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DESIGN SYNTHESIS FOR CANARD-DELTA COMBAT AIRCRAFT (OPTIMIZATION)

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SUMMARY

This report presents a fully computerized Design Synthesis and Optimization system for Canard-Delta Combat Aircraft,which was developed by interfacing the Design Synthesis program CANARD with the Numerical Multivariate Optimization program RQPMIN.

The background and the objectives of this Research Programme are initially examined.The Design Synthesis and the Numerical Multivariate Optimization processes and computer programs are then described.The gradual interfacing of programs CANARD and RQPMIN is explained in detail.A description of the computer program architecture is also included.A User's guide for this system is provided in the appendices together with an optimization example.

ACKNOWLEDGEMENTS

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I am deeply grateful to my supervisor Dr.J.P.Fielding,for his continued support,invaluable advice and suggestions.

I also wish to express my sincere appreciation and gratitude to Professor D.Howe,for his continued interest in this Programme and for offerring me the opportunity to undertake this work in the College of Aeronautics.

I am particularly indebted to Mr.J.Smith and Mr.C.Lee,from the Aerodynamics Department,RAE Farnborough,who closely monitored this Research Programme on behalf of the RAE and provided invaluable assistance and information.

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CHAPTER 1

INTRODUCTION

1.1 General

The Research Programme presented in this Report was undertaken in October 1987, following the successful development of a computerized Design Synthesis for Canard-Delta Combat Aircraft (ref.1).The main objective of this Research was to automate the Design Optimization process by interfacing the new Synthesis program CANARD,with the existing RAE Multivariate Optimization program RQPMIN.

1.2 Background

The Royal Aerospace Establishment (Farnborough) has been studying Multivariate Optimization (MVO) since 1970.The initial work concentrated on Transport Aircraft design.Research into the application of MVO to Combat Aircraft design began in 1976 and this in 1980 led to the development of a computerized Design Synthesis for conventional high-wing,aft-tail,single-engine combat aircraft, with side air intakes and trapezoidal,aft-swept fixed geometry wings (ref.2).A twin-engine version was also produced a year later.

The rapidly changing design requirements and the increasing interest in Canard-Delta layout with the forthcoming European Fighter Aircraft (EFA),created a need for a more sophisticated and flexible Design Synthesis suitable for use with this new generation of combat aircraft.The development of the new synthesis began in

October 1985. Two years later,a fully computerized design synthesis and analysis system was successfully produced and tested ,which is applicable to the preliminary design of highly manoeuvrable supersonic combat aircraft with a low cropped delta wing and a close coupled foreplane, single or twin fins,twin engines and chin air intakes (ref. 1).This system incorporates new methods for the automated development of the aircraft configuration and provides solutions to special preliminary design problems associated with advances in Aerospace Technology,the new Canard-Delta layout and in particular,the aerodynamic interference between the foreplane and the delta wing.The Synthesis is implemented by a large modular computer program (CANARD),written in standard Fortran 77.This performs,quickly and accurately,the complex calculations for the sizing of the fixed items of the aircraft,the detailed estimation of the fuselage and flying surface geometry, packaging,aerodynamic lift and drag,static longitudinal stability and finally the prediction of the sortie,point and field performance of the synthesized aircraft.These calculations are based on a set of independent (IV's) and external (EV's) variables,the values of which are specified at the start of the process.A companion graphics program (VIEW) was also developed,which generates three clear and detailed images of the synthesized configuration,from the geometric data produced by the previously executed program CANARD.Program VIEW,is also modular and written in Fortran 77 using GINO-F library subroutines.These programs are described in greater depth in the following chapters of this report.

With the first version of program CANARD, optimization of the synthesized configuration for satisfying a set of requirements may be only roughly achieved by manually repeating the the execution of the program for a number of loops. During each loop the User examines the numerical output critically, asseses how the results compare to the requirements and then reassigns appropriate values to those independent variables that need to be varied in order to reach an optimum design. This process is stopped when the User decides that the results are within acceptable limits from the desired optimum values. The total number of loops required for the optimization to be completed is largely dependent on the User's aircraft design experience.

The above manual process may be fully automated and its accuracy considerably increased with the use of numerical optimization. Program CANARD was therefore designed from the outset to be compatible with existing RAE numerical optimization algorithms in order to be able, during the present Research Programme, to interface it with program RQPMIN (ref.3). The latter was developed in 1986 and it is designed to solve the constrained optimization problem, i.e. the problem of minimizing or maximizing a function subject to the problem variables satisfying User-specified constraints as well as simple lower and upper bounds. RQPMIN supersedes the previous RAE optimization program M04IPF used with the swept synthesis.

1.3 Research Programme Objectives

The main objectives of this Research Programme were:

a) An initial exploratory study of RQPMIN.

b) Investigation into methods for increasing its convergence during optimization.

c) Selection of Independent Variables,Optimization Constraints and Objective functions.

d) Creation of a User-subroutine for RQPMIN.

e) Interfacing of programs RQPMIN and CANARD.

f) Minimization of the CPU time required for program execution.

g) Optimization testing.

CHAPTER 2

DESIGN SYNTHESIS FOR CANARD-DELTA COMBAT AIRCRAFT

2.1 General

This chapter provides an overall summary of the Design Synthesis for Canard-Delta combat aircraft.The development of the Synthesis,the preliminary design methods it incorporates and the computer program architecture,are fully presented in ref.1.

2.2 Applicability

The applicability of the Design Synthesis is fully defined by the baseline aircraft design which formed the basis for its development.

The baseline aircraft(fig.2.1) has a low cropped-delta wing with an all-moving, close-coupled foreplane located above the wing-chord plane and behind the cockpit.A single fin is located on the flat upper surface of the fuselage afterbody.A twin-fin option is also provided.The fuselage is aerodynamically shaped for minimum supersonic drag.Chin air intakes with limited variable geometry supply a continuous and undistorted flow of air to the engines through two smooth 'S'-shaped diffusers. Propulsion is provided by two low-bypass ratio,reheated turbofans, fitted with thrust reversers.An advanced high-'g' cockpit is used with an inclined ejection seat,raised heel platform and bubble canopy. The undercarriage is designed for operation from semi-prepared runways.Four semi-submerged medium range missiles and a single-barrel gun are fitted under the fuselage.A combination of stores may be carried on four wing-pylons.The aircraft is equipped with the latest state-of-the-art systems,including fly-by-wire or fly-by-light, auxiliary power unit,radar,sophisticated avionics and cockpit displays.Both composite and metal structural materials are being used. The aircraft has a good STOL performance,is highly manoeuvrable and capable of speeds in excess of Mach 2.0.

2.3 Design Synthesis Operation

The design synthesis calculations start with the sizing of the fixed items.This involves the estimation of the physical dimensions of the cockpit,the dimensions of the main and nose undercarriage legs and bays,the selection of suitable standard-size tyres for each leg,the sizing of the engines and engine bays,the estimation of the dimensions of the intake diffuser inlets,and the size and geometric characteristics of the gross-wing.The dimensions of the above fixed items are obtained using standard design data and expressions,together with several specially derived mathematical models.These dimensions are used in conjunction with other design data to define the actual aircraft length and the longitudinal positions of various significant fuselage stations.The fixed item sizing calculations finish with the estimation of the b.l.diverter dimensions at the intake plane.The fixed items impose physical constraints on the fuselage geometry.

The fuselage geometry calculations start by determining the cross- sectional area at the radar dish location.This is used in the development of a fairing curve which defines the optimum logitudinal cross-sectional area distribution of the fuselage,for minimum supersonic drag.The fuselage geometry at the principal stations and also at any station in between them,is determined by considering the corresponding fairing curve area and the geometry of the intake diffusers,b.l.diverter,underfuselage weapons and engine bays,which are all mathematically modelled by complex 3-D expressions.These expressions adjust the fuselage dimensions to match the optimum cross-sectional area distribution without violating any geometric constraints imposed by the fixed items or the requirements for uniform surface blending between successive fuselage sections.

Following the definition of the fuselage shape,the sizes and geometric characteristics of the net wing,foreplane and fin are then determined. The gross foreplane geometry is determined by considering the net foreplane dimensions.

The next step in the Design Synthesis is the estimation of the volume of the fuselage,intake diffusers and engine bays,the gross surface area of the fuselage ,the surface area of the canopy and the moment arms of the fuselage structure and skin.These calculations are based on multiple numerical integrations.The net surface area of the fuselage,is obtained by calculating and subtracting the total footprint area of the flying surfaces ,from the gross surface area of the fuselage.The volume of the fuel tanks inside the fuselage is estimated by considering the available volume and specified utilization factors.

The packaging calculations then start with the aircraft mass prediction.The aircraft is divided into main systems and components and their masses are predicted from their physical characteristics and a specified set of empirical constants,using well-established empirical methods.A volume accounting is then performed for everything installed inside the fuselage,to ensure that the previously estimated actual fuselage volume is greater than the volume required to adequately accomodate all the systems,components and fuel tanks installed inside the fuselage.The volume accounting calculations are based on predicted mass information and recommended density figures. The moment arms,including those of the external stores are next determined by assumung that fixed mass proportions of each system group are installed at specific points of the aircraft anatomy.The moment arms are used to calculate the forward and aft longitudinal centre of gravity positions of the aircraft,by considering various extreme loading combinations.

The aerodynamics calculations start with the lift-curve-slopes of the wing,foreplane and fuselage which are initially estimated separately.These are then used to determine the lift-curve-slopes of the isolated wing-fuselage and foreplane-fuselage combinations,by considering the associated interference.The lift-curve-slope values of the isolated combinations,at a given Mach number are individually corrected by the corresponding canard-delta interference factors.These factors were determined after a long and detailed analysis of relevant wind-tunnel data.The values of these factors depend on the flight Mach number,the leading-edge sweep of the wing,the ratio of the exposed foreplane area to gross wing area and the ratio of the foreplane height above the wing-chord plane to the mean geometric chord of the wing.The total aircraft lift-curve-slope is finally estimated by appropriately adding together the corrected lift-curve-slope values of the wing-fuselage and foreplane-fuselage combinations.

The lift increment due to flaps and the total aircraft lift coefficient at a given incidence and Mach number,are estimated next, while the corresponding maximum trimmed lift coefficient is externally supplied.The aerodynamic centre and its transonic shift are then calculated.The aerodynamic centre and centre of gravity positions are appropriately compared to establish the longitudinal static stability of the aircraft.

The engine performance for specified flight conditions is estimated using empirical relationships,based on a modern military turbofan engine.

The next Synthesis step is the estimation of the total aircraft drag coefficient.This is the sum of the basic zero-lift drag,wave drag, spillage drag,store drag and lift-dependent drag components which are calculated separately at first using detailed aerodynamic methods.The lift-dependent drag parameters K1 and K2 which define the lower and upper regions of the drag polar are corrected for the effects of canard-delta interference by means of factors determined from a detailed wind-tunnel data analysis similar to that used for the lift- curve-slope.

The aircraft performance estimation is the last part of the Design Synthesis calculations,during which the above lift,drag and engine performance calculations are carried out for each specified set of flight conditions.A sortie analysis is carried out during which the synthesized aircraft is assumed to fly a hypothetical sortie and its performance and fuel consumption are estimated for each sortie leg. The take-off and landing performance is determined by considering the aircraft mass at the start and finish of the sortie.Six point performance parameters are finally calculated.These are the sustained and attained turn rates,specific excess power,maximum Mach number, acceleration time and aircraft ride quality factor.Each of these parameters may be estimated for any number of times and for different flight conditions.

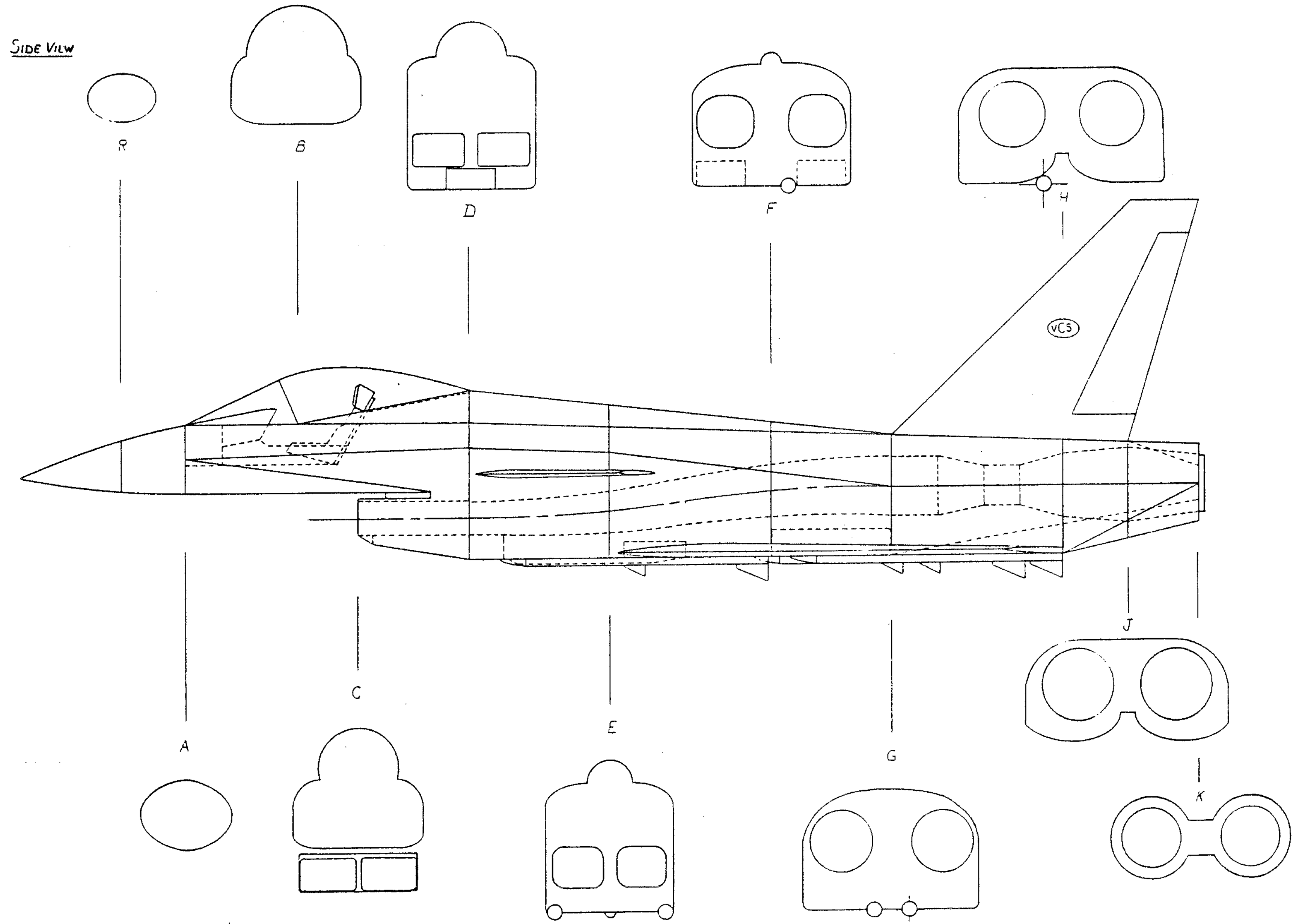
The Design Synthesis is based on sound methods and it is detailed, accurate,flexible and sensitive to minor configurational changes.

