683.1   190.7  43860.  5049.3  140.6  126.0  .209     .02 1.6983  .1995  6.57  1.27    316.1  1.00   6118.    2843.   5.84


      ACCELERATE - STOP DISTANCE =     6762.3 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     7036.4 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     5212.8 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     5994.8 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5455.8 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .180 HRS   FUEL USED=     209. LBS   WEIGHT=  43841. LBS   ALT.=    5500. FT.


    ACCELERATE TO MACH NO. = .415

0                  FUEL                                                        FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

   .180     .00   209.5  43841.    5500.    163.    150.   .251  .724  11950.    5579.
   .188    1.99   260.3  43790.    5500.    269.    248.   .415  .806  10197.    5733.

  END OF ACCELERATION SEGMENT
  TIME=  .188 HRS   FUEL USED=   260.3 LBS   WEIGHT=  43790. LBS   RANGE=    2. NM
0   CLIMB TO   35000. FT. AT MAXIMUM RATE OF CLIMB
0                  FUEL                                                                             FUS.                     FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    CL     CD    ALPHA GAMMA ANGLE    R/C   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV                  (DEG) (DEG) (DEG)   (FPM)   (LBS)   (LB/HR)

   .188      2.     260.  43790.    5500.    247.    228.  .380  .798  .5214  .0389  4.24  7.68  9.92   3344.    9091.   5042.
   .191      3.     273.  43777.    6000.    248.    227.  .382  .797  .5255  .0391  4.28  7.27  9.55   3179.    9011.   4994.
   .196      4.     299.  43751.    7000.    251.    226.  .388  .797  .5291  .0393  4.31  6.89  9.20   3051.    8826.   4895.
   .202      5.     326.  43724.    8000.    254.    225.  .394  .797  .5331  .0395  4.34  6.68  9.02   2993.    8640.   4795.
   .207      7.     352.  43698.    9000.    263.    229.  .409  .799  .5148  .0385  4.11  5.61  7.71   2598.    8383.   4691.
   .214      8.     383.  43667.   10000.    265.    228.  .415  .798  .5198  .0388  4.15  6.16  8.31   2884.    8214.   4587.
   .219     10.     409.  43641.   11000.    268.    227.  .421  .797  .5254  .0391  4.20  6.34  8.54   2994.    8047.   4486.
   .225     11.     434.  43616.   12000.    270.    225.  .426  .797  .5319  .0395  4.26  5.76  8.02   2751.    7880.   4387.
   .231     13.     461.  43589.   13000.    273.    224.  .432  .796  .5381  .0398  4.32  5.56  7.88   2683.    7714.   4290.
   .237     15.     487.  43563.   14000.    276.    223.  .438  .795  .5445  .0402  4.38  5.37  7.74   2614.    7549.   4196.
   .244     16.     514.  43536.   15000.    279.    221.  .444  .794  .5510  .0406  4.43  5.17  7.60   2543.    7385.   4104.
   .250     18.     541.  43509.   16000.    285.    222.  .456  .795  .5455  .0402  4.34  4.55  6.90   2289.    7179.   4009.
   .257     20.     570.  43480.   17000.    288.    221.  .462  .794  .5522  .0406  4.40  4.69  7.10   2384.    7001.   3908.
   .264     22.     597.  43453.   18000.    290.    220.  .469  .793  .5594  .0411  4.46  4.48  6.95   2300.    6826.   3809.
   .272     24.     625.  43425.   19000.    293.    218.  .475  .792  .5666  .0415  4.53  4.27  6.80   2215.    6654.   3712.
   .279     27.     653.  43397.   20000.    296.    217.  .482  .791  .5739  .0419  4.59  4.07  6.66   2131.    6485.   3617.
   .287     29.     681.  43369.   21000.    299.    215.  .489  .791  .5814  .0424  4.65  3.87  6.52   2047.    6318.   3524.
   .295     31.     710.  43340.   22000.    303.    214.  .497  .790  .5861  .0427  4.68  3.59  6.27   1927.    6149.   3434.
   .304     34.     740.  43310.   23000.    307.    213.  .505  .789  .5920  .0430  4.72  3.42  6.14   1857.    5985.   3346.
   .313     37.     770.  43280.   24000.    314.    214.  .519  .790  .5861  .0427  4.61  2.95  5.56   1635.    5800.   3267.
   .323     40.     803.  43247.   25000.    318.    213.  .527  .789  .5923  .0431  4.65  2.99  5.64   1676.    5628.   3187.
   .333     43.     835.  43215.   26000.    321.    212.  .535  .788  .5992  .0435  4.70  2.79  5.49   1586.    5460.   3109.
   .343     46.     867.  43183.   27000.    326.    211.  .546  .788  .6030  .0437  4.71  2.53  5.24   1457.    5291.   3033.
   .355     50.     902.  43148.   28000.    330.    210.  .554  .787  .6098  .0442  4.75  2.39  5.14   1394.    5130.   2957.
   .367     54.     937.  43113.   29000.    334.    209.  .564  .786  .6164  .0446  4.79  2.20  4.98   1296.    4972.   2882.
   .380     58.     974.  43076.   30000.    361.    221.  .611  .795  .5482  .0404  3.92  1.13  3.05    721.    4747.   2847.
   .403     67.    1040.  43010.   31000.    363.    219.  .618  .793  .5596  .0411  4.01  1.76  3.77   1129.    4587.   2750.
   .418     72.    1081.  42969.   32000.    366.    216.  .626  .792  .5715  .0418  4.10  1.58  3.68   1021.    4431.   2656.
   .434     78.    1124.  42926.   33000.    369.    214.  .634  .790  .5835  .0425  4.19  1.40  3.59    916.    4278.   2564.
   .452     85.    1171.  42879.   34000.    374.    213.  .645  .789  .5902  .0429  4.21  1.17  3.38    771.    4128.   2478.
   .474     93.    1224.  42826.   35000.    378.    211.  .656  .789  .5971  .0434  4.23  1.01  3.24    673.    3982.   2393.
0   END OF CLIMB TO   35000. FT
 TIME=   .474 HRS   FUEL USED=     1224. LBS   WEIGHT=   42826. LBS   RANGE=     93. NM

0ALTITUDE=      35000. FT   TAS=      459.35 KTS   MACH NO=       .7959


   ACCELERATE TO MACH NO. = .800

0                  FUEL                                                        FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

   .474   92.90  1224.5  42826.   35000.    378.    211.   .656  .788   4255.    2721.
   .525  115.47  1372.4  42678.   35000.    461.    258.   .800  .812   4348.    2842.

  END OF ACCELERATION SEGMENT
  TIME=  .525 HRS   FUEL USED=  1372.4 LBS   WEIGHT=  42678. LBS   RANGE=  115. NM
***SPECIFIED MACH NUMBER CONDITION CAN NOT BE PERFORMED AT NORMAL RATED POWER CONDITION***
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Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

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  ACCELERATE TO MACH NO. = .796

0                  FUEL                                                             FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV    (LBS)   (LB/HR)

   .474    92.90  1224.5  42826.  35000.    378.    211.  .656  .788   4255.    2721.
   .523   114.77  1368.2  42682.  35000.    459.    256.  .796  .812   4345.    2839.

  END OF ACCELERATION SEGMENT
  TIME=  .523 HRS   FUEL USED=  1368.2 LBS   WEIGHT=  42682. LBS   RANGE=  115. NM


  ACCELERATE TO MACH NO. = .813

0                  FUEL                                                             FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV    (LBS)   (LB/HR)

   .474    92.90  1224.5  42826.  35000.    378.    211.  .656  .788   4255.    2721.
   .529   117.77  1386.4  42664.  35000.    469.    262.  .813  .813   4359.    2851.

  END OF ACCELERATION SEGMENT
  TIME=  .529 HRS   FUEL USED=  1386.4 LBS   WEIGHT=  42664. LBS   RANGE=  118. NM


0                                     DESIGN CASE
                                      CRUISE PERFORMANCE SUMMARY
                                                FOR
                                      ***** DESIGN PAYLOAD *****
                                      **** MAXIMUM PAYLOAD *****
                                      ****** MAXIMUM FUEL ******
                                      FUEL AVAILABLE=   8372.
0                              AT                     AT                      AT
                         SPECIFIED SPEED         NORMAL POWER          BEST SPEC. RANGE
                         START     END           START    END          START    END
                         CRUISE    CRUISE        CRUISE   CRUISE       CRUISE   CRUISE
                         -------   -------       -------  -------      -------  -------
  TIME           HRS.      .000      .000          .523    2.634         .529    2.838
  RANGE          N.MI        0.        0.          115.    1084.         118.    1202.
  FUEL USED      LBS.        0.        0.         1368.    6008.        1386.    6627.
  WEIGHT         LBS.        0.        0.        42682.   38042.       42664.   37423.
  ALTITUDE       FT.         0.        0.        35000.   35000.       35000.   35000.
  TAS            KTS.        .0        .0         459.3    459.3        469.3    469.3
  EAS            KTS.        .0        .0         256.0    256.0        261.6    261.6
  MACH NO.                .0000     .0000         .7959    .7959        .8133    .8133
  DIV. MACH               .0000     .0000         .8120    .8188        .8141    .8199
  ANGLE ATTACK DEG.        .000      .000         1.880    1.403        1.661    1.260
  FUSE. ANGLE  DEG.        .000      .000         -.120    -.597        -.339    -.740
  CL                      .0000     .0000         .4068    .3509        .3895    .3416
  L/D                      .000      .000        12.261   11.328       12.042   11.188
  FUEL FLOW    LB/HR         .0        .0        2262.5   2137.6       2327.1   2216.9
  BREG. FACTOR N.MI.         0.        0.         8671.    8180.        8610.    7928.
  SPEC. RANGE  NM/LB     .00000    .00000        .20303   .21489       .20169   .21172


0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
            (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
0                  FUEL                                                                            FUS.                            FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   CL       CD    ALPHA GAMMA ANGLE     R/S    THRUST     FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)   NO.   DIV                   (DEG) (DEG) (DEG)    (FPM)   (LBS)    (LB/HR)

  2.647   1090.   6027.   38023.   35000.   459.   256.   .796  .818  .3589  .0312  1.47 -1.65 -2.18    1339.    2209.    1538.  R
  2.659   1096.   6048.   38002.   34000.   461.   263.   .796  .820  .3422  .0306  1.33 -1.60 -2.27    1306.    2332.    1627.  R
  2.672   1102.   6071.   37979.   33000.   463.   269.   .796  .822  .3265  .0300  1.19 -1.55 -2.36    1271.    2463.    1721.  R
  2.686   1108.   6095.   37955.   32000.   465.   275.   .796  .824  .3115  .0295  1.07 -1.51 -2.44    1241.    2597.    1819.  R
  2.700   1115.   6121.   37929.   31000.   468.   281.   .796  .825  .2974  .0291   .94 -1.46 -2.52    1209.    2739.    1922.  R
  2.714   1121.   6150.   37900.   30000.   470.   288.   .796  .827  .2840  .0287   .83 -1.42 -2.59    1180.    2885.    2029.  R
  2.728   1128.   6181.   37869.   29000.   472.   295.   .796  .829  .2713  .0283   .72 -1.38 -2.66    1153.    3035.    2140.  R
  2.743   1135.   6214.   37836.   28000.   474.   301.   .796  .830  .2593  .0280   .62 -1.34 -2.73    1127.    3190.    2255.  R
  2.758   1143.   6250.   37800.   27000.   476.   308.   .796  .831  .2478  .0277   .52 -1.31 -2.79    1100.    3354.    2377.  R
  2.774   1150.   6289.   37761.   26000.   478.   315.   .796  .833  .2370  .0274   .43 -1.27 -2.85    1077.    3537.    2509.  R
  2.789   1158.   6331.   37719.   25000.   480.   322.   .796  .834  .2267  .0271   .34 -1.24 -2.90    1053.    3711.    2640.  R
  2.806   1165.   6376.   37674.   24000.   482.   329.   .796  .835  .2169  .0269   .26 -1.21 -2.96    1032.    3889.    2775.  R
  2.822   1173.   6424.   37626.   23000.   484.   336.   .796  .836  .2075  .0267   .18 -1.18 -3.01    1011.    4075.    2916.  R
  2.839   1181.   6475.   37575.   22000.   486.   343.   .796  .837  .1987  .0265   .10 -1.15 -3.05     992.    4265.    3062.  R
  2.856   1190.   6530.   37520.   21000.   484.   348.   .790  .838  .1930  .0264   .06 -1.13 -3.07     972.    4390.    3165.  R
  2.861   1192.   6533.   37517.   20000.   415.   303.   .675  .831  .2525  .0278   .83 -4.83 -6.00    3543.     951.     685.  A
  2.866   1194.   6536.   37514.   19000.   410.   305.   .665  .831  .2497  .0277   .82 -4.82 -6.00    3498.     991.     717.  A
  2.870   1196.   6540.   37510.   18000.   406.   307.   .655  .832  .2469  .0276   .81 -4.81 -6.00    3452.    1033.     750.  A
  2.875   1198.   6544.   37506.   17000.   401.   308.   .645  .832  .2442  .0276   .80 -4.80 -6.00    3407.    1076.     784.  A
  2.880   1200.   6548.   37502.   16000.   397.   310.   .636  .832  .2414  .0275   .79 -4.79 -6.00    3363.    1121.     820.  A
  2.885   1202.   6552.   37498.   15000.   393.   312.   .626  .833  .2387  .0274   .78 -4,78 -6.00    3319.    1167.     857.  A
  2.890   1203.   6557.   37493.   14000.   389.   314.   .618  .833  .2359  .0273   .77 -4.77 -6.00    3275.    1215.     895.  A
  2.895   1205.   6562.   37488.   13000.   385.   316.   .609  .833  .2332  .0273   .75 -4.75 -6.00    3232.    1264.     935.  A
  2.901   1207.   6567.   37483.   12000.   381.   317.   .601  .834  .2304  .0272   .74 -4.74 -6.00    3189.    1315.     977.  A
  2.906   1209.   6572.   37478.   11000.   377.   319.   .592  .834  .2277  .0271   .72 -4.72 -6.00    3147.    1368.    1020.  A
  2.916   1212.   6580.   37470.   10000.   291.   250.   .455  .816  .3718  .0316  2.45 -3.21 -2.76    1653.    1079.     776.  S
  2.926   1215.   6588.   37462.    9000.   286.   250.   .446  .816  .3717  .0316  2.47 -3.16 -2.69    1599.    1116.     805.  S
  2.937   1218.   6597.   37453.    8000.   282.   250.   .438  .816  .3716  .0316  2.48 -3.10 -2.62    1546.    1154.     835.  S
  2.948   1222.   6607.   37443.    7000.   277.   250.   .430  .816  .3715  .0316  2.49 -3.04 -2.55    1493.    1193.     866.  S
  2.960   1225.   6617.   37433.    6000.   273.   250.   .422  .816  .3714  .0316  2.50 -2.98 -2.48    1441.    1233.     898.  S
  2.972   1228.   6628.   37422.    5000.   269.   250.   .414  .816  .3713  .0316  2.51 -2.92 -2.41    1389.    1275.     930.  S
  2.984   1231.   6640.   37410.    4000.   265.   250.   .406  .816  .3712  .0316  2.52 -2.85 -2.33    1338.    1318.     965.  S
  2.997   1235.   6653.   37397.    3000.   261.   250.   .399  .816  .3711  .0316  2.53 -2.78 -2.25    1287.    1362.    1000.  S
  3.011   1238.   6667.   37383.    2000.   257.   250.   .391  .816  .3710  .0316  2.54 -2.72 -2.18    1236.    1407.    1036.  S
  3.018   1240.   6675.   37375.    1500.   255.   250.   .388  .816  .3708  .0316  2.54 -2.68 -2.14    1211.    1430.    1055.  S
0  END OF DSCNT TO     1500. FT
 TIME=  3.018 HRS   FUEL USED=     6675. LBS   WEIGHT=    37375. LBS   RANGE=   1240. NM

0      RESERVE FUEL(LBS)        0.                 1697.                  1745.
         (   45.0 MIN.)

   ***********************************************************************************
0      RANGE = 1240.    BLOCK TIME= 3.018    USED FOR DESIGN RANGE AND COST

   ***********************************************************************************
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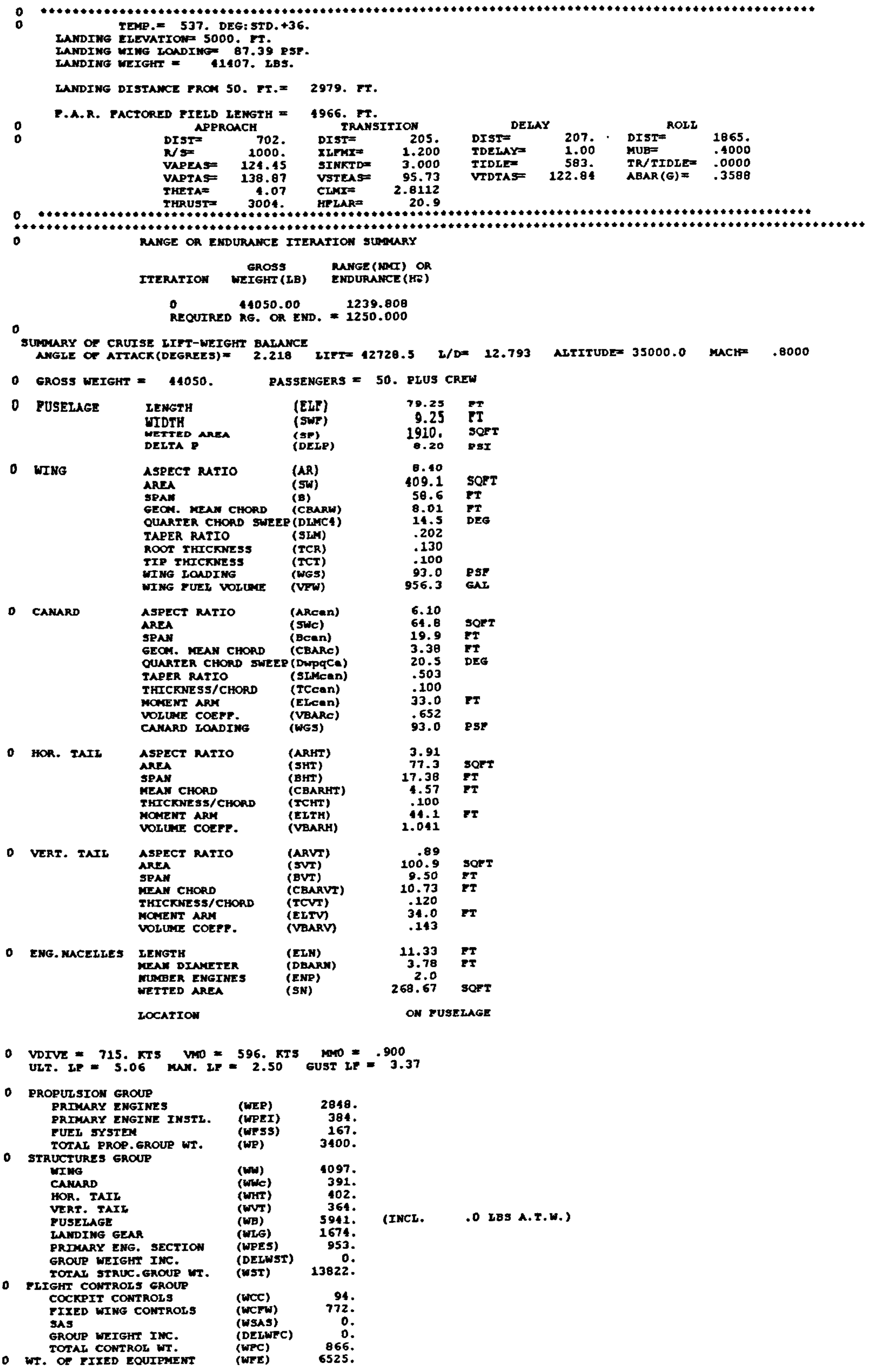
Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)



```
0 ****************************************************************************************************
0            TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  87.39 PSF.
     LANDING WEIGHT =    41407. LBS.

     LANDING DISTANCE FROM 50. FT.=   2979. FT.

     F.A.R. FACTORED FIELD LENGTH =   4966. FT.
0                    APPROACH              TRANSITION             DELAY                ROLL
0                DIST=        702.    DIST=        205.    DIST=        207. .  DIST=        1865.
                 R/S=        1000.    XLFMX=      1.200    TDELAY=      1.00    MUB=         .4000
                 VAPEAS=    124.45    SINKTD=     3.000    TIDLE=       583.    TR/TIDLE=    .0000
                 VAPTAS=    138.87    VSTEAS=     95.73    VTDTAS=    122.84    ABAR(G)=     .3588
                 THETA=       4.07    CLMX=      2.8112
                 THRUST=     3004.    HPLAR=       20.9
0 ****************************************************************************************************
**************************************************************************************************************
0                RANGE OR ENDURANCE ITERATION SUMMARY

                                 GROSS       RANGE(NMI) OR
                ITERATION    WEIGHT(LB)    ENDURANCE(HR)

                     0         44050.00       1239.808
                     REQUIRED RG. OR END. * 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.218   LIFT= 42728.5   L/D=  12.793   ALTITUDE= 35000.0   MACH=   .8000

0  GROSS WEIGHT =   44050.        PASSENGERS =  50. PLUS CREW

0  FUSELAGE       LENGTH               (ELF)            79.25   FT
                  WIDTH                (SWF)             9.25   FT
                  WETTED AREA          (SP)             1910.   SQFT
                  DELTA P              (DELP)            8.20   PSI

0  WING           ASPECT RATIO         (AR)              8.40
                  AREA                 (SW)             409.1   SQFT
                  SPAN                 (B)               58.6   FT
                  GEOM. MEAN CHORD     (CBARW)           8.01   FT
                  QUARTER CHORD SWEEP(DLMC4)             14.5   DEG
                  TAPER RATIO          (SLM)             .202
                  ROOT THICKNESS       (TCR)             .130
                  TIP THICKNESS        (TCT)             .100
                  WING LOADING         (WGS)             93.0   PSF
                  WING FUEL VOLUME     (VFW)            956.3   GAL

0  CANARD         ASPECT RATIO         (ARcan)           6.10
                  AREA                 (SWc)             64.8   SQFT
                  SPAN                 (Bcan)            19.9   FT
                  GEOM. MEAN CHORD     (CBARc)           3.38   FT
                  QUARTER CHORD SWEEP(DwpqCa)            20.5   DEG
                  TAPER RATIO          (SLMcan)          .503
                  THICKNESS/CHORD      (TCcan)           .100
                  MOMENT ARM           (ELcan)           33.0   FT
                  VOLUME COEFF.        (VBARc)           .652
                  CANARD LOADING       (WGS)             93.0   PSF

0  HOR. TAIL      ASPECT RATIO         (ARHT)            3.91
                  AREA                 (SHT)             77.3   SQFT
                  SPAN                 (BHT)            17.38   FT
                  MEAN CHORD           (CBARHT)          4.57   FT
                  THICKNESS/CHORD      (TCHT)            .100
                  MOMENT ARM           (ELTH)            44.1   FT
                  VOLUME COEFF.        (VBARH)          1.041

0  VERT. TAIL     ASPECT RATIO         (ARVT)             .89
                  AREA                 (SVT)            100.9   SQFT
                  SPAN                 (BVT)             9.50   FT
                  MEAN CHORD           (CBARVT)         10.73   FT
                  THICKNESS/CHORD      (TCVT)            .120
                  MOMENT ARM           (ELTV)            34.0   FT
                  VOLUME COEFF.        (VBARV)           .143

0  ENG.NACELLES   LENGTH               (ELN)            11.33   FT
                  MEAN DIAMETER        (DBARN)           3.78   FT
                  NUMBER ENGINES       (ENP)              2.0
                  WETTED AREA          (SN)            268.67   SQFT

                  LOCATION                             ON FUSELAGE


0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
   ULT. LF =  5.06   MAN. LF =  2.50   GUST LF =  3.37

0  PROPULSION GROUP
      PRIMARY ENGINES          (WEP)       2848.
      PRIMARY ENGINE INSTL.    (WPEI)       384.
      FUEL SYSTEM              (WFSS)       167.
      TOTAL PROP.GROUP WT.     (WP)        3400.
0  STRUCTURES GROUP
      WING                     (WW)        4097.
      CANARD                   (WWc)        391.
      HOR. TAIL                (WHT)        402.
      VERT. TAIL               (WVT)        364.
      FUSELAGE                 (WB)        5941.   (INCL.      .0 LBS A.T.W.)
      LANDING GEAR             (WLG)       1674.
      PRIMARY ENG. SECTION     (WPES)       953.
      GROUP WEIGHT INC.        (DELWST)       0.
      TOTAL STRUC.GROUP WT.    (WST)      13822.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS         (WCC)         94.
      FIXED WING CONTROLS      (WCFW)       772.
      SAS                      (WSAS)         0.
      GROUP WEIGHT INC.        (DELWFC)       0.
      TOTAL CONTROL WT.        (WPC)        866.
0  WT. OF FIXED EQUIPMENT      (WFE)       6525.
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

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    WEIGHT EMPTY                (WE)       24612.

    FIXED USEFUL LOAD           (WFUL)      1065. (INC. CREW )

    OPERATING WEIGHT EMPTY      (OWE)      25678.
 0  PAYLOAD                     (WPL)      10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

    FUEL                        (WFA)       8372. (WFW= 6394.) (WFTP=    0.)

    GROSS WEIGHT                (WG)       44050.
 0         FIXED EQUIP GROUP                        FIXED USEFUL LOAD
 0     WAPU               372.27         WCREW ( 2.)          340.00
       WINSTR             225.76         WSTU  ( 1.)          130.00
       WHYD               354.45         WCBAG                110.00
       WELEC              970.00         WUF                  121.36
       WAV                500.00         WOIL                 120.11
       WFUR              3410.00         WSRV                 116.00
       WAC                477.91         WH2O                  53.00
       WAI                194.63         WEMER                 40.00
       WAUXG               20.00         WCATER                35.00

       WFE               6525.03         WFUL                1065.47


 0  DESIGN MACH =  .800         DESIGN ALTITUDE =  35000.         DESIGN Q (PSF) =224.03
 0  DESIGN RE.NUM. PER FT.    = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274
 0  AERODYNAMIC DATA

 0                           FLATPLATE              WETTED
    DRAG BREAKDOWN           AREA(SQFT)     CDO     AREA(SQFT)
 0       WING                  2.7286     .00576      616.77
         CANARD                 .4755     .00100       58.57
         FUSELAGE              5.4592     .01152     1910.38
         VERT.TAIL              .6238     .00132      201.76
         HOR. TAIL              .5241     .00111      154.56
         ENGINE NAC.           1.2147     .00256      268.67
         TIP TANKS              .0000     .00000         .00
         INCREMENTAL            .7107     .00150         .00
 0           TOTAL            11.7367     .02477     3210.72

             MEAN SKIN FRICTION COEF.=  .003655


 0  AERODYNAMIC COEFF.                             AIRCRAFT          WING                      CANARD
                                          (except Wing and Canard)
       A1                                                             .8019                     .8441
       A2                                                            -.1227                    -.1244
       A3                                                             .0381                     .0263
       A4=.75X(T/C)                                                   .0902                     .0750
       A5=CDO--                                         .0152
       A6                                                            2.4345                    2.6794
       A7=1/(PI.SEE.AR)                                               .0478                     .0625
       3-D LIFT SLOPE AT CRUISE MACH     (CLALPH)                    6.7297 PER RAD.   (CLALFc) 5.6718 PER RAD.
       OSWALD FACTOR                     (SEE)                        .7932            (SEEcan)  .8353


 0  CRUISE CD =  .0246 +   .0498 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
 0  RETRACTABLE LANDING GEAR CD INC.= .03079


 0 CRUISE DRAG
 0CL=   .2000
            MACH      CD     L/D   CLALPH    ALPHA
           .50000  .02659  7.5214  5.3570    .5391
           .55000  .02659  7.5214  5.4905    .4871
           .60000  .02659  7.5214  5.6500    .4282
           .65000  .02659  7.5214  5.8418    .3616
           .70000  .02659  7.5214  6.0753    .2862
           .75000  .02659  7.5214  6.3640    .2006
           .80000  .02659  7.5214  6.7297    .1028
           .85000  .02664  7.5064  7.2091   -.0105
 0CL=   .3000
            MACH      CD     L/D   CLALPH    ALPHA
           .50000  .02922 10.2671  5.3570   1.6086
           .55000  .02922 10.2671  5.4905   1.5306
           .60000  .02922 10.2671  5.6500   1.4423
           .65000  .02922 10.2671  5.8418   1.3423
           .70000  .02922 10.2671  6.0753   1.2293
           .75000  .02922 10.2671  6.3640   1.1009
           .80000  .02922 10.2671  6.7297    .9542
           .85000  .02962 10.1268  7.2091    .7843
 0CL=   .4000
            MACH      CD     L/D   CLALPH    ALPHA
           .50000  .03284 12.1786  5.3570   2.6782
           .55000  .03284 12.1786  5.4905   2.5742
           .60000  .03284 12.1786  5.6500   2.4563
           .65000  .03284 12.1786  5.8418   2.3231
           .70000  .03284 12.1786  6.0753   2.1724
           .75000  .03284 12.1786  6.3640   2.0012
           .80000  .03284 12.1786  6.7297   1.8056
           .85000  .03419 11.6999  7.2091   1.5791
 0CL=   .5000
            MACH      CD     L/D   CLALPH    ALPHA
           .50000  .03764 13.2845  5.3570   3.7477
           .55000  .03764 13.2845  5.4905   3.6177
           .60000  .03764 13.2845  5.6500   3.4704
           .65000  .03764 13.2845  5.8418   3.3039
           .70000  .03764 13.2845  6.0753   3.1155
           .75000  .03764 13.2845  6.3640   2.9016
           .80000  .03764 13.2845  6.7297   2.6569
           .85000  .04080 12.2559  7.2091   2.3739
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

```
0CL=    .6000
               MACH      CD    L/D   CLALPH   ALPHA
             .50000  .04343 13.8161  5.3570  4.8173
             .55000  .04343 13.8161  5.4905  4.6613
             .60000  .04343 13.8161  5.6500  4.4845
             .65000  .04343 13.8161  5.8418  4.2847
             .70000  .04343 13.8161  6.0753  4.0586
             .75000  .04343 13.8161  6.3640  3.8019
             .80000  .04347 13.8027  6.7297  3.5083
             .85000  .04957 12.1050  7.2091  3.1686

0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                              FLAPS UP                           TAKEOFF                        LANDING
          ALPHA       CL       CD      L/D        CL       CD      L/D        CL         CD       L/D
       -2.00000  -.03407   .02473 -1.37780    .96336   .07973 12.08279  1.65029    .21535  7.66337
         .00000   .13627   .02550  5.34366   1.13371   .09249 12.25703  1.82063    .23184  7.85291
        2.00000   .30662   .02943 10.41896   1.30405   .10919 11.94293  1.99097    .25290  7.87242
        4.00000   .47696   .03645 13.08700   1.47439   .13105 11.25101  2.16131    .28033  7.70978
        6.00000   .64730   .04668 13.86744   1.64473   .15719 10.46357  2.33166    .31114  7.49381
        8.00000   .81764   .06036 13.54670   1.81507   .18628  9.74394  2.50200    .34533  7.24514
       10.00000   .98798   .07804 12.66043   1.98542   .21832  9.09418  2.67234    .38291  6.97911
 •     11.60582  1.12475   .09671 11.63045   2.12219   .24618  8.62057  2.80911    .41552  6.76050
       11.60582  1.12475   .09671 11.63045   2.12219   .24618  8.62057  2.80911    .41552  6.76050
       11.60582  1.12475   .09671 11.63045   2.12219   .24618  8.62057  2.80911    .41552  6.76050

0                         DFLAP=      .00       DFLAP=    15.00        DFLAP=    40.00
0                         CLMAX=  1.12475       CLMAX=  2.13630        CLMAX=  2.81117

0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
     FLAP DEFL.     CLMAX     CL        CD       L/D
       10.000     1.82484
                            .66395    .06004 11.05910
                            .83430    .07012 11.89819
                           1.00464    .08363 12.01243
                           1.17498    .10126 11.60323
                           1.34532    .12461 10.79634
                           1.51566    .15133 10.01548
                           1.68601    .18097  9.31626
                           1.82484    .20729  8.80317
                           1.82484    .20729  8.80317
                           1.82484    .20729  8.80317
       20.000     2.34077
                           1.17988    .10274 11.48397
                           1.35022    .11692 11.54853
                           1.52057    .13515 11.25095
                           1.69091    .15947 10.60310
                           1.86125    .18692  9.95752
                           2.03159    .21734  9.34732
                           2.20193    .25075  8.78138
                           2.34077    .28018  8.35450
                           2.34077    .28018  8.35450
                           2.34077    .28018  8.35450
       30.000     2.64425
                           1.48337    .15076  9.83947
                           1.65371    .16650  9.93248
                           1.82405    .18676  9.76676
                           1.99440    .21270  9.37637
                           2.16474    .24174  8.95486
                           2.33508    .27386  8.52641
                           2.50542    .30908  8.10603
                           2.64425    .34007  7.77562
                           2.64425    .34007  7.77562
                           2.64425    .34007  7.77562


0ALTITUDE=     35000. FT   TAS=     464.69 KTS   MACH NO=      .8052

0                            RDT&E AND AIRFRAME PRODUCTION COSTS
                                          (1993. DOLLARS)
0                        TOTAL RDT&E COSTS              993.3629 MILLION
0                                 AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                   500. AIRCRAFT
                                         WEIGHT(LB)     COST($)     COST($/LB)
         STRUCTURE(  3995327.$)
                             WING                4097.    1043440.      254.67
                             CANARD               391.     172598.      441.25
                             EMPENNAGE            765.     303602.      396.75
                             FUSELAGE            5941.    1651581.      277.99
                             LANDING GEAR        1674.     299190.      178.74
                             NACELLES             953.     524917.      550.85
         PROPULSION INSTAL(  163700.$)
                             ENGINE INSTALLAT.    384.     139967.      364.08
                             FUEL SYSTEM          167.      23733.      141.74
         SYSTEMS(  2518139.$)
                             FLIGHT CONTROLS      866.     406655.      469.41
                             HYDRAULIC            354.      44153.      124.57
                             ELECTRICAL           970.     464214.      478.57
                             AIR CONDITIONING     478.     256070.      535.82
                             ANTI-ICING           195.     102504.      526.66
                             AUX. POWER UNIT      372.     207143.      556.42
                             FURNISHINGS         3410.     796443.      233.56
                             INSTRUMENTS          226.     187254.      829.44
                             AVIONICS INSTALL.    250.      49032.      196.13
                             AUX. ITEMS            20.       4671.      233.56
         INTEGRATION(  1669292.$)
0                              AIRFRAME TOTALS  21515.    8346460.      387.94
0                              ENGINES                    2633756.
                               PROPELLER                        0.
                               AVIONICS                   4000000.
                               A/C COST(NO RD)           14980216.
                               R&D PER A/C                1986726.
                               TOTAL A/C COST            16966942.

0                  ENGINES      NUMBER =     2.  TYPE=     7

0 EMPTY WEIGHT= 24612.     AIRFRAME WEIGHT= 21765.     WEIGHT OF 1 ENGINE=  1424.     CRUISE SPEED= 465. KTS
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (continued)

```
0 THRUST/ENGINE=   8899.
0 TOTAL AIRCRAFT COST= 16966942.    AIRFRAME COST= 14333186.     COST OF 1 ENGINE=  1316878.    COST OF 1 PROP.=        0.


0                             --- COST DATA ---
                           GASP SHORTHAUL METHOD
0          DESIGN MISSION
0              OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0  *************************************************************************************************
0                   RANGE=    1240. N.M.    BLOCK FUEL=    6675. LBS    BLOCK TIME=  3.0178 HRS.
0   UTILIZATION                        3200.
 FLYING OPERATIONS
    FLIGHT CREW                      377.221
    FUEL,OIL,AND TAXES( .850$/G)     886.612
    INSURANCE                         80.003
 DIRECT MAINTENANCE
    AIRFRAME                         166.277
    ENGINE                           285.988
 MAINTENANCE BURD.                   368.498
 DEPRECIATION                       1075.247

    TOTAL DOC ($/TRIP)              3239.846
              ($/B.HR.)             1073.592
              ($/N.MI.)                2.613
```

Fig E8 - Three-Lifting Surface Configuration optimised for minimum D.O.C. -GASP solution (concluded)

```
c
c
c                        SUBROUTINES USERF & USERD
c
c                                   BY
c
c                                J.NUNES
c
c                                  1993
c
c                       College of Aeronautics
c
c                   CRANFIELD INSTITUTE OF TECHNOLOGY
c

      SUBROUTINE USERF(x,func,iocode,nprob,icallf,nfe)

      integer iocode(76)
      real x(50),func(76)

C     Variable declarations:
      ..............
      ..............

C     Common Block declarations:
      ..............
      ..............

C     Assignment of the Independent Variable values:

      WGS    = X(1)
      AR     = X(2)
      DLMC4  = X(3)
      SLM    = X(4)
      ARHT   = X(5)
      DWPQCH = X(6)
      ARVT   = X(7)
      DWPQCV = X(8)
      ARcan  = X(9)
      DwpqCa = X(10)
      SLMcan = X(11)
      EYEcan = X(12)
      SWcOSW = X(13)
      RELP   = X(14)

C     Execution of the Design Synthesis subroutine.

      CALL MAIN(icallf,nfe)

C     Objective Function:

      FUNC(1) = DATOUT(5)

C     Inequality Constraints:

      FUNC(2) = 6000. - DATOUT(92)
      FUNC(3) = 5000. - DATOUT(49)
      FUNC(4) = 125. - DATOUT(51)
      FUNC(5) = DATOUT(109) - .76
      FUNC(6) = .86 - DATOUT(109)

      DO I=2,6
      FUNC(I) = -FUNC(I)
```

Fig E9 - USERF.F and USERD.F subroutines used for the Maximum Take-off Weight optimisation cases

```
      END DO

      RETURN
      END


      SUBROUTINE USERD(x,gradcd,iocode,nprob)

      integer iocode(76)
      real x(50),gradcd(50)

      WRITE(2,100)
100   FORMAT(  'SUBROUTINE USERD CALLED, NO DERIVATIVES AVAILABLE')
      END
```

Fig E9 - USERF.F and USERD.F subroutines used for the Maximum Take-off Weight optimisation cases (concluded)

```
*....data for 50 Pax turbofan airliner

VARIABLES
01 1  95.0           83.000          80.000     105.000
02 1   9.0            8.300           8.000      10.000
03 1  23.0           14.500          11.000      35.000
04 1    .235           .200            .160        .310
05 1   4.0            4.000           3.800       4.300
06 1  27.5           27.500          20.000      35.000
07 1   1.0            1.000            .800       1.200
08 1  46.5           50.500          40.000      53.000
09 0   6.0            5.500           4.000       8.000
10 0  23.0           15.000          10.000      35.000
11 0    .43            .500            .160        .700
12 0   1.5            2.000            .000       3.000
13 0    .15            .15             .145        .175
14 0    .8             .75             .75         .85
FUNCTIONS
01 00 0045000.0        1
02 -1 00 6000.0
03 -1 00 5000.0
04 -1 00  120.0
05 -1 00     .8
06 -1 00     .8
CONTROLS
XTOLU = .0001
XTOLV = .0001
OFROM = 1
OFREQ = 10
RFREQ = 50
NFEMAX = 20000
RUN
END
```

Fig E10 - RQPMIN.DAT file for the Conventional M.T.O.W. optimisation case

```
1Program  RQPMIN  Version 1.0  for VAX

 ANALYSIS OF  INPUT FILE DATA  AND  CONTROL PARAMETERS

 Input file: rqpmin.dat
 Output file: rqpmin.res


 Variable data
 -------------

 Number of variables =    14

 Index      Status        Scale          Starting value       Lower bound          Upper bound
     1          1      .9500000E+02       .8736842E+00       .8421053E+00        .1105263E+01
     2          1      .9000000E+01       .9222223E+00       .8888889E+00        .1111111E+01
     3          1      .2300000E+02       .6304348E+00       .4782609E+00        .1521739E+01
     4          1      .2350000E+00       .8510638E+00       .6808510E+00        .1319149E+01
     5          1      .4000000E+01       .1000000E+01       .9500000E+00        .1075000E+01
     6          1      .2750000E+02       .1000000E+01       .7272727E+00        .1272727E+01
     7          1      .1000000E+01       .1000000E+01       .8000000E+00        .1200000E+01
     8          1      .4650000E+02       .1086022E+01       .8602151E+00        .1139785E+01
     9          0      .6000000E+01       .9166667E+00       .6666667E+00        .1333333E+01
    10          0      .2300000E+02       .6521739E+00       .4347826E+00        .1521739E+01
    11          0      .4300000E+00       .1162791E+01       .3720930E+00        .1627907E+01
    12          0      .1500000E+01       .1333333E+01       .0000000E+00        .2000000E+01
    13          0      .1500000E+00       .1000000E+01       .9666666E+00        .1166667E+01
    14          0      .8000000E+00       .9375000E+00       .9375000E+00        .1062500E+01

 Problem function data
 ---------------------

 Number of constraints =     5

 Index     Status       Type         Scale                 Index     Status       Type         Scale
    1          0          0       .5000000E+04                2         -1          0       .6000000E+04
    3         -1          0       .5000000E+04                4         -1          0       .1200000E+03
    5         -1          0       .8000000E+00                6         -1          0       .8000000E+00

 objective is function     1                     problem number =     1

 Control parameters
 ------------------

 nfemax = 20000     nimax  =  1000     nsmax  =    20
 nsetc  =     4     nsetcf =     8     nsetv  =     4     nsetvf =     8
 ofreq  =    10     ofrom  =     1     rfreq  =    50     rfrom  =     1

 centrl = F     fdset  = F     norep  = F     cheats = T     fast   = T     quasi  = T
 fixrp  = F     timid  = F     monitr = F     nofrec = F     yesbc  = F     shrnk  = T     project = T

 xtol   =   .1000000E-05     xtolu  =   .1000000E-03     xtolv  =   .1000000E-03     gtol   =   .1000000E-02
 rtol   =   .1000000E+00     omegar =   .1000000E+00     rpmax  =   .2000000E+00
 umin   =   .1000000E-05     vminf  =   .1000000E-02     vminc  =   .1000000E-05     ctol   =   .1000000E-02
 umax   =   .1000000E+00     vmax   =   .1000000E+00     omega  =   .1000000E+00     mu     =   .1000000E-03
 bdtol  =   .1000000E+00     lmtol  =   .1000000E+00     mtol   =   .5000000E+00     cmax   =   .1000000E-01
 subtol =   .1000000E-02     qrtol  =   .1000000E+02     bfstol =   .1000000E-05     diftol =   .5000000E-03
 ztol   =   .1000000E-29

 End of input data
 -----------------
1Program  RQPMIN  Version 1.0  for VAX

 STARTING POINT



 free variables
 --------------

  1   .8736842E+00  2   .9222223E+00  3   .6304348E+00  4   .8510638E+00  5   .1000000E+01  6   .1000000E+01  7   .1000000E+01
  8   .1086022E+01

 objective function
 ------------------

 f(x) =   .9575167E+01

 inactive inequality constraints
 -------------------------------

  2  -.2268463E+00  3  -.1966434E+00  4  -.1322222E+00  5  -.4365869E-01  6  -.8134134E-01
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number     1
 -----------------------------

 end of a successful minimization step
 number of calls made to user function so far =    27
```

Fig E11 - RQPMIN.RES file for the Conventional M.T.O.W. optimisation case

```
 free variables
 --------------

  1   .8736842E+00  2   .9392896E+00  3   .6464515E+00  4   .8668453E+00  5   .1000924E+01  6   .1016447E+01  7   .1018135E+01
  8   .1112819E+01

 objective function
 ------------------

 f(x) =   .9570577E+01

 inactive inequality constraints
 -------------------------------

  2  -.2270100E+00  3  -.1968953E+00  4  -.1324241E+00  5  -.4551008E-01  6  -.7948995E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  1  -.1502991E+01  2   .1175308E+02  3   .1850128E+00  4   .4781723E+01  5  -.1098633E+01  6   .5340576E+00  7  -.8049011E+00
  8   .1109314E+02

 convergence criteria
 --------------------

 pdatum =   .9570577E+01     ldatum =   .9570577E+01     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .8903503E+01     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .1175308E+02
 nde    =     0     ndef =     3     ndec =     0     ncalls =     6     nfuncs =     3
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number    11
 ----------------------------

 minimization step has failed
 number of calls made to user function so far =   297

 free variables
 --------------

  1   .9627149E+00  8   .1082364E+01  3   .8325341E+00  4   .8193237E+00  5   .1045072E+01  6   .1029811E+01  2   .1069379E+01
  7   .1200000E+01

 objective function
 ------------------

 f(x) =   .9472170E+01

 inactive inequality constraints
 -------------------------------

  2  -.1665633E+00  3  -.1197927E+00  4  -.7908026E-01  5  -.8440509E-01  6  -.4059494E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  1   .2964020E+01  8   .7272720E+01  3   .7078170E+01  4   .1119614E+01  5   .1642609E+02  6   .1851082E+02  2   .7215499E+01
  7   .1245308E+02

 convergence criteria
 --------------------

 pdatum =   .9472170E+01     ldatum =   .9472170E+01     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .1851082E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .1851082E+02
 nde    =     0     ndef =    33     ndec =     0     ncalls =    66     nfuncs =    33
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number    21
 ----------------------------

 end of a successful minimization step
 number of calls made to user function so far =   738
```

Fig E11 - RQPMIN.RES file for the Conventional M.T.O.W. optimisation case (continued)

```
 free variables
 --------------

  2   .9725208E+00  7   .1057822E+01  3   .8046101E+00  4   .7233416E+00  5   .1012133E+01  6   .8519230E+00  8   .1124150E+01

 variables fixed at or near their upper bounds
 ---------------------------------------------

  1   .1105263E+01

 objective function
 ------------------

 f(x) =   .9131113E+01

 inactive inequality constraints
 -------------------------------

  2  -.6815552E-01  3  -.1309531E-01  4  -.7352257E-02  5  -.9465128E-01  6  -.3034875E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  2   .4110336E+00  7   .3074646E+01  3  -.1782417E+01  4   .1993179E+00  5   .2183914E+00  6  -.1083755E+02  8  -.4628181E+01
  1  -.9355544E+00

 convergence criteria
 --------------------

 pdatum =   .9131113E+01     ldatum =   .9131113E+01     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .2496624E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .1083755E+02
 nde    =     0     ndef =    33     ndec =    26     ncalls =   117     nfuncs =    58
1Program  RQPMIN  Version 1.0  for VAX                    18-Feb-94

 end of iteration number    27
 ----------------------------

 CONVERGENCE DETECTED  [ Code B ]     after  1164 calls to user routine



 free variables
 --------------

  2   .9686060E+00  7   .1041446E+01  3   .8073457E+00  4   .7236404E+00  5   .1009009E+01  6   .8706698E+00  8   .1131737E+01
  1   .1105215E+01

 objective function
 ------------------

 f(x) =   .9127748E+01

 inactive inequality constraints
 -------------------------------

  2  -.6698120E-01  3  -.1189326E-01  4  -.6593640E-02  5  -.9479500E-01  6  -.3020503E-01

 Partial derivatives of Lagrangian function
 ------------------------------------------

  2   .3111744E+02  7  -.1266479E+01  3  -.2857399E+02  4   .1151085E+01  5   .1411438E+01  6   .1898765E+01  8  -.2594280E+02
  1  -.4071236E+01

 convergence criteria
 --------------------

 pdatum =   .9127748E+01     ldatum =   .9127748E+01     gdatum =   .0000000E+00
 nu     =   .0000000E+00     numax  =    infinite
 unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
 vnormx =   .3111744E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .3111744E+02
 nde    =     0     ndef =    33     ndec =    51     ncalls =   168     nfuncs =    84
```

Fig E11 - RQPMIN.RES file for the Conventional M.T.O.W. optimisation case (concluded)

```
                                  50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - CONVENTIONAL CONFIG.
0                                            ENGINE CYCLE IS G. E.  CF-34
                                                 INPUT DATA FOLLOW
                                                ********************

0                                    *****GEOMETRY*****
0 CONFIG  WG      =   44050.         KWRITE  =        2  FUSEL SAB     =       4.          ELODN   =    1.000
          WGS     =  104.995         IGEAR   =        0        WS      =   20.000          ELODT   =    3.200
          PAX     =      50.         KCONFG  =        0        AS      =       1.          BMLOD   =   14.500
          EMCRU   =     .800         KTIPX   =        0        WAS     =   19.000  NACELLE KNAC    =        1
          HNCRU   =   35000.         ENP     =       2.        PS      =     31.0          ELN     =   11.874
                                     NTYE    =        7        ELPC    =   11.220          DBARN   =    3.958
          Kanard  =        0         KPLOT   =        1        HCK     =    2.470          ELRW    =   10.000

0   WING  TCT     =     .100  HORIZ  VBARHX  =    .0000  VERT  VBARVX  =    .0000  Canard  TCcan   =     .100
          TCR     =     .130  TAIL   TCHT    =     .100  TAIL  TCVT    =     .120          ARcan   =    5.500
          AR      =    8.717         ARHT    =    4.036        ARVT    =    1.041          SLMcan  =     .500
          SLM     =     .170         SLMH    =    1.000        SLMV    =     .700          DwpqCa  =   15.000
          DLMC4   =   18.569         DWPQCH  =   23.943        DWPQCV  =   52.626          EYEcan  =    2.000
          EYEW    =    2.000         COELTH  =     .000        BOELTV  =     .000          SWcOSW  =     .150
                                     SAH     =    1.000

0                                    ***AERODYNAMICS***
0         CKW     =   -1.000         CKHT    =   -1.000        GRFE    =     .000          DCDSE   =  -1.0000
          CKF     =   -1.000         CKTP    =   -1.000        SCFAC   =     .750          CKWc    =    2.497
          CKN     =   -1.000         DELCD   =   .00150        DLSWSW  =     .000          cmacw   =    -.060
          CKVT    =   -1.000         DELFE   =     .200        ALPHLO  =   -1.600          alzerc  =   -1.000

0         KWCD    =       12
          ACLS    =   -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR  =    2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                    *HIGH LIFT DEVICES*
0         RCLMAX  =    1.200  FLAPS  JFLTYP  =        7  LED   CLEOC   =     .000
          ALTFLP  =    5000.         DFLPTO  =   15.000        DELLED  =     .000
          FLAPN   =       1.         DFLPLD  =   40.000        DCLMLE  =     .930
          WCFLAP  =   -1.000         CFOC    =     .300        DELLEO  =   45.000
          BENGOB  =     .000         BTEOB   =     .750
                                     DCLMTE  =     .000
                                     DCDOTE  =     .000
                                     DELTEO  =     .000

0                                    ****PROPULSION****
0         JENGSZ  =        2         HPORT   =    5000.        RCCRU   =   50.000          RWCRTX  =     .970
          IPART   =        1         TDELTO  =      36.        XTORQ   =   99999.          HSCREQ  =       0.
          KODETO  =        5         KODECL  =        7        SM1D    =     .500          THIN    =       0.
          KODETR  =        5         KODEAC  =        5        HBTP    =     .437          PR      =    1.000

0                                    *****WEIGHTS*****
0         SKPEI   =    .1350         SKY     =    .1800        SKB     =  107.000          SKFS    =    .0200
          SKLG    =    .0380         SKZ     =    .2200        SKCC    =   20.000          SKWF    =    .4300
          SKMG    =    .8000         SKTL    =   1.0000        SKFW    =    .4300          SKFT    =    .9790
          SKPES   =    .3380         SKWW    =  133.400        SKSAS   =     .000          SKWTP   =   1.8900
          WPLX    =       .0         YMG     =    .2500        EGMRGN  =    .0000          LCWING  =        2
          WPEX    =       .0         RELP    =    .7500        CPMRGN  =    .2000
          WFUL    =   1078.9         RELR    =    .4500        STMRGN  =    .0000          LDCKMX  =    8.000
          UWPAX   =    200.0         CATD    =       3.        DELP    =    8.200          ATMXQC  =    3.160
          STRUT   =    .0000         VMLFSL  =    685.0        YP      =    .0000          DELWST  =       .0
          DELWFC  =       .0
0 ENGINE  WENG    =       .0         WNAC    =       .0        WPYLON  =       .0
          SWSLS   =     .160         UWNAC   =    2.287        FPYL    =     .700          XLQDE   =    3.000

0                                    *STABILITY AND CONTROL*
0         KSFixd  =        1         STATIC  =     .100        ZCG     =    5.500          CNPAC   =    .0020
          CMFLPL  =  999.000         CHALF   =  999.000        TP      =       .0          ARVTE   =   -1.000
          CMFLPT  =  999.000         CHDEL   =  999.000        CXA     =     .520          RV      =     .300
                                     RH      =     .350        DCMCLP  =     .000          TAUV    =  999.000
          CMPLD   =     .000         DEMAX   =    -25.0        HWING   =       0.          RVMCS   =     .990
                                     EYET    =       .0        dcmcpi  =     .030          DRMAX   =     25.0
                                     TAUH    =  999.000        rc      =     .350

0,                                   ***PERFORMANCE***
0   TAXI  DELTT   =     .167         XLFMAX  =    1.100        DVR     =    5.000          TDELTX  =   36.000
      TO  IFLY    =        1         DELTVR  =    3.500        UM      =     .020          HTMAX   =  500.000
          THEMAX  =   15.000         DV1     =    5.000        MUB     =     .400          NFAIL   =        0
          H00     =    5000.         VRAT    =     1.10        WTMISN  =       0.

0  CLIMB  ICLM    =        1  CRUISE CRMACH  =     .800        PRESF   =    1.000          FACW1   =     .820
          DELH    =    1000.         CRALT   =   35000.        RCRRQ   =   1250.0          ISWING  =        0
          VCLMB   =       .0         ICRUS   =        1        OFALT   =   25000.          OFEM    =     .500
0   LAND  IWLD    =        2         XLDGRQ  =   99999.        VRATT   =    1.300          HAPP    =      50.
          TDELLD  =     36.0         ALTLND  =    5000.        RSMX    =    1000.          SINKTD  =      3.0
          TDELAY  =      1.0         WLPCT   =    .9400        TROTID  =     .000          XLFMX   =    1.200
          HTG     =      5.5         TIDLE   =       .0        VTDRAT  =      1.1

0                                    ******COST******
0         NCADE   =        1         HIR     =     .005        RI      =     .300          CMV     =     .800
          CLIAB   =   1993.0         TR      =    2.000        OHR     =  500.000          CCRW    =       0.
          HRI     =4000000.          PRV     =     .100        CRWOH   =   23.000          UCSENG  =     .000
          CMF     =       .2         DYR     =     15.0        CINP    =       0.          UCSPP   =     .000
          TBO     =   3200.0         SRPM    =       .0        CP      =       0.          ALR     =    1.120
          FCSF    =     .850
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution

```
***************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1   .0115   .6741
  GROSS WGT, GROSS WGT MINUS1     45638.7     45776.5


0  ***********************************************************************************************
0                          FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                      CLMAX       VSTALL,KTS  FLAP ANGLE   LE ANGLE    DELTA CL    DELTA CD
 FLAPS UP             1.3109       165.9          .0          .0        .0000       .0000
 T.O. CONFIG          2.4320       121.7        15.0          .0       1.1077       .0428
 LDG. CONFIG          3.1874       106.3        40.0          .0       1.8745       .1904

0                        DOUBLE SLOTTED FOWLER FLAPS
                        OPT ANGLE    DELCL AT OPT   DELCD AT OPT    AREA(FT2)      WEIGHT(LB)

 FLAPS                    30.0          2.2500          .1500          89.9           668.5
0  **********************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.362   LIFT= 44269.6   L/D=  12.612   ALTITUDE= 35000.0   MACH=   .8000

1                                         ENGINE SIZING DATA FOLLOW
                                         **************************
0VSTLKT= 112.8 KTS EAS   VRAT= 1.100 CLTO= 2.0099
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   25.6 AND TAS=   136.9 EAS=   122.8)
 LIFTOFF (TIME=   27.8 DIST=   3719.0 TAS=   145.8 EAS=   130.8)
 DISTANCE TO 35 FT.=  5055.5   TAS=   160.1 EAS=   143.5 V35/VS=  1.2718
 GEAR RETRACTION STARTED AT   33.9 SEC,COMPLETE AT   40.9 SEC
 FLAP RETRACTION STARTED AT   44.0 SEC,COMPLETE AT   48.5 SEC
0VSTLKT= 112.8 KTS EAS   VRAT= 1.100 CLTO= 2.0099
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  211.2 KNOTS EAS
 ENGINE FAILURE (TIME=   24.2 AND TAS=   131.4 EAS=   117.8)
0
 ROTATION (TIME=   27.6 AND TAS=   136.9 EAS=   122.8)
 LIFTOFF (TIME=   30.6 DIST=   4351.3 TAS=   140.5 EAS=   126.0)
 DISTANCE TO 35 FT.=  6115.9   TAS=   142.4 EAS=   127.7 V35/VS=  1.1318


     ACCELERATE - STOP DISTANCE =     6350.3 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      6115.9 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5055.5 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     5813.9 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5301.5 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .013 HRS   FUEL USED=      76. LBS   WEIGHT=   45563. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                         VS                  V      GRAD      R/C    REQ.R/C
   CONFIGURATION                               ALT (FT)  KEAS     V/VS     KTAS    (PCT)     (FPM)    (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT 5000.  113.0  1.1239  141.6   1.835   262.86     1.00  1.933  8.139
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT         5250.  113.0  1.2000  151.7   4.041   620.45   368.54  1.696 10.173
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT       6500.  153.1  1.2500  218.4   4.655  1028.65   265.18   .851 13.013
   APPROACH FLAPS -ONE ENG OUT                  5000.  108.4  1.3736  166.1   4.521   759.86   352.95  1.405 10.941
   LANDING FLAPS - ALL ENGINES                  5000.   98.7  1.3000  143.0  13.519  1956.94   463.21  1.893  6.814

     APPROACH FLAP SETTING = 19.5 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 21958.9 FT.
         BEST RATE OF CLIMB SPEED   =   275.9 KTAS
         ENGINE-OUT RATE OF CLIMB   =     49.6 FPM
         WEIGHT AT ALTITUDE         = 43813.2 LBS

0                           ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE               1500.2
   NACELLE WEIGHT/ENGINE               337.4
   PYLON WEIGHT/ENGINE                 176.8
      PROP OR QFAN             .0
      GEARBOX                  .0
      SHROUD                   .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)          3.96
   NACELLE LENGTH(FT)               11.87


0VSTLKT= 112.8 KTS EAS   VRAT= 1.100 CLTO= 2.0099
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   24.4 AND TAS=   136.9 EAS=   122.8)
 LIFTOFF (TIME=   26.6 DIST=   3565.8 TAS=   146.2 EAS=   131.2)
 DISTANCE TO 35 FT.=  4893.9   TAS=   161.4 EAS=   144.7 V35/VS=  1.2821
 GEAR RETRACTION STARTED AT   32.6 SEC,COMPLETE AT   39.6 SEC
 FLAP RETRACTION STARTED AT   42.7 SEC,COMPLETE AT   47.2 SEC
0VSTLKT= 112.8 KTS EAS   VRAT= 1.100 CLTO= 2.0099
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  205.4 KNOTS EAS
 ENGINE FAILURE (TIME=   23.1 AND TAS=   131.4 EAS=   117.8)
0
 ROTATION (TIME=   26.4 AND TAS=   136.9 EAS=   122.8)
 LIFTOFF (TIME=   29.4 DIST=   4198.6 TAS=   140.9 EAS=   126.4)
 DISTANCE TO 35 FT.=  5756.8   TAS=   143.0 EAS=   128.2 V35/VS=  1.1359
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
     ACCELERATE - STOP DISTANCE =     6220.5 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      5756.8 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      4893.9 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =      5628.0 FEET
 ALL ENGINE DISTANCE TO 50 FT. =      5141.0 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .012 HRS   FUEL USED=       77. LBS   WEIGHT=   45561. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                           VS               V      GRAD      R/C   REQ.R/C
   CONFIGURATION                                 ALT (FT)   KEAS     V/VS    KTAS    (PCT)     (FPM)    (FPM)    CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  113.0  1.1239  141.6   2.176   311.79     1.00  1.933  7.962
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  113.0  1.2000  151.7   4.354   668.58   368.54  1.696  9.881
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  153.1  1.2500  218.4   4.712  1041.31   265.18   .851 12.248
   APPROACH FLAPS -ONE ENG OUT                   5000.  108.4  1.3736  166.1   4.790   805.04   352.95  1.405 10.564
   LANDING FLAPS - ALL ENGINES                   5000.   98.7  1.3000  143.0  14.660  2122.02   463.21  1.893  6.774

     APPROACH FLAP SETTING = 19.5 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 22502.2 FT.
         BEST RATE OF CLIMB SPEED   =   277.3 KTAS
         ENGINE-OUT RATE OF CLIMB   =    50.1 FPM
         WEIGHT AT ALTITUDE         = 43813.2 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    383.71

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    383.71

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   9784.7 LBS
*************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE            1565.6
   NACELLE WEIGHT/ENGINE            337.4
   PYLON WEIGHT/ENGINE              181.4
      PROP OR QFAN          .0
      GEARBOX               .0
      SHROUD                .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)        3.96
   NACELLE LENGTH(FT)             11.87

0************************************************************************************************
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
                        ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                  MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
                  WT          CG         WT          CG         WT          CG

 A/C OWE     26618.58      43.82    26618.58      43.82    26618.58      43.82
 PAX          6120.00                2040.00                8500.00
 BAGGAGE          .00      56.36     1500.00      56.36     1500.00      56.36
 WING FUEL    1394.15      44.75     6970.73      44.75     6970.73      44.75
 TIP FUEL         .00        .00         .00        .00         .00        .00
 FUS FUEL         .00      44.75         .00      44.75     2049.43      44.75
 TOTAL       34132.73      41.39    37129.31      44.74    45638.74      43.08

0                       ---TAIL SIZING SUMMARY---

         Static Longitudinal Stability, Stick-fixed, considered


0                     WING                     CANARD          TAIL         DOWN    FLAP
 CONDITION  ALPHA    CL     CLA     CMac   ALPHA    CLA     CLA    EFF.     WASH    CM

  CRUISE   2.4843  .4693  .1149 -.0600  .0000  .0000  .0788 1.0000
  LIFTOFF  2.0000 1.4182  .0661 -.0600  .0000  .0000  .0650 1.0000  .3391 -.1031
  LANDING 14.0334 3.1874  .0840 -.0600  .0000  .0000  .0650 1.0000 2.3793 -.2000

0          --FUSELAGE-- ---NACELLE--         ------POWER-------            L.GEAR ROT.POWER
 CONDITION  DCM    CM     DCM    CM  DCMdth DCMfinc CMdth  CMfinc    CT      CM      CM

  CRUISE    .5211         .1222          .0000  .0300                 .0000
  LIFTOFF   .9056  .0000  .1222  .0000                 .0000  .0425  .0000 -.7098 5.2860
  LANDING   .7130  .7205  .1222  .1235                 .0000  .0956

0     ELEVATOR PARAMETERS
          CMDELTE(CONTROL POWER)        =  -.06030            WING DE/DALPHA =   .33909
          TAUH(EFFECTIVENESS)           =   .48250
          DEMAX(MAX.ELEVATOR DEFLEC.)   =-25.00000


0                                 FRACTION    STATION         HORIZONTAL TAIL SIZES
                                    MAC     (DATUM NOSE)
      NEUTRAL POINT                .4484      45.293          STATIC STABILITY AND LANDING TRIM     158.9859
      STATIC MARGIN                .1000                      STATIC STABILITY AND LIFTOFF ROT.     158.8368
      AFT CG LIMIT(STABILITY)      .3484      44.468
      CG RANGE(LOADING)            .4061                      REQUIRED TAIL SIZE                    158.9859
      FWD CG LIMIT(CONTROL)       -.0576      41.160          TAIL ARM(ELTH)                        44.1675

0     VERTICAL TAIL AREA =   96.9749 FOR DIRECTIONAL STABILITY OF      .00200
0     RUDDER POWER AT MAX.DEFL.=   .0183 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4568
0     VERTICAL TAIL AREA=  85.2550 FOR MINIMUM CONTROL SPEED =    111.70 KTS
0     REQUIRED VERTICAL TAIL AREA =   96.9749  TAIL ARM(ELTV) =   33.1806

**************************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.362   LIFT= 44269.6   L/D=  12.137   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25        H-TAIL VOL. ARM       =   44.17        C.G.LOCATION OF PROPULSION=   59.43
 WING 1/4C LOC.ON C.L.=   39.79        H-TAIL C.G.LOCATION   =   88.41        C.G.OF REMAINING WEIGHT   =   35.66
 MAC 1/4C LOCATION     =   43.74        H-TAIL MAC FROM C.L. =    6.33
 MAC DIST.FROM C.L.    =   11.75        H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   45.39        V-TAIL VOL. ARM       =   33.18
 TIP TANKS C.G.LOCATE =     .00        V-TAIL C.G.LOCATION   =   77.70        DIST.L.E.VERT.TO L.E.HORZ.=    1.67
0                        WING       H-TAIL       V-TAIL

   AREA               434.674     158.986       96.975
   SPAN                61.557      25.331       10.050
   ASPECT RATIO         8.717       4.036        1.041
   TAPER RATIO           .170       1.000         .700
   1/4C. SWEEP         18.569      23.943       52.626
   L.E. SWEEP          22.651      23.943       54.343
   C.L. CHORD          12.070       6.276       11.353
   MEAN CHORD           8.246       6.276        9.750
   TIP CHORD            2.053       6.276        7.947
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
0                                   MISSION PERFORMANCE DATA FOLLOWS
                                    ********************************
0   TAXI AT IDLE THRUST

                    FUEL                          FUEL
  TIME    RANGE     USED     WEIGHT    ALT.       FLOW
  (HRS)   (NM)      (LBS)    (LBS)     (FT)     (LB/HR)

   .000       0.        0.   45639.    5000.      894.
   .167       0.      149.   45490.    5000.      894.
0VSTLKT= 112.7 KTS EAS   VRAT= 1.100 CLTO= 2.0099
      VEND =  250.0 KNOTS EAS
0             (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                    FUEL                                                                                                                     FUEL     FUS.
   TIME     DIST.   USED    WEIGHT     ALT.      TAS      EAS    MACH  ACCEL      CL        CD  ALPHA GAMMA       ROC    LOAD THRUST       FLOW    ANGLE
   (SEC)   (FEET)   (LBS)   (LBS)      (FT)     (KTS)    (KTS)    NO. (FPS2)                    (DEG) (DEG)      (FPM)   FACT  (LBS)    (LB/HR)   (DEG)

     .0        .0   149.0  45490.   5000.0       .0       .0   .000  11.63 1.4158   .1276  2.00   .00          .0    .00 17354.     6180.     .00
    1.0       5.8   150.7  45488.   5000.0      6.8      6.1   .010  11.47 1.4158   .1276  2.00   .00          .0    .00 17134.     6180.     .00
    2.0      23.1   152.4  45486.   5000.0     13.6     12.2   .020  11.30 1.4158   .1276  2.00   .00          .0    .00 16918.     6181.     .00
    3.0      51.7   154.1  45485.   5000.0     20.3     18.2   .030  11.13 1.4159   .1276  2.00   .00          .0    .00 16706.     6182.     .00
    4.0      91.5   155.8  45483.   5000.0     26.8     24.1   .040  10.96 1.4160   .1276  2.00   .00          .0    .00 16498.     6184.     .00
    5.0     142.3   157.6  45481.   5000.0     33.3     29.9   .049  10.79 1.4161   .1276  2.00   .00          .0    .00 16294.     6186.     .00
    6.0     203.9   159.3  45479.   5000.0     39.6     35.6   .059  10.61 1.4162   .1276  2.00   .00          .0    .00 16093.     6188.     .00
    7.0     276.2   161.0  45478.   5000.0     45.9     41.2   .068  10.42 1.4163   .1276  2.00   .00          .0    .00 15895.     6190.     .00
    8.0     358.9   162.7  45476.   5000.0     52.0     46.7   .077  10.23 1.4164   .1277  2.00   .00          .0    .00 15701.     6192.     .00
    9.0     451.9   164.4  45474.   5000.0     58.1     52.1   .086  10.04 1.4166   .1277  2.00   .00          .0    .00 15510.     6195.     .00
   10.0     554.9   166.2  45473.   5000.0     64.0     57.4   .095   9.85 1.4168   .1277  2.00   .00          .0    .00 15323.     6198.     .00
   11.0     667.9   167.9  45471.   5000.0     69.8     62.6   .104   9.67 1.4170   .1277  2.00   .00          .0    .00 15157.     6201.     .00
   12.0     790.6   169.6  45469.   5000.0     75.5     67.7   .112   9.50 1.4172   .1277  2.00   .00          .0    .00 15018.     6204.     .00
   13.0     922.8   171.3  45467.   5000.0     81.1     72.7   .120   9.33 1.4174   .1277  2.00   .00          .0    .00 14881.     6207.     .00
   14.0    1064.3   173.0  45466.   5000.0     86.6     77.7   .129   9.16 1.4176   .1277  2.00   .00          .0    .00 14747.     6211.     .00
   15.0    1215.1   174.8  45464.   5000.0     92.0     82.5   .137   8.99 1.4178   .1278  2.00   .00          .0    .00 14615.     6215.     .00
   16.0    1374.9   176.5  45462.   5000.0     97.3     87.2   .144   8.82 1.4181   .1278  2.00   .00          .0    .00 14486.     6219.     .00
   17.0    1543.6   178.2  45461.   5000.0    102.4     91.9   .152   8.64 1.4183   .1278  2.00   .00          .0    .00 14360.     6223.     .00
   18.0    1720.9   180.0  45459.   5000.0    107.5     96.5   .160   8.46 1.4186   .1278  2.00   .00          .0    .00 14236.     6227.     .00
   19.0    1906.7   181.7  45457.   5000.0    112.5    100.9   .167   8.29 1.4189   .1278  2.00   .00          .0    .00 14114.     6232.     .00
   20.0    2100.8   183.4  45455.   5000.0    117.4    105.3   .174   8.11 1.4192   .1279  2.00   .00          .0    .00 13995.     6236.     .00
   21.0    2303.1   185.2  45454.   5000.0    122.1    109.6   .181   7.93 1.4195   .1279  2.00   .00          .0    .00 13878.     6240.     .00
   22.0    2513.4   186.9  45452.   5000.0    126.8    113.8   .188   7.75 1.4197   .1279  2.00   .00          .0    .00 13764.     6245.     .00
   23.0    2731.4   188.6  45450.   5000.0    131.4    117.9   .195   7.58 1.4200   .1279  2.00   .00          .0    .00 13653.     6250.     .00
   24.0    2957.1   190.4  45448.   5000.0    135.8    121.8   .202   7.40 1.4203   .1280  2.00   .00          .0    .00 13551.     6254.     .00
0
 ROTATION (TIME=   24.2 AND TAS=   136.7 EAS=   122.7)
   25.0  3190.2    192.1  45447.  5000.0  140.2  125.7  .208    7.15 1.5204  .1360  3.20   .00        .0   .78  13473.    6259.  1.20
   26.0  3430.4    193.8  45445.  5000.0  144.3  129.5  .214    6.79 1.6888  .1507  5.27   .00        .0   .92  13398.    6264.  3.27
 LIFTOFF (TIME=   26.4 DIST=   3528.5 TAS=   145.9 EAS=   130.9)
   27.0  3677.5    195.6  45443.  5000.1  148.2  133.0  .220    6.30 1.8291  .1640  7.05   .13     35.0  1.06  13328.    6268.  5.18
   28.0  3930.9    197.3  45441.  5002.1  151.8  136.2  .225    5.68 1.7985  .1670  6.55   .80    214.4  1.09  13263.    6272.  5.34
   29.0  4189.9    199.1  45440.  5007.3  155.0  139.0  .230    5.01 1.7332  .1724  5.65  1.48    405.7  1.10  13205.    6275.  5.13
   30.0  4454.0    200.8  45438.  5015.7  157.8  141.5  .234    4.39 1.6732  .1759  4.95  2.16    603.5  1.10  13152.    6277.  5.11
   31.0  4722.3    202.6  45436.  5027.4  160.2  143.7  .238    3.86 1.6275  .1765  4.45  2.82    800.1  1.10  13105.    6279.  5.27
 DISTANCE TO 35 FT.=  4867.9   TAS=   161.4 EAS=   144.8 V35/VS=  1.2849
   32.0  4994.4    204.3  45434.  5042.3  162.4  145.6  .241    3.43 1.5828  .1736  3.95  3.47    997.6  1.09  13062.    6279.  5.42
 GEAR RETRACTION STARTED AT   32.4 SEC,COMPLETE AT   39.4 SEC
   33.0  5269.8    206.0  45433.  5060.6  164.4  147.3  .244    3.08 1.5479  .1678  3.55  4.12   1196.3  1.10  13023.    6279.  5.66
   34.0  5548.1    207.8  45431.  5082.2  166.1  148.9  .247    2.79 1.5223  .1605  3.25  4.75   1394.8  1.10  12987.    6278.  6.00
   35.0  5829.0    209.5  45429.  5107.1  167.7  150.2  .249    2.55 1.4883  .1518  2.85  5.39   1596.1  1.09  12952.    6277.  6.23
   36.0  6112.1    211.3  45428.  5135.4  169.2  151.5  .251    2.30 1.4628  .1441  2.55  6.01   1794.3  1.09  12919.    6275.  6.55
   37.0  6397.3    213.0  45426.  5166.9  170.5  152.6  .253    2.05 1.4459  .1376  2.35  6.62   1991.7  1.10  12889.    6272.  6.97
   38.0  6684.2    214.8  45424.  5201.8  171.7  153.5  .255    1.80 1.4289  .1312  2.15  7.23   2188.9  1.10  12860.    6269.  7.37
   39.0  6972.5    216.5  45422.  5239.9  172.7  154.4  .257    1.57 1.4119  .1248  1.95  7.84   2386.0  1.10  12833.    6265.  7.78
   40.0  7262.0    218.2  45421.  5281.3  173.6  155.1  .258    1.28 1.3948  .1210  1.75  8.44   2581.5  1.10  12808.    6260.  8.19
   41.0  7552.4    220.0  45419.  5325.9  174.3  155.6  .259     .94 1.3863  .1201  1.65  9.04   2774.4  1.10  12785.    6255.  8.68
   42.0  7843.3    221.7  45417.  5373.8  174.8  155.9  .260     .61 1.3778  .1192  1.55  9.63   2963.0  1.10  12766.    6249.  9.18
 FLAP RETRACTION STARTED AT   42.5 SEC,COMPLETE AT   47.0 SEC
   43.0  8134.3    223.4  45415.  5424.6  175.0  156.0  .260     .36 1.2860  .1174  1.85 10.13   3119.1  1.03  12749.    6242.  9.97
   44.0  8425.5    225.2  45414.  5476.5  175.3  156.1  .261     .28 1.1601  .1238  3.25  9.96   3070.9   .94  12733.    6235. 11.20
0VSTLKT= 112.7 KTS EAS   VRAT= 1.100 CLTO= 2.0099
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  208.9 KNOTS EAS
0             (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF  (ELEVATION=  5000. FT)

                    FUEL                                                                                                                     FUEL     FUS.
   TIME     DIST.   USED    WEIGHT     ALT.      TAS      EAS    MACH  ACCEL      CL        CD  ALPHA GAMMA       ROC    LOAD THRUST       FLOW    ANGLE
   (SEC)   (FEET)   (LBS)   (LBS)      (FT)     (KTS)    (KTS)    NO. (FPS2)                    (DEG) (DEG)      (FPM)   FACT  (LBS)    (LB/HR)   (DEG)

     .0        .0   149.0  45490.   5000.0       .0       .0   .000  11.63 1.4158   .1276  2.00   .00          .0    .00 17354.     6180.     .00
    1.0       5.8   150.7  45488.   5000.0      6.8      6.1   .010  11.47 1.4158   .1276  2.00   .00          .0    .00 17134.     6180.     .00
    2.0      23.1   152.4  45486.   5000.0     13.6     12.2   .020  11.30 1.4158   .1276  2.00   .00          .0    .00 16918.     6181.     .00
    3.0      51.7   154.1  45485.   5000.0     20.3     18.2   .030  11.13 1.4159   .1276  2.00   .00          .0    .00 16706.     6182.     .00
    4.0      91.5   155.8  45483.   5000.0     26.8     24.1   .040  10.96 1.4160   .1276  2.00   .00          .0    .00 16498.     6184.     .00
    5.0     142.3   157.6  45481.   5000.0     33.3     29.9   .049  10.79 1.4161   .1276  2.00   .00          .0    .00 16294.     6186.     .00
    6.0     203.9   159.3  45479.   5000.0     39.6     35.6   .059  10.61 1.4162   .1276  2.00   .00          .0    .00 16093.     6188.     .00
    7.0     276.2   161.0  45478.   5000.0     45.9     41.2   .068  10.42 1.4163   .1276  2.00   .00          .0    .00 15895.     6190.     .00
    8.0     358.9   162.7  45476.   5000.0     52.0     46.7   .077  10.23 1.4164   .1277  2.00   .00          .0    .00 15701.     6192.     .00
    9.0     451.9   164.4  45474.   5000.0     58.1     52.1   .086  10.04 1.4166   .1277  2.00   .00          .0    .00 15510.     6195.     .00
   10.0     554.9   166.2  45473.   5000.0     64.0     57.4   .095   9.85 1.4168   .1277  2.00   .00          .0    .00 15323.     6198.     .00
   11.0     667.9   167.9  45471.   5000.0     69.8     62.6   .104   9.67 1.4170   .1277  2.00   .00          .0    .00 15157.     6201.     .00
   12.0     790.6   169.6  45469.   5000.0     75.5     67.7   .112   9.50 1.4172   .1277  2.00   .00          .0    .00 15018.     6204.     .00
   13.0     922.8   171.3  45467.   5000.0     81.1     72.7   .120   9.33 1.4174   .1277  2.00   .00          .0    .00 14881.     6207.     .00
   14.0    1064.3   173.0  45466.   5000.0     86.6     77.7   .129   9.16 1.4176   .1277  2.00   .00          .0    .00 14747.     6211.     .00
   15.0    1215.1   174.8  45464.   5000.0     92.0     82.5   .137   8.99 1.4178   .1278  2.00   .00          .0    .00 14615.     6215.     .00
   16.0    1374.9   176.5  45462.   5000.0     97.3     87.2   .144   8.82 1.4181   .1278  2.00   .00          .0    .00 14486.     6219.     .00
   17.0    1543.6   178.2  45461.   5000.0    102.4     91.9   .152   8.64 1.4183   .1278  2.00   .00          .0    .00 14360.     6223.     .00
   18.0    1720.9   180.0  45459.   5000.0    107.5     96.5   .160   8.46 1.4186   .1278  2.00   .00          .0    .00 14236.     6227.     .00
   19.0    1906.7   181.7  45457.   5000.0    112.5    100.9   .167   8.29 1.4189   .1278  2.00   .00          .0    .00 14114.     6232.     .00
   20.0    2100.8   183.4  45455.   5000.0    117.4    105.3   .174   8.11 1.4192   .1279  2.00   .00          .0    .00 13995.     6236.     .00
   21.0    2303.1   185.2  45454.   5000.0    122.1    109.6   .181   7.93 1.4195   .1279  2.00   .00          .0    .00 13878.     6240.     .00
   22.0    2513.4   186.9  45452.   5000.0    126.8    113.8   .188   7.75 1.4197   .1279  2.00   .00          .0    .00 13764.     6245.     .00
   23.0    2731.4   188.6  45450.   5000.0    131.4    117.9   .195   7.58 1.4200   .1279  2.00   .00          .0    .00 13653.     6250.     .00
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
 ENGINE FAILURE (TIME=   23.0 AND TAS=   131.2 EAS=   117.7)
   24.0  2955.1    189.5  45449.  5000.0  133.2  119.5  .198    2.56 1.4202  .1367  2.00    .00        .0   .00   6804.    3126.   .00
   25.0  3181.3    190.4  45448.  5000.0  134.7  120.8  .200    2.51 1.4203  .1364  2.00    .00        .0   .00   6785.    3127.   .00
   26.0  3410.1    191.2  45448.  5000.0  136.2  122.2  .202    2.47 1.4204  .1362  2.00    .00        .0   .00   6772.    3127.   .00
0
 ROTATION (TIME=   26.4 AND TAS=   136.7 EAS=   122.7)
   27.0  3641.3    192.1  45447.  5000.0  137.6  123.5  .204    2.36 1.4929  .1417  2.87    .00        .0   .74   6759.    3128.   .87
   28.0  3874.9    193.0  45446.  5000.0  139.0  124.7  .206    2.14 1.6613  .1559  4.93    .00        .0   .84   6747.    3129.  2.93
   29.0  4110.7    193.8  45445.  5000.0  140.2  125.8  .208    1.89 1.8297  .1715  7.07    .00        .0   .95   6736.    3129.  5.07
 LIFTOFF (TIME=    29.4 DIST=   4205.6 TAS=    140.6 EAS=    126.1)
   30.0  4348.4    194.7  45444.  5000.1  141.2  126.7  .210    1.58 1.9684  .1854  8.90    .09     22.8  1.04   6727.    3130.  6.99
   31.0  4587.6    195.6  45443.  5001.4  142.0  127.4  .211    1.11 2.0099  .1948  9.32    .57    143.1  1.07   6720.    3130.  7.89
   32.0  4827.9    196.4  45442.  5005.0  142.5  127.8  .212     .51 2.0099  .2088  9.06   1.17    296.0  1.08   6715.    3130.  8.24
   33.0  5068.6    197.3  45441.  5011.3  142.6  127.9  .212     .00 1.9598  .2176  8.35   1.79    451.5  1.06   6713.    3130.  8.14
   34.0  5309.3    198.2  45441.  5019.3  142.6  127.9  .212    -.01 1.8576  .2130  7.15   1.95    491.7  1.00   6712.    3129.  7.10
   35.0  5550.1    199.1  45440.  5027.3  142.6  127.9  .212    -.01 1.8383  .2155  6.95   1.88    474.3   .99   6711.    3129.  6.83
 DISTANCE TO 35 FT.=  5789.4    TAS=    142.6 EAS=    127.9 V35/VS=  1.1351
   36.0  5790.8    199.9  45439.  5035.0  142.6  127.9  .212     .00 1.8368  .2183  6.95   1.78    449.5   .99   6710.    3128.  6.74
   37.0  6031.6    200.8  45438.  5042.3  142.6  127.9  .212    -.01 1.8444  .2212  7.05   1.69    427.4   .99   6709.    3128.  6.75
   38.0  6272.4    201.7  45437.  5049.3  142.6  127.9  .212     .01 1.8439  .2222  7.05   1.63    411.3   .99   6708.    3127.  6.68


      ACCELERATE - STOP DISTANCE =      6204.4 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=        5789.4 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =       4867.9 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =       5598.1 FEET
 ALL ENGINE DISTANCE TO 50 FT. =       5115.5 FEET
0    AT END OF TAKEOFF PHASE
 TIME=    .179 HRS   FUEL USED=      226. LBS   WEIGHT=   45413. LBS   ALT.=     5500. FT.


    ACCELERATE TO MACH NO. = .418

0                  FUEL                                                              FUEL
  TIME   RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST     FLOW
 (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)   (LB/HR)

  .179      .00   226.0  45413.    5500.    169.    156.   .261  .713  13022.     6143.
  .187     1.84   276.9  45362.    5500.    271.    250.   .418  .808  11170.     6304.

  END OF ACCELERATION SEGMENT
  TIME=  .187 HRS   FUEL USED=  276.9 LBS   WEIGHT=  45362. LBS   RANGE=    2. NM
0   CLIMB TO   35000. FT. AT MAXIMUM RATE OF CLIMB
0                  FUEL                                                                              FUS.                        FUEL
  TIME   RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    CL      CD   ALPHA GAMMA ANGLE    R/C    THRUST      FLOW
 (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV                (DEG) (DEG) (DEG)   (FPM)    (LBS)    (LB/HR)

  .187       2.    277.   45362.    5500.    252.    232.   .388  .801  .5650  .0432  4.77  8.20 10.97   3641.     9904.    5551.
  .189       2.    290.   45349.    6000.    253.    231.   .390  .800  .5696  .0435  4.82  7.75 10.57   3457.     9817.    5498.
  .194       4.    316.   45323.    7000.    262.    236.   .406  .803  .5482  .0422  4.55  6.32  8.87   2923.     9520.    5388.
  .200       5.    347.   45292.    8000.    265.    235.   .412  .802  .5503  .0424  4.56  6.90  9.46   3231.     9324.    5268.
  .205       6.    374.   45265.    9000.    268.    234.   .418  .802  .5563  .0427  4.61  6.79  9.41   3213.     9140.    5153.
  .210       8.    401.   45238.   10000.    271.    233.   .424  .801  .5625  .0431  4.67  6.58  9.25   3144.     8957.    5041.
  .215       9.    427.   45211.   11000.    273.    231.   .430  .800  .5685  .0434  4.72  6.79  9.51   3276.     8774.    4931.
  .220      11.    453.   45186.   12000.    276.    230.   .435  .799  .5755  .0438  4.79  6.16  8.95   3002.     8592.    4824.
  .226      12.    479.   45159.   13000.    279.    229.   .441  .798  .5823  .0442  4.85  5.95  8.80   2930.     8411.    4719.
  .232      14.    506.   45133.   14000.    282.    228.   .448  .798  .5878  .0445  4.89  5.69  8.58   2834.     8228.    4617.
  .238      15.    533.   45105.   15000.    286.    227.   .456  .797  .5919  .0447  4.92  5.42  8.34   2734.     8042.    4518.
  .244      17.    561.   45078.   16000.    291.    228.   .467  .798  .5878  .0445  4.85  4.91  7.76   2526.     7828.    4419.
  .250      19.    590.   45049.   17000.    295.    226.   .473  .797  .5940  .0449  4.90  4.99  7.88   2595.     7632.    4309.
  .257      21.    618.   45021.   18000.    298.    226.   .482  .797  .5979  .0451  4.92  4.67  7.59   2465.     7433.    4203.
  .263      23.    646.   44993.   19000.    302.    225.   .490  .796  .6019  .0454  4.94  4.44  7.38   2375.     7238.    4098.
  .270      25.    675.   44964.   20000.    306.    224.   .498  .795  .6076  .0457  4.98  4.27  7.25   2310.     7050.    3995.
  .278      27.    704.   44935.   21000.    310.    223.   .506  .795  .6137  .0461  5.02  4.06  7.08   2221.     6866.    3895.
  .285      30.    733.   44906.   22000.    314.    222.   .514  .794  .6187  .0464  5.05  3.81  6.86   2114.     6682.    3797.
  .293      32.    763.   44876.   23000.    317.    220.   .522  .793  .6267  .0470  5.11  3.68  6.80   2064.     6508.    3699.
  .301      35.    793.   44846.   24000.    321.    219.   .531  .792  .6321  .0473  5.14  3.41  6.55   1936.     6332.    3606.
  .310      37.    824.   44815.   25000.    329.    221.   .546  .793  .6246  .0468  5.01  2.90  5.91   1686.     6124.    3525.
  .320      41.    859.   44780.   26000.    332.    219.   .553  .792  .6348  .0475  5.10  3.06  6.15   1793.     5945.    3437.
  .329      44.    891.   44748.   27000.    335.    217.   .560  .791  .6453  .0482  5.18  2.85  6.03   1688.     5771.    3351.
  .339      47.    924.   44715.   28000.    366.    233.   .615  .801  .5595  .0429  4.10  1.31  3.41    851.     5494.    3321.
  .358      54.    989.   44650.   29000.    370.    231.   .624  .800  .5682  .0434  4.15  2.24  4.40   1466.     5353.    3238.
  .370      58.   1026.   44613.   30000.    373.    229.   .633  .799  .5777  .0439  4.22  2.09  4.31   1381.     5212.    3156.
  .382      63.   1064.   44575.   31000.    377.    227.   .641  .798  .5880  .0445  4.29  1.92  4.20   1276.     5037.    3050.
  .395      68.   1103.   44535.   32000.    381.    225.   .652  .797  .5952  .0450  4.32  1.67  3.99   1128.     4865.    2950.
  .410      73.   1147.   44492.   33000.    386.    224.   .663  .796  .6017  .0454  4.33  1.48  3.81   1011.     4697.    2853.
  .426      80.   1194.   44445.   34000.    392.    223.   .676  .796  .6056  .0456  4.31  1.27  3.58    880.     4532.    2759.
  .445      87.   1246.   44392.   35000.    396.    221.   .687  .794  .6149  .0462  4.36  1.16  3.52    816.     4373.    2666.
0   END OF CLIMB TO   35000. FT
 TIME=   .445 HRS   FUEL USED=     1246. LBS   WEIGHT=    44392. LBS   RANGE=      87. NM

0ALTITUDE=      35000. FT   TAS=      482.37 KTS   MACH NO=       .8358


    ACCELERATE TO MACH NO. = .800

0                  FUEL                                                              FUEL
  TIME   RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST     FLOW
 (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)   (LB/HR)

  .445    87.27  1246.3  44392.   35000.    396.    221.   .687  .794   4695.     3020.
  .478   102.03  1351.4  44287.   35000.    461.    258.   .800  .813   4780.     3123.

  END OF ACCELERATION SEGMENT
  TIME=  .478 HRS   FUEL USED=  1351.4 LBS   WEIGHT=  44287. LBS   RANGE=  102. NM


    ACCELERATE TO MACH NO. = .836

0                  FUEL                                                              FUEL
  TIME   RANGE     USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST     FLOW
 (HRS)   (NM)     (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)   (LB/HR)

  .445    87.27  1246.3  44392.   35000.    396.    221.   .687  .794   4695.     3020.
  .490   108.21  1392.2  44247.   35000.    482.    269.   .836  .819   4807.     3167.

  END OF ACCELERATION SEGMENT
  TIME=  .490 HRS   FUEL USED=  1392.2 LBS   WEIGHT=  44247. LBS   RANGE=  108. NM
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

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  ACCELERATE TO MACH NO. = .853

0                   FUEL                                                          FUEL
  TIME    RANGE     USED     WEIGHT     ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)      (LBS)    (LBS)      (FT)   (KTS)  (KTS)     NO.   DIV     (LBS)  (LB/HR)

   .445    87.27   1246.3   44392.   35000.    396.   221.   .687  .794    4695.    3020.
   .495   110.91   1409.6   44229.   35000.    492.   275.   .853  .820    4809.    3189.

  END OF ACCELERATION SEGMENT
  TIME=  .495 HRS   FUEL USED=  1409.6 LBS   WEIGHT=  44229. LBS   RANGE=  111. NM


0                                          DESIGN CASE
                                           CRUISE PERFORMANCE SUMMARY
                                                   FOR
                                           ***** DESIGN PAYLOAD *****
                                           **** MAXIMUM PAYLOAD *****
                                           ****** MAXIMUM FUEL ******
                                           FUEL AVAILABLE=   9020.
0                              AT                      AT                     AT
                        SPECIFIED SPEED          NORMAL POWER          BEST SPEC. RANGE
                         START     END            START     END          START     END
                         CRUISE    CRUISE         CRUISE    CRUISE       CRUISE    CRUISE
                         -------   -------        -------   -------      -------   -------
   TIME           HRS.      .478     3.010          .490     2.520         .495     2.689
   RANGE          N.MI      102.     1271.          108.     1088.         111.     1191.
   FUEL USED      LBS.     1351.     7219.         1392.     6360.        1410.     7037.
   WEIGHT         LBS.    44287.    38420.        44247.    39279.       44229.    38602.
   ALTITUDE       FT.     35000.    35000.        35000.    35000.       35000.    35000.
   TAS            KTS.     461.7     461.7         482.4     482.4        492.4     492.4
   EAS            KTS.     257.3     257.3         268.8     268.8        274.4     274.4
   MACH NO.                .8000     .8000         .8358     .8358        .8532     .8532
   DIV. MACH               .8142     .8217         .8190     .8264        .8211     .8274
   ANGLE ATTACK DEG.       2.363     1.838         1.869     1.369        1.649     1.236
   FUSE. ANGLE  DEG.        .363     -.162         -.131     -.631        -.351     -.764
   CL                      .4554     .3951         .4168     .3568        .3999     .3490
   L/D                    12.139    11.317        11.684    10.725       11.237    10.480
   FUEL FLOW     LB/HR    2402.1    2236.1        2530.3    2368.5       2644.1    2492.7
   BREG. FACTOR N.MI.      8518.     7938.         8441.     8005.        8242.     7630.
   SPEC. RANGE  NM/LB     .19220    .20647        .19064    .20366       .18622    .19753


0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
           (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
0                  FUEL                                                                           FUS.                            FUEL
  TIME    RANGE    USED     WEIGHT     ALT.     TAS    EAS    MACH  MACH    CL      CD    ALPHA GAMMA ANGLE     R/S    THRUST     FLOW
  (HRS)   (NM)     (LBS)    (LBS)      (FT)   (KTS)  (KTS)    NO.   DIV                   (DEG) (DEG) (DEG)    (FPM)    (LBS)   (LB/HR)

  2.533   1094.    6382.   39256.   35000.    482.   269.   .836  .825  .3662  .0335   1.45 -1.57 -2.12    1339.    2513.    1782.  R
  2.546   1100.    6406.   39232.   34000.    485.   276.   .836  .827  .3492  .0329   1.31 -1.52 -2.22    1306.    2649.    1884.  R
  2.559   1106.    6433.   39206.   33000.    487.   282.   .836  .829  .3331  .0323   1.17 -1.48 -2.30    1271.    2794.    1991.  R
  2.572   1113.    6461.   39178.   32000.    489.   289.   .836  .831  .3179  .0318   1.05 -1.43 -2.39    1241.    2942.    2102.  R
  2.586   1119.    6491.   39147.   31000.    491.   296.   .836  .833  .3035  .0314    .93 -1.39 -2.47    1209.    3098.    2219.  R
  2.600   1126.    6524.   39114.   30000.    493.   302.   .836  .835  .2898  .0310    .81 -1.35 -2.54    1180.    3258.    2340.  R
  2.615   1134.    6560.   39079.   29000.    495.   309.   .836  .836  .2768  .0306    .70 -1.32 -2.61    1153.    3424.    2466.  R
  2.629   1141.    6598.   39040.   28000.    497.   316.   .836  .838  .2645  .0303    .60 -1.28 -2.68    1127.    3598.    2598.  R
  2.645   1149.    6640.   38999.   27000.    499.   323.   .836  .839  .2528  .0300    .50 -1.24 -2.74    1100.    3797.    2745.  R
  2.660   1156.    6685.   38954.   26000.    502.   331.   .836  .841  .2417  .0297    .41 -1.21 -2.80    1077.    3981.    2887.  R
  2.676   1164.    6733.   38906.   25000.    504.   338.   .836  .842  .2311  .0295    .32 -1.18 -2.86    1053.    4173.    3035.  R
  2.692   1172.    6784.   38855.   24000.    506.   345.   .836  .843  .2211  .0292    .24 -1.15 -2.91    1032.    4370.    3188.  R
  2.708   1181.    6839.   38799.   23000.    508.   353.   .836  .844  .2116  .0290    .16 -1.13 -2.96    1011.    4573.    3348.  R
  2.725   1189.    6897.   38742.   22000.    505.   357.   .827  .845  .2068  .0289    .14 -1.11 -2.97     992.    4674.    3437.  R
  2.742   1198.    6957.   38682.   21000.    499.   359.   .814  .845  .2041  .0289    .15 -1.10 -2.95     972.    4734.    3496.  R
  2.747   1200.    6961.   38678.   20000.    430.   314.   .699  .838  .2642  .0303    .93 -4.93 -6.00    3750.    1088.     788.  A
  2.751   1202.    6964.   38674.   19000.    425.   316.   .689  .838  .2611  .0302    .93 -4.93 -6.00    3703.    1135.     825.  A
  2.756   1204.    6968.   38670.   18000.    421.   318.   .679  .839  .2581  .0301    .92 -4.92 -6.00    3655.    1182.     863.  A
  2.761   1206.    6973.   38666.   17000.    416.   320.   .669  .839  .2550  .0301    .90 -4.90 -6.00    3608.    1232.     903.  A
  2.765   1207.    6977.   38662.   16000.    412.   322.   .659  .839  .2520  .0300    .89 -4.89 -6.00    3561.    1283.     944.  A
  2.770   1209.    6982.   38657.   15000.    408.   324.   .650  .840  .2490  .0299    .88 -4.88 -6.00    3515.    1336.     987.  A
  2.775   1212.    7002.   38637.   14000.    511.   413.   .812  .852  .1537  .0280   -.28 -3.61 -5.89    3262.    4601.    3933.  A
  2.780   1214.    7007.   38632.   13000.    399.   328.   .632  .841  .2430  .0298    .85 -4.85 -6.00    3422.    1447.    1077.  A
  2.785   1216.    7013.   38626.   12000.    396.   330.   .624  .841  .2400  .0297    .83 -4.83 -6.00    3377.    1505.    1124.  A
  2.790   1218.    7018.   38620.   11000.    392.   332.   .615  .841  .2370  .0296    .81 -4.81 -6.00    3333.    1565.    1174.  A
  2.800   1221.    7027.   38611.   10000.    291.   250.   .455  .819  .4175  .0355   3.00 -3.09 -2.09    1590.    1187.     854.  S
  2.811   1224.    7037.   38602.    9000.    286.   250.   .446  .819  .4174  .0355   3.02 -3.03 -2.02    1535.    1227.     885.  S
  2.822   1227.    7047.   38592.    8000.    282.   250.   .438  .819  .4173  .0354   3.03 -2.97 -1.94    1481.    1269.     918.  S
  2.834   1230.    7058.   38580.    7000.    277.   250.   .430  .819  .4172  .0354   3.04 -2.91 -1.87    1427.    1312.     952.  S
  2.846   1234.    7070.   38568.    6000.    273.   250.   .422  .819  .4171  .0354   3.05 -2.84 -1.79    1374.    1356.     987.  S
  2.859   1237.    7083.   38556.    5000.    269.   250.   .414  .819  .4169  .0354   3.06 -2.77 -1.71    1321.    1402.    1023.  S
  2.872   1241.    7097.   38542.    4000.    265.   250.   .406  .819  .4168  .0354   3.07 -2.71 -1.63    1269.    1449.    1061.  S
  2.886   1244.    7112.   38527.    3000.    261.   250.   .399  .819  .4166  .0354   3.08 -2.63 -1.55    1217.    1497.    1099.  S
  2.900   1248.    7129.   38510.    2000.    257.   250.   .391  .819  .4165  .0354   3.09 -2.56 -1.47    1165.    1547.    1139.  S
  2.907   1250.    7137.   38502.    1500.    255.   250.   .388  .819  .4163  .0354   3.10 -2.52 -1.43    1139.    1573.    1160.  S
0  END OF DSCNT TO    1500. FT
 TIME=  2.907 HRS   FUEL USED=    7137. LBS   WEIGHT=   38502. LBS   RANGE=   1250. NM

0      RESERVE FUEL(LBS)     1802.                 1898.                1983.
         (   45.0 MIN.)

   ************************************************************************************
0      RANGE = 1250.    BLOCK TIME= 2.907    USED FOR DESIGN RANGE AND COST

   ************************************************************************************
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Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
0  *************************************************************************************
0           TEMP.=  537. DEG:STD.+36.
    LANDING ELEVATION= 5000. FT.
    LANDING WING LOADING=  98.70 PSF.
    LANDING WEIGHT =    42900. LBS.

    LANDING DISTANCE FROM 50. FT.=   2964. FT.

    F.A.R. FACTORED FIELD LENGTH =   4941. FT.
0                   APPROACH          TRANSITION            DELAY              ROLL
0               DIST=      700.    DIST=       204.     DIST=       207.    DIST=       1853.
                R/S=      1000.    XLFMX=     1.200     TDELAY=     1.00    MUB=        .4000
                VAPEAS=  124.21    SINKTD=    3.000     TIDLE=      640.    TR/TIDLE=   .0000
                VAPTAS=  138.59    VSTEAS=    95.55     VTDTAS=   122.60    ABAR(G)=    .3599
                THETA=     4.08    CLMX=     3.1874
                THRUST=   3304.    HFLAR=      20.9
0  *************************************************************************************
*******************************************************************************************
0              RANGE OR ENDURANCE ITERATION SUMMARY

                            GROSS     RANGE(NMI) OR
               ITERATION  WEIGHT(LB)  ENDURANCE(HR)

                   0       44050.00     1066.847
                   1       53719.51     2092.646
                   2       45776.46     1264.360
                   3       45638.74     1249.734
                   REQUIRED RG. OR END. = 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.362   LIFT= 44269.6   L/D=  12.137   ALTITUDE= 35000.0   MACH=   .8000

 0  GROSS WEIGHT =   45639.       PASSENGERS =  50. PLUS CREW

 0  FUSELAGE      LENGTH              (ELF)           79.25   FT
                  WIDTH               (SWF)            9.25   FT
                  WETTED AREA         (SF)            1910.   SQFT
                  DELTA P             (DELP)           8.20   PSI

 0  WING          ASPECT RATIO        (AR)             8.72
                  AREA                (SW)            434.7   SQFT
                  SPAN                (B)              61.6   FT
                  GEOM. MEAN CHORD    (CBARW)          8.25   FT
                  QUARTER CHORD SWEEP(DLMC4)           18.6   DEG
                  TAPER RATIO         (SLM)            .170
                  ROOT THICKNESS      (TCR)            .130
                  TIP THICKNESS       (TCT)            .100
                  WING LOADING        (WGS)           105.0   PSF
                  WING FUEL VOLUME    (VFW)          1042.4   GAL

 0  HOR. TAIL     ASPECT RATIO        (ARHT)           4.04
                  AREA                (SHT)           159.0   SQFT
                  SPAN                (BHT)           25.33   FT
                  MEAN CHORD          (CBARHT)         6.28   FT
                  THICKNESS/CHORD     (TCHT)           .100
                  MOMENT ARM          (ELTH)           44.2   FT
                  VOLUME COEFF.       (VBARH)         1.959

 0  VERT. TAIL    ASPECT RATIO        (ARVT)           1.04
                  AREA                (SVT)            97.0   SQFT
                  SPAN                (BVT)           10.05   FT
                  MEAN CHORD          (CBARVT)         9.75   FT
                  THICKNESS/CHORD     (TCVT)           .120
                  MOMENT ARM          (ELTV)           33.2   FT
                  VOLUME COEFF.       (VBARV)          .120

 0  ENG.NACELLES  LENGTH              (ELN)           11.87   FT
                  MEAN DIAMETER       (DBARN)          3.96   FT
                  NUMBER ENGINES      (ENP)             2.0
                  WETTED AREA         (SN)           295.05   SQFT

                  LOCATION                           ON FUSELAGE

 0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
    ULT. LF =  4.94   MAN. LF =  2.50   GUST LF =  3.30

 0  PROPULSION GROUP
       PRIMARY ENGINES           (WEP)      3131.
       PRIMARY ENGINE INSTL.     (WPEI)      423.
       FUEL SYSTEM               (WFSS)      180.
       TOTAL PROP.GROUP WT.      (WP)       3734.
 0  STRUCTURES GROUP
       WING                      (WW)       4389.
       HOR. TAIL                 (WHT)       748.
       VERT. TAIL                (WVT)       449.
       FUSELAGE                  (WB)       5990.   (INCL.     .0 LBS A.T.W.)
       LANDING GEAR              (WLG)      1734.
       PRIMARY ENG. SECTION      (WPES)     1038.
       GROUP WEIGHT INC.         (DELWST)      0.
       TOTAL STRUC.GROUP WT.     (WST)     14348.
 0  FLIGHT CONTROLS GROUP
       COCKPIT CONTROLS          (WCC)        96.
       FIXED WING CONTROLS       (WCFW)      796.
       SAS                       (WSAS)        0.
       GROUP WEIGHT INC.         (DELWFC)      0.
       TOTAL CONTROL WT.         (WFC)       891.
 0  WT. OF FIXED EQUIPMENT       (WFE)      6566.

    WEIGHT EMPTY                 (WE)      25540.

    FIXED USEFUL LOAD            (WFUL)     1079. (INC. CREW )

    OPERATING WEIGHT EMPTY       (OWE)     26619.
 0  PAYLOAD                      (WPL)     10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

    FUEL                         (WFA)      9020. (WFW= 6971.) (WFTP=    0.)

    GROSS WEIGHT                 (WG)      45639.
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
0          FIXED EQUIP GROUP                     FIXED USEFUL LOAD
0     WAPU                  372.27          WCREW ( 2.)          340.00
      WINSTR                236.82          WSTU  ( 1.)          130.00
      WHYD                  366.62          WCBAG                110.00
      WELEC                 970.00          WUF                  125.09
      WAV                   500.00          WOIL                 129.68
      WFUR                 3410.00          WSRV                 116.00
      WAC                   477.91          WH2O                  53.00
      WAI                   212.29          WEMER                 40.00
      WAUXG                  20.00          WCATER                35.00

      WFE                  6565.91          WFUL                1078.77

0   DESIGN MACH =   .800          DESIGN ALTITUDE =  35000.          DESIGN Q (PSF) =224.03
0   DESIGN RE.NUM. PER FT.    = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274

0   AERODYNAMIC DATA

0                              FLATPLATE                 WETTED
    DRAG BREAKDOWN             AREA(SQFT)      CDO       AREA(SQFT)
0          WING                   2.8925     .00665         659.97
           FUSELAGE               5.4592     .01256        1910.38
           VERT.TAIL               .6086     .00140         193.95
           HOR. TAIL              1.0247     .00236         317.97
           ENGINE NAC.            1.1899     .00274         295.05
           TIP TANKS               .0000     .00000            .00
           INCREMENTAL             .6520     .00150            .00
0              TOTAL             11.8269     .02721        3377.32

             MEAN SKIN FRICTION COEF.=  .003502


0   AERODYNAMIC COEFF.
         A1                                              .8107
         A2                                             -.1242
         A3                                              .0360
         A4=.75X(T/C)                                    .0910
         A5=CDO--                                        .0178
         A6                                             2.4286
         A7=1/(PI.SEE.AR)                                .0473
         3-D LIFT SLOPE AT CRUISE MACH       (CLALPH)   6.5841    PER RADIAN
         OSWALD FACTOR                       (SEE)       .7712

0   CRUISE CD =   .0272 +    .0473 CL2   (ASSUMES MINIMUM WING PROFILE DRAG)
0   RETRACTABLE LANDING GEAR CD INC.= .03451


0 CRUISE DRAG
0CL=    .2000
            MACH       CD     L/D    CLALPH   ALPHA
          .50000   .02914   6.8644   5.2969    .5634
          .55000   .02914   6.8644   5.4242    .5126
          .60000   .02914   6.8644   5.5757    .4552
          .65000   .02914   6.8644   5.7572    .3904
          .70000   .02914   6.8644   5.9767    .3173
          .75000   .02914   6.8644   6.2462    .2346
          .80000   .02914   6.8644   6.5841    .1404
          .85000   .02914   6.8640   7.0206    .0322
0CL=    .3000
            MACH       CD     L/D    CLALPH   ALPHA
          .50000   .03164   9.4818   5.2969   1.6451
          .55000   .03164   9.4818   5.4242   1.5689
          .60000   .03164   9.4818   5.5757   1.4828
          .65000   .03164   9.4818   5.7572   1.3856
          .70000   .03164   9.4818   5.9767   1.2759
          .75000   .03164   9.4818   6.2462   1.1519
          .80000   .03164   9.4818   6.5841   1.0106
          .85000   .03176   9.4467   7.0206    .8483
0CL=    .4000
            MACH       CD     L/D    CLALPH   ALPHA
          .50000   .03509 11.3992   5.2969   2.7268
          .55000   .03509 11.3992   5.4242   2.6252
          .60000   .03509 11.3992   5.5757   2.5104
          .65000   .03509 11.3992   5.7572   2.3808
          .70000   .03509 11.3992   5.9767   2.2346
          .75000   .03509 11.3992   6.2462   2.0691
          .80000   .03509 11.3992   6.5841   1.8809
          .85000   .03572 11.1971   7.0206   1.6644
0CL=    .5000
            MACH       CD     L/D    CLALPH   ALPHA
          .50000   .03966 12.6080   5.2969   3.8085
          .55000   .03966 12.6080   5.4242   3.6815
          .60000   .03966 12.6080   5.5757   3.5380
          .65000   .03966 12.6080   5.7572   3.3760
          .70000   .03966 12.6080   5.9767   3.1932
          .75000   .03966 12.6080   6.2462   2.9864
          .80000   .03966 12.6080   6.5841   2.7511
          .85000   .04151 12.0464   7.0206   2.4805
0CL=    .6000
            MACH       CD     L/D    CLALPH   ALPHA
          .50000   .04517 13.2827   5.2969   4.8902
          .55000   .04517 13.2827   5.4242   4.7378
          .60000   .04517 13.2827   5.5757   4.5656
          .65000   .04517 13.2827   5.7572   4.3712
          .70000   .04517 13.2827   5.9767   4.1519
          .75000   .04517 13.2827   6.2462   3.9037
          .80000   .04517 13.2823   6.5841   3.6213
          .85000   .04924 12.1861   7.0206   3.2966
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                              FLAPS UP                              TAKEOFF                           LANDING
        ALPHA       CL        CD        L/D         CL        CD        L/D         CL        CD        L/D
     -2.00000   -.03378   .02736 -1.23449   1.07389   .09225 11.64121   1.84073   .25101   7.33333
       .00000    .13512   .02808  4.81130   1.24279   .10567 11.76150   2.00964   .26866   7.48034
      2.00000    .30403   .03176  9.57267   1.41170   .12285 11.49101   2.17854   .29151   7.47326
      4.00000    .47293   .03833 12.33925   1.58061   .14590 10.83338   2.34745   .31899   7.35910
      6.00000    .64184   .04790 13.39877   1.74951   .17178 10.18484   2.51636   .34962   7.19741
      8.00000    .81075   .06069 13.35837   1.91842   .20041  9.57260   2.68526   .38341   7.00358
     10.00000    .97965   .07731 12.67110   2.08732   .23179  9.00504   2.85417   .42037   6.78973
     12.00000   1.14856   .09943 11.55143   2.25623   .26594  8.48400   3.02307   .46048   6.56508
     13.92202   1.31088   .12360 10.60608   2.41855   .30135  8.02572   3.18539   .50200   6.34536
     13.92202   1.31088   .12360 10.60608   2.41855   .30135  8.02572   3.18539   .50200   6.34536

0                             DFLAP=      .00          DFLAP=    15.00          DFLAP=    40.00
0                             CLMAX=  1.31088          CLMAX=  2.43199          CLMAX=  3.18742

0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
    FLAP DEFL.    CLMAX      CL        CD       L/D
      10.000    2.08973
                           .74305   .06904 10.76197
                           .91195   .07966 11.44762
                          1.08086   .09370 11.53470
                          1.24976   .11179 11.17940
                          1.41867   .13525 10.48931
                          1.58757   .16144  9.83412
                          1.75648   .19035  9.22762
                          1.92538   .22199  8.67314
                          2.08973   .25540  8.18210
                          2.08973   .25540  8.18210
      20.000    2.66391
                          1.31722   .11933 11.03880
                          1.48613   .13455 11.04532
                          1.65503   .15432 10.72435
                          1.82394   .17880 10.20125
                          1.99284   .20605  9.67158
                          2.16175   .23609  9.15637
                          2.33065   .26892  8.66678
                          2.49956   .30453  8.20795
                          2.66391   .34185  7.79257
                          2.66391   .34185  7.79257
      30.000    3.00166
                          1.65497   .17549  9.43078
                          1.82388   .19236  9.48172
                          1.99278   .21444  9.29303
                          2.16169   .24043  8.99096
                          2.33059   .26931  8.65398
                          2.49950   .30108  8.30183
                          2.66840   .33574  7.94792
                          2.83731   .37328  7.60094
                          3.00166   .41259  7.27512
                          3.00166   .41259  7.27512


0ALTITUDE=     35000. FT   TAS=     485.85 KTS   MACH NO=      .8419


0                                RDT&E AND AIRFRAME PRODUCTION COSTS
                                            (1993. DOLLARS)
0                            TOTAL RDT&E COSTS            1076.8734 MILLION
0                                         AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                                  500. AIRCRAFT
                                                    WEIGHT(LB)     COST($)     COST($/LB)
          STRUCTURE(  4058315.$)
                                 WING                    4389.    1099938.       250.60
                                 EMPENNAGE               1197.     427746.       357.30
                                 FUSELAGE                5990.    1661996.       277.46
                                 LANDING GEAR            1734.     308317.       177.78
                                 NACELLES                1038.     560318.       539.98
          PROPULSION INSTAL(     179467.$)
                                 ENGINE INSTALLAT.        423.     153896.       364.08
                                 FUEL SYSTEM              180.      25570.       141.74
          SYSTEMS(  2549885.$)
                                 FLIGHT CONTROLS          891.     418411.       469.41
                                 HYDRAULIC                367.      45668.       124.57
                                 ELECTRICAL               970.     464214.       478.57
                                 AIR CONDITIONING         478.     256070.       535.82
                                 ANTI-ICING               212.     111802.       526.66
                                 AUX. POWER UNIT          372.     207143.       556.42
                                 FURNISHINGS             3410.     796443.       233.56
                                 INSTRUMENTS              237.     196430.       829.44
                                 AVIONICS INSTALL.        250.      49032.       196.13
                                 AUX. ITEMS                20.       4671.       233.56
          INTEGRATION(  1696917.$)
0                                  AIRFRAME TOTALS     22159.    8484584.       382.90
0                                  ENGINES                       2914463.
                                   PROPELLER                           0.
                                   AVIONICS                      4000000.
                                   A/C COST(NO RD)              15399047.
                                   R&D PER A/C                   2153747.
                                   TOTAL A/C COST               17552794.

0                   ENGINES      NUMBER =     2.  TYPE=     7

0 EMPTY WEIGHT= 25540.     AIRFRAME WEIGHT= 22409.     WEIGHT OF 1 ENGINE=  1566.     CRUISE SPEED= 486. KTS
0 THRUST/ENGINE=    9785.
0 TOTAL AIRCRAFT COST= 17552794.     AIRFRAME COST= 14638331.     COST OF 1 ENGINE=  1457232.     COST OF 1 PROP.=         0.
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
0                              --- COST DATA ---
                            GASP SHORTHAUL METHOD
0          DESIGN MISSION
0              OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0  ****************************************************************************************************
0                   RANGE=    1250. N.M.    BLOCK FUEL=    7137. LBS    BLOCK TIME=  2.9073 HRS.
0   UTILIZATION                         3200.
 FLYING OPERATIONS
    FLIGHT CREW                       363.415
    FUEL,OIL,AND TAXES( .850$/G)      948.029
    INSURANCE                          79.737
 DIRECT MAINTENANCE
    AIRFRAME                          165.025
    ENGINE                            281.055
 MAINTENANCE BURD.                    360.700
 DEPRECIATION                        1071.663

    TOTAL DOC ($/TRIP)               3269.624
              ($/B.HR.)              1124.618
              ($/N.MI.)                 2.616
```

Fig E12 - Conventional Configuration optimised for minimum M.T.O.W. - GASP solution (concluded)

```
*....data for 50 Pax turbofan airliner

VARIABLES
01 1  95.0            86.750              80.000       105.000
02 1   9.0             8.300               8.000        10.000
03 1  23.0            14.500              11.000        35.000
04 1    .235            .200                .160          .310
05 1   4.0             4.000               3.800         4.300
06 1  27.5            27.500              20.000        35.000
07 1   1.0             1.000                .800         1.200
08 1  46.5            50.500              40.000        53.000
09 1   6.0             5.500               4.000         8.000
10 1  23.0            15.000              10.000        35.000
11 1    .43             .500                .160          .700
12 1   1.5             2.000                .000         3.000
13 1    .15             .15                 .145          .175
14 1    .8              .75                 .75           .85
FUNCTIONS
01 00 0045000.0        1
02 -1 00 6000.0
03 -1 00 5000.0
04 -1 00  120.0
05 -1 00     .8
06 -1 00     .8
CONTROLS
XTOLU = .0001
XTOLV = .0001
OFROM = 1
OFREQ = 10
RFREQ = 50
NFEMAX = 20000
RUN
END
```

Fig E13 - RQPMIN.DAT file for the Three-Lifting Surface M.T.O.W. optimisation case

```
1Program  RQPMIN  Version 1.0  for VAX

 ANALYSIS OF  INPUT FILE DATA  AND  CONTROL PARAMETERS

 Input file: rqpmin.dat
 Output file: rqpmin.res


 Variable data
 -------------

 Number of variables =     14

 Index       Status          Scale            Starting value          Lower bound           Upper bound
     1          1         .9500000E+02          .9131579E+00          .8421053E+00          .1105263E+01
     2          1         .9000000E+01          .9222223E+00          .8888889E+00          .1111111E+01
     3          1         .2300000E+02          .6304348E+00          .4782609E+00          .1521739E+01
     4          1         .2350000E+00          .8510638E+00          .6808510E+00          .1319149E+01
     5          1         .4000000E+01          .1000000E+01          .9500000E+00          .1075000E+01
     6          1         .2750000E+02          .1000000E+01          .7272727E+00          .1272727E+01
     7          1         .1000000E+01          .1000000E+01          .8000000E+00          .1200000E+01
     8          1         .4650000E+02          .1086022E+01          .8602151E+00          .1139785E+01
     9          1         .6000000E+01          .9166667E+00          .6666667E+00          .1333333E+01
    10          1         .2300000E+02          .6521739E+00          .4347826E+00          .1521739E+01
    11          1         .4300000E+00          .1162791E+01          .3720930E+00          .1627907E+01
    12          1         .1500000E+01          .1333333E+01          .0000000E+00          .2000000E+01
    13          1         .1500000E+00          .1000000E+01          .9666666E+00          .1166667E+01
    14          1         .8000000E+00          .9375000E+00          .9375000E+00          .1062500E+01

 Problem function data
 ---------------------

 Number of constraints =     5

 Index     Status     Type          Scale                 Index     Status     Type          Scale
    1         0         0       .5000000E+04                 2         -1        0       .6000000E+04
    3        -1         0       .5000000E+04                 4         -1        0       .1200000E+03
    5        -1         0       .8000000E+00                 6         -1        0       .8000000E+00

 objective is function     1                       problem number =     1


 Control parameters
 ------------------

 nfemax = 20000     nimax  =  1000     nsmax  =    20
 nseto  =     4     nsetcf =     8     nsetv  =     4     nsetvf =     8
 ofreq  =    10     ofrom  =     1     rfreq  =    50     rfrom  =     1

 centrl = F     fdset  = F     norep  = F     cheats = T     fast   = T     quasi  = T
 fixrp  = F     timid  = F     monitr = F     nofrec = F     yesbc  = F     shrnk  = T     projct = T

 xtol   =   .1000000E-05    xtolu  =   .1000000E-03    xtolv  =   .1000000E-03    gtol   =   .1000000E-02
 rtol   =   .1000000E+00    omegar =   .1000000E+00    rpmax  =   .2000000E+00
 umin   =   .1000000E-05    vminf  =   .1000000E-02    vminc  =   .1000000E-05    ctol   =   .1000000E-02
 umax   =   .1000000E+00    vmax   =   .1000000E+00    omega  =   .1000000E+00    mu     =   .1000000E-03
 bdtol  =   .1000000E+00    lmtol  =   .1000000E+00    mtol   =   .5000000E+00    cmax   =   .1000000E-01
 subtol =   .1000000E-02    qrtol  =   .1000000E+02    bfstol =   .1000000E-05    diftol =   .5000000E-03
 ztol   =   .1000000E-29

 End of input data
 -----------------

1Program  RQPMIN  Version 1.0  for VAX

 STARTING POINT


 free variables
 --------------

 1   .9131579E+00  2   .9222223E+00  3   .6304348E+00  4   .8510638E+00  5   .1000000E+01  6   .1000000E+01  7   .1000000E+01
 8   .1086022E+01  9   .9166667E+00 10   .6521739E+00 11   .1162791E+01 12   .1333333E+01 13   .1000000E+01 14   .9375000E+00

 objective function
 ------------------

 f(x) =   .9313772E+01

 inactive inequality constraints
 -------------------------------

 2  -.2221938E+00  3  -.2112215E+00  4  -.1449613E+00  5  -.4113428E-01  6  -.8386575E-01
1Program  RQPMIN  Version 1.0  for VAX

 end of iteration number     1
 ----------------------------

 end of a successful minimization step
 number of calls made to user function so far =    30
```

Fig E14 - RQPMIN.RES file for the Three-Lifting Surface M.T.O.W. optimisation case

```
free variables
--------------

 1   .9153786E+00  2   .9999178E+00  3   .6547356E+00  4   .9143497E+00  5   .1063544E+01  6   .9908860E+00  7   .1100000E+01
 8   .1136797E+01  9   .9806426E+00 10   .7156005E+00 11   .1226368E+01 12   .1417440E+01 13   .1064629E+01

variables fixed at or near their lower bounds
---------------------------------------------

14   .9375000E+00

objective function
------------------

f(x) =   .9300725E+01

inactive inequality constraints
-------------------------------

 2  -.2105103E+00  3  -.2153489E+00  4  -.1476603E+00  5  -.2702467E-01  6  -.9797536E-01

Partial derivatives of Lagrangian function
------------------------------------------

 1   .3650665E+01  2   .7869720E+01  3  -.8361816E+01  4   .2096939E+02  5   .3242493E-01  6   .3051758E-01  7  -.8201598E-01
 8  -.2193451E+00  9  -.2079010E+00 10  -.2254867E+02 11   .2670288E-01 12   .2079582E+02 13  -.5836487E+00 14  -.1087189E+01

convergence criteria
--------------------

pdatum =   .9300725E+01     ldatum =   .9300725E+01     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .5694389E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .2254867E+02
nde    =     0     ndef =     2     ndec =     0     ncalls =     4     nfuncs =     2
1Program  RQPMIN  Version 1.0  for VAX                     16-Feb-94

end of iteration number    11
----------------------------

restart after premature convergence
number of calls made to user function so far =   388

free variables
--------------

 1   .9228305E+00  2   .9185433E+00  3   .6036867E+00  4   .8181030E+00  5   .9551157E+00  6   .9431822E+00  7   .1073791E+01
13   .1006602E+01  9   .9015445E+00 10   .6543043E+00 11   .1170526E+01 12   .1330351E+01  8   .1119945E+01

variables fixed at or near their lower bounds
---------------------------------------------

14   .9375000E+00

objective function
------------------

f(x) =   .9224617E+01

inactive inequality constraints
-------------------------------

 2  -.2036912E+00  3  -.1951350E+00  4  -.1333703E+00  5  -.4177324E-01  6  -.8322679E-01

Partial derivatives of Lagrangian function
------------------------------------------

 1  -.3369331E+01  2  -.3032684E+01  3  -.2365112E+01  4  -.1057911E+02  5  -.2176571E+02  6   .1144409E-01  7  -.8740425E+01
13  -.7804870E+01  9  -.3172874E+01 10   .1029968E+00 11   .7896423E+01 12   .9975433E+01  8   .1761913E+02 14  -.1115131E+02

convergence criteria
--------------------

pdatum =   .9224617E+01     ldatum =   .9224617E+01     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .3566933E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .2176571E+02
nde    =     0     ndef =    24     ndec =     1     ncalls =    49     nfuncs =    24
1Program  RQPMIN  Version 1.0  for VAX                     16-Feb-94

end of iteration number    21
----------------------------

end of a successful minimization step
number of calls made to user function so far =  1029
```

Fig E14 - RQPMIN.RES file for the Three-Lifting Surface M.T.O.W. optimisation case (continued)

```
free variables
--------------

 1   .1010227E+01  2   .9823352E+00  3   .7007083E+00  4   .7784299E+00 14   .1014215E+01  6   .9579575E+00  7   .1142082E+01
13   .1143976E+01  9   .1000860E+01 10   .7929409E+00 11   .1152595E+01 12   .1352062E+01  5   .9956403E+00

variables fixed at or near their lower bounds
---------------------------------------------

 8   .8602151E+00

objective function
------------------

f(x) =   .8915198E+01

inactive inequality constraints
-------------------------------

 2   .8142090E-03  3  -.1764121E-01  4  -.1165155E-01  5  -.4023626E-01  6  -.8476377E-01

Partial derivatives of Lagrangian function
------------------------------------------

 1   .2312088E+02  2   .5202293E+01  3   .3226280E+02  4   .2381706E+02 14   .3458881E+02  6   .0000000E+00  7  -.5254745E+00
13  -.2198696E+02  9  -.3209496E+02 10   .0000000E+00 11  -.2177524E+02 12   .0000000E+00  5   .0000000E+00  8  -.1465797E+01

convergence criteria
--------------------

pdatum =   .8915198E+01     ldatum =   .8915198E+01     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .5574258E+01     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .3458881E+02
nde    =     0      ndef =    24      ndec =    23      ncalls =    96      nfuncs =    49
1Program  RQPMIN  Version 1.0  for VAX                    16-Feb-94

end of iteration number    23
-----------------------------

CONVERGENCE DETECTED  [ Code B ]     after  1349 calls to user routine



free variables
--------------

 1   .1010227E+01  2   .9823352E+00  3   .7007083E+00  4   .7784299E+00 14   .1014215E+01  6   .9579575E+00  7   .1142082E+01
13   .1143976E+01  9   .1000860E+01 10   .7929409E+00 11   .1152595E+01 12   .1352062E+01  5   .9956403E+00

variables fixed at or near their lower bounds
---------------------------------------------

 8   .8602151E+00

objective function
------------------

f(x) =   .8915198E+01

inactive inequality constraints
-------------------------------

 2   .8142090E-03  3  -.1764121E-01  4  -.1165155E-01  5  -.4023626E-01  6  -.8476377E-01

Partial derivatives of Lagrangian function
------------------------------------------

 1   .2312088E+02  2   .5202293E+01  3   .3226280E+02  4   .2381706E+02 14   .3458881E+02  6   .0000000E+00  7  -.5254745E+00
13  -.2198696E+02  9  -.3209496E+02 10   .0000000E+00 11  -.2177524E+02 12   .0000000E+00  5   .0000000E+00  8  -.1465797E+01

convergence criteria
--------------------

pdatum =   .8915198E+01     ldatum =   .8915198E+01     gdatum =   .0000000E+00
nu     =   .0000000E+00     numax  =    infinite
unormx =   .0000000E+00     unormd =   .0000000E+00     rtol   =   .1000000E+00     xtolu  =   .1000000E-03
vnormx =   .3458881E+02     vnorm  =   .1000000E+00     xtolv  =   .1000000E-03     grdldn =   .3458881E+02
nde    =     0      ndef =    24      ndec =    34      ncalls =   119      nfuncs =    61
```

Fig E14 - RQPMIN.RES file for the Three-Lifting Surface M.T.O.W. optimisation case (concluded)

```
                           50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - THREE-SURF. CONFIG.
0                                         ENGINE CYCLE IS G. E.  CF-34
                                              INPUT DATA FOLLOW
                                             ******************

0                                            *****GEOMETRY*****
0 CONFIG  WG     =  44050.              KWRITE  =      2        FUSEL  SAB    =      4.               ELODN  =   1.000
          WGS    =  95.972              IGEAR   =      0               WS     =  20.000               ELODT  =   3.200
          PAX    =     50.              KCONFG  =      0               AS     =      1.               BMLOD  =  14.500
          EMCRU  =    .800              KTIPX   =      0               WAS    =  19.000      NACELLE  KNAC   =       1
          HNCRU  =  35000.              ENP     =     2.               PS     =    31.0               ELN    =  11.295
                                        NTYE    =      7               ELPC   =  11.220               DBARN  =   3.765
          Kanard =       1              KPLOT   =      1               HCK    =   2.470               ELRW   =  10.000

0   WING  TCT    =    .100      HORIZ   VBARHX  =  .0000        VERT   VBARVX =   .0000      Canard   TCcan  =    .100
          TCR    =    .130      TAIL    TCHT    =   .100        TAIL   TCVT   =    .120               ARcan  =   6.005
          AR     =   8.841              ARHT    =  3.983               ARVT   =   1.142               SLMcan =    .496
          SLM    =    .183              SLMH    =   .550               SLMV   =    .700               DwpqCa =  18.238
          DLMC4  =  16.116              DWPQCH  = 26.344               DWPQCV =  40.000               EYEcan =   2.028
          EYEW   =   2.000              COELTH  =   .000               BOELTV =    .000               SWcOSW =    .172
                                        SAH     =  1.000

0                                          ***AERODYNAMICS***
0         CKW    =  -1.000              CKHT    = -1.000               GRFE   =    .000               DCDSE  = -1.0000
          CKF    =  -1.000              CKTP    = -1.000               SCFAC  =    .750               CKWc   =   2.497
          CKN    =  -1.000              DELCD   = .00150               DLSWSW =    .000               cmacw  =   -.060
          CKVT   =  -1.000              DELFE   =   .200               ALPHL0 =  -1.600               alzerc =  -1.000

0         KWCD   =      12
          ACLS   =  -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR =   2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                          *HIGH LIFT DEVICES*
0         RCLMAX =   1.200       FLAPS  JFLTYP  =      7         LED  CLEOC  =    .000
          ALTFLP =   5000.              DFLPTO  = 15.000              DELLED =    .000
          FLAPN  =      1.              DFLPLD  = 40.000              DCLMLE =    .930
          WCFLAP =  -1.000              CFOC    =   .300              DELLEO =  45.000
          BENGOB =    .000              BTEOB   =   .750
                                        DCLMTE  =   .000
                                        DCDOTE  =   .000
                                        DELTEO  =   .000

0                                          ****PROPULSION****
0         JENGSZ =       2              HPORT   =  5000.               RCCRU  =  50.000               RWCRTX =    .970
          IPART  =       1              TDELTO  =    36.               XTORQ  =  99999.               HSCREQ =      0.
          KODETO =       5              KODECL  =      7               SM1D   =    .500               THIN   =      0.
          KODETR =       5              KODEAC  =      5               HBTP   =    .437               PR     =   1.000

0                                          *****WEIGHTS*****
0         SKPEI  =   .1350              SKY     =  .1800               SKB    = 107.000               SKFS   =   .0200
          SKLG   =   .0380              SKZ     =  .2200               SKCC   =  20.000               SKWF   =   .4300
          SKMG   =   .8000              SKTL    = 1.0000               SKFW   =   .4300               SKFT   =   .9790
          SKPES  =   .3380              SKWW    = 133.400              SKSAS  =    .000               SKWTP  =  1.8900
          WPLX   =      .0              YMG     =  .2500               EGMRGN =   .0000               LCWING =       2
          WPEX   =      .0              RELP    =  .8114               CPMRGN =   .2000
          WPUL   =  1066.3              RELR    =  .4500               STMRGN =   .0000               LDCKMX =   8.000
          UWPAX  =   200.0              CATD    =     3.               DELP   =   8.200               ATMXQC =   3.160
          STRUT  =   .0000              VMLFSL  =  685.0               YP     =   .0000               DELWST =      .0
          DELWPC =      .0
0 ENGINE  WENG   =      .0              WNAC    =     .0               WPYLON =      .0
          SWSLS  =    .160              UWNAC   =  2.287               FPYL   =    .700               XLQDE  =   3.000

0                                        *STABILITY AND CONTROL*
0         KSFixd =       1              STATIC  =   .100               ZCG    =   5.500               CNPAC  =   .0020
          CMFLPL = 999.000              CHALF   = 999.000              TP     =      .0               ARVTE  =  -1.000
          CMFLPT = 999.000              CHDEL   = 999.000              CXA    =    .520               RV     =    .300
                                        RH      =   .350               DCMCLP =    .000               TAUV   = 999.000
          CMFLD  =    .000              DEMAX   =  -25.0               HWING  =      0.               RVMCS  =    .990
                                        EYET    =     .0               dcmcpi =    .030               DRMAX  =    25.0
                                        TAUH    = 999.000              rc     =    .350

0,                                        ***PERFORMANCE***
0   TAXI  DELTT  =    .167              XLFMAX  =  1.100               DVR    =   5.000               TDELTX =  36.000
      TO  IFLY   =       1              DELTVR  =  3.500               UM     =    .020               HTMAX  = 500.000
          THEMAX =  15.000              DV1     =  5.000               MUB    =    .400               NFAIL  =       0
          H00    =   5000.              VRAT    =   1.10               WTMISN =      0.