2.4 Computer Programs

The Design Synthesis is automatically implemented by a large modular computer program ,written in standard Fortran 77.This has a total length of about 8500 lines and consists of 77 modules and 15 auxiliary data files,two of which are User-created,plus a main input data file. Additionally,it produces two output files,one of which contains the main numerical results of the Design Synthesis and the other the input data for the Graphics.The program uses about 1500 variables,346 of which are classified as input.The program is compatible with existing RAE multivariate optimization algorithms.

A graphical output may be also provided by a separate graphics program which receives its input directly from the Synthesis program,but its execution is controlled by the User.It is also written in Fortran 77 using GINO-F library subroutines.It has a total length of about 1600 lines and consists of three large independent modules which produce clear and detailed 2-D computer generated images of the side view, lower plan view and upper plan view of the synthesized configuration. These images allow easy and quick assessment of the aircraft geometry.

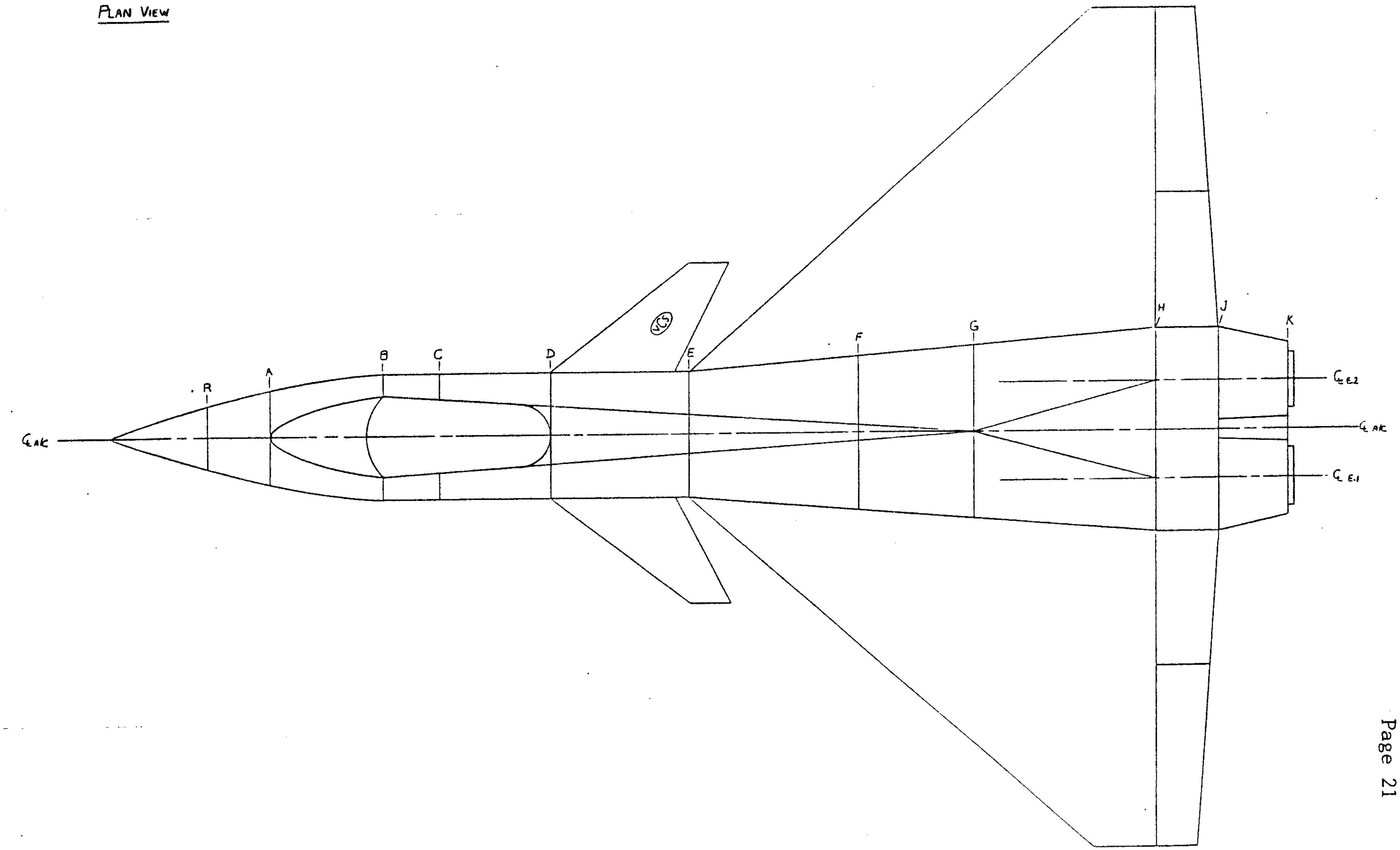
The interrelation between Synthesis,User and Graphics is diagrammatically presented in fig.2.2.



DRAWN	CHK'D	APPV'D	SCALE	TITLE:- CANARD / DELTA COMBAT AIRCRAFT (BASELINE CONFIGURATION)
S.E.GHIDESY			1:25	
COLLEGE OF AERONAUTICS CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD				DRAWING No.
				SHT 1 OF 4 SHEETS

FIG.2.1 BASELINE CONFIGURATION DRAWINGS

PLAN VIEW



DRAWN	CHK'D	APP'D	SCALE	TITLE:-CANARD/DELTA COMBAT AIRCRAFT (BASELINE CONFIGURATION)
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FIG.2.1 (Continued ...)

Bottom View

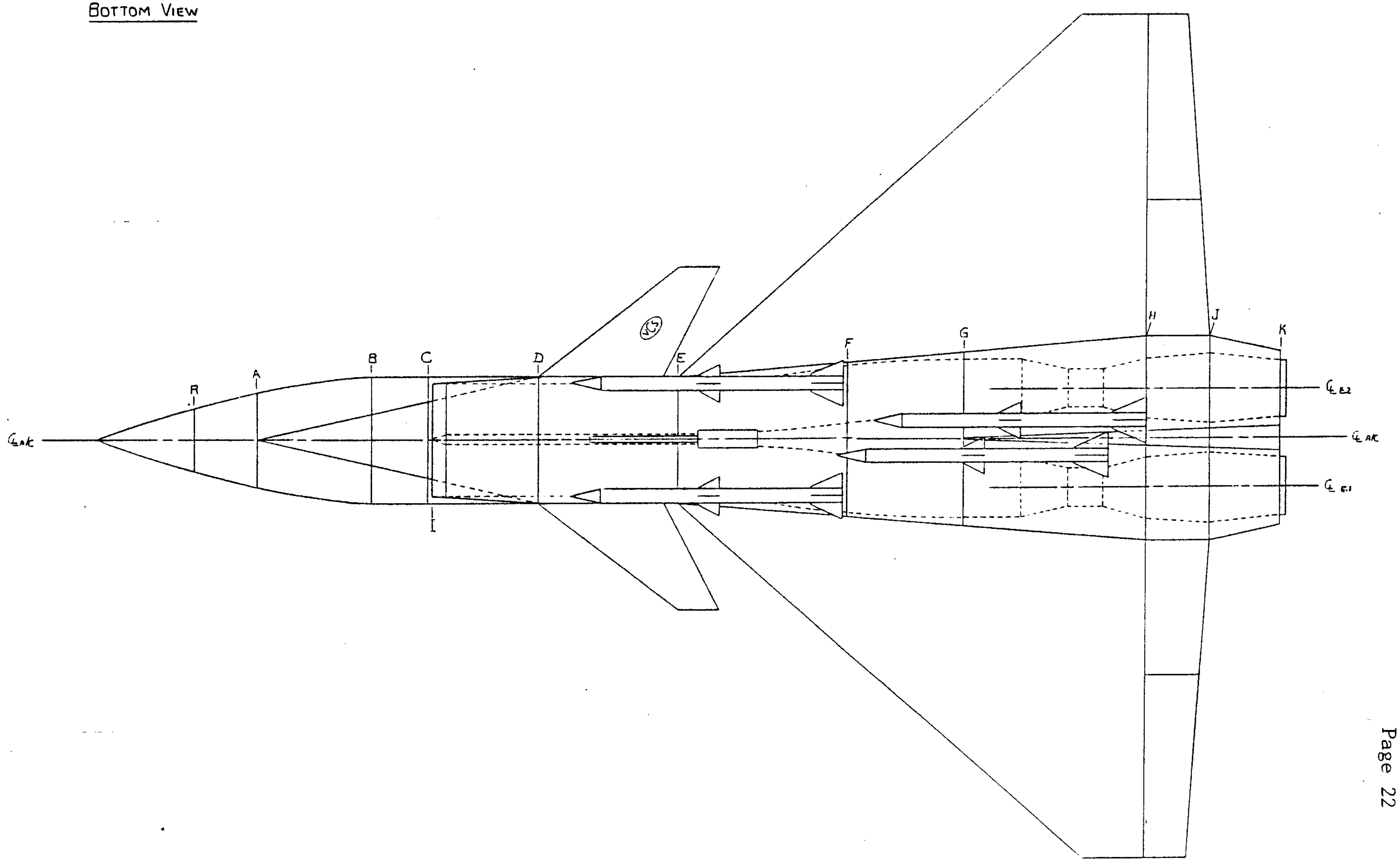

FIG.2.1 (Continued ...)

DRAWN	CHK'D	APP'D	SCALE	TITLE:- CANARD / DELTA COMBAT AIRCRAFT (BASELINE CONFIGURATION)
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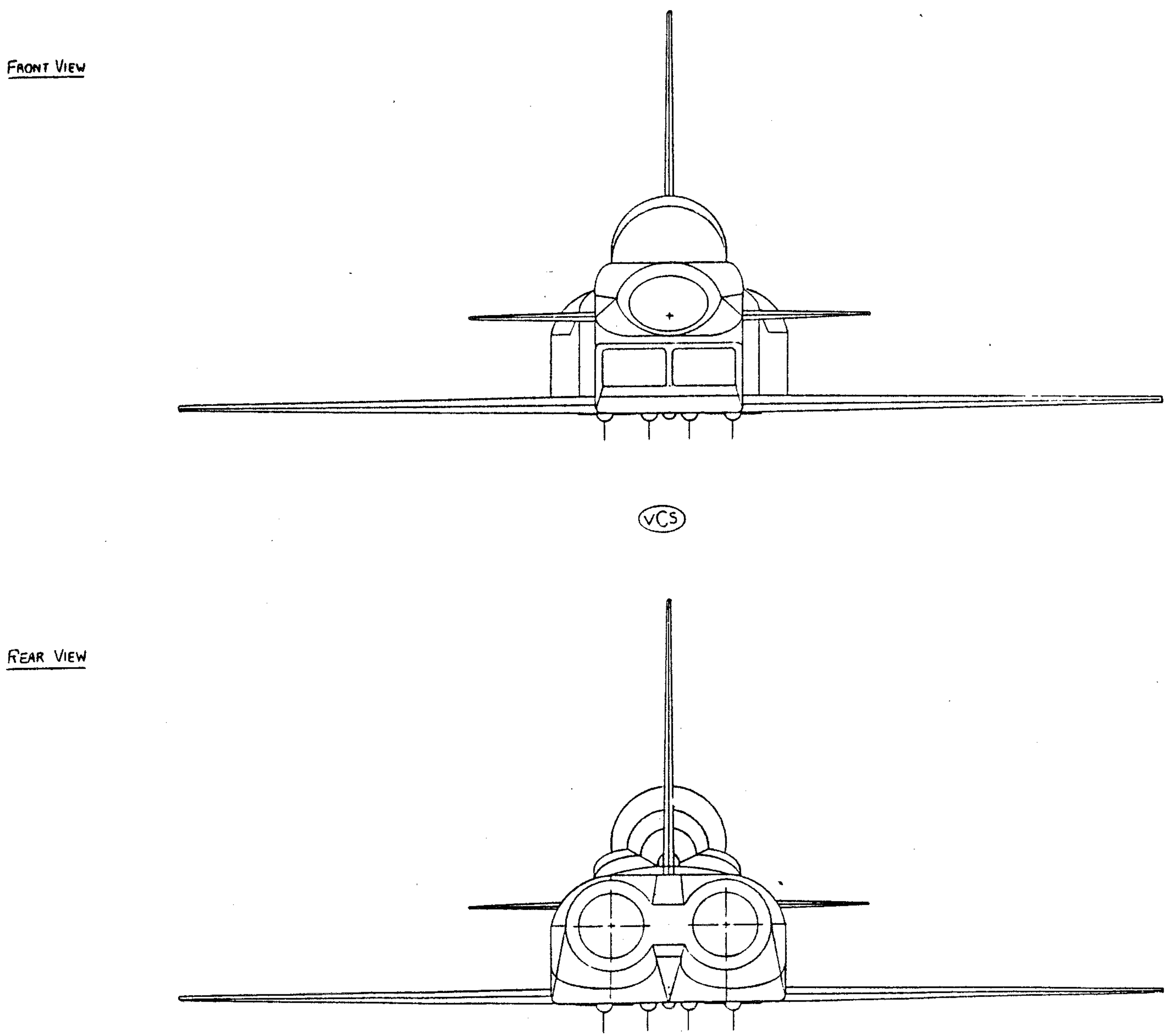