0  CLIMB  ICLM   =       1     CRUISE   CRMACH  =   .800               FRESF  =   1.000               FACW1  =    .988
          DELH   =   1000.              CRALT   = 35000.               RCRRQ  =  1250.0               ISWING =       0
          VCLMB  =      .0              ICRUS   =      1               OPALT  =  25000.               OPEM   =    .500
0   LAND  IWLD   =       2              XLDGRQ  = 99999.               VRATT  =   1.300               HAPP   =     50.
          TDELLD =    36.0              ALTLND  =  5000.               RSMX   =   1000.               SINKTD =     3.0
          TDELAY =     1.0              WLPCT   =  .9400               TROTID =    .000               XLFMX  =   1.200
          HTG    =     5.5              TIDLE   =     .0               VTDRAT =     1.1

0                                         ******COST******
0         NCADE  =       1              HIR     =   .005               RI     =    .300               CMV    =    .800
          CLIAB  =  1993.0              TR      =  2.000               OHR    = 500.000               CCRW   =      0.
          HRI    =4000000.              PRV     =   .100               CRWOH  =  23.000               UCSENG =    .000
          CMF    =      .2              DYR     =   15.0               CINP   =      0.               UCSPP  =    .000
          TBO    =  3200.0              SRPM    =     .0               CP     =      0.               ALR    =   1.120
          PCSF   =    .850
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution

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**********************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1  -.0569  1.0000
  GROSS WGT, GROSS WGT MINUS1      44576.0     44050.0


0  ***************************************************************************************************
0                      FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                   CLMAX     VSTALL,KTS  FLAP ANGLE   LE ANGLE     DELTA CL     DELTA CD

 FLAPS UP         1.1243       170.9          .0           .0        .0000        .0000
 T.O. CONFIG      2.1192       124.7        15.0           .0        .9844        .0365
 LDG. CONFIG      2.7832       108.8        40.0           .0       1.6611        .1626

0                     DOUBLE SLOTTED FOWLER FLAPS
                      OPT ANGLE    DELCL AT OPT   DELCD AT OPT    AREA(FT2)      WEIGHT(LB)

 FLAPS                  30.0         2.2500          .1500          81.5           628.1
0  ***************************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.927   LIFT= 43238.7   L/D=  13.657   ALTITUDE= 35000.0   MACH=   .8000

1                                     ENGINE SIZING DATA FOLLOW
                                      *************************
0VSTLKT= 115.6 KTS EAS   VRAT= 1.100 CLTO= 1.7514
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   29.2 AND TAS=   140.0 EAS=   125.6)
 LIFTOFF (TIME=   31.6 DIST=   4352.3 TAS=   147.8 EAS=   132.6)
 DISTANCE TO 35 FT.=  5691.0   TAS=   159.1 EAS=   142.6 V35/VS=  1.2343
 GEAR RETRACTION STARTED AT   37.7 SEC,COMPLETE AT   44.7 SEC
 FLAP RETRACTION STARTED AT   47.9 SEC,COMPLETE AT   52.4 SEC
0VSTLKT= 115.6 KTS EAS   VRAT= 1.100 CLTO= 1.7514
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  212.1 KNOTS EAS
 ENGINE FAILURE (TIME=   27.6 AND TAS=   134.4 EAS=   120.6)
0
 ROTATION (TIME=   32.5 AND TAS=   140.0 EAS=   125.6)
 LIFTOFF (TIME=   35.8 DIST=   5323.3 TAS=   142.2 EAS=   127.6)
 DISTANCE TO 35 FT.=  8098.9   TAS=   142.9 EAS=   128.1 V35/VS=  1.1086


     ACCELERATE - STOP DISTANCE =     6952.9 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=      8098.9 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5691.0 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =      6544.7 FEET
 ALL ENGINE DISTANCE TO 50 FT. =      5936.6 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .014 HRS   FUEL USED=      75. LBS   WEIGHT=   44501. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                               VS              V      GRAD      R/C     REQ.R/C
   CONFIGURATION                                    ALT (FT)   KEAS    V/VS    KTAS    (PCT)     (FPM)     (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT    5000.   115.7  1.1210  144.6   1.661   243.05      1.00  1.694  8.792
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT              5250.   115.7  1.2000  155.4   3.902   613.68    377.45  1.478 11.250
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT           6500.   158.1  1.2500  225.5   4.287   978.39    273.87   .729 14.231
   APPROACH FLAPS -ONE ENG OUT                       5000.   111.0  1.3240  163.8   4.068   674.28    348.09  1.320 11.583
   LANDING FLAPS - ALL ENGINES                       5000.   101.0  1.3000  146.3  11.861  1756.68    473.92  1.653  7.065

     APPROACH FLAP SETTING = 19.7 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 21989.1 FT.
         BEST RATE OF CLIMB SPEED   =   273.4 KTAS
         ENGINE-OUT RATE OF CLIMB   =    49.7 FPM
         WEIGHT AT ALTITUDE         = 42793.0 LBS

 0                        ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE               1358.0
   NACELLE WEIGHT/ENGINE               305.4
   PYLON WEIGHT/ENGINE                 164.3
      PROP OR QFAN          .0
      GEARBOX               .0
      SHROUD                .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)          3.77
   NACELLE LENGTH(FT)               11.30


0VSTLKT= 115.6 KTS EAS   VRAT= 1.100 CLTO= 1.7514
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   27.8 AND TAS=   140.0 EAS=   125.6)
 LIFTOFF (TIME=   30.2 DIST=   4160.3 TAS=   148.1 EAS=   132.9)
 DISTANCE TO 35 FT.=  5501.7   TAS=   160.3 EAS=   143.8 V35/VS=  1.2438
 GEAR RETRACTION STARTED AT   36.2 SEC,COMPLETE AT   43.2 SEC
 FLAP RETRACTION STARTED AT   46.4 SEC,COMPLETE AT   50.9 SEC
0VSTLKT= 115.6 KTS EAS   VRAT= 1.100 CLTO= 1.7514
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  206.8 KNOTS EAS
 ENGINE FAILURE (TIME=   26.3 AND TAS=   134.4 EAS=   120.6)
0
 ROTATION (TIME=   31.1 AND TAS=   140.0 EAS=   125.6)
 LIFTOFF (TIME=   34.4 DIST=   5131.5 TAS=   142.6 EAS=   127.9)
 DISTANCE TO 35 FT.=  7378.4   TAS=   143.4 EAS=   128.6 V35/VS=  1.1127
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W. - GASP solution (continued)

```
     ACCELERATE - STOP DISTANCE =    6797.7 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     7378.4 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5501.7 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6327.0 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5748.4 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .013 HRS   FUEL USED=      76. LBS   WEIGHT=   44500. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS                  V       GRAD       R/C    REQ.R/C
   CONFIGURATION                                ALT (FT)  KEAS     V/VS     KTAS     (PCT)      (FPM)    (FPM)      CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.   115.7   1.1210   144.6    1.940     283.96      1.00   1.694  8.593
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.   115.7   1.2000   155.4    4.153     653.19    377.45   1.478 10.903
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.   158.1   1.2500   225.5    4.280     976.81    273.87    .729 13.323
   APPROACH FLAPS -ONE ENG OUT                   5000.   111.0   1.3240   163.8    4.295     711.92    348.09   1.320 11.191
   LANDING FLAPS - ALL ENGINES                   5000.   101.0   1.3000   146.3   12.866    1905.50    473.92   1.653  7.025

     APPROACH FLAP SETTING = 19.7 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 22512.9 FT.
         BEST RATE OF CLIMB SPEED    =   273.8 KTAS
         ENGINE-OUT RATE OF CLIMB    =    50.0 FPM
         WEIGHT AT ALTITUDE          = 42793.0 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    346.74

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    346.74

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   8841.9 LBS
*******************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE           1414.7
   NACELLE WEIGHT/ENGINE           305.4
   PYLON WEIGHT/ENGINE             168.4
      PROP OR QFAN          .0
      GEARBOX               .0
      SHROUD                .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)        3.77
   NACELLE LENGTH(FT)             11.30

0*******************************************************************************************
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Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

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                         ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                   MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
                    WT          CG         WT          CG         WT          CG

 A/C OWE     26235.95      42.56    26235.95      42.56    26235.95      42.56
 PAX          5440.00                2040.00                8500.00
 BAGGAGE          .00      56.36     1500.00      56.36     1500.00      56.36
 WING FUEL    1303.62      42.32     1303.62      42.32     6518.08      42.32
 TIP FUEL         .00        .00         .00        .00         .00        .00
 FUS FUEL         .00      42.32         .00      42.32     1821.97      42.32
 TOTAL       32979.56      40.27    31079.56      43.58    44575.99      41.85
0                        ---TAIL SIZING SUMMARY---

          Static Longitudinal Stability, Stick-fixed, considered


0                    WING                  CANARD          TAIL        DOWN   FLAP
 CONDITION  ALPHA    CL     CLA     CMac  ALPHA   CLA    CLA   EFF.    WASH   CM

  CRUISE   2.0363  .4290   .1180 -.0600 3.0644  .1002  .0768 1.0000
  LIFTOFF  2.0000 1.3020   .0682 -.0600 3.0281  .0768  .0639 1.0000  .3440 -.1031
  LANDING 11.5540 2.7832   .0853 -.060012.5821  .0769  .0639 1.0000 1.9871 -.2000

0             --FUSELAGE-- ---NACELLE--         ------POWER-------         L.GEAR ROT.POWER
 CONDITION   DCM     CM      DCM    CM  DCMdth DCMfinc CMdth  CMfinc    CT      CM      CM

  CRUISE    .4731          .2109          .0000  .0300                .0000
  LIFTOFF   .8178  .0000  .2109  .0000                .0000   .0391  .0000 -.3324 5.2752
  LANDING   .6543  .5332  .2109  .1719                .0000   .0835

0     CANARD PARAMETERS
          CMDELTC(CONTROL POWER)       =  -.02832
          TAUc(EFFECTIVENESS)          =   .48250
          DcMAX(MAX.CANARDVATOR DEFLEC)= 37.32742

0     ELEVATOR PARAMETERS
          CMDELTE(CONTROL POWER)       =  -.03419            WING DE/DALPHA =    .34396
          TAUH(EFFECTIVENESS)          =   .48250
          DEMAX(MAX.ELEVATOR DEFLEC.)  =-25.00000


0                                  FRACTION    STATION          CANARD AND HORIZONTAL TAIL SIZES
                                     MAC     (DATUM NOSE)                                              CANARD          HOR.TAIL


      NEUTRAL POINT                 .6584       44.458          STATIC STABILITY AND LANDING TRIM
      STATIC MARGIN                 .1000                       STATIC STABILITY AND LIFTOFF ROT.
      AFT CG LIMIT(STABILITY)       .5584       43.660
      CG RANGE(LOADING)             .4144                       REQUIRED SIZES                         71.9126         94.4135
      FWD CG LIMIT(CONTROL)         .1439       40.353          CANARD AND TAIL ARMS (ELcan,ELTH)      33.0524         41.7515
0     VERTICAL TAIL AREA =   90.3807 FOR DIRECTIONAL STABILITY OF      .00200
0     RUDDER POWER AT MAX.DEFL.=   .0193 PER DEG.   RUDDER CL AT MAX.DEFL.=   .4826
0     VERTICAL TAIL AREA=   69.4408 FOR MINIMUM CONTROL SPEED =    114.40 KTS
0     REQUIRED VERTICAL TAIL AREA =    90.3807  TAIL ARM(ELTV) =   34.2879
**********************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.927   LIFT= 43238.7   L/D=  12.729   ALTITUDE= 35000.0   MACH=   .8000

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   79.25        H-TAIL VOL. ARM       =   41.75        C.G.LOCATION OF PROPULSION=  64.30
 WING 1/4C LOC.ON C.L.=   37.74        H-TAIL C.G.LOCATION   =   83.27        C.G.OF REMAINING WEIGHT   =  35.66
 MAC 1/4C LOCATION     =   41.12        H-TAIL MAC FROM C.L. =    4.38
 MAC DIST.FROM C.L.    =   11.71        H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   42.72        V-TAIL VOL. ARM       =   34.29
 TIP TANKS C.G.LOCATE =      .00        V-TAIL C.G.LOCATION   =   76.13        DIST.L.E.VERT.TO L.E.HORZ.=   1.04

 CANARD 1/4C LOC. ON C.L. =    6.55
 CANARD MAC DIST.FROM C.L.=    4.61
 CANARD VOLUME ARM        =   33.05
 CANARD C.G. LOCATION     =    8.36


0                         WING        CANARD        H-TAIL       V-TAIL

   AREA               419.080       71.913       94.414       90.381
   SPAN                60.869       20.781       19.391       10.160
   ASPECT RATIO         8.841        6.005        3.983        1.142
   TAPER RATIO           .183         .496         .550         .700
   1/4C. SWEEP         16.116       18.238       26.344       40.000
   L.E. SWEEP          20.156       21.090       29.600       42.500
   C.L. CHORD          11.640        4.628        6.283       10.466
   MEAN CHORD           7.980        3.592        5.006        8.988
   TIP CHORD            2.129        2.293        3.455        7.326
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
0                                     MISSION PERFORMANCE DATA FOLLOWS
                                     ********************************
0    TAXI AT IDLE THRUST

                     FUEL                          FUEL
   TIME    RANGE     USED    WEIGHT     ALT.       FLOW
  (HRS)    (NM)     (LBS)    (LBS)      (FT)     (LB/HR)

   .000       0.        0.   44576.    5000.       808.
   .167       0.      135.   44441.    5000.       808.
0VSTLKT= 112.2 KTS EAS    VRAT= 1.100 CLTO= 1.7514
      VEND =   246.7 KNOTS EAS
0              (TEMP.=  537.  DEG:STD.+36.)
0    TAKEOFF   (ELEVATION=  5000. FT)
                                                                                                                      FUEL    FUS.
                   FUEL                                                                                                
   TIME    DIST.   USED    WEIGHT     ALT.     TAS     EAS   MACH  ACCEL     CL      CD  ALPHA GAMMA      ROC  LOAD  THRUST    FLOW   ANGLE
  (SEC)   (FEET)  (LBS)    (LBS)      (FT)    (KTS)   (KTS)   NO. (FPS2)                (DEG) (DEG)    (FPM)  FACT   (LBS) (LB/HR)  (DEG)

     .0      .0   134.6   44441.   5000.0      .0      .0  .000  10.70 1.2994  .1329  2.00   .00       .0   .00  15682.   5585.    .00
    1.0     5.3   136.2   44440.   5000.0     6.3     5.7  .009  10.57 1.2994  .1329  2.00   .00       .0   .00  15499.   5585.    .00
    2.0    21.3   137.7   44438.   5000.0    12.5    11.3  .019  10.43 1.2995  .1329  2.00   .00       .0   .00  15319.   5585.    .00
    3.0    47.7   139.3   44437.   5000.0    18.7    16.8  .028  10.28 1.2995  .1330  2.00   .00       .0   .00  15142.   5586.    .00
    4.0    84.4   140.8   44435.   5000.0    24.7    22.2  .037  10.13 1.2996  .1330  2.00   .00       .0   .00  14968.   5587.    .00
    5.0   131.2   142.4   44434.   5000.0    30.7    27.6  .046   9.97 1.2996  .1330  2.00   .00       .0   .00  14797.   5589.    .00
    6.0   188.1   143.9   44432.   5000.0    36.6    32.8  .054   9.81 1.2997  .1330  2.00   .00       .0   .00  14630.   5591.    .00
    7.0   254.7   145.5   44431.   5000.0    42.4    38.0  .063   9.64 1.2999  .1330  2.00   .00       .0   .00  14465.   5592.    .00
    8.0   331.1   147.0   44429.   5000.0    48.0    43.1  .071   9.47 1.3000  .1330  2.00   .00       .0   .00  14302.   5594.    .00
    9.0   417.0   148.6   44427.   5000.0    53.6    48.1  .080   9.30 1.3001  .1330  2.00   .00       .0   .00  14143.   5596.    .00
   10.0   512.2   150.1   44426.   5000.0    59.1    53.0  .088   9.12 1.3003  .1330  2.00   .00       .0   .00  13986.   5598.    .00
   11.0   616.5   151.7   44424.   5000.0    64.5    57.8  .096   8.94 1.3005  .1331  2.00   .00       .0   .00  13833.   5601.    .00
   12.0   729.9   153.3   44423.   5000.0    69.7    62.5  .104   8.77 1.3006  .1331  2.00   .00       .0   .00  13698.   5603.    .00
   13.0   852.0   154.8   44421.   5000.0    74.9    67.2  .111   8.61 1.3008  .1331  2.00   .00       .0   .00  13584.   5606.    .00
   14.0   982.8   156.4   44420.   5000.0    80.0    71.7  .119   8.45 1.3010  .1331  2.00   .00       .0   .00  13472.   5609.    .00
   15.0  1122.0   157.9   44418.   5000.0    84.9    76.2  .126   8.28 1.3012  .1331  2.00   .00       .0   .00  13362.   5612.    .00
   16.0  1269.6   159.5   44416.   5000.0    89.8    80.6  .133   8.12 1.3015  .1332  2.00   .00       .0   .00  13255.   5615.    .00
   17.0  1425.3   161.0   44415.   5000.0    94.6    84.8  .140   7.95 1.3017  .1332  2.00   .00       .0   .00  13149.   5618.    .00
   18.0  1589.0   162.6   44413.   5000.0    99.3    89.0  .147   7.78 1.3019  .1332  2.00   .00       .0   .00  13046.   5621.    .00
   19.0  1760.5   164.2   44412.   5000.0   103.8    93.1  .154   7.61 1.3022  .1332  2.00   .00       .0   .00  12945.   5624.    .00
   20.0  1939.7   165.7   44410.   5000.0   108.3    97.2  .161   7.44 1.3024  .1333  2.00   .00       .0   .00  12847.   5628.    .00
   21.0  2126.3   167.3   44409.   5000.0   112.7   101.1  .167   7.27 1.3027  .1333  2.00   .00       .0   .00  12750.   5631.    .00
   22.0  2320.2   168.9   44407.   5000.0   117.0   104.9  .174   7.10 1.3029  .1333  2.00   .00       .0   .00  12656.   5635.    .00
   23.0  2521.3   170.4   44406.   5000.0   121.1   108.7  .180   6.93 1.3032  .1333  2.00   .00       .0   .00  12564.   5638.    .00
   24.0  2729.3   172.0   44404.   5000.0   125.2   112.3  .186   6.76 1.3035  .1334  2.00   .00       .0   .00  12474.   5642.    .00
   25.0  2944.2   173.6   44402.   5000.0   129.2   115.9  .192   6.59 1.3037  .1334  2.00   .00       .0   .00  12386.   5645.    .00
   26.0  3165.6   175.1   44401.   5000.0   133.0   119.4  .198   6.42 1.3040  .1334  2.00   .00       .0   .00  12300.   5649.    .00
   27.0  3393.5   176.7   44399.   5000.0   136.8   122.7  .203   6.26 1.3043  .1335  2.00   .00       .0   .00  12229.   5653.    .00
0
 ROTATION (TIME=    26.9 AND TAS=    136.3 EAS=    122.2)           5.89 1.4255  .1480  3.42   .00       .0   .85  12170.   5656.   1.42
   28.0  3627.7   178.3   44398.   5000.0   140.4   126.0  .208   5.42 1.5532  .1663  4.95   .00       .0   .97  12115.   5659.   2.95
   29.0  3867.8   179.8   44396.   5000.0   143.8   129.0  .213
 LIFTOFF (TIME=    29.0 DIST=    3867.8 TAS=    143.8 EAS=    129.0) 4.78 1.6527  .1816  6.16   .26     68.6  1.09  12066.   5663.   4.42
   30.0  4113.3   181.4   44395.   5000.3   146.9   131.7  .218   4.35 1.6096  .1749  5.56   .98    258.4  1.10  12021.   5665.   4.54
   31.0  4363.6   183.0   44393.   5003.0   149.6   134.2  .222   3.96 1.5611  .1677  4.96  1.68    450.9  1.10  11979.   5667.   4.64
   32.0  4618.3   184.6   44391.   5008.9   152.0   136.4  .226   3.60 1.5149  .1609  4.46  2.36    643.6  1.09  11941.   5668.   4.82
   33.0  4876.8   186.1   44390.   5018.1   154.3   138.4  .229   3.22 1.4770  .1555  4.06  3.04    840.4  1.09  11905.   5669.   5.10
   34.0  5138.9   187.7   44388.   5030.4   156.3   140.2  .232
 DISTANCE TO 35 FT.=  5221.6    TAS=    156.9 EAS=    140.7 V35/VS=   1.2535
                                                                    2.84 1.4493  .1516  3.76  3.71   1036.1  1.10  11873.   5669.   5.47
   35.0  5404.0   189.3   44387.   5046.1   158.1   141.8  .235
 GEAR RETRACTION STARTED AT    35.2 SEC,COMPLETE AT    42.2 SEC     2.53 1.4228  .1450  3.46  4.37   1232.3  1.10  11843.   5668.   5.83
   36.0  5671.8   190.9   44385.   5065.0   159.7   143.2  .237   2.27 1.3969  .1378  3.16  5.02   1428.9  1.10  11814.   5667.   6.18
   37.0  5941.9   192.4   44384.   5087.2   161.2   144.4  .239   2.01 1.3710  .1307  2.86  5.67   1626.7  1.09  11788.   5665.   6.53
   38.0  6214.1   194.0   44382.   5112.6   162.5   145.5  .241   1.74 1.3539  .1250  2.66  6.30   1820.6  1.10  11764.   5663.   6.96
   39.0  6488.0   195.6   44380.   5141.4   163.6   146.4  .243   1.48 1.3367  .1194  2.46  6.95   2017.3  1.09  11742.   5660.   7.41
   40.0  6763.2   197.2   44379.   5173.3   164.6   147.2  .244   1.21 1.3281  .1148  2.36  7.58   2211.6  1.10  11721.   5656.   7.94
   41.0  7039.6   198.7   44377.   5208.6   165.4   147.9  .246    .97 1.3109  .1092  2.16  8.21   2403.4  1.09  11703.   5652.   8.37
   42.0  7316.9   200.3   44376.   5247.0   166.0   148.4  .247    .65 1.3022  .1075  2.06  8.84   2592.5  1.09  11686.   5648.   8.90
   43.0  7594.6   201.9   44374.   5288.7   166.5   148.7  .247    .29 1.3023  .1075  2.06  9.45   2776.5  1.10  11672.   5642.   9.51
   44.0  7872.6   203.4   44373.   5333.4   166.8   148.9  .248    .01 1.2762  .1048  1.76 10.08   2960.0  1.08  11661.   5636.   9.84
   45.0  8150.3   205.0   44371.   5381.2   166.9   148.8  .248
 FLAP RETRACTION STARTED AT    45.4 SEC,COMPLETE AT    49.9 SEC      .00 1.1531  .1011  1.91 10.27   3014.2   .97  11651.   5630.  10.18
   46.0  8427.7   206.6   44369.   5431.3   166.9   148.7  .248    .00 1.0734  .1096  3.51  9.85   2894.0   .91  11640.   5624.  11.36
   47.0  8705.2   208.1   44368.   5480.7   166.9   148.6  .248
0VSTLKT= 112.2 KTS EAS    VRAT= 1.100 CLTO= 1.7514
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =   203.1 KNOTS EAS
0              (TEMP.=  537.  DEG:STD.+36.)
0    TAKEOFF   (ELEVATION=  5000. FT)                                                                                  FUEL    FUS.
                   FUEL                                                                                                FLOW   ANGLE
   TIME    DIST.   USED    WEIGHT     ALT.     TAS     EAS   MACH  ACCEL     CL      CD  ALPHA GAMMA      ROC  LOAD  THRUST (LB/HR)  (DEG)
  (SEC)   (FEET)  (LBS)    (LBS)      (FT)    (KTS)   (KTS)   NO. (FPS2)                (DEG) (DEG)    (FPM)  FACT   (LBS)

     .0      .0   134.6   44441.   5000.0      .0      .0  .000  10.70 1.2994  .1329  2.00   .00       .0   .00  15682.   5585.    .00
    1.0     5.3   136.2   44440.   5000.0     6.3     5.7  .009  10.57 1.2994  .1329  2.00   .00       .0   .00  15499.   5585.    .00
    2.0    21.3   137.7   44438.   5000.0    12.5    11.3  .019  10.43 1.2995  .1329  2.00   .00       .0   .00  15319.   5585.    .00
    3.0    47.7   139.3   44437.   5000.0    18.7    16.8  .028  10.28 1.2995  .1330  2.00   .00       .0   .00  15142.   5586.    .00
    4.0    84.4   140.8   44435.   5000.0    24.7    22.2  .037  10.13 1.2996  .1330  2.00   .00       .0   .00  14968.   5587.    .00
    5.0   131.2   142.4   44434.   5000.0    30.7    27.6  .046   9.97 1.2996  .1330  2.00   .00       .0   .00  14797.   5589.    .00
    6.0   188.1   143.9   44432.   5000.0    36.6    32.8  .054   9.81 1.2997  .1330  2.00   .00       .0   .00  14630.   5591.    .00
    7.0   254.7   145.5   44431.   5000.0    42.4    38.0  .063   9.64 1.2999  .1330  2.00   .00       .0   .00  14465.   5592.    .00
    8.0   331.1   147.0   44429.   5000.0    48.0    43.1  .071   9.47 1.3000  .1330  2.00   .00       .0   .00  14302.   5594.    .00
    9.0   417.0   148.6   44427.   5000.0    53.6    48.1  .080   9.30 1.3001  .1330  2.00   .00       .0   .00  14143.   5596.    .00
   10.0   512.2   150.1   44426.   5000.0    59.1    53.0  .088   9.12 1.3003  .1330  2.00   .00       .0   .00  13986.   5598.    .00
   11.0   616.5   151.7   44424.   5000.0    64.5    57.8  .096   8.94 1.3005  .1331  2.00   .00       .0   .00  13833.   5601.    .00
   12.0   729.9   153.3   44423.   5000.0    69.7    62.5  .104   8.77 1.3006  .1331  2.00   .00       .0   .00  13698.   5603.    .00
   13.0   852.0   154.8   44421.   5000.0    74.9    67.2  .111   8.61 1.3008  .1331  2.00   .00       .0   .00  13584.   5606.    .00
   14.0   982.8   156.4   44420.   5000.0    80.0    71.7  .119   8.45 1.3010  .1331  2.00   .00       .0   .00  13472.   5609.    .00
   15.0  1122.0   157.9   44418.   5000.0    84.9    76.2  .126   8.28 1.3012  .1331  2.00   .00       .0   .00  13362.   5612.    .00
   16.0  1269.6   159.5   44416.   5000.0    89.8    80.6  .133   8.12 1.3015  .1332  2.00   .00       .0   .00  13255.   5615.    .00
   17.0  1425.3   161.0   44415.   5000.0    94.6    84.8  .140   7.95 1.3017  .1332  2.00   .00       .0   .00  13149.   5618.    .00
   18.0  1589.0   162.6   44413.   5000.0    99.3    89.0  .147   7.78 1.3019  .1332  2.00   .00       .0   .00  13046.   5621.    .00
   19.0  1760.5   164.2   44412.   5000.0   103.8    93.1  .154   7.61 1.3022  .1332  2.00   .00       .0   .00  12945.   5624.    .00
   20.0  1939.7   165.7   44410.   5000.0   108.3    97.2  .161   7.44 1.3024  .1333  2.00   .00       .0   .00  12847.   5628.    .00
   21.0  2126.3   167.3   44409.   5000.0   112.7   101.1  .167   7.27 1.3027  .1333  2.00   .00       .0   .00  12750.   5631.    .00
   22.0  2320.2   168.9   44407.   5000.0   117.0   104.9  .174   7.10 1.3029  .1333  2.00   .00       .0   .00  12656.   5635.    .00
   23.0  2521.3   170.4   44406.   5000.0   121.1   108.7  .180   6.93 1.3032  .1333  2.00   .00       .0   .00  12564.   5638.    .00
   24.0  2729.3   172.0   44404.   5000.0   125.2   112.3  .186   6.76 1.3035  .1334  2.00   .00       .0   .00  12474.   5642.    .00
   25.0  2944.2   173.6   44402.   5000.0   129.2   115.9  .192   6.59 1.3037  .1334  2.00   .00       .0   .00  12386.   5645.    .00
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

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 ENGINE FAILURE (TIME=   25.4 AND TAS=   130.7 EAS=   117.2)
   26.0  3165.1   174.7  44401.  5000.0  131.7  118.1  .196    1.89 1.3039  .1407  2.00    .00       .0   .00   6165.   2824.   .00
   27.0  3388.4   175.4  44401.  5000.0  132.8  119.1  .197    1.86 1.3040  .1405  2.00    .00       .0   .00   6153.   2824.   .00
   28.0  3613.6   176.2  44400.  5000.0  133.9  120.1  .199    1.82 1.3041  .1404  2.00    .00       .0   .00   6141.   2825.   .00
   29.0  3840.7   177.0  44399.  5000.0  135.0  121.1  .200    1.78 1.3042  .1402  2.00    .00       .0   .00   6130.   2825.   .00
   30.0  4069.5   177.8  44398.  5000.0  136.0  122.0  .202    1.74 1.3043  .1401  2.00    .00       .0   .00   6121.   2826.   .00
0
 ROTATION (TIME=   30.2 AND TAS=   136.3 EAS=   122.2)
   31.0  4300.1   178.6  44397.  5000.0  137.0  122.9  .203    1.59 1.3756  .1478  2.83    .00       .0   .78   6113.   2826.   .83
   32.0  4532.2   179.4  44397.  5000.0  137.9  123.7  .205    1.28 1.5033  .1653  4.35    .00       .0   .87   6106.   2827.  2.35
   33.0  4765.7   180.2  44396.  5000.0  138.5  124.3  .206     .94 1.6311  .1844  5.91    .00       .0   .95   6100.   2827.  3.91
 LIFTOFF (TIME=   33.4 DIST=   4859.4 TAS=   138.7 EAS=   124.5)
   34.0  5000.1   180.9  44395.  5000.0  139.0  124.7  .206     .56 1.7473  .2032  7.37    .06     14.2  1.03   6097.   2827.  5.43
   35.0  5235.1   181.7  44394.  5000.8  139.3  124.9  .207     .37 1.7514  .2039  7.38    .33     82.0  1.04   6094.   2827.  5.71
   36.0  5470.4   182.5  44394.  5002.8  139.4  125.1  .207     .19 1.7514  .2040  7.29    .64    156.6  1.04   6093.   2827.  5.92
   37.0  5706.0   183.3  44393.  5006.1  139.5  125.1  .207     .01 1.7514  .2041  7.22    .95    234.6  1.04   6092.   2827.  6.17
   38.0  5941.5   184.1  44392.  5010.5  139.5  125.1  .207     .02 1.7090  .1971  6.71   1.17    287.6  1.01   6092.   2827.  5.87
   39.0  6177.1   184.9  44391.  5015.5  139.5  125.1  .207     .00 1.6990  .1955  6.61   1.25    308.7  1.01   6091.   2827.  5.86
   40.0  6412.6   185.7  44390.  5020.7  139.5  125.1  .207     .02 1.6885  .1938  6.51   1.28    317.0  1.00   6090.   2826.  5.79
   41.0  6648.2   186.4  44390.  5026.0  139.5  125.1  .207     .01 1.6868  .1936  6.51   1.30    320.2  1.00   6090.   2826.  5.80
   42.0  6883.8   187.2  44389.  5031.4  139.5  125.1  .207     .01 1.6856  .1934  6.51   1.30    321.8  1.00   6089.   2826.  5.81
 DISTANCE TO 35 FT.=  7043.1   TAS=   139.5 EAS=   125.1 V35/VS=  1.1147
   43.0  7119.4   188.0  44388.  5036.7  139.5  125.1  .207     .01 1.6847  .1933  6.51   1.31    322.1  1.00   6088.   2825.  5.81
   44.0  7355.0   188.8  44387.  5042.1  139.6  125.1  .207     .02 1.6841  .1932  6.51   1.30    321.5  1.00   6088.   2825.  5.81
   45.0  7590.7   189.6  44386.  5047.5  139.6  125.1  .207     .02 1.6836  .1931  6.51   1.30    320.4  1.00   6087.   2825.  5.81


      ACCELERATE - STOP DISTANCE =     6584.9 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     7043.1 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =      5221.6 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6004.9 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     5463.2 FEET
0   AT END OF TAKEOFF PHASE
 TIME=    .180 HRS   FUEL USED=     209. LBS   WEIGHT=   44367. LBS   ALT.=    5500. FT.


    ACCELERATE TO MACH NO. = .412

0                                                                                 FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    THRUST    FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV     (LBS)   (LB/HR)

   .180     .00    208.8  44367.   5500.    161.    149.  .248  .726  11905.    5541.
   .189    2.00    259.9  44316.   5500.    268.    247.  .412  .809  10154.    5696.

  END OF ACCELERATION SEGMENT
  TIME=  .189 HRS   FUEL USED=   259.9 LBS   WEIGHT=  44316. LBS   RANGE=    2. NM
0   CLIMB TO   35000. FT. AT MAXIMUM RATE OF CLIMB
0                  FUEL                                                                      FUS.                           FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    CL      CD    ALPHA GAMMA ANGLE    R/C    THRUST    FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV                   (DEG) (DEG) (DEG)   (FPM)    (LBS)  (LB/HR)

   .189      2.     260.  44316.   5500.    245.    226.  .378  .801  .5156  .0376  4.15  7.59  9.74    3285.    9057.   5008.
   .191      3.     273.  44303.   6000.    246.    225.  .380  .801  .5195  .0378  4.19  7.17  9.36    3119.    8977.   4960.
   .196      4.     299.  44277.   7000.    249.    225.  .386  .800  .5233  .0380  4.22  6.83  9.05    3004.    8794.   4861.
   .202      5.     326.  44250.   8000.    251.    223.  .390  .799  .5309  .0384  4.29  6.77  9.06    3002.    8623.   4761.
   .208      7.     353.  44223.   9000.    261.    228.  .407  .802  .5094  .0372  4.02  5.46  7.48    2515.    8350.   4662.
   .214      8.     383.  44193.  10000.    263.    227.  .412  .801  .5143  .0375  4.07  6.10  8.17    2836.    8182.   4559.
   .220     10.     410.  44166.  11000.    266.    225.  .418  .801  .5199  .0378  4.12  6.27  8.38    2942.    8015.   4457.
   .226     11.     435.  44140.  12000.    269.    224.  .424  .800  .5264  .0382  4.18  5.71  7.88    2707.    7849.   4359.
   .232     13.     462.  44114.  13000.    271.    223.  .429  .799  .5327  .0385  4.23  5.51  7.75    2641.    7684.   4262.
   .238     15.     489.  44087.  14000.    274.    221.  .435  .798  .5391  .0389  4.29  5.32  7.61    2574.    7520.   4168.
   .245     17.     516.  44060.  15000.    277.    220.  .442  .798  .5453  .0392  4.34  5.11  7.46    2500.    7356.   4076.
   .251     18.     543.  44033.  16000.    283.    221.  .453  .798  .5401  .0389  4.26  4.52  6.79    2260.    7150.   3981.
   .259     20.     573.  44003.  17000.    286.    219.  .459  .797  .5469  .0393  4.32  4.65  6.98    2348.    6973.   3880.
   .266     23.     600.  43976.  18000.    288.    218.  .465  .797  .5540  .0397  4.38  4.45  6.83    2266.    6799.   3782.
   .273     25.     628.  43948.  19000.    291.    217.  .472  .796  .5613  .0401  4.45  4.24  6.69    2184.    6627.   3685.
   .281     27.     656.  43920.  20000.    294.    215.  .479  .795  .5686  .0405  4.51  4.04  6.55    2102.    6459.   3590.
   .289     29.     685.  43891.  21000.    297.    214.  .485  .794  .5759  .0410  4.57  3.84  6.41    2018.    6292.   3498.
   .297     32.     714.  43862.  22000.    300.    212.  .493  .793  .5835  .0414  4.63  3.65  6.28    1938.    6129.   3407.
   .306     34.     743.  43833.  23000.    304.    211.  .500  .792  .5902  .0418  4.68  3.44  6.12    1846.    5967.   3318.
   .315     37.     773.  43803.  24000.    311.    212.  .514  .793  .5829  .0414  4.56  2.92  5.48    1603.    5778.   3241.
   .325     40.     807.  43769.  25000.    314.    211.  .521  .792  .5915  .0419  4.63  3.04  5.67    1686.    5610.   3161.
   .335     43.     838.  43738.  26000.    319.    210.  .531  .791  .5953  .0421  4.64  2.73  5.37    1537.    5438.   3084.
   .346     47.     871.  43705.  27000.    323.    209.  .540  .791  .6008  .0425  4.67  2.56  5.23    1464.    5272.   3008.
   .357     50.     905.  43671.  28000.    327.    208.  .549  .790  .6073  .0429  4.71  2.39  5.10    1379.    5111.   2932.
   .369     54.     941.  43635.  29000.    332.    207.  .560  .790  .6107  .0431  4.71  2.15  4.85    1259.    4950.   2859.
   .382     59.     979.  43597.  30000.    335.    205.  .568  .788  .6206  .0438  4.78  2.07  4.85    1226.    4800.   2785.
   .396     63.    1017.  43559.  31000.    359.    216.  .612  .796  .5588  .0400  4.00  1.07  3.06     678.    4559.   2726.
   .421     72.    1084.  43492.  32000.    362.    214.  .619  .795  .5704  .0407  4.09  1.58  3.67    1015.    4404.   2632.
   .437     78.    1127.  43449.  33000.    365.    212.  .627  .793  .5825  .0414  4.18  1.41  3.59     911.    4252.   2541.
   .455     85.    1173.  43403.  34000.    369.    210.  .637  .792  .5896  .0418  4.20  1.18  3.39     772.    4103.   2455.
   .477     93.    1226.  43350.  35000.    376.    210.  .651  .792  .5913  .0419  4.17   .97  3.13     643.    3957.   2374.
0   END OF CLIMB TO   35000. FT
 TIME=   .477 HRS   FUEL USED=    1226. LBS   WEIGHT=   43350. LBS   RANGE=     93. NM

0ALTITUDE=     35000. FT   TAS=     457.18 KTS   MACH NO=      .7922


    ACCELERATE TO MACH NO. = .800

0                 FUEL                                                           FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH    THRUST    FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV     (LBS)   (LB/HR)

   .477   92.75  1226.4  43350.  35000.    376.    210.  .651  .791   4226.    2700.
   .530  116.02  1378.3  43198.  35000.    461.    258.  .800  .816   4319.    2822.

  END OF ACCELERATION SEGMENT
  TIME=  .530 HRS   FUEL USED=  1378.3 LBS   WEIGHT=  43198. LBS   RANGE=  116. NM
 ***SPECIFIED MACH NUMBER CONDITION CAN NOT BE PERFORMED AT NORMAL RATED POWER CONDITION***
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
     ACCELERATE TO MACH NO. = .792

 0                      FUEL                                                         FUEL
    TIME    RANGE      USED     WEIGHT    ALT.     TAS    EAS      MACH  MACH   THRUST    FLOW
    (HRS)   (NM)      (LBS)     (LBS)     (FT)   (KTS)  (KTS)      NO.   DIV    (LBS)   (LB/HR)

     .477    92.75   1226.4   43350.   35000.    376.    210.   .651  .791    4226.    2700.
     .527   114.68   1370.2   43206.   35000.    457.    255.   .792  .815    4313.    2816.

    END OF ACCELERATION SEGMENT
    TIME=  .527 HRS   FUEL USED=  1370.2 LBS   WEIGHT=  43206. LBS   RANGE=  115. NM

     ACCELERATE TO MACH NO. = .810

 0                      FUEL                                                         FUEL
    TIME    RANGE      USED     WEIGHT    ALT.     TAS    EAS      MACH  MACH   THRUST    FLOW
    (HRS)   (NM)      (LBS)     (LBS)     (FT)   (KTS)  (KTS)      NO.   DIV    (LBS)   (LB/HR)

     .477    92.75   1226.4   43350.   35000.    376.    210.   .651  .791    4226.    2700.
     .533   117.66   1388.3   43188.   35000.    467.    261.   .810  .817    4326.    2829.

    END OF ACCELERATION SEGMENT
    TIME=  .533 HRS   FUEL USED=  1388.3 LBS   WEIGHT=  43188. LBS   RANGE=  118. NM


 0                                             DESIGN CASE
                                               CRUISE PERFORMANCE SUMMARY
                                                        FOR
                                               ***** DESIGN PAYLOAD *****
                                               **** MAXIMUM PAYLOAD *****
                                               ****** MAXIMUM FUEL ******
                                               FUEL AVAILABLE=   8340.
 0                                AT                      AT                      AT
                           SPECIFIED SPEED         NORMAL POWER          BEST SPEC. RANGE
                            START    END           START    END           START    END
                            CRUISE   CRUISE        CRUISE   CRUISE        CRUISE   CRUISE
                            -------  -------       -------  -------       -------  -------
    TIME          HRS.        .000     .000           .527    2.646          .533    2.850
    RANGE         N.MI         0.       0.            115.    1084.          118.    1200.
    FUEL USED     LBS.         0.       0.           1370.    5996.         1388.    6609.
    WEIGHT        LBS.         0.       0.          43206.   38580.        43188.   37967.
    ALTITUDE      FT.          0.       0.          35000.   35000.        35000.   35000.
    TAS           KTS.         .0       .0           457.2    457.2         467.2    467.2
    EAS           KTS.         .0       .0           254.8    254.8         260.4    260.4
    MACH NO.                 .0000    .0000          .7922    .7922         .8095    .8095
    DIV. MACH                .0000    .0000          .8154    .8220         .8175    .8232
    ANGLE ATTACK DEG.         .000     .000          1.832    1.369         1.616    1.228
    FUSE. ANGLE  DEG.         .000     .000          -.168    -.631         -.384    -.772
    CL                       .0000    .0000          .4012    .3470         .3840    .3376
    L/D                       .000     .000         12.495   11.538        12.261   11.390
    FUEL FLOW     LB/HR        .0       .0          2242.3   2126.9        2308.5   2202.5
    BREG. FACTOR N.MI.         0.       0.           8815.    8298.         8746.    8059.
    SPEC. RANGE   NM/LB    .00000   .00000          .20389   .21495        .20238   .21212


 0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
          (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
 0                     FUEL                                                                           FUS.                            FUEL
   TIME    RANGE      USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    CL       CD   ALPHA GAMMA ANGLE     R/S    THRUST     FLOW
   (HRS)   (NM)      (LBS)    (LBS)      (FT)   (KTS)  (KTS)     NO.   DIV                   (DEG) (DEG) (DEG)   (FPM)    (LBS)   (LB/HR)

   2.659   1089.    6015.   38561.   35000.    457.    255.   .792  .821  .3546  .0302  1.43 -1.66 -2.22   1339.    2174.    1514.  R
   2.671   1095.    6035.   38541.   34000.    459.    261.   .792  .823  .3381  .0297  1.29 -1.61 -2.31   1306.    2299.    1604.  R
   2.685   1101.    6057.   38519.   33000.    461.    268.   .792  .825  .3226  .0291  1.16 -1.56 -2.40   1271.    2432.    1698.  R
   2.698   1107.    6082.   38494.   32000.    463.    274.   .792  .827  .3078  .0287  1.03 -1.51 -2.48   1241.    2568.    1797.  R
   2.712   1114.    6108.   38468.   31000.    465.    280.   .792  .829  .2939  .0282   .91 -1.47 -2.55   1209.    2711.    1900.  R
   2.726   1120.    6136.   38440.   30000.    467.    287.   .792  .830  .2807  .0279   .80 -1.43 -2.63   1180.    2858.    2007.  R
   2.740   1127.    6167.   38409.   29000.    469.    293.   .792  .832  .2681  .0275   .69 -1.39 -2.69   1153.    3010.    2118.  R
   2.755   1134.    6200.   38376.   28000.    471.    300.   .792  .833  .2562  .0272   .59 -1.35 -2.76   1127.    3167.    2233.  R
   2.770   1141.    6235.   38341.   27000.    473.    306.   .792  .835  .2449  .0269   .50 -1.31 -2.82   1100.    3332.    2355.  R
   2.786   1149.    6274.   38302.   26000.    475.    313.   .792  .836  .2342  .0266   .40 -1.28 -2.88   1077.    3516.    2487.  R
   2.802   1156.    6315.   38261.   25000.    477.    320.   .792  .837  .2240  .0264   .32 -1.25 -2.93   1053.    3691.    2618.  R
   2.818   1164.    6360.   38216.   24000.    479.    327.   .792  .838  .2143  .0262   .23 -1.22 -2.98   1032.    3871.    2753.  R
   2.834   1172.    6407.   38168.   23000.    481.    334.   .792  .840  .2051  .0260   .15 -1.19 -3.03   1011.    4058.    2894.  R
   2.851   1180.    6459.   38117.   22000.    483.    341.   .792  .841  .1963  .0258   .08 -1.16 -3.08    992.    4250.    3040.  R
   2.868   1188.    6512.   38064.   21000.    482.    346.   .786  .841  .1908  .0257   .04 -1.14 -3.10    972.    4374.    3142.  R
   2.873   1190.    6516.   38060.   20000.    414.    302.   .673  .834  .2487  .0270   .79 -4.79 -6.00   3500.     941.     677.  A
   2.878   1192.    6519.   38057.   19000.    409.    304.   .663  .834  .2460  .0269   .78 -4.78 -6.00   3455.     981.     709.  A
   2.883   1194.    6523.   38053.   18000.    404.    306.   .653  .835  .2433  .0269   .77 -4.77 -6.00   3410.    1023.     742.  A
   2.888   1196.    6527.   38049.   17000.    400.    307.   .643  .835  .2406  .0268   .76 -4.76 -6.00   3366.    1065.     776.  A
   2.893   1198.    6531.   38045.   16000.    396.    309.   .634  .835  .2379  .0267   .75 -4.75 -6.00   3322.    1110.     811.  A
   2.898   1200.    6535.   38041.   15000.    392.    311.   .624  .836  .2352  .0267   .74 -4.74 -6.00   3278.    1155.     848.  A
   2.903   1202.    6540.   38036.   14000.    387.    313.   .616  .836  .2326  .0266   .72 -4.72 -6.00   3235.    1203.     886.  A
   2.908   1204.    6544.   38032.   13000.    383.    314.   .607  .836  .2299  .0265   .71 -4.71 -6.00   3192.    1251.     925.  A
   2.913   1206.    6549.   38026.   12000.    380.    316.   .598  .837  .2272  .0265   .69 -4.69 -6.00   3150.    1302.     966.  A
   2.919   1208.    6555.   38021.   11000.    376.    318.   .590  .837  .2246  .0264   .68 -4.68 -6.00   3108.    1354.    1009.  A
   2.929   1211.    6563.   38013.   10000.    291.    250.   .455  .820  .3640  .0306  2.35 -3.18 -2.84   1637.    1073.     771.  S
   2.939   1214.    6571.   38005.    9000.    286.    250.   .446  .820  .3640  .0306  2.36 -3.13 -2.77   1584.    1109.     800.  S
   2.950   1217.    6580.   37996.    8000.    282.    250.   .438  .820  .3639  .0306  2.37 -3.07 -2.70   1532.    1146.     830.  S
   2.962   1220.    6590.   37986.    7000.    277.    250.   .430  .820  .3638  .0306  2.38 -3.01 -2.63   1480.    1185.     860.  S
   2.973   1224.    6600.   37976.    6000.    273.    250.   .422  .820  .3637  .0306  2.39 -2.95 -2.56   1428.    1225.     892.  S
   2.985   1227.    6611.   37964.    5000.    269.    250.   .414  .820  .3636  .0306  2.40 -2.89 -2.49   1377.    1266.     924.  S
   2.998   1230.    6624.   37952.    4000.    265.    250.   .406  .820  .3635  .0306  2.41 -2.83 -2.41   1327.    1309.     958.  S
   3.011   1234.    6636.   37939.    3000.    261.    250.   .399  .820  .3634  .0305  2.42 -2.76 -2.34   1277.    1353.     993.  S
   3.025   1237.    6650.   37926.    2000.    257.    250.   .391  .820  .3633  .0305  2.43 -2.69 -2.26   1227.    1398.    1030.  S
   3.031   1239.    6658.   37918.    1500.    255.    250.   .388  .820  .3631  .0305  2.43 -2.66 -2.23   1202.    1421.    1048.  S
 0  END OF DSCNT TO      1500. FT
  TIME=  3.031 HRS   FUEL USED=      6658. LBS   WEIGHT=    37918. LBS   RANGE=    1239. NM

 0       RESERVE FUEL(LBS)         0.                  1682.                  1731.
          (   45.0 MIN.)

    ******************************************************************************
 0       RANGE = 1239.    BLOCK TIME= 3.031    USED FOR DESIGN RANGE AND COST

    ******************************************************************************
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
0   *******************************************************************************************
0               TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  85.34 PSF.
     LANDING WEIGHT =    41901. LBS.

     LANDING DISTANCE FROM 50. FT.=   2947. FT.

     F.A.R. FACTORED FIELD LENGTH =   4912. FT.
0                        APPROACH           TRANSITION              DELAY              ROLL
0                   DIST=        697.    DIST=          203.    DIST=          206.    DIST=        1841.
                    R/S=        1000.    XLFMX=        1.200    TDELAY=        1.00    MUB=         .4000
                    VAPEAS=    123.60    SINKTD=       3.000    TIDLE=         579.    TR/TIDLE=    .0000
                    VAPTAS=    137.92    VSTEAS=       95.08    VTDTAS=      122.00    ABAR(G)=     .3587
                    THETA=       4.10    CLMX=        2.7832
                    THRUST=     3016.    HFLAR=         20.9
0   *******************************************************************************************
**************************************************************************************************
0                RANGE OR ENDURANCE ITERATION SUMMARY

                           GROSS      RANGE(NMI) OR
                 ITERATION  WEIGHT(LB)   ENDURANCE(HR)

                     0        44050.00       1178.872
                     1        44575.99       1238.908
                     REQUIRED RG. OR END. = 1250.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   1.927   LIFT= 43238.7   L/D=  12.729   ALTITUDE= 35000.0   MACH=   .8000

0  GROSS WEIGHT =   44576.       PASSENGERS =  50. PLUS CREW

0  FUSELAGE       LENGTH              (ELF)            79.25   FT
                  WIDTH               (SWF)             9.25   FT
                  WETTED AREA         (SF)             1910.   SQFT
                  DELTA P             (DELP)            8.20   PSI

0  WING           ASPECT RATIO        (AR)              8.84
                  AREA                (SW)             419.1   SQFT
                  SPAN                (B)               60.9   FT
                  GEOM. MEAN CHORD    (CBARW)           7.98   FT
                  QUARTER CHORD SWEEP(DLMC4)            16.1   DEG
                  TAPER RATIO         (SLM)             .183
                  ROOT THICKNESS      (TCR)             .130
                  TIP THICKNESS       (TCT)             .100
                  WING LOADING        (WGS)             90.8   PSF
                  WING FUEL VOLUME    (VFW)            974.7   GAL

0  CANARD         ASPECT RATIO        (ARcan)           6.01
                  AREA                (SWc)             71.9   SQFT
                  SPAN                (Bcan)            20.8   FT
                  GEOM. MEAN CHORD    (CBARc)           3.59   FT
                  QUARTER CHORD SWEEP(DwpqCa)           18.2   DEG
                  TAPER RATIO         (SLMcan)          .496
                  THICKNESS/CHORD     (TCcan)           .100
                  MOMENT ARM          (ELcan)           33.1   FT
                  VOLUME COEFF.       (VBARc)           .711
                  CANARD LOADING      (WGS)             90.8   PSF

0  HOR. TAIL      ASPECT RATIO        (ARHT)            3.98
                  AREA                (SHT)             94.4   SQFT
                  SPAN                (BHT)            19.39   FT
                  MEAN CHORD          (CBARHT)          5.01   FT
                  THICKNESS/CHORD     (TCHT)            .100
                  MOMENT ARM          (ELTH)            41.8   FT
                  VOLUME COEFF.       (VBARH)          1.179

0  VERT. TAIL     ASPECT RATIO        (ARVT)            1.14
                  AREA                (SVT)             90.4   SQFT
                  SPAN                (BVT)            10.16   FT
                  MEAN CHORD          (CBARVT)          8.99   FT
                  THICKNESS/CHORD     (TCVT)            .120
                  MOMENT ARM          (ELTV)            34.3   FT
                  VOLUME COEFF.       (VBARV)           .121

0  ENG.NACELLES   LENGTH              (ELN)            11.30   FT
                  MEAN DIAMETER       (DBARN)           3.77   FT
                  NUMBER ENGINES      (ENP)              2.0
                  WETTED AREA         (SN)            267.08   SQFT

                  LOCATION                           ON FUSELAGE

0  VDIVE =  715. KTS   VMO =  596. KTS   MMO =  .900
   ULT. LF =  5.33   MAN. LF =  2.50   GUST LF =  3.55

0  PROPULSION GROUP
      PRIMARY ENGINES           (WEP)        2829.
      PRIMARY ENGINE INSTL.     (WPEI)        382.
      FUEL SYSTEM               (WFSS)        167.
      TOTAL PROP.GROUP WT.      (WP)         3378.
0  STRUCTURES GROUP
      WING                      (WW)         4415.
      CANARD                    (WWc)         424.
      HOR. TAIL                 (WHT)         468.
      VERT. TAIL                (WVT)         398.
      FUSELAGE                  (WB)         5991.   (INCL.     .0 LBS A.T.W.)
      LANDING GEAR              (WLG)        1694.
      PRIMARY ENG. SECTION      (WPES)        948.
      GROUP WEIGHT INC.         (DELWST)        0.
      TOTAL STRUC.GROUP WT.     (WST)       14338.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS          (WCC)          95.
      FIXED WING CONTROLS       (WCFW)        809.
      SAS                       (WSAS)          0.
      GROUP WEIGHT INC.         (DELWFC)        0.
      TOTAL CONTROL WT.         (WFC)         904.
0  WT. OF FIXED EQUIPMENT       (WFE)        6550.
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
   WEIGHT EMPTY              (WE)      25170.

   FIXED USEFUL LOAD         (WFUL)     1066. (INC. CREW )

   OPERATING WEIGHT EMPTY    (OWE)     26236.
0  PAYLOAD                   (WPL)     10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

   FUEL                      (WFA)      8340. (WFW= 6518.) (WFTP=    0.)

   GROSS WEIGHT              (WG)      44576.
0        FIXED EQUIP GROUP                  FIXED USEFUL LOAD
0    WAPU              372.27      WCREW ( 2.)          340.00
     WINSTR            232.85      WSTU  ( 1.)          130.00
     WHYD              361.40      WCBAG                110.00
     WELEC             970.00      WUF                  122.83
     WAV               500.00      WOIL                 119.49
     WFUR             3410.00      WSRV                 116.00
     WAC               477.91      WH2O                  53.00
     WAI               205.11      WEMER                 40.00
     WAUXG              20.00      WCATER                35.00

     WFE              6549.54      WFUL                1066.32


0  DESIGN MACH =  .800          DESIGN ALTITUDE =  35000.          DESIGN Q (PSF) =224.03
0  DESIGN RE.NUM. PER FT.    = 1.922E+06    FLATPLATE CF AT RE=10EX7 IS  .00274

0  AERODYNAMIC DATA

0                         FLATPLATE              WETTED
   DRAG BREAKDOWN         AREA(SQFT)     CDO     AREA(SQFT)
0       WING                2.8007     .00570      636.18
        CANARD               .5226     .00106       67.83
        FUSELAGE            5.4592     .01112     1910.38
        VERT.TAIL            .5744     .00117      180.76
        HOR. TAIL            .6310     .00129      188.83
        ENGINE NAC.         1.1474     .00234      267.08
        TIP TANKS            .0000     .00000         .00
        INCREMENTAL          .7365     .00150         .00
0           TOTAL          11.8719     .02418     3251.06

            MEAN SKIN FRICTION COEF.=  .003652


0  AERODYNAMIC COEFF.                            AIRCRAFT           WING                           CANARD
                                        (except Wing and Canard)
      A1                                                             .8048                          .8384
      A2                                                           -.1232                          -.1236
      A3                                                             .0375                          .0273
      A4=.75X(T/C)                                                   .0907                          .0750
      A5=CDO--                                           .0149
      A6                                                           2.4391                          2.6524
      A7=1/(PI.SEE.AR)                                               .0457                          .0632
      3-D LIFT SLOPE AT CRUISE MACH     (CLALPH)                   6.7596 PER RAD.     (CLALFc)   5.7419 PER RAD.
      OSWALD FACTOR                     (SEE)                        .7875             (SEEcan)    .8390


0  CRUISE CD =  .0240 +   .0483 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
0  RETRACTABLE LANDING GEAR CD INC.= .02999


0 CRUISE DRAG
0CL=   .2000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .02592  7.7147  5.3851   .5279
         .55000  .02592  7.7147  5.5192   .4762
         .60000  .02592  7.7147  5.6792   .4177
         .65000  .02592  7.7147  5.8716   .3516
         .70000  .02592  7.7147  6.1055   .2769
         .75000  .02592  7.7147  6.3944   .1921
         .80000  .02592  7.7147  6.7596   .0952
         .85000  .02595  7.7073  7.2371  -.0166
0CL=   .3000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .02848 10.5348  5.3851  1.5919
         .55000  .02848 10.5348  5.5192  1.5144
         .60000  .02848 10.5348  5.6792  1.4266
         .65000  .02848 10.5348  5.8716  1.3274
         .70000  .02848 10.5348  6.1055  1.2153
         .75000  .02848 10.5348  6.3944  1.0881
         .80000  .02848 10.5348  6.7596   .9428
         .85000  .02876 10.4305  7.2371   .7751
0CL=   .4000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .03200 12.5019  5.3851  2.6558
         .55000  .03200 12.5019  5.5192  2.5525
         .60000  .03200 12.5019  5.6792  2.4355
         .65000  .03200 12.5019  5.8716  2.3032
         .70000  .03200 12.5019  6.1055  2.1537
         .75000  .03200 12.5019  6.3944  1.9841
         .80000  .03200 12.5019  6.7596  1.7905
         .85000  .03307 12.0966  7.2371  1.5668
0CL=   .5000
           MACH      CD    L/D   CLALPH   ALPHA
         .50000  .03665 13.6421  5.3851  3.7198
         .55000  .03665 13.6421  5.5192  3.5906
         .60000  .03665 13.6421  5.6792  3.4443
         .65000  .03665 13.6421  5.8716  3.2790
         .70000  .03665 13.6421  6.1055  3.0922
         .75000  .03665 13.6421  6.3944  2.8802
         .80000  .03665 13.6421  6.7596  2.6381
         .85000  .03933 12.7125  7.2371  2.3585
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
0CL=    .6000
             MACH      CD     L/D   CLALPH   ALPHA
            .50000   .04227 14.1935  5.3851  4.7838
            .55000   .04227 14.1935  5.5192  4.6287
            .60000   .04227 14.1935  5.6792  4.4532
            .65000   .04227 14.1935  5.8716  4.2548
            .70000   .04227 14.1935  6.1055  4.0306
            .75000   .04227 14.1935  6.3944  3.7762
            .80000   .04229 14.1868  6.7596  3.4857
            .85000   .04768 12.5851  7.2371  3.1502

0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                                FLAPS UP                                 TAKEOFF                                  LANDING
         ALPHA        CL         CD         L/D         CL         CD        L/D          CL         CD        L/D
      -2.00000   -.03425     .02412 -1.41986     .95011     .07801 12.17970   1.62688     .21281   7.64476
        .00000    .13699     .02488  5.50656    1.12135     .09032 12.41566   1.79812     .22868   7.86316
       2.00000    .30823     .02873 10.72856    1.29259     .10648 12.13919   1.96936     .24896   7.91030
       4.00000    .47948     .03562 13.46205    1.46383     .12769 11.46379   2.14060     .27572   7.76370
       6.00000    .65072     .04567 14.24829    1.63507     .15326 10.66895   2.31184     .30579   7.56027
       8.00000    .82196     .05913 13.89993    1.80632     .18171  9.94076   2.48308     .33917   7.32108
      10.00000    .99320     .07652 12.98036    1.97756     .21305  9.28214   2.65433     .37586   7.06199
      11.50561   1.12430     .09411 11.94631    2.10865     .23900  8.82296   2.78324     .40567   6.86088
      11.50561   1.12430     .09411 11.94631    2.10865     .23900  8.82296   2.78324     .40567   6.86088
      11.50561   1.12430     .09411 11.94631    2.10865     .23900  8.82296   2.78324     .40567   6.86088

0                            DFLAP=       .00         DFLAP=    15.00          DFLAP=    40.00
0                            CLMAX=   1.12430         CLMAX=  2.11925          CLMAX=  2.78324

0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
     FLAP DEFL.     CLMAX     CL          CD       L/D
      10.000      1.81051
                            .65415     .05871 11.14144
                            .82539     .06843 12.06252
                            .99663     .08150 12.22905
                           1.16787     .09867 11.83605
                           1.33911     .12144 11.02722
                           1.51035     .14760 10.23242
                           1.68159     .17663  9.52031
                           1.81051     .20037  9.03576
                           1.81051     .20037  9.03576
                           1.81051     .20037  9.03576
      20.000      2.31932
                           1.16296     .10068 11.55109
                           1.33420     .11431 11.67153
                           1.50544     .13201 11.40379
                           1.67668     .15561 10.77475
                           1.84792     .18242 10.12982
                           2.01917     .21216  9.51741
                           2.19041     .24480  8.94757
                           2.31932     .27131  8.54862
                           2.31932     .27131  8.54862
                           2.31932     .27131  8.54862
      30.000      2.61862
                           1.46226     .14838  9.85464
                           1.63350     .16353  9.98925
                           1.80474     .18305  9.85937
                           1.97598     .20837  9.48326
                           2.14723     .23671  9.07110
                           2.31847     .26808  8.64829
                           2.48971     .30249  8.23085
                           2.61862     .33038  7.92608
                           2.61862     .33038  7.92608
                           2.61862     .33038  7.92608


0ALTITUDE=      35000. FT    TAS=      462.24 KTS    MACH NO=       .8010


0                                 RDT&E AND AIRFRAME PRODUCTION COSTS
                                                (1993. DOLLARS)
0                             TOTAL RDT&E COSTS            1009.2150 MILLION
0                                         AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                                  500. AIRCRAFT
                                                     WEIGHT(LB)      COST($)      COST($/LB)
          STRUCTURE(  4109540.$)
                                  WING                    4415.     1104832.        250.26
                                  CANARD                   424.      183527.        433.06
                                  EMPENNAGE                867.      333989.        385.36
                                  FUSELAGE                5991.     1662262.        277.45
                                  LANDING GEAR            1694.      302217.        178.42
                                  NACELLES                 948.      522713.        551.56
          PROPULSION INSTAL(      162710.$)
                                  ENGINE INSTALLAT.        382.      139067.        364.08
                                  FUEL SYSTEM              167.       23642.        141.74
          SYSTEMS(  2548004.$)
                                  FLIGHT CONTROLS          904.      424255.        469.41
                                  HYDRAULIC                361.       45018.        124.57
                                  ELECTRICAL               970.      464214.        478.57
                                  AIR CONDITIONING         478.      256070.        535.82
                                  ANTI-ICING               205.      108021.        526.66
                                  AUX. POWER UNIT          372.      207143.        556.42
                                  FURNISHINGS             3410.      796443.        233.56
                                  INSTRUMENTS              233.      193137.        829.44
                                  AVIONICS INSTALL.        250.       49032.        196.13
                                  AUX. ITEMS                20.        4671.        233.56
         INTEGRATION(  1705064.$)
0                                   AIRFRAME TOTALS      22090.     8525318.        385.93
0                                   ENGINES                         2615686.
                                    PROPELLER                             0.
                                    AVIONICS                        4000000.
                                    A/C COST(NO RD)                15141004.
                                    R&D PER A/C                     2018430.
                                    TOTAL A/C COST                 17159434.

0                   ENGINES       NUMBER =      2.   TYPE=      7

0 EMPTY WEIGHT= 25170.     AIRFRAME WEIGHT= 22340.     WEIGHT OF 1 ENGINE=  1415.     CRUISE SPEED= 462. KTS
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (continued)

```
0 THRUST/ENGINE=   8842.
0 TOTAL AIRCRAFT COST= 17159434.     AIRFRAME COST= 14543748.     COST OF 1 ENGINE=  1307843.     COST OF 1 PROP.=        0.