DRAWN	CHK'D	APPV'D	SCALE	TITLE:- CANARD/DELTA COMBAT AIRCRAFT (BASELINE CONFIGURATION)
ÆRGHIDES V.			1:25	

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FIG.2.1 (Continued)

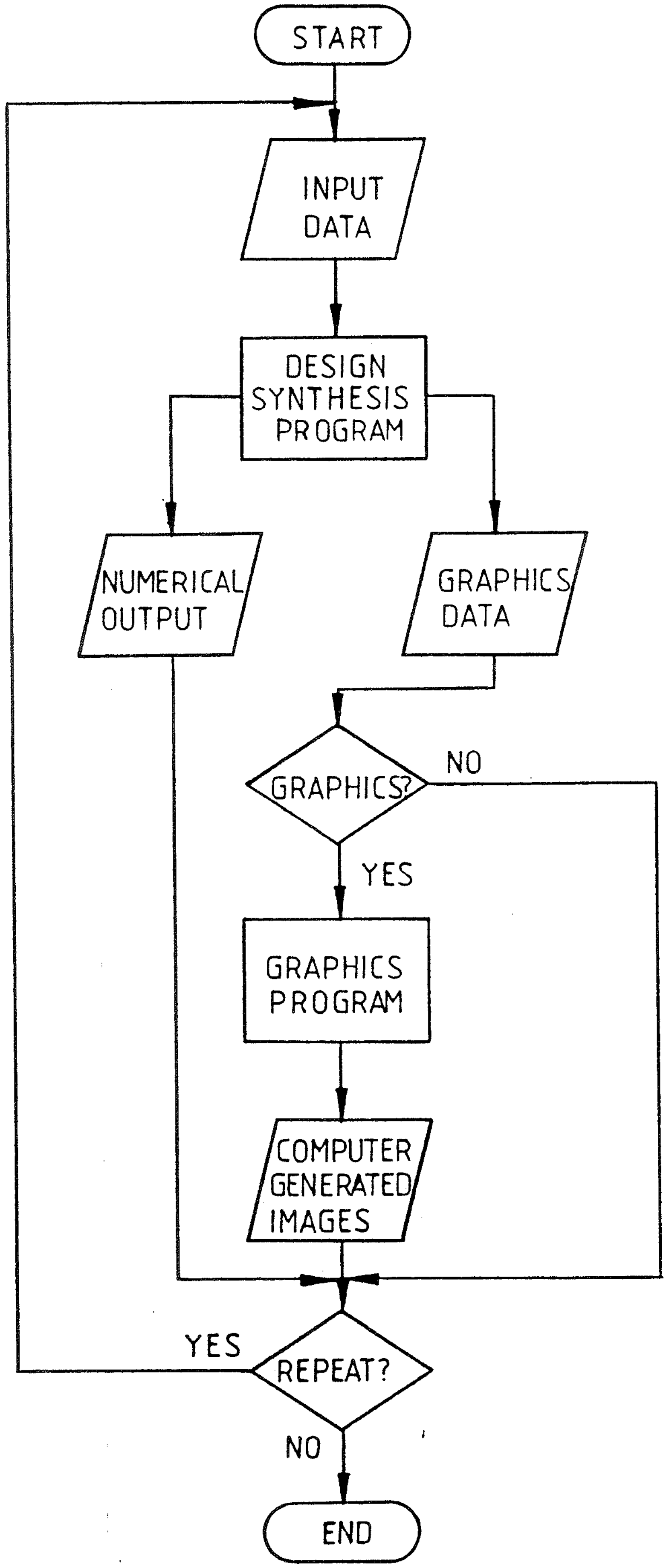

FIG. 2.2 USER/PROGRAM INTERRELATION - SIMPLIFIED FLOW CHART

CHAPTER 3

NUMERICAL MULTIVARIATE OPTIMIZATION

3.1 General

As mentioned earlier in this report,the main objective of this Research Programme was the automation of the initially adopted manual optimization process for the Design Synthesis for Canard-Delta combat aircraft,by interfacing program CANARD with the numerical multivariate optimization program RQPMIN,supplied by the RAE.

A general qualitative description of RQPMIN is presented in the following paragraphs of this chapter.The development of the mathematical method of RQPMIN is described in detail in ref.4.

3.2 Applicability

RQPMIN is a general numerical optimization program. It can be therefore applied in a wide variety of situations for the solution of many problems in science,engineering and commerce,involving the calculation of an optimum value.It is designed to solve the constrained optimization problem,i.e.,the problem of minimizing a function,subject to the variables satisfying User-specified constraints as well as simple lower and upper bounds.If it is required to find the maximum of a function,then RQPMIN should be used to find the negative of that function.

The program can handle problems with up to 75 constraints and up to 50 variables.It can also be used if there are no constraint functions. It is assumed that the problem functions are continuously differentiable.However,no assumption is made regarding the linearity or otherwise,of the problem functions.RQPMIN was designed with nonlinear constraints specifically in mind,but if any of the problem functions are linear then RQPMIN takes advantage of this fact.Only in the special case that all the problem functions are linear is the method of RQPMIN not recommended.In such a case the method is still valid but linear programming codes will be more efficient.

Program RQPMIN is modular and is written in standard Fortran 77.It supersedes the earlier RAE numerical optimization programs,M0402, M0420,M211PF and M04IPF.

3.3 The RQPMIN Method

The mathematical method of RQPMIN is based on the Langrange-Newton approach,i.e.,a stationary point of the Langrangian function is calculated by Newton's method.However,the RQPMIN method differs from other such methods in that it does not use a penalty or a criterion function to force global convergence.Instead,the concept of pseudo- feasibility is used,i.e., 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.The latter is initially given a relatively large value and is only reduced when necessary.In many cases the radius of pseudo-feasibility retains its initial value throughout the calculation.

3.4 Optimization Terminology

The various terms assigned to the variables,functions and constraints, used in the numerical multivariate optimization of an aircraft design, are defined below:-

An Independent Variable (IV) is a variable quantity in the mathematical model of an aircraft,that is chosen to be at the disposal of the optimization algorithm.

A Dependent Variable (DV) is a variable in the mathematical model, whose value is dependent on the set of values of the independent and external variables.

An External Variable (EV) is a quantity that is variable externally to the optimization process,i.e.,part of the design data.

An Objective Function (OF) is a function in the mathematical model, that is chosen to minimize or maximize in the optimization process.

An Equality Constraint (EC) is function in the mathematical model, that must be satisfied within a specified tolerance in the solution aircraft obtained by the optimization process.This type of constraint will thus exert an influence throughout the optimization and is therefore always Active.

An Inequality Constraint (IC) is a function in the mathematical model, that must be satisfied within a specified tolerance in the solution aircraft.This type of constraint remains Inactive,unless a set of values of the IV's would cause it to be broken.Thus the membership of the set of constraints that are Active in the optimization will change as IC values vary with different sets of values of the IV's.

3.5 RQPMIN Operation

The independent variables,objective function and constraints are selected by the User and incorporated in a User-created subroutine (USERF),as explained in detail in the following chapters of this report.The initial values of the IV's and also their lower and upper bounds and scale factors,are specified in an RQPMIN input file,together with the scale factors for the objective function and constraints and those values of any assignment keywords which are different from the default ones.The values of all the EV's are specified in a separate file,as design data for the Synthesis.The latter is treated as an RQPMIN subroutine during optimization.

At first,RQPMIN checks the input data and if no error is detected it proceeds with the actual optimization process.During program initialization,RQPMIN calls the

Design Synthesis and USERF subroutines for a few times and evaluates the objective and constraint functions using the initial values of the IV's.The program then begins a series of feasibility steps,during which it automatically varies the initial values of some IV's,in order to locate a feasible path,subject to the set constraints,from which it can start minimizing the objective function.During the feasibility steps,the values of those IV's that RQPMIN identifies as relevant to the optimum solution,may vary quite significantly,but always within the User-specified IV-bounds.The values of the rest of the IV's,however,may remain unchanged throughout the process.If no feasible path has been located,RQPMIN will stop and notify the User that no further progress is possible.If this occurs,the program may be restarted with a new set of initial values for the IV's.It is advisable,though,to use the IV values assigned by RQPMIN during the last feasibility step,just before the program stopped.This process may have to be repeated until a feasible path is located,after which the program begins a long series of minimization steps which continues until the objective and constraint function values minimize within the prescribed tolerances and a convergence is detected.Prior to convergence or after the feasilibity steps have failed,the program may change its mode to central differences.

RQPMIN may converge in any one of three forms,i.e.,A,B or C.

Convergence A occurs when the program has located a point at which the estimated distances to the minimum of the criterion function and to the minimum of the sum of the squares of the constraint functions are less than the prescribed tolerances.

Convergence B occurs when 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 prescribed tolerance and a value of the criterion function sufficiently smaller than the current value cannot be found.

Convergence C occurs when 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 prescribed tolerance and no IV's exist.

CHAPTER 4

PROGRAM INTERFACING PROCESS

4.1 General

The interfacing of programs CANARD and RQPMIN was carried out gradually, in order to ensure a successful and efficient program operation during optimization.The various steps involved in this process,are described in the following paragraphs of this chapter.

4.2 RQPMIN Installation

The Multics version of RQPMIN was supplied by RAE on a mag-tape and it was subsequently mounted on the CoA VAX computer system,following a number of system-related modifications,which were successfully carried out by the author.An example USERF subroutine and the associated input data file were also supplied with RQPMIN,in order to test the correct installation and operation of the program.The above subroutine also provided a simple illustration of how a typical constrained minimization problem should be coded for use with RQPMIN.The example problem was to find the smallest triangle which contains two non-overlapping circular discs,with each disc having a unit radius.RQPMIN was compiled successfully and it was then run with the example subroutine.A convergence was detected in less than 50 loops.The solution was identical to that supplied by RAE.This concluded the program installation.

4.3 Exploratory study of RQPMIN

An exploratory study of RQPMIN was initially conducted in order to be familiarized with its operation.This study mainly concentrated on the preparation of the User-created subroutine and input data file and it was assisted by a brief RQPMIN User-guide (ref.5).This includes fundamental information on how to set up correctly the variable function and control definition records and also,the command and assignment keywords in the input data file.It also explains how to set up the main segment of subroutine USERF and how to run the program and obtain the output.It provides comprehensive explanations of the various reporting formats and stop messages and a complete list of RQPMIN diagnostics.The User-guide,however,does not include any information on how to set up the optimization constraints or how the program operates.The guidelines for determining the variable and function scale factors were found to be insufficient and the supplied example could not adequately fill the above gaps.These were later better clarified by a closer examination of the program code,a study of the mathematical method of RQPMIN (ref.4) and subsequently by running the program in conjunction with the Design Synthesis.

4.4 Division of the Design Synthesis

The next step in the program interfacing process,was the division of program CANARD into four separate sections,i.e.,Geometry,Packaging, Aerodynamics and Performance.This was done in order to link the two programs,gradually and methodically,in minimum time and without any unnecessary waste of CPU time during the early stages.The division process was relatively easy because of the modular structure of program CANARD.

4.5 Selection of IV's

The IV's for the optimization of the Design Synthesis,were selected and finalized earlier,during the development of program CANARD.The selection process was largely based on RAE requirements for for compatibility with the swept synthesis.Variations in the values of these IV's may produce significant changes to the overall design of the aircraft.This allows easy convergence to an optimum solution.

Twenty-three IV's were finally selected for this Synthesis.These are listed and defined together with their units and typical values,in fig.4.1.They are related to the wing geometry,wing span positions, flap size,flying surface positions,engine scale,fuselage fairing curve and internal fuel tanks.

These IV's were assigned to RQPMIN variables in the USERF subroutine, in the order shown below:

X(1)=SW	X(7)=FCWD	X(13)=XFN	X(19)=FBWNF
X(2)=AW	X(8)=FBWF	X(14)=RLTMFN	X(20)=UWBCF
X(3)=UW	X(9)=RXWCQM	X(15)=RLTFFN	X(21)=UFIFD
X(4)=QW4	X(10)=RXCCQM	X(16)=RLTCFN	X(22)=UFIFEF
X(5)=RTW	X(11)=RZCC	X(17)=RLTAFN	X(23)=UFIFFG
X(6)=FCWR	X(12)=RTP	X(18)=FOT6N	

4.6 Gradual Interfacing and Optimization

The aircraft geometry section was the first to be interfaced with RQPMIN.The corresponding segment of program CANARD was converted into a subroutine and it was also modified in order to remove the IV values from the main input data file of the Design Synthesis and include them in the input file for RQPMIN.The input and output channel units were also altered to prevent any conflict with identical RQPMIN units.The output channel of the geometry modules was temporarily suppressed,to prevent exceeding the allocated disc-space by the unnecessary creation of intermediate result files during the optimization process. Additionally,several other modifications were also carried out.An initial version of subroutine USERF was then created,in which the IV's,objective function and optimization constraints,were defined in a manner understandable to RQPMIN.