0                              --- COST DATA ---
                            GASP SHORTHAUL METHOD
0          DESIGN MISSION
0              OPERATING COST FOR NOR.RATED POWER AND  35000. ALTITUDE
0  ****************************************************************************************************
0                   RANGE=    1239. N.M.    BLOCK FUEL=    6658. LBS    BLOCK TIME=  3.0315 HRS.
0   UTILIZATION                         3200.
 FLYING OPERATIONS
    FLIGHT CREW                       378.932
    FUEL,OIL,AND TAXES( .850$/G)      884.361
    INSURANCE                          81.278
 DIRECT MAINTENANCE
    AIRFRAME                          170.286
    ENGINE                            286.822
 MAINTENANCE BURD.                    373.355
 DEPRECIATION                        1092.378

    TOTAL DOC ($/TRIP)               3267.413
              ($/B.HR.)              1077.837
              ($/N.MI.)                 2.637
```

Fig E15 - Three-Lifting Surface Configuration optimised for minimum M.T.O.W.
- GASP solution (concluded)

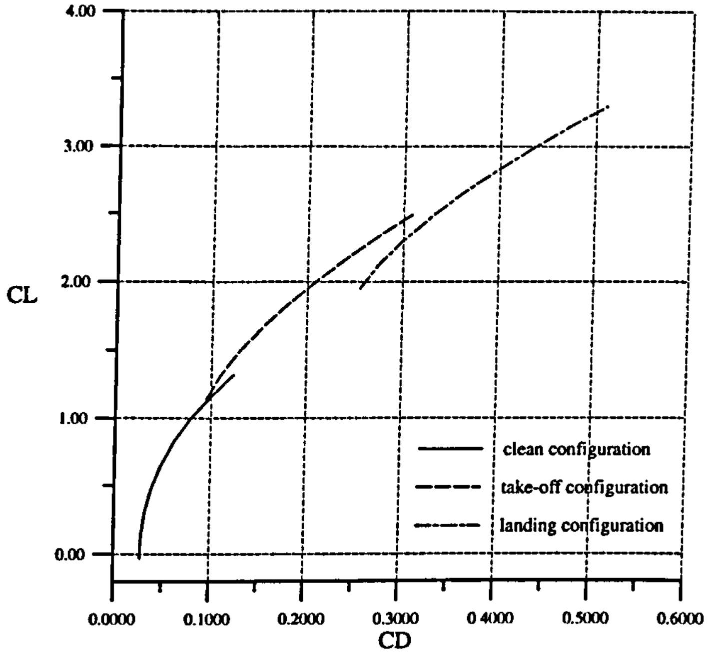

Fig E16.1 - Minimum D.O.C. Conventional concept low speed drag polars

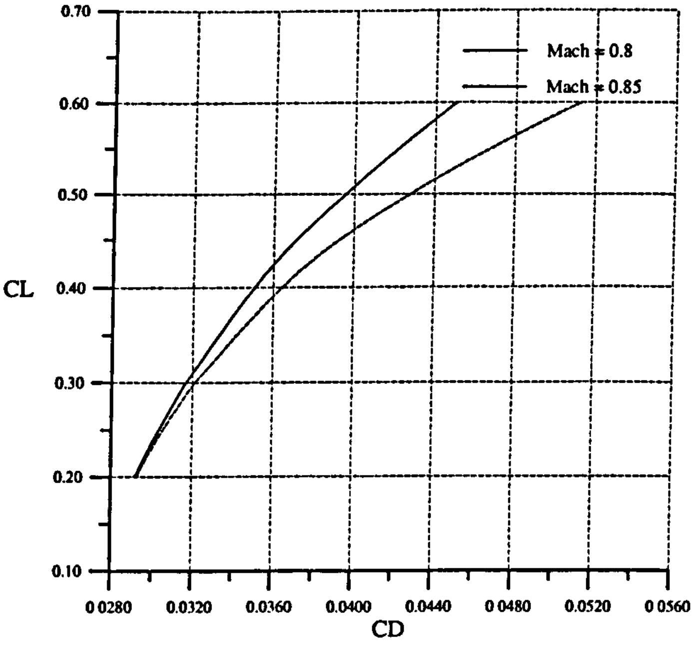

Fig E16.2 - Minimum D.O.C. Conventional concept Cruise drag polar

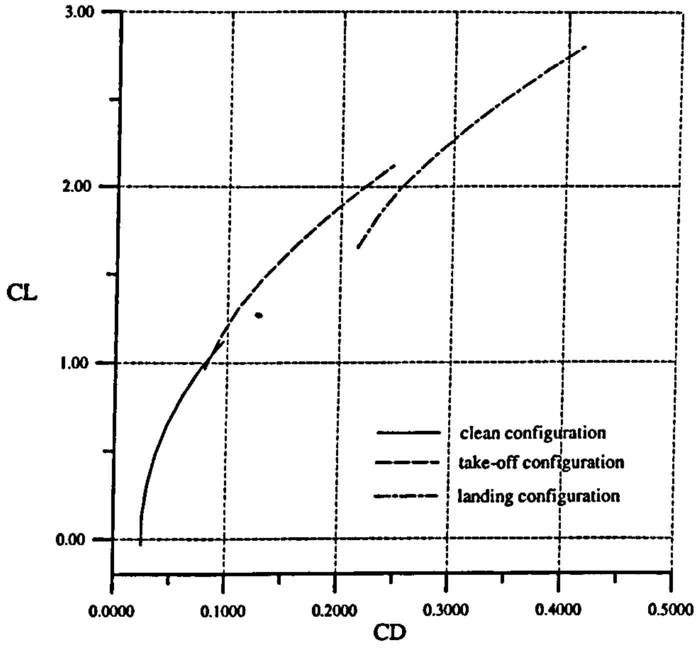

Fig E17.1 - Minimum D.O.C. Three-lifting Surface concept low speed drag polars

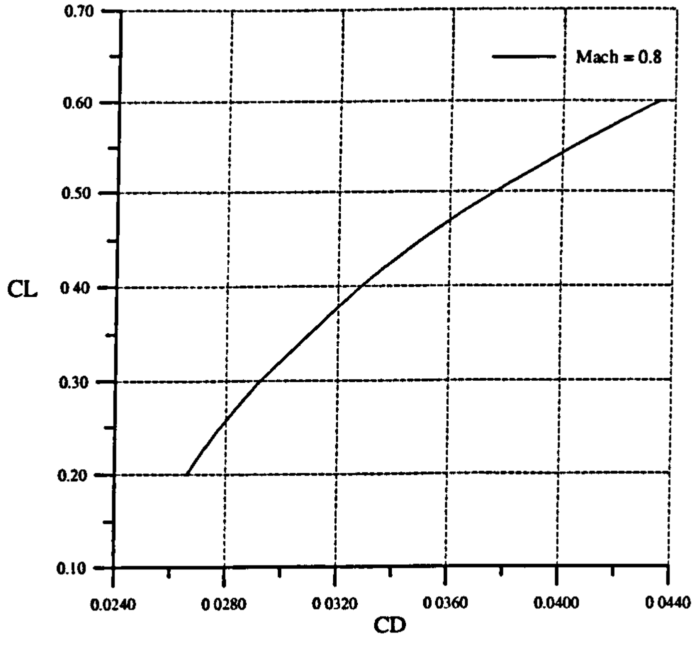

Fig E17.2 - Minimum D.O.C. Three-lifting Surface concept Cruise drag polar

APPENDIX F

Optimisation Convergence Histories

Introduction

Design optimisation was performed using the RAE Recursive Quadratic Programming Minimization (RQPMIN) numerical technique. This Appendix illustrates the convergence histories of the problem functions and design variables for the direct operating costs optimisation cases (first solutions) performed on both configurations. The behaviour of RQPMIN-GASP is represented in figures F1 and F2, respectively for the conventional and the three-surface optimum designs. An analysis of these historical diagrams was done in section 5.4 where some explanation on the reasons leading to its peculiar behaviour was given, as well as suggestions for improvement.

In complement to the discussion given in section 5.4, an additional comment is herein given. It is seen on fig F1 a very sharp jump at about iteration number 82. This reflects the very irregular nature of the multidimentional design surface topology. This jump means that a preferential feasible path to minimize the objective function was located at a particular design point (corresponding to this iteration). As shown, this path effectively headed the search on the right direction, toward the local minimum convergence point obtained at the end.

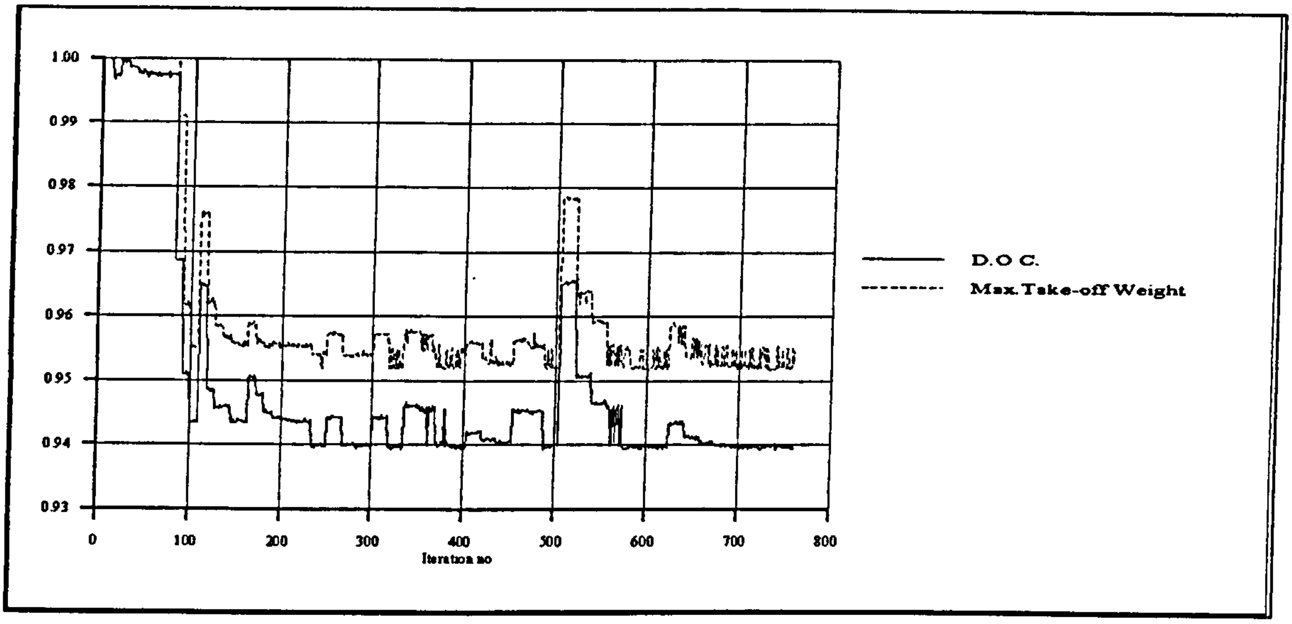

Fig F1.1 - History of the Objective Function (D.O.C) and Maximum Take-off Weight

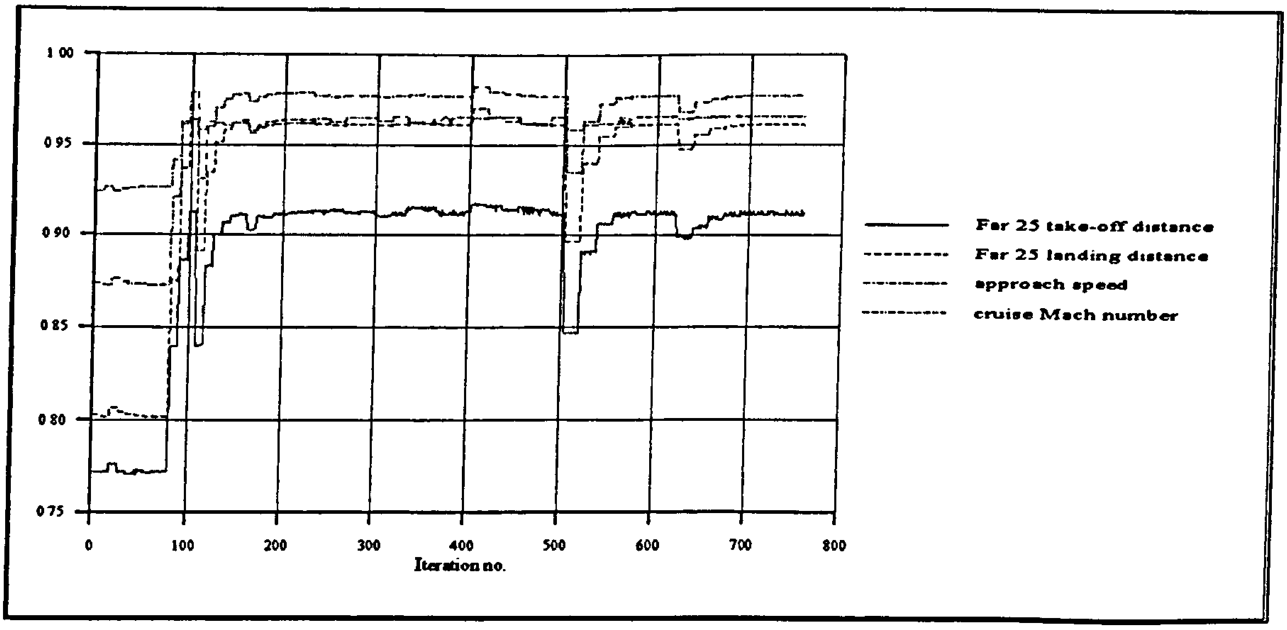

Fig F1.2 - History of the Constraint Functions

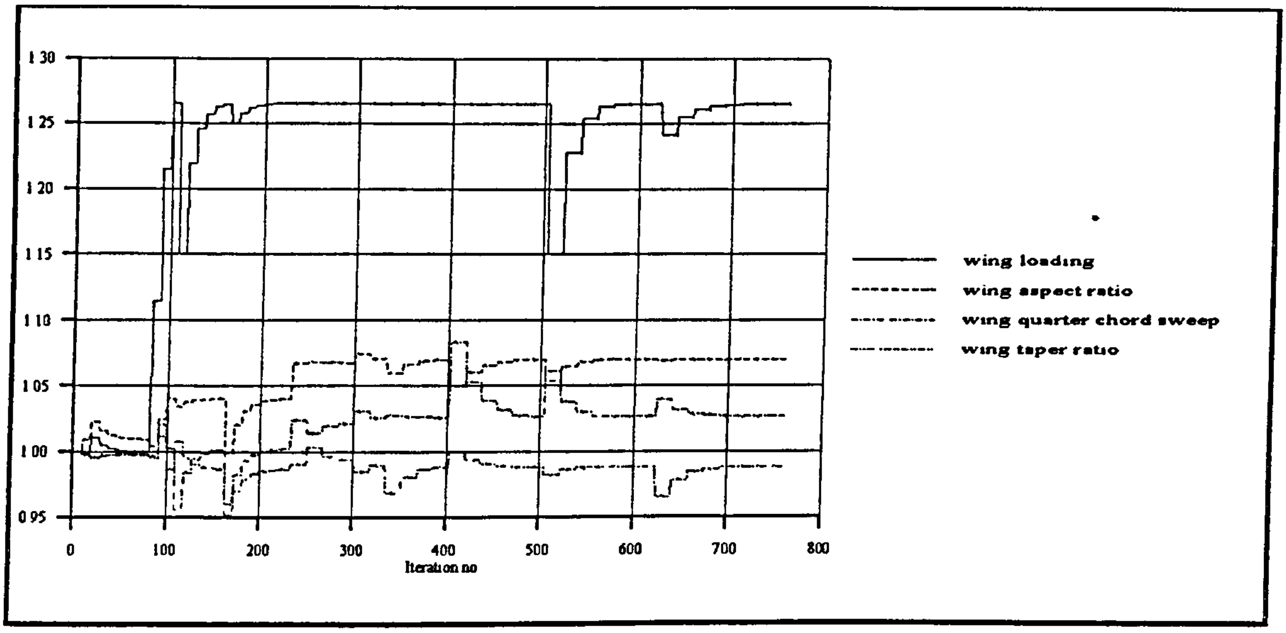

Fig F1.3 - History of the Wing design variables

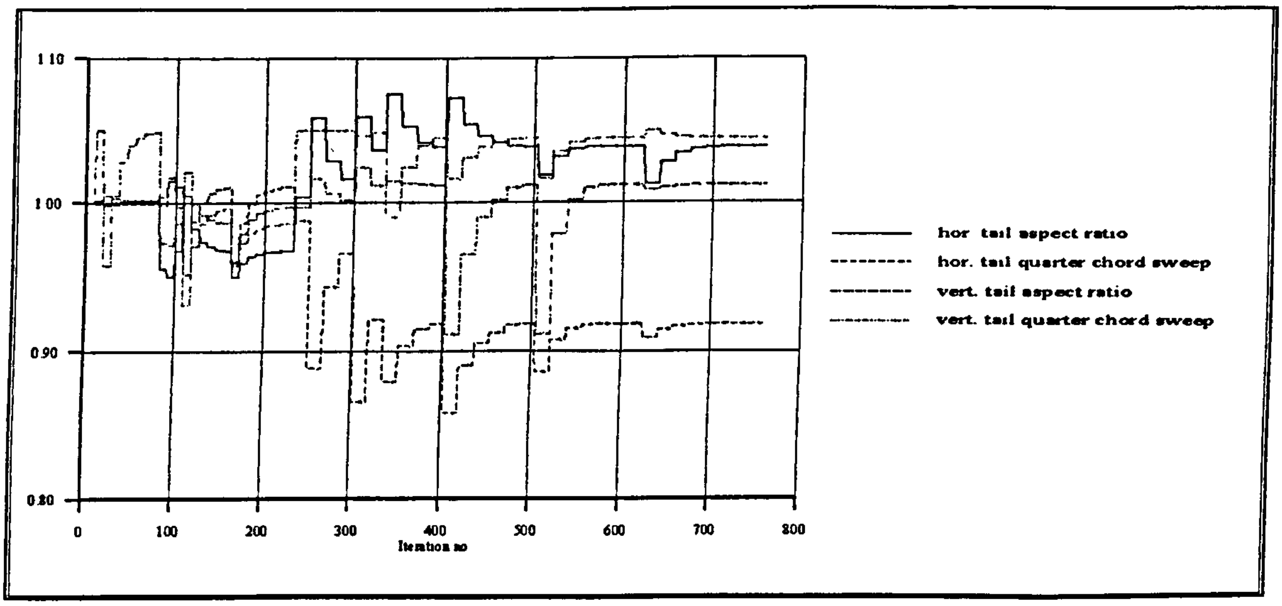

Fig F1.4 - History of the tail design variables

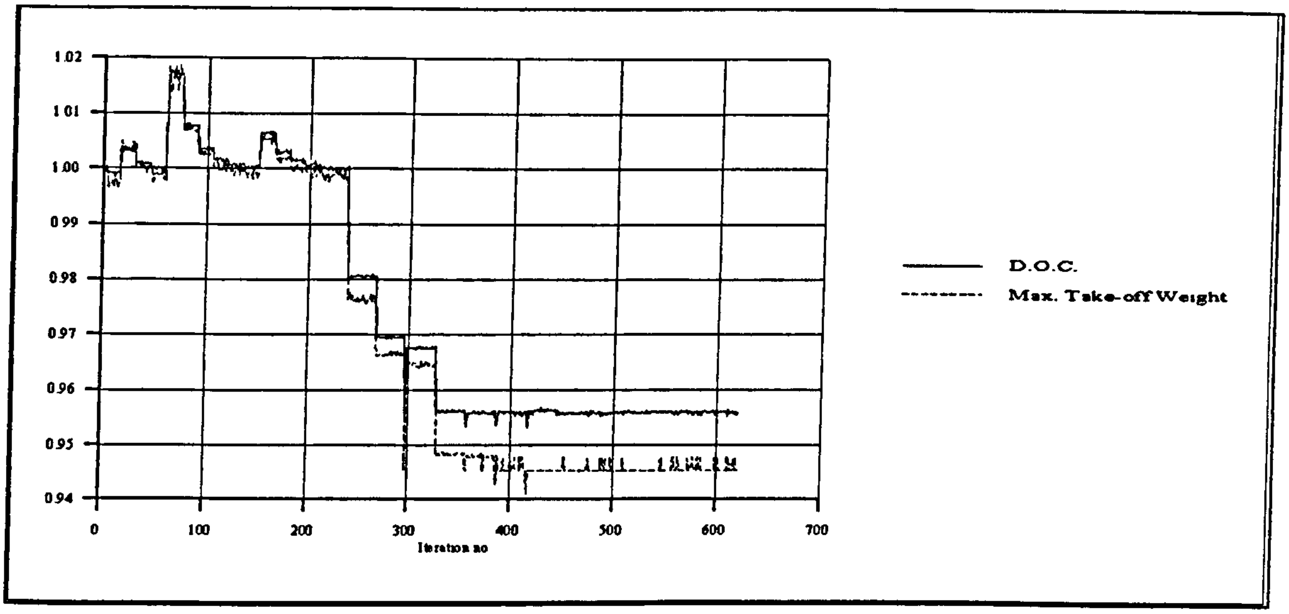

Fig F2.1 - History of the Objective Function (D.O.C.) and Maximum Take-off Weight

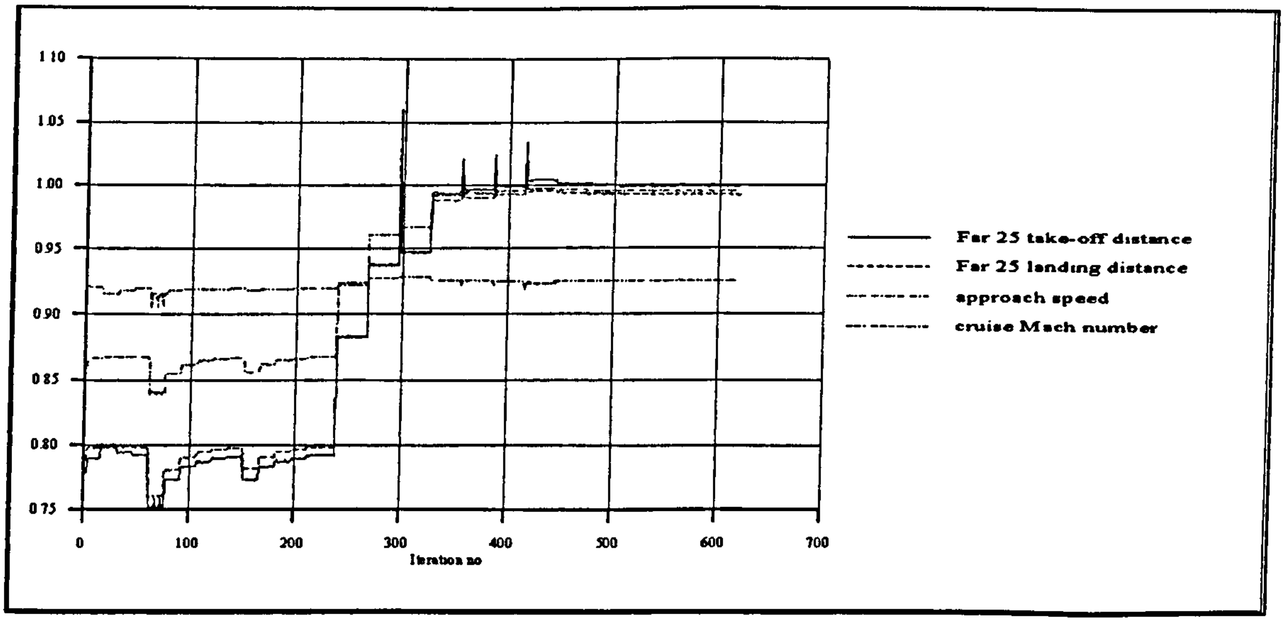

Fig F2.2 - History of the Constraint Functions

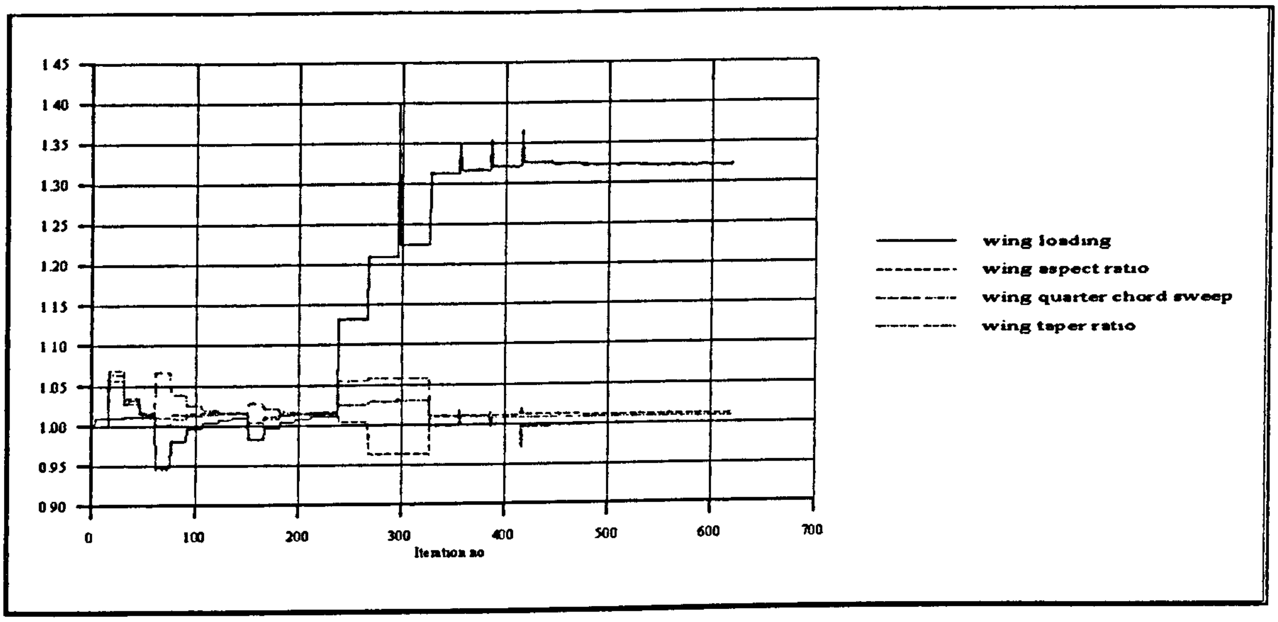

Fig F2.3 - History of the Wing design variables

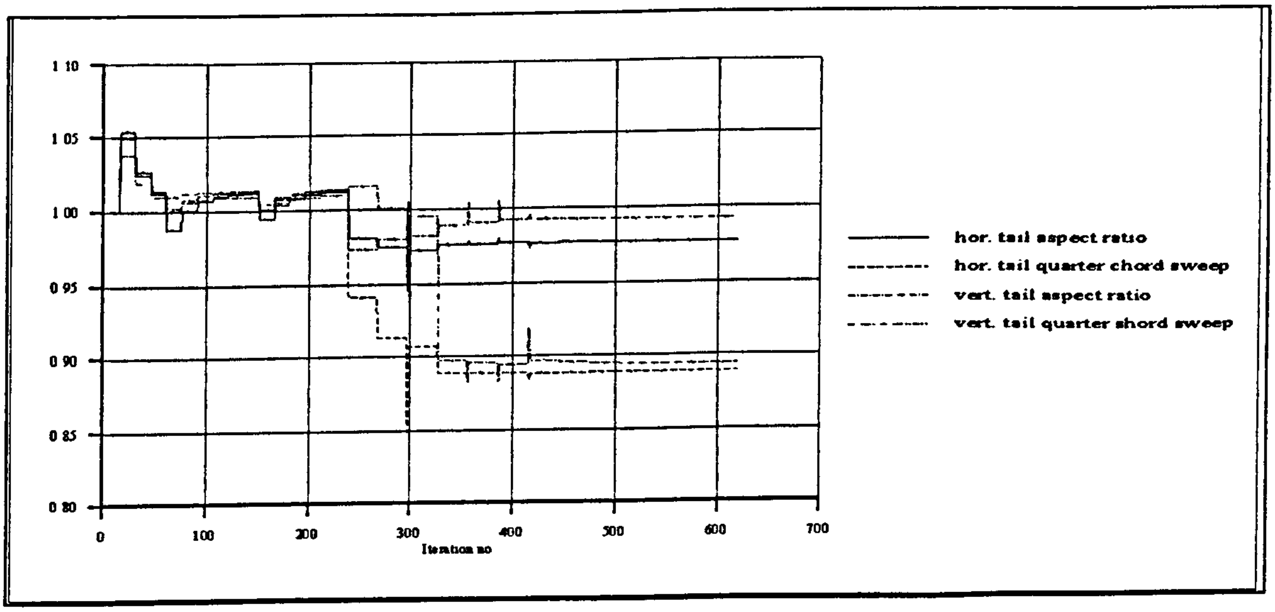

Fig F2.4 - History of the Tail design variables

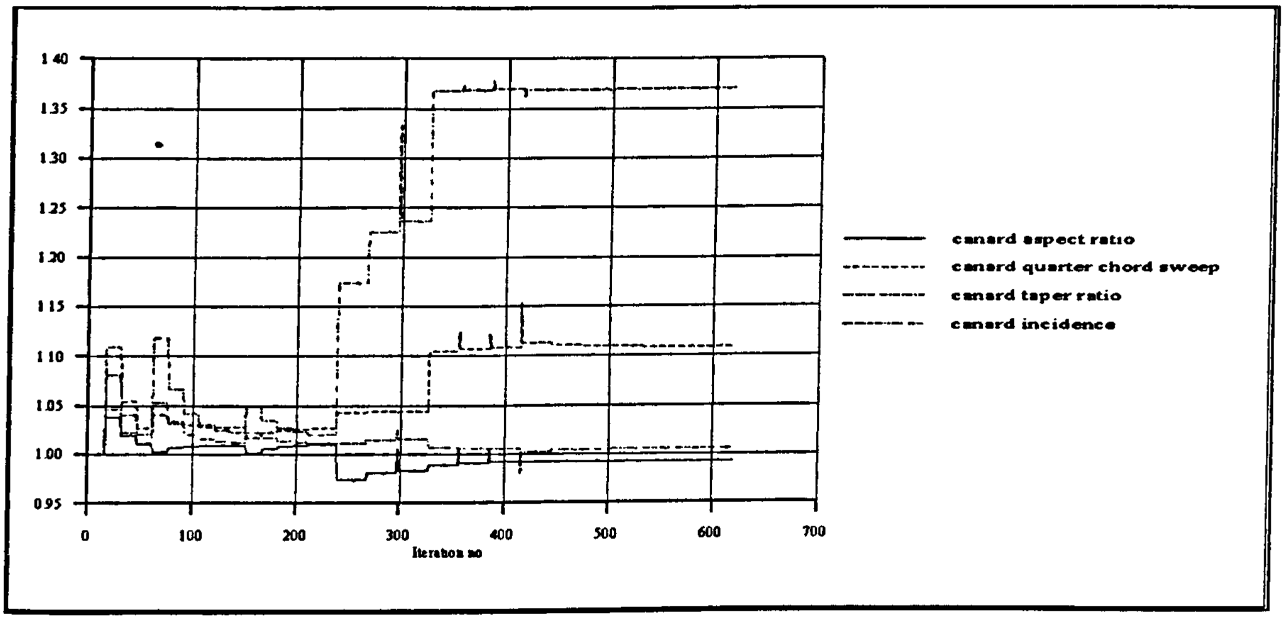

Fig F2.5 - History of the Canard design variables

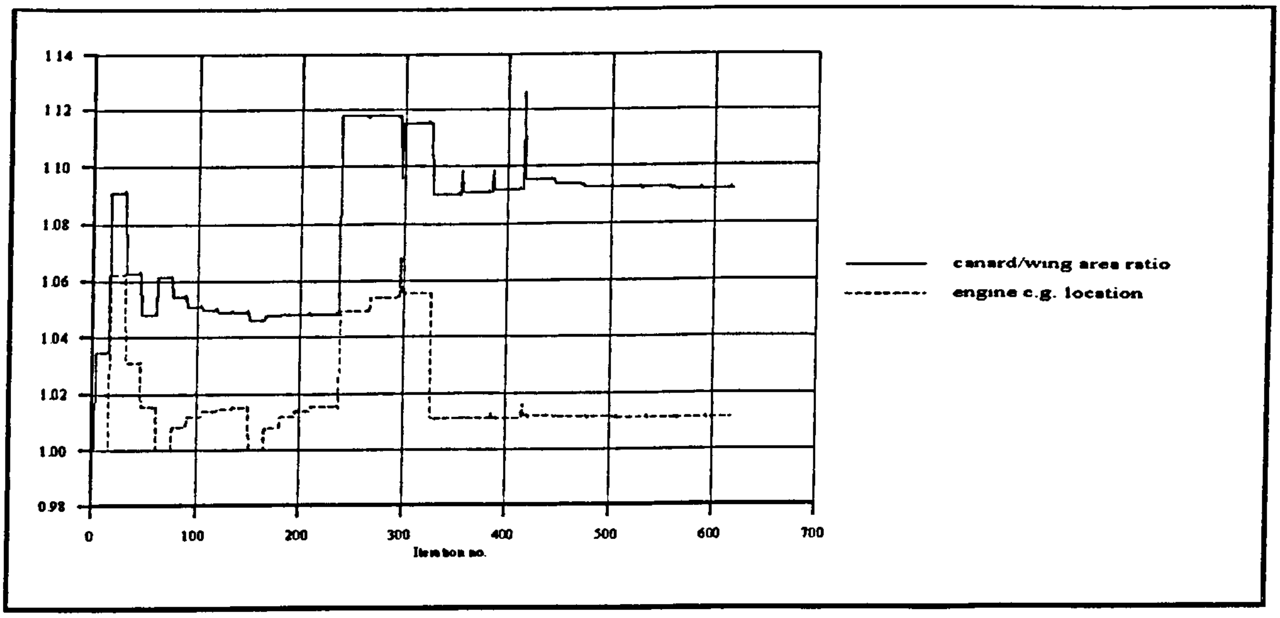

Fig F2.6 - History of the Miscellaneous design variables

APPENDIX G

Conventional Concept Drag and Handling Qualities Evaluation

Introduction

In this Appendix, the low speed and high speed drag polars for the baseline and the minimum DOC conventional aircraft configurations, as obtained by GASP aerodynamic module, are compared with those obtained using the DELTADD program. Analysis of the dynamic stability and control of these conventional designs is also performed using the revised MITCHELL program.

G.1 Conventional-Concept Drag Estimation

Aerodynamic drag estimates were performed on the baseline and D.O.C. optimum aft-tail designs using the CoA DELTADD program to check the drag polar predictions computed by the GASP aerodynamic module during the design synthesis runs. As referred to in Chapter 3, the former program is based on the Lockheed Delta empirical drag build-up technique[G1] and is claimed to give good results within sufficient accuracy for the initial processes of preliminary design.

The original Delta method was most applicable near the cruise flight conditions and was not appropriate for performance analysis near maximum lift coefficients. However, this restriction was overcome by Professor Howe in the College of Aeronautics who included the effects of high lift devices and undercarriage in the later version of the program allowing for the prediction of the low speed aerodynamic characteristics.

Figures G1 and G2 present the DELTADD results for both designs, including cruise flight and flight at low speeds for clean wing, take-off and landing configurations.

Assuming an additional correction of about 33 drag counts on the zero-lift drag coefficient, DELTADD estimates a drag polar that almost overlaps that obtained by GASP for the useful range of cruise lift coefficients of the baseline concept, as shown on fig G3. Regarding the D.O.C. optimum solution, GASP seems to overestimate the drag coefficient in about 20 drag counts. Figures G4 and G5 show the GASP obtained low speed drag polars together with DELTADD point performance estimates which remarkably lye very closely on the curves. Additional work could be done on the DELTADD flap input details in order to increase the take-off and landing lift coefficients required by the designs.

Concluding Remarks

For the initial preliminary design purposes and with limited knowledge of the aircraft geometric parameters and design details, the agreement obtained on these curves can be considered fairly good. Therefore, GASP aerodynamic results are assumed correct within the degree of accuracy usually expected during this initial design phase.

G.2 Conventional-Concept Handling Qualities Evaluation

GASP program is able to select the tail surface areas and volume coefficients to comply with a given set of important static trim and stability conditions as reported in Chapter 3. This capability will ensure satisfactory handling on most conventional designs but minor configuration changes or the use of some kind of stability augmentation system may be required. The prediction of the dynamic stability of the aircraft and the responses to control inputs is usually done on a later stage in the design process because it requires considerable effort and specialised knowledge and experience. However, an early assessment of the aircraft handling qualities is wellcome in providing greater confidence to the designer.

This will be illustrated in the present appendix by using MITCHELL program[G2,G3], already introduced in Chapter 3. Using information available early in the design process such as aircraft geometry, weight, propulsion and flight conditions the program predicts the aerodynamic stability and control derivatives, estimates the aircraft moments of inertia, calculates the characteristics of the longitudinal and lateral stick-fixed modes, predicts the responses to certain disturbances at the specified flight condition and calculates the limiting speeds for low-speed flight at sea level assuming the aircraft as a rigid body.

Time shortage didn't allow appropriate changes to be included in the program in order to simulate the stability and control characteristics of a three-lifting surface aircraft, thus only the results obtained for the conventional designs are shown (both for the baseline and D.O.C. optimised solutions, figures G6 and G7 respectively). These results were produced with respect to the initial cruise flight condition using GASP geometry, weight and performance data as input, together with a slight adjustment on the aircraft C.G. location to maintain the desired cruise stability static margin of 10% MAC. In spite of the aircraft model simplifications, the program gives reasonably accurate answers[G2], so due credibility is given to the predictions made.

A brief analysis of the longitudinal and lateral-directional stick-fixed modes is performed based on the results obtained for the conventional baseline concept which is compared to the military analytical specifications set out in the MIL-F-8785 C[G4]. This reflects current practice since the civil airworthiness regulations do not generally provide any analytical performance criteria for the dynamic behaviour of piloted aircraft.

The military specification defines aircraft classes, flight phases and flying quality levels, specifying different modes so that different combinations can be assessed. The flying quality levels are related to the Cooper-Harper[G5] pilot opinion rating scale. The transport under study can be classified as a Class II aircraft and the particular flight condition analysed corresponds to flight phase Category B.

Longitudinal modes

Phugoid

MIL specification[G4] dictates that for level 1 flying qualities the damping ratio of the phugoid mode shall be at least ζ_p=0.04. Figure G6 states for the conventional baseline concept a phugoid oscillation damping ratio of ζ_p=0.061 which meets the desired level.

Short-Period

Ref G4 sets limits on the short-period equivalent undamped natural frequency, ω_n and on the equivalent damping ratio, ζ_{sp}, respectivelly on Figure B2 and Table IV. For the particular flight condition (Cat. B), fig G6 gives ω_n= 1.821 rad sec^{-1}, ζ_{sp}= 0.722 and the load-factor response to angle of attack, $n/\alpha = 0.378$ g deg^{-1}.

For level 1 flying qualities Fig B2 (MIL) requires $\omega^2_n/(n/\alpha) \in [0.085,3.6]$. Computing for the specific aircraft, this parameter reads $\omega^2_n/(n/\alpha) = 0.153$ $rad^3sec^{-2}g^{-1}$ which satisfies the specification. The same conclusion is found for the equivalent damping ratio, ζ_{sp} which falls within Table IV (MIL) requirements, where $\zeta_{sp} \in [0.30,2.00]$, for the same flying qualities level.

Lateral-directional modes

Dutch Roll

Ref G4 states that the undamped frequency, ω_{nd} and the damping ratio, ζ_d of the Dutch roll mode following a yaw disturbance shall exceed the minimum values of Table VI. For level 1 and Cat B phase, these figures are respectivelly ω_{nd} = 0.4 rad sec^{-1} and ζ_d = 0.08, while the results for the tail-aft baseline aircraft as shown in figure G6 reads respectivelly ω_{nd} = 1.721 rad sec^{-1} and ζ_d = 0.068. The later suggests that the oscillation is very poorly damped which would make landing in gusty wind difficult to the pilot and a very uncomfortable flight in turbulence for passengers sitting near the tail. The addition of a convenient stability augmentation system or simply a yaw-damper, as is usually done on jet-transport aircraft, would improve this lateral-directional oscillation mode.

Roll Subsidence

Table VII (MIL) establishes maximum roll mode time constant values. For flight Cat B and level 1, this value is T_r= 1.4 sec which is well above the time constant shown in fig G6 for the study aircraft, T_r= 0.393 sec. This value also suggests a fast roll response.

Spiral Stability

The spiral mode is allowed to be unstable, so limits are placed on the minimum time for the bank angle to double, following a disturbance in bank of up to 20 degrees from trimmed, wings-level, zero-yaw-rate flight with cockpit controls free. These limits are shown on Table VIII (MIL) and to satisfy level 1 handling it shall be T_{2s}= 20 sec. MITCHELL results for the case aircraft, fig G6, unvails a stable exponential spiral mode with a very long time constant of T_s= 185.5 sec which will be in favour.

Concluding Remarks

MITCHELL results for the conventional baseline concept, fig G6, show two stable longitudinal oscillatory modes, the phugoid and the short-period modes, that satisfy reasonably well the military analytical specifications of the MIL-F-8785 C[G4]. Regarding the lateral-directional modes, both the roll and the spiral modes are adequate stable subsidences, while the Dutch roll oscillation indicates some deficiency in damping ratio which can be corrected with the addition of a convenient yaw-damper. Analysis of the results regarding the stability and control dynamics of the D.O.C. optimised conventional design, as presented in fig G7, would qualitatively lead to similar conclusions, but in this particular case, the dutch roll mode would require more yaw-damping compensation.

References:

G1. Feagin,R.C.;Morrison,W.D.,Jr.
DELTA Method, an Empirical Drag Build-up Technique
Final Report, Lockheed-California Co., Burbank, Dec 1978

G2. Mitchell,C.G.B.
A Computer Program to Predict the Stability and Control Characteristics of Subsonic Aircraft
RAE TR no. 73079, Sept 1973

G3. Theophilou,M.K.
Development of Computer Programs for Initial Project Design of Combat Aircraft
M.Sc. Thesis, CIT, Sept 1983

G4. Anon.
MIL-F-8785C- U. S. DoD Military Specification: Flying Qualities of Piloted Airplanes
Nov. 1980

G5. Cooper,G.E.;Harper,R.P.,Jr.
The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities
NASA, TN D-5153, Washington, D.C.,1969

```
            ** DELTADD DRAG ESTIMATE - VERSION 4.42 **

                       - INPUT DATA -

TITLE :  conv_bl                                        DATA VERSION :  3.32


GENERAL :
     INPUT DATA UNITS [0=imperial 1=metric]                      0
     OUTPUT TYPE [1=report 2=detailed]                           1
     TEMP DIFF FROM ISA CONDITIONS [C]                          20.0
     ADDITIONAL ZERO LIFT DRAG COFFICIENT                       -1.000

WING :
     AEROFOIL TYPE [1=conventional 2=advanced]                   2
     SPAN [m or ft]                                             69.190
     AREA [m2 or ft2]                                          576.783
     WETTED AREA [m2 or ft2]                                   910.280
     MEAN AERO. CHORD [m or ft]                                  9.571
     ASPECT RATIO                                                8.300
     C/4 SWEEP                                                  14.5
     LE SWEEP                                                   18.7
     TAPER RATIO                                                  .200
     t/c [ratio]                                                  .115
     CAMBER [100{z(u)-z(l)}/2c  @ 70% semi-span]                  .000

FUSELAGE :
     LENGTH [m or ft]                                           79.250
     HEIGHT [m or ft]                                            9.250
     WIDTH [m or ft]                                             9.250
     BASE AREA [m2 or ft2]                                        .795
     MAX XSECT AREA EXCLUDING INLETS [m2  or  ft2]              67.200
     WETTED AREA [m2 or ft2]                                  1910.380

TAILPLANE :
     MAC [m or ft]                                               8.247
     WETTED AREA [m2 or ft2]                                   540.590
     t/c [ratio]                                                  .100

FIN :
     MAC [m or ft]                                              11.156
     WETTED AREA [m2 or ft2]                                   243.810
     t/c [ratio]                                                  .120

NACELLES  AND PYLONS :
     NUMBER                                                      2
     LENGTH [m or ft]                                           11.960
     WETTED AREA - SINGLE NACELLE   [m2 or ft2]                149.920
                 - SINGLE  PYLON    [m2 or ft2]                 36.000
```

Fig. G1 - Conventional Baseline Concept Drag Estimate Deltadd Output file

```
EXTRA DRAG DATA :

     flap type [0=split 1=slotted or fowler]                   1
     flap chord/wing chord ratio _ 1                            .060
     .... .......... ..... ..... _ 2                            .240
     .... .......... ..... ..... _ 3                            .000
     flap outer end semi-span (ratio)                           .884
     flap inner end semi-span (ratio)                           .134
     number of piston engines                                  0
     max design all-up mass                                47873.0
     max design diving speed [Mach no.]                         .900
     max lift coefficient - CLMAX                              1.200
     miscellaneous additional coefficient                       .003
```

Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (continued)

```
CASE DATA :

     CASE No.          MACH No.             ALTITUDE            AIRCRAFT MASS
                                            m or ft              Kg or lb

        1                .80                35000.0               46442.0
        2                .25                 5000.0               47648.0
        3                .20                 5000.0               47680.0
        4                .17                 5000.0               45001.0

     CASE No.        UNDERCARRIAGE        FLAP DEFLNS   deg       FLAP EXTN
                     0=up   1=down        -1-    -2-    -3-        ratio

        1                0.                .0     .0     .0         1.00
        2                0.                .0     .0     .0         1.00
        3                0.               7.5   15.0     .0         1.29
        4                0.              20.0   40.0     .0         1.24
```

Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_bl


CASE  1 OF  4

     FREE STREAM MACH No. =        .80
     ALTITUDE             =   10668.0  m
     AIRCRAFT MASS        =   21076.8  Kg
     UNDERCARRIAGE (0=up) =         0
     FLAP DEFLECTION  -1- =        .0  deg
                      -2- =        .0  deg
                      -3- =        .0  deg
     FLAP EXTENSION RATIO =     1.00
     TRUE AIRSPEED        =     250.5  m/s
     AIR TEMPERATURE      =     243.9  K
     AIR DENSITY          =     .384   Kg/m3
     UNIT REYNOLDS NO.    =     6.138E+06 per m

ZERO LIFT DRAG COEFFICIENT :       * Additional drag function called *
                                    Landing gear .... CDADDL =  .0000
     CDF   =  .0190                 Flaps zero lift . CDADDF =  .0000
     CDC   =  .0015                 Engine cooling .. CDADDC =  .0000
     CDADD =  .0033                 Stores .......... CDADDS =  .0000
     CDMIN =  .0237                 Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :    CD = .0237 + .0500 CL2

               CL          CD

             .1240       .0251
             .2240       .0259
             .3240       .0285
             .4240       .0322
             .4740       .0344
             .5240       .0375
             .5740       .0409
             .6240       .0447
             .7240       .0549
             .8240       .0680

Flap lift coefficient increment = .0000
FLAP PRESSURE DRAG COEFFICIENT  = .0000  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD              =  .0284
     CASE CL              =  .3199
     BUFFET ONSET CL      =  .6326
     DESIGN CL            =  .5240
     DRAG RISE MACH No. = .8166
     CASE DRAG FORCE      =   18.5  KN
```

**Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (continued)**

```
DELTADD DRAG ESTIMATE :  conv_bl


CASE  2 OF  4

     FREE STREAM MACH No. =       .25
     ALTITUDE             =    1524.0  m
     AIRCRAFT MASS        =   21624.2  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =        .0  deg
                      -2- =        .0  deg
                      -3- =        .0  deg
     FLAP EXTENSION RATIO =      1.00
     TRUE AIRSPEED        =      86.7  m/s
     AIR TEMPERATURE      =     298.9  K
     AIR DENSITY          =      .995  Kg/m3
     UNIT REYNOLDS NO.    =    4.684E+06 per m


ZERO LIFT DRAG COEFFICIENT :         * Additional drag function called *
                                      Landing gear .... CDADDL =   .0000
     CDF   =  .0206                   Flaps zero lift . CDADDF =   .0000
     CDC   =  .0015                   Engine cooling .. CDADDC =   .0000
     CDADD =  .0033                   Stores .......... CDADDS =   .0000
     CDMIN =  .0253                   Misc. extra ..... CDADDX =   .0033


OVERALL DRAG POLAR  :     CD = .0253 + .0480 CL2

              CL          CD

            .1240       .0264
            .2240       .0274
            .3240       .0299
            .4240       .0336
            .4740       .0356
            .5240       .0385
            .5740       .0423
            .6240       .0456
            .7240       .0551
            .8240       .0689

Flap lift coefficient increment = .0000
FLAP PRESSURE DRAG COEFFICIENT  = .0000  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD            =  .0858
     CASE CL            = 1.0584
     BUFFET ONSET CL    = 1.1812
     DESIGN CL          =  .5240
     DRAG RISE MACH No. =  .8166
     CASE DRAG FORCE    =   17.3   KN
```

Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_bl


CASE  3 OF  4

     FREE STREAM MACH No. =      .20
     ALTITUDE             =   1524.0  m
     AIRCRAFT MASS        =  21638.7  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =      7.5  deg
                      -2- =     15.0  deg
                      -3- =       .0  deg
     FLAP EXTENSION RATIO =     1.29
     TRUE AIRSPEED        =     69.3  m/s
     AIR TEMPERATURE      =    298.9  K
     AIR DENSITY          =     .995  Kg/m3
     UNIT REYNOLDS NO.    =    3.747E+06 per m

ZERO LIFT DRAG COEFFICIENT :      * Additional drag function called *
                                   Landing gear .... CDADDL =  .0000
     CDF   =  .0214                Flaps zero lift . CDADDF =  .0028
     CDC   =  .0015                Engine cooling .. CDADDC =  .0000
     CDADD =  .0060                Stores .......... CDADDS =  .0000
     CDMIN =  .0289                Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :    CD = .0289 + .0000 CL2

              CL           CD

            .1240        .0300
            .2240        .0310
            .3240        .0335
            .4240        .0371
            .4740        .0392
            .5240        .0421
            .5740        .0459
            .6240        .0491
            .7240        .0586
            .8240        .0724

Flap lift coefficient increment = .9240
FLAP PRESSURE DRAG COEFFICIENT  = .0111  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD            =  .1625
     CASE CL            = 1.6549
     BUFFET ONSET CL    = 1.1927
     DESIGN CL          =  .5240
     DRAG RISE MACH No. =  .8166
     CASE DRAG FORCE    =   21.0  KN
```

Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_bl


CASE  4 OF  4

     FREE STREAM MACH No. =      .17
     ALTITUDE             =   1524.0  m
     AIRCRAFT MASS        =  20422.9  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =     20.0  deg
                      -2- =     40.0  deg
                      -3- =       .0  deg
     FLAP EXTENSION RATIO =     1.24
     TRUE AIRSPEED        =     57.6  m/s
     AIR TEMPERATURE      =    298.9  K
     AIR DENSITY          =     .995  Kg/m3
     UNIT REYNOLDS NO.    =    3.110E+06 per m

ZERO LIFT DRAG COEFFICIENT :       * Additional drag function called *
                                    Landing gear .... CDADDL =  .0000
     CDF   =  .0221                 Flaps zero lift . CDADDF =  .0178
     CDC   =  .0015                 Engine cooling .. CDADDC =  .0000
     CDADD =  .0210                 Stores .......... CDADDS =  .0000
     CDMIN =  .0446                 Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :    CD = .0446 + .0000 CL2

             CL          CD

           .1240       .0457
           .2240       .0467
           .3240       .0491
           .4240       .0528
           .4740       .0548
           .5240       .0578
           .5740       .0616
           .6240       .0648
           .7240       .0743
           .8240       .0881

Flap lift coefficient increment =1.3352
FLAP PRESSURE DRAG COEFFICIENT  = .0232  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD            =  .2824
     CASE CL            = 2.2672
     BUFFET ONSET CL    = 1.1927
     DESIGN CL          =  .5240
     DRAG RISE MACH No. =  .8166
     CASE DRAG FORCE    =   25.1  KN
```

Fig. G1 - Conventional Baseline Concept Drag Estimate
Deltadd Output file (concluded)

```
                ** DELTADD DRAG ESTIMATE - VERSION 4.42 **

                            - INPUT DATA -

 TITLE :  conv_doc                                        DATA VERSION :  3.32

 GENERAL :
      INPUT DATA UNITS [0=imperial 1=metric]                  0
      OUTPUT TYPE [1=report 2=detailed]                       1
      TEMP DIFF FROM ISA CONDITIONS [C]                      20.0
      ADDITIONAL ZERO LIFT DRAG COFFICIENT                   -1.000

 WING :
      AEROFOIL TYPE [1=conventional 2=advanced]               2
      SPAN [m or ft]                                         62.171
      AREA [m2 or ft2]                                      435.303
      WETTED AREA [m2 or ft2]                               667.210
      MEAN AERO. CHORD [m or ft]                              8.049
      ASPECT RATIO                                            8.879
      C/4 SWEEP                                              14.9
      LE SWEEP                                               18.8
      TAPER RATIO                                              .198
      t/c [ratio]                                              .115
      CAMBER [100{z(u)-z(l)}/2c  @ 70% semi-span]              .000

 FUSELAGE :
      LENGTH [m or ft]                                       79.250
      HEIGHT [m or ft]                                        9.250
      WIDTH [m or ft]                                         9.250
      BASE AREA [m2 or ft2]                                    .795
      MAX XSECT AREA EXCLUDING INLETS [m2  or  ft2]          67.200
      WETTED AREA [m2 or ft2]                              1910.380

 TAILPLANE :
      MAC [m or ft]                                           6.312
      WETTED AREA [m2 or ft2]                               330.120
      t/c [ratio]                                              .100

 FIN :
      MAC [m or ft]                                          10.034
      WETTED AREA [m2 or ft2]                               199.550
      t/c [ratio]                                              .120

 NACELLES  AND PYLONS :
      NUMBER                                                  2
      LENGTH [m or ft]                                       11.860
      WETTED AREA - SINGLE NACELLE  [m2 or ft2]             147.105
                  - SINGLE  PYLON   [m2 or ft2]              36.000
```

Fig. G2 - Conventional D.O.C. optimised Concept Drag Estimate
Deltadd Output file

```
EXTRA DRAG DATA :

     flap type [0=split 1=slotted or fowler]                  1
     flap chord/wing chord ratio _ 1                           .060
     .... .......... ..... ..... _ 2                           .240
     .... .......... ..... ..... _ 3                           .000
     flap outer end semi-span (ratio)                          .899
     flap inner end semi-span (ratio)                          .149
     number of piston engines                                 0
     max design all-up mass                               45707.0
     max design diving speed [Mach no.]                        .900
     max lift coefficient - CLMAX                             1.200
     miscellaneous additional coefficient                      .003
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (continued)

```
CASE DATA :

     CASE No.         MACH No.          ALTITUDE           AIRCRAFT MASS
                                        m or ft              Kg or lb

        1               .80             35000.0              44315.0
        2               .27              5000.0              45482.0
        3               .22              5000.0              45512.0
        4               .19              5000.0              42964.0

     CASE No.      UNDERCARRIAGE      FLAP DEFLNS   deg      FLAP EXTN
                   0=up   1=down      -1-    -2-    -3-        ratio

        1               0.             .0     .0     .0        1.00
        2               0.             .0     .0     .0        1.00
        3               0.            7.5   15.0     .0        1.29
        4               0.           20.0   40.0     .0        1.24
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_doc


CASE  1 OF  4

     FREE STREAM MACH No. =      .80
     ALTITUDE             =  10668.0  m
     AIRCRAFT MASS        =  20111.5  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =       .0  deg
                      -2- =       .0  deg
                      -3- =       .0  deg
     FLAP EXTENSION RATIO =     1.00
     TRUE AIRSPEED        =    250.5  m/s
     AIR TEMPERATURE      =    243.9  K
     AIR DENSITY          =     .384  Kg/m3
     UNIT REYNOLDS NO.    =    6.138E+06 per m

ZERO LIFT DRAG COEFFICIENT :      * Additional drag function called *
                                   Landing gear .... CDADDL =  .0000
     CDF   =  .0213                Flaps zero lift . CDADDF =  .0000
     CDC   =  .0016                Engine cooling .. CDADDC =  .0000
     CDADD =  .0033                Stores .......... CDADDS =  .0000
     CDMIN =  .0261                Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :    CD = .0261 + .0461 CL2

            CL          CD

          .1403       .0275
          .2403       .0283
          .3403       .0310
          .4403       .0345
          .4903       .0366
          .5403       .0395
          .5903       .0429
          .6403       .0466
          .7403       .0566
          .8403       .0697

Flap lift coefficient increment = .0000
FLAP PRESSURE DRAG COEFFICIENT  = .0000  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD            =  .0332
     CASE CL            =  .4045
     BUFFET ONSET CL    =  .6550
     DESIGN CL          =  .5403
     DRAG RISE MACH No. =  .8149
     CASE DRAG FORCE    =   16.3  KN
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_doc


CASE  2 OF  4

     FREE STREAM MACH No. =      .27
     ALTITUDE             =   1524.0  m
     AIRCRAFT MASS        =  20641.2  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =       .0  deg
                      -2- =       .0  deg
                      -3- =       .0  deg
     FLAP EXTENSION RATIO =     1.00
     TRUE AIRSPEED        =     93.6  m/s
     AIR TEMPERATURE      =    298.9  K
     AIR DENSITY          =     .995  Kg/m3
     UNIT REYNOLDS NO.    =    5.059E+06 per m

ZERO LIFT DRAG COEFFICIENT :        * Additional drag function called *
                                     Landing gear .... CDADDL =  .0000
     CDF    =  .0228                 Flaps zero lift . CDADDF =  .0000
     CDC    =  .0015                 Engine cooling .. CDADDC =  .0000
     CDADD =  .0033                  Stores .......... CDADDS =  .0000
     CDMIN =  .0276                  Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :     CD = .0276 + .0446 CL2

             CL           CD

           .1403        .0288
           .2403        .0298
           .3403        .0322
           .4403        .0358
           .4903        .0378
           .5403        .0406
           .5903        .0442
           .6403        .0473
           .7403        .0562
           .8403        .0704

Flap lift coefficient increment = .0000
FLAP PRESSURE DRAG COEFFICIENT  = .0000  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD            =  .0923
     CASE CL            = 1.1477
     BUFFET ONSET CL    = 1.2366
     DESIGN CL          =  .5403
     DRAG RISE MACH No. =  .8149
     CASE DRAG FORCE    =   16.4   KN
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (continued)

```
DELTADD DRAG ESTIMATE :  conv_doc


CASE  3 OF  4

     FREE STREAM MACH No. =       .22
     ALTITUDE             =    1524.0  m
     AIRCRAFT MASS        =   20654.8  Kg
     UNDERCARRIAGE (0=up) =        0
     FLAP DEFLECTION  -1- =       7.5  deg
                      -2- =      15.0  deg
                      -3- =        .0  deg
     FLAP EXTENSION RATIO =      1.29
     TRUE AIRSPEED        =      76.3  m/s
     AIR TEMPERATURE      =     298.9  K
     AIR DENSITY          =      .995  Kg/m3
     UNIT REYNOLDS NO.    =     4.122E+06 per m

ZERO LIFT DRAG COEFFICIENT :         * Additional drag function called *
                                      Landing gear .... CDADDL =  .0000
     CDF   =  .0236                   Flaps zero lift . CDADDF =  .0028
     CDC   =  .0015                   Engine cooling .. CDADDC =  .0000
     CDADD =  .0060                   Stores .......... CDADDS =  .0000
     CDMIN =  .0311                   Misc. extra ..... CDADDX =  .0033

OVERALL DRAG POLAR  :    CD = .0311 + .0000 CL2

             CL           CD

            .1403        .0323
            .2403        .0333
            .3403        .0357
            .4403        .0393
            .4903        .0413
            .5403        .0441
            .5903        .0477
            .6403        .0508
            .7403        .0597
            .8403        .0739

Flap lift coefficient increment = .9479
FLAP PRESSURE DRAG COEFFICIENT  = .0123  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD              =  .1681
     CASE CL              = 1.7298
     BUFFET ONSET CL      = 1.2550
     DESIGN CL            =  .5403
     DRAG RISE MACH No.   =  .8149
     CASE DRAG FORCE      =   19.8   KN
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (continued)

```
 DELTADD DRAG ESTIMATE :  conv_doc


 CASE  4 OF  4

      FREE STREAM MACH No. =       .19
      ALTITUDE             =    1524.0  m
      AIRCRAFT MASS        =   19498.4  Kg
      UNDERCARRIAGE (0=up) =         0
      FLAP DEFLECTION  -1- =      20.0  deg
                       -2- =      40.0  deg
                       -3- =        .0  deg
      FLAP EXTENSION RATIO =      1.24
      TRUE AIRSPEED        =      64.5  m/s
      AIR TEMPERATURE      =     298.9  K
      AIR DENSITY          =      .995  Kg/m3
      UNIT REYNOLDS NO.    =     3.485E+06 per m


 ZERO LIFT DRAG COEFFICIENT :        * Additional drag function called *
                                      Landing gear .... CDADDL =  .0000
     CDF   =  .0243                   Flaps zero lift . CDADDF =  .0175
     CDC   =  .0015                   Engine cooling .. CDADDC =  .0000
     CDADD =  .0208                   Stores .......... CDADDS =  .0000
     CDMIN =  .0465                   Misc. extra ..... CDADDX =  .0033


 OVERALL DRAG POLAR  :     CD = .0465 + .0000 CL2

               CL           CD

             .1403        .0478
             .2403        .0488
             .3403        .0512
             .4403        .0548
             .4903        .0567
             .5403        .0596
             .5903        .0632
             .6403        .0663
             .7403        .0752
             .8403        .0894

Flap lift coefficient increment =1.3525
FLAP PRESSURE DRAG COEFFICIENT  = .0250  [NOT included in above CD values]

SPECIFIC CASE OUTPUT :

     CASE CD             =  .2761
     CASE CL             = 2.2845
     BUFFET ONSET CL     = 1.2569
     DESIGN CL           =  .5403
     DRAG RISE MACH No.  =  .8149
     CASE DRAG FORCE     =   23.3  KN
```

Fig. G2 - Conventional D.O.C. Optimised Concept Drag Estimate
Deltadd Output file (concluded)

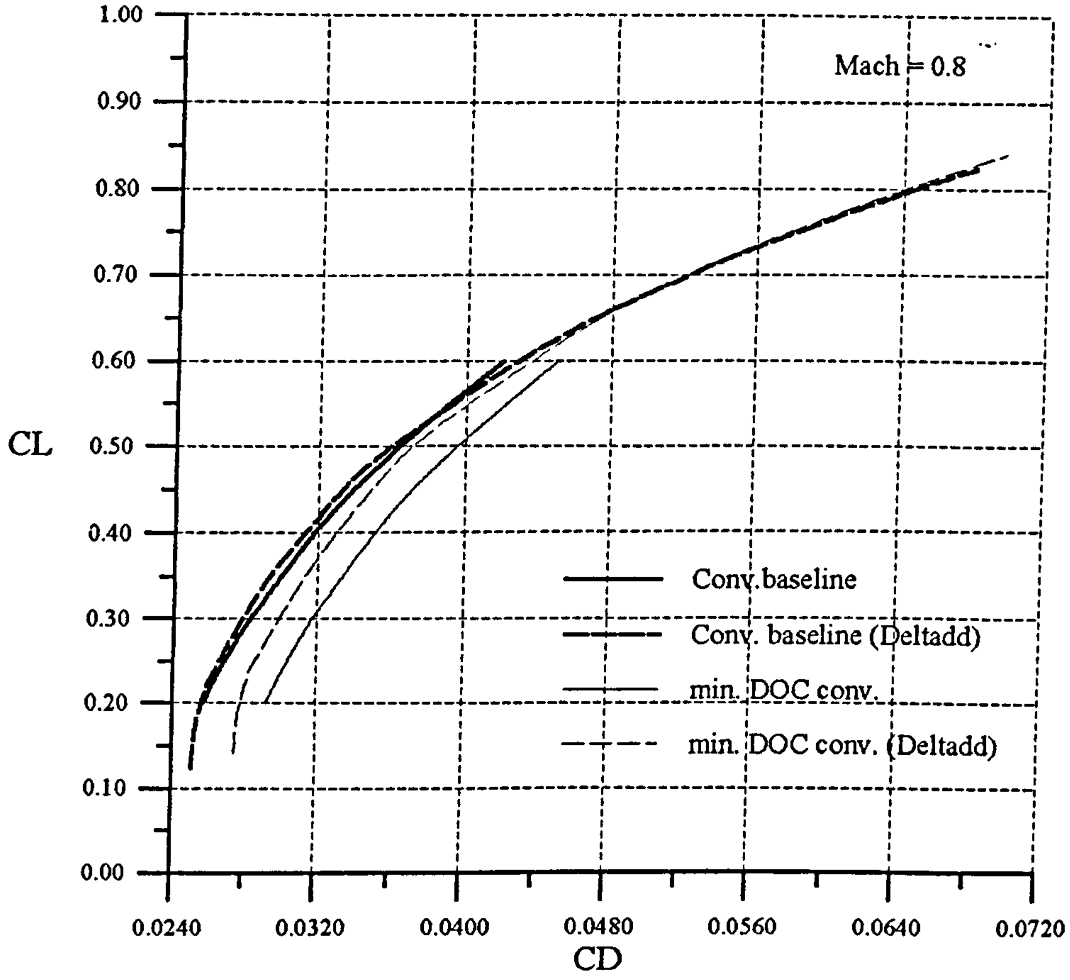

Fig. G3 - Conventional concepts cruise drag polars (comparision with Deltadd results)

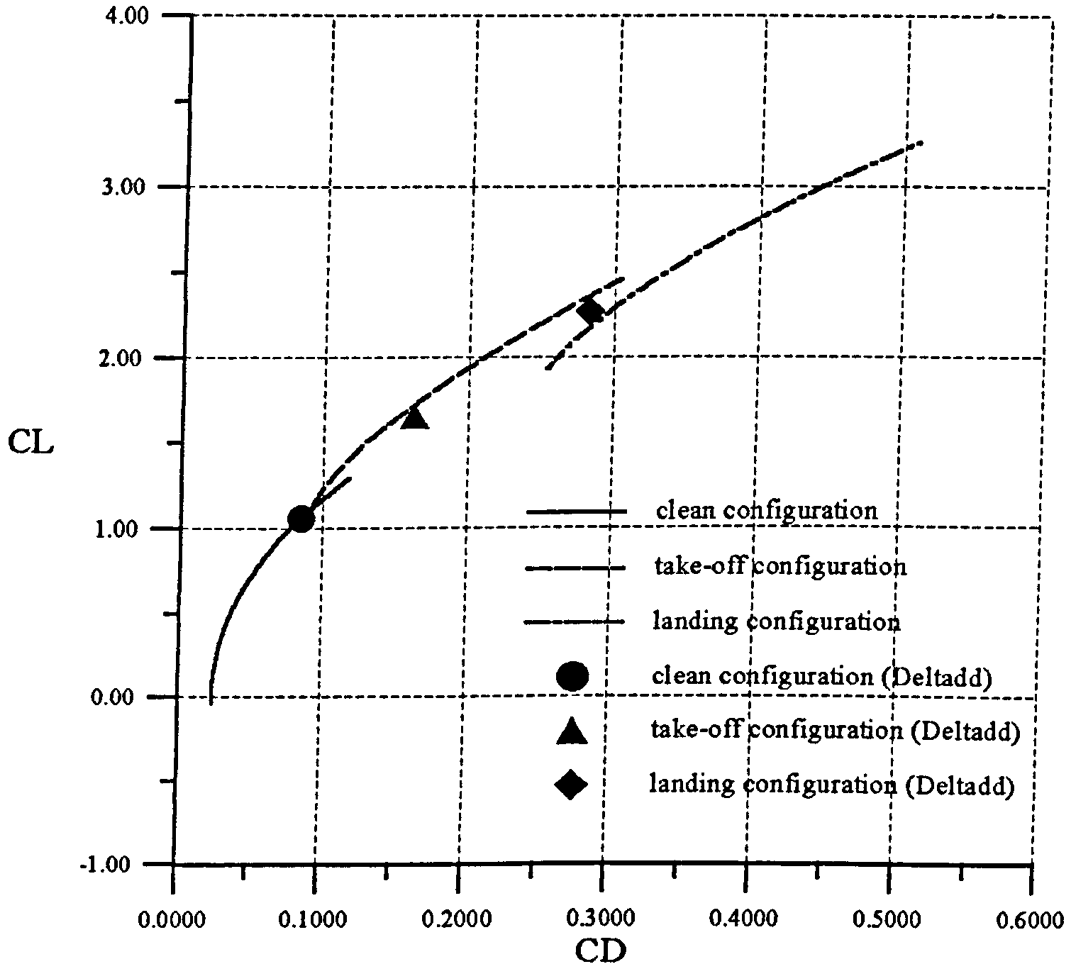

Fig. G4 - Conventional baseline concept low speed drag polars (comparision with Deltadd case results)

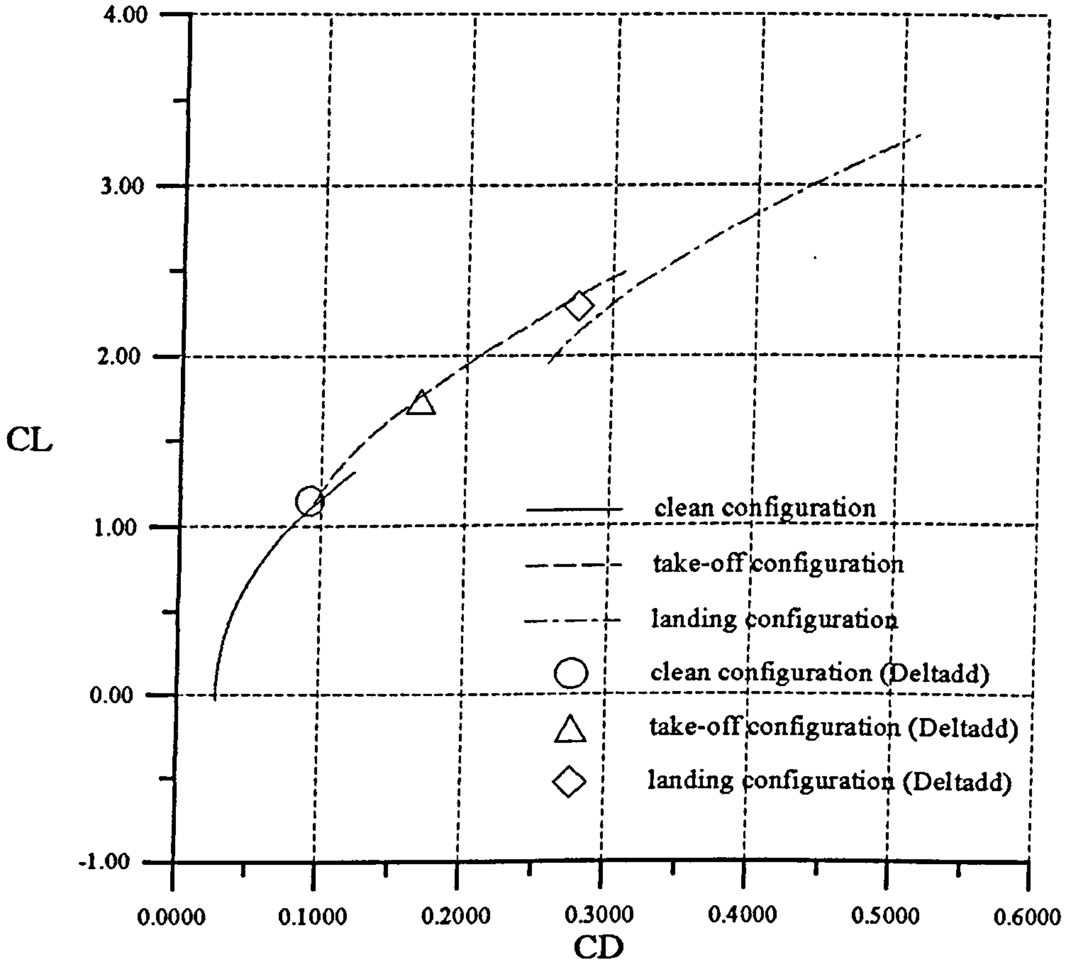

Fig. G5 - Minimum D.O.C. Conventional concept low speed drag polars (comparision with Deltadd case results)

```
6
'50 Pax Turbofan Conventional Airliner (Baseline)'

4.368851 5.278069 13.390931 10.764469 2.8194 2.8194 .762 2.907082 .0
4.234891 .8470392 18.723 10.544556 .115 2. 2.333 .846978 .169408
9.530156 10.444556 -25. 15. .0 .0 .0 .0 .0
7.597141 4.456842 2.771546 52.459 4.774997 4.774997 .12 1.4097 1.337053
.831464 1.4859 4.4196 25.
13.831248 2.751125 2.259787 28.593 5.011064 .962894 .790926 .231648
4.8768 .1 .0 -25. 15. -7. 7.
2.234794 7.349795 -.8001 44126.80 -98.060 .16343 -5.134196 1.216152
.0 .0 .0 .0 .0 .0 .0 .0
-1.6 .0238 -.021 1.2 .0
.0 .0 .0 .0
8169.1986 2439.4198 246.7542 430.9128 408.5733 3609.6881 4535.9237 .8
1
10668.0 .8 21065.737 3.486 .0 .0
```

Fig. G6.1 - Conventional Baseline Concept Stability and Control Evaluation Mitchell Program Input file

```
1STABILITY WITH CONTROLS FIXED AND RESPONSE TO CONTROLS FOR A RIGID AIRCRAFT (METRIC UNITS)

 DESCRIPTION : '50 Pax Turbofan Conventional Airliner (Baseline)'

 OCASE  1 OF  1

 0PRINCIPAL GEOMETRIC PARAMETERS
 0WING SPAN =  21.1    OVERALL LENGTH =  29.6    FUSELAGE LENGTH =  24.2
 0WING
 0AREA =   53.6    ASPECT RATIO =  8.30    TAPER RATIO =  .200    1/4C SWEEP = 14.5
 0SMC =  2.54     MAC =  2.92    LE OF MAC FROM APEX DATUM =  1.39
 0TAILPLANE
 0AREA =   25.1    ASPECT RATIO =  4.00    TAPER RATIO =  .821    1/4C SWEEP = 27.5
 0ARM =  12.3    HEIGHT =  4.84    VOLUME = 2.267
 0FIN
 0AREA(GROSS) =  16.3    AREA(NET) =  11.3    ASPECT RAIO (GROSS) = 1.494    1/4C SWEEP = 50.5
 0ARM =   8.9    HEIGHT TO CP =  3.1    VOLUME =  .128


 0CONFIGURATION DATA INSERTED
 0WING AND FLAPS
 0ALPHA 0(3-D) =  -1.6 DEGREES   DCL-FLAP (2-D) =  .000    CLMAX (3-D) = 1.200    CM0 =  -.0210
 0CDO A/C =  .0238    TAILPLANE SETTING =   .0 DEGREES


 0FLIGHT CONDITIONS
 0MASS =  21065.7    HEIGHT = 10668.0    SPEED =  237.2    MACH NO =  .800
 0CG FROM DATUM =  3.49    CG POSITION = 82.49% SMC    CG ABOVE DATUM =   .00
 0INCIDENCE (ALPHA) =   1.3    CL =   .361


 0LONGITUDINAL STABILITY
 0WING CL =   .330    TAIL CL =   .066    TAIL LOAD UP =  17786.0N   ELEVATOR ANGLE TO TRIM =   3.9
 0WING AC FROM DATUM =  2.17 (= 30.55% SMC)    WING A1 = 6.533    A/C A1 = 7.791
 0NEUTRAL POINT (TAIL OFF) =  1.41 (=   .88% SMC)    (TAIL ON) =  3.78 (= 94.08% SMC)    STATIC MARGIN =  11.58%
 SMC
 0DOWNWASH GRADIENT DE/DA =  .377   Q/QO AT TAILPLANE = 1.000    TAIL A1 = 4.311    ELEVATOR A2 = 2.946

 0LONGITUDINAL STABILITY DERIVATIVES
 0  XU =  -.0284    XW =   .0896    XQ =  0.0000
 0  ZU =  -.3609    ZW = -3.9097    ZQ = -1.0101
 0  MU =  0.0000    MW =  -.0932    MQ = -1.0404    MDW =  -.3809


 0LATERAL STABILITY DERIVATIVES
 0  LV =  -.1236        NV =   .1551        YV =  -.4728    NV (TAIL OFF) =  -.1169
 0  LR =   .1085        NR =  -.2304
 0  LP =  -.5127        NP =  -.0232


 0LATERAL CONTROL DERIVATIVES
 0FIN A1 = 2.131    RUDDER A2 =  .789
 0AILERON LXI =  -.0305   NXI =   .0014
 0SPOILER  L =  .0000     N =  .0000
 0RUDDER LZETA =   .0353   NZETA =  -.1007
 1MOMENTS OF INERTIA (M.KG.UNITS)
 0IX =     110284.    IY =     596303.    IZ =     696728.    IXZ =           0.
 0NON-DIMENSIONAL QUANTITIES
  AERO T =  4.365    MU1 = 84.247    MU2 = 98.213
  IX =  .04712    IZ =  .29742    IXZ = -.00309
  IY =  .18733
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation
Mitchell Program Output file

```
0LONGITUDINAL MODES, STICK FIXED

 ROOTS OF          REAL PART   IMAG. PART

 MODE 1             -1.3144      1.2599
 MODE 2             -1.3144     -1.2599
 MODE 3              -.0029       .0475
 MODE 4              -.0029      -.0475



 VECTORS     REAL PART    IMAG.PART    AMPLITUDE     PHASE


 MODE 2

 U            -.0009       .0011       .0014     -130.11
 W            -.0526       .1583       .1668     -108.37
 Q             .9783       .0000       .9783        .00
 THETA          -.0889       .0852       .1231     -136.22

 MODE 4

 U            -.0574      -.6440       .6466      95.10
 W             .0018       .0205       .0205     -84.93
 Q            -.0095      -.1549       .1552      93.52
 THETA          .7466       .0000       .7466        .00

0STABILITY PARAMETERS

0MODE 2 IS OSCILLATORY
0      FREQUENCY= .2005HZ (= 1.260RAD/S)   PERIOD= 4.987SEC.
          UNDAMPED FREQ.= 1.821RAD/S
0      DAMPING-- ANGLE=46.22DEG.   RATIO(ZETA)= .722
         TIME TO HALF-AMP= .527SEC.    CYCLES TO HALF-AMP= .106
          LOG.DEC.= 6.555

0MODE 4 IS OSCILLATORY
0      FREQUENCY= .0076HZ (= .048RAD/S)   PERIOD=132.159SEC.
          UNDAMPED FREQ.= .048RAD/S
0      DAMPING-- ANGLE= 3.51DEG.   RATIO(ZETA)= .061
         TIME TO HALF-AMP=237.671SEC.    CYCLES TO HALF-AMP= 1.798
          LOG.DEC.= .385

0NORMAL ACCELERATION NZ/ALPHA = .378 G/DEGREE
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation Mitchell Program Output file (continued)

```
1LATERAL MODES, STICK FIXED

 ROOTS OF          REAL PART   IMAG. PART

 MODE 1             -.1167      1.7170
 MODE 2             -.1167     -1.7170
 MODE 3            -2.5453       .0000
 MODE 4             -.0054       .0000
 MODE 5              .0000       .0000



 VECTORS     REAL PART    IMAG.PART    AMPLITUDE      PHASE


 MODE 2

 V          -.0388       .0244        .0459     -147.83
 P           .9350       .0000        .9350         .00
 R          -.1860      -.2676        .3259      124.81
 PHI        -.0084       .1242        .1245      -93.90
 PSI         .0372      -.0223        .0434       30.92

 MODE 3

 V           .0008
 P           .9959
 R          -.0076
 PHI        -.0896
 PSI         .0007

 MODE 4

 V          -.0003
 P           .0031
 R          -.0233
 PHI        -.1301
 PSI         .9912

 MODE 5 HAS ONLY CONSTANT TERMS


0STABILITY PARAMETERS

0MODE 2 IS OSCILLATORY
0      FREQUENCY= .2733HZ (= 1.717RAD/S)   PERIOD= 3.659SEC.
          UNDAMPED FREQ.= 1.721RAD/S
0      DAMPING-- ANGLE= 3.89DEG.   RATIO(ZETA)= .068
         TIME TO HALF-AMP= 5.937SEC.   CYCLES TO HALF-AMP= 1.622
          LOG.DEC.= .427

0MODE 3 IS EXPONENTIAL     TIME CONSTANT= .393SEC.

0MODE 4 IS EXPONENTIAL     TIME CONSTANT=185.507SEC.

0MODE 5 IS NEUTRALLY STABLE


0SINGLE DEGREE OF FREEDOM ROLLING DUE TO AILERONS
0ROLL ACCELERATION = 1.164 RAD.SEC-2    STEADY ROLL RATE = .467 RAD/SEC    TIME FROM +30 TO -30 BANK =
3.029 SEC
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation
Mitchell Program Output file (continued)

```
1FULL RESPONSE TO A STEP APPLICATION OF FULL AILERON AND SPOILER
0 TIME     SLIP   DP/DT      P       PHI     DR/DT     R      PSI
   .000    .000    .000    .000    .000    .000    .000    .000
   .218   -.001   -.645   -.195   -.023    .016    .004    .000
   .437   -.002   -.346   -.306   -.079    .010    .007    .002
   .655   -.005   -.170   -.365   -.153    .001    .008    .003
   .873   -.008   -.071   -.391   -.236   -.008    .008    .005
  1.091   -.012   -.002   -.399   -.323   -.018    .005    .007
  1.310   -.016    .035   -.395   -.409   -.027    .000    .007
  1.528   -.019    .048   -.386   -.495   -.034   -.007    .007
  1.746   -.021    .044   -.375   -.578   -.039   -.015    .004
  1.964   -.022    .029   -.366   -.658   -.039   -.023    .000
  2.183   -.021    .007   -.361   -.738   -.037   -.032   -.006
  2.401   -.020   -.014   -.361   -.816   -.031   -.039   -.013
  2.619   -.018   -.032   -.365   -.896   -.025   -.046   -.023
  2.838   -.016   -.048   -.373   -.976   -.016   -.050   -.033
  3.056   -.013   -.055   -.384  -1.059   -.010   -.053   -.045
  3.274   -.011   -.055   -.397  -1.144   -.003   -.055   -.057
  3.492   -.009   -.046   -.408  -1.232    .001   -.055   -.069
  3.711   -.009   -.032   -.417  -1.322    .003   -.055   -.081
  3.929   -.009   -.013   -.423  -1.414    .001   -.054   -.093
  4.147   -.010    .004   -.425  -1.506   -.002   -.054   -.104
  4.365   -.012    .024   -.422  -1.599   -.008   -.055   -.116
  4.584   -.014    .038   -.416  -1.690   -.014   -.057   -.129
  4.802   -.017    .046   -.407  -1.780   -.019   -.061   -.141
  5.020   -.019    .049   -.397  -1.868   -.024   -.065   -.155
  5.238   -.021    .045   -.386  -1.953   -.029   -.071   -.170
  5.457   -.022    .035   -.377  -2.037   -.031   -.078   -.186
  5.675   -.023    .020   -.371  -2.118   -.031   -.084   -.204
  5.893   -.022    .006   -.367  -2.199   -.029   -.091   -.223
  6.112   -.022   -.009   -.367  -2.279   -.025   -.097   -.244
  6.330   -.020   -.023   -.370  -2.359   -.020   -.102   -.265
  6.548   -.019   -.030   -.376  -2.441   -.016   -.106   -.288

1FULL RESPONSE TO A STEP APPLICATION OF FULL RUDDER
0 TIME     SLIP   DP/DT      P       PHI     DR/DT     R      PSI
   .000    .000   -.030    .000    .000   -.016    .000    .000
   .218    .023    .600    .262    .033   -.671   -.161   -.018
   .437    .078   -.277    .305    .098   -.497   -.292   -.068
   .655    .156  -1.022    .164    .153   -.264   -.377   -.142
   .873    .244  -1.570   -.118    .160    .007   -.408   -.229
  1.091    .331  -1.808   -.487    .095    .245   -.384   -.316
  1.310    .405  -1.770   -.883   -.055    .429   -.314   -.393
  1.528    .456  -1.495  -1.247   -.288    .542   -.208   -.450
  1.746    .478   -.957  -1.530   -.593    .574   -.085   -.483
  1.964    .470   -.413  -1.696   -.948    .523    .038   -.488
  2.183    .434    .188  -1.728  -1.324    .404    .141   -.468
  2.401    .377    .774  -1.627  -1.692    .222    .212   -.428
  2.619    .307   1.232  -1.415  -2.026    .005    .242   -.378
  2.838    .234   1.467  -1.124  -2.304   -.191    .227   -.326
  3.056    .169   1.499   -.798  -2.514   -.348    .171   -.282
  3.274    .119   1.330   -.483  -2.653   -.468    .083   -.254
  3.492    .091   1.018   -.221  -2.729   -.519   -.026   -.247
  3.711    .088    .543   -.046  -2.756   -.504   -.139   -.265
  3.929    .108    .055    .025  -2.756   -.428   -.242   -.307
  4.147    .147   -.473   -.015  -2.753   -.287   -.323   -.369
  4.365    .200   -.853   -.153  -2.770   -.134   -.373   -.446
  4.584    .258  -1.122   -.366  -2.825    .038   -.387   -.529
  4.802    .313  -1.210   -.621  -2.933    .173   -.366   -.612
  5.020    .358  -1.132   -.881  -3.097    .294   -.315   -.687
  5.238    .387   -.933  -1.111  -3.315    .352   -.245   -.748
  5.457    .397   -.599  -1.280  -3.577    .363   -.166   -.793
  5.675    .387   -.140  -1.369  -3.868    .310   -.090   -.821
  5.893    .360    .258  -1.369  -4.168    .217   -.029   -.834
  6.112    .320    .564  -1.285  -4.459    .112    .009   -.835
  6.330    .273    .849  -1.131  -4.724   -.035    .019   -.832
  6.548    .226    .966   -.933  -4.950   -.148    .001   -.829
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation
Mitchell Program Output file (continued)

```
1FULL RESPONSE TO AN ENGINE FAILURE, CONTROLS FIXED
0  TIME     SLIP   DP/DT     P       PHI    DR/DT     R        PSI
   .000    .000    .966    .000    .000   -.148    .000    .000
   .218   -.001    .011    .001    .000    .026    .006    .001
   .437   -.003    .031    .005    .001    .019    .011    .003
   .655   -.005    .048    .013    .002    .012    .015    .006
   .873   -.009    .064    .025    .006    .002    .017    .009
  1.091   -.012    .071    .040    .014   -.008    .016    .013
  1.310   -.015    .069    .056    .024   -.014    .014    .016
  1.528   -.017    .057    .070    .038   -.019    .010    .019
  1.746   -.018    .038    .081    .054   -.021    .006    .020
  1.964   -.017    .016    .088    .073   -.019    .001    .021
  2.183   -.016   -.007    .090    .092   -.014   -.002    .021
  2.401   -.014   -.027    .086    .112   -.008   -.005    .020
  2.619   -.012   -.044    .079    .130    .000   -.006    .019
  2.838   -.009   -.054    .068    .146    .007   -.005    .018
  3.056   -.006   -.057    .056    .159    .013   -.003    .017
  3.274   -.004   -.050    .044    .170    .019    .000    .016
  3.492   -.003   -.039    .034    .178    .020    .005    .017
  3.711   -.003   -.020    .027    .185    .020    .009    .018
  3.929   -.004    .000    .024    .190    .017    .013    .021
  4.147   -.005    .017    .025    .195    .012    .016    .024
  4.365   -.007    .031    .030    .201    .007    .019    .028
  4.584   -.009    .041    .037    .209    .000    .020    .032
  4.802   -.011    .045    .047    .218   -.005    .019    .036
  5.020   -.013    .043    .056    .229   -.010    .018    .040
  5.238   -.014    .034    .065    .242   -.012    .015    .044
  5.457   -.014    .022    .072    .257   -.013    .012    .047
  5.675   -.014    .006    .075    .273   -.011    .010    .049
  5.893   -.013   -.010    .076    .290   -.007    .008    .051
  6.112   -.012   -.022    .073    .306   -.003    .006    .053
  6.330   -.010   -.031    .067    .322    .002    .006    .054
  6.548   -.008   -.036    .060    .335    .006    .007    .056
```

```
1FULL RESPONSE TO A 10  M/S SIDE GUST, CONTROLS FIXED
0  TIME     SLIP   DP/DT     P       PHI    DR/DT     R        PSI
   .000    .000   -.036    .000    .000    .006    .000    .000
   .218   -.004   -.261   -.092   -.011    .101    .025    .003
   .437   -.012   -.040   -.129   -.036    .071    .044    .010
   .655   -.025    .110   -.124   -.065    .035    .057    .022
   .873   -.038    .208   -.090   -.088   -.002    .061    .035
  1.091   -.052    .264   -.038   -.102   -.041    .056    .047
  1.310   -.064    .266    .021   -.104   -.072    .044    .059
  1.528   -.072    .230    .076   -.093   -.089    .027    .066
  1.746   -.076    .160    .120   -.072   -.095    .007    .070
  1.964   -.075    .063    .146   -.042   -.087   -.014    .069
  2.183   -.069   -.027    .151   -.009   -.069   -.031    .064
  2.401   -.060   -.116    .136    .022   -.041   -.043    .056
  2.619   -.049   -.189    .103    .049   -.008   -.049    .046
  2.838   -.038   -.228    .058    .066    .024   -.048    .035
  3.056   -.028   -.233    .007    .073    .051   -.040    .025
  3.274   -.020   -.210   -.042    .070    .067   -.028    .018
  3.492   -.016   -.152   -.083    .056    .076   -.012    .013
  3.711   -.015   -.089   -.111    .034    .074    .005    .013
  3.929   -.018    .002   -.122    .009    .060    .020    .015
  4.147   -.025    .071   -.116   -.018    .041    .031    .021
  4.365   -.033    .132   -.095   -.041    .017    .038    .029
  4.584   -.042    .176   -.061   -.058   -.011    .039    .037
  4.802   -.051    .190   -.021   -.067   -.032    .035    .045
  5.020   -.058    .177    .019   -.067   -.051    .026    .052
  5.238   -.062    .143    .056   -.059   -.060    .014    .057
  5.457   -.064    .086    .082   -.044   -.061    .001    .058
  5.675   -.063    .024    .097   -.024   -.053   -.012    .057
  5.893   -.059   -.039    .097   -.003   -.039   -.023    .053
  6.112   -.052   -.088    .084    .017   -.022   -.030    .048
  6.330   -.045   -.128    .061    .033   -.002   -.032    .041
  6.548   -.038   -.150    .030    .043    .018   -.031    .034
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation Mitchell Program Output file (continued)

```
1LOW SPEED HANDLING AT SEA LEVEL
0STALL SPEED = 134.0KN    INCIDENCE = 13.2
0TAILPLANE SETTING =  -7.0    ELEVATOR ANGLE =   7.8    TAIL CL =   .266    TAIL INCIDENCE =   -.9
0NOSEWHEEL LIFTED BY THRUST
0MINIMUM CONTROL SPEED = 104.6 KNOTS

0STEADY SIDESLIP AT SPEED   174.2 KNOTS
0AILERON LIMITED (AILERONS AND SPOILERS AT 0.8 OF MAXIMUM DEFLECTIONS)
0SLIP ANGLE =   .043 RADS    CROSSWIND SPEED =   7.4 KNOTS    RUDDER ANDLE =   3.6 DEG.
0
```

Fig. G6.2 - Conventional Baseline Concept Stability and Control Evaluation
Mitchell Program Output file (concluded)

```
6
'50 Pax Turbofan Conventional Airliner (DOC optimised)'

3.473348 6.173572 12.495428 11.659972 2.8194 2.8194 .762 2.399093 .0
3.798418 .6269736 16.859 9.115958 .115 2. 2.333 .7596835 .1253947
8.246669 8.9916 -25. 15. .0 .0 .0 .0 .0
7.519788 3.569822 2.199742 52.435 4.522013 4.522013 .12 1.4097 .942838
.659922 1.4859 4.2672 25.
13.575951 2.022958 2.022958 20.951 3.96682 .708035 .708035 .231648
3.9624 .1 .0 -25. 15. -7. 7.
2.227722 6.454292 -.8001 43960.88 -97.691 .16282 -4.324694 1.213104
.0 .0 .0 .0 .0 .0 .0 .0
-1.6 .0273 -.025 1.2 .0
.0 .0 .0 .0
7941.9488 1989.4561 205.0238 337.0191 401.7694 3524.4127 4535.9237 .8
1
10668. .8 20048.783 2.62207 .0 .0
```

Fig. G7.1 - Conventional D.O.C. optimised Concept Stability and Control Evaluation Mitchell Program Input file

```
1STABILITY WITH CONTROLS FIXED AND RESPONSE TO CONTROLS FOR A RIGID AIRCRAFT (METRIC UNITS)

 DESCRIPTION : '50 Pax Turbofan Conventional Airliner (DOC optimised)'

 OCASE  1 OF  1

 0PRINCIPAL GEOMETRIC PARAMETERS
 0WING SPAN =  18.2   OVERALL LENGTH =  28.8   FUSELAGE LENGTH =  24.2
 0WING
 0AREA =   40.3   ASPECT RATIO =  8.24   TAPER RATIO =  .165   1/4C SWEEP = 12.2
 0SMC =  2.21    MAC =  2.59   LE OF MAC FROM APEX DATUM =  1.05
 0TAILPLANE
 0AREA =   16.0   ASPECT RATIO =  3.92   TAPER RATIO = 1.000   1/4C SWEEP = 21.0
 0ARM =  12.2   HEIGHT =  4.59   VOLUME = 2.197
 0FIN
 0AREA(GROSS) =  12.2   AREA(NET) =   8.3   ASPECT RAIO (GROSS) = 1.592   1/4C SWEEP = 50.8
 0ARM =   9.3   HEIGHT TO CP =  2.9   VOLUME =  .155


 0CONFIGURATION DATA INSERTED
 0WING AND FLAPS
 0ALPHA 0(3-D) =  -1.6 DEGREES   DCL-FLAP (2-D) =  .000   CLMAX (3-D) = 1.200   CM0 =  -.0250
 0CDO A/C =  .0273   TAILPLANE SETTING =   .0 DEGREES


 0FLIGHT CONDITIONS
 0MASS =  20048.8   HEIGHT = 10668.0   SPEED =  237.2   MACH NO =  .800
 0CG FROM DATUM =  2.62   CG POSITION = 70.99% SMC   CG ABOVE DATUM =   .00
 0INCIDENCE (ALPHA) =   2.1   CL =   .456


 0LONGITUDINAL STABILITY
 0WING CL =   .430   TAIL CL =   .067   TAIL LOAD UP =  11469.5N  ELEVATOR ANGLE TO TRIM =   3.1
 0WING AC FROM DATUM =  1.74 (= 30.96% SMC)   WING A1 = 6.572   A/C A1 = 7.685
 0NEUTRAL POINT (TAIL OFF) =   .82 (=-10.63% SMC)   (TAIL ON) =  2.89 (= 82.89% SMC)   STATIC MARGIN =  11.90%
 SMC
 0DOWNWASH GRADIENT DE/DA =  .365   Q/QO AT TAILPLANE = 1.000   TAIL A1 = 4.405   ELEVATOR A2 = 2.980

 0LONGITUDINAL STABILITY DERIVATIVES
 0  XU =  -.0351    XW =   .1082    XQ =  0.0000
 0  ZU =  -.4563    ZW = -3.8600    ZQ =  -.8762
 0  MU =  0.0000    MW =  -.0828    MQ =  -.8914    MDW =  -.3197


 0LATERAL STABILITY DERIVATIVES
 0  LV =  -.1313      NV =   .1715      YV =  -.5427     NV (TAIL OFF) =  -.1824
 0  LR =   .1445      NR =  -.3634
 0  LP =  -.5117      NP =  -.0294


 0LATERAL CONTROL DERIVATIVES
 0FIN A1 = 2.289   RUDDER A2 =  .869
 0AILERON LXI =  -.0276   NXI =   .0016
 0SPOILER  L =   .0000    N =   .0000
 0RUDDER LZETA =   .0411   NZETA =  -.1343
 1MOMENTS OF INERTIA (M.KG.UNITS)
 0IX =       73823.    IY =      562709.    IZ =      627646.    IXZ =           0.
 0NON-DIMENSIONAL QUANTITIES
 AERO T =  5.519   MU1 =107.146   MU2 =143.618
 IX =  .04431   IZ =  .37672   IXZ =  .00085
 IY =  .18798
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation
Mitchell Program Output file

```
0LONGITUDINAL MODES, STICK FIXED

 ROOTS OF        REAL PART   IMAG. PART

 MODE 1           -.9327      1.1266
 MODE 2           -.9327     -1.1266
 MODE 3           -.0027       .0497
 MODE 4           -.0027      -.0497



 VECTORS    REAL PART   IMAG.PART   AMPLITUDE    PHASE


 MODE 2

 U         -.0006       .0018       .0019     -109.80
 W         -.0309       .1501       .1532     -101.66
 Q          .9807       .0000       .9807        .00
 THETA        -.0775       .0936       .1215     -129.63

 MODE 4

 U         -.0544      -.6217       .6241       95.00
 W          .0021       .0207       .0208      -84.17
 Q         -.0111      -.2065       .2068       93.09
 THETA         .7532       .0000       .7532        .00

0STABILITY PARAMETERS

0MODE 2 IS OSCILLATORY
0       FREQUENCY= .1793HZ (= 1.127RAD/S)   PERIOD= 5.577SEC.
          UNDAMPED FREQ.= 1.463RAD/S
0       DAMPING-- ANGLE=39.62DEG.  RATIO(ZETA)= .638
          TIME TO HALF-AMP= .743SEC.   CYCLES TO HALF-AMP= .133
          LOG.DEC.= 5.202

0MODE 4 IS OSCILLATORY
0       FREQUENCY= .0079HZ (= .050RAD/S)   PERIOD=126.452SEC.
          UNDAMPED FREQ.= .050RAD/S
0       DAMPING-- ANGLE= 3.08DEG.  RATIO(ZETA)= .054
          TIME TO HALF-AMP=259.178SEC.   CYCLES TO HALF-AMP= 2.050
          LOG.DEC.= .338

0NORMAL ACCELERATION NZ/ALPHA = .295 G/DEGREE
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation Mitchell Program Output file (continued)

```
1LATERAL MODES, STICK FIXED

 ROOTS OF        REAL PART  IMAG. PART

 MODE 1           -.0697     1.5418
 MODE 2           -.0697    -1.5418
 MODE 3          -2.2158      .0000
 MODE 4           -.0092      .0000
 MODE 5            .0000      .0000



VECTORS   REAL PART   IMAG.PART   AMPLITUDE   PHASE


MODE 2

V          -.0264     .0177     .0318   -146.14
P           .9606     .0000     .9606      .00
R          -.1478    -.2018     .2501    126.23
PHI        -.0051     .1127     .1128    -92.60
PSI         .0245    -.0163     .0294     33.63

MODE 3

V           .0016
P           .9967
R           .0001
PHI        -.0815
PSI         .0000

MODE 4

V          -.0007
P           .0111
R          -.0495
PHI        -.2182
PSI         .9746

MODE 5 HAS ONLY CONSTANT TERMS

0STABILITY PARAMETERS

0MODE 2 IS OSCILLATORY
0     FREQUENCY= .2454HZ (= 1.542RAD/S)   PERIOD= 4.075SEC.
        UNDAMPED FREQ.= 1.543RAD/S
0     DAMPING-- ANGLE= 2.59DEG.   RATIO(ZETA)= .045
       TIME TO HALF-AMP= 9.940SEC.    CYCLES TO HALF-AMP= 2.439
        LOG.DEC.= .284

0MODE 3 IS EXPONENTIAL     TIME CONSTANT=  .451SEC.

0MODE 4 IS EXPONENTIAL     TIME CONSTANT=108.754SEC.

0MODE 5 IS NEUTRALLY STABLE


0SINGLE DEGREE OF FREEDOM ROLLING DUE TO AILERONS
0ROLL ACCELERATION = 1.025 RAD.SEC-2    STEADY ROLL RATE =  .490 RAD/SEC    TIME FROM +30 TO -30 BANK =
3.055 SEC
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation
Mitchell Program Output file (continued)

```
1FULL RESPONSE TO A STEP APPLICATION OF FULL AILERON AND SPOILER
0 TIME    SLIP   DP/DT     P      PHI    DR/DT    R      PSI
   .000   .000   .000   .000   .000   .000   .000   .000
   .276   .000  -.569  -.214  -.032   .008   .002   .000
   .552  -.002  -.291  -.332  -.109   .006   .004   .001
   .828  -.005  -.137  -.391  -.210   .001   .005   .002
  1.104  -.009  -.024  -.413  -.322  -.008   .004   .004
  1.380  -.014   .037  -.412  -.436  -.018   .001   .004
  1.656  -.018   .064  -.399  -.548  -.026  -.005   .004
  1.932  -.022   .072  -.380  -.656  -.033  -.013   .001
  2.207  -.025   .059  -.361  -.758  -.037  -.023  -.004
  2.483  -.025   .031  -.347  -.855  -.036  -.033  -.011
  2.759  -.025   .002  -.341  -.950  -.033  -.043  -.022
  3.035  -.022  -.030  -.344 -1.044  -.026  -.051  -.035
  3.311  -.019  -.053  -.355 -1.140  -.018  -.058  -.050
  3.587  -.016  -.068  -.371 -1.240  -.010  -.062  -.067
  3.863  -.013  -.069  -.390 -1.345  -.004  -.064  -.084
  4.139  -.011  -.058  -.408 -1.456   .001  -.064  -.102
  4.415  -.010  -.037  -.422 -1.570   .002  -.063  -.119
  4.691  -.011  -.005  -.429 -1.688   .000  -.063  -.137
  4.967  -.013   .023  -.428 -1.806  -.005  -.063  -.154
  5.243  -.016   .044  -.420 -1.924  -.011  -.065  -.172
  5.519  -.020   .060  -.405 -2.038  -.018  -.069  -.190
  5.795  -.023   .067  -.388 -2.147  -.025  -.075  -.210
  6.071  -.026   .062  -.370 -2.252  -.029  -.082  -.232
  6.347  -.028   .044  -.354 -2.351  -.031  -.091  -.256
  6.622  -.028   .024  -.344 -2.447  -.031  -.099  -.282
  6.898  -.027  -.001  -.340 -2.542  -.027  -.108  -.311
  7.174  -.025  -.024  -.343 -2.636  -.022  -.115  -.341
  7.450  -.023  -.042  -.352 -2.731  -.015  -.120  -.374
  7.726  -.020  -.051  -.365 -2.830  -.009  -.123  -.407
  8.002  -.018  -.050  -.379 -2.933  -.005  -.126  -.442
  8.278  -.017  -.041  -.392 -3.039  -.002  -.126  -.476

1FULL RESPONSE TO A STEP APPLICATION OF FULL RUDDER
0 TIME    SLIP   DP/DT     P      PHI    DR/DT    R      PSI
   .000   .000  -.041   .000   .000  -.002   .000   .000
   .276   .033   .542   .345   .056  -.626  -.191  -.027
   .552   .112  -.715   .344   .158  -.412  -.341  -.101
   .828   .223 -1.601   .042   .218  -.167  -.427  -.209
  1.104   .345 -2.168  -.480   .161   .088  -.441  -.331
  1.380   .456 -2.347 -1.113  -.057   .328  -.383  -.446
  1.656   .536 -2.062 -1.736  -.452   .494  -.270  -.537
  1.932   .573 -1.478 -2.238 -1.004   .548  -.125  -.591
  2.207   .562  -.524 -2.532 -1.668   .493   .023  -.605
  2.483   .506   .318 -2.575 -2.378   .365   .145  -.581
  2.759   .417  1.225 -2.366 -3.065   .142   .218  -.530
  3.035   .311  1.790 -1.952 -3.665  -.077   .230  -.466
  3.311   .207  2.077 -1.412 -4.131  -.316   .178  -.409
  3.587   .124  1.980  -.845 -4.442  -.464   .072  -.373
  3.863   .074  1.488  -.351 -4.604  -.557  -.070  -.372
  4.139   .066   .792  -.012 -4.650  -.545  -.224  -.413
  4.415   .099  -.028   .117 -4.630  -.445  -.366  -.495
  4.691   .165  -.767   .023 -4.606  -.288  -.471  -.611
  4.967   .251 -1.405  -.269 -4.636  -.079  -.527  -.750
  5.243   .342 -1.736  -.699 -4.767   .117  -.527  -.897
  5.519   .421 -1.752 -1.187 -5.027   .281  -.475 -1.036
  5.795   .475 -1.457 -1.645 -5.420   .380  -.385 -1.156
  6.071   .494  -.924 -1.992 -5.925   .400  -.277 -1.247
  6.347   .477  -.233 -2.172 -6.503   .342  -.171 -1.309
  6.622   .428   .405 -2.159 -7.105   .231  -.089 -1.344
  6.898   .357  1.043 -1.962 -7.678   .058  -.047 -1.362
  7.174   .276  1.421 -1.622 -8.175  -.108  -.052 -1.374
  7.450   .200  1.568 -1.203 -8.565  -.269  -.104 -1.395
  7.726   .142  1.426  -.782 -8.839  -.384  -.194 -1.435
  8.002   .112   .998  -.432 -9.004  -.433  -.308 -1.504
  8.278   .112   .519  -.210 -9.089  -.414  -.426 -1.605
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation
Mitchell Program Output file (continued)

```
1FULL RESPONSE TO AN ENGINE FAILURE, CONTROLS FIXED
0 TIME     SLIP   DP/DT     P      PHI    DR/DT    R       PSI
   .000   .000    .519   .000    .000   -.414   .000   .000
   .276  -.001    .022   .002    .000    .028   .009   .001
   .552  -.005    .051   .011    .002    .020   .016   .005
   .828  -.009    .080   .029    .007    .009   .020   .010
  1.104  -.014    .101   .054    .019   -.003   .021   .015
  1.380  -.019    .104   .083    .037   -.013   .019   .021
  1.656  -.023    .091   .110    .064   -.020   .014   .025
  1.932  -.024    .061   .132    .098   -.022   .008   .028
  2.207  -.024    .020   .145    .136   -.019   .002   .030
  2.483  -.021   -.020   .147    .177   -.013  -.002   .030
  2.759  -.017   -.051   .138    .217   -.005  -.005   .029
  3.035  -.013   -.079   .120    .252    .005  -.005   .027
  3.311  -.008   -.090   .097    .282    .015  -.003   .026
  3.587  -.005   -.084   .073    .306    .022   .002   .026
  3.863  -.002   -.066   .051    .323    .025   .009   .027
  4.139  -.002   -.036   .036    .335    .025   .016   .031
  4.415  -.003   -.002   .031    .344    .021   .022   .036
  4.691  -.006    .031   .035    .353    .014   .027   .043
  4.967  -.010    .061   .047    .364    .005   .030   .051
  5.243  -.014    .074   .066    .379   -.003   .031   .060
  5.519  -.017    .075   .086    .400   -.011   .029   .068
  5.795  -.019    .064   .106    .427   -.015   .025   .075
  6.071  -.020    .042   .121    .458   -.016   .021   .082
  6.347  -.020    .008   .129    .493   -.013   .017   .087
  6.622  -.017   -.022   .128    .528   -.007   .014   .091
  6.898  -.014   -.045   .120    .563   -.001   .012   .095
  7.174  -.011   -.061   .105    .594    .006   .013   .098
  7.450  -.007   -.068   .087    .620    .013   .016   .102
  7.726  -.005   -.062   .068    .642    .018   .020   .107
  8.002  -.004   -.046   .053    .658    .020   .025   .113
  8.278  -.004   -.023   .044    .672    .019   .031   .121
```

```
1FULL RESPONSE TO A 10  M/S SIDE GUST, CONTROLS FIXED
0 TIME     SLIP   DP/DT     P      PHI    DR/DT    R       PSI
   .000   .000   -.023   .000    .000    .019   .000   .000
   .276  -.004   -.268  -.116   -.018    .078   .023   .003
   .552  -.015   -.012  -.155   -.057    .051   .042   .012
   .828  -.030    .158  -.138   -.099    .017   .052   .026
  1.104  -.046    .253  -.082   -.130   -.016   .053   .040
  1.380  -.060    .293  -.006   -.142   -.047   .044   .054
  1.656  -.071    .265   .074   -.133   -.070   .028   .064
  1.932  -.077    .198   .139   -.103   -.078   .008   .069
  2.207  -.076    .072   .179   -.058   -.071  -.013   .068
  2.483  -.069   -.043   .187   -.007   -.053  -.031   .062
  2.759  -.058   -.149   .163    .042   -.028  -.043   .051
  3.035  -.044   -.229   .110    .081    .002  -.047   .039
  3.311  -.031   -.269   .041    .102    .033  -.043   .026
  3.587  -.020   -.259  -.033    .103    .053  -.031   .016
  3.863  -.013   -.198  -.098    .084    .066  -.014   .009
  4.139  -.012   -.114  -.144    .050    .066   .004   .008
  4.415  -.016    .003  -.162    .008    .052   .021   .012
  4.691  -.024    .096  -.152   -.036    .033   .034   .019
  4.967  -.036    .180  -.115   -.074    .006   .040   .030
  5.243  -.048    .226  -.060   -.098   -.019   .039   .041
  5.519  -.058    .232   .004   -.106   -.040   .031   .050
  5.795  -.066    .200   .065   -.096   -.054   .018   .057
  6.071  -.069    .129   .112   -.071   -.058   .002   .060
  6.347  -.067    .048   .138   -.036   -.053  -.014   .058
  6.622  -.061   -.044   .138    .002   -.038  -.026   .053
  6.898  -.052   -.133   .115    .038   -.014  -.034   .044
  7.174  -.041   -.182   .072    .064    .007  -.035   .034
  7.450  -.032   -.203   .018    .076    .028  -.031   .025
  7.726  -.024   -.189  -.037    .074    .043  -.021   .018
  8.002  -.020   -.139  -.083    .057    .050  -.008   .014
  8.278  -.020   -.072  -.113    .029    .049   .006   .014
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation
Mitchell Program Output file (continued)

```
1LOW SPEED HANDLING AT SEA LEVEL
0STALL SPEED = 153.1KN    INCIDENCE = 13.1
0TAILPLANE SETTING =  -7.0    ELEVATOR ANGLE =   6.2    TAIL CL =   .207   TAIL INCIDENCE =   -.7
0NOSEWHEEL LIFT SPEED =  25.7KNOTS WITH TAILPLANE SET TO   -1.2DEGREES
0MINIMUM CONTROL SPEED = 111.4 KNOTS

0STEADY SIDESLIP AT SPEED   199.1 KNOTS
0AILERON LIMITED (AILERONS AND SPOILERS AT 0.8 OF MAXIMUM DEFLECTIONS)
0SLIP ANGLE =   .041 RADS    CROSSWIND SPEED =   8.1 KNOTS    RUDDER ANDLE =   2.9 DEG.
0
```

Fig. G7.2 - Conventional D.O.C. optimised Concept Stability and Control Evaluation Mitchell Program Output file (concluded)

APPENDIX H

List of GASP Input Variable Names

Introduction

This Appendix includes a complete list of GASP input variable names. These are grouped by disciplinary areas. Parameters related to the modifications done in GASP are shown in italics as well as their respective control options. The values included correspond to those proposed and used for the initial trial baseline configurations, both conventional and unconventional. These values also correspond to the starting point, or the initial estimate of the optimum solutions.

List of GASP Input Variable Names

Geometry

General data

IENGSZ	Engine cycle indicator - General Electric CF 34	5
Kanard	*Conventional (0) or Three-Lifting Surface concept (1) (option)*	
WG	take-off gross weight (initial guess) [lb]	44050
WGS	take-off wing loading (initial guess) [lb/sqft]	83
PAX	number of passengers	50
EMCRU	design cruise Mach number	0.8
HNCRU	design cruise altitude [ft]	35000
ENP	number of engines	2

KWRITE	selected summary statements are printed (option)	2
IGEAR	retractable landing gear (option)	0
KCONFG	conventional fuselage tail cone (option)	0
KTIPX	no tip tanks (option)	0
NTYE	turbofan engine (option)	7
KPLOT	plots aerodynamic data (option)	1

Fuselage data

SAB	seats abreast in fuselage	4
WS	seat width [in]	20
AS	number of aisles	1
WAS	aisle width [in]	19
PS	seat pitch [in]	31
ELPC	length of flight deck plus passenger door allowance [ft]	11.22
HCK	mean fuselage diameter minus nose cone max. diameter [ft] (≈ windscreen height)	2.47
ELODN	fuselage nose cone fineness ratio	1
ELODT	fuselage tail cone fineness ratio (assuming allowances for galley, toilet and rear passenger door)	3.2

Nacelle

KNAC	nacelle drag assumed as part of aircraft drag (option)	1
ELRW	length of pylon attachment for fuselage mounted engines [ft]	10
ELN	nacelle length [ft] (computed by program)	0
DBARN	nacelle mean diameter [ft] (computed by program)	0

Wing

AR	wing aspect ratio	8.3
TCT	wing tip thickness to chord ratio	0.10
TCR	wing root thickness to chord ratio	0.13

SLM	wing taper ratio	0.20
DLMC4	sweep of wing 1/4 chord [degrees]	14.5
EYEW	wing incidence to fuselage horizontal datum line [degrees]	2

Canard

ARcan	*canard aspect ratio*	*5.5*
TCcan	*canard thickness to chord ratio*	*0.10*
SLMcan	*canard taper ratio*	*0.50*
DwpqCa	*sweep of canard 1/4 chord [degrees]*	*15*
EYEcan	*canard incidence to fuselage horizontal datum line [degrees]*	*2*
SWcOSW	*canard to wing area ratio*	*0.145*

Horizontal tail

SAH	location of tailplane on vertical fin as a fraction of fin span	1
ARHT	tailplane aspect ratio	4
TCHT	tailplane thickness to chord ratio	0.10
SLMH	tailplane taper ratio (initial value)	0.55
DWPQCH	sweep of tailplane 1/4 chord [degrees]	27.5

Vertical tail

ARVT	fin aspect ratio	1
TCVT	fin thickness to chord ratio	0.12
SLMV	fin taper ratio	0.70
DWPQCV	sweep of fin 1/4 chord [degrees]	50.5

Aerodynamics

KWCD	number of points in wing/canard profile drag table	12
ACLS	values of C_L in wing/canard profile drag table: -1.0, -0.6, -0.4, -0.2, 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.2	
ACDCDR	normalized wing/canard profile drag values in wing/canard profile drag table: 2.400, 1.466, 1.221, 1.066, 1.005, 1.000, 1.005, 1.046, 1.138, 1.333, 1.743, 2.718	
DELCD	increment in overall drag coefficient	0.0015
DELFE	increment in equivalent flat plate area of fuselage [sqft]	0.2
SCFAC	shift in drag divergence Mach number due to supercritical aerofoil design	0.75
DLSWSW	increment in wetted area/wing area	0
ALPHL0	wing zero lift angle of attack [degrees]	-1.6
DCDSE	program computes increment in drag coefficient due to engine out (option)	-1.0
RCLMAX	maximum clean basic wing lift coefficient at reference conditions	1.2
ALTFLP	altitude for Reynolds number calculation (field conditions) [ft]	5000
cmacw	*wing pitching moment coefficient*	*-0.06*
alzerc	*canard zero lift angle of attack [degrees]*	*-1.0*
CKWc	*canard aerodynamic form factor (computed by program)*	*-1.0*

CKW	wing aerodynamic form factor (computed by program)	-1.0
CKHT	tailplane aerodynamic form factor (computed by program)	-1.0
CKVT	fin aerodynamic form factor (computed by program)	-1.0
CKF	fuselage aerodynamic form factor (computed by program)	-1.0
CKN	nacelle aerodynamic form factor (computed by program)	-1.0

Flaps

FLAPN	number of flap segments per wing panel	1
BENGOB	fraction of wing span without flaps due to wing mounted engine	0
JFLTYP	double slotted Fowler flaps (selection)	7
DFLPTO	take-off flap deflection [degrees]	15
DFLPLD	landing flap deflection [degrees]	40
CFOC	flap chord to wing chord ratio	0.30
BTEOB	flap span to wing span ratio	0.75
WCFLAP	flap weight trend coefficient (default function of flap type)	-1.0

Propulsion

JENGSZ	engines sized for cruise, take-off and climb (option)	2
IPART	FAR Part 25 turbine propulsion sizing requirements (option)	1
KODETO	engine power setting during take-off, maximum power (option)	5
KODECL	engine power setting during climb, maximum climb power (option)	7
KODEAC	engine power setting during acceleration, maximum power (option)	5
HPORT	take-off field altitude [ft]	5000
TDELTO	increment in take-off ambient temperature above ISA standard day [degree F]	36
RCCRU	required rate of climb at cruise conditions [fpm]	50
XTORQ	required take-off distance to 35 ft (not constrained)	99999
SM1D	engine face sea level static Mach number	0.5
HBTP	engine face hub/tip ratio	0.437
RWCRTX	ratio of cruise weight to maximum take-off gross weight (for engine sizing)	0.97
HSCREQ	engine out service ceiling required [ft]	0
THIN	input maximum static thrust for one engine (if engine known) [lb]	0
PR	inlet pressure recovery factor	1

Weights

SKPEI	weight trend coefficient of engine installation, fraction of dry engine	0.135
SKLG	weight trend coefficient of landing gear, fraction of gross weight	0.038
SKMG	main gear weight fraction of landing gear weight	0.8
SKPES	weight trend coefficient of engine nacelle, fraction of dry engine	0.338
UWPAX	weight per passenger including luggage [lb]	200

STRUT	wing/canard strut attachment point, fraction of semi-span (for cantilever wing/canard = 0)	0
DELWFC	incremental control group weight [lb]	0
SKY	weight trend coefficient of horizontal tail	0.18
SKZ	weight trend coefficient of vertical tail	0.22
SKWW	weight trend coefficient of wing and canard, excluding high lift devices	133.4
YMG	location of main gear on wing, fraction of wing semi-span	0.25
RELP	engine c.g. fraction of fuselage length (for fuselage mounted engines)	0.75
RELR	c.g. of fuselage and contents, fraction of fuselage length	0.45
CATD	transport design structural category, FAR Part 25 (used to determine allowable load factors and design speeds)	3
VMLFSL	maximum operating design flight speed, structural [mph]	685
SKB	weight trend coefficient of fuselage	107
SKCC	weight trend coefficient of cockpit controls	20
SKFW	weight trend coefficient of fixed wing controls	0.43
SKSAS	weight of stability augmentation system [lb]	0
EGMRGN	engine c.g. in relation to the leading edge of the wing mean aerodynamic chord (mac), as a fraction of mac, for wing mounted engines, positive aft	0
CPMRGN	wing/canard c.g. with respect to mac quarter chord point, fraction of mac	0.2
STMRGN	aircraft c.g. with respect to mac quarter chord point, fraction of mac	0
DELP	fuselage pressure differential in order to maintain an 8000 ft cabin at 40000 ft altitude [psi]	8.2
YP	location of engines on wing (on fuselage = 0)	0
SKFS	weight trend coefficient for fuel system	0.02
SKWF	fraction of total theoretical wing volume used for wing fuel	0.43
LCWING	program computes fwd and aft c.g. limits and sizes canard and, or horizontal and vertical tail for stability and control	2
DELWST	incremental structural weight [lb]	0
WPLX	design payload [lb] (default function of passenger number)	0
WFEX	fixed equipment weight [lb] (computed by program)	0
WFUL	fixed useful load weight [lb] (computed by program)	0
WENG	dry weight of one engine, function of engine size [lb]	0
SWSLS	engine specific weight [$\text{lb}/\text{lb}_{\text{Thrust}}$]	0.16
WNAC	weight of one nacelle, function of engine size [lb]	0
UWNAC	nacelle weight to nacelle surface area ratio [lb/sqft]	2.287
WPYLON	weight of one pylon, function of engine size [lb]	0
FPYL	factor for turbofan engine pylon weight	0.7
XLQDE	nacelle length to diameter ratio	3

Stability and Control (Canard and/or Tail Sizing)

KSFixd	*controls free (0) or controls locked (1) (option)*	*1*
CMPLD	pitching moment coefficient about centre of gravity due to all engines during landing (direct thrust effect only)	0

STATIC	aircraft static margin, fraction of mac	0.1
RH	elevator chord to horizontal tail chord ratio	0.35
DEMAX	maximum up elevator deflection, negative for trailing edge up (degrees)	-25
EYET	tailplane incidence angle relative to fuselage horizontal datum line (degrees)	0
TP	vertical position of thrust line relative to c.g., positive for thrust below c.g.	0
CXA	distance of main wheel contact point aft of mac leading edge, fraction of mac	0.52
HWING	low wing position on fuselage	0
CNPAC	required directional stability of aircraft, function of take-off gross weight and wing span [degree^{-1}]	0.002
RV	rudder chord to vertical tail chord	0.30
RVMCS	ratio of minimum control speed to stall speed in take-off configuration	0.99
DRMAX	maximum rudder deflection [degrees]	25
rc	*canardvator chord to canard chord ratio*	*0.35*
dcmcpi	*jet-flow inclination contribution to the aircraft longitudinal static stability*	*0.03*
CMFLPL	wing pitching moment coefficient about c.g., landing flaps (function of flap deflection, computed by program)	999
CMFLPT	wing pitching moment coefficient about c.g., take-off flaps (function of flap deflection, computed by program)	999
CHALF	two dimensional variation of elevator hinge moment coefficient with angle of attack (computed by program)	999
CHDEL	two dimensional variation of elevator hinge moment coefficient with elevator deflection (computed by program)	999
TAUH	elevator effectiveness (computed by program)	999
TAUV	rudder effectiveness (computed by program)	999
ZCG	height above runway of c.g. at nose wheel lift off [ft] (computed by program)	999
DCMCLP	direct thrust engine stability term (computed by program)	9999
ARVTE	vertical tail effective aspect ratio (computed by program)	-1.0

Performance

Taxi

DELTT	time spent taxiing before take-off and after landing [hr]	0.1666

Take-off

IFLY	program computes full mission (option)	1
NFAIL	program computes engine-out and acceleration/stop distance (option)	0
THEMAX	maximum allowable fuselage floor angle [degrees]	15
H00	altitude at start of mission [ft]	5000
XLFMAX	maximum load factor during take-off rotation	1.1

DELTVR	estimate of time required to rotate aircraft during take-off [sec]	3.5
DV1	increment of engine failure decision speed above stall [kt]	5
DVR	increment of take-off rotation speed above engine failure decision speed [kt]	5
VRAT	ratio of allowable lift-off speed to stall speed	1.1
UM	coefficient of rolling friction	0.02
MUB	coefficient of braking friction	0.4
TDELTX	increment in take-off ambient temperature above ISA standard day [degree F]	36
HTMAX	terminal altitude for take-off segment [ft]	500

Climb

ICLM	climb at maximum rate of climb (option)	1
DELH	altitude increment during climb [ft]	1000

Cruise

ICRUS	cruise flown at speed at normal rated cruise power, for cost and range calculation (option)	1
ISWING	hold wing loading fixed during range balance (option)	0
FRESF	required fuel reserve, fraction of 45 min	1
RCRRQ	required design range [NM]	1250
OFALT	off-design mission altitude [ft]	25000
OFEM	off-design specified Mach number	0.5
FACW1	maximum take-off gross weight scale factor for range balance iterations (default function of gross weight and range)	0.80

Landing

IWLD	landing weight as a fraction of gross weight (option)	2
TDELLD	increment in landing ambient temperature above ISA standard day (degree F)	36
TDELAY	time delay for brake and reverse thrust application during landing (sec)	1
HTG	wing height above ground during ground run (ft)	5.5
XLDGRQ	required landing distance (not constrained)	99999
ALTLND	altitude of landing field (ft)	5000
WLPCT	ratio of landing weight to maximum take-off gross weight	0.94
VRATT	ratio of approach speed to stall speed	1.3
RSMX	maximum allowable rate of sink during approach [ft/min]	1000
TROTID	ratio of reverse thrust to idle thrust during landing	0
VTDRAT	ratio of touchdown speed to stall speed	1.15
HAPP	obstacle height (ft)	50
SINKTD	landing touchdown sink rate (ft/sec)	3
XLFMX	landing flare load factor	1.2

Costs

NCADE	additional equipment cost as a function of base cost (option)	1
CLIAB	year of cost calculation	1993
HRI	cost of avionic equipment (US$)	4.E06
TBO	aircraft utilization per year (hr/annum)	3200
FCSF	fuel cost (US$/US gallon)	0.85
HIR	insurance as a fraction of flyaway price per annum	0.005
TR	maintenance burden factor	2
PRV	aircraft residual value as a fraction of initial value	0.10
DYR	aircraft depreciation period [years]	15
OHR	production quantity	500
CRWOH	maintenance labour cost (US$/man-hour)	23
CINP	annual average inflation rate	0.08

Note: The GASP Input Data templates show some variables that are not employed in the present computations. They consist of parameters with default values that relate to program or configuration options not used in the present work. So, they are not reproduced in the variable list.

APPENDIX I

Validation of the Design Model

Introduction

In this Appendix, validation of the GASP design model is demonstrated for two conventional aircraft configurations.

For the purpose, two actual aircraft were chosen, a similar size aircraft as represented by the Canadair Regional Jet 100, and the Fokker 100. The latter one would require additional tabulation of the Rolls-Royce Tay engine performance data, since this powerplant is not considered in the GASP Propulsion module. This module, however, incorporates other powerplant performance data which include the Garrett TFE 731-2 turbo-fan. This engine powers the Learjet 35A business aircraft, thus making GASP readily suitable for the design synthesis of the corporate aircraft. As a result, this one was used in place of the Fokker aeroplane.

Figures I1 and I2 show the detailed output results for both aircraft, RJ 100 and Learjet 35A, as were modelled by the GASP program. Tables I1 and I2 present a summary of the main characteristics together with the actual values, compiled from "Jane's All The World Aircraft", and show the model accuracy. Figures I3 and I4 illustrate the aircraft geometries corresponding to the present results.

Note that the computed Maximum Take-off Weights are within 7% of those of the actual aircraft using similar requirements, geometric parameters and wing loadings. Although the overall results show slightly over-powered designs, with slightly increased tail areas, when compared with the real aircraft, GASP model accuracy may be considered good for initial conceptual design work.

For the purposes of the present research work where different concepts are compared, using the same assumptions, design criteria and analysis methods, relative trade-offs and trends are more important issues than the absolute precision of a given performance index. These relative differences are usually much more accurate and meaningful, providing sufficient detail is embodied in the methods and that they are used within their range of validity. Only then, will the changes correctly reflect in the results. This is especially true of GASP where the analysis modules are considerably detailed, thus producing reasonably good answers to comparative performance and economic assessments, trade-off and sensitivity studies of conventional configurations[I1].

References:

I1. Galloway,T.L.;Hague,D.S. and al
GASP - General Aviation Synthesis Program
NASA CR-152303, Jan 1978

		GASP Results	Actual Values (*)	Accuracy [%]
Fuselage Length	ft	80.0	80.0	0
Wing Area	sqft	547.2	587.1	-6.8
Wing Aspect Ratio		8.85	8.85	0
Tailplane Area	sqft	132.4	101.6	30.3
Fin Area	sqft	118.3	98.8	19.7
Engine Max. St. T/O Thrust	lb	9241.9	9220.0	0.2
M.T.O.W.	lb	44222	47450	-6.8
O.E.W.	lb	27245	30100	-9.5
E.W.	lb	26157	29180	-10.4
Fuel Weight	lb	6976		
Wing Fuel Volume	US gal	1439.4	1400.0	2.8
Maximum Fuel Weight	lb	9625	9380	2.6
T/O Wing Loading	lb/sq ft	80.82	80.82	0
T/O Thrust to Weight Ratio		0.418	0.389	7.5
Cruise Mach No.		0.81	0.74	9.5
Cruise Speed (TAS)	kt	465.9	424.0	9.5
Cruise Height	ft	37000	37000	0
Approach Speed (TAS)	kt	133.83	137.0	-2.3
T/O Flap (angle/CLmax)		15./2.093	15./	
Landing Flap (angle/CLmax)		45./2.537	45./	
FAR 25 T/O Field Length	ft	5198	5265 (S/L,ISA)	
FAR 25 Land. Field Length	ft	4714	4725 (S/L,ISA)	
Mission Range	nm	983.09	980.0	0.3

Table II - GASP Validation for Canadair Regional Jet 100

(*) source: Jane's All The World Aircraft

		GASP Results	Actual Values (*)	Accuracy [%]
Fuselage Length	ft	43.7	45.8	-4.6
Wing Area	sqft	241.8	253.3	-4.6
Wing Aspect Ratio		5.74	5.74	0
Tailplane Area	sqft	71.3	54.0	32.0
Fin Area	sqft	51.3	37.37	37.3
Engine Max. St. T/O Thrust	lb	3968.2	3500.0	13.4
M.T.O.W.	lb	17457	18300	-4.6
O.E.W.	lb	10411		
E.W.	lb	9850	10119	-2.7
Fuel Weight	lb	5447		
T/O Wing Loading	lb/sq ft	72.2	72.2	0
T/O Thrust to Weight Ratio		0.455	0.383	18.8
Cruise Mach No.		0.81	0.73	10.7
Cruise Speed (TAS)	kt	463.3	418.0	10.7
Cruise Height	ft	45000	45000	0
Landing Stall Speed (TAS)	kt	105.5	96.0	9.9
T/O Flap (angle/CLmax)		20./1.447	20./	
Landing Flap (angle/CLmax)		40./1.599	40./	
FAR 25 Balanced Field Length	ft	6765.9	4972 (S/L,ISA)	
FAR 25 Land. Field Length	ft	5978.0	3075 (S/L,ISA)	
Mission Range	nm	1913	2196 (with 4 pax)	

(*) source: Jane's All The World Aircraft

Table I2 - GASP Validation for Learjet 35A

```
1                              50 PAX TURBOFAN AIRLINER USING SCALED GE CF-34 - CANADAIR RJ 100
0                                            ENGINE CYCLE IS G. E.  CF-34


                                             INPUT DATA FOLLOW
                                            ******************

0                                           *****GEOMETRY*****
0 CONFIG  WG      =  44050.                 KWRITE  =       2       FUSEL  SAB     =      4.                   ELODN   =   1.000
          WGS     =  80.820                 IGEAR   =       0              WS      =  19.000                   ELODT   =   3.200
          PAX     =     50.                 KCONFG  =       0              AS      =      1.                   BMLOD   =  14.500
          EMCRU   =   0.740                 KTIPX   =       0              WAS     =  18.000         NACELLE   KNAC    =       1
          HNCRU   =  37000.                 ENP     =      2.              PS      =    31.0                   ELN     =   0.000
                                            NTYE    =       7              ELPC    =  13.720                   DBARN   =   0.000
          Kanard  =       0                 KPLOT   =       1              HCK     =   2.470                   ELRW    =  10.000

0    WING TCT     =   0.100          HORIZ  VBARHX  =  0.0000       VERT   VBARVX  =  0.0000         Canard    TCcan   =   0.100
          TCR     =   0.132          TAIL   TCHT    =   0.100       TAIL   TCVT    =   0.120                   ARcan   =   5.500
          AR      =   8.850                 ARHT    =   4.069              ARVT    =   1.050                   SLMcan  =   0.500
          SLM     =   0.250                 SLMH    =   0.530              SLMV    =   0.679                   DwpqCa  =  15.000
          DLMC4   =  24.750                 DWPQCH  =  30.000              DWPQCV  =  43.000                   EYEcan  =   2.000
          EYEW    =   2.000                 COELTH  =   0.000              BOELTV  =   0.000                   SWcOSW  =   0.145
                                            SAH     =   1.000

0                                          ***AERODYNAMICS***
0         CKW     =  -1.000                 CKHT     =  -1.000             GRFE    =   0.000                   DCDSE   = -1.0000
          CKF     =  -1.000                 CKTP     =  -1.000             SCFAC   =   0.750                   CKWc    =  -1.000
          CKN     =  -1.000                 DELCD    = 0.00150             DLSWSW  =   0.000                   cmacw   =  -0.060
          CKVT    =  -1.000                 DELFE    =   0.200             ALPHL0  =  -1.600                   alzero  =  -1.000

0         KWCD    =      12
          ACLS    =  -1.000  -0.600  -0.400  -0.200   0.000   0.100   0.200   0.400   0.600   0.800   1.000   1.200
          ACDCDR  =   2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                          *HIGH LIFT DEVICES*
0         RCLMAX  =   1.200          FLAPS  JFLTYP  =       7       LED  CLEOC   =   0.000
          ALTFLP  =   5000.                 DFLPTO  =  15.000            DELLED  =   0.000
          FLAPN   =      2.                 DFLPLD  =  45.000            DCLMLE  =   0.930
          WCFLAP  =  -1.000                 CFOC    =   0.300            DELLEO  =  45.000
          BENGOB  =   0.000                 BTEOB   =   0.560
                                            DCLMTE  =   0.000
                                            DCDOTE  =   0.000
                                            DELTEO  =   0.000

0                                          ****PROPULSION****
0         JENGSZ  =       2                 HPORT   =   5000.              RCCRU   = 200.000                   RWCRTX  =   0.970
          IPART   =       1                 TDELTO  =     36.              XTORQ   =  99999.                   HSCREQ  =      0.
          KODETO  =       5                 KODECL  =       7              SM1D    =   0.500                   THIN    =      0.
          KODETR  =       5                 KODEAC  =       5              HBTP    =   0.437                   PR      =   1.000

0                                          *****WEIGHTS*****
0         SKPEI   =  0.1350                 SKY     =  0.1800              SKB     = 107.000                   SKFS    =  0.0200
          SKLG    =  0.0380                 SKZ     =  0.2200              SKCC    =  20.000                   SKWF    =  0.4300
          SKMG    =  0.8000                 SKTL    =  1.0000              SKFW    =  0.4300                   SKFT    =  0.9790
          SKPES   =  0.3380                 SKWW    = 133.400              SKSAS   =   0.000                   SKWTP   =  1.8900
          WPLX    =     0.0                 YMG     =  0.1500              EGMRGN  =  0.0000                   LCWING  =       2
          WPEX    =     0.0                 RELP    =  0.7550              CPMRGN  =  0.2000
          WPUL    =     0.0                 RELR    =  0.4500              STMRGN  =  0.0000                   LDCRMX  =   8.000
          UWPAX   =   200.0                 CATD    =      3.              DELP    =   8.300                   ATMXOC  =   3.160
          STRUT   =  0.0000                 VMLFSL  =   685.0              YP      =  0.0000                   DELWST  =     0.0
          DELWFC  =     0.0
0 ENGINE  WENG    =     0.0                 WNAC    =     0.0              WPYLON  =     0.0
          SWSLS   =   0.160                 UWNAC   =   2.287              FPYL    =   0.700                   XLQDE   =   3.000

0                                        *STABILITY AND CONTROL*
0         KSFixd  =       1                 STATIC  =   0.100              ZCG     = 999.000                   CNPAC   =  0.0020
          CMFLPL  = 999.000                 CHALF   = 999.000              TP      =     0.0                   ARVTE   =  -1.000
          CMFLPT  = 999.000                 CHDEL   = 999.000              CXA     =   0.700                   RV      =   0.300
                                            RH      =   1.000              DCMCLP  =9999.000                   TAUV    = 999.000
          CMPLD   =   0.000                 DEMAX   =   -25.0              HWING   =      0.                   RVMCS   =   0.990
                                            EYET    =     0.0              dcmcpi  =   0.030                   DRMAX   =    25.0
                                            TAUH    = 999.000              rc      =   0.350

0,                                         ***PERFORMANCE***
0   TAXI  DELTT   =   0.167                 XLFMAX  =   1.100              DVR     =   5.000                   TDELTX  =  36.000
      TO  IFLY    =       1                 DELTVR  =   3.500              UM      =   0.020                   HTMAX   = 500.000
          THEMAX  =  15.000                 DV1     =   5.000              MUB     =   0.400                   NFAIL   =       0
          H00     =   5000.                 VRAT    =    1.10              WTMISN  =      0.