For this initial optimization of the fuselage geometry,the fuselage volume was appropriately selected as the objective function.The optimization started without any constraints.After a number of initial trial runs which helped to clarify some of the previous uncertainties of RQPMIN,a convergence was detected.During these initial steps,only the fuselage length was free to vary.The number of IV's was then increased and optimization constraints were eventually added to the problem.The objective function was then modified to minimize the actual relative to the required fuselage volume,which is more appropriate for the Design Synthesis.At that stage,however,the required volume was temporarily specified in the input data.The optimization of the aircraft geometry was completed with two constraints and six free IV's for the fuselage fairing curve. Convergence was relatively fast but depended on the starting values of the IV's.These exploratory runs,had shown that RQPMIN,by default, minimizes the objective function with a very fine tolerance,which is unnecessary for this particular application.

The packaging modules of the Design Synthesis,were then added to the previously used geometry modules,the subroutine USERF was expanded with more constraints and they were all linked and run successfully with RQPMIN.This was followed by several other runs,during which the use of various different constraints was investigated.The aircraft empty mass was set as the new objective function,although it was found that minimizing the actual fuselage volume relative to the required volume was more appropriate and also faster with regard to convergence.The total number of constraints was gradually increased to eleven and all the twenty-three IV's were used in the optimization.

Following the interfacing and optimization of the geometry and packaging,the aerodynamics and performance modules were added to the rest in a single operation because of their close interdependence.They all together formed a large modular Design Synthesis subroutine which was linked to RQPMIN.The subroutine USERF was appropriately revised and extended further with more constraints and the program was successfully run for a number of times,with a gradually increasing number and varying combinations of constraints,each time.The number of loops required for convergence was again largely variable and depended on the number and type of constraints and also on the starting values and bounds of the IV's.

4.7 Convergence

During the gradual interfacing and optimization described in the previous paragraph,the convergence characteristics and behaviour of RQPMIN were carefully observed and various ways were investigated in order to externally enhance this convergence.

The initial optimization of the aircraft geometry had shown that,although convergence to an optimum solution was reached relatively quickly,the values of the set objective function and optimization constraints were reaching practically acceptable limits of accuracy for this particular application,well before the optimization cycle was terminated by RQPMIN.This suggested that RQPMIN was operating on extremely fine tolerances which are not always necessary in aircraft design,considering the large values of the variables and constraints involved.It was therefore decided to appropriately alter the default values of various assignment keywords used in RQPMIN and hence investigate their effects on convergence.

The values of most keywords are frequently associated and hence an alteration of a default value usually imposes a simultaneous change of the others,in order to maintain the normal operation of RQPMIN. Several keywords are purely associated with the complex mathematical operation of the optimization process and have little or no effect on convergence.The range of acceptable values for some other keywords could not be established with certainty because of their ambiguous role in the optimizer and hence their default values were not changed.Finally,only the keywords XTOLU and XTOLV were found to have a significant effect on convergence.XTOLU controls the accuracy with which the constraints are solved ans XTOLV controls the accuracy with which the objective function is minimized.The default values of both these keywords in the input file of RQPMIN,were increased to 0.001.This is the maximum value that can be used for these two keywords without any need to alter the default values of any other associated keywords.The above alteration led in some cases, up to a 25% reduction in the number of iterations required for convergence A.This reduction did not violate the practical accuracy limits of the values of the optimization constraints.

The investigation into the convergence characteristics of RQPMIN continued by examining the effects of various types and combinations of constraints.It was observed that the program inherently tends to satisfy any equality constraints much faster than any inequality constraints. Therefore,as the number of equality constraints increases,the number of feasibility steps increases too and the more difficult it becomes to converge. It was also observed that as the total number of constraints increases, RQPMIN takes longer to converge.The convergence is also adversely affected,if the constraints are closely interrelated.

Clearly,the total number of constraints that can be used at any one time with RQPMIN without severely degrading its convergence is in practice very limited and well below the maximum allowable default value.In order to alleviate this problem and allow the use of several essential constraints in subroutine USERF,the author devised a method with which RQPMIN during each loop automatically considers only those constraints which are not satisfied.This method increases the convergence and reduces the number of feasibility steps at the start of the process.The arrangement of the constraints in USERF,according to this method is explained in appendix A.

4.8 CPU Time Reduction

As it was anticipated at the beginning of this Research Programme,the addition of the performance modules in the optimization process produced a sharp rise in the CPU time required for the execution of the programs.This is because the performance calculations involve a large number of internal iterations,which make multiple use of the complex aerodynamics modules.It therefore became necessary to find ways to reduce the CPU time requirement to an acceptable level,without degrading the accuracy of the Design Synthesis calculations.

The above objective was successfully achieved by mainly integrating the permanent auxiliary data files with their corresponding aerodynamics modules.This in conjunction with a simplified hypothetical sortie and some other minor modifications,produced about ninety percent overall reduction in the CPU time required for the execution of each optimization loop.

4.9 Final Constraint Selection

Several different types and combinations of optimization constraints were investigated during the program interfacing process,in order to determine which were the most significant in the optimization process. Fifteen constraints were finally selected for this particular application,three of which are equality and the rest inequality constraints.These are used in conjunction with an objective function for the empty aircraft mass.This and the final constraints,are listed and explained below,in the order in which they appear in USERF.

The objective function is:

FUNC(1)=ABS(MTT-MTP-MTGFI-MTOUF-MXTF-MTES)

where, MTT=Total aircraft take-off mass

MTP=Total aircraft payload

MTGFI=Total internal fuel mass

MTOUF=Mass of oil and unused fuel

MXTF=Total mass of externally carried fuel

MTES=Minimum allowable empty aircraft mass

The above objective function is designed to minimize the absolute difference between the actual empty mass (MTT-MTP-MTGFI-MTOUF-MXTF) of the synthesized aircraft and the externally specified MTES. Using the mathematical absolute in the objective function,is essential because it prevents the empty aircraft mass from minimizing further, if it happens to be lower at the start of the optimization process.In this way the empty aircraft mass will always converge towards the specified MTES.

The first optimization constraint,denoted in USERF as FUNC(2),is an equality constraint related to the aircraft fuel load.

FUNC(2)=MTGFI+MXTF-MPFB2T-MTLF

where, MPFB2T=Total fuel mass consumed during a hypothetical sortie,up to the beginning of the landing phase.

MTLF=Fuel mass required for landing

The above constraint ensures that the aircraft carries just enough fuel to complete the specified hypothetical sortie.The reserve fuel is included in the value of MTLF.

The next constraint is also an equality constraint,related to the fuselage volume.

FUNC(3)=VFG-VFCR

where, VFG=Actual fuselage volume

VFCR=Required fuselage volume

FUNC(3) provides just adequate volume for accomodating everything that is installed inside the fuselage.

FUNC(4) is the third and last equality constraint,used in this optimization process and is related to the static longitudinal stability of the aircraft.

FUNC(4)=SMSUBR-SMSUB

where, SMSUB=Maximum longitudinal static stability margin with the aerodynamic centre in its most forward position (Subsonic flight)

SMSUBR=Required value for SMSUB

The above constraint equalizes the value of SMSUB for the solution aircraft with the externally specified value of SMSUBR.This is mainly used to ensure that the aircraft has the desired static longitudinal stability.

The aircraft geometry was found to be sufficiently constrained within the Design Synthesis modules and also by the user-created upper and lower bounds of the IV's,therefore only the following three geometric inequality constraints were finally included in USERF.

FUNC(5)=XWLB-XCLB-CCB-XCWBS

where, XWLB=Distance of the wing root leading edge from the aircraft nose

XCLB=Distance of the foreplane root leading edge from the aircraft nose

CCB=Net foreplane root chord

XCWBS=Minimum allowable separation between the wing root leading edge and foreplane root trailing edge

FUNC(5) prevents a wing-foreplane overlap and maintains a specified minimum longitudinal separation between the two.

FUNC(6)=XFN-XWLB-CWCB

where, XFN=Axial distance of the nozzle exit from the aircraft nose

CWCB=Net wing root chord

FUNC(6) ensures that the wing root trailing edge does not extent aft of the nozzle exit datum.

FUNC(7)=XWLB-XUNBF-LUNLB

where, XUNBF=Axial distance of the forward end of the nose undercarriage bay from the aircraft nose

LUNLB=Length of the front section of the nose undercarriage bay

FUNC(7) is the last of the three geometric inequality constraints.It prevents the wing root leading edge from moving further forward than the rear section of the nose undercarriage bay.

The following six inequality constraints are related to the aircraft point performance.

FUNC(8)=STR-STRS

where, STR=Sustained turn rate

STRS=Minimum allowable STR

FUNC(8) ensures that STR is higher than externally specified STRS. Similarly,

FUNC(9)=ATR-ATRS

where, ATR=Attained turn rate

ATRS=Minimum allowable ATR

and

FUNC(10)=SEP-SEPS

where, SEP=Specific excess power

SEPS=Minimum allowable SEP

The maximum Mach number in level flight,at a given throttle setting, is constrained between lower and upper limits,by FUNC(11) and FUNC(12), respectively.

FUNC(11)=MMAX-MMAXL

where, MMAX=Maximum Mach number

MMAXL=Allowable lower limit for MMAX

and

FUNC(12)=MMAXU-MMAX

where, MMAXU=Allowable upper limit for MMAX

FUNC(13) imposes a maximum limit to the total time required to accelerate over a Mach number increment.

FUNC(13)=SDTH-SDT

where, SDT=Total time to accelerate over a Mach number increment

SDTH=Maximum allowable SDT

The final point performance constraint imposes a maximum limit for the aircraft ride quality factor.

FUNC(14)=RQFH-RQF

where, RQF=Ride quality factor

RQFH=Maximum allowable RQF

The remaining two inequality constraints are related to the aircraft field performance.FUNC(15) and FUNC(16) keep the take-off and landing distances below the externally specified maximum allowable limits.

FUNC(15)=TODH-TOD

where, TOD=Total take-off distance

TODH=Maximum allowable TOD

and

FUNC(16)=LDH-LD

where, LD=Total landing distance

LDH=Maximum allowable LD

INDEPENDENT VARIABLES

Symbol	Definition	Units	Typical Values
AW	Gross wing aspect ratio.		1.00-4.00
FBWF	Fractional gross span of T.E. flaps.		0.30-0.70
FBWNF	Fractional span of the net wing-box containing fuel tanks.		0.00-1.00
FCWD	Front spar position as a fraction of the local wing chord.		0.05-0.30
FCWR	Rear spar position as a fraction of the local wing chord.		0.50-0.80
FOT6N	Increment in cross-sectional area at the nozzle exit above datum value (OII+OVI).	m2	0.00-2.00
QW4	Quarter-chord sweep of the wing.	rads	0.55-0.95
RLTAFN	Ratio of the axial distance from the end of the center-section to the point at which the decrease in cross-sectional area is half the maximum increment to the length of the aft fairing.		0.50-1.00
RLTCFN	Ratio of the length of the center-section to length of the fuselage aft of the fwd fairing.		0.00-1.00
RLTFFN	Ratio of the axial distance from the end of the radome to the point at which the increase in cross-sectional area is half of the maximum increment to the length of the fwd fairing.		0.00-0.50
RLTMFN	Ratio of the length of the fwd fairing to the overall fuselage length minus the length of the radome.		0.00-1.00
RTP	Engine scale factor.		0.50-2.00
RTW	Thickness to chord ratio of the wing.		0.02-0.08
RXCCQM	Fraction of the fuselage length defining the distance of the mean 0.25-chord point of the foreplane from the aircraft nose.		0.25-0.55
RXWCQM	Fraction of fuselage length defining the distance of the mean 0.25-chord point of the wing from the a/c nose.		0.45-0.75
RZCC	Ratio of the foreplane height above the wing-chord plane to the mean		0.00-0.19
SW	Gross wing area.	m2	30.0-60.0
UFIFDE	Volume utilization factor for the fuel stored inside section D-E.		0.00-0.40
UFIFEF	Volume utilization factor for the fuel stored inside section E-F.		0.00-0.40
UFIFFG	Volume utilization factor for the fuel stored inside section F-G.		0.00-0.40
UW	Gross wing taper ratio.		0.05-0.50
UWBCF	Volume utilization factor of the center-section of the wing-box for fuel storage.		0.00-0.90
XFN	Axial distance of the nozzle exit from the a/c nose.	m	14.0-19.0

FIG. 4.1 LIST OF INDEPENDENT VARIABLES

CHAPTER 5

COMPUTER PROGRAM ARCHITECTURE

5.1 General

The computer program architecture is presented in this chapter.A User's guide is provided in appendix A of this report.An optimization example, showing the application of these programs,is presented in appendix B.

5.2 Subroutine CANAR

Subroutine CANAR is the Design Synthesis subroutine.This is basically program CANARD,converted into a subroutine in order to interface it with the numerical multivariate optimization program RQPMIN.During optimization,subroutine CANAR is called by subroutine USERF.The name CANAR prevents any conflict with program CANARD and allows them both to coexist in the same computer file directory.The architecture of program CANARD is described in full detail in ref.1,therefore,only the differences between CANAR and CANARD will be reported in this section.

Subroutine CANAR is about 10000 lines long and incorporates some essential and other modifications which were carried out during the interfacing process.These modifications are presented below.

5.2.1 Modifications

At the beginning of the main segment,the statement PROGRAM CANARD was changed to SUBROUTINE CANAR(icallf,nfe).The arguments icallf and nfe are RQPMIN variables and they were incorporated in this subroutine to allow the creation of the graphics input data file VIEW.DAT,at optimization intervals defined by the values of these two variables.Icallf,indicates the context in which USERF is being called during the optimization process. Nfe,indicates the number of times USERF has been called.They both have integer values.In order to conform with the subroutine conversion the STOP statement at the end of the main segment,was replaced by a RETURN statement.

The previously missing variable FCWLFT,related to the net wing geometry, was added to common block NWINGG.

The input and output units 1 and 2,were changed to 31 and 32,respectively, to prevent them from conflicting with the already used RQPMIN units 1 and 2. The main input and output filenames CANARD.DAT and CANARD.RES were changed to CANAR.DAT and CANAR.RES,respectively,to conform with the subroutine name change.

The IV READ statements in the main segment were deleted,because the initial IV values are now specified in the RQPMIN input file RQPMIN.DAT and transferred to subroutine CANAR via common blocks.Additionally,two more statements were incorporated in the main segment,for reading from file CANAR.DAT, the optimization constraint variables,MTES,MTGFE,VFCRE,SMSUBR,XCWBS,STRS, ATRS,SEPS,MMAXU,MMAXL,SDTH,RQFH,TODH,LDH and CSW.

An IF statement was also incorporated in the main segment,which allows the creation of file VIEW.DAT only during the initial and final calls to USERF(i.e.,icallf=0 or 3) and also at 500 loop intervals in between,up to a maximum of 5000 loops(i.e.,nfe=500,1000,......5000).This facility saves both filespace and CPU time and allows the User to visually monitor at the above intervals,the design variations that take place during the optimization process.Another similar IF statement was also incorporated in the main segment,which only allows the creation of the main output file CANAR.RES, at the start and finish of the optimization(icallf=0 or 3).

The order in which the Design Synthesis modules were listed after the main segment,was rearranged in the order in which they are called for execution.Additionally,the order in which the modules FUSSTNC and FUSSTNB were called in the main segment was reversed and new constraints on minimum fuselage width were incorporated in modules FUSSTNB and FSECTAB.

In module INTDIFG,the variable XD used in the equations for ZIDLX,ZIDCX and ZIDUX,was replaced by XII,in order to allow the cross-sectional area of the intake diffusers to start increasing from the intake plane.

In module LENGTH,the constraint on the most forward position of the mean quarter-chord point of the foreplane relative to the aircraft nose(XCCQMS), was changed,to allow it to move further forward,up to station C.

In module MOMARM,the previously undefined variable LP24,was replaced by the sum of the engine section lengths,LP23 and LP34.

Finally the permanent auxiliary data files,LCS1.DAT-LCS9.DAT, AEROC.DAT and LDD1.DAT,were integrated with their corresponding aerodynamic modules, to reduce the CPU time required for the execution of subroutine CANAR.

5.2.2 Data Files

Subroutine CANAR,uses one main input data file(CANAR.DAT),two main output files(CANAR.RES and VIEW.DAT) and four auxiliary data files(TYREM.DAT,LDD2.DAT,STDRAG.DAT,GINTEGR.DAT).TYREM.DAT is a permanent file,LDD2.DAT and STDRAG.DAT are User-created files and GINTEGR.DAT is a scratch file.More information about these files is provided in ref.1. The output file CANAR.RES is exactly the same in format,as CANARD.RES, but the main input file CANAR.DAT differs slightly from CANARD.DAT in the fact that it does not contain the initial values of the IV's, but only the values of the external variables for the Design Synthesis together with those of the optimization constraint variables.The new arrangement of the variables in file CANAR.DAT is presented in appendix A.

5.3 Subroutine USERF

This is a User-created subroutine for program RQPMIN.This subroutine is called by RQPMIN on every loop of the optimization process.USERF provides an interface between RQPMIN and CANAR.

The structure of USERF consists of a set of declarators,a section where the IV's are defined in a manner in which they are recognized by RQPMIN, a call to subroutine CANAR,an objective function and finally,a set of equality and inequality constraints.Two User-selected constraint arrangements are provided for this application.

Communication between USERF and RQPMIN is established by means of arguments, while communication between USERF and CANAR is achieved by common blocks.

5.4 Program RQPMIN

The numerical multivariate optimization program RQPMIN was supplied by RAE and it was installed and compiled on the CoA VAX,following minor,system related modifications.

5.4.1 Modifications

The INCLUDE statements used in the supplied Multics version of the program, were converted to a form acceptable to the VAX.

The common,array,integer and real declarators used in the various modules of RQPMIN,were stored in two separate permanent auxiliary files(RQPMIN.CMN and INPUT.CMN).

The CLOCK and USERD subroutines of RQPMIN,are not needed and therefore not used in this system.

5.4.2 Data Files

Apart from files RQPMIN.CMN and INPUT.CMN,program RQPMIN uses three more data files.These are RQPMIN.DAT,RQPMIN.RES and RQPMIN.REP.These file names are those used by the author,but there is also a provision for using alternative names,if required.

5.4.2.1 File RQPMIN.DAT

This is the main input data file of RQPMIN.It is User-created and contains the variable definition records,the function definition records and the control records.The variable definition records consist of data relevant to the problem variables,i.e.,the variable index number,status and scale factor,the unscaled starting values of the variables and also their unscaled lower and upper bounds. The function definition records contain data relevant to the problem functions, i.e.,the function index number,function status,derivative status and scale factor.The control records are keywords which control the execution of RQPMIN. These may be either command or assignment keywords.

5.4.2.2 File RQPMIN.RES

This is the main results file of RQPMIN.It consists of three sections which are always printed,as well as two optional sections.

The first section is optional and it is a listing of the input file,with diagnostic messages for any input errors detected.

The second section is always printed and consists of a list of all the variable, function and control data(including defaults),as understood by the program.

The third section is always printed and lists the starting values of the variable and problem functions.The variables are separated into free variables, variables on their lower bounds,variables on their upper bounds and fixed variables.The free variables,include variables on their bounds which will be allowed to leave their bounds during the subsequent iteration.The variables on their bounds and the fixed variables,will remain at their current values during the subsequent iteration.The integer printed to the left of each variable value,is the corresponding variable index as understood by the input file and the user-written subroutine USERF.The problem functions are separated into the objective function,equality and inequality constraints.The integer printed to the left of each constraint value,is the corresponding constraint index,as understood by the input file and the user-written subroutine.

The fourth section is optional and lists the best values of the variables and problem functions found so far.The format is identical to that used in the third section.In addition,a message is printed,giving the reason for the termination of the current iteration.The fourth section also lists the corresponding values of the Langrange multiplier estimates,the partial derivatives of the Langrangian function,the norms of the active constraints and the values of the various convergence criteria.

The fifth and final section of RQPMIN.RES,is always printed when the program stops.The format is identical to that used in the fourth section.It also lists any warnings that were reported during the run.

5.4.2.3 File RQPMIN.REP

This is an optional auxiliary output file,called the report file.It provides a copy of the RQPMIN progress reports which are sent to the User's terminal. The frequency of the progress reports is controlled by the User,via the input file.

5.5 Program VIEW

Program VIEW is the graphics program of the Design Synthesis.It produces three computer generated images of the synthesized configuration.The program and its architecture are described in ref.1.No modifications were made to this program.

The input data file for program VIEW,is VIEW.DAT and it is generated by subroutine CANAR,at specified intervals of the optimization process.The corresponding graphics output file is FOR007.DAT and it is created after the execution of program VIEW.File FOR007.DAT contains the side,lower plan and upper plan views of the aircraft,which can be displayed on a graphics terminal or plotter.These images are displayed in sequence.

5.6 System Operation

The interrelation between the above programs and files,is diagrammatically presented by the flow-chart in fig.5.1.The operation of the complete system is briefly described below,with the aid of this flow-chart.

Prior to program execution,the User prepares the files RQPMIN.DAT, CANAR.DAT, STDRAG.DAT and LDD2.DAT,with appropriately selected data.Then the User initiates the execution of program RQPMIN.After an initial check of the input data,RQPMIN begins a series of optimization loops.During each of these loops,RQPMIN calls subroutine USERF,which in turn calls subroutine CANAR.The latter is executed using the data stored in the files CANAR.DAT,STDRAG.DAT,LDD2.DAT,TYREM.DAT and the temporarilly created GINTEGR.DAT.During the first loop,subroutine CANAR creates a file CANAR.RES,with the results of the initial aircraft design and also a file VIEW.DAT,with the graphics data for the initial configuration. The results of subroutine CANAR,are transferred after each loop,to USERF, where they are used to evaluate the objective function and constraints.The results are then transferred to RQPMIN,which examines them mathematically and appropriately varies the values of some IV's,for the next loop.The loops continue until a convergence is detected by RQPMIN.At specified intermediate steps of the optimization process,additional versions of file VIEW.DAT are created and stored.At the end of the optimization process the output files RQPMIN.RES and RQPMIN.REP,are closed and the files CANAR.RES and VIEW.DAT for the final aircraft design,are created and stored.Finally, the User examines the numerical results and then runs program VIEW for each version of file VIEW.DAT, created during the optimization process and examines the images stored in each version of file FOR007.DAT.

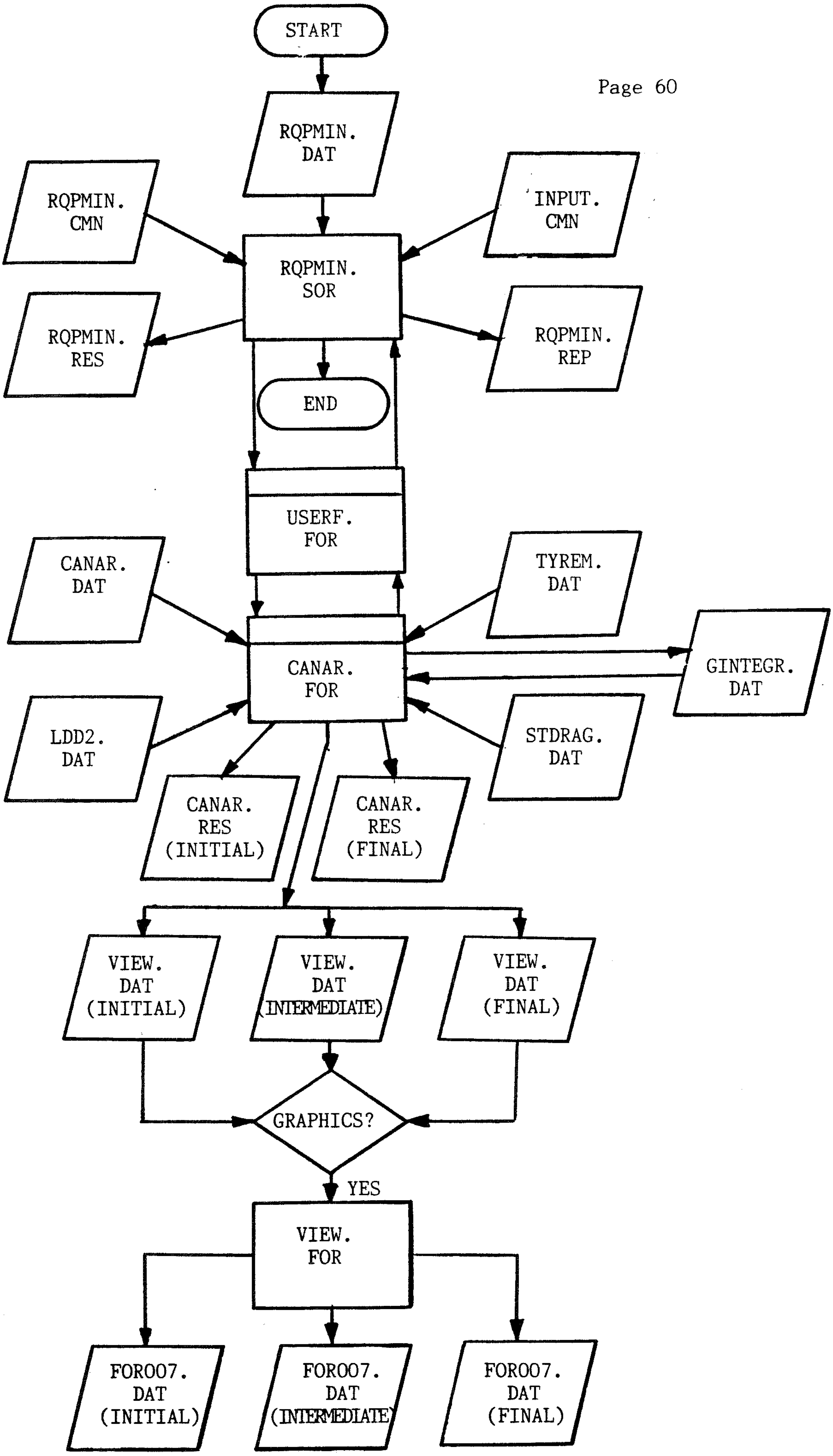

FIG.5.1 PROGRAM INTERRELATION - SIMPLIFIED FLOW CHART

CHAPTER 6

DISCUSSION

6.1 General

All the objectives set at the beginning of this Research Programme, have now been fully achieved.The optimization program RQPMIN,was explored and various methods were investigated,to increase its convergence.Various IV's,constraints and objective functions were investigated and the most significant ones were selected for use in conjunction with the Design Synthesis.These were included in a specially developed subroutine USERF and the programs CANARD and RQPMIN were successfully interfaced and run together.The CPU time required for the execution of these programs was significantly reduced.The optimization process was tested to a considerable extent.

6.2 Program RQPMIN

RQPMIN is a general numerical optimization program. Therefore,the accuracy with which it minimizes the objective function and solves the constraints,is by default extremely high.This high accuracy,however,is not always necessary in aircraft design optimization,considering the large values of the variables and constraints involved.As a result,RQPMIN takes longer to converge to an optimum solution,although,the results reach acceptable values well before the program terminates the process.

The application of RQPMIN to this complex optimization problem was not a sraight forward process,mainly because RQPMIN is not well documented.The information provided in its user-guide,is in several cases insufficient for a complex application,like this.The example given,is oversimplified and not representative of the program's applicability.The explanations given,in most cases are purely mathematical and of no practical use to the general user.Consequently, many of the uncertainties related to its operation,were clarified only after long exploratory studies and testing.

The program's convergence depends on the initial values of the IV's and constraints and also on the types,combinations and number of constraints.The program's ability to reach an optimum solution, subject to several equality constraints,was found to be rather limited.