0  CLIMB  ICLM    =       1          CRUISE CRMACH  =   0.000              FRESF   =   1.000                   FACWL   =   0.800
          DELH    =   1000.                 CRALT   =      0.              RCRRQ   =   980.0                   ISWING  =       0
          VCLMB   =     0.0                 ICRUS   =       1              OPALT   =  25000.                   OFEM    =   0.500
0   LAND  IWLD    =       2                 XLDGRQ  =  99999.              VRATT   =   1.300                   HAPP    =     50.
          TDELLD  =    36.0                 ALTLND  =   5000.              RSMX    =   1000.                   SINKTD  =     3.0
          TDELAY  =     1.0                 WLPCT   =  0.9062              TROTID  =   0.000                   XLFMX   =   1.200
          HTG     =     5.5                 TIDLE   =     0.0              VTDRAT  =     1.1

0                                         ******COST******
0         NCADE   =       1                 HIR     =   0.005              RI      =   0.300                   CMV     =   0.800
          CLIAB   =  1993.0                 TR      =   2.000              CHR     = 500.000                   CCRW    =      0.
          HRI     =4000000.                 PRV     =   0.100              CRWOH   =  23.000                   UCSENG  =   0.000
          CMF     =     0.2                 DYR     =    15.0              CINP    =      0.                   UCSPP   =   0.000
          TBO     =  3200.0                 SRPM    =     0.0              CP      =      0.                   ALR     =   3.400
          FCSF    =   0.850

1
0+++++ H.TAIL C.L. CHORD MUST =     7.827 TO BE LOCATED AT SPECIFIED POSITION ON VERTICAL+++++
 +++++ H.TAIL TAPER CHANGED TO   0.9262
```

Fig I1 - Canadair Regional Jet 100 GASP result

```
**********************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1  1.2560 -0.0199
  GROSS WGT, GROSS WGT MINUS1      44221.6    55062.5

 0   *************************************************************************************************
 0                      FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                    CLMAX      VSTALL,KTS  FLAP ANGLE   LE ANGLE    DELTA CL     DELTA CD

  FLAPS UP          1.3235       144.8         0.0          0.0     0.0000      0.0000
  T.O. CONFIG       2.0934       115.1        15.0          0.0     0.7700      0.0336
  LDG. CONFIG       2.5369       104.6        45.0          0.0     1.2189      0.1790

 0                     DOUBLE SLOTTED FOWLER FLAPS
                     OPT ANGLE     DELCL AT OPT   DELCD AT OPT    AREA(FT2)      WEIGHT(LB)

  FLAPS                30.0          2.2500         0.1500          89.7          424.5
 0   *************************************************************************************************
 0
  SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
    ANGLE OF ATTACK(DEGREES)=   2.805   LIFT= 42894.9   L/D=  14.152   ALTITUDE= 37000.0   MACH=  0.7400

 1                                       ENGINE SIZING DATA FOLLOW
                                         *************************
 0VSTLKT= 106.7 KTS EAS   VRAT= 1.100 CLTO= 1.7301
       VEND =  234.2 KNOTS EAS
 0
  ROTATION (TIME=   24.4 AND TAS=   130.1 EAS=   116.7)
  LIFTOFF (TIME=   26.6 DIST=   3372.3 TAS=   139.1 EAS=   124.8)
  DISTANCE TO 35 FT.=  4682.3   TAS=   154.4 EAS=   138.4 V35/VS=  1.2969
  GEAR RETRACTION STARTED AT   32.8 SEC,COMPLETE AT   39.8 SEC
  FLAP RETRACTION STARTED AT   42.9 SEC,COMPLETE AT   47.4 SEC
 0VSTLKT= 106.7 KTS EAS   VRAT= 1.100 CLTO= 1.7301
 0 ENGINE OUT PERFORMANCE FOLLOWS
       VEND =  199.2 KNOTS EAS
  ENGINE FAILURE (TIME=   23.1 AND TAS=   124.5 EAS=   111.7)
 0
  ROTATION (TIME=   26.3 AND TAS=   130.1 EAS=   116.7)
  LIFTOFF (TIME=   29.4 DIST=   3973.8 TAS=   134.1 EAS=   120.3)
  DISTANCE TO 35 FT.=  5379.4   TAS=   136.0 EAS=   121.9 V35/VS=  1.1427


      ACCELERATE - STOP DISTANCE =     5668.9 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=      5379.4 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =      4682.3 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =     5384.7 FEET
  ALL ENGINE DISTANCE TO 50 FT. =     4919.5 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=  0.012 HRS   FUEL USED=      71. LBS   WEIGHT=  44151. LBS   ALT.=    5500. FT.
 0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
    AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS                V      GRAD       R/C    REQ.R/C
   CONFIGURATION                                ALT (FT)  KEAS    V/VS    KTAS    (PCT)     (FPM)     (FPM)    CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.   106.8  1.1310  134.7    2.660    362.71      1.00  1.643  8.828
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.   106.8  1.2000  143.5    4.557    661.69    348.51  1.460 10.859
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.   134.4  1.2500  191.7    5.505   1067.80    232.74  0.851 14.111
   APPROACH FLAPS -ONE ENG OUT                   5000.   106.6  1.3997  166.4    5.011    844.02    353.68  1.077 11.919
   LANDING FLAPS - ALL ENGINES                   5000.    97.1  1.3000  140.7   10.855   1545.27    455.54  1.507  5.915

     APPROACH FLAP SETTING = 15.5 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 25080.3 FT.
         BEST RATE OF CLIMB SPEED    =    265.5 KTAS
         ENGINE-OUT RATE OF CLIMB    =     49.8 FPM
         WEIGHT AT ALTITUDE          = 42452.7 LBS

 0                        ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

 0PROPULSION SYSTEM WEIGHTS
    ENGINE WEIGHT/ENGINE               1426.7
    NACELLE WEIGHT/ENGINE               320.9
    PYLON WEIGHT/ENGINE                 170.4
       PROP OR QFAN            0.0
       GEARBOX                 0.0
       SHROUD                  0.0

 0ENGINE POD DIMENSIONS
    ENGINE FACE DIAMETER(FT)           3.86
    NACELLE LENGTH(FT)                11.58


 0VSTLKT= 106.7 KTS EAS   VRAT= 1.100 CLTO= 1.7301
       VEND =  234.2 KNOTS EAS
 0
  ROTATION (TIME=   23.4 AND TAS=   130.1 EAS=   116.7)
  LIFTOFF (TIME=   25.8 DIST=   3294.3 TAS=   140.1 EAS=   125.6)
  DISTANCE TO 35 FT.=  4534.7   TAS=   155.0 EAS=   139.0 V35/VS=  1.3028
  GEAR RETRACTION STARTED AT   31.7 SEC,COMPLETE AT   38.7 SEC
  FLAP RETRACTION STARTED AT   41.7 SEC,COMPLETE AT   46.2 SEC
 0VSTLKT= 106.7 KTS EAS   VRAT= 1.100 CLTO= 1.7301
 0 ENGINE OUT PERFORMANCE FOLLOWS
       VEND =  197.1 KNOTS EAS
  ENGINE FAILURE (TIME=   22.2 AND TAS=   124.5 EAS=   111.7)
 0
  ROTATION (TIME=   25.4 AND TAS=   130.1 EAS=   116.7)
  LIFTOFF (TIME=   28.4 DIST=   3848.5 TAS=   134.4 EAS=   120.6)
  DISTANCE TO 35 FT.=  5188.1   TAS=   136.6 EAS=   122.4 V35/VS=  1.1474


      ACCELERATE - STOP DISTANCE =     5571.7 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=      5188.1 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =      4534.7 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =     5215.0 FEET
  ALL ENGINE DISTANCE TO 50 FT. =     4771.2 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=  0.012 HRS   FUEL USED=      71. LBS   WEIGHT=  44150. LBS   ALT.=    5500. FT.
```

Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS              V       GRAD       R/C    REQ.R/C
   CONFIGURATION                                ALT (FT)  KEAS    V/VS   KTAS     (PCT)     (FPM)    (FPM)     CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  106.8  1.1310  134.7    2.924    398.62     1.00  1.643  8.640
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  106.8  1.2000  143.5    4.800    696.97   348.51  1.460 10.563
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  134.4  1.2500  191.7    5.595   1085.23   232.74  0.851 13.413
   APPROACH FLAPS -ONE ENG OUT                   5000.  106.6  1.3997  166.4    5.189    873.93   353.68  1.077 11.493
   LANDING FLAPS - ALL ENGINES                   5000.   97.1  1.3000  140.7   11.782   1677.22   455.54  1.507  5.886

     APPROACH FLAP SETTING = 15.5 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 25443.8 FT.
         BEST RATE OF CLIMB SPEED   =   263.4 KTAS
         ENGINE-OUT RATE OF CLIMB   =    49.9 FPM
         WEIGHT AT ALTITUDE         = 42452.7 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    362.43

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    362.43

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   9241.9 LBS
*********************************************************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE            1478.7
   NACELLE WEIGHT/ENGINE            320.9
   PYLON WEIGHT/ENGINE              174.1
      PROP OR QFAN         0.0
      GEARBOX              0.0
      SHROUD               0.0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)         3.86
   NACELLE LENGTH(FT)              11.58

0******************************************************************************************************************************************************0*************
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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                      ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                  MOST FWD LOAD          MOST AFT LOAD          DESIGN LOAD
                    WT         CG          WT         CG          WT        CG

  A/C OWE     27245.11      45.16    27245.11      45.16    27245.11     45.16
  PAX          6120.00                2040.00                8500.00
  BAGGAGE         0.00      58.67     1500.00      58.67     1500.00     58.67
  WING FUEL    1395.30      49.20     9625.40      49.20     6976.49     49.20
  TIP FUEL        0.00       0.00        0.00       0.00        0.00      0.00
  FUS FUEL        0.00      49.20        0.00      49.20        0.00     49.20
  TOTAL       34760.41      43.03    40410.51      46.88    44221.59     45.03


 0                     ---TAIL SIZING SUMMARY---

        Static Longitudinal Stability, Stick-fixed, considered


 0                       WING               CANARD        TAIL       DOWN   FLAP
  CONDITION  ALPHA    CL     CLA     CMac  ALPHA    CLA    CLA   EFF.    WASH   CM

   CRUISE   2.9416 0.4645 0.1023-0.0600 0.0000 0.0000 0.0729 1.0000
   LIFTOFF  2.0000 1.0856 0.0671-0.0600 0.0000 0.0000 0.0631 1.0000 0.3248-0.1031
   LANDING 14.5325 2.5369 0.0817-0.0600 0.0000 0.0000 0.0631 1.0000 2.3601-0.2081

 0            --FUSELAGE-- ---NACELLE--         ------POWER-------         L.GEAR ROT.POWER
  CONDITION   DCM     CM     DCM     CM  DCMdth DCMfinc CMdth  CMfinc   CT      CM      CM

   CRUISE   0.4475        0.0907        0.0000 0.0300                0.0000
   LIFTOFF  0.6822 0.0000 0.0907 0.0000                0.0000 0.0326 0.0000-1.4765 4.3412
   LANDING  0.5604 0.5737 0.0907 0.0929                0.0000 0.0761

 0     ELEVATOR PARAMETERS
           CMDELTE(CONTROL POWER)         = -0.06820            WING DE/DALPHA =  0.32481
           TAUH(EFFECTIVENESS)            =  1.00000
           DEMAX(MAX.ELEVATOR DEFLEC.)    =-25.00000


 0                              FRACTION    STATION             HORIZONTAL TAIL SIZES
                                   MAC    (DATUM NOSE)
       NEUTRAL POINT              0.2016      47.430            STATIC STABILITY AND LANDING TRIM     132.3745
       STATIC MARGIN              0.1000                        STATIC STABILITY AND LIFTOFF ROT.      88.6605
       AFT CG LIMIT(STABILITY)    0.1016      46.549
       CG RANGE(LOADING)          0.4372                        REQUIRED TAIL SIZE                    132.3745
       FWD CG LIMIT(CONTROL)     -0.3357      42.775            TAIL ARM(ELTH)                         38.0349

 0      VERTICAL TAIL AREA =  118.2915 FOR DIRECTIONAL STABILITY OF    0.00200
 0      RUDDER POWER AT MAX.DEFL.=  0.0184 PER DEG.   RUDDER CL AT MAX.DEFL.=  0.4590
 0      VERTICAL TAIL AREA=   98.3197 FOR MINIMUM CONTROL SPEED =    105.63 KTS
 0      REQUIRED VERTICAL TAIL AREA =  118.2915  TAIL ARM(ELTV) =   27.2696

*********************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.805   LIFT= 42894.9   L/D=  13.638   ALTITUDE= 37000.0   MACH=  0.7400

0 WING LOCATION INFO.
 FUSELAGE LENGTH      =   80.00       H-TAIL VOL. ARM       =   38.03       C.G.LOCATION OF PROPULSION=   60.40
 WING 1/4C LOC.ON C.L.=   41.69       H-TAIL C.G.LOCATION   =   86.60       C.G.OF REMAINING WEIGHT   =   36.00
 MAC 1/4C LOCATION    =   48.11       H-TAIL MAC FROM C.L.  =    5.73
 MAC DIST.FROM C.L.   =   13.92       H-TAIL LOCAT ON VERT.=     1.00
 WING C.G.LOCATION    =   49.87       V-TAIL VOL. ARM       =   27.27
 TIP TANKS C.G.LOCATE =    0.00       V-TAIL C.G.LOCATION   =   76.24       DIST.L.E.VERT.TO L.E.HORZ.=    2.66

0                          WING         H-TAIL       V-TAIL

    AREA                 547.161       132.374      118.291
    SPAN                  69.587        23.208       11.145
    ASPECT RATIO           8.850         4.069        1.050
    TAPER RATIO            0.250         0.926        0.679
    1/4C. SWEEP           24.750        30.000       43.000
    L.E. SWEEP            27.870        30.402       45.666
    C.L. CHORD            12.581         5.922       12.643
    MEAN CHORD             8.807         5.707       10.743
    TIP CHORD              3.145         5.485        8.585
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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0                                    MISSION PERFORMANCE DATA FOLLOWS
                                     ********************************
0   TAXI AT IDLE THRUST

                  FUEL                            FUEL
  TIME   RANGE    USED    WEIGHT   ALT.           FLOW
 (HRS)   (NM)    (LBS)    (LBS)    (FT)   (LB/HR)

  0.000      0.      0.  44222.   5000.     845.
  0.167      0.    141.  44081.   5000.     845.
0VSTLKT= 106.5 KTS EAS   VRAT= 1.100 CLTO= 1.7301
      VEND =  234.1 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0    TAKEOFF   (ELEVATION=  5000. FT)

                FUEL                                                                                                           FUEL   FUS.
TIME   DIST.    USED   WEIGHT     ALT.      TAS     EAS   MACH  ACCEL      CL       CD  ALPHA GAMMA       ROC   LOAD THRUST     FLOW  ANGLE
(SEC)  (FEET)   (LBS)   (LBS)     (FT)    (KTS)   (KTS)    NO.  (FPS2)                  (DEG) (DEG)     (FPM)   FACT  (LBS)   (LB/HR) (DEG)

  0.0     0.0   140.7  44081.   5000.0     0.0     0.0 0.000  11.32 1.0836 0.0951  2.00   0.00        0.0   0.00  16391.   5837.   0.00
  1.0     5.6   142.3  44079.   5000.0     6.7     6.0 0.010  11.16 1.0836 0.0951  2.00   0.00        0.0   0.00  16189.   5837.   0.00
  2.0    22.5   143.9  44078.   5000.0    13.3    11.9 0.020  11.01 1.0837 0.0951  2.00   0.00        0.0   0.00  15991.   5838.   0.00
  3.0    50.3   145.6  44076.   5000.0    19.7    17.7 0.029  10.85 1.0837 0.0951  2.00   0.00        0.0   0.00  15796.   5839.   0.00
  4.0    89.1   147.2  44074.   5000.0    26.1    23.4 0.039  10.69 1.0838 0.0951  2.00   0.00        0.0   0.00  15604.   5840.   0.00
  5.0   138.6   148.8  44073.   5000.0    32.4    29.1 0.048  10.52 1.0839 0.0951  2.00   0.00        0.0   0.00  15416.   5842.   0.00
  6.0   198.6   150.4  44071.   5000.0    38.6    34.7 0.057  10.35 1.0840 0.0951  2.00   0.00        0.0   0.00  15231.   5844.   0.00
  7.0   269.0   152.1  44070.   5000.0    44.7    40.1 0.066  10.18 1.0841 0.0952  2.00   0.00        0.0   0.00  15048.   5846.   0.00
  8.0   349.7   153.7  44068.   5000.0    50.7    45.5 0.075  10.00 1.0842 0.0952  2.00   0.00        0.0   0.00  14869.   5848.   0.00
  9.0   440.3   155.3  44066.   5000.0    56.6    50.8 0.084   9.82 1.0843 0.0952  2.00   0.00        0.0   0.00  14693.   5851.   0.00
 10.0   540.9   156.9  44065.   5000.0    62.4    56.0 0.093   9.64 1.0845 0.0952  2.00   0.00        0.0   0.00  14520.   5853.   0.00
 11.0   651.1   158.6  44063.   5000.0    68.1    61.1 0.101   9.46 1.0847 0.0952  2.00   0.00        0.0   0.00  14355.   5856.   0.00
 12.0   770.8   160.2  44061.   5000.0    73.7    66.1 0.109   9.31 1.0849 0.0952  2.00   0.00        0.0   3.00  14227.   5859.   0.00
 13.0   899.8   161.8  44060.   5000.0    79.1    71.0 0.117   9.15 1.0851 0.0952  2.00   0.00        0.0   0.00  14100.   5862.   0.00
 14.0  1038.0   163.4  44058.   5000.0    84.5    75.8 0.125   8.99 1.0853 0.0952  2.00   0.00        0.0   0.00  13976.   5865.   0.00
 15.0  1185.3   165.1  44057.   5000.0    89.8    80.6 0.133   8.82 1.0855 0.0952  2.00   0.00        0.0   0.00  13854.   5869.   0.00
 16.0  1341.4   166.7  44055.   5000.0    95.0    85.2 0.141   8.66 1.0857 0.0952  2.00   0.00        0.0   0.00  13734.   5872.   0.00
 17.0  1506.2   168.3  44053.   5000.0   100.1    89.8 0.149   8.49 1.0859 0.0952  2.00   0.00        0.0   0.00  13617.   5876.   0.00
 18.0  1679.5   170.0  44052.   5000.0   105.1    94.3 0.156   8.33 1.0862 0.0952  2.00   0.00        0.0   0.00  13502.   5880.   0.00
 19.0  1861.2   171.6  44050.   5000.0   110.0    98.7 0.163   8.16 1.0864 0.0952  2.00   0.00        0.0   0.00  13389.   5884.   0.00
 20.0  2051.0   173.2  44048.   5000.0   114.8   103.0 0.170   7.99 1.0867 0.0953  2.00   0.00        0.0   0.00  13278.   5888.   0.00
 21.0  2248.9   174.9  44047.   5000.0   119.5   107.2 0.177   7.83 1.0869 0.0953  2.00   0.00        0.0   0.00  13169.   5892.   0.00
 22.0  2454.7   176.5  44045.   5000.0   124.1   111.4 0.184   7.66 1.0872 0.0953  2.00   0.00        0.0   0.00  13063.   5896.   0.00
 23.0  2668.2   178.2  44043.   5000.0   128.6   115.4 0.191   7.49 1.0875 0.0953  2.00   0.00        0.0   0.00  12959.   5900.   0.00
0
 ROTATION (TIME=   23.3 AND TAS=   129.9 EAS=   116.5)
 24.0  2889.1   179.8  44042.   5000.0   133.0   119.3 0.197   7.28 1.1814 0.0999  3.11   0.00        0.0   0.71  12857.   5905.   1.11
 25.0  3117.4   181.4  44040.   5000.0   137.3   123.1 0.204   6.95 1.3650 0.1113  5.33   0.00        0.0   0.88  12775.   5909.   3.33
  LIFTOFF (TIME=   25.6 DIST=   3257.8 TAS=   139.7 EAS=   125.3)
 26.0  3352.7   183.1  44039.   5000.1   141.3   126.7 0.210   6.47 1.5353 0.1251  7.48   0.08       20.8   1.05  12706.   5913.   5.56
 27.0  3594.4   184.7  44037.   5001.7   144.9   130.0 0.215   5.87 1.5144 0.1269  7.18   0.75      192.1   1.09  12644.   5917.   5.92
 28.0  3842.0   186.4  44035.   5006.5   148.2   133.0 0.220   5.21 1.4508 0.1301  6.38   1.47      384.7   1.09  12587.   5919.   5.84
 29.0  4094.8   188.0  44034.   5014.6   151.2   135.6 0.224   4.56 1.4037 0.1339  5.88   2.18      581.4   1.10  12535.   5922.   6.05
 30.0  4352.1   189.7  44032.   5025.9   153.7   137.9 0.228   4.02 1.3550 0.1341  5.38   2.88      781.6   1.10  12489.   5923.   6.25
 DISTANCE TO 35 FT.=  4519.9   TAS=   155.2 EAS=   139.2 V35/VS=  1.3063
 31.0  4613.2   191.3  44030.   5040.6   156.0   139.9 0.232   3.54 1.3172 0.1327  4.98   3.55      980.0   1.10  12447.   5924.   6.53
 GEAR RETRACTION STARTED AT   31.5 SEC,COMPLETE AT   38.5 SEC
 32.0  4877.8   192.9  44029.   5058.6   158.0   141.6 0.235   3.17 1.2819 0.1285  4.58   4.22     1179.4   1.09  12409.   5924.   6.80
 33.0  5145.4   194.6  44027.   5079.9   159.8   143.2 0.237   2.84 1.2564 0.1231  4.28   4.88     1378.8   1.10  12374.   5923.   7.16
 34.0  5415.5   196.2  44025.   5104.5   161.4   144.6 0.240   2.55 1.2315 0.1175  3.98   5.53     1577.1   1.10  12341.   5921.   7.51
 35.0  5688.0   197.9  44024.   5132.5   162.9   145.8 0.242   2.28 1.2068 0.1118  3.68   6.17     1774.7   1.09  12310.   5919.   7.85
 36.0  5962.4   199.5  44022.   5163.7   164.2   146.9 0.244   1.99 1.1904 0.1069  3.48   6.81     1973.7   1.09  12282.   5917.   8.29
 37.0  6238.5   201.2  44020.   5198.2   165.3   147.8 0.246   1.73 1.1740 0.1020  3.28   7.44     2170.2   1.09  12255.   5914.   8.72
 38.0  6516.0   202.8  44019.   5236.0   166.3   148.6 0.247   1.45 1.1659 0.0980  3.18   8.08     2366.7   1.10  12231.   5910.   9.25
 39.0  6794.5   204.4  44017.   5277.1   167.1   149.2 0.248   1.17 1.1494 0.0946  2.98   8.69     2559.0   1.09  12208.   5905.   9.67
 40.0  7073.7   206.1  44016.   5321.3   167.7   149.7 0.249   0.82 1.1412 0.0938  2.88   9.31     2747.6   1.10  12188.   5900.  10.18
 41.0  7353.3   207.7  44014.   5368.7   168.1   149.9 0.250   0.48 1.1330 0.0931  2.78   9.92     2934.3   1.09  12171.   5894.  10.70
 FLAP RETRACTION STARTED AT   41.6 SEC,COMPLETE AT   46.1 SEC
 42.0  7632.8   209.4  44012.   5419.1   168.3   150.0 0.250   0.18 1.0859 0.0918  2.98  10.50     3108.3   1.05  12157.   5888.  11.48
 43.0  7912.3   211.0  44011.   5471.2   168.4   150.0 0.250   0.13 0.9978 0.0925  3.98  10.55     3125.6   0.97  12144.   5881.  12.53
0VSTLKT= 106.5 KTS EAS   VRAT= 1.100 CLTO= 1.7301
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  196.9 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0    TAKEOFF   (ELEVATION=  5000. FT)

                FUEL                                                                                                           FUEL   FUS.
TIME   DIST.    USED   WEIGHT     ALT.      TAS     EAS   MACH  ACCEL      CL       CD  ALPHA GAMMA       ROC   LOAD THRUST     FLOW  ANGLE
(SEC)  (FEET)   (LBS)   (LBS)     (FT)    (KTS)   (KTS)    NO.  (FPS2)                  (DEG) (DEG)     (FPM)   FACT  (LBS)   (LB/HR) (DEG)

  0.0     0.0   140.7  44061.   5000.0     0.0     0.0 0.000  11.32 1.0836 0.0951  2.00   0.00        0.0   0.00  16391.   5837.   0.00
  1.0     5.6   142.3  44079.   5000.0     6.7     6.0 0.010  11.16 1.0836 0.0951  2.00   0.00        0.0   0.00  16189.   5837.   0.00
  2.0    22.5   143.9  44078.   5000.0    13.3    11.9 0.020  11.01 1.0837 0.0951  2.00   0.00        0.0   0.00  15991.   5838.   0.00
  3.0    50.3   145.6  44076.   5000.0    19.7    17.7 0.029  10.85 1.0837 0.0951  2.00   0.00        0.0   0.00  15796.   5839.   0.00
  4.0    89.1   147.2  44074.   5000.0    26.1    23.4 0.039  10.69 1.0838 0.0951  2.00   0.00        0.0   0.00  15604.   5840.   0.00
  5.0   138.6   148.8  44073.   5000.0    32.4    29.1 0.048  10.52 1.0839 0.0951  2.00   0.00        0.0   0.00  15416.   5842.   0.00
  6.0   198.6   150.4  44071.   5000.0    38.6    34.7 0.057  10.35 1.0840 0.0951  2.00   0.00        0.0   0.00  15231.   5844.   0.00
  7.0   269.0   152.1  44070.   5000.0    44.7    40.1 0.066  10.18 1.0841 0.0952  2.00   0.00        0.0   0.00  15048.   5846.   0.00
  8.0   349.7   153.7  44068.   5000.0    50.7    45.5 0.075  10.00 1.0842 0.0952  2.00   0.00        0.0   0.00  14869.   5848.   0.00
  9.0   440.3   155.3  44066.   5000.0    56.6    50.8 0.084   9.82 1.0843 0.0952  2.00   0.00        0.0   0.00  14693.   5851.   0.00
 10.0   540.9   156.9  44065.   5000.0    62.4    56.0 0.093   9.64 1.0845 0.0952  2.00   0.00        0.0   0.00  14520.   5853.   0.00
 11.0   651.1   158.6  44063.   5000.0    68.1    61.1 0.101   9.46 1.0847 0.0952  2.00   0.00        0.0   0.00  14355.   5856.   0.00
 12.0   770.8   160.2  44061.   5000.0    73.7    66.1 0.109   9.31 1.0849 0.0952  2.00   0.00        0.0   0.00  14227.   5859.   0.00
 13.0   899.8   161.8  44060.   5000.0    79.1    71.0 0.117   9.15 1.0851 0.0952  2.00   0.00        0.0   0.00  14100.   5862.   0.00
 14.0  1038.0   163.4  44058.   5000.0    84.5    75.8 0.125   8.99 1.0853 0.0952  2.00   0.00        0.0   0.00  13976.   5865.   0.00
 15.0  1185.3   165.1  44057.   5000.0    89.8    80.6 0.133   8.82 1.0855 0.0952  2.00   0.00        0.0   0.00  13854.   5869.   0.00
 16.0  1341.4   166.7  44055.   5000.0    95.0    85.2 0.141   8.66 1.0857 0.0952  2.00   0.00        0.0   0.00  13734.   5872.   0.00
 17.0  1506.2   168.3  44053.   5000.0   100.1    89.8 0.149   8.49 1.0859 0.0952  2.00   0.00        0.0   0.00  13617.   5876.   0.00
 18.0  1679.5   170.0  44052.   5000.0   105.1    94.3 0.156   8.33 1.0862 0.0952  2.00   0.00        0.0   0.00  13502.   5880.   0.00
 19.0  1861.2   171.6  44050.   5000.0   110.0    98.7 0.163   8.16 1.0864 0.0952  2.00   0.00        0.0   0.00  13389.   5884.   0.00
 20.0  2051.0   173.2  44048.   5000.0   114.8   103.0 0.170   7.99 1.0867 0.0953  2.00   0.00        0.0   0.00  13278.   5888.   0.00
 21.0  2248.9   174.9  44047.   5000.0   119.5   107.2 0.177   7.83 1.0869 0.0953  2.00   0.00        0.0   0.00  13169.   5892.   0.00
 22.0  2454.7   176.5  44045.   5000.0   124.1   111.4 0.184   7.66 1.0872 0.0953  2.00   0.00        0.0   0.00  13063.   5896.   0.00
 ENGINE FAILURE (TIME=   22.0 AND TAS=   124.3 EAS=   111.5)
 23.0  2667.0   177.5  44044.   5000.0   126.6   113.6 0.188   2.68 1.0874 0.1034  2.00   0.00        0.0   0.00   6503.   2949.   0.00
 24.0  2882.1   178.3  44043.   5000.0   128.2   115.0 0.190   2.64 1.0875 0.1031  2.00   0.00        0.0   0.00   6485.   2950.   0.00
 25.0  3099.9   179.1  44042.   5000.0   129.7   116.4 0.193   2.59 1.0876 0.1028  2.00   0.00        0.0   0.00   6467.   2951.   0.00
0
 ROTATION (TIME=   25.1 AND TAS=   129.9 EAS=   116.5)
 26.0  3320.4   180.0  44042.   5000.0   131.3   117.7 0.195   2.48 1.2140 0.1087  3.50   0.00        0.0   0.71   6449.   2951.   1.50
 27.0  3543.3   180.8  44041.   5000.0   132.7   119.0 0.197   2.27 1.3976 0.1208  5.74   0.00        0.0   0.84   6433.   2952.   3.74
 28.0  3768.4   181.6  44040.   5000.0   133.9   120.2 0.199   1.99 1.5811 0.1358  8.08   0.00        0.0   0.97   6418.   2953.   6.08
  LIFTOFF (TIME=   28.0 DIST=   3768.4 TAS=   133.9 EAS=   120.2)
 29.0  3995.6   182.4  44039.   5000.2   135.0   121.1 0.200   1.65 1.6862 0.1453  9.46   0.19       46.1   1.06   6406.   2953.   7.66
 30.0  4224.4   183.2  44038.   5002.2   135.8   121.8 0.202   1.04 1.7224 0.1548  9.84   0.87      210.0   1.10   6399.   2954.   8.71
 31.0  4454.1   184.1  44038.   5007.3   136.2   122.2 0.202   0.33 1.7162 0.1674  9.65   1.65      397.5   1.10   6395.   2953.   9.30
 32.0  4684.1   184.9  44037.   5015.4   136.3   122.2 0.202   0.02 1.6060 0.1658  8.35   2.26      544.3   1.03   6394.   2953.   8.61
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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33.0  4914.1   185.7  44036.  5024.6  136.3  122.2 0.202   0.01 1.5497 0.1653  7.75  2.29   552.9  0.99   6393.   2952.  8.04
34.0  5144.1   186.5  44035.  5033.6  136.3  122.2 0.202   0.00 1.5453 0.1683  7.75  2.20   530.3  0.99   6392.   2952.  7.95
 DISTANCE TO 35 FT.=  5179.8   TAS=   136.3 EAS=   122.2 V35/VS=  1.1470
35.0  5374.1   187.3  44034.  5042.3  136.3  122.2 0.202   0.00 1.5510 0.1711  7.85  2.10   505.7  0.99   6391.   2951.  7.95
36.0  5604.2   188.2  44033.  5050.5  136.3  122.2 0.202  -0.01 1.5577 0.1733  7.95  2.03   488.2  1.00   6390.   2951.  7.97


     ACCELERATE - STOP DISTANCE =     5556.7 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     5179.8 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     4519.9 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     5197.9 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     4757.1 FEET
0   AT END OF TAKEOFF PHASE
 TIME=  0.179 HRS   FUEL USED=     212. LBS   WEIGHT=   44010. LBS   ALT.=    5500. FT.


   ACCELERATE TO MACH NO. =0.391

0                 FUEL                                                      FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)   (KTS)     NO.   DIV     (LBS)   (LB/HR)

  0.179    0.00    211.9  44010.    5500.    163.    150. 0.251 0.750   12418.    5793.
  0.185    1.46    252.3  43969.    5500.    254.    234. 0.391 0.827   10860.    5933.

  END OF ACCELERATION SEGMENT
  TIME= 0.185 HRS   FUEL USED=   252.3 LBS   WEIGHT=  43969. LBS    RANGE=     1. NM
0   CLIMB TO    37000. FT. AT MAXIMUM RATE OF CLIMB
0                 FUEL                                                                               FUS.                       FUEL
  TIME    RANGE    USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    CL       CD    ALPHA GAMMA ANGLE    R/C    THRUST     FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)   (KTS)     NO.   DIV                     (DEG) (DEG) (DEG)   (FPM)    (LBS)   (LB/HR)

  0.185       1.     252.  43969.    5500.    242.    223. 0.372 0.824 0.4718 0.0338   3.94   8.39 10.33    3577.    9529.    5230.
  0.188       2.     264.  43957.    6000.    243.    222. 0.375 0.823 0.4751 0.0339   3.97   7.91  9.88    3387.    9443.    5180.
  0.193       3.     290.  43932.    7000.    246.    221. 0.380 0.823 0.4794 0.0341   4.01   7.62  9.63    3298.    9253.    5076.
  0.198       4.     316.  43906.    8000.    247.    219. 0.384 0.822 0.4872 0.0345   4.10   7.56  9.66    3298.    9077.    4970.
  0.203       6.     341.  43881.    9000.    249.    218. 0.388 0.821 0.4954 0.0349   4.19   7.36  9.55    3234.    8900.    4865.
  0.208       7.     366.  43856.   10000.    252.    217. 0.395 0.821 0.4986 0.0350   4.21   6.91  9.12    3073.    8701.    4763.
  0.213       8.     392.  43830.   11000.    262.    222. 0.411 0.823 0.4769 0.0340   3.93   6.98  8.91    3226.    8427.    4660.
  0.218      10.     416.  43806.   12000.    264.    220. 0.417 0.822 0.4832 0.0343   4.00   6.39  8.39    2984.    8253.    4555.
  0.224      11.     441.  43781.   13000.    267.    219. 0.423 0.822 0.4893 0.0346   4.06   6.19  8.25    2917.    8080.    4453.
  0.230      13.     467.  43755.   14000.    270.    218. 0.428 0.821 0.4955 0.0349   4.12   5.99  8.10    2850.    7908.    4354.
  0.236      14.     492.  43730.   15000.    273.    217. 0.436 0.821 0.4977 0.0350   4.13   5.61  7.74    2708.    7725.    4258.
  0.242      16.     518.  43703.   16000.    278.    217. 0.445 0.821 0.4970 0.0349   4.10   5.25  7.35    2577.    7517.    4154.
  0.248      18.     545.  43677.   17000.    281.    216. 0.451 0.820 0.5037 0.0353   4.17   5.29  7.45    2620.    7331.    4048.
  0.255      19.     571.  43651.   18000.    283.    214. 0.457 0.819 0.5106 0.0356   4.23   5.07  7.30    2537.    7148.    3944.
  0.261      21.     597.  43625.   19000.    286.    213. 0.463 0.818 0.5177 0.0360   4.30   4.86  7.16    2454.    6968.    3843.
  0.268      23.     623.  43599.   20000.    289.    211. 0.470 0.817 0.5249 0.0363   4.37   4.64  7.01    2371.    6791.    3743.
  0.275      25.     649.  43572.   21000.    292.    210. 0.476 0.816 0.5322 0.0367   4.44   4.44  6.88    2288.    6617.    3646.
  0.282      27.     676.  43546.   22000.    295.    208. 0.483 0.815 0.5397 0.0371   4.51   4.23  6.74    2205.    6446.    3550.
  0.290      30.     703.  43519.   23000.    298.    207. 0.491 0.814 0.5463 0.0374   4.56   4.01  6.57    2109.    6275.    3457.
  0.298      32.     730.  43492.   24000.    305.    208. 0.503 0.815 0.5415 0.0372   4.48   3.47  5.95    1867.    6076.    3377.
  0.307      35.     760.  43462.   25000.    307.    206. 0.510 0.814 0.5508 0.0377   4.57   3.61  6.18    1961.    5900.    3293.
  0.315      37.     788.  43434.   26000.    310.    204. 0.516 0.813 0.5605 0.0382   4.66   3.41  6.07    1867.    5728.    3209.
  0.324      40.     817.  43405.   27000.    313.    202. 0.523 0.811 0.5702 0.0387   4.75   3.21  5.96    1773.    5560.    3127.
  0.334      43.     846.  43376.   28000.    315.    201. 0.530 0.810 0.5801 0.0393   4.84   3.01  5.85    1680.    5394.    3046.
  0.343      46.     876.  43345.   29000.    319.    199. 0.539 0.809 0.5868 0.0397   4.89   2.75  5.63    1551.    5229.    2968.
  0.354      50.     908.  43313.   30000.    323.    198. 0.547 0.808 0.5950 0.0401   4.95   2.58  5.54    1474.    5068.    2890.
  0.365      53.     941.  43281.   31000.    327.    197. 0.557 0.808 0.6010 0.0405   4.99   2.31  5.30    1338.    4874.    2793.
  0.378      57.     976.  43246.   32000.    334.    198. 0.572 0.808 0.5963 0.0402   4.89   1.91  4.80    1131.    4672.    2705.
  0.393      62.    1015.  43206.   33000.    355.    206. 0.609 0.814 0.5498 0.0376   4.27   1.21  3.48     758.    4449.    2638.
  0.415      70.    1074.  43148.   34000.    363.    206. 0.626 0.815 0.5457 0.0374   4.17   1.42  3.59     908.    4292.    2554.
  0.433      77.    1120.  43101.   35000.    371.    207. 0.643 0.815 0.5417 0.0372   4.07   1.23  3.31     809.    4135.    2474.
  0.454      84.    1171.  43050.   36000.    376.    206. 0.655 0.814 0.5463 0.0374   4.08   1.16  3.24     773.    3980.    2394.
  0.475      92.    1223.  42999.   37000.    380.    204. 0.662 0.813 0.5594 0.0381   4.19   1.05  3.23     706.    3827.    2322.
0   END OF CLIMB TO    37000. FT
 TIME=  0.475 HRS   FUEL USED=     1223. LBS   WEIGHT=    42999. LBS    RANGE=      92. NM

0ALTITUDE=      37000. FT    TAS=      465.92 KTS    MACH NO=     0.8116


   ACCELERATE TO MACH NO. =0.740

0                 FUEL                                                      FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)   (KTS)     NO.   DIV     (LBS)   (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812    4059.    2609.
  0.501   103.54  1296.2  42925.   37000.    425.    227. 0.740 0.826    4122.    2703.

  END OF ACCELERATION SEGMENT
  TIME= 0.501 HRS   FUEL USED=  1296.2 LBS   WEIGHT=  42925. LBS   RANGE=  104. NM


   ACCELERATE TO MACH NO. =0.812

0                 FUEL                                                      FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)   (KTS)     NO.   DIV     (LBS)   (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812    4059.    2609.
  0.528   116.06  1372.3  42849.   37000.    466.    249. 0.812 0.835    4173.    2763.

  END OF ACCELERATION SEGMENT
  TIME= 0.528 HRS   FUEL USED=  1372.3 LBS   WEIGHT=  42849. LBS   RANGE=  116. NM

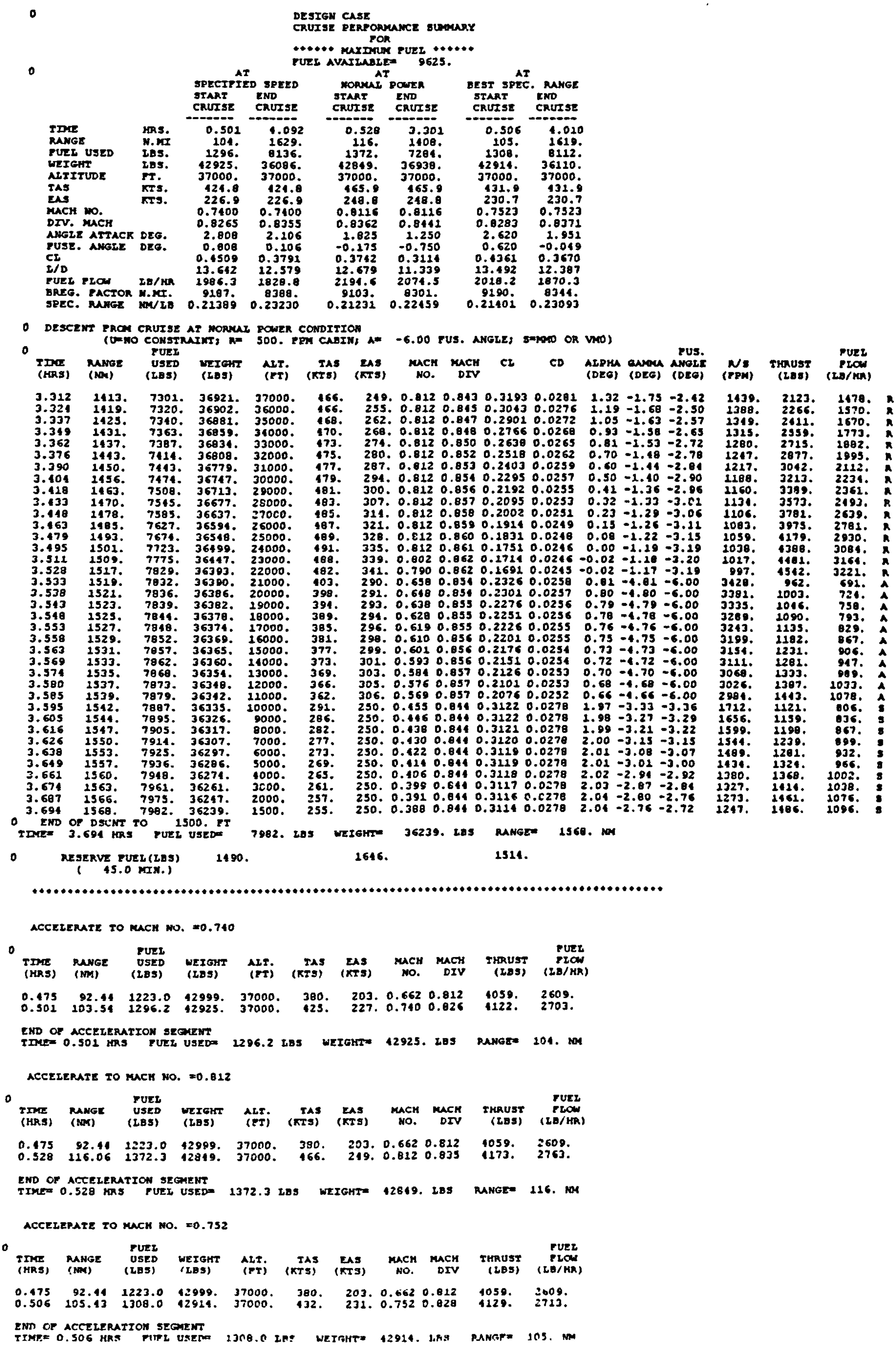

   ACCELERATE TO MACH NO. =0.752

0                 FUEL                                                      FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)   (KTS)     NO.   DIV     (LBS)   (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812    4059.    2609.
  0.506   105.43  1308.0  42914.   37000.    432.    231. 0.752 0.828    4129.    2713.

  TIME= 0.506 HRS   FUEL USED=  1308.0 LBS   WEIGHT=  42914. LBS   RANGE=  105. NM
```

Fig I1 - Canadair Regional Jet 100 GASP result (continued)



```
0                                        DESIGN CASE
                                         CRUISE PERFORMANCE SUMMARY
                                                  FOR
                                         ****** MAXIMUM FUEL ******
                                         FUEL AVAILABLE=    9625.
0                                   AT                     AT                     AT
                          SPECIFIED SPEED         NORMAL POWER          BEST SPEC. RANGE
                           START     END           START     END          START     END
                          CRUISE    CRUISE        CRUISE    CRUISE       CRUISE    CRUISE
                          -------   -------       -------   -------      -------   -------
   TIME          HRS.      0.501     4.092         0.528     3.301        0.506     4.010
   RANGE         N.MI       104.     1629.          116.     1408.         105.     1619.
   FUEL USED     LBS.      1296.     8136.         1372.     7284.        1308.     8112.
   WEIGHT        LBS.     42925.    36086.        42849.    36938.       42914.    36110.
   ALTITUDE      FT.      37000.    37000.        37000.    37000.       37000.    37000.
   TAS           KTS.      424.8     424.8         465.9     465.9        431.9     431.9
   EAS           KTS.      226.9     226.9         248.8     248.8        230.7     230.7
   MACH NO.               0.7400    0.7400        0.8116    0.8116       0.7523    0.7523
   DIV. MACH              0.8265    0.8355        0.8362    0.8441       0.8283    0.8371
   ANGLE ATTACK DEG.       2.808     2.106         1.825     1.250        2.620     1.951
   FUSE. ANGLE  DEG.       0.808     0.106        -0.175    -0.750        0.620    -0.049
   CL                     0.4509    0.3791        0.3742    0.3114       0.4361    0.3670
   L/D                    13.642    12.579        12.679    11.339       13.492    12.387
   FUEL FLOW     LB/HR    1986.3    1828.8        2194.6    2074.5       2018.2    1870.3
   BREG. FACTOR N.MI.      9187.     8388.         9103.     8301.        9190.     8344.
   SPEC. RANGE  NM/LB    0.21389   0.23230       0.21231   0.22459      0.21401   0.23093

0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
           (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
0                   FUEL                                                                                  FUS.                                   FUEL
  TIME     RANGE    USED     WEIGHT    ALT.     TAS    EAS    MACH  MACH    CL       CD      ALPHA GAMMA ANGLE      R/S     THRUST       FLOW
  (HRS)    (NM)     (LBS)    (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV                     (DEG) (DEG) (DEG)     (FPM)    (LBS)      (LB/HR)

  3.312    1413.    7301.   36921.   37000.    466.    249. 0.812 0.843 0.3193 0.0281  1.32 -1.75 -2.42     1439.     2123.      1478.  R
  3.324    1419.    7320.   36902.   36000.    466.    255. 0.812 0.845 0.3043 0.0276  1.19 -1.68 -2.50     1388.     2266.      1570.  R
  3.337    1425.    7340.   36881.   35000.    468.    262. 0.812 0.847 0.2901 0.0272  1.05 -1.63 -2.57     1349.     2411.      1670.  R
  3.349    1431.    7363.   36859.   34000.    470.    268. 0.812 0.848 0.2766 0.0268  0.93 -1.58 -2.65     1315.     2559.      1773.  R
  3.362    1437.    7387.   36834.   33000.    473.    274. 0.812 0.850 0.2638 0.0265  0.81 -1.53 -2.72     1280.     2715.      1882.  R
  3.376    1443.    7414.   36808.   32000.    475.    280. 0.812 0.852 0.2518 0.0262  0.70 -1.48 -2.78     1247.     2877.      1995.  R
  3.390    1450.    7443.   36779.   31000.    477.    287. 0.812 0.853 0.2403 0.0259  0.60 -1.44 -2.84     1217.     3042.      2112.  R
  3.404    1456.    7474.   36747.   30000.    479.    294. 0.812 0.854 0.2295 0.0257  0.50 -1.40 -2.90     1188.     3213.      2234.  R
  3.418    1463.    7508.   36713.   29000.    481.    300. 0.812 0.856 0.2192 0.0255  0.41 -1.36 -2.96     1160.     3389.      2361.  R
  3.433    1470.    7545.   36677.   28000.    483.    307. 0.812 0.857 0.2095 0.0253  0.32 -1.33 -3.01     1134.     3573.      2493.  R
  3.448    1478.    7585.   36637.   27000.    485.    314. 0.812 0.858 0.2002 0.0251  0.23 -1.29 -3.06     1106.     3781.      2639.  R
  3.463    1485.    7627.   36594.   26000.    487.    321. 0.812 0.859 0.1914 0.0249  0.15 -1.26 -3.11     1083.     3975.      2781.  R
  3.479    1493.    7674.   36548.   25000.    489.    328. 0.812 0.860 0.1831 0.0248  0.08 -1.22 -3.15     1059.     4179.      2930.  R
  3.495    1501.    7723.   36499.   24000.    491.    335. 0.812 0.861 0.1751 0.0246  0.00 -1.19 -3.19     1038.     4388.      3084.  R
  3.511    1509.    7775.   36447.   23000.    488.    339. 0.802 0.862 0.1714 0.0246 -0.02 -1.18 -3.20     1017.     4481.      3164.  R
  3.528    1517.    7829.   36393.   22000.    482.    341. 0.790 0.862 0.1691 0.0245 -0.02 -1.17 -3.19      997.     4542.      3221.  R
  3.533    1519.    7832.   36390.   21000.    403.    290. 0.658 0.854 0.2326 0.0258  0.81 -4.81 -6.00     3428.      962.       691.  A
  3.538    1521.    7836.   36386.   20000.    398.    291. 0.648 0.854 0.2301 0.0257  0.80 -4.80 -6.00     3381.     1003.       724.  A
  3.543    1523.    7839.   36382.   19000.    394.    293. 0.638 0.855 0.2276 0.0256  0.79 -4.79 -6.00     3335.     1046.       758.  A
  3.548    1525.    7844.   36378.   18000.    389.    294. 0.628 0.855 0.2251 0.0256  0.78 -4.78 -6.00     3289.     1090.       793.  A
  3.553    1527.    7848.   36374.   17000.    385.    296. 0.619 0.855 0.2226 0.0255  0.76 -4.76 -6.00     3243.     1135.       829.  A
  3.558    1529.    7852.   36369.   16000.    381.    298. 0.610 0.856 0.2201 0.0255  0.75 -4.75 -6.00     3199.     1182.       867.  A
  3.563    1531.    7857.   36365.   15000.    377.    299. 0.601 0.856 0.2176 0.0254  0.73 -4.73 -6.00     3154.     1231.       906.  A
  3.569    1533.    7862.   36360.   14000.    373.    301. 0.593 0.856 0.2151 0.0254  0.72 -4.72 -6.00     3111.     1281.       947.  A
  3.574    1535.    7868.   36354.   13000.    369.    303. 0.584 0.857 0.2126 0.0253  0.70 -4.70 -6.00     3068.     1333.       989.  A
  3.580    1537.    7873.   36348.   12000.    366.    305. 0.576 0.857 0.2101 0.0253  0.68 -4.68 -6.00     3026.     1387.      1033.  A
  3.585    1539.    7879.   36342.   11000.    362.    306. 0.569 0.857 0.2076 0.0252  0.66 -4.66 -6.00     2984.     1443.      1078.  A
  3.595    1542.    7887.   36335.   10000.    291.    250. 0.455 0.844 0.3122 0.0278  1.97 -3.33 -3.36     1712.     1121.       806.  S
  3.605    1544.    7895.   36326.    9000.    286.    250. 0.446 0.844 0.3122 0.0278  1.98 -3.27 -3.29     1656.     1159.       836.  S
  3.616    1547.    7905.   36317.    8000.    282.    250. 0.438 0.844 0.3121 0.0278  1.99 -3.21 -3.22     1599.     1198.       867.  S
  3.626    1550.    7914.   36307.    7000.    277.    250. 0.430 0.844 0.3120 0.0278  2.00 -3.15 -3.15     1544.     1239.       899.  S
  3.638    1553.    7925.   36297.    6000.    273.    250. 0.422 0.844 0.3119 0.0278  2.01 -3.08 -3.07     1489.     1281.       932.  S
  3.649    1557.    7936.   36286.    5000.    269.    250. 0.414 0.844 0.3119 0.0278  2.01 -3.01 -3.00     1434.     1324.       966.  S
  3.661    1560.    7948.   36274.    4000.    265.    250. 0.406 0.844 0.3118 0.0278  2.02 -2.94 -2.92     1380.     1368.      1002.  S
  3.674    1563.    7961.   36261.    3000.    261.    250. 0.399 0.844 0.3117 0.0278  2.03 -2.87 -2.84     1327.     1414.      1038.  S
  3.687    1566.    7975.   36247.    2000.    257.    250. 0.391 0.844 0.3116 0.0278  2.04 -2.80 -2.76     1273.     1461.      1076.  S
  3.694    1568.    7982.   36239.    1500.    255.    250. 0.388 0.844 0.3114 0.0278  2.04 -2.76 -2.72     1247.     1486.      1096.  S
0   END OF DSCNT TO     1500. FT
 TIME=  3.694 HRS   FUEL USED=     7982. LBS   WEIGHT=    36239. LBS    RANGE=    1568. NM

0       RESERVE FUEL(LBS)      1490.                 1646.                 1514.
          (   45.0 MIN.)

   ************************************************************************************


   ACCELERATE TO MACH NO. =0.740

0                  FUEL                                                         FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST   FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812   4059.   2609.
  0.501   103.54  1296.2  42925.   37000.    425.    227. 0.740 0.826   4122.   2703.

  END OF ACCELERATION SEGMENT
  TIME= 0.501 HRS   FUEL USED=  1296.2 LBS   WEIGHT=  42925. LBS   RANGE=  104. NM


   ACCELERATE TO MACH NO. =0.812

0                  FUEL                                                         FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST   FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812   4059.   2609.
  0.528   116.06  1372.3  42849.   37000.    466.    249. 0.812 0.835   4173.   2763.

  END OF ACCELERATION SEGMENT
  TIME= 0.528 HRS   FUEL USED=  1372.3 LBS   WEIGHT=  42849. LBS   RANGE=  116. NM


   ACCELERATE TO MACH NO. =0.752

0                  FUEL                                                         FUEL
  TIME    RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH   THRUST   FLOW
  (HRS)   (NM)     (LBS)   (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

  0.475    92.44  1223.0  42999.   37000.    380.    203. 0.662 0.812   4059.   2609.
  0.506   105.43  1308.0  42914.   37000.    432.    231. 0.752 0.828   4129.   2713.

  END OF ACCELERATION SEGMENT
  TIME= 0.506 HRS   FUEL USED=  1308.0 LBS   WEIGHT=  42914. LBS   RANGE=  105. NM
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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0                                            DESIGN CASE
                                             CRUISE PERFORMANCE SUMMARY
                                                         FOR
                                             ***** DESIGN PAYLOAD *****
                                             **** MAXIMUM PAYLOAD *****
                                             FUEL AVAILABLE=    6976.
0                                 AT                     AT                    AT
                             SPECIFIED SPEED        NORMAL POWER        BEST SPEC. RANGE
                             START     END          START    END        START    END
                             CRUISE   CRUISE        CRUISE   CRUISE     CRUISE   CRUISE
                             -------  -------       -------  -------    -------  -------
   TIME              HRS.     0.501    2.662         0.528    2.042      0.506    2.609
   RANGE             N.MI      104.    1021.          116.     822.       105.    1014.
   FUEL USED         LBS.     1296.    5487.         1372.    4634.      1308.    5463.
   WEIGHT            LBS.    42925.   38735.        42849.   39588.     42914.   38759.
   ALTITUDE          FT.     37000.   37000.        37000.   37000.     37000.   37000.
   TAS               KTS.     424.8    424.8         465.9    465.9      431.9    431.9
   EAS               KTS.     226.9    226.9         248.8    248.8      230.7    230.7
   MACH NO.                  0.7400   0.7400        0.8116   0.8116     0.7523   0.7523
   DIV. MACH                 0.8265   0.8320        0.8362   0.8412     0.8283   0.8337
   ANGLE ATTACK DEG.          2.808    2.378         1.825    1.462      2.620    2.212
   FUSE. ANGLE  DEG.          0.808    0.378        -0.175   -0.538      0.620    0.212
   CL                        0.4509   0.4069        0.3742   0.3346     0.4361   0.3939
   L/D                       13.642   13.047        12.679   11.872     13.492   12.872
   FUEL FLOW         LB/HR   1986.3   1896.7        2194.6   2116.2     2018.2   1935.5
   BREG. FACTOR N.MI.         9187.    8682.         9103.    8722.      9190.    8655.
   SPEC. RANGE       NM/LB  0.21389  0.22399       0.21231  0.22017    0.21401  0.22316


0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
            (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
0                    FUEL                                                                           FUS.                        FUEL
  TIME    RANGE     USED    WEIGHT     ALT.     TAS    EAS     MACH  MACH    CL       CD    ALPHA GAMMA ANGLE      R/S     THRUST     FLOW
  (HRS)   (NM)     (LBS)    (LBS)      (FT)    (KTS)  (KTS)     NO.  DIV                    (DEG) (DEG) (DEG)     (FPM)    (LBS)    (LB/HR)

  2.054    827.    4651.   39571.   37000.    466.    249. 0.812 0.840 0.3422 0.0288  1.53 -1.75 -2.21    1439.    2126.    1480.  R
  2.066    833.    4670.   39552.   36000.    466.    255. 0.812 0.842 0.3261 0.0283  1.38 -1.68 -2.30    1388.    2268.    1571.  R
  2.078    838.    4690.   39531.   35000.    468.    262. 0.812 0.844 0.3108 0.0278  1.25 -1.63 -2.38    1349.    2412.    1670.  R
  2.091    844.    4713.   39509.   34000.    470.    268. 0.812 0.846 0.2964 0.0274  1.11 -1.58 -2.47    1315.    2559.    1773.  R
  2.104    851.    4737.   39484.   33000.    473.    274. 0.812 0.848 0.2828 0.0270  0.99 -1.53 -2.54    1280.    2714.    1882.  R
  2.117    857.    4761.   39458.   32000.    475.    280. 0.812 0.849 0.2698 0.0267  0.87 -1.48 -2.61    1247.    2875.    1995.  R
  2.131    863.    4793.   39429.   31000.    477.    287. 0.812 0.851 0.2576 0.0263  0.76 -1.44 -2.68    1217.    3039.    2111.  R
  2.145    870.    4824.   39397.   30000.    479.    294. 0.812 0.852 0.2460 0.0261  0.65 -1.40 -2.75    1188.    3209.    2233.  R
  2.160    877.    4858.   39363.   29000.    481.    300. 0.812 0.854 0.2350 0.0258  0.55 -1.36 -2.81    1160.    3385.    2359.  R
  2.174    884.    4895.   39327.   28000.    483.    307. 0.312 0.855 0.2245 0.0256  0.46 -1.33 -2.87    1134.    3568.    2491.  R
  2.189    892.    4935.   39287.   27000.    485.    314. 0.812 0.856 0.2146 0.0254  0.36 -1.29 -2.92    1106.    3775.    2636.  R
  2.205    899.    4977.   39244.   26000.    487.    321. 0.812 0.857 0.2052 0.0252  0.28 -1.26 -2.98    1083.    3967.    2777.  R
  2.220    907.    5023.   39198.   25000.    489.    328. 0.812 0.859 0.1963 0.0250  0.20 -1.22 -3.03    1059.    4169.    2926.  R
  2.237    915.    5073.   39149.   24000.    491.    335. 0.812 0.860 0.1878 0.0248  0.12 -1.19 -3.08    1038.    4378.    3079.  R
  2.253    923.    5125.   39097.   23000.    488.    339. 0.803 0.860 0.1834 0.0248  0.09 -1.18 -3.08    1017.    4479.    3164.  R
  2.270    931.    5178.   39043.   22000.    482.    341. 0.791 0.861 0.1811 0.0247  0.09 -1.17 -3.08     997.    4539.    3222.  R
  2.274    933.    5191.   39030.   21000.    497.    357. 0.812 0.863 0.1643 0.0245 -0.10 -3.90 -6.00    3432.    3155.    2661.  A
  2.279    935.    5195.   39027.   20000.    409.    299. 0.665 0.854 0.2342 0.0258  0.82 -4.82 -6.00    3483.    1003.     724.  A
  2.284    937.    5199.   39023.   19000.    404.    301. 0.655 0.854 0.2317 0.0257  0.81 -4.81 -6.00    3436.    1046.     758.  A
  2.289    939.    5202.   39019.   18000.    400.    302. 0.645 0.854 0.2293 0.0257  0.80 -4.80 -6.00    3389.    1090.     793.  A
  2.294    941.    5207.   39015.   17000.    395.    304. 0.635 0.855 0.2268 0.0256  0.79 -4.79 -6.00    3343.    1135.     829.  A
  2.299    943.    5211.   39011.   16000.    391.    305. 0.626 0.855 0.2244 0.0256  0.77 -4.77 -6.00    3298.    1182.     867.  A
  2.304    945.    5216.   39006.   15000.    387.    307. 0.617 0.855 0.2219 0.0255  0.76 -4.76 -6.00    3253.    1231.     906.  A
  2.309    947.    5220.   39001.   14000.    383.    309. 0.608 0.856 0.2195 0.0255  0.74 -4.74 -6.00    3208.    1281.     947.  A
  2.315    949.    5226.   38996.   13000.    379.    310. 0.599 0.856 0.2170 0.0254  0.73 -4.73 -6.00    3165.    1333.     989.  A
  2.320    951.    5231.   38990.   12000.    375.    312. 0.591 0.856 0.2146 0.0254  0.71 -4.71 -6.00    3122.    1387.    1033.  A
  2.325    953.    5237.   38985.   11000.    371.    314. 0.583 0.857 0.2121 0.0253  0.70 -4.70 -6.00    3079.    1443.    1078.  A
  2.335    956.    5245.   38976.   10000.    291.    250. 0.455 0.841 0.3349 0.0286  2.23 -3.22 -3.00    1658.    1121.     806.  S
  2.346    959.    5254.   38968.    9000.    286.    250. 0.446 0.841 0.3349 0.0286  2.24 -3.17 -2.93    1604.    1159.     836.  S
  2.357    962.    5263.   38958.    8000.    282.    250. 0.438 0.841 0.3348 0.0285  2.25 -3.11 -2.86    1551.    1198.     867.  S
  2.368    965.    5273.   38948.    7000.    277.    250. 0.430 0.841 0.3347 0.0285  2.26 -3.05 -2.79    1498.    1239.     899.  S
  2.379    968.    5284.   38938.    6000.    273.    250. 0.422 0.841 0.3346 0.0285  2.27 -2.99 -2.72    1446.    1281.     932.  S
  2.391    971.    5295.   38926.    5000.    269.    250. 0.414 0.841 0.3346 0.0285  2.28 -2.93 -2.65    1394.    1324.     966.  S
  2.404    975.    5308.   38914.    4000.    265.    250. 0.406 0.841 0.3345 0.0285  2.29 -2.86 -2.58    1343.    1368.    1002.  S
  2.417    978.    5321.   38900.    3000.    261.    250. 0.399 0.841 0.3344 0.0285  2.29 -2.80 -2.50    1292.    1414.    1038.  S
  2.430    981.    5336.   38886.    2000.    257.    250. 0.391 0.841 0.3342 0.0285  2.30 -2.73 -2.43    1242.    1461.    1076.  S
  2.437    983.    5343.   38878.    1500.    255.    250. 0.388 0.841 0.3341 0.0285  2.30 -2.69 -2.39    1217.    1486.    1096.  S
0  END OF DSCNT TO     1500. FT
 TIME=  2.437 HRS   FUEL USED=    5343. LBS   WEIGHT=   38878. LBS   RANGE=    983. NM

0      RESERVE FUEL(LBS)      1490.                 1646.                1514.
         (   45.0 MIN.)

   ****************************************************************************
0      RANGE =  983.    BLOCK TIME= 2.437    USED FOR DESIGN RANGE AND COST

   ****************************************************************************
0  ************************************************************************************
0            TEMP.=  537. DEG:STD.+36.
    LANDING ELEVATION= 5000. FT.
    LANDING WING LOADING=  73.24 PSF.
    LANDING WEIGHT =     40074. LBS.

    LANDING DISTANCE FROM 50. FT.=   2829. FT.

    F.A.R. FACTORED FIELD LENGTH =   4714. FT.
0                     APPROACH             TRANSITION             DELAY                ROLL
0                  DIST=       676.     DIST=         197.     DIST=        200.     DIST=        1755.
                   R/S=       1000.     XLFMX=       1.200     TDELAY=      1.00     MUB=        0.4000
                   VAPEAS=   119.93     SINKTD=      3.000     TIDLE=       604.     TR/TIDLE=  0.0000
                   VAPTAS=   133.83     VSTEAS=      92.26     VTDTAS=    118.38     ABAR(G)=   0.3541
                   THETA=      4.23     CLMX=       2.5369
                   THRUST=    3857.     HFLAR=        20.9
0  ************************************************************************************
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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**************************************************************************************************************
0               RANGE OR ENDURANCE ITERATION SUMMARY

                              GROSS      RANGE(NMI) OR
                ITERATION   WEIGHT(LB)   ENDURANCE(HR)

                    0         44050.00      960.518
                    1         55062.50     2210.849
                    2         44221.59      983.085
                    REQUIRED RG. OR END. =  980.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   2.805   LIFT= 42894.9   L/D=  13.638   ALTITUDE= 37000.0   MACH=  0.7400

0  GROSS WEIGHT =   44222.       PASSENGERS =  50. PLUS CREW

0  FUSELAGE      LENGTH              (ELF)          80.00   FT
                 WIDTH               (SWF)           8.83   FT
                 WETTED AREA         (SF)           1846.   SQFT
                 DELTA P             (DELP)          8.30   PSI

0  WING          ASPECT RATIO        (AR)            8.85
                 AREA                (SW)           547.2   SQFT
                 SPAN                (B)             69.6   FT
                 GEOM. MEAN CHORD    (CBARW)         8.81   FT
                 QUARTER CHORD SWEEP(DLMC4)          24.8   DEG
                 TAPER RATIO         (SLM)          0.250
                 ROOT THICKNESS      (TCR)          0.132
                 TIP THICKNESS       (TCT)          0.100
                 WING LOADING        (WGS)           80.8   PSF
                 WING FUEL VOLUME    (VFW)         1439.4   GAL

0  HOR. TAIL     ASPECT RATIO        (ARHT)          4.07
                 AREA                (SHT)          132.4   SQFT
                 SPAN                (BHT)          23.21   FT
                 MEAN CHORD          (CBARHT)        5.71   FT
                 THICKNESS/CHORD     (TCHT)         0.100
                 MOMENT ARM          (ELTH)          38.0   FT
                 VOLUME COEFF.       (VBARH)        1.045

   VERT. TAIL    ASPECT RATIO        (ARVT)          1.05
                 AREA                (SVT)          118.3   SQFT
                 SPAN                (BVT)          11.14   FT
                 MEAN CHORD          (CBARVT)       10.74   FT
                 THICKNESS/CHORD     (TCVT)         0.120
                 MOMENT ARM          (ELTV)          27.3   FT
                 VOLUME COEFF.       (VBARV)        0.085

0  ENG.NACELLES  LENGTH              (ELN)          11.58   FT
                 MEAN DIAMETER       (DBARN)         3.86   FT
                 NUMBER ENGINES      (ENP)           2.0
                 WETTED AREA         (SN)          280.59   SQFT

                 LOCATION                          ON FUSELAGE

0  VDIVE =  715. KTS   VMO =  596. KTS   MMO = 0.900
   ULT. LF =  5.92   MAN. LF =  2.50   GUST LF =  3.94

0  PROPULSION GROUP
      PRIMARY ENGINES         (WEP)        2957.
      PRIMARY ENGINE INSTL.   (WPEI)        399.
      FUEL SYSTEM             (WFSS)        140.
      TOTAL PROP.GROUP WT.    (WP)         3496.
0  STRUCTURES GROUP
      WING                    (WW)         5384.
      HOR. TAIL               (WHT)         698.
      VERT. TAIL              (WVT)         519.
      FUSELAGE                (WB)         5773.   (INCL.    0.0 LBS A.T.W.)
      LANDING GEAR            (WLG)        1680.
      PRIMARY ENG. SECTION    (WPES)        990.
      GROUP WEIGHT INC.       (DELWST)        0.
      TOTAL STRUC.GROUP WT.   (WST)       15045.
0  FLIGHT CONTROLS GROUP
      COCKPIT CONTROLS        (WCC)          95.
      FIXED WING CONTROLS     (WCFW)        939.
      SAS                     (WSAS)          0.
      GROUP WEIGHT INC.       (DELWFC)        0.
      TOTAL CONTROL WT.       (WFC)        1034.
0  WT. OF FIXED EQUIPMENT     (WFE)        6582.

   WEIGHT EMPTY               (WE)        26157.

   FIXED USEFUL LOAD          (WFUL)       1088. (INC. CREW )

   OPERATING WEIGHT EMPTY     (OWE)       27245.
0  PAYLOAD                    (WPL)       10000. (PAX.VOL.= 50.    DESIGN PAX= 50.)

   FUEL                       (WFA)        6976. (WFW= 6976.) (WFTP=    0.)

   GROSS WEIGHT               (WG)        44222.


0          FIXED EQUIP GROUP                    FIXED USEFUL LOAD
0    WAPU              372.27       WCREW ( 2.)          340.00
     WINSTR            254.92       WSTU  ( 1.)          130.00
     WHYD              372.24       WCBAG                110.00
     WELEC             970.00       WUF                  140.35
     WAV               500.00       WOIL                 123.81
     WFUR             3374.86       WSRV                 116.00
     WAC               463.26       WH2O                  53.00
     WAI               254.82       WEMER                 40.00
     WAUXG              20.00       WCATER                35.00

     WFE              6582.37       WFUL                1088.16
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Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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0  DESIGN MACH = 0.740            DESIGN ALTITUDE =  37000.           DESIGN Q (PSF) =174.22
0  DESIGN RE.NUM. PER FT.    = 1.638E+06    FLATPLATE CF AT RE=10EX7 IS 0.00276

0  AERODYNAMIC DATA

0                             FLATPLATE                WETTED
   DRAG BREAKDOWN             AREA(SQFT)      CDO      AREA(SQFT)
0        WING                   3.7255     0.00681       882.64
         FUSELAGE               5.3604     0.00980      1845.60
         VERT.TAIL              0.7548     0.00138       236.58
         HOR. TAIL              0.8949     0.00164       264.75
         ENGINE NAC.            1.1723     0.00214       280.59
         TIP TANKS              0.0000     0.00000         0.00
         INCREMENTAL            0.8207     0.00150         0.00
0           TOTAL              12.7286     0.02326      3510.17

           MEAN SKIN FRICTION COEF.= 0.003626


0  AERODYNAMIC COEFF.
       A1                                              0.8234
       A2                                             -0.1262
       A3                                              0.0323
       A4=.75X(T/C)                                    0.0914
       A5=CDO--                                        0.0143
       A6                                              2.4681
       A7=1/(PI.SEE.AR)                                0.0458
       3-D LIFT SLOPE AT CRUISE MACH       (CLALPH)    5.8606   PER RADIAN
       OSWALD FACTOR                       (SEE)       0.7858

0  CRUISE CD = 0.0233 +  0.0458 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
0  RETRACTABLE LANDING GEAR CD INC.=0.02674


0 CRUISE DRAG
0CL=  0.2000
           MACH       CD     L/D    CLALPH   ALPHA
        0.50000 0.02513  7.9593  5.0970  0.6482
        0.55000 0.02513  7.9593  5.2087  0.6000
        0.60000 0.02513  7.9593  5.3405  0.5457
        0.65000 0.02513  7.9593  5.4969  0.4847
        0.70000 0.02513  7.9593  5.6837  0.4161
        0.75000 0.02513  7.9593  5.9094  0.3391
        0.80000 0.02513  7.9593  6.1866  0.2523
        0.85000 0.02513  7.9593  6.5347  0.1536
0CL=  0.3000
           MACH       CD     L/D    CLALPH   ALPHA
        0.50000 0.02756 10.8868  5.0970  1.7723
        0.55000 0.02756 10.8868  5.2087  1.7000
        0.60000 0.02756 10.8868  5.3405  1.6186
        0.65000 0.02756 10.8868  5.4969  1.5270
        0.70000 0.02756 10.8868  5.6837  1.4242
        0.75000 0.02756 10.8868  5.9094  1.3087
        0.80000 0.02756 10.8868  6.1866  1.1784
        0.85000 0.02756 10.8859  6.5347  1.0304
0CL=  0.4000
           MACH       CD     L/D    CLALPH   ALPHA
        0.50000 0.03090 12.9450  5.0970  2.8964
        0.55000 0.03090 12.9450  5.2087  2.8000
        0.60000 0.03090 12.9450  5.3405  2.6914
        0.65000 0.03090 12.9450  5.4969  2.5693
        0.70000 0.03090 12.9450  5.6837  2.4323
        0.75000 0.03090 12.9450  5.9094  2.2783
        0.80000 0.03090 12.9450  6.1866  2.1045
        0.85000 0.03103 12.8905  6.5347  1.9072
0CL=  0.5000
           MACH       CD     L/D    CLALPH   ALPHA
        0.50000 0.03533 14.1511  5.0970  4.0205
        0.55000 0.03533 14.1511  5.2087  3.9000
        0.60000 0.03533 14.1511  5.3405  3.7643
        0.65000 0.03533 14.1511  5.4969  3.6117
        0.70000 0.03533 14.1511  5.6837  3.4404
        0.75000 0.03533 14.1511  5.9094  3.2478
        0.80000 0.03533 14.1511  6.1866  3.0306
        0.85000 0.03602 13.8815  6.5347  2.7840
0CL=  0.6000
           MACH       CD     L/D    CLALPH   ALPHA
        0.50000 0.04068 14.7488  5.0970  5.1446
        0.55000 0.04068 14.7488  5.2087  5.0001
        0.60000 0.04068 14.7488  5.3405  4.8371
        0.65000 0.04068 14.7488  5.4969  4.6540
        0.70000 0.04068 14.7488  5.6837  4.4485
        0.75000 0.04068 14.7488  5.9094  4.2174
        0.80000 0.04068 14.7488  6.1866  3.9568
        0.85000 0.04267 14.0627  6.5347  3.6608


0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                            FLAPS UP                            TAKEOFF                          LANDING
       ALPHA       CL         CD        L/D        CL         CD        L/D        CL         CD        L/D
    -2.00000 -0.03274  0.02341 -1.39811  0.73729  0.06674 11.04784  1.18620  0.21457  5.52836
     0.00000  0.13094  0.02406  5.44266  0.90096  0.07540 11.94900  1.34987  0.22532  5.99099
     2.00000  0.29462  0.02740 10.75160  1.06464  0.08710 12.22328  1.51355  0.23972  6.31374
     4.00000  0.45829  0.03337 13.73255  1.22832  0.10232 12.00441  1.67723  0.25830  6.49338
     6.00000  0.62197  0.04206 14.78909  1.39199  0.12221 11.39020  1.84090  0.28219  6.52357
     8.00000  0.78565  0.05369 14.63337  1.55567  0.14576 10.67263  2.00458  0.31034  6.45935
    10.00000  0.94932  0.06887 13.78489  1.71935  0.17182 10.00679  2.16826  0.34161  6.34710
    12.00000  1.11300  0.08878 12.53712  1.88302  0.20038  9.39744  2.33193  0.37602  6.20161
    14.00000  1.27667  0.11211 11.38740  2.04670  0.23144  8.84345  2.49561  0.41356  6.03447
    14.50408  1.32348  0.11924 11.09953  2.09337  0.24075  8.69514  2.53686  0.42351  5.99004

0                         DFLAP=     0.00         DFLAP=    15.00         DFLAP=    45.00
0                         CLMAX=  1.32348         CLMAX=  2.09337         CLMAX=  2.53686
```

Fig I1 - Canadair Regional Jet 100 GASP result (continued)

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0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
     FLAP DEFL.    CLMAX    CL         CD        L/D
      10.000     1.86055
                         0.50989  0.05145   9.90973
                         0.67356  0.05850  11.51320
                         0.83724  0.06840  12.24059
                         1.00092  0.08139  12.29716
                         1.16459  0.09792  11.89361
                         1.32827  0.11988  11.08043
                         1.49194  0.14431  10.33845
                         1.65562  0.17122   9.66940
                         1.81930  0.20061   9.06871
                         1.86055  0.20841   8.92732
      20.000     2.26162
                         0.91095  0.08628  10.55842
                         1.07463  0.09601  11.19289
                         1.23831  0.10682  11.37902
                         1.40198  0.12516  11.20151
                         1.56566  0.14701  10.65006
                         1.72934  0.17155  10.08058
                         1.89301  0.19862   9.53076
                         2.05669  0.22822   9.01188
                         2.22036  0.26035   8.52849
                         2.26162  0.26884   8.41241
      30.000     2.49754
                         1.14688  0.12877   8.90653
                         1.31055  0.13948   9.39582
                         1.47423  0.15350   9.60419
                         1.63791  0.17136   9.55818
                         1.80158  0.19452   9.26144
                         1.96526  0.22031   8.92037
                         2.12893  0.24872   8.55954
                         2.29261  0.27975   8.19512
                         2.45629  0.31341   7.83733
                         2.49754  0.32231   7.74899
      40.000     2.62730
                         1.27663  0.18785   6.79607
                         1.44031  0.19914   7.23252
                         1.60399  0.21392   7.49795
                         1.76766  0.23260   7.59953
                         1.93134  0.25714   7.51089
                         2.09502  0.28454   7.36271
                         2.25869  0.31482   7.17460
                         2.42237  0.34796   6.96162
                         2.58604  0.38397   6.73499
                         2.62730  0.39350   6.67674


0ALTITUDE=     37000. FT   TAS=     470.12 KTS   MACH NO=     0.8189


 0                            RDT&E AND AIRFRAME PRODUCTION COSTS
                                          (1993. DOLLARS)
 0                       TOTAL RDT&E COSTS              1071.7244 MILLION
 0                                 AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                   500. AIRCRAFT
                                          WEIGHT(LB)     COST($)     COST($/LB)
          STRUCTURE(  4175819.$)
                             WING                   5384.   1286296.      238.90
                             EMPENNAGE              1217.    433284.      355.90
                             FUSELAGE               5773.   1615574.      279.87
                             LANDING GEAR           1680.    300178.      178.63
                             NACELLES                990.    540488.      545.96
          PROPULSION INSTAL(  165136.$)
                             ENGINE INSTALLAT.       399.    145359.      364.08
                             FUEL SYSTEM             140.     19777.      141.74
          SYSTEMS(  2638784.$)
                             FLIGHT CONTROLS        1034.    485255.      469.41
                             HYDRAULIC               372.     46369.      124.57
                             ELECTRICAL              970.    464214.      478.57
                             AIR CONDITIONING        463.    248223.      535.82
                             ANTI-ICING              255.    134201.      526.66
                             AUX. POWER UNIT         372.    207143.      556.42
                             FURNISHINGS            3375.    788235.      233.56
                             INSTRUMENTS             255.    211440.      829.44
                             AVIONICS INSTALL.       250.     49032.      196.13
                             AUX. ITEMS               20.      4671.      233.56
          INTEGRATION(  1744935.$)
0                              AIRFRAME TOTALS     22950.   8724673.      380.17
0                              ENGINES                      2742208.
                               PROPELLER                          0.
                               AVIONICS                     4000000.
                               A/C COST(NO RD)             15466880.
                               R&D PER A/C                  2143449.
                               TOTAL A/C COST              17610328.