RQPMIN may not always vary the values of those IV's which are technically relevant to the imposed constraints.

All the above RQPMIN limitations may be overcome by a careful selection of the optimization constraints and IV's.

6.3 Subroutine CANAR

Program CANARD was converted to subroutine CANAR,following a number of modifications,in order to be used with RQPMIN.The operation of subroutine CANAR over a wide range of IV values was fully tested during hundreds of optimization cycles in which,the subroutine was successfully executed for several thousands of times.

The subroutine proved to be flexible and very sensitive to minor variations in the values of the IV's,during optimization.These characteristics are very desirable because they produce significant variations in the values of the imposed constraints,which quickly lead to an optimum solution.

The internally constrained geometry modules of the Design Synthesis subroutine,made the use of several geometric constraints in USERF, redundant and this reduced considerably the total number of loops required for convergence.

The integration of the auxiliary data files with their corresponding aerodynamic modules,made subroutine CANAR,extremely efficient, considering its large size and complexity.

6.4 Subroutine USERF

Subroutine USERF includes twenty-three IV's,one objective function and fifteen constraints,three of which are equality constraints.USERF, therefore imposes a complex optimization problem to RQPMIN.

The method with which the constraints are arranged in USERF,allows RQPMIN to consider only those constraints which are not satisfied.This method significantly enhances the convergence characteristics and allows the use of several essential constraints.A switch is also incorporated in USERF,which allows the User to bypass this method, without changing the subroutine.

The desired values for the objective function and constraints may be altered externally.This is very useful for changing the optimization problem quickly.

6.5 Optimization

After RQPMIN, CANAR and USERF were finalized,several optimization tests were successfully carried out.During these tests the programs were run with various different initial conditions,by changing the initial values and bounds of the IV's and the values of the external variables of the constraints.The number of loops required for convergence,was largely variable,but it never exceeded 3500 loops.In the majority of tests a type B convergence was detected after a continuous optimization cycle. In some cases,however,the optimization cycle had to be restarted from the point it stopped after reaching a state where no further progress was possible,until a convergence was finally detected.

An optimization example is included in appendix B of this report.This is a good,representative example of this complex optimization process.It shows the application and the various modes of program operation,during a continuous optimization cycle.It also clearly demonstrates the significant design variations that occur,between the start and finish of the optimization process.All the finalized IV's and constraints were used in this example.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Programs CANARD and RQPMIN have been successfully interfaced and formed a single, fully automated, Design Synthesis and Optimization System for Canard-Delta combat aircraft.

This system satisfies all RAE requirements and it is accurate, flexible and computationally extremely efficient, despite its large size and enormous complexity.

The system converges to an optimum solution relatively quickly, compared to other existing systems of less size and complexity. The convergence is dependent on the total number and initial values of the IV's and constraints and also on the types and combinations of these constraints. The convergence is adversely affected as the number of equality constraints increases.

The numerical optimization program RQPMIN imposes some limitations, with regard to the maximum number, types and combinations of constraints used in the optimization process. These limitations increase with problem complexity and they are mainly due to RQPMIN's high default accuracy.

The Design Synthesis subroutine CANAR has fully proved its flexibility, sensitivity, accuracy, efficiency and reliability, after several thousands of executions during optimization testing.

Various different versions of subroutine USERF may be developed in the future,based on the principles presented in this report,by using different problem functions.

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APPENDIX A

USER-GUIDE

A.1 General

Appendix A is the User-Guide for the Design Synthesis and Optimization System for Canard-Delta Combat Aircraft.Wherever possible,reference is made in this appendix,to the User-Guides in refs. 1 and 5,which should be available to the User of this system.This appendix concentrates on the preparation of the User-created subroutines and data files,the program compilation and execution and its statistics.

A.2 User-Created Subroutines

Program RQPMIN has two User-created subroutines,USERF and USERD.Subroutine USERF returns the values of the problem functions at a given point and USERD returns the derivatives of the problem functions.Subroutine USERD is not used in this application,therefore only USERF needs to be discussed in this paragraph.

A.2.1 USERF

The subroutine USERF for the optimization example,is presented in appendix B. This should be used as a template,whenever a new subroutine needs to be created, with different problem functions.Normally,for this application,USERF should remain unchanged.The optimization problem may be changed by simply altering externally,the values of the optimization constraint variables,specified in file CANAR.DAT.These constraints were incorporated in the final problem functions,in USERF (FUNC(1) to FUNC(16)),to allow the User to set different optimization problems without re-editing USERF.

A.2.1.1 USERF Structure

Subroutine USERF must always start with the following:

```
SUBROUTINE USERF(x,func,iocode,nprob,icallf,nfe)
integer iocode(76)
real x(50),func(76)
```

The meaning of each of the arguments in the above subroutine statement is explained in ref.5.

The next USERF section(shown abbreviated in the example USERF,for clarity), consists of the declarations of all array,integer and real variables and common blocks used in subroutine CANAR,together with the declarations of the constraint variables used in subroutine USERF.

Following next,is a section in which the IV names used in subroutine CANAR, are assigned with RQPMIN variable names corresponding to the order in which the IV initial values and bounds are specified in file RQPMIN.DAT.

The next USERF section consists of a call to subroutine CANAR.

This is followed by an objective function which is specified as FUNC(1).

After the objective function,is a section for the selection of one of two constraint arrangements.The selection is automatic and depends on the integer value of the constraint switch CSW,which is externally specified in file CANAR.DAT.The first constraint arrangement(CSW=0) is the one recommended by the author.With this,RQPMIN considers only those constraints which are not satisfied,at that time.With the second constraint arrangement (CSW=1),it considers all the set constraints,during every loop,irrespective of their values.In both arrangements,all the equality constraints are set before the inequality constraints.

Subroutine USERF always finishes with the statements,RETURN,END.

A.2.1.2 Setting New Constraints

In order to set new optimization constraints in USERF,the User must first consider their basic mathematical definitions,i.e.,

Equality Constraint: $-e < \text{function} < e$

Inequality Constraint: $\text{function} > e$

where,e is the error tolerance

function is the constraint function(e.g. FUNC(3)).

A function may be mathematically set up,using one or more variables from subroutine CANAR,together with an optimization constraint variable.It must be remembered,however,that if a new constraint variable is used,it must be incorporated and read from file CANAR.DAT and also properly declared in subroutines USERF and CANAR.Alternatively,provided the optimization problem is unique,a constraint variable may be simply replaced in a function,with its numerical value and hence no changes will be necessary in subroutine CANAR and its input file CANAR.DAT.

A.2.1.3 Constraint Arrangement

As mentioned earlier in paragraph A.2.1.1,two different constraint arrangements may be used in USERF.The second arrangement is straight forward,because with that the constraints are simply listed one after the other.The first arrangement ,which is the one recommended by the author,is a little more complicated,but it may be fully clarified by examining the example USERF in appendix B.

With the recommended arrangement,an IF statement block must be set up for each constraint.When the constraint is not satisfied with the current data,the IF statement allows RQPMIN to evaluate that constraint function.Otherwise if the constraint is satisfied,then the constraint function is set to zero and the corresponding RQPMIN variable,IOCODE,is set equal to -1.With this IOCODE value, the corresponding constraint function will not be evaluated.

With the recommended arrangement,the error tolerance for the equality constraints may be increased as in FUNC(2),FUNC(3) and FUNC(4) of the optimization example,by incorporating extra,practical tolerances in their IF statements(e.g. MTGFE,VFCRE,0.005).

A.3 User-Created Data Files

Only the files LDD2.DAT,STDRAG.DAT,CANAR.DAT and RQPMIN.DAT,may be created or revised by the User.All the other files of this system must not be edited or deleted.

Full guidelines on the preparation of files LDD2.DAT and STDRAG.DAT, are given in appendix J of ref.1,therefore these will not be repeated in this User-guide.These files,however and the data they contain for the optimization example,are included in appendix B of this report.

A.3.1 File CANAR.DAT

This file is basically the same as file CANARD.DAT,apart from a couple of differences.File CANAR does not contain the values of the IV,but it contains the values of all the External Variables,as in CANARD.DAT,plus the values of the optimization constraint variables,which were inserted just before the external variables for the aircraft performance.The new arrangement of variables in file CANAR.DAT is presented in fig.A.1.The guidelines for the selection of the external variable values remain the same and they are given in appendix J of ref.1.

The optimization constraint variables are:MTES, MTGFE, VFCRE, SMSUBR, XCWBS, STRS, ATRS, SEPS, MMAXU, MMAXL, SDTH, RQFH, TODH, LDH and CSW.All these variables apart from MTGFE,VFCRE and CSW,were defined earlier in section 4.9 of this report.The other three variables are defined below:

MTGFE,is the maximum allowable excess fuel.It specifies the maximum mass of fuel that can remain in the tanks of the solution aircraft,after completing the hypothetical sortie.

VFCRE,is the maximum allowable extra fuselage volume.It specifies the maximum difference between the actual and required fuselage volume of the solution aircraft.

CSW,is the optimization constraint switch(see paragraph A.2.1.1)

The User should also note that for this application,the point performance variables,NPP1,NPP2,NPP3,NPP4,NPP5 and NPP6,must all be set equal to 1.

A.3.2 File RQPMIN.DAT

Full guidelines on the preparation and format of this file are given in section 3,ref.5.These are not therefore included in this User-guide.The contents of this file,for the optimization example,are shown in appendix B of this report.

A.4 Program Compilation and Execution

Step by step guidelines are given in this section,for the compilation and execution of the computer programs,on DEC VAX-11/750/780/8650 mainframe computer systems.

Step 1:Enter the necessary input data in the files CANAR.DAT, LDD2.DAT, STDRAG.DAT and RQPMIN.DAT,following the appropriate guidelines given in the User-guides.

Step 2:Confirm that the following files are all included in the User's directory:CANAR.FOR, CANAR.DAT, LDD2.DAT, STDRAG.DAT, TYREM.DAT, USERF.FOR, RQPMIN.SOR, RQPMIN.CMN, INPUT.CMN, RQPMIN.DAT and VIEW.FOR.

Step 3:Compile the main program RQPMIN.SOR and the subroutines CANAR.FOR and USERF.FOR as shown below:

```
$ FOR RQPMIN
$ FOR USERF
$ FOR CANAR
```

After the compilation process is complete,the following files should appear in the User's directory:RQPMIN.OBJ, USERF.OBJ and CANAR.OBJ.

Step 4:Link the main program to the subroutines by the following command:

```
$ LINK RQPMIN,USERF,CANAR
```

This creates a file RQPMIN.EXE in the User's directory.

Step 5:Run program RQPMIN.SOR using the command,

```
$ RUN RQPMIN
```

Then answer the prompts as follows:

```
 INPUT FILE? RQPMIN.DAT
OUTPUT FILE? RQPMIN.REP/report
OUTPUT FILE? RQPMIN.RES
```

If the optional output file RQPMIN is not required,then,enter the name of the main output file,RQPMIN.RES,in response to the second prompt.The third prompt will then not appear.

It is most likely,however,that the program will be submitted to a batch stream for execution and therefore a command file,RQPMIN.COM, with the following contents,will be necessary:

```
$ RUN RQPMIN
 INPUT FILE? RQPMIN.DAT
OUTPUT FILE? RQPMIN.REP/report
OUTPUT FILE? RQPMIN.RES
```

Then the program may be submitted by the following command:

```
$ SUBMIT RQPMIN.COM
```

A batch queue may be also specified with the above command.

Step 6:After the program execution is complete,the following files should appear in the User's directory:CANAR.RES;1,CANAR.RES;2,RQPMIN.RES, RQPMIN.REP(If specified) and several versions of file VIEW.DAT.The contents of these files may be displayed on the User's terminal,or listed on paper by an on-line printer,using the commands:

$ TYPE filename

$ PRINT filename

Step 6:Compile program VIEW.FOR and link it to the GINO-F library,by the following commands:

$ FOR VIEW

$ LINK VIEW,'GINLIB

Step 7:Run the program VIEW.FOR for each created version of VIEW.DAT,using the command,

$ RUN VIEW

Each run will produce a version of file FOR007.DAT,corresponding to the version of VIEW.DAT used.The three images of the synthesized aircraft, contained in each file version,may be then displayed on a suitable graphics terminal(e.g.,WESTWARD) or plotted on paper by an on-line plotter(e.g.,BENSON), using the following command:

$ DISPLAY

Then answer the prompts as follows:

DEVICE: WESTWARD or BENSON

FILE: FOR007.DAT

A.5 Program Statistics

This computerized Design Synthesis and Optimization System,requires at least 10000 blocks of computer disc space for its operation.The size of the output files depends on the length of the optimization cycle and the values of the control keywords specified in RQPMIN.DAT.

The CPU time required for the execution of a single optimization loop on a VAX-11/8650,is currently 2.3 seconds.A total of about one to two CPU hours is usually required for the completion of a whole optimization cycle.

A single execution of program VIEW.FOR on a VAX-11/750 system ,requires about thirty CPU seconds.

ARRANGEMENT OF INPUT VARIABLES (FILE : CANAR .DAT)
==

Cockpit.
HC1,HC2,HC3,HC4,EHC5,HCSEAT
QCSEAT,QCEYE,LCFOOT,LCNSPR,GTCPH

Undercarriage and Bays.
PUMW1,PUNW1,RPUMLV,FPUNLV,FDUNL,VTLV,RLUPCW,DHUP
EUML,EUMW,ELUMBF,ELUMBA,EHUMBL,ELUNBF,ELUNBA,EHUNBL

Datum Propulsion System.
LP12R,LP22AR,LP2A4R,LP34R,FLP1K,FLP2K,FLP3K
DP1R,DP2R,DP3R,DP4R,MPBR,MPRR,MPTR,FMPBK,FMPRK,FMPIK
TPGD1,TPGD2,MPFD1,MPAD1,OPJD1

Engine Bays.
FHP1K,FBP1K,FHP2K,FBP2K,FHP3K,FBP3K,FHP4K,FBP4K
EHP1S,EHP1H,EBP1S,EBP1H,EHP2S,EHP2H,EBP2S,EBP2H
EHP3S,EHP3H,EBP3S,EBP3H,EHP4S,EHP4H,EBP4S,EBP4H

Inlet and B.l.diverter.
MHH,HTH,FLVK,RIDX1,AII,ROIEI,RCDK

Fuselage.
RXFR,RXB,RXE,RIDL,RIDLS,LAR,LAX,LCCAN,EXUNBF,ELMUFA
HRA,BRA,EHRA,EBRA,EYFC,EBFD,EYPCH,HFA1,YCCANC,HFDCU
QCWSC,QCCAN,QFPR,QFPRU,FZCAN1,FZCAN2,FVCKPT

Flying Surfaces.
FCWLFT,FCWLHT,FCWTFT,FCWTHL,RSLEW,QWST,AWA,FBWA
RCDVK,FMD1,FMD2,CLDES,HTR
RCSW,ACN,UCN,RTC,QCL,RSLEC,QCST
REFFC,AEFN,UEFN,RTEF,QEFL,NFIN

Fuel.
RMTLFI,UWBEF,MXTF1,MXTF2

Design Loads and Speeds.
MTTR,MTPR,ULTN,VD,AMMX

Mass.
FMUMK,FMUNK,FMUHK,FMSAK,FMSEK,FMSCK,FMSFK
FMSA,FMSC,FMFIR,FMUM,FMUN,FMF1,FMF2,FMC
FMEF,FMEF2,FMWB,FMWT,FMWL
MUMK,MUNK,MUHK,MSAK,MSEK,MSCK
MC1K,MC2K,MC3K,MEF1K,MEF2K,MEF3K,MEF4K
MAR,MAX,MCSEAT,MCP,MCFI,MCPI,MCMI,MLMUF,MAPU
EQWFH,NWFK,LWFK,SFAIB

Densities.
RFUL,RGC,RGA,RLMUF,RAPU,RAR,RAX
RSC,RSE,RSA,RSF,RFW,RFIR,RFAIB

Underfuselage Missiles.
RXMUF1,RXMUF2,RXMUF3,RXMUF4
LMUF1,LMUF2,LMUF3,LMUF4
FLMUF1,FLMUF2,FLMUF3,FLMUF4
DMUF1,DMUF2,DMUF3,DMUF4
MMUF1,MMUF2,MMUF3,MMUF4

External Variables

External Variables

Exter

nal Variables

DCMUF1,DCMUF2,DCMUF3,DCMUF4

Gun.
RXGF,LGC,BGFA,OGFA,PGFA,MGC,MGA

Wing-Stores.
FYB1,FYB2,FYB3,FYB4,FXWPCG
NB1,NB2,NB3,NB4
MB1,MB2,MB3,MB4
FMCB1,FMCB2,FMCB3,FMCB4
DCB1,DCB2,DCB3,DCB4

Wing-Pylons.
MXP1,MXP2,MXP3,MXP4
DCXP1,DCXP2,DCXP3,DCXP4

Optimization Constraint Variables.
MTES,MTGFE,VFCRE,SMSUBR,XCWBS,STRS,ATRS
SEPS,MMAXU,MMAXL,SDTH,RQFH,TODH,LDH,CSW

AIRCRAFT PERFORMANCE

External Variables

Sortie Performance.

NSTAG,MTTF,MTLF

The following data are specified for each sortie-leg:
(x NSTAG)

SLEG,HT,M,GN,EQWF,TPG1,CL1,AL,MPFB1
SRMUF1,SRMUF2,SRMUF3,SRMUF4,SRB1,SRB2,SRB3,SRB4,SUC
....
....

Take-off and Landing Performance.

HTF,TRATE,EQWFT,FVSTTO,FCLT,FRK,FTPGC,EQWFL,FVSTAP,FCLL

Point performance.

External Variables

NPP1,NPP2,NPP3,NPP4,NPP5,NPP6
SRMUF1,SRMUF2,SRMUF3,SRMUF4,SRB1,SRB2,SRB3,SRB4,SUC

The following data are specified for each point:

Sustained Turn Rate.
HT,M,WT,XV,EQWF,CL3
.... (x NPP1)
....

Attained Turn Rate
HT,M,WT,XV,EQWF
.... (x NPP2)
....

Specific Excess Power.
HT,M,WT,XV
.... (x NPP3)
....

Maximum Mach Number.
HT,M,WT,XV
.... (x NPP4)

```
..........

Acceleration Time.
HT,MSTART,WT,XV,DM
..................                  ( x NPP5 )
..................

Ride Quality Factor.
HT,M,WT
.......                             ( x NPP6 )
.......
```

FIG.A.1 ARRANGEMENT OF INPUT VARIABLES IN FILE CANAR.DAT

APPENDIX B

OPTIMIZATION EXAMPLE

```
0.762 0.700 0.400 0.254 0.250 0.190
0.524  0.262 0.850  1.700  9.000
950000.0  950000.0  3.000  1.500  0.500 4.000  0.250 0.150
0.700 0.470 0.050  0.050  0.030  0.050  0.050  0.030
1.600 0.400  1.400  0.900 0.870 0.500 0.500
0.690 0.760 0.890 0.770 600.0 200.0 100.0 0.940 0.650 0.130
45000.0 80000.0 5.000 70.000 0.400
0.100 1.000 0.303 0.400 0.129 0.397 0.100 0.100
0.160 0.714 0.278 0.927 0.128 0.332 0.085 0.439
0.043 0.110 0.172 0.304 0.000 0.110 0.000 0.300
2.000 12000.0 0.800 0.040 0.700 1.100 0.200
1.668 0.700 0.230 15.000 6.000 0.835 0.000 3.500 0.124  0.500
0.600 0.800 0.0375 0.0375 0.250 0.150 0.350 0.400 0.42 0.325
0.442 0.175 0.185 0.282 0.750  0.750  1.100
0.050  0.050  0.030  0.030  0.600 6.000 4.570 0.435
1.000 0.150 0.000 0.700 0.000015
0.038 2.500 0.300 0.030 0.923 0.600 6.000
0.033 1.600 0.250 0.040 0.800 1
0.800  0.250 800.0  0.000
15000.0 670.0  15.000 400.0 2.200
0.0468 0.0064 0.0068 0.011 0.0267 0.0293 0.0759
0.750 1.000 0.950 1.000 1.000 1.070 1.000 0.800
0.800 1.000 0.950 0.900 0.900
-42.000 6.000 4.000 -15.900 29.900 22.200
0.004356 1.549 0.3433 0.11156 1.300 0.7812 0.2422
150.0 300.0 100.0  100.0 30.0 20.0 10.0 160.0 50.0
0.873  6    0.200 1.000
800.0 801.0 801.0 801.0 480.6 640.8 640.8
160.2 480.6 480.6 480.6 101.0 101.0 101.0
0.412  0.412  0.637  0.669
3.550 3.550 3.550 3.550
0.106  0.106  0.106  0.106
0.175 0.175 0.175 0.175
```

```
150.0 150.0 150.0 150.0

1      1      1      1

0.428 2.350 0.090 0.010 0.300 160.0 80.0

0.800 0.400 0.400 0.800 0.250

1   2   1   1

90.0  0.0   0.0   90.0

1.000 1.250 1.000 1.000

2    3    5    2

60.0  65.0  65.0  60.0

4     4     4     4

10000.0 50.0 0.50 -0.040 0.10 23.0 10.0

150.0 2.20 1.80 33.0 2.0 450.0 770.0  0

3     300.0  150.0

120.0  2500.0  0.8  1.1  0.0  60000.0  0.25  0.05 1300.0
1.0    1.0    1.0    1.0    1.0  0.0  0.0  1.0  0.0
  5.0 10000.0  1.1  5.0 10.0  90000.0  0.20  0.05  800.0
1.0    1.0    1.0    1.0    1.0  0.0  0.0  1.0  0.0
120.0  7500.0  1.5  0.8  0.0  50000.0  0.20  0.06 1000.0
1.0    1.0    1.0    1.0    0.0  0.0  0.0  0.0  0.0

0.0    0.95  15.0  1.10   1.00 0.35 0.25  35.0  1.20   1.00

1    1    1    1    1    1
1.0    1.0    1.0    1.0    0.0  0.0  0.0  0.0  0.0

1000.0  0.60 140000.0 100.0 10.0 1.00

9000.0  1.60 140000.0 100.0 10.0

6000.0 0.70 130000.0 100.0

10000.0 2.10 140000.0 100.0

12000.0 0.80   145000.0 100.0 0.30

1000.0 0.50 150000.0
```

FIG.B.1 FILE CANAR.DAT (EXAMPLE)

0.0	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.1	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.2	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.3	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.4	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.5	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.6	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.7	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.8	0.00030	0.00088	0.00061	0.00067	0.00146	0.00000	0.00000	0.0
0.9	0.00040	0.00097	0.00067	0.00079	0.00170	0.00000	0.00000	0.0
1.0	0.00052	0.00134	0.00161	0.00109	0.00368	0.00000	0.00000	0.0
1.1	0.00058	0.00140	0.00000	0.00134	0.00432	0.00000	0.00000	0.0
1.2	0.00058	0.00140	0.00000	0.00140	0.00429	0.00000	0.00000	0.0
1.3	0.00055	0.00134	0.00000	0.00140	0.00423	0.00000	0.00000	0.0
1.4	0.00052	0.00122	0.00000	0.00137	0.00417	0.00000	0.00000	0.0
1.5	0.00052	0.00112	0.00000	0.00134	0.00401	0.00000	0.00000	0.0
1.6	0.00049	0.00106	0.00000	0.00131	0.00392	0.00000	0.00000	0.0
1.7	0.00046	0.00100	0.00000	0.00131	0.00380	0.00000	0.00000	0.0
1.8	0.00046	0.00097	0.00000	0.00128	0.00374	0.00000	0.00000	0.0
1.9	0.00043	0.00097	0.00000	0.00128	0.00362	0.00000	0.00000	0.0
2.0	0.00040	0.00097	0.00000	0.00128	0.00353	0.00000	0.00000	0.0
2.1	0.00036	0.00097	0.00000	0.00128	0.00347	0.00000	0.00000	0.0
2.2	0.00033	0.00097	0.00000	0.00128	0.00341	0.00000	0.00000	0.0
2.3	0.00033	0.00094	0.00000	0.00128	0.00337	0.00000	0.00000	0.0
2.4	0.00033	0.00094	0.00000	0.00128	0.00337	0.00000	0.00000	0.0

FIG.B.2 FILE STDRAG.DAT (EXAMPLE)

0.0	0.79	0.5	1.30
0.1	0.79	0.5	1.30
0.2	0.79	0.5	1.30
0.3	0.79	0.5	1.30
0.4	0.79	0.5	1.30
0.5	0.73	0.5	1.30
0.6	0.67	0.5	1.25
0.7	0.63	0.6	1.20
0.8	0.69	0.7	1.15
0.9	0.75	0.8	1.10
1.0	0.84	0.8	1.10
1.1	0.82	0.8	1.10
1.2	0.80	0.8	1.10
1.3	0.70	0.8	1.08
1.4	0.60	0.7	1.06
1.5	0.50	0.6	1.04
1.6	0.40	0.6	1.02
1.7	0.40	0.6	1.01
1.8	0.40	0.5	1.00
1.9	0.40	0.5	1.00
2.0	0.40	0.5	1.00
2.1	0.40	0.5	1.00
2.2	0.40	0.4	1.00
2.3	0.40	0.4	1.00
2.4	0.40	0.4	1.00