0                   ENGINES      NUMBER =      2.  TYPE=      7

0 EMPTY WEIGHT= 26157.     AIRFRAME WEIGHT= 23200.     WEIGHT OF 1 ENGINE=  1479.     CRUISE SPEED= 470. KTS
0 THRUST/ENGINE=   9242.
0 TOTAL AIRCRAFT COST= 17610328.     AIRFRAME COST= 14868122.     COST OF 1 ENGINE=  1371104.     COST OF 1 PROP.=        0.


0                             --- COST DATA ---
                           GASP SHORTHAUL METHOD
0          DESIGN MISSION
0               OPERATING COST FOR NOR.RATED POWER AND  37000. ALTITUDE
0  ***************************************************************************************
0                    RANGE=     983. N.M.    BLOCK FUEL=    5343. LBS    BLOCK TIME=  2.4368 HRS.
0   UTILIZATION                          3200.
 FLYING OPERATIONS
    FLIGHT CREW                        304.598
    FUEL,OIL,AND TAXES(0.850$/G)       709.752
    INSURANCE                           67.051
 DIRECT MAINTENANCE
    AIRFRAME                           147.362
    ENGINE                             240.401
 MAINTENANCE BURD.                     314.806
 DEPRECIATION                          901.162

    TOTAL DOC  ($/TRIP)               2685.132
               ($/B.HR.)              1101.918
               ($/N.MI.)                 2.731
```

Fig I1 - Canadair Regional Jet 100 GASP result (concluded)

```
1                   BUSINESS JET USING SCALED GARRETT TFE 731-2    - LEARJET 35A
0                            ENGINE CYCLE IS GARRETT TFE731-2


                                        INPUT DATA FOLLOW
                                        *****************

0                                       *****GEOMETRY*****
0 CONFIG  WG      =  19000.              KWRITE  =        2        FUSEL  SAB     =       2.            ELODN   =   2.000
          WGS     =  72.200              IGEAR   =        0               WS      =  18.000             ELODT   =   3.300
          PAX     =      8.              KCONFG  =        0               AS      =       1.            BMLOD   =  14.500
          EMCRU   =    .730              KTIPX   =        1               WAS     =  18.000    NACELLE  KNAC    =       1
          HNCRU   =  45000.              ENP     =       2.               PS      =    51.5             ELN     =    .000
                                         NTYE    =        7               ELPC    =   4.440             DBARN   =    .000
          Kanard  =       0              KPLOT   =        1               HCK     =   2.470             ELRW    =   9.000

0   WING  TCT     =    .090        HORIZ VBARHX  =    .0000        VERT   VBARVX  =   .0000    Canard   TCcan   =    .100
          TCR     =    .090        TAIL  TCHT    =     .080        TAIL   TCVT    =    .100             ARcan   =   5.300
          AR      =   5.740              ARHT    =    3.984               ARVT    =    .879             SLMcan  =    .500
          SLM     =    .550              SLMH    =     .500               SLMV    =    .537             DwpqCa  =  15.000
          DLMC4   =  12.500              DWPQCH  =   24.000               DWPQCV  =  38.000             EYEcan  =   2.000
          EYEW    =   1.000              COELTH  =     .000               BOELTV  =    .000             SWcOSW  =    .145
                                         SAH     =    1.000

0                                       ***AERODYNAMICS***
0         CKW     =  -1.000              CKHT    =  -1.000                GRFE    =    .000             LCDSE   = -1.0000
          CKF     =  -1.000              CKTP    =  -1.000                SCFAC   =    .000             CKWc    =  -1.000
          CKN     =  -1.000              DELCD   =  .00000                DLSWSW  =    .000             cmacw   =   -.020
          CKVT    =  -1.000              DELFE   =    .200                ALPHLO  =  -1.000             alzero  =  -1.000

0         KWCD    =      12
          ACLS    =  -1.000   -.600   -.400   -.200    .000    .100    .200    .400    .600    .800   1.000   1.200
          ACDCDR  =   2.400   1.466   1.221   1.066   1.005   1.000   1.005   1.046   1.138   1.333   1.743   2.718

0                                       *HIGH LIFT DEVICES*
0         RCLMAX  =   1.200        FLAPS JFLTYP  =       3         LED  CLEOC   =    .000
          ALTFLP  =   5000.              DFLPTO  =  20.000              DELLED  =    .000
          FLAPN   =      1.              DFLPLD  =  40.000              DCLMLE  =    .930
          WCFLAP  =  -1.000              CFOC    =    .280              DELLEO  =  45.000
          BENGOB  =    .000              BTEOB   =    .560
                                         DCLMTE  =    .000
                                         DCDOTE  =    .000
                                         DELTEO  =    .000

0                                       ****PROPULSION****
0         JENGSZ  =       2              HPORT   =   5000.              RCCRU   = 100.000           RMCRTX  =     .970
          IPART   =       1              TDELTO  =     36.              XTORQ   =  99999.           HSCREQ  =       0.
          KODETO  =       5              KODECL  =       7              SMLD    =    .500           THIN    =       0.
          KODETR  =       5              KODEAC  =       5              HBTP    =    .498           PR      =    1.000

0                                       *****WEIGHTS*****
0         SKPEI   =   .1350              SKY     =   .1800              SKB     = 136.000           SKFS    =    .0200
          SKLG    =   .0318              SKZ     =   .2200              SKCC    =  11.000           SKWF    =    .4300
          SKMG    =   .8000              SKTL    =  1.0000              SKFW    =   .4040           SKPT    =    .9790
          SKPES   =   .3380              SKWW    = 133.400              SKSAS   =    .000           SKWTP   =   1.8900
          WPLX    =      .0              YMG     =   .2286              EGMRGN  =   .0000           LCWING  =        2
          WPEX    =      .0              RELP    =   .6530              CPMRGN  =   .2000
          WFUL    =      .0              RELR    =   .4500              STMRGN  =   .0000           LDCKMX  =    8.000
          UWPAX   =   200.0              CATD    =      3.              DELP    =   9.400           ATMXOC  =    3.160
          STRUT   =   .0000              VMLFSL  =   616.5              YP      =   .0000           DELWST  =       .0
          DELWFC  =      .0
0 ENGINE  WENG    =      .0              WNAC    =      .0              WPYLON  =      .0
          SWSLS   =    .203              UWNAC   =   2.287              FPYL    =    .700           XLODE   =    3.120

0                                       *STABILITY AND CONTROL*
0         KSFixd  =       0              STATIC  =    .100              ZCG     = 995.000           CNPAC   =    .0020
          CMFLPL  = 999.000              CHALF   = 999.000              TP      =      .0           ARVTE   =   -1.000
          CMFLPT  = 999.000              CHDEL   = 999.000              CXA     =    .350           RV      =     .250
                                         RH      =    .333              DCMCLP  =9999.000           TAUV    =  999.000
          CMPLD   =    .000              DEMAX   =   -25.0              HWING   =      0.           RVMCS   =     .990
                                         EYET    =      .0              dcmcpl  =    .030           DRMAX   =     25.0
                                         TAUH    = 999.000              zc      =    .350

0,                                      ***PERFORMANCE***
0   TAXI  DELTT   =    .167              XLFMAX  =   1.100              DVR     =   5.000           TDELTX  =   36.000
      TO  IFLY    =       1              DELTVR  =   3.500              UM      =    .020           HTMAX   =  500.000
          THEMAX  =  15.000              DV1     =   5.000              MUB     =    .400           NFAIL   =        0
          H00     =   5000.              VRAT    =    1.10              WTMISN  =      0.

0  CLIMB  ICLM    =       1       CRUISE CRMACH  =    .000              FRESF   =   1.000           FACWL   =     .830
          DELH    =   1000.              CRALT   =      0.              RCRRQ   =  1900.0           ISWING  =        0
          VCLMB   =      .0              ICRUS   =       1              OPALT   =  25000.           OPEM    =     .500
0   LAND  IWLD    =       2              XLDGRQ  =  99999.              VRATT   =   1.300           HAPP    =      50.
          TDELLD  =    36.0              ALTLND  =   5000.              RSMX    =   1000.           SINKTD  =      3.0
          TDELAY  =     1.0              WLPCT   =   .8360              TROTID  =    .000           XLFMX   =    1.200
          HTG     =     3.2              TIDLE   =      .0              VTDRAT  =     1.1

0                                       ******COST******
0         NCADE   =       1              HIR     =    .005              RI      =    .300           CMV     =     .800
          CLIAB   =  1993.0              TR      =   2.000              OHR     = 700.000           CCRW    =       0.
          HRI     =1000000.              PRV     =    .100              CRWOH   =  23.000           UCSENG  =     .000
          CMF     =      .2              DYR     =    15.0              CINP    =      0.           UCSPP   =     .000
          TBO     =   800.0              SRPM    =      .0              CP      =      0.           ALR     =    3.400
          FCSF    =    .850

1
0+++++ H.TAIL C.L. CHORD MUST =    4.743 TO BE LOCATED AT SPECIFIED POSITION ON VERTICAL+++++
 +++++ H.TAIL TAPER CHANGED TO     .6892
```

Fig I2 - Learjet 35A GASP result

```
**************************************************************************************************
 ITERATION TO BALANCE RANGE
  RANGE ERROR, RANGE ERROR MINUS 1   .0439  -.2002
  GROSS WGT, GROSS WGT MINUS1     17457.1     17827.2


0  ******************************************************************************************
0                       FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                   CLMAX     VSTALL,KTS  FLAP ANGLE   LE ANGLE    DELTA CL    DELTA CD

 FLAPS UP          1.0593       152.9          .0          .0       .0000       .0000
 T.O. CONFIG       1.4469       130.9        20.0          .0       .3903       .0247
 LDG. CONFIG       1.5993       124.5        40.0          .0       .5472       .0667

0                     SINGLE SLOTTED FLAPS
                    OPT ANGLE    DELCL AT OPT   DELCD AT OPT    AREA(FT2)     WEIGHT(LB)

 FLAPS                40.0         1.1800          .1300          33.2          121.7
0  ******************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   5.345   LIFT= 16933.4   L/D=  13.630   ALTITUDE= 45000.0   MACH=   .7300

1                                    ENGINE SIZING DATA FOLLOW
                                     ****************************
0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   29.4 AND TAS=   146.4 EAS=   131.3)
 LIFTOFF (TIME=   32.2 DIST=   4619.7 TAS=   156.9 EAS=   140.7)
 DISTANCE TO 35 FT.=  6011.4   TAS=   169.4 EAS=   151.9 V35/VS=  1.2517
 GEAR RETRACTION STARTED AT   38.1 SEC,COMPLETE AT   45.1 SEC
 FLAP RETRACTION STARTED AT   48.4 SEC,COMPLETE AT   54.4 SEC
0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  213.1 KNOTS EAS
 ENGINE FAILURE (TIME=   27.9 AND TAS=   140.8 EAS=   126.3)
0
 ROTATION (TIME=   32.1 AND TAS=   146.4 EAS=   131.3)
 LIFTOFF (TIME=   35.4 DIST=   5384.8 TAS=   150.0 EAS=   134.6)
 DISTANCE TO 35 FT.=  7708.7   TAS=   151.7 EAS=   136.0 V35/VS=  1.1211


     ACCELERATE - STOP DISTANCE =    7008.5 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     7708.7 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     6011.4 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6913.2 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     6273.8 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .014 HRS   FUEL USED=      41. LBS   WEIGHT=   17416. LBS   ALT.=    5500. FT.
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                           VS             V      GRAD      R/C   REQ.R/C
   CONFIGURATION                                ALT (FT)  KEAS    V/VS   KTAS    (PCT)    (FPM)    (FPM)     CL    L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  121.5  1.1153  151.0    1.277   195.17     1.00  1.168  8.117
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  121.5  1.2000  163.1    3.757   620.23   396.21  1.009 10.354
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  142.1  1.2500  202.7    5.042  1034.43   246.18   .679 12.788
   APPROACH FLAPS -ONE ENG OUT                   5000.  126.8  1.3210  186.8    3.957   747.90   396.91   .764 11.116
   LANDING FLAPS - ALL ENGINES                   5000.  115.5  1.3000  167.5   12.144  2057.85   542.27   .950  6.913

     APPROACH FLAP SETTING = 12.9 DEG.



     +++ ENGINE-OUT SERVICE CEILING = 31585.4 FT.
          BEST RATE OF CLIMB SPEED    =   317.6 KTAS
          ENGINE-OUT RATE OF CLIMB    =    49.9 FPM
          WEIGHT AT ALTITUDE          = 16758.8 LBS

0                            ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE                  764.1
   NACELLE WEIGHT/ENGINE                 124.8
   PYLON WEIGHT/ENGINE                   103.6
      PROP OR QFAN                .0
      GEARBOX                     .0
      SHROUD                      .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)            2.36
   NACELLE LENGTH(FT)                  7.36


0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
      VEND =  250.0 KNOTS EAS
0
 ROTATION (TIME=   28.5 AND TAS=   146.4 EAS=   131.3)
 LIFTOFF (TIME=   31.4 DIST=   4515.8 TAS=   157.3 EAS=   141.1)
 DISTANCE TO 35 FT.=  5889.9   TAS=   170.0 EAS=   152.5 V35/VS=  1.2567
 GEAR RETRACTION STARTED AT   37.3 SEC,COMPLETE AT   44.3 SEC
 FLAP RETRACTION STARTED AT   47.5 SEC,COMPLETE AT   53.5 SEC
0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  205.2 KNOTS EAS
 ENGINE FAILURE (TIME=   27.2 AND TAS=   140.8 EAS=   126.3)
0
 ROTATION (TIME=   31.1 AND TAS=   146.4 EAS=   131.3)
 LIFTOFF (TIME=   34.4 DIST=   5231.7 TAS=   150.3 EAS=   134.8)
 DISTANCE TO 35 FT.=  7297.2   TAS=   152.0 EAS=   136.3 V35/VS=  1.1237


     ACCELERATE - STOP DISTANCE =    6907.4 FEET.
0  ENGINE OUT DISTANCE TO 35 FT.=     7297.2 FEET
0ALL ENGINE DISTANCE TO 35 FT. (L) =     5889.9 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =     6773.4 FEET
 ALL ENGINE DISTANCE TO 50 FT. =     6153.1 FEET
0   AT END OF TAKEOFF PHASE
 TIME=   .014 HRS   FUEL USED=      42. LBS   WEIGHT=   17415. LBS   ALT.=    5500. FT.
```

Fig I2 - Learjet 35A GASP result (continued)

```
0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
   AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS                 V      GRAD        R/C    REQ.R/C
   CONFIGURATION                                ALT (FT)  KEAS    V/VS    KTAS    (PCT)      (FPM)     (FPM)     CL     L/D

   1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  121.5  1.1153  151.0    1.408    215.26      1.00  1.168  7.972
   2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  121.5  1.2000  163.1    3.871    639.01    396.21  1.009 10.106
   FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  142.1  1.2500  202.7    5.078   1041.84    246.18   .679 12.315
   APPROACH FLAPS -ONE ENG OUT                   5000.  126.8  1.3210  186.8    4.019    759.70    396.91   .764 10.784
   LANDING FLAPS - ALL ENGINES                   5000.  115.5  1.3000  167.5   12.710   2153.88    542.27   .950  6.852

     APPROACH FLAP SETTING = 12.9 DEG.


     +++ ENGINE-OUT SERVICE CEILING = 31544.6 FT.
         BEST RATE OF CLIMB SPEED   =    314.2 KTAS
         ENGINE-OUT RATE OF CLIMB   =     49.8 FPM
         WEIGHT AT ALTITUDE         = 16758.8 LBS

 ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    124.76

 ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    124.76

 ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

 RATED SEA LEVEL STATIC THRUST PER ENGINE=   3864.3 LBS
*******************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE              784.1
   NACELLE WEIGHT/ENGINE             124.8
   PYLON WEIGHT/ENGINE               105.3
      PROP OR QFAN          .0
      GEARBOX               .0
      SHROUD                .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)          2.36
   NACELLE LENGTH(FT)                7.36

 0                          ****RESIZE ENGINES TO ACCOUNT FOR TIP TANKS****

 0
  SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
    ANGLE OF ATTACK(DEGREES)=    5.345   LIFT= 16933.4   L/D=  13.275   ALTITUDE= 45000.0   MACH=    .7300

 1                                    ENGINE SIZING DATA FOLLOW
                                     **************************
 0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
       VEND =  250.0 KNOTS EAS
 0
  ROTATION (TIME=   27.8 AND TAS=   146.4 EAS=   131.3)
  LIFTOFF (TIME=   30.6 DIST=   4402.7 TAS=   157.4 EAS=   141.2)
  DISTANCE TO 35 FT.=  5791.0    TAS=   170.8 EAS=   153.2 V35/VS=  1.2624
  GEAR RETRACTION STARTED AT   36.5 SEC,COMPLETE AT   43.5 SEC
  FLAP RETRACTION STARTED AT   46.7 SEC,COMPLETE AT   52.7 SEC
 0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
 0 ENGINE OUT PERFORMANCE FOLLOWS
       VEND =  203.6 KNOTS EAS
  ENGINE FAILURE (TIME=   26.5 AND TAS=   140.8 EAS=   126.3)
 0
  ROTATION (TIME=   30.1 AND TAS=   146.4 EAS=   131.3)
  LIFTOFF (TIME=   33.4 DIST=   5070.3 TAS=   150.2 EAS=   134.7)
  DISTANCE TO 35 FT.=  7152.1    TAS=   152.1 EAS=   136.3 V35/VS=  1.1239


      ACCELERATE - STOP DISTANCE =     6814.4 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=      7152.1 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =      5791.0 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =     6659.7 FEET
  ALL ENGINE DISTANCE TO 50 FT. =     6055.7 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=   .014 HRS   FUEL USED=       42. LBS   WEIGHT=   17415. LBS   ALT.=    5500. FT.
 0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
    AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                          VS                 V      GRAD        R/C    REQ.R/C
    CONFIGURATION                               ALT (FT)  KEAS    V/VS    KTAS    (PCT)      (FPM)     (FPM)     CL     L/D

    1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT 5000.  121.5  1.1153  151.0    1.693    258.73      1.00  1.168  7.934
    2ND SEG: T.O. FLAPS - ONE ENGINE OUT         5250.  121.5  1.2000  163.1    4.116    679.53    396.21  1.009 10.009
    FINAL T.O. CRUISE CONFIG - ONE ENG OUT       6500.  142.1  1.2500  202.7    5.236   1074.15    246.18   .679 12.063
    APPROACH FLAPS -ONE ENG OUT                  5000.  126.8  1.3000  183.8    4.235    787.67    390.61   .789 10.590
    LANDING FLAPS - ALL ENGINES                  5000.  115.5  1.3000  167.5   13.271   2248.93    542.27   .950  6.798

      APPROACH FLAP SETTING = 12.9 DEG.


      +++ ENGINE-OUT SERVICE CEILING = 31524.8 FT.
          BEST RATE OF CLIMB SPEED   =    310.1 KTAS
          ENGINE-OUT RATE OF CLIMB   =     49.6 FPM
          WEIGHT AT ALTITUDE         = 16758.8 LBS
0                           ****RESIZE ENGINES AT CRUISE TO ACCOUNT FOR RESIZED NACELLES****

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE              803.5
   NACELLE WEIGHT/ENGINE             131.2
   PYLON WEIGHT/ENGINE               107.5
      PROP OR QFAN          .0
      GEARBOX               .0
      SHROUD                .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)          2.42
   NACELLE LENGTH(FT)                7.55
```

Fig I2 - Learjet 35A GASP result (continued)

```
 0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
       VEND =  250.0 KNOTS EAS
 0
  ROTATION (TIME=   27.7 AND TAS=   146.4 EAS=   131.3)
  LIFTOFF (TIME=   30.4 DIST=   4357.9 TAS=   156.9 EAS=   140.8)
  DISTANCE TO 35 FT.=  5813.2   TAS=   171.2 EAS=   153.5 V35/VS=  1.2656
  GEAR RETRACTION STARTED AT   36.5 SEC,COMPLETE AT   43.5 SEC
  FLAP RETRACTION STARTED AT   46.7 SEC,COMPLETE AT   52.7 SEC
 0VSTLKT= 121.3 KTS EAS   VRAT= 1.100 CLTO= 1.1958
 0 ENGINE OUT PERFORMANCE FOLLOWS
       VEND =  198.3 KNOTS EAS
  ENGINE FAILURE (TIME=   26.4 AND TAS=   140.8 EAS=   126.3)
 0
  ROTATION (TIME=   30.2 AND TAS=   146.4 EAS=   131.3)
  LIFTOFF (TIME=   33.6 DIST=   5126.0 TAS=   150.4 EAS=   134.9)
  DISTANCE TO 35 FT.=  7077.4   TAS=   152.2 EAS=   136.5 V35/VS=  1.1249


      ACCELERATE - STOP DISTANCE =    6806.6 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=     7077.4 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =     5813.2 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =    6685.2 FEET
  ALL ENGINE DISTANCE TO 50 FT. =    6079.1 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=   .014 HRS   FUEL USED=      42. LBS   WEIGHT=   17415. LBS   ALT.=    5500. FT.
 0TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 25
    AIRPORT ALTITUDE=   5000. FT;   AMBIENT TEMP ABOVE STD. DAY=    36.0 DEG F

                                                            VS             V      GRAD       R/C   REQ.R/C
    CONFIGURATION                                 ALT (FT)  KEAS    V/VS   KTAS   (PCT)     (FPM)    (FPM)    CL     L/D

    1ST SEG:T.O. FLAPS+LD GEAR EXT - ONE ENG OUT  5000.  121.5  1.1153  151.0   1.704   260.38     1.00  1.168  7.922
    2ND SEG: T.O. FLAPS - ONE ENGINE OUT          5250.  121.5  1.2000  163.1   4.125   681.06   396.21  1.009  9.989
    FINAL T.O. CRUISE CONFIG - ONE ENG OUT        6500.  142.1  1.2500  202.7   5.239  1074.71   246.18   .679 12.027
    APPROACH FLAPS -ONE ENG OUT                   5000.  126.8  1.3000  183.8   4.240   788.70   390.61   .789 10.564
    LANDING FLAPS - ALL ENGINES                   5000.  115.5  1.3000  167.5  13.318  2256.90   542.27   .950  6.793

      APPROACH FLAP SETTING = 12.9 DEG.


      +++ ENGINE-OUT SERVICE CEILING = 31522.8 FT.
          BEST RATE OF CLIMB SPEED   =   309.8 KTAS
          ENGINE-OUT RATE OF CLIMB   =    49.6 FPM
          WEIGHT AT ALTITUDE         = 16758.8 LBS

  ENGINE SIZED TO MATCH CRUISE DRAG - SLS AIRFLOW=    128.11

  ENGINE SIZED TO MATCH T.O. DISTANCE OF 99999. FT (STD DAY+  36. DEG R;ALT=   5000.) SLS AIRFLOW=    128.11

  ENGINE SIZE MEETS ALL RATE OF CLIMB REQUIREMENTS

  RATED SEA LEVEL STATIC THRUST PER ENGINE=   3968.2 LBS
**********************************************************************************************************************

0PROPULSION SYSTEM WEIGHTS
   ENGINE WEIGHT/ENGINE            805.1
   NACELLE WEIGHT/ENGINE           131.2
   PYLON WEIGHT/ENGINE             107.7
      PROP OR QFAN           .0
      GEARBOX                .0
      SHROUD                 .0

0ENGINE POD DIMENSIONS
   ENGINE FACE DIAMETER(FT)       2.42
   NACELLE LENGTH(FT)             7.55

0*********************************************************************************************************************
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Fig I2 - Learjet 35A GASP result (continued)

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                    ---AIRCRAFT C.G. SUMMARY (DATUM=NOSE)---

                MOST FWD LOAD            MOST AFT LOAD            DESIGN LOAD
                WT           CG          WT           CG          WT           CG

 A/C OWE     10410.50      23.52     10410.50      23.52      10410.50      23.52
 PAX           680.00                  340.00                  1360.00
 BAGGAGE          .00      28.93       240.00      28.93        240.00      28.93
 WING FUEL        .00      24.01      2360.34      24.01       2360.34      24.01
 TIP FUEL      472.07      23.01      2467.89      23.01       2467.89      23.01
 FUS FUEL         .00      24.01          .00      24.01        618.36      24.01
 TOTAL       11562.57      23.02     15818.72      23.65      17457.08      23.31

0                     ---TAIL SIZING SUMMARY---

         Static Longitudinal Stability, Stick-free, considered

0                      WING                CANARD         TAIL          DOWN   FLAP
 CONDITION  ALPHA    CL     CLA    CMac  ALPHA   CLA     CLA   EFF.     WASH   CM

  CRUISE   5.5417  .6255  .0956 -.0200  .0000  .0000  .0751 1.0000
  LIFTOFF  1.0000  .5711  .0656 -.0200  .0000  .0000  .0646 1.0000  .2229 -.1300
  LANDING 12.6061 1.5993  .0773 -.0200  .0000  .0000  .0647 1.0000 2.8103 -.2000

0          --FUSELAGE-- ---NACELLE--         ------POWER-------           L.GEAR ROT.POWER
 CONDITION  DCM     CM     DCM     CM  DCMdth DCMfinc CMdth  CMfinc   CT      CM      CM

  CRUISE    .2748         -.0024         .0000  .0300                .0000
  LIFTOFF   .4007  .0000 -.0024  .0000                 .0000  .0171  .0000 -.3409 1.1795
  LANDING   .3398  .3049 -.0024 -.0021                 .0000  .0480

0      ELEVATOR PARAMETERS
           CHALPHA(FLOATING TENDENCY)    =  -.00460          WING DE/DALPHA =    .44586
           CHDELTE(RESTORING TENDENCY)   =  -.01181
           CMDELTA(CONTROL POWER)        =  -.02648
           TAUH(EFFECTIVENESS)           =   .46295
           DEMAX (MAX.ELEVATOR DEFLEC.)  =-25.00000

0                                   FRACTION    STATION          HORIZONTAL TAIL SIZES
                                      MAC     (DATUM NOSE)
      NEUTRAL POINT                  .2627      23.231          STATIC STABILITY AND LANDING TRIM      71.2921
      STATIC MARGIN                  .1000                      STATIC STABILITY AND LIFTOFF ROT.      35.2682
      AFT CG LIMIT(STABILITY)        .1627      22.564
      CG RANGE(LOADING)              .0939                      REQUIRED TAIL SIZE                     71.2921
      FWD CG LIMIT(CONTROL)          .0689      21.861          TAIL ARM(ELTH)                        19.4081
0      VERTICAL TAIL AREA =   47.7328 FOR DIRECTIONAL STABILITY OF      .00200
0      RUDDER POWER AT MAX.DEFL.=   .0143 PER DEG.   RUDDER CL AT MAX.DEFL.=   .3585
0      VERTICAL TAIL AREA=   51.3112 FOR MINIMUM CONTROL SPEED =    120.08 KTS
0      REQUIRED VERTICAL TAIL AREA =   51.3112  TAIL ARM(ELTV) =   14.5560

******************************************************************************************
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=   5.345   LIFT= 16933.4   L/D=  12.523   ALTITUDE= 45000.0   MACH=   .7300

0 WING LOCATION INFO.
 FUSELAGE LENGTH       =   43.66        H-TAIL VOL. ARM        =   19.41        C.G.LOCATION OF PROPULSION=   28.51
 WING 1/4C LOC.ON C.L.=   22.14        H-TAIL C.G.LOCATION    =   43.76        C.G.OF REMAINING WEIGHT   =   19.65
 MAC 1/4C LOCATION     =   24.01        H-TAIL MAC FROM C.L. =    4.02
 MAC DIST.FROM C.L.    =    8.41        H-TAIL LOCAT ON VERT.=    1.00
 WING C.G.LOCATION     =   25.34        V-TAIL VOL. ARM        =   14.56
 TIP TANKS C.G.LOCATE =   24.01        V-TAIL C.G.LOCATION    =   39.19        DIST.L.E.VERT.TO L.E.HORZ.=     .52
0                      WING         H-TAIL        V-TAIL

   AREA              241.788        71.292        51.311
   SPAN               37.254        16.852         6.718
   ASPECT RATIO        5.740         3.984          .879
   TAPER RATIO          .550          .757          .537
   1/4C. SWEEP        12.500        24.000        38.000
   L.E. SWEEP         15.231        25.638        43.607
   C.L. CHORD          8.375         4.816         9.939
   MEAN CHORD          6.673         4.257         7.869
   TIP CHORD           4.606         3.645         5.337
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Fig I2 - Learjet 35A GASP result (continued)

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0                                     MISSION PERFORMANCE DATA FOLLOWS
                                      ********************************
0   TAXI AT IDLE THRUST

                   FUEL                          FUEL
  TIME    RANGE    USED    WEIGHT     ALT.       FLOW
  (HRS)   (NM)     (LBS)   (LBS)      (FT)     (LB/HR)

   .000      0.       0.   17457.     5000.      574.
   .167      0.      96.   17361.     5000.      574.
0VSTLKT= 121.0 KTS EAS   VRAT= 1.100 CLTO= 1.1958
      VEND =  249.9 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF   (ELEVATION=  5000. FT)
                                                                                                                FUEL   FUS.
               FUEL                                                                                             FLOW   ANGLE
TIME   DIST.   USED   WEIGHT    ALT.     TAS     EAS   MACH  ACCEL    CL      CD   ALPHA GAMMA    ROC  LOAD THRUST
(SEC)  (FEET)  (LBS)  (LBS)     (FT)    (KTS)   (KTS)   NO. (FPS2)                (DEG) (DEG)   (FPM)  FACT (LBS)  (LB/HR)(DEG)

  .0      .0   95.6  17361.   5000.0      .0      .0  .000 10.80  .5696  .0774  1.00   .00      .0   .00  6178.  3104.   .00
 1.0     5.4   96.5  17361.   5000.0     6.4     5.7  .009 10.69  .5696  .0774  1.00   .00      .0   .00  6119.  3104.   .00
 2.0    21.5   97.4  17360.   5000.0    12.7    11.4  .019 10.57  .5696  .0774  1.00   .00      .0   .00  6060.  3104.   .00
 3.0    48.2   98.2  17359.   5000.0    18.9    17.0  .028 10.45  .5696  .0774  1.00   .00      .0   .00  6002.  3104.   .00
 4.0    85.3   99.1  17358.   5000.0    25.1    22.5  .037 10.32  .5697  .0774  1.00   .00      .0   .00  5944.  3105.   .00
 5.0   132.8  100.0  17357.   5000.0    31.2    28.0  .046 10.19  .5697  .0774  1.00   .00      .0   .00  5887.  3105.   .00
 6.0   190.6  100.8  17356.   5000.0    37.2    33.3  .055 10.05  .5698  .0774  1.00   .00      .0   .00  5831.  3106.   .00
 7.0   258.4  101.7  17355.   5000.0    43.1    38.7  .064  9.91  .5698  .0774  1.00   .00      .0   .00  5776.  3106.   .00
 8.0   336.1  102.5  17355.   5000.0    48.9    43.9  .073  9.77  .5699  .0774  1.00   .00      .0   .00  5721.  3107.   .00
 9.0   423.6  103.4  17354.   5000.0    54.7    49.1  .081  9.62  .5700  .0774  1.00   .00      .0   .00  5668.  3107.   .00
10.0   520.8  104.3  17353.   5000.0    60.4    54.2  .090  9.47  .5701  .0774  1.00   .00      .0   .00  5615.  3108.   .00
11.0   627.5  105.1  17352.   5000.0    65.9    59.2  .098  9.32  .5702  .0774  1.00   .00      .0   .00  5563.  3108.   .00
12.0   743.5  106.0  17351.   5000.0    71.4    64.1  .106  9.18  .5703  .0774  1.00   .00      .0   .00  5523.  3109.   .00
13.0   868.7  106.9  17350.   5000.0    76.8    68.9  .114  9.05  .5704  .0774  1.00   .00      .0   .00  5488.  3110.   .00
14.0  1003.0  107.7  17349.   5000.0    82.2    73.7  .122  8.92  .5705  .0774  1.00   .00      .0   .00  5453.  3110.   .00
15.0  1146.3  108.6  17349.   5000.0    87.4    78.4  .130  8.78  .5706  .0774  1.00   .00      .0   .00  5418.  3111.   .00
16.0  1298.4  109.5  17348.   5000.0    92.6    83.1  .137  8.65  .5707  .0774  1.00   .00      .0   .00  5385.  3112.   .00
17.0  1459.1  110.3  17347.   5000.0    97.7    87.7  .145  8.51  .5709  .0774  1.00   .00      .0   .00  5351.  3113.   .00
18.0  1628.4  111.2  17346.   5000.0   102.7    92.2  .153  8.37  .5710  .0774  1.00   .00      .0   .00  5318.  3114.   .00
19.0  1806.0  112.0  17345.   5000.0   107.7    96.6  .160  8.22  .5711  .0774  1.00   .00      .0   .00  5286.  3115.   .00
20.0  1992.0  112.9  17344.   5000.0   112.5   100.9  .167  8.08  .5713  .0774  1.00   .00      .0   .00  5254.  3115.   .00
21.0  2186.0  113.8  17343.   5000.0   117.3   105.2  .174  7.93  .5714  .0774  1.00   .00      .0   .00  5223.  3116.   .00
22.0  2388.0  114.6  17342.   5000.0   121.9   109.4  .181  7.79  .5716  .0774  1.00   .00      .0   .00  5193.  3117.   .00
23.0  2597.8  115.5  17342.   5000.0   126.5   113.5  .188  7.64  .5717  .0774  1.00   .00      .0   .00  5162.  3118.   .00
24.0  2815.2  116.4  17341.   5000.0   131.0   117.5  .194  7.49  .5719  .0774  1.00   .00      .0   .00  5133.  3119.   .00
25.0  3040.2  117.2  17340.   5000.0   135.4   121.5  .201  7.34  .5721  .0774  1.00   .00      .0   .00  5104.  3120.   .00
26.0  3272.6  118.1  17339.   5000.0   139.7   125.4  .207  7.19  .5722  .0774  1.00   .00      .0   .00  5075.  3121.   .00
27.0  3512.2  119.0  17338.   5000.0   144.0   129.2  .214  7.05  .5724  .0775  1.00   .00      .0   .00  5047.  3122.   .00
0
 ROTATION (TIME=    27.5 AND TAS=    146.0 EAS=    131.0)
28.0  3758.9  119.8  17337.   5000.0   148.1   132.9  .220  6.89  .6276  .0790  1.62   .00      .0   .52  5020.  3123.   .62
29.0  4012.4  120.7  17336.   5000.0   152.1   136.5  .226  6.65  .8057  .0856  3.67   .00      .0   .72  4993.  3124.  2.67
30.0  4272.7  121.6  17336.   5000.0   156.0   139.9  .232  6.32  .9838  .0947  5.81   .00      .0   .93  4968.  3125.  4.81
 LIFTOFF (TIME=   30.2 DIST=    4325.5 TAS=    156.8 EAS=    140.6)
31.0  4539.2  122.4  17335.   5000.3   159.6   143.2  .237  5.76 1.1087  .1036  7.40   .25    69.5  1.10  4944.  3125.  6.64
32.0  4811.6  123.3  17334.   5003.0   162.8   146.1  .242  5.07 1.0660  .1083  7.10   .90   258.0  1.10  4923.  3126.  6.99
33.0  5089.0  124.2  17333.   5008.9   165.7   148.6  .246  4.35 1.0306  .1146  6.90  1.53   447.9  1.10  4904.  3127.  7.43
34.0  5370.7  125.1  17332.   5018.0   168.1   150.7  .250  3.77 1.0012  .1172  6.70  2.15   638.9  1.10  4889.  3128.  7.85
35.0  5656.2  125.9  17331.   5030.2   170.2   152.6  .253  3.33  .9715  .1161  6.40  2.77   832.8  1.09  4875.  3129.  8.16
 DISTANCE TO 35 FT.=   5751.1   TAS=    170.8 EAS=    153.2 V35/VS=   1.2660
36.0  5944.8  126.8  17330.   5045.7   172.1   154.2  .255  2.93  .9541  .1150  6.20  3.37  1024.7  1.10  4864.  3129.  8.57
 GEAR RETRACTION STARTED AT        36.2 SEC,COMPLETE AT    43.2 SEC
37.0  6236.2  127.7  17329.   5064.4   173.7   155.7  .258  2.65  .9383  .1109  6.00  3.96  1216.8  1.10  4853.  3130.  8.96
38.0  6530.1  128.5  17329.   5086.3   175.2   157.0  .260  2.42  .9229  .1059  5.80  4.56  1411.9  1.10  4844.  3131.  9.36
39.0  6826.2  129.4  17328.   5111.4   176.6   158.2  .262  2.21  .9075  .1009  5.60  5.15  1606.0  1.10  4836.  3132.  9.74
40.0  7124.3  130.3  17327.   5139.8   177.9   159.3  .264  2.01  .8921  .0959  5.40  5.73  1798.6  1.09  4829.  3133. 10.12
41.0  7424.1  131.1  17326.   5171.4   179.1   160.2  .266  1.80  .8844  .0917  5.30  6.30  1992.0  1.10  4823.  3133. 10.60
42.0  7725.4  132.0  17325.   5206.2   180.1   161.0  .268  1.62  .8689  .0867  5.10  6.88  2186.5  1.09  4818.  3134. 10.98
43.0  8027.9  132.9  17324.   5244.3   181.0   161.8  .269  1.44  .8612  .0826  5.00  7.45  2377.2  1.09  4814.  3135. 11.44
44.0  8331.5  133.8  17323.   5285.5   181.8   162.4  .270  1.15  .8535  .0810  4.90  8.01  2568.3  1.09  4811.  3136. 11.91
45.0  8635.9  134.6  17322.   5329.9   182.4   162.8  .271   .85  .8457  .0802  4.80  8.58  2758.9  1.09  4809.  3137. 12.38
46.0  8940.7  135.5  17322.   5377.4   182.8   163.1  .272   .53  .8458  .0802  4.80  9.13  2940.6  1.10  4808.  3138. 12.93
 FLAP RETRACTION STARTED AT        46.5 SEC,COMPLETE AT    52.5 SEC
47.0  9245.5  136.4  17321.   5427.9   183.1   163.1  .272   .19  .8418  .0811  5.20  9.69  3121.5  1.10  4809.  3139. 13.88
48.0  9550.0  137.2  17320.   5481.3   183.1   163.0  .272   .00  .8004  .0794  5.50 10.17  3275.7  1.05  4811.  3140. 14.67
0VSTLKT= 121.0 KTS EAS   VRAT= 1.100 CLTO= 1.1958
0 ENGINE OUT PERFORMANCE FOLLOWS
      VEND =  202.1 KNOTS EAS
0              (TEMP.=  537. DEG:STD.+36.)
0   TAKEOFF   (ELEVATION=  5000. FT)
                                                                                                                FUEL   FUS.
               FUEL                                                                                             FLOW   ANGLE
TIME   DIST.   USED   WEIGHT    ALT.     TAS     EAS   MACH  ACCEL    CL      CD   ALPHA GAMMA    ROC  LOAD THRUST
(SEC)  (FEET)  (LBS)  (LBS)     (FT)    (KTS)   (KTS)   NO. (FPS2)                (DEG) (DEG)   (FPM)  FACT (LBS)  (LB/HR)(DEG)

  .0      .0   95.6  17361.   5000.0      .0      .0  .000 10.80  .5696  .0774  1.00   .00      .0   .00  6178.  3104.   .00
 1.0     5.4   96.5  17361.   5000.0     6.4     5.7  .009 10.69  .5696  .0774  1.00   .00      .0   .00  6119.  3104.   .00
 2.0    21.5   97.4  17360.   5000.0    12.7    11.4  .019 10.57  .5696  .0774  1.00   .00      .0   .00  6060.  3104.   .00
 3.0    48.2   98.2  17359.   5000.0    18.9    17.0  .028 10.45  .5696  .0774  1.00   .00      .0   .00  6002.  3104.   .00
 4.0    85.3   99.1  17358.   5000.0    25.1    22.5  .037 10.32  .5697  .0774  1.00   .00      .0   .00  5944.  3105.   .00
 5.0   132.8  100.0  17357.   5000.0    31.2    28.0  .046 10.19  .5697  .0774  1.00   .00      .0   .00  5887.  3105.   .00
 6.0   190.6  100.8  17356.   5000.0    37.2    33.3  .055 10.05  .5698  .0774  1.00   .00      .0   .00  5831.  3106.   .00
 7.0   258.4  101.7  17355.   5000.0    43.1    38.7  .064  9.91  .5698  .0774  1.00   .00      .0   .00  5776.  3106.   .00
 8.0   336.1  102.5  17355.   5000.0    48.9    43.9  .073  9.77  .5699  .0774  1.00   .00      .0   .00  5721.  3107.   .00
 9.0   423.6  103.4  17354.   5000.0    54.7    49.1  .081  9.62  .5700  .0774  1.00   .00      .0   .00  5668.  3107.   .00
10.0   520.8  104.3  17353.   5000.0    60.4    54.2  .090  9.47  .5701  .0774  1.00   .00      .0   .00  5615.  3108.   .00
11.0   627.5  105.1  17352.   5000.0    65.9    59.2  .098  9.32  .5702  .0774  1.00   .00      .0   .00  5563.  3108.   .00
12.0   743.5  106.0  17351.   5000.0    71.4    64.1  .106  9.18  .5703  .0774  1.00   .00      .0   .00  5523.  3109.   .00
13.0   868.7  106.9  17350.   5000.0    76.8    68.9  .114  9.05  .5704  .0774  1.00   .00      .0   .00  5488.  3110.   .00
14.0  1003.0  107.7  17349.   5000.0    82.2    73.7  .122  8.92  .5705  .0774  1.00   .00      .0   .00  5453.  3110.   .00
15.0  1146.3  108.6  17349.   5000.0    87.4    78.4  .130  8.78  .5706  .0774  1.00   .00      .0   .00  5418.  3111.   .00
16.0  1298.4  109.5  17348.   5000.0    92.6    83.1  .137  8.65  .5707  .0774  1.00   .00      .0   .00  5385.  3112.   .00
17.0  1459.1  110.3  17347.   5000.0    97.7    87.7  .145  8.51  .5709  .0774  1.00   .00      .0   .00  5351.  3113.   .00
18.0  1628.4  111.2  17346.   5000.0   102.7    92.2  .153  8.37  .5710  .0774  1.00   .00      .0   .00  5318.  3114.   .00
19.0  1806.0  112.0  17345.   5000.0   107.7    96.6  .160  8.22  .5711  .0774  1.00   .00      .0   .00  5286.  3115.   .00
20.0  1992.0  112.9  17344.   5000.0   112.5   100.9  .167  8.08  .5713  .0774  1.00   .00      .0   .00  5254.  3115.   .00
21.0  2186.0  113.8  17343.   5000.0   117.3   105.2  .174  7.93  .5714  .0774  1.00   .00      .0   .00  5223.  3116.   .00
22.0  2388.0  114.6  17342.   5000.0   121.9   109.4  .181  7.79  .5716  .0774  1.00   .00      .0   .00  5193.  3117.   .00
23.0  2597.6  115.5  17342.   5000.0   126.5   113.5  .188  7.64  .5717  .0774  1.00   .00      .0   .00  5162.  3118.   .00
24.0  2815.2  116.4  17341.   5000.0   131.0   117.5  .194  7.49  .5719  .0774  1.00   .00      .0   .00  5133.  3119.   .00
25.0  3040.2  117.2  17340.   5000.0   135.4   121.5  .201  7.34  .5721  .0774  1.00   .00      .0   .00  5104.  3120.   .00
26.0  3272.6  118.1  17339.   5000.0   139.7   125.4  .207  7.19  .5722  .0774  1.00   .00      .0   .00  5075.  3121.   .00
 ENGINE FAILURE (TIME=    26.2 AND TAS=    140.4 EAS=    126.0)
27.0  3511.0  118.6  17338.   5000.0   142.0   127.4  .211  2.28  .5723  .0833  1.00   .00      .0   .00  2530.  1561.   .00
28.0  3751.9  119.1  17338.   5000.0   143.3   128.6  .213  2.24  .5724  .0831  1.00   .00      .0   .00  2526.  1561.   .00
29.0  3995.1  119.5  17338.   5000.0   144.6   129.7  .215  2.20  .5725  .0830  1.00   .00      .0   .00  2522.  1561.   .00
30.0  4240.4  119.9  17337.   5000.0   145.9   130.9  .217  2.17  .5725  .0828  1.00   .00      .0   .00  2517.  1561.   .00
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Fig I2 - Learjet 35A GASP result (continued)

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  ROTATION (TIME=   30.1 AND TAS=   146.0 EAS=   131.0)
 31.0  4488.0    120.4  17337.   5000.0  147.2  132.1  .219    2.09  .7037  .0867  2.49   .00       .0   .58   2513.    1561.  1.49
 32.0  4737.6    120.8  17336.   5000.0  148.4  133.1  .220    1.95  .8818  .0942  4.58   .00       .0   .75   2509.    1561.  3.58
 33.0  4989.2    121.2  17336.   5000.0  149.5  134.1  .222    1.71 1.0599  .1045  6.77   .00       .0   .91   2505.    1562.  5.77
  LIFTOFF (TIME=   33.4 DIST=    5090.3 TAS=    149.9 EAS=    134.5)
 34.0  5242.5    121.7  17335.   5000.1  150.4  134.9  .223    1.36 1.1958  .1150  8.52   .11     30.2  1.05   2502.    1562.  7.64
 35.0  5497.2    122.1  17335.   5001.4  151.1  135.6  .224     .97 1.1958  .1202  8.67   .49    130.3  1.06   2500.    1562.  8.15
 36.0  5752.8    122.5  17335.   5004.5  151.5  135.9  .225     .42 1.1958  .1304  8.85   .92    247.8  1.06   2499.    1562.  8.78
 37.0  6008.7    123.0  17334.   5009.7  151.6  136.0  .225     .02 1.1614  .1355  8.61  1.36    365.5  1.04   2499.    1562.  8.97
 38.0  6264.7    123.4  17334.   5016.0  151.6  136.0  .225     .02 1.1110  .1347  8.11  1.41    378.6   .99   2499.    1562.  8.52
 39.0  6520.8    123.8  17333.   5022.1  151.6  136.0  .225     .02 1.1055  .1364  8.11  1.32    353.8   .98   2499.    1562.  8.43
 40.0  6776.8    124.3  17333.   5027.8  151.6  136.0  .225     .02 1.1106  .1383  8.21  1.24    331.7   .99   2499.    1562.  8.45
 41.0  7032.9    124.7  17332.   5033.2  151.7  136.0  .225     .01 1.1170  .1398  8.31  1.18    316.0  1.00   2499.    1562.  8.49
  DISTANCE TO 35 FT.=  7120.1    TAS=    151.7 EAS=    136.0 V35/VS=  1.1239
 42.0  7289.0    125.1  17332.   5038.4  151.7  136.0  .225     .02 1.1163  .1401  8.31  1.14    306.4   .99   2499.    1562.  8.45
 43.0  7545.1    125.6  17332.   5043.4  151.7  136.0  .225     .00 1.1237  .1414  8.41  1.11    297.8  1.00   2499.    1562.  8.52
 44.0  7801.2    126.0  17331.   5048.4  151.7  136.0  .225     .00 1.1235  .1415  8.41  1.10    295.9  1.00   2499.    1562.  8.51


      ACCELERATE - STOP DISTANCE =     6765.9 FEET.
 0  ENGINE OUT DISTANCE TO 35 FT.=     7120.1 FEET
 0ALL ENGINE DISTANCE TO 35 FT. (L) =      5751.1 FEET
  FAR 25 T.O. DISTANCE (1.15XL) =     6613.8 FEET
  ALL ENGINE DISTANCE TO 50 FT. =     6015.9 FEET
 0   AT END OF TAKEOFF PHASE
  TIME=   .180 HRS   FUEL USED=      138. LBS   WEIGHT=   17320. LBS   ALT.=     5500. FT.


    ACCELERATE TO MACH NO. = .418

 0                 FUEL                                                         FUEL
   TIME   RANGE    USED    WEIGHT    ALT.    TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

   .180     .00   137.5  17320.    5500.   177.    163.  .272  .736   6046.   3831.
   .185    1.24   158.6  17299.    5500.   271.    250.  .418  .791   5626.   3916.

  END OF ACCELERATION SEGMENT
  TIME=  .185 HRS   FUEL USED=   158.6 LBS   WEIGHT=  17299. LBS   RANGE=     1. NM
 0   CLIMB TO   45000. FT. AT MAXIMUM RATE OF CLIMB
 0                 FUEL                                                                               FUS.                            FUEL
   TIME   RANGE    USED    WEIGHT    ALT.     TAS    EAS    MACH  MACH    CL       CD   ALPHA GAMMA ANGLE      R/C    THRUST      FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   !KTS)  (KTS)     NO.   DIV                  (DEG) (DEG) (DEG)    (FPM)    (LBS)    (LB/HR)

   .185      1.     159.  17299.    5500.   271.    250.  .418  .793  .3296  .0291  3.05 12.64 14.69     6015.    5277.     3665.
   .187      2.     164.  17293.    6000.   273.    250.  .421  .793  .3311  .0291  3.06 11.32 13.38     5434.    5224.     3633.
   .190      2.     175.  17282.    7000.   277.    250.  .429  .793  .3313  .0291  3.05 10.94 12.99     5336.    5110.     3565.
   .193      3.     186.  17271.    8000.   282.    250.  .438  .793  .3315  .0291  3.04 10.56 12.61     5233.    4997.     3499.
   .196      4.     197.  17260.    9000.   286.    250.  .446  .793  .3317  .0291  3.04 10.18 12.22     5126.    4884.     3432.
   .199      5.     208.  17249.   10000.   291.    250.  .455  .793  .3319  .0291  3.03  9.80 11.83     5014.    4770.     3366.
   .203      6.     219.  17238.   11000.   309.    261.  .485  .796  .3028  .0280  2.63 10.14 11.77     5507.    4602.     3315.
   .206      7.     229.  17228.   12000.   311.    259.  .491  .795  .3084  .0282  2.69  9.23 10.92     5057.    4499.     3248.
   .209      8.     240.  17217.   13000.   314.    257.  .496  .795  .3136  .0284  2.75  8.94 10.69     4941.    4398.     3181.
   .212      9.     251.  17206.   14000.   316.    255.  .502  .794  .3188  .0286  2.80  8.67 10.46     4826.    4297.     3114.
   .216     10.     262.  17195.   15000.   319.    253.  .508  .794  .3242  .0288  2.85  8.39 10.24     4708.    4198.     3047.
   .219     11.     272.  17185.   16000.   321.    251.  .514  .793  .3297  .0291  2.91  8.11 10.02     4590.    4099.     2981.
   .223     12.     283.  17174.   17000.   324.    249.  .520  .792  .3354  .0293  2.97  7.84  9.80     4472.    4002.     2916.
   .227     14.     294.  17163.   18000.   326.    247.  .526  .791  .3411  .0296  3.02  7.56  9.59     4353.    3906.     2851.
   .231     15.     305.  17152.   19000.   329.    245.  .533  .791  .3470  .0298  3.08  7.30  9.38     4233.    3811.     2786.
   .234     16.     316.  17141.   20000.   332.    242.  .539  .790  .3530  .0301  3.14  7.03  9.17     4114.    3717.     2722.
   .239     17.     327.  17130.   21000.   334.    240.  .546  .789  .3592  .0304  3.20  6.77  8.97     3994.    3624.     2659.
   .243     19.     338.  17119.   22000.   338.    239.  .553  .789  .3648  .0307  3.25  6.45  8.70     3840.    3532.     2597.
   .247     20.     349.  17108.   23000.   349.    242.  .574  .790  .3547  .0302  3.09  4.91  7.01     3025.    3417.     2545.
   .253     22.     363.  17094.   24000.   371.    254.  .614  .794  .3238  .0288  2.66  3.40  5.06     2231.    3294.     2512.
   .260     25.     382.  17075.   25000.   375.    251.  .622  .793  .3280  .0290  2.69  5.12  6.81     3389.    3203.     2451.
   .265     27.     394.  17063.   26000.   378.    249.  .630  .792  .3343  .0293  2.74  4.97  6.71     3317.    3114.     2390.
   .270     29.     406.  17051.   27000.   381.    247.  .638  .791  .3408  .0296  2.80  4.73  6.53     3186.    3027.     2329.
   .275     31.     418.  17039.   28000.   384.    264.  .646  .791  .3473  .0299  2.85  4.50  6.36     3056.    2942.     7270.
   .281     33.     431.  17026.   29000.   387.    242.  .654  .790  .3540  .0302  2.91  4.28  6.18     2927.    2858.     2212.
   .286     35.     443.  17014.   30000.   391.    240.  .662  .789  .3607  .0305  2.96  4.05  6.02     2799.    2776.     2155.
   .292     37.     456.  17001.   31000.   394.    237.  .671  .788  .3676  .0308  3.01  3.84  5.85     2671.    2696.     2098.
   .299     40.     469.  16988.   32000.   398.    235.  .680  .787  .3746  .0312  3.06  3.62  5.69     2545.    2617.     2043.
   .305     42.     483.  16974.   33000.   401.    233.  .689  .787  .3816  .0315  3.11  3.41  5.53     2419.    2540.     1989.
   .312     45.     496.  16961.   34000.   405.    231.  .699  .786  .3886  .0319  3.16  3.20  5.36     2289.    2464.     1935.
   .319     48.     511.  16947.   35000.   409.    229.  .709  .785  .3954  .0322  3.20  2.98  5.18     2154.    2390.     1884.
   .327     51.     525.  16932.   36000.   415.    227.  .722  .784  .4001  .0324  3.21  2.68  4.89     1962.    2318.     1834.
   .336     55.     541.  16916.   37000.   419.    224.  .730  .783  .4098  .0330  3.29  2.49  4.77     1842.    2216.     1760.
   .345     59.     557.  16901.   38000.   419.    219.  .730  .781  .4295  .0341  3.49  2.62  5.11     1940.    2112.     1677.
   .353     62.     571.  16886.   39000.   419.    214.  .730  .778  .4502  .0353  3.71  2.34  5.05     1735.    2013.     1599.
   .363     66.     586.  16871.   40000.   419.    209.  .730  .776  .4719  .0366  3.94  2.07  5.01     1536.    1919.     1524.
   .374     71.     603.  16854.   41000.   419.    204.  .730  .773  .4946  .0381  4.17  1.81  4.98     1340.    1829.     1453.
   .386     76.     621.  16836.   42000.   419.    199.  .730  .770  .5183  .0397  4.42  1.55  4.97     1148.    1744.     1385.
   .401     82.     641.  16816.   43000.   419.    194.  .730  .767  .5431  .0414  4.68  1.29  4.97      959.    1662.     1320.
   .418     89.     664.  16793.   44000.   419.    190.  .730  .764  .5689  .0433  4.95  1.04  4.99      773.    1585.     1259.
   .440     98.     691.  16766.   45000.   419.    185.  .730  .761  .5958  .0454  5.23   .80  5.03      590.    1511.     1200.
 0   END OF CLIMB TO   45000. FT
  TIME=   .440 HRS   FUEL USED=      691. LBS   WEIGHT=   16766. LBS   RANGE=      98. NM

 0ALTITUDE=      45000. FT   TAS=      463.31 KTS   MACH NO=       .8070


    ACCELERATE TO MACH NO. = .807

 0                 FUEL                                                         FUEL
   TIME   RANGE    USED    WEIGHT    ALT.    TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

   .440   98.32   691.2  16766.   45000.   419.    185.  .730  .760   1566.   1256.
   .482  118.27 ` 749.0  16708.   45000.   463.    205.  .807  .773   1578.   1307.

  END OF ACCELERATION SEGMENT
  TIME=  .482 HRS   FUEL USED=   749.0 LBS   WEIGHT=  16708. LBS   RANGE=  118. NM


    ACCELERATE TO MACH NO. = .790

 0                 FUEL                                                         FUEL
   TIME   RANGE    USED    WEIGHT    ALT.    TAS    EAS     MACH  MACH   THRUST    FLOW
  (HRS)   (NM)    (LBS)    (LBS)     (FT)   (KTS)  (KTS)     NO.   DIV    (LBS)  (LB/HR)

   .440   98.32   691.2  16766.   45000.   419.    185.  .730  .760   1566.   1256.
   .473  113.58   735.7  16721.   45000.   453.    200.  .790  .770   1578.   1296.

  END OF ACCELERATION SEGMENT
  TIME=  .473 HRS   FUEL USED=   735.7 LBS   WEIGHT=  16721. LBS   RANGE=  114. NM
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Fig I2 - Learjet 35A GASP result (continued)

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0                                       DESIGN CASE
                                        CRUISE PERFORMANCE SUMMARY
                                                  FOR
                                        ***** DESIGN PAYLOAD *****
                                        **** MAXIMUM PAYLOAD *****
                                        ****** MAXIMUM FUEL ******
                                        FUEL AVAILABLE=    5447.
0                              AT                      AT                      AT
                         SPECIFIED SPEED         NORMAL  POWER          BEST SPEC. RANGE
                         START     END           START    END           START     END
                         CRUISE    CRUISE        CRUISE   CRUISE        CRUISE    CRUISE
                         -------   -------       -------  -------       -------   -------
   TIME            HRS.     .440     4.743          .482    3.986          .473     4.483
   RANGE           N.MI      98.     1902.          118.    1741.          114.     1931.
   FUEL USED       LBS.     691.     4667.          749.    4261.          736.     4642.
   WEIGHT          LBS.   16766.    12790.        16708.   13196.        16721.    12815.
   ALTITUDE        FT.    45000.    45000.        45000.   45000.        45000.    45000.
   TAS             KTS.    419.1     419.1         463.3    463.3         453.3     453.3
   EAS             KTS.    184.8     184.8         204.3    204.3         199.9     199.9
   MACH NO.                .7300     .7300         .8070    .8070         .7896     .7896
   DIV. MACH               .7601     .7773         .7735    .7880         .7708     .7852
   ANGLE ATTACK DEG.       5.283     3.793         3.775    2.604         4.081     2.894
   FUSE. ANGLE  DEG.       4.283     2.793         2.775    1.604         3.081     1.894
   CL                      .6007     .4583         .4898    .3697         .5121     .3925
   L/D                    12.530    12.123        12.189   11.376        12.476    11.684
   FUEL FLOW    LB/HR     1039.4     817.2        1111.7    901.0        1072.9     881.4
   BREG. FACTOR N.MI.      6764.     6563.         6968.    6790.         7070.     6595.
   SPEC. RANGE  NM/LB     .40320    .51282        .41677   .51422        .42252    .51429


0  DESCENT FROM CRUISE AT NORMAL POWER CONDITION
           (U=NO CONSTRAINT; R=  500. FPM CABIN; A=  -6.00 FUS. ANGLE; S=MMO OR VMO)
0                     FUEL                                                                              FUS.                           FUEL
  TIME    RANGE       USED    WEIGHT    ALT.      TAS    EAS     MACH  MACH    CL       CD    ALPHA GAMMA ANGLE     R/S     THRUST     FLOW
  (HRS)   (NM)        (LBS)   (LBS)     (FT)     (KTS)  (KTS)    NO.   DIV                    (DEG) (DEG) (DEG)    (FPM)    (LBS)    (LB/HR)

  3.996   1746.    4265.  13192.   45000.    463.   205.   .807  .786  .3821   .0333  2.73 -2.00  -.27    1636.     687.     394.  U
  4.006   1751.    4269.  13188.   44000.    463.   210.   .807  .789  .3642   .0323  2.55 -2.01  -.46    1650.     705.     406.  U
  4.016   1755.    4273.  13184.   43000.    463.   215.   .807  .791  .3471   .0315  2.38 -2.04  -.66    1673.     724.     419.  U
  4.026   1760.    4277.  13180.   42000.    463.   220.   .807  .793  .3309   .0307  2.23 -2.08  -.86    1706.     742.     432.  U
  4.035   1764.    4282.  13175.   41000.    463.   225.   .807  .795  .3154   .0300  2.07 -2.13 -1.06    1748.     762.     445.  U
  4.045   1769.    4288.  13169.   40000.    463.   231.   .807  .796  .3006   .0294  1.93 -2.13 -1.20    1742.     798.     690.  R
  4.055   1773.    4296.  13162.   39000.    463.   236.   .807  .798  .2864   .0288  1.79 -2.04 -1.25    1676.     853.     733.  R
  4.065   1778.    4304.  13154.   38000.    463.   242.   .807  .800  .2729   .0283  1.66 -1.96 -1.30    1611.     911.     780.  R
  4.076   1783.    4312.  13145.   37000.    463.   248.   .807  .801  .2600   .0279  1.53 -1.89 -1.36    1550.     972.     830.  R
  4.087   1788.    4322.  13135.   36000.    464.   254.   .807  .803  .2477   .0275  1.42 -1.82 -1.41    1494.    1035.     882.  R
  4.099   1794.    4333.  13124.   35000.    466.   260.   .807  .804  .2361   .0271  1.30 -1.76 -1.46    1452.    1098.     939.  R
  4.110   1799.    4345.  13112.   34000.    468.   266.   .807  .805  .2251   .0267  1.19 -1.71 -1.51    1413.    1164.     999.  R
  4.123   1805.    4358.  13099.   33000.    470.   273.   .807  .807  .2146   .0264  1.09 -1.65 -1.56    1375.    1232.    1060.  R
  4.135   1811.    4372.  13085.   32000.    472.   279.   .807  .808  .2047   .0261  1.00 -1.60 -1.61    1339.    1303.    1125.  R
  4.148   1817.    4387.  13070.   31000.    474.   285.   .807  .809  .1954   .0259   .90 -1.55 -1.65    1304.    1381.    1196.  R
  4.161   1823.    4404.  13054.   30000.    476.   292.   .807  .810  .1865   .0257   .82 -1.51 -1.69    1271.    1454.    1264.  R
  4.174   1830.    4422.  13036.   29000.    478.   299.   .807  .811  .1780   .0255   .74 -1.47 -1.73    1240.    1536.    1339.  R
  4.188   1836.    4441.  13016.   28000.    480.   305.   .807  .812  .1700   .0253   .66 -1.42 -1.77    1209.    1612.    1411.  R
  4.202   1843.    4462.  12995.   27000.    482.   312.   .807  .813  .1624   .0251   .58 -1.39 -1.80    1183.    1700.    1492.  R
  4.217   1850.    4485.  12972.   26000.    484.   319.   .807  .814  .1552   .0250   .51 -1.35 -1.83    1155.    1787.    1574.  R
  4.220   1852.    4487.  12970.   25000.    486.   326.   .807  .815  .1479   .0248   .44 -5.04 -5.60    4336.    1027.     650.  U
  4.224   1854.    4490.  12967.   24000.    488.   333.   .807  .815  .1416   .0247   .38 -5.37 -5.99    4631.    1039.     661.  U
  4.228   1855.    4492.  12965.   23000.    482.   335.   .793  .816  .1405   .0247   .39 -5.39 -6.00    4587.    1051.     673.  A
  4.231   1857.    4495.  12962.   22000.    475.   336.   .779  .816  .1396   .0247   .40 -5.40 -6.00    4532.    1062.     684.  A
  4.235   1859.    4497.  12960.   21000.    468.   337.   .765  .816  .1387   .0247   .41 -5.41 -6.00    4476.    1072.     695.  A
  4.239   1861.    4500.  12957.   20000.    462.   338.   .751  .816  .1379   .0247   .42 -5.42 -6.00    4420.    1082.     706.  A
  4.243   1862.    4503.  12954.   19000.    455.   338.   .737  .816  .1372   .0246   .43 -5.43 -6.00    4364.    1091.     717.  A
  4.247   1864.    4505.  12952.   18000.    449.   339.   .724  .816  .1365   .0246   .43 -5.43 -6.00    4309.    1099.     727.  A
  4.250   1866.    4508.  12949.   17000.    442.   340.   .711  .816  .1359   .0246   .44 -5.44 -6.00    4253.    1106.     737.  A
  4.254   1868.    4511.  12946.   16000.    436.   341.   .698  .816  .1353   .0246   .45 -5.45 -6.00    4198.    1113.     747.  A
  4.258   1869.    4514.  12943.   15000.    430.   341.   .685  .816  .1348   .0246   .46 -5.46 -6.00    4143.    1119.     756.  A
  4.263   1871.    4517.  12940.   14000.    423.   342.   .673  .816  .1343   .0246   .46 -5.46 -6.00    4089.    1124.     765.  A
  4.267   1873.    4521.  12936.   13000.    417.   342.   .660  .816  .1339   .0246   .47 -5.47 -6.00    4034.    1128.     774.  A
  4.271   1874.    4524.  12933.   12000.    411.   343.   .648  .816  .1336   .0246   .48 -5.48 -6.00    3981.    1131.     782.  A
  4.275   1876.    4527.  12930.   11000.    405.   343.   .636  .816  .1333   .0246   .49 -5.49 -6.00    3927.    1134.     790.  A
  4.289   1880.    4536.  12921.   10000.    291.   250.   .455  .802  .2512   .0276  2.05 -2.33 -1.29    1201.     888.     624.  S
  4.303   1884.    4545.  12912.    9000.    286.   250.   .446  .802  .2511   .0276  2.05 -2.35 -1.30    1190.     884.     627.  S
  4.317   1888.    4554.  12904.    8000.    282.   250.   .438  .802  .2509   .0276  2.06 -2.37 -1.31    1181.     880.     629.  S
  4.331   1892.    4563.  12895.    7000.    277.   250.   .430  .802  .2507   .0276  2.07 -2.39 -1.32    1174.     875.     632.  S
  4.346   1896.    4572.  12886.    6000.    273.   250.   .422  .802  .2505   .0275  2.07 -2.42 -1.34    1168.     870.     633.  S
  4.360   1900.    4581.  12876.    5000.    269.   250.   .414  .802  .2504   .0275  2.08 -2.44 -1.36    1163.     864.     635.  S
  4.374   1904.    4590.  12867.    4000.    265.   250.   .406  .802  .2502   .0275  2.08 -2.47 -1.39    1158.     858.     634.  S
  4.389   1907.    4599.  12858.    3000.    261.   250.   .399  .802  .2500   .0275  2.09 -2.50 -1.41    1154.     852.     633.  S
  4.403   1911.    4608.  12849.    2000.    257.   250.   .391  .802  .2498   .0275  2.09 -2.53 -1.44    1152.     845.     631.  S
  4.410   1913.    4613.  12844.    1500.    255.   250.   .388  .802  .2496   .0275  2.09 -2.55 -1.46    1152.     841.     630.  S
0  END OF DSCNT TO     1500. FT
 TIME=  4.410 HRS   FUEL USED=     4613. LBS   WEIGHT=   12844. LBS   RANGE=   1913. NM

0      RESERVE FUEL(LBS)       780.                834.                805.
         (   45.0 MIN.)

    ***************************************************************************************
0      RANGE = 1913.    BLOCK TIME= 4.410    USED FOR DESIGN RANGE AND COST

    ***************************************************************************************
0   ************************************************************************************************
0            TEMP.=  537. DEG:STD.+36.
     LANDING ELEVATION= 5000. FT.
     LANDING WING LOADING=  60.36 PSF.
     LANDING WEIGHT =    14594. LBS.

     LANDING DISTANCE FROM 50. FT.=   3587. FT.

     F.A.R. FACTORED FIELD LENGTH =   5978. FT.
0                   APPROACH              TRANSITION              DELAY               ROLL
0               DIST=       774.     DIST=        225.     DIST=        229.     DIST=        2359.
                R/S=       1000.     XLFMX=      1.200     TDELAY=      1.00     MUB=         .4000
                VAPEAS=   137.13     SINKTD=     3.000     TIDLE=       389.     TR/TIDLE=    .0000
                VAPTAS=   153.01     VSTEAS=    105.48     VTDTAS=    135.36     ABAR(G)=     .3445
                THETA=      3.70     CLMX=      1.5993
                THRUST=    1215.     HFLAR=       20.9
0   ************************************************************************************************
```

Fig I2 - Learjet 35A GASP result (continued)

```
****************************************************************************************************
 0                RANGE OR ENDURANCE ITERATION SUMMARY

                                GROSS       RANGE(NMI) OR
                  ITERATION   WEIGHT(LB)   ENDURANCE(HR)

                      0         19000.00      2116.848
                      1         15770.00      1519.653
                      2         17827.15      1983.431
                      3         17457.08      1913.034
                      REQUIRED RG. OR END. = 1900.000
0
 SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
   ANGLE OF ATTACK(DEGREES)=    5.345   LIFT= 16933.4   L/D=  12.523   ALTITUDE= 45000.0   MACH=   .7300

 0  GROSS WEIGHT =    17457.        PASSENGERS =   8. PLUS CREW

 0  FUSELAGE        LENGTH              (ELF)           43.66   FT
                    WIDTH               (SWF)            5.50   FT
                    WETTED AREA         (SF)             613.   SQFT
                    DELTA P             (DELP)           9.40   PSI

 0  WING            ASPECT RATIO        (AR)             5.74
                    AREA                (SW)            241.8   SQFT
                    SPAN                (B)              37.3   FT
                    GEOM. MEAN CHORD    (CBARW)          6.67   FT
                    QUARTER CHORD SWEEP(DLMC4)           12.5   DEG
                    TAPER RATIO         (SLM)            .550
                    ROOT THICKNESS      (TCR)            .090
                    TIP THICKNESS       (TCT)            .090
                    WING LOADING        (WGS)            72.2   PSF
                    WING FUEL VOLUME    (VFW)           353.0   GAL

 0  HOR. TAIL       ASPECT RATIO        (ARHT)           3.98
                    AREA                (SHT)            71.3   SQFT
                    SPAN                (BHT)           16.85   FT
                    MEAN CHORD          (CBARHT)         4.26   FT
                    THICKNESS/CHORD     (TCHT)           .080
                    MOMENT ARM          (ELTH)           19.4   FT
                    VOLUME COEFF.       (VBARH)          .858

 0  VERT. TAIL      ASPECT RATIO        (ARVT)            .88
                    AREA                (SVT)            51.3   SQFT
                    SPAN                (BVT)            6.72   FT
                    MEAN CHORD          (CBARVT)         7.67   FT
                    THICKNESS/CHORD     (TCVT)           .100
                    MOMENT ARM          (ELTV)           14.6   FT
                    VOLUME COEFF.       (VBARV)          .083

 0  ENG.NACELLES    LENGTH              (ELN)            7.55   FT
                    MEAN DIAMETER       (DBARN)          2.42   FT
                    NUMBER ENGINES      (ENP)            2.0
                    WETTED AREA         (SN)           114.75   SQFT

                    LOCATION                          ON FUSELAGE
 0  TIP TANKS       VOLUME              (VFTP)          24.67   CUFT
                    DIAMETER            (BXIS)           1.82   FT
                    LENGTH              (AXIS)          14.55   FT
                    WETTED AREA         (STIP)         128.54   SQFT

 0  VDIVE =  643. KTS   VMO =  536. KTS   MMO =  .900
    ULT. LF =  6.21   MAN. LF =  2.50   GUST LF =  4.14

 0  PROPULSION GROUP
        PRIMARY ENGINES           (WEP)       1610.
        PRIMARY ENGINE INSTL.     (WPEI)       217.
        FUEL SYSTEM               (WFSS,       109.
        TOTAL PROP.GROUP WT.      (WP)        1937.
 0  STRUCTURES GROUP
        WING                      (WW)        1819.
        HOR. TAIL                 (WHT)        317.
        VERT. TAIL                (WVT)        187.
        FUSELAGE                  (WB)        1963.   (INCL.      .0 LBS A.T.W.)
        LANDING GEAR              (WLG)        555.
        PRIMARY ENG. SECTION      (WPES)       478.
        TIP TANKS                 (WTIP)       243.
        GROUP WEIGHT INC.         (DELWST)       0.
        TOTAL STRUC.GROUP WT.     (WST)       5562.
 0  FLIGHT CONTROLS GROUP
        COCKPIT CONTROLS          (WCC)         36.
        FIXED WING CONTROLS       (WCFW)       373.
        SAS                       (WSAS)         0.
        GROUP WEIGHT INC.         (DELWFC)       0.
        TOTAL CONTROL WT.         (WFC)        409.
 0  WT. OF FIXED EQUIPMENT        (WFE)       1943.

    WEIGHT EMPTY                  (WE)        9850.

    FIXED USEFUL LOAD             (WFUL)       560. (INC. CREW )

    OPERATING WEIGHT EMPTY        (OWE)      10411.
 0  PAYLOAD                       (WPL)       1600. (PAX.VOL.=  8.    DESIGN PAX=  8.)

    FUEL                          (WFA)       5447. (WFW= 2360.) (WFTP= 2468.)

    GROSS WEIGHT                  (WG)       17457.

 0         FIXED EQUIP GROUP                   FIXED USEFUL LOAD
 0    WAPU                    .00          WCREW ( 2.)          340.00
      WINSTR               111.83          WSTU  ( 0.)             .00
      WHYD                 129.70          WCBAG                 50.00
      WELEC                541.59          WUF                   93.30
      WAV                  340.00          WOIL                  66.86
      WFUR                 534.00          WSRV                    .00
      WAC                  237.00          WH2O                    .00
      WAI                   46.11          WEMER                 10.00
      WAUXG                  3.00          WCATER                  .00

      WFE                 1943.24          WFUL                 560.16
```

Fig I2 - Learjet 35A GASP result (continued)

```
0   DESIGN MACH =  .730           DESIGN ALTITUDE =  45000.          DESIGN Q (PSF) =115.60
0   DESIGN RE.NUM. PER FT.     = 1.102E+06    FLATPLATE CF AT RE=10EX7 IS  .00276

0   AERODYNAMIC DATA

0                               FLATPLATE              WETTED
    DRAG BREAKDOWN              AREA(SQFT)     CDO     AREA(SQFT)
0         WING                    1.7180     .00711       394.52
          FUSELAGE                2.2462     .00929       613.17
          VERT.TAIL                .3515     .00145       102.62
          HOR. TAIL                .5198     .00215       142.58
          ENGINE NAC.              .5451     .00225       114.75
          TIP TANKS                .3745     .00155       128.54
          INCREMENTAL              .0000     .00000          .00
0             TOTAL               5.7551     .02380      1496.17

              MEAN SKIN FRICTION COEF.=  .003847


0  AERODYNAMIC COEFF.
        A1                                             .8326
        A2                                            -.1207
        A3                                             .0249
        A4=.75X(T/C)                                   .0675
        A5=CDO--                                       .0144
        A6                                            2.5727
        A7=1/(PI.SEE.AR)                               .0641
        3-D LIFT SLOPE AT CRUISE MACH     (CLALPH)    5.4782    PER RADIAN
        OSWALD FACTOR                     (SEE)        .8442

0   CRUISE CD =  .0238 +   .0641 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)
0   RETRACTABLE LANDING GEAR CD INC.= .02918


0 CRUISE DRAG
0CL=    .2000
              MACH      CD     L/D   CLALPH   ALPHA
            .50000  .02640  7.5750  4.8041  1.3853
            .55000  .02640  7.5750  4.9083  1.3346
            .60000  .02640  7.5750  5.0317  1.2774
            .65000  .C2640  7.5750  5.1785  1.2128
            .70000  .02640  7.5750  5.3548  1.1400
            .7500C  .02640  7.5750  5.5692  1.0576
            .80000  .02640  7.5750  5.8350   .9639
            .85000  .02816  7.1025  6.1734   .8562
0CL=    .3000
              MACH      CD     L/D   CLALPH   ALPHA
            .50000  .02975 10.0825  4.8041  2.5779
            .55000  .02975 10.0825  4.9083  2.5020
            .60000  .02975 10.0825  5.0317  2.4161
            .65000  .02975 10.0825  5.1785  2.3192
            .70000  .02975 10.0825  5.3548  2.2100
            .75000  .02975 10.0825  5.5692  2.0864
            .80000  .02976 10.0821  5.8350  1.9458
            .85000  .03353  8.9476  6.1734  1.7843
0CL=    .4000
              MACH      CD     L/D   CLALPH   ALPHA
            .50000  .03439 11.6317  4.8041  3.7705
            .55000  .03439 11.6317  4.9083  3.6693
            .60000  .03439 11.6317  5.0317  3.5548
            .65000  .03439 11.6317  5.1785  3.4257
            .70000  .03439 11.6317  5.3548  3.2800
            .75000  .03439 11.6317  5.5692  3.1152
            .80000  .03448 11.5998  5.8350  2.9277
            .85000  .04133  9.6787  6.1734  2.7124
0CL=    .5000
              MACH      CD     L/D   CLALPH   ALPHA
            .50000  .04049 12.3497  4.8041  4.9632
            .55000  .04049 12.3497  4.9083  4.8366
            .60000  .04049 12.3497  5.0317  4.6935
            .65000  .04049 12.3497  5.1785  4.5321
            .70000  .04049 12.3497  5.3548  4.3499
            .75000  .04049 12.3497  5.5692  4.1439
            .80000  .04101 12.1919  5.8350  3.9097
            .85000  .05200  9.6163  6.1734  3.6405
0CL=    .6000
              MACH      CD     L/D   CLALPH   ALPHA
            .50000  .04787 12.5346  4.8041  6.1558
            .55000  .04787 12.5346  4.9083  6.0039
            .60000  .04787 12.5346  5.0317  5.8322
            .65000  .04787 12.5346  5.1785  5.6385
            .70000  .04787 12.5346  5.3548  5.4199
            .75000  .04787 12.5346  5.5692  5.1727
            .80000  .04941 12.1423  5.8350  4.8916
            .85000  .06561  9.1452  6.1734  4.5686


0 LOW SPEED LIFT/DRAG-GR.UP(IF R)O.G.E.
                                 FLAPS UP                          TAKEOFF                           LANDING
        ALPHA        CL         CD       L/D        CL         CD       L/D         CL        CD       L/D
     -2.00000   -.07723    .02439 -3.16690    .31307    .04987  6.27781    .47002    .09231  5.09177
       .00000    .07723    .02419  3.19240    .46753    .05454  8.57307    .62448    .09781  6.38483
      2.00000    .23170    .02733  8.47897    .62200    .06251  9.94993    .77895    .10705  7.27662
      4.00000    .38616    .03367 11.46869    .77647    .07386 10.51336    .93341    .12009  7.77232
      6.00000    .54063    .04333 12.47679    .93093    .08889 10.47254   1.08788    .13723  7.92760
      8.00000    .69510    .05642 12.31925   1.08540    .10797 10.05297   1.24234    .15889  7.81879
     10.00000    .84956    .07317 11.61047   1.23986    .13190  9.39994   1.39681    .18596  7.51152
     12.00000   1.00403    .09386 10.69678   1.39433    .16068  8.67752   1.55127    .21810  7.11252
     12.62174   1.05929    .10309 10.27554   1.44694    .17121  8.45143   1.59929    .22883  6.98905
     12.62174   1.05929    .10309 10.27554   1.44694    .17121  8.45143   1.59929    .22883  6.98905

0                           DFLAP=      .00        DFLAP=     20.00        DFLAP=    40.00
0                           CLMAX=  1.05929        CLMAX=  1.44694        CLMAX=  1.59929
```

Fig I2 - Learjet 35A GASP result (continued)

```
  0 LOW SPEED AERO FOR OTHER FLAP DEFLECTIONS
       FLAP DEFL.    CLMAX    CL       CD      L/D
          10.000    1.27642
                             .14714   .03627  4.05679
                             .30160   .03956  7.62314
                             .45607   .04609  9.89514
                             .61054   .05597 10.90773
                             .76500   .06933 11.03418
                             .91947   .08640 10.64223
                            1.07393   .10751  9.98888
                            1.22840   .13462  9.12502
                            1.27642   .14367  8.88407
                            1.27642   .14367  8.88407
          30.000    1.55004
                             .42076   .06900  6.09789
                             .57523   .07425  7.74730
                             .72969   .08294  8.79793
                             .88416   .09515  9.29264
                            1.03863   .11110  9.34866
                            1.19309   .13135  9.08338
                            1.34756   .15681  8.59383
                            1.50202   .18686  8.03839
                            1.55004   .19687  7.87362
                            1.55004   .19687  7.87362


 0ALTITUDE=     45000. FT   TAS=     465.73 KTS   MACH NO=      .8112


 0                               RDT&E AND AIRFRAME PRODUCTION COSTS
                                             (1993. DOLLARS)
 0                          TOTAL RDT&E COSTS            435.6924 MILLION
 0                                      AIRFRAME PRODUCTION COSTS(INCLUDING 10% PROFIT)
                                                             700. AIRCRAFT
                                                  WEIGHT(LB)    COST($)    COST($/LB)
            STRUCTURE(  1833739.$)
                                WING                     2062.    573065.     277.90
                                EMPENNAGE                 503.    204737.     406.63
                                FUSELAGE                 1963.    657176.     334.74
                                LANDING GEAR              555.    111313.     200.52
                                NACELLES                  478.    287447.     601.65
            PROPULSION INSTAL(   91778.$)
                                ENGINE INSTALLAT.         217.     76797.     353.27
                                FUEL SYSTEM               109.     14981.     137.53
            SYSTEMS(   808136.$)
                                FLIGHT CONTROLS           409.    186171.     455.47
                                HYDRAULIC                 130.     15676.     120.87
                                ELECTRICAL                542.    251494.     464.36
                                AIR CONDITIONING          237.    123219.     519.90
                                ANTI-ICING                 46.     23562.     511.02
                                AUX. POWER UNIT             0.         0.        .00
                                FURNISHINGS               534.     88984.     166.64
                                INSTRUMENTS               112.     87191.     779.65
                                AVIONICS INSTALL.         170.     31340.     184.35
                                AUX. ITEMS                  3.       500.     166.64
           INTEGRATION(   683414.$)
 0                                 AIRFRAME TOTALS       8070.   3417068.     423.43
 0                                 ENGINES                       1105750.
                                   PROPELLER                           0.
                                   AVIONICS                      1000000.
                                   A/C COST(NO RD)               5522817.
                                   R&D PER A/C                    622418.
                                   TOTAL A/C COST                6145235.

 0                  ENGINES      NUMBER =     2.  TYPE=     7

 0 EMPTY WEIGHT=  9850.     AIRFRAME WEIGHT=  8240.     WEIGHT OF 1 ENGINE=   805.     CRUISE SPEED= 466. KTS
 0 THRUST/ENGINE=   3968.
 0 TOTAL AIRCRAFT COST=  6145235.     AIRFRAME COST=  5039485.     COST OF 1 ENGINE=   552875.     COST OF 1 PROP.=        0.


 0                             --- COST DATA ---
                            GASP SHORTHAUL METHOD
 0          DESIGN MISSION
 0              OPERATING COST FOR NOR.RATED POWER AND  45000. ALTITUDE
 0  *************************************************************************************
 0                   RANGE=    1913. N.M.    BLOCK FUEL=    4613. LBS    BLOCK TIME=  4.4104 HRS.
 0   UTILIZATION                          800.
 FLYING OPERATIONS
    FLIGHT CREW                          99.235
    FUEL,OIL,AND TAXES( .850$/G)        612.710
    INSURANCE                           169.395
 DIRECT MAINTENANCE
    AIRFRAME                            111.025
    ENGINE                              367.249
 MAINTENANCE BURD.                      384.490
 DEPRECIATION                          2154.708

    TOTAL DOC  ($/TRIP)                3898.811
               ($/B.HR.)                883.994
               ($/N.MI.)                  2.038
```

Fig I2 - Learjet 35A GASP result (concluded)

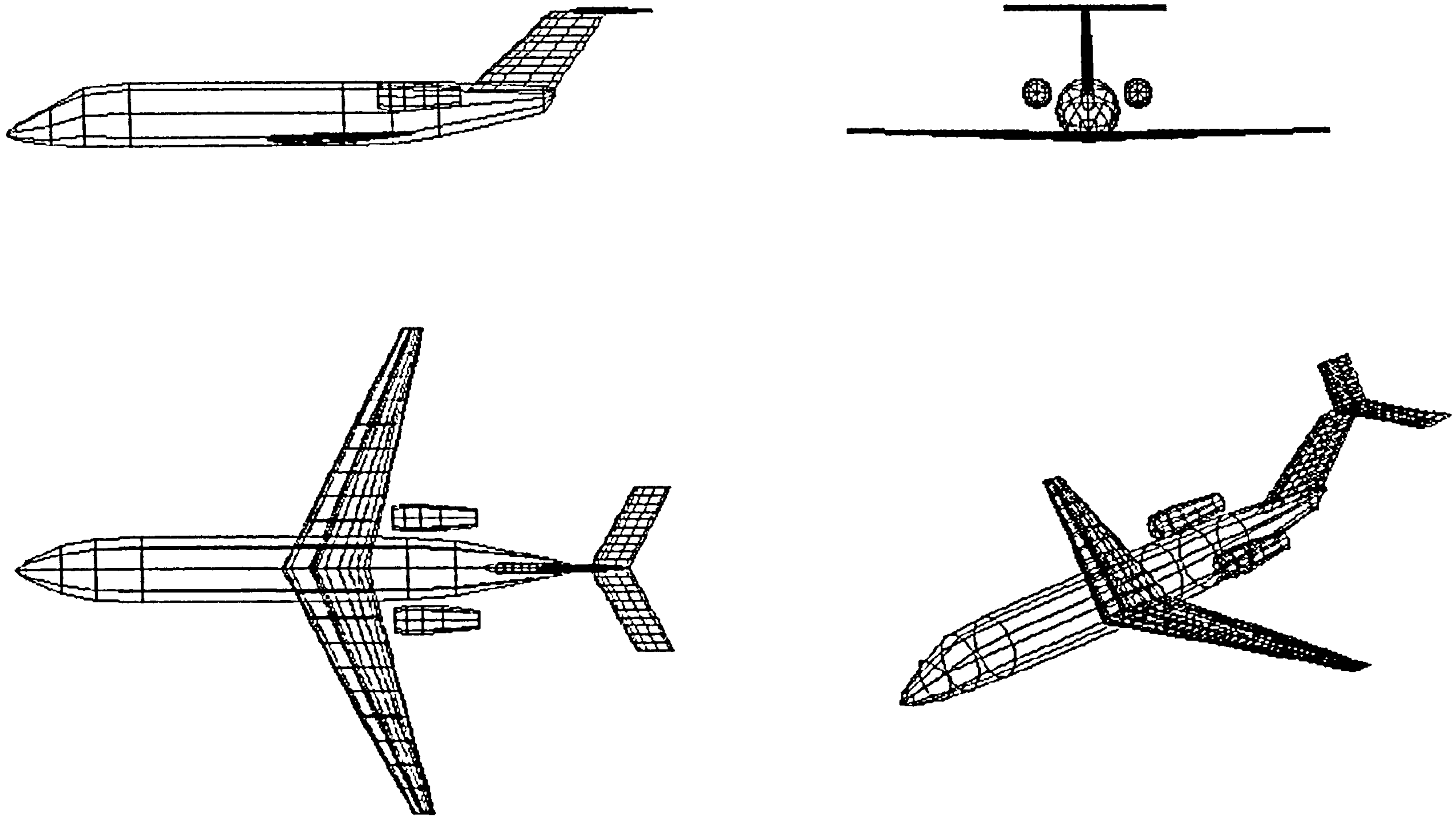

Fig I3 - Canadair Regional Jet 100 GASP model

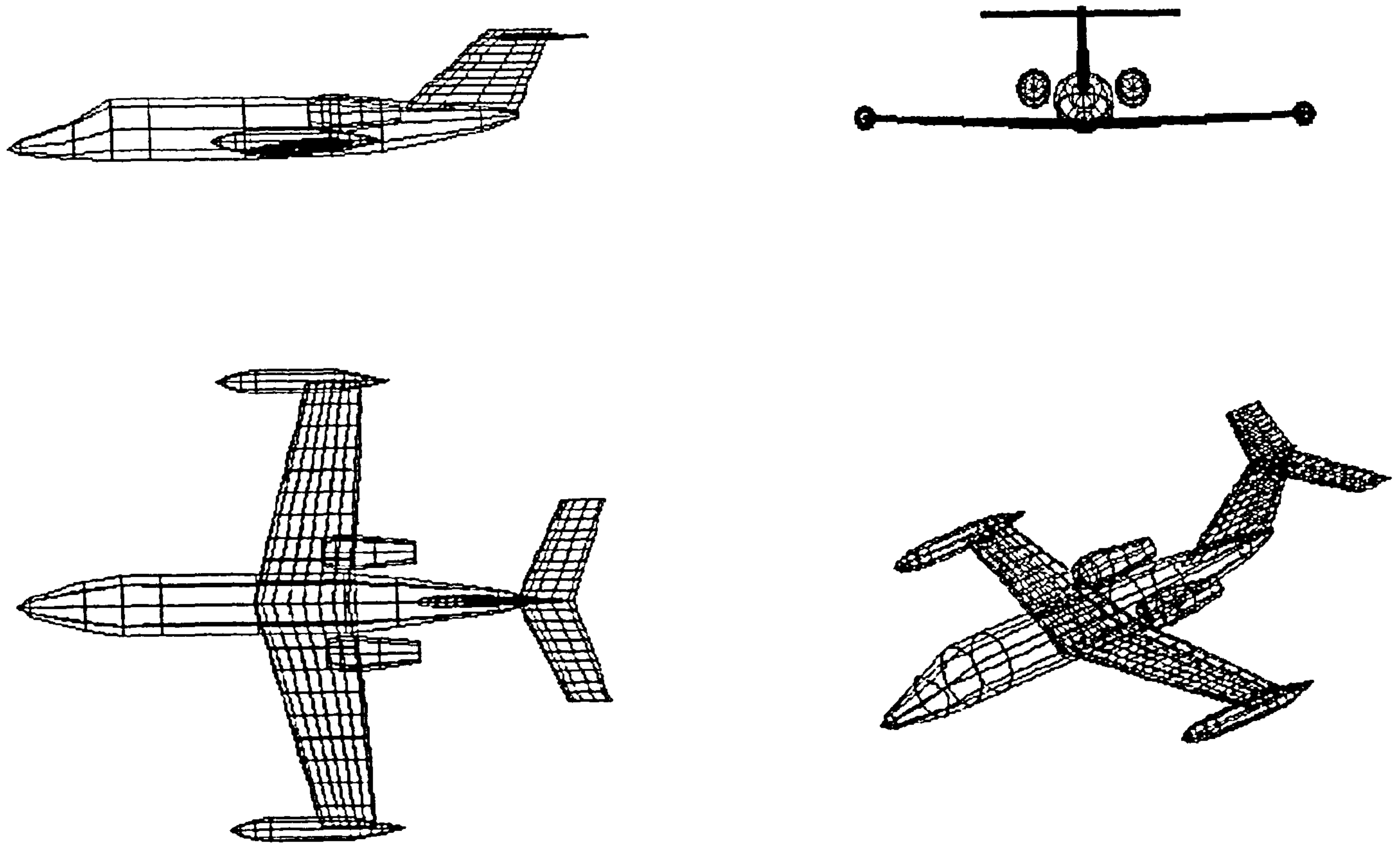

Fig I4 - Learjet 35A GASP model

APPENDIX J

Sensitivity Analysis

Introduction

This Appendix shows the results of the sensitivity analysis performed on the Min DOC conventional configuration to changes of fuselage mass and drag. All other parameters were kept as unchanged as possible and consistent with the GASP design synthesis procedure. GASP options for fixed engine, fixed wing area and tail volume coefficients were now used to simulate the same basic optimised configuration.

The final optimised answer, as obtained with these options, came up with some slight differences. These discrepancies are due to the small longitudinal shift experienced by the wing location on the fuselage, changing slightly the aircraft cg location. Since the differences are relatively small, they will not affect the validity of the final sensitivity analysis results. Thus, the solution just obtained is taken as the datum design, which the present investigation will be based on.

Incremental changes of -10% and +10% of the fuselage mass and drag were independently assumed. All the results reflect the effect of the changes on the final optimum design. Table J1 summarises the main results and shows the effect of the changes in terms of a percentage variation on the final performance and cost figures.

J.1 Fuselage Mass Sensitivity

By keeping the aircraft maximum Take-off Weight unchanged, Table J1 shows that a 10% fuselage structural weight reduction results in increases in both maximum fuel weight and design range amounting to 7.3% and 10.9% respectively, with a slight improvement in DOC figures. The reverse is true for a 10% increase of the fuselage structural weight. These results indicate a high sensitivity in performance due to fuselage weight changes experienced by this type of aircraft and considerable benefits may be achieved by keeping fuselage mass as low as possible. Operating on the design range or on shorter routes, providing adequate provision for cargo hold is incorporated in the design, means that fuel can be traded with freight improving the air carrier revenue potential. To fly the same distance, DOC values also decrease relatively.

As seen, for fuselage mass variations it appears that a critical trend exists in terms of exchanging mass between this component and fuel. It is worth noting that fuselage is the structural component which contributes more to the aircraft empty weight (about 23 to 24% of this weight) and it is roughly about the same order as the fuel weight. So, any means to reduce its structural mass are welcome, which may include the use of advanced technology features (materials, design and manufacturing methods) or even by adopting an unusual concept, changing radically the current design practice, or both.

On conventional aircraft, tail loads are generally very large which contribute heavily to bending the rearward fuselage. A critical combination of inertia loads, trimming load in the landing configuration with forward cg during the landing impact, especially on aircraft with fuselage mounted engines, may determine the design loading condition. Critical loads may also arise from nose landing gear loads. If a three surface concept of the type developed in this research is sought, where half the pitching moment required to trim the aircraft is produced by the canard useful lift, a significant reduction on the above critical loads is expected, on the front fuselage, because the canard lift will damp the fuselage inertia loads. And on the rear fuselage, because the tail downward load will be significantly lower than in the equivalent conventional aircraft case, in addition to being a smaller and lighter tailplane (lower inertia). These effects will likely contribute to limit fuselage bending moments to lower levels in order to produce savings in structural weight, even without the consideration of advanced materials.

J.2 Drag Sensitivity

Table J1 also shows that a 10% decrease in overall drag results in a slight increase of both cruise Mach number and design range which amount respectively to 3% and 2.9%, with a slight improvement in the lift to drag ratio and DOC figures. For a 10% drag increase a slight degradation in these parameters is noticed. Very small changes in field length performance are also experienced. Although drag decrease offers scope for some improvement in the performance and cost parameters, the results indicate a very low sensitivity to drag variations.

It may be reasonable to assume that similar drag sensitivity holds for the three-surface configuration transport. This increases confidence in the computed performance and economics by minimising the impact of drag uncertainties in the final optimised solution, arising from the fuselage/canard interference. This concern was explained in section 6.2 of the main text.

Concluding Remarks

This sensitivity study shows that benefits arise from reducing both fuselage structural mass and drag. This is especially interesting of fuselage mass due to the large impact its changes have on range performance. Fuselage mass decrease also improves the aircraft economic worth by additionally increasing its cargo payload potential.

		Min DOC Conv	Fuselage Weight Sensitivity				Drag Sensitivity			
		Datum Design	(-)10% fus weight	% change	(+)10% fus weight	% change	(-)10% drag	% change	(+)10% drag	% change
Fuselage Weight	lb	6184	5565	-10.0	6802	10.0	6184	.0	6184	.0
Total Cruise Drag	counts	351	351	.0	351	.0	315.4	-10.1	385.7	9.9
Fuselage Length	ft	79.25	79.25	.0	79.25	.0	79.25	.0	79.25	.0
Wing Area	sqft	435.30	435.30	.0	435.30	.0	435.30	.0	435.30	.0
Wing Aspect Ratio		8.88	8.88	.0	8.88	.0	8.88	.0	8.88	.0
Tailplane Area	sqft	158.00	158.01	.0	157.99	.0	158.00	.0	158.00	.0
Fin Area	sqft	93.51	93.52	.0	93.50	.0	93.51	.0	93.51	.0
Engine Max. St. T/O Thrust	lb	9756	9756	.0	9756	.0	9756	.0	9756	.0
M.T.O.W.	lb	45707	45707	.0	45707	.0	45707	.0	45707	.0
O.E.W.	lb	27429	26823	-2.2	28035	2.2	27429	.0	27429	.0
E.W.	lb	26351	25744	-2.3	26957	2.3	26351	.0	26351	.0
Fuel Weight	lb	8278	8884	7.3	7671	-7.3	8278	.0	8278	.0
T/O Wing Loading	lb/sqft	105	105	.0	105	.0	105	.0	105	.0
T/O Thrust to Weight Ratio		0.427	0.427	.0	0.427	.0	0.427	.0	0.427	.0
Cruise Mach No.		0.83	0.83	.0	0.83	.0	0.86	3.0	0.80	-3.9
Cruise Speed (TAS)	kt	480.8	480.8	.0	480.8	.0	493.6	2.7	460.2	-4.3
Cruise Height	ft	35000	35000	.0	35000	.0	35000	.0	35000	.0
Cruise L/D		11.73	11.73	.0	11.73	.0	11.83	.8	11.63	-.9
Approach Speed (EAS)	kt	122.2	122.2	.0	122.2	.0	122.2	.0	122.2	.0
Approach Speed (TAS)	kt	136.3	136.3	.0	136.3	.0	136.3	.0	136.3	.0
T/O Stall Speed (TAS)	kt	120.0	120.0	.0	120.0	.0	120.0	.0	120.0	.0
Landing Stall Speed (TAS)	kt	104.7	104.7	.0	104.7	.0	104.7	.0	104.7	.0
T/O Flap (angle/CLmax)		15./2.503	15./2.503		15./2.503		15./2.503		15./2.503	
Landing Flap (angle/CLmax)		40./3.296	40./3.296		40./3.296		40./3.296		40./3.296	
FAR 25 T/O Field Length	ft	5478.4	5478.4	.0	5478.4	.0	5456.8	-.4	5489.5	.2
FAR 25 Land. Field Length	ft	4808.0	4808.0	.0	4808.0	.0	4812.0	.1	4804.0	-.1
Mission Range	nm	1104	1224	10.9	982	-11.1	1136	2.9	1077	-2.4
Aircraft Price	US$	1.78E+07	1.76E+07	-1.2	1.80E+07	1.2	1.79E+07	.4	1.77E+07	-.6
D.O.C./N Mile	US$/nm	2.69	2.63	-2.2	2.76	2.6	2.62	-2.6	2.78	3.3

Table J1 - Analysis of Fuselage Weight and Drag Sensitivities on Min DOC Conventional Transport

APPENDIX K

Optimisation Jumps

Introduction

This Appendix describes the additional work done to identify reasons which could better explain the difficulties encountered during the optimisation process. GASP drag, mass and cost equations were reviewed and an additional analysis of the convergence history diagrams of figure F1, in Appendix F, was performed.

K.1 Review of GASP Equations

A detailed review of the equations employed in the synthesis program for drag, mass and cost predictions was undertaken.

Optimisation jumps, as shown in the objective function convergence histories of Appendix F, might result from possible discontinuities in the functions as described by these equations. Careful inspection of these relationships showed that, within the ranges for which they were used during the individual design synthesis runs (performed throughout the optimisation process), no discontinuities were present. These could occur whether the aircraft size was on the boundary of particular classes of aircraft, or if the optimisation process was allowed to change configurational features (such as conventional fuselage or twin boom, braced or cantilever wing, turbo-propeller or turbo-fan engines, fuselage mounted or wing podded engines, etc). The first situation could activate different or slightly different correlations for component/ system mass or cost estimating relationships producing comparatively different results for these items. The second one can not occur because the configuration is generally defined with the starting point and kept unchanged during the optimisation.

As an example, a list of the cost estimating relationships (CER) used, where discontinuities (step functions) could be found, is shown below. These CERs are weight based relationships^{K1}.

	Item Weight [lb]	
Cost Item	Discontinuity Point	Order used
Landing gear structure	10000	2000
Electrical System	5000	1000
Furnishings	3000 & 25000	3500

Since the item weights predicted during GASP runs are relatively apart from the discontinuity points, no "jumps" on the respective cost results would result so as to significantly affect the trends of the objective and constraint functions, from one design iteration to the next one.

K.2 Difficulties During the Optimisation

In this section, a particular region of the history diagrams of figure F1, related to the optimisation of the conventional transport for minimum DOC, is further analysed. As described in section 5.4.5, the numerical technique failed to satisfy the convergence criteria at iteration 487. At this point, the design corresponds to the optimised one as obtained at the end of the optimisation process (iteration 759). Following iteration 487, the designs tend to stabilise but sudden surges in the design variables and problem functions occur at iteration 504. Then, the process tries the convergence towards the minimum of the figure of merit and another excursion happens at iteration 623. Another subsidence takes place before finally meeting the convergence criteria.

Figures K1 through K4 represent similar history diagrams where the objective function (DOC), the MTOW and the design variables are, as before, normalised by the corresponding values of the initial design point. The constraint functions are normalised by their maximum constraint limit as defined in section 5.4.2. These graphs show the evolution of the problem functions and design variables between iterations 480 and 530.

Another set of history diagrams, figures K5 through K8, was devised where all the design parameters and functions are normalised by the respective values as obtained in the previous iteration. These diagrams show the magnitude of the large excursions both at iteration 504, in the wrong direction, and iteration 521, now in the right direction in its attempt to improve the cost function. They also allow for comparison with the usual small variations produced during most of the time.

A sample of intermediate design results, as obtained during the RQPMIN-GASP operation, is presented in table K1 for iterations 485 through 510. Tables K2 and K3 show the respective normalised values as employed in figures K1 through K4 and figures K5 through K8, respectively. This subset was selected to include iteration 487 and the large diversion of iteration 504.

Looking at figures K3/ K4 and K7/ K8, regarding the design variables evolution, as well as at the design variables related portion of table K3, a similar cyclic pattern is seen to repeat every 17 iterations with very slight changes in one or two of these variables. At the 17th iteration, a large excursion on all of them may occur which greatly explains the "jumps" on the cost figure and constraints (figures K1/ K2, K5/ K6 and tables). Iteration numbers 487, 504, 521, 623 as well as the final one, 759, pertain to this class of iteration.

It appears that RQPMIN collects data from 16 GASP successive iterations, corresponding to 16 very close design points, to determine the derivatives of the design surface functions with respect to the design variables at those points. Based on this information, RQPMIN will decide how to perturb the design variables in an attempt to effectively improve the figure of merit. However, the move at iteration 504 was in the wrong direction. An explanation for this occurrence may be as follows.

The convergence at iteration 487 was not satisfied probably because a very small tolerance on the problem functions was imposed in combination with some difficulty experienced in improving the objective function. This latter difficulty can be related with the particular design surface topology. One way to overcome this problem consists of re-starting the optimisation process with a different starting point. With this in mind, RQPMIN may have possibly built in such a mechanism to solve this kind of difficulty. Thus, it may purposely generate a new starting design point to improve on when these difficulties arise.

Concluding Remarks

"Jumps" observed in the optimisation history diagrams are not induced by discontinuities of the disciplinary analysis equations. The reason being that these discontinuities are unlikely for the aircraft sizes studied.

The large excursions experienced during the optimisation process seem to result from:
- the proper operation of RQPMIN while improving the performance index, i.e. when effectively converging towards its optimum value, usually a local minimum, or
- difficulties encountered by the numerical technique to meet the convergence criteria (probably with very tight tolerances on the problem functions), when it finds unable to improve the objective function. Instead of stopping, the process suddenly diverges, possibly to re-initiate a new minimisation.

Note: the nomenclature in the tables follows the order by which the design variables (DV) and the constraint functions (CF) appear on the figures K3/ K4, and K2, respectively.

References:

K1. Beltramo,M.N.;Trapp,D.L.;Kimoto,B.W.;Marsh,D.P.
Parametric Study of Transport Aircraft Systems Cost and Weight
NASA CR 151970, Apr 1977

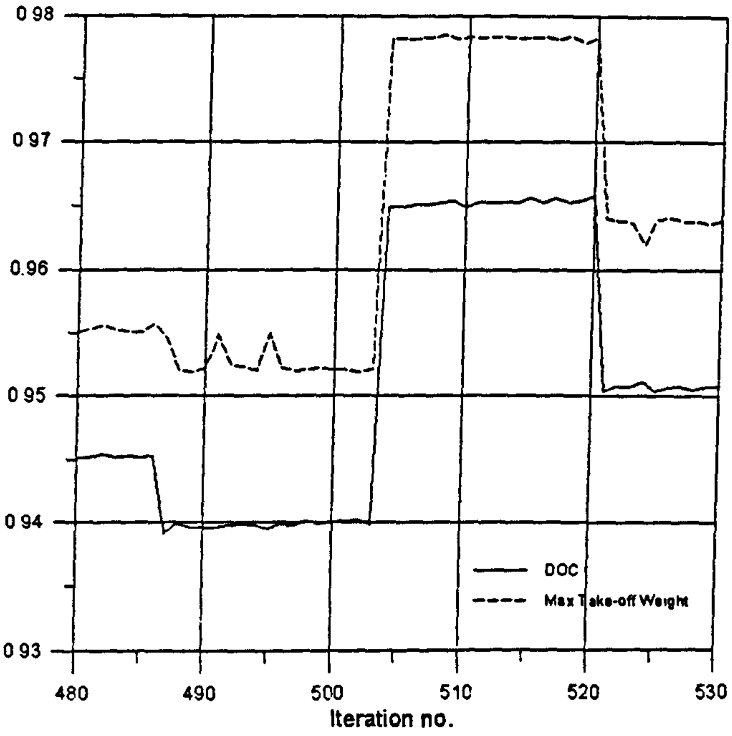

Fig K1 - History of the Objective Function (DOC) and MTOW

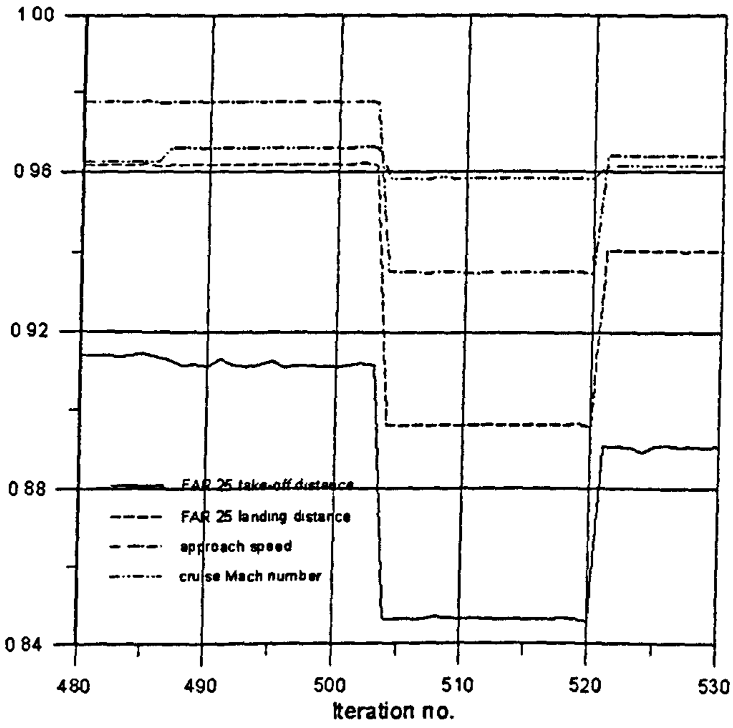

Fig K2 - History of the Constraint Functions

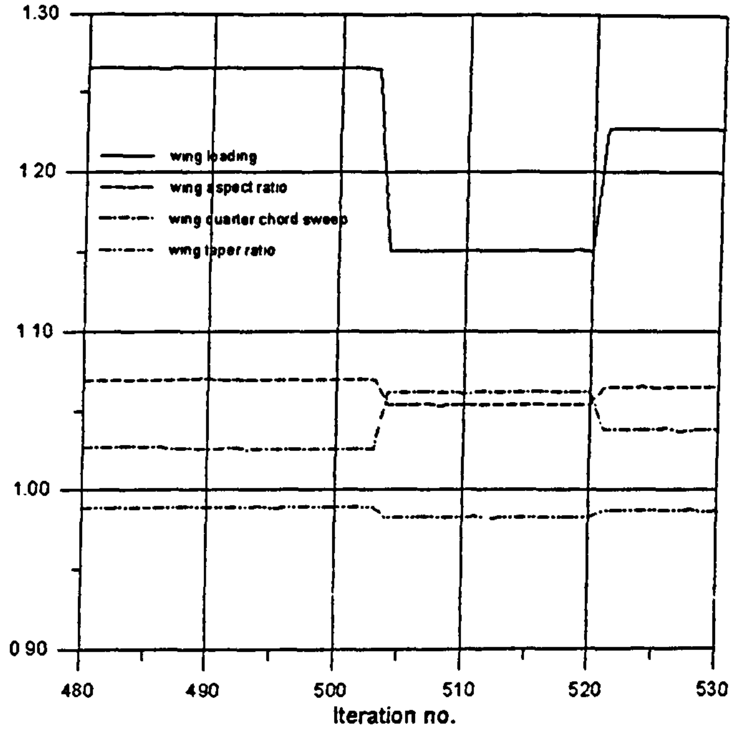

Fig K3 - History of the Wing Design Variables

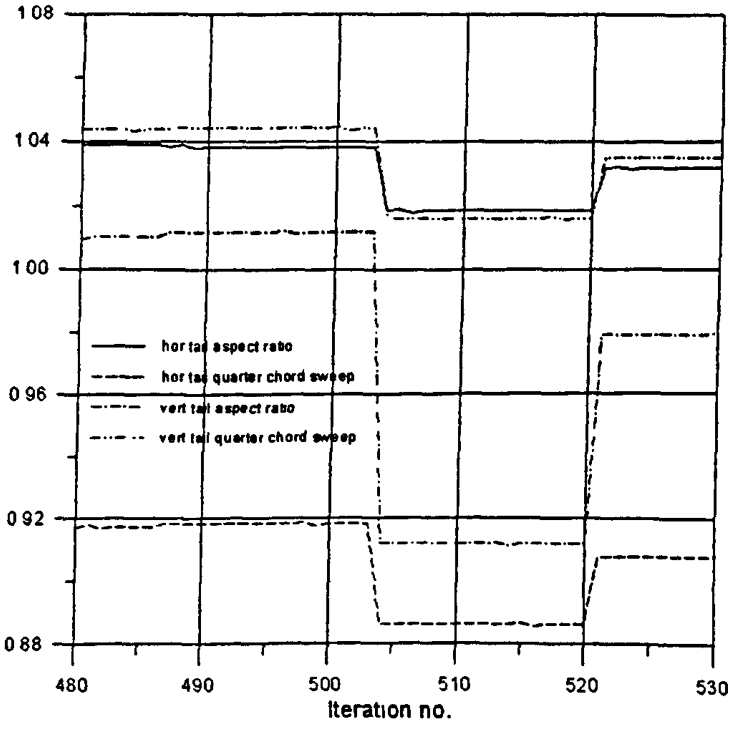

Fig K4 - History of the Tail Design Variables

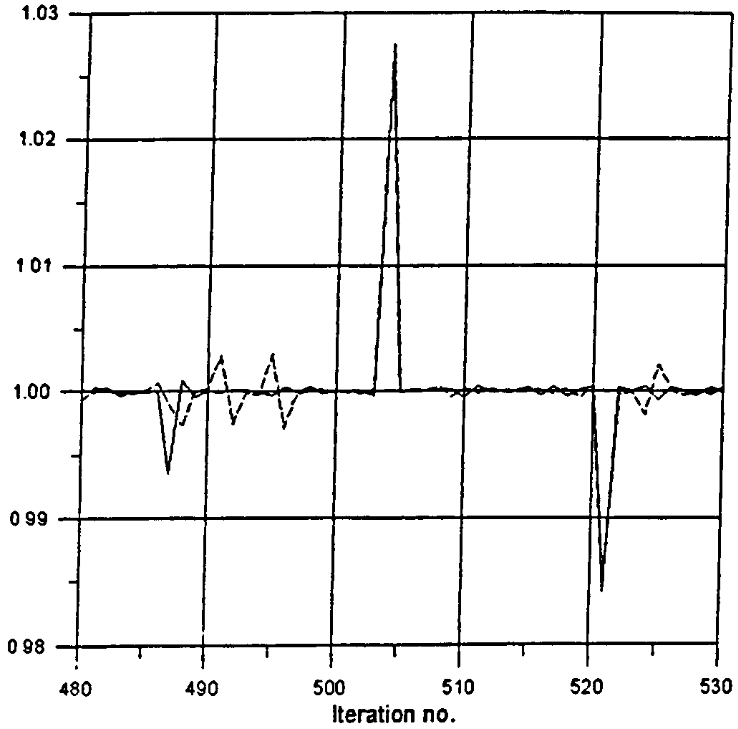

Fig K5 - History of the Objective Function (DOC) and MTOW (normalised by previous iteration data)

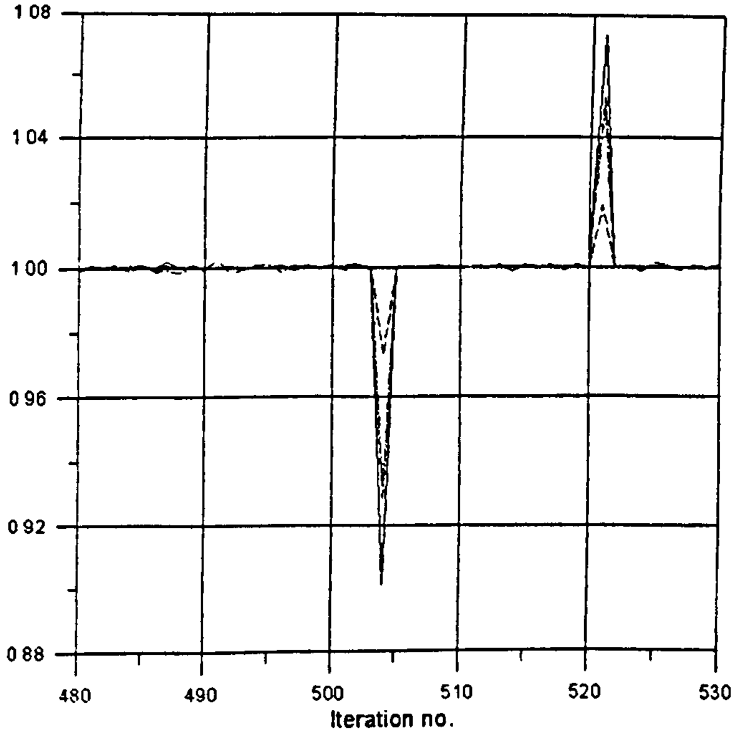

Fig K6 - History of the Constraint Functions (normalised by previous iteration data)

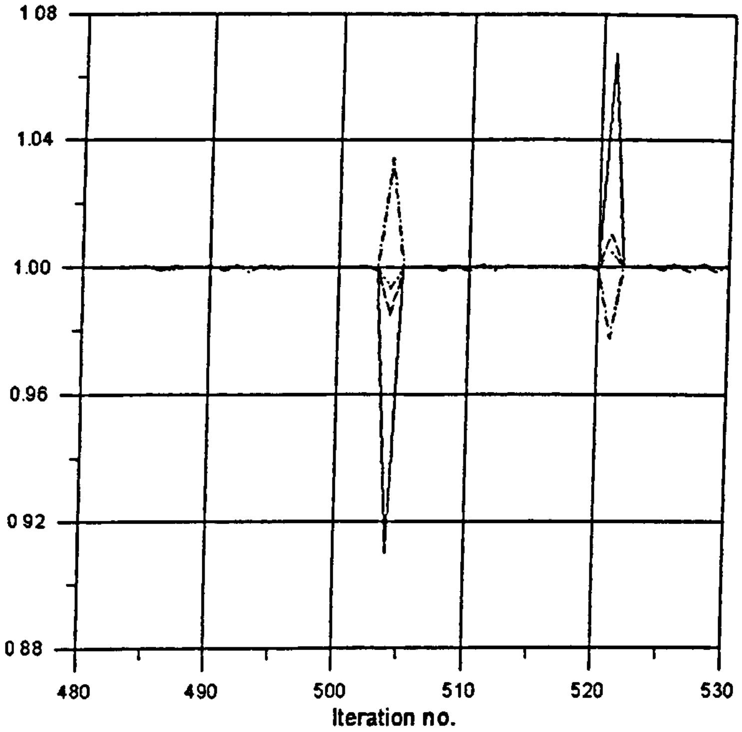

Fig K7 - History of the Wing Design Variables (normalised by previous iteration data)

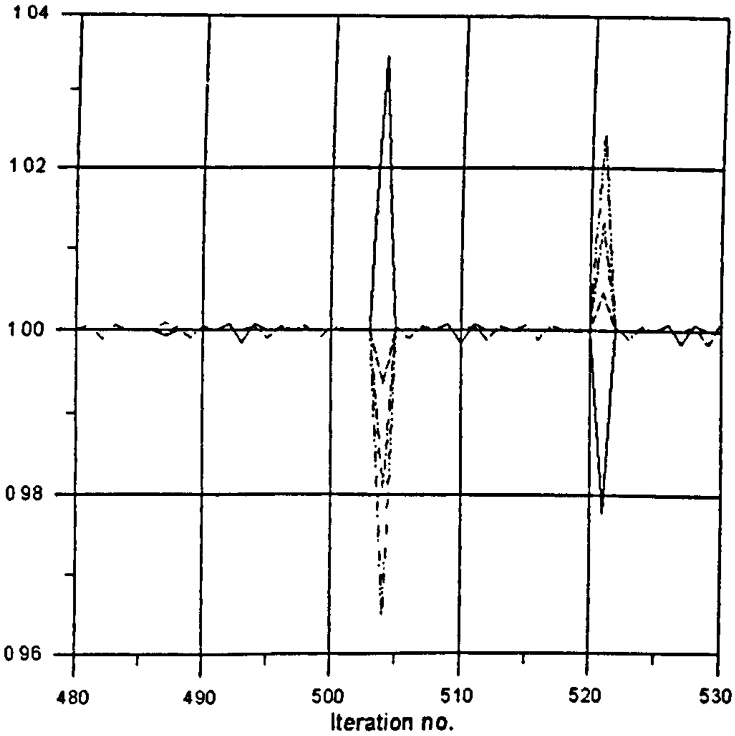

Fig K8 - History of the Tail Design Variables (normalised by previous iteration data)

Iter no.	Design Variables								Constraint Functions				Obj Function	MTOW
	DV1	DV2	DV3	DV4	DV5	DV6	DV7	DV8	CF1	CF2	CF3	CF4	DOC	
485	105.048	8.877	14.890	0.198	4.155	25.228	1.010	52.704	5486.85	4809.69	122.194	0.828	2.6376	45729.4
486	104.952	8.877	14.890	0.198	4.155	25.228	1.010	52.704	5480.54	4806.08	122.137	0.828	2.6377	45757.9
487	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5475.67	4807.55	122.153	0.831	2.6205	45706.8
488	105.000	8.879	14.878	0.198	4.155	25.253	1.012	52.725	5467.37	4808.28	122.162	0.831	2.6228	45580.7
489	105.000	8.879	14.878	0.198	4.151	25.253	1.012	52.725	5469.44	4808.29	122.162	0.831	2.6217	45578.4
490	105.000	8.884	14.878	0.198	4.153	25.253	1.012	52.725	5465.12	4807.79	122.154	0.831	2.6219	45589.0
491	105.000	8.875	14.878	0.198	4.153	25.253	1.012	52.725	5478.47	4807.93	122.159	0.831	2.6218	45718.5
492	105.000	8.879	14.890	0.198	4.153	25.253	1.012	52.725	5470.13	4808.51	122.166	0.831	2.6222	45602.8
493	105.000	8.879	14.867	0.198	4.153	25.253	1.012	52.725	5466.13	4807.83	122.155	0.831	2.6225	45596.0
494	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5468.61	4808.32	122.162	0.831	2.6224	45584.1
495	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5474.44	4807.40	122.151	0.830	2.6216	45722.0
496	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5465.58	4808.23	122.161	0.831	2.6225	45589.3
497	105.000	8.879	14.878	0.198	4.153	25.253	1.011	52.725	5468.18	4808.26	122.162	0.831	2.6224	45582.8
498	105.000	8.879	14.878	0.198	4.153	25.267	1.012	52.725	5466.78	4808.25	122.161	0.831	2.6233	45585.6
499	105.000	8.879	14.878	0.198	4.153	25.239	1.012	52.725	5465.79	4808.23	122.161	0.831	2.6229	45589.6
500	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.748	5465.04	4808.24	122.161	0.831	2.6231	45587.2
501	105.000	8.879	14.878	0.198	4.153	25.253	1.012	52.702	5466.94	4808.24	122.161	0.831	2.6233	45586.0
502	105.048	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5471.10	4810.02	122.189	0.831	2.6235	45579.2
503	104.952	8.879	14.878	0.198	4.153	25.253	1.012	52.725	5467.65	4806.52	122.134	0.831	2.6226	45586.2
504	95.500	8.746	15.391	0.196	4.073	24.366	0.912	51.304	5078.65	4480.50	116.858	0.824	2.6925	46838.3
505	95.500	8.746	15.391	0.196	4.075	24.366	0.912	51.304	5078.11	4480.51	116.858	0.824	2.6924	46836.7
506	95.500	8.746	15.391	0.196	4.071	24.366	0.912	51.304	5078.76	4480.50	116.858	0.824	2.6928	46838.2
507	95.500	8.750	15.391	0.196	4.073	24.366	0.912	51.304	5077.65	4480.08	116.852	0.824	2.6929	46839.3
508	95.500	8.741	15.391	0.196	4.073	24.366	0.912	51.304	5080.96	4480.83	116.864	0.824	2.6933	46855.0
509	95.500	8.746	15.403	0.196	4.073	24.366	0.912	51.304	5079.20	4480.86	116.864	0.824	2.6937	46834.7
510	95.500	8.746	15.380	0.196	4.073	24.366	0.912	51.304	5078.77	4480.12	116.852	0.824	2.6924	46844.8

Table K1 - Min DOC Conv Aircraft Design Optimisation History (sample of intermediate results)

Iter no.	Design Variables								Constraint Functions				Obj Function	
	DV1	DV2	DV3	DV4	DV5	DV6	DV7	DV8	CF1	CF2	CF3	CF4	DOC	MTOW
0	83.000	8.300	14.500	0.200	4.000	27.500	1.000	50.500	6000.000	5000.000	125.000	0.860	2.7904	47880.4
485	1.26564	1.06951	1.02692	0.9885	1.03875	0.91739	1.0101	1.04364	0.91448	0.96194	0.97755	0.96244	0.94524	0.95508
486	1.26448	1.06951	1.02692	0.9885	1.03875	0.91739	1.0101	1.04364	0.91342	0.96122	0.97710	0.96244	0.94528	0.95567
487	1.26506	1.06980	1.02607	0.9885	1.03823	0.91828	1.0116	1.04406	0.91261	0.96151	0.97722	0.96570	0.93911	0.95460
488	1.26506	1.06980	1.02607	0.9885	1.03873	0.91828	1.0116	1.04406	0.91123	0.96166	0.97730	0.96570	0.93994	0.95197
489	1.26506	1.06980	1.02607	0.9885	1.03773	0.91828	1.0116	1.04406	0.91157	0.96166	0.97730	0.96570	0.93954	0.95192
490	1.26506	1.07034	1.02607	0.9885	1.03823	0.91828	1.0116	1.04406	0.91085	0.96156	0.97723	0.96570	0.93961	0.95214
491	1.26506	1.06925	1.02607	0.9885	1.03823	0.91828	1.0116	1.04406	0.91308	0.96159	0.97727	0.96570	0.93958	0.95485
492	1.26506	1.06980	1.02686	0.9885	1.03823	0.91828	1.0116	1.04406	0.91169	0.96170	0.97733	0.96570	0.93972	0.95243
493	1.26506	1.06980	1.02528	0.9885	1.03823	0.91828	1.0116	1.04406	0.91102	0.96157	0.97724	0.96570	0.93983	0.95229
494	1.26506	1.06980	1.02607	0.9890	1.03823	0.91828	1.0116	1.04406	0.91144	0.96166	0.97730	0.96570	0.93979	0.95204
495	1.26506	1.06980	1.02607	0.9880	1.03823	0.91828	1.0116	1.04406	0.91241	0.96148	0.97721	0.96558	0.93951	0.95492
496	1.26506	1.06980	1.02607	0.9885	1.03823	0.91828	1.0121	1.04406	0.91093	0.96165	0.97729	0.96570	0.93983	0.95215
497	1.26506	1.06980	1.02607	0.9885	1.03823	0.91828	1.0111	1.04406	0.91136	0.96165	0.97730	0.96570	0.93979	0.95201
498	1.26506	1.06980	1.02607	0.9885	1.03823	0.91879	1.0116	1.04406	0.91113	0.96165	0.97729	0.96570	0.94012	0.95207
499	1.26506	1.06980	1.02607	0.9885	1.03823	0.91779	1.0116	1.04406	0.91097	0.96165	0.97729	0.96570	0.93997	0.95216
500	1.26506	1.06980	1.02607	0.9885	1.03823	0.91828	1.0116	1.04452	0.91084	0.96165	0.97729	0.96570	0.94004	0.95211
501	1.26506	1.06980	1.02607	0.9885	1.03823	0.91828	1.0116	1.04360	0.91116	0.96165	0.97729	0.96570	0.94012	0.95208
502	1.26564	1.06980	1.02607	0.9885	1.03823	0.91828	1.0116	1.04406	0.91185	0.96200	0.97751	0.96581	0.94019	0.95194
503	1.26448	1.06980	1.02607	0.9885	1.03823	0.91828	1.0116	1.04406	0.91128	0.96130	0.97707	0.96570	0.93987	0.95208
504	1.15060	1.05372	1.06146	0.9820	1.01825	0.88603	0.9118	1.01592	0.84644	0.89610	0.93486	0.95826	0.96492	0.97824
505	1.15060	1.05372	1.06146	0.9820	1.01875	0.88603	0.9118	1.01592	0.84635	0.89610	0.93486	0.95826	0.96488	0.97820
506	1.15060	1.05372	1.06146	0.9820	1.01775	0.88603	0.9118	1.01592	0.84646	0.89610	0.93486	0.95826	0.96502	0.97823
507	1.15060	1.05427	1.06146	0.9820	1.01825	0.88603	0.9118	1.01592	0.84628	0.89602	0.93482	0.95826	0.96506	0.97826
508	1.15060	1.05318	1.06146	0.9820	1.01825	0.88603	0.9118	1.01592	0.84683	0.89617	0.93491	0.95837	0.96520	0.97858
509	1.15060	1.05372	1.06226	0.9820	1.01825	0.88603	0.9118	1.01592	0.84653	0.89617	0.93491	0.95826	0.96535	0.97816
510	1.15060	1.05372	1.06067	0.9820	1.01825	0.88603	0.9118	1.01592	0.84646	0.89602	0.93482	0.95826	0.96488	0.97837

Table K2 - Min DOC Conv Aircraft Design Optimisation History (sample of intermediate normalised results)

Iter no.	Design Variables								Constraint Functions				Obj Function	
	DV1	DV2	DV3	DV4	DV5	DV6	DV7	DV8	CF1	CF2	CF3	CF4	DOC	MTOW
485	1.00046	1.0	1.0	1.0	1.0	1.0	1.0	1.00044	1.00057	1.00042	1.00026	1.0	0.999962	1.000033
486	0.99909	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.99885	0.99925	0.99953	1.0	1.000038	1.000623
487	1.00046	1.00027	0.99917	1.0	0.99949	1.00097	1.00149	1.0004	0.99911	1.00031	1.00013	1.00338	0.993479	0.998883
488	1.0	1.0	1.0	1.0	1.00048	1.0	1.0	1.0	0.99848	1.00015	1.00007	1.0	1.000878	0.997241
489	1.0	1.0	1.0	1.0	0.99904	1.0	1.0	1.0	1.00038	1.0	1.0	1.0	0.999581	0.999950
490	1.0	1.00051	1.0	1.0	1.00048	1.0	1.0	1.0	0.99921	0.9999	0.99993	1.0	1.000076	1.000233
491	1.0	0.99899	1.0	1.0	1.0	1.0	1.0	1.0	1.00244	1.00003	1.00004	1.0	0.999962	1.002841
492	1.0	1.00051	1.00077	1.0	1.0	1.0	1.0	1.0	0.99848	1.00012	1.00006	1.0	1.000153	0.997469
493	1.0	1.0	0.99846	1.0	1.0	1.0	1.0	1.0	0.99927	0.99986	0.99991	1.0	1.000114	0.999851
494	1.0	1.0	1.00077	1.00051	1.0	1.0	1.0	1.0	1.00045	1.0001	1.00006	1.0	0.999962	0.999739
495	1.0	1.0	1.0	0.99899	1.0	1.0	1.0	1.0	1.00107	0.99981	0.99991	0.99988	0.999695	1.003025
496	1.0	1.0	1.0	1.00051	1.0	1.0	1.00049	1.0	0.99838	1.00017	1.00008	1.00012	1.000343	0.997098
497	1.0	1.0	1.0	1.0	1.0	1.0	0.99901	1.0	1.00048	1.00001	1.00001	1.0	0.999962	0.999857
498	1.0	1.0	1.0	1.0	1.0	1.00055	1.00049	1.0	0.99974	1.0	0.99999	1.0	1.000343	1.000061
499	1.0	1.0	1.0	1.0	1.0	0.99891	1.0	1.0	0.99982	1.0	1.0	1.0	0.999848	1.000088
500	1.0	1.0	1.0	1.0	1.0	1.00054	1.0	1.00044	0.99986	1.0	1.0	1.0	1.000076	0.999947
501	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.99912	1.00035	1.0	1.0	1.0	1.000076	0.999974
502	1.00046	1.0	1.0	1.0	1.0	1.0	1.0	1.00044	1.00076	1.00037	1.00023	1.00012	1.000076	0.999851
503	0.99909	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.99937	0.99927	0.99955	0.99988	0.999657	1.000154
504	0.90994	0.98498	1.03449	0.99342	0.98076	0.96487	0.90134	0.97305	0.92885	0.93217	0.9568	0.99229	1.026653	1.027467
505	1.0	1.0	1.0	1.0	1.00049	1.0	1.0	1.0	0.99989	1.0	1.0	1.0	0.999963	0.999966
506	1.0	1.0	1.0	1.0	0.99902	1.0	1.0	1.0	1.00013	1.0	1.0	1.0	1.000149	1.000032
507	1.0	1.00051	1.0	1.0	1.00049	1.0	1.0	1.0	0.99978	0.99991	0.99995	1.0	1.000037	1.000023
508	1.0	0.99897	1.0	1.0	1.0	1.0	1.0	1.0	1.00065	1.00017	1.0001	1.00012	1.000149	1.000335
509	1.0	1.00051	1.00075	1.0	1.0	1.0	1.0	1.0	0.99965	1.00001	1.0	0.99988	1.000149	0.999567
510	1.0	1.0	0.99851	1.0	1.0	1.0	1.0	1.0	0.99992	0.99983	0.9999	1.0	0.999517	1.000216

Table K3 - Min DOC Conv Aircraft Design Optimisation History (sample of intermediate results normalised by previous iteration data)