FIG.B.3 FILE LDD2.DAT (EXAMPLE)

```
      SUBROUTINE USERF(x,func,iocode,nprob,icallf,nfe)

      integer iocode(76)
      real x(50),func(76)

*     Declaration of the dimensions of all array variables.

      DIMENSION .........................................

*     Declaration of all integer variables.

      INTEGER ...........................................

*     Declaration of all real variables.

      REAL ..............................................

*     Declaration of all common blocks.

      COMMON.............................................

*     Assignment of Independent Variable values.

      SW=X(1)
      AW=X(2)
      UW=X(3)
      QW4=X(4)
      RTW=X(5)
      FCWR=X(6)
      FCWD=X(7)
      FBWF=X(8)
      RXWCQM=X(9)
      RXCCQM=X(10)
      RZCC=X(11)
      RTP=X(12)
      XFN=X(13)
      RLTMFN=X(14)
      RLTFFN=X(15)
      RLTCFN=X(16)
      RLTAFN=X(17)
      FOT6N=X(18)
      FBWNF=X(19)
      UWBCF=X(20)
      UFIFDE=X(21)
      UFIFEF=X(22)
      UFIFFG=X(23)

*     Execution of the Design Synthesis subroutine.

      CALL CANAR(ICALLF,NFE)

*     Objective Function.

      FUNC(1)=ABS(MTT-MTP-MTGFI-MTOUF-MXTF-MTES)

*     Constraint Arrangement Selection.

      IF (CSW.EQ.0) THEN
         GOTO 5
      ELSE IF (CSW.EQ.1) THEN
         GOTO 10
      END IF

*     Recommended Constraint Arrangement (CSW=0).
```

```
*       Equality Constraints.

5       IF ((MTGFI+MXTF).LT.(MPFB2T+MTLF).OR.(MTGFI+MXTF).GT.
     1                                  (MPFB2T+MTLF+MTGFE)) THEN
           FUNC(2)=MTGFI+MXTF-MPFB2T-MTLF
        ELSE
           FUNC(2)=0.0
           IOCODE(2)=-1
        END IF

        IF (VFG.LT.VFCR.OR.VFG.GT.(VFCR+VFCRE)) THEN
           FUNC(3)=VFG-VFCR
        ELSE
           FUNC(3)=0.0
           IOCODE(3)=-1
        END IF

        IF (SMSUB.LT.(SMSUBR-0.005).OR.SMSUB.GT.(SMSUBR+0.005)) THEN
           FUNC(4)=SMSUBR-SMSUB
        ELSE
           FUNC(4)=0.0
           IOCODE(4)=-1
        END IF

*       Inequality Constraints.

        IF ((XCLB+CCB).GE.(XWLB-XCWBS)) THEN
           FUNC(5)=XWLB-XCLB-CCB-XCWBS
        ELSE
           FUNC(5)=0.0
           IOCODE(5)=-1
        END IF

        IF ((XWLB+CWCB).GE.XFN) THEN
           FUNC(6)=XFN-XWLB-CWCB
        ELSE
           FUNC(6)=0.0
           IOCODE(6)=-1
        END IF

        IF (XWLB.LE.(XUNBF+LUNLB)) THEN
           FUNC(7)=XWLB-XUNBF-LUNLB
        ELSE
           FUNC(7)=0.0
           IOCODE(7)=-1
        END IF

        IF (STR.LE.STRS) THEN
           FUNC(8)=STR-STRS
        ELSE
           FUNC(8)=0.0
           IOCODE(8)=-1
        END IF

        IF (ATR.LE.ATRS) THEN
           FUNC(9)=ATR-ATRS
        ELSE
           FUNC(9)=0.0
           IOCODE(9)=-1
        END IF

        IF (SEP.LE.SEPS) THEN
           FUNC(10)=SEP-SEPS
        ELSE
           FUNC(10)=0.0
```

```
         IOCODE(10)=-1
      END IF

      IF (MMAX.LE.MMAXL) THEN
         FUNC(11)=MMAX-MMAXL
      ELSE
         FUNC(11)=0.0
         IOCODE(11)=-1
      END IF

      IF (MMAX.GE.MMAXU) THEN
         FUNC(12)=MMAXU-MMAX
      ELSE
         FUNC(12)=0.0
         IOCODE(12)=-1
      END IF

      IF (SDT.GE.SDTH) THEN
         FUNC(13)=SDTH-SDT
      ELSE
         FUNC(13)=0.0
         IOCODE(13)=-1
      END IF

      IF (RQF.GE.RQFH) THEN
         FUNC(14)=RQFH-RQF
      ELSE
         FUNC(14)=0.0
         IOCODE(14)=-1
      END IF

      IF (TOD.GE.TODH) THEN
         FUNC(15)=TODH-TOD
      ELSE
         FUNC(15)=0.0
         IOCODE(15)=-1
      END IF

      IF (LD.GE.LDH) THEN
         FUNC(16)=LDH-LD
      ELSE
         FUNC(16)=0.0
         IOCODE(16)=-1
      END IF

      GOTO 15

*     Alternative Constraint Arrangement (CSW=1).

*     Equality Constraints.

10    FUNC(2)=MTGFI+MXTF-MPFB2T-MTLF
      FUNC(3)=VFG-VFCR
      FUNC(4)=SMSUBR-SMSUB

*     Inequality Constraints.

      FUNC(5)=XWLB-XCLB-CCB-XCWBS
      FUNC(6)=XFN-XWLB-CWCB
      FUNC(7)=XWLB-XUNBF-LUNLB
      FUNC(8)=STR-STRS
      FUNC(9)=ATR-ATRS
      FUNC(10)=SEP-SEPS
      FUNC(11)=MMAX-MMAXL
      FUNC(12)=MMAXU-MMAX
      FUNC(13)=SDTH-SDT
```

```
      FUNC(14)=RQFH-RQF
      FUNC(15)=TODH-TOD
      FUNC(16)=LDH-LD
15    RETURN
      END
```

FIG.B.4 SUBROUTINE USERF (EXAMPLE)

```
VARIABLES
01 1  10.0          48.000          40.000      53.000
02 1   1.0           2.250           1.700       3.000
03 1   0.1           0.175           0.100       0.300
04 1   0.1           0.700           0.600       0.900
05 1   0.01          0.055           0.050       0.070
06 1   0.1           0.800           0.750       0.950
07 1   0.1           0.150           0.100       0.200
08 1   0.1           0.650           0.600       0.700
09 1   0.1           0.690           0.400       0.750
10 1   0.1           0.350           0.100       0.650
11 1   0.1           0.195           0.100       0.200
12 1   1.0           1.000           0.800       1.500
13 1  10.0          15.900          14.500      16.500
14 1   0.1           0.350           0.250       0.400
15 1   0.1           0.300           0.250       0.400
16 1   0.1           0.550           0.500       0.700
17 1   0.1           0.350           0.300       0.550
18 1   0.1           0.200           0.150       0.600
19 1   0.1           0.250           0.200       0.700
20 1   0.1           0.350           0.300       0.700
21 1   0.1           0.180           0.010       0.250
22 1   0.1           0.150           0.010       0.250
23 1   0.1           0.100           0.010       0.250
FUNCTIONS
01 00 00  1000.0
02 01 00  1000.0
03 01 00  10.0
04 01 00  0.01
05 -1 00  1.00
06 -1 00  1.00
07 -1 00  1.00
08 -1 00  10.0
09 -1 00  10.0
10 -1 00  100.0
11 -1 00  1.0
12 -1 00  1.0
13 -1 00  10.0
14 -1 00  1.0
15 -1 00  100.0
16 -1 00  100.0
CONTROLS
OFROM = 1
OFREQ = 20
RFREQ = 50
NFEMAX=6000
RUN
END
```

FIG.B.5 FILE RQPMIN.DAT (EXAMPLE)

```
nfe =      1   context:  initial call to user routine
fdatum =  0.7687110E-01 gdatum =  0.2546725E+03

nfe =     51   context:  feasibility step
fdatum =  0.4774902E-01 gdatum =  0.1392896E+03
unormx =  0.9137943E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    101   context:  feasibility step
fdatum =  0.3650957E+00 gdatum =  0.9694338E+02
unormx =  0.8554494E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    151   context:  feasibility step
fdatum =  0.5515615E+00 gdatum =  0.5678778E+02
unormx =  0.8954431E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    201   context:  feasibility step
fdatum =  0.4236328E+00 gdatum =  0.3558123E+02
unormx =  0.9222155E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    251   context:  feasibility step
fdatum =  0.4329727E+00 gdatum =  0.3546571E+01
unormx =  0.7322766E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    301   context:  feasibility step
fdatum =  0.5338662E+00 gdatum =  0.1495623E-01
unormx =  0.6283209E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    351   context:  feasibility step
fdatum =  0.1619531E+00 gdatum =  0.5981447E-02
unormx =  0.4624004E+00 uscale =  0.1000000E+01 rtol    =  0.1000000E+00

nfe =    401   context:  minimization step
fstart =  0.8238672E-01     gstart =  0.8251593E-05
pstart =  0.8805902E-01     lstart =  0.8805902E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.1819177E-01     rtol   =  0.1000000E+00
vnormx =  0.1276281E+02     vscale =  0.1000000E+01

nfe =    451   context:  minimization step
fstart =  0.7885254E-01     gstart =  0.3043730E-05
pstart =  0.7801398E-01     lstart =  0.7801398E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.2269249E-02     rtol   =  0.1000000E+00
vnormx =  0.2284280E+01     vscale =  0.1000000E+01

nfe =    501   context:  minimization step
fstart =  0.7885254E-01     gstart =  0.3043730E-05
pstart =  0.7801398E-01     lstart =  0.7801398E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.2269249E-02     rtol   =  0.1000000E+00
vnormx =  0.2284280E+01     vscale =  0.1000000E+01

nfe =    551   context:  minimization step
fstart =  0.7563281E-01     gstart =  0.2496647E-05
pstart =  0.7475851E-01     lstart =  0.7475851E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.2070509E-02     rtol   =  0.1000000E+00
vnormx =  0.5207594E+01     vscale =  0.1000000E+01

nfe =    601   context:  minimization step
fstart =  0.7563281E-01     gstart =  0.2496647E-05
pstart =  0.7475851E-01     lstart =  0.7475851E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.2070509E-02     rtol   =  0.1000000E+00
vnormx =  0.5207594E+01     vscale =  0.1000000E+01
```

```
nfe =    651   context:  minimization step
fstart =  0.7563281E-01      gstart =  0.2496647E-05
pstart =  0.7475851E-01      lstart =  0.7475851E-01
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.2070509E-02      rtol   =  0.1000000E+00
vnormx =  0.5207594E+01      vscale =  0.1000000E+01

nfe =    701   context:  minimization step
fstart =  0.7433984E-01      gstart =  0.1148707E-05
pstart =  0.7379326E-01      lstart =  0.7379326E-01
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.1397843E-02      rtol   =  0.1000000E+00
vnormx =  0.2427713E+02      vscale =  0.1000000E+01

nfe =    751   context:  minimization step
fstart =  0.7433984E-01      gstart =  0.1148707E-05
pstart =  0.7379326E-01      lstart =  0.7379326E-01
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.1397843E-02      rtol   =  0.1000000E+00
vnormx =  0.2427713E+02      vscale =  0.1000000E+01

nfe =    801   context:  minimization step
fstart =  0.7317968E-01      gstart =  0.8137837E-06
pstart =  0.7018700E-01      lstart =  0.7018700E-01
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.1172112E-02      rtol   =  0.1000000E+00
vnormx =  0.9353134E+00      vscale =  0.1000000E+01

nfe =    851   context:  minimization step
fstart =  0.2133496E-01      gstart =  0.4108242E-03
pstart = -0.1956603E-01      lstart = -0.1956603E-01
nu     =  0.0000000E+00      numax  =  0.2188890E+03
unrmxs =  0.2372986E-01      rtol   =  0.1000000E+00
vnormx =  0.1184076E+01      vscale =  0.1000000E+01

nfe =    901   context:  feasibility step
fdatum =  0.1592871E-01 gdatum =  0.3309717E-03
unormx =  0.2372986E-01 uscale =  0.1000000E+01 rtol    =   0.1000000E-01

nfe =    951   context:  feasibility step
fdatum =  0.1126660E-01 gdatum =  0.2964265E-03
unormx =  0.1344871E+00 uscale =  0.1000000E+01 rtol    =   0.1000000E-01

nfe =   1001   context:  feasibility step
fdatum =  0.7258789E-02 gdatum =  0.2173321E-03
unormx =  0.1247090E-01 uscale =  0.1000000E+01 rtol    =   0.1000000E-01

nfe =   1051   context:  feasibility step
fdatum =  0.1554199E+00 gdatum =  0.0000000E+00
unormx =  0.1275431E-01 uscale =  0.1000000E+01 rtol    =   0.1000000E-01

nfe =   1101   context:  minimization step
fstart =  0.1554199E+00      gstart =  0.0000000E+00
pstart =  0.1554199E+00      lstart =  0.1554199E+00
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.3891751E+00      vscale =  0.1000000E+01

nfe =   1151   context:  minimization step
fstart =  0.1058945E+00      gstart =  0.0000000E+00
pstart =  0.1058945E+00      lstart =  0.1058945E+00
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.5550536E+00      vscale =  0.1000000E+01
```

```
nfe =  1201   context:  minimization step
fstart =  0.1005469E+00     gstart =  0.0000000E+00
pstart =  0.1005469E+00     lstart =  0.1005469E+00
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.6893197E+02     vscale =  0.1000000E+01

nfe =  1251   context:  minimization step
fstart =  0.9620898E-01     gstart =  0.0000000E+00
pstart =  0.9620898E-01     lstart =  0.9620898E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1469474E+01     vscale =  0.1000000E+01

nfe =  1301   context:  minimization step
fstart =  0.4396484E-01     gstart =  0.0000000E+00
pstart =  0.4396484E-01     lstart =  0.4396484E-01
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.6030415E+02     vscale =  0.1000000E+01

nfe =  1351   context:  minimization step
fstart =  0.9327148E-02     gstart =  0.0000000E+00
pstart =  0.9327148E-02     lstart =  0.9327148E-02
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1438020E+01     vscale =  0.1000000E+01

nfe =  1401   context:  minimization step
fstart =  0.3313476E-02     gstart =  0.0000000E+00
pstart =  0.3313476E-02     lstart =  0.3313476E-02
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.2347728E+00     vscale =  0.1000000E+01

nfe =  1451   context:  minimization step
fstart =  0.3250000E-02     gstart =  0.0000000E+00
pstart =  0.3250000E-02     lstart =  0.3250000E-02
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.7985686E-01     vscale =  0.1000000E+01

nfe =  1501   context:  minimization step
fstart =  0.1946289E-02     gstart =  0.0000000E+00
pstart =  0.1946289E-02     lstart =  0.1946289E-02
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1717107E+01     vscale =  0.1000000E+01

nfe =  1551   context:  minimization step
fstart =  0.5341797E-03     gstart =  0.0000000E+00
pstart =  0.5341797E-03     lstart =  0.5341797E-03
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.8346602E-01     vscale =  0.1000000E+01

nfe =  1601   context:  minimization step
fstart =  0.5341797E-03     gstart =  0.0000000E+00
pstart =  0.5341797E-03     lstart =  0.5341797E-03
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.8346602E-01     vscale =  0.1000000E+01

nfe =  1651   context:  minimization step
fstart =  0.8203125E-04     gstart =  0.0000000E+00
pstart =  0.8203125E-04     lstart =  0.8203125E-04
```

```
nu      =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.2061713E+00      vscale =  0.1000000E+01
```



```
nfe =  1701   context:  minimization step
fstart =  0.8203125E-04      gstart =  0.0000000E+00
pstart =  0.8203125E-04      lstart =  0.8203125E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.2061713E+00      vscale =  0.1000000E+01

nfe =  1751   context:  minimization step
fstart =  0.8203125E-04      gstart =  0.0000000E+00
pstart =  0.8203125E-04      lstart =  0.8203125E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1211260E+01      vscale =  0.1000000E+01

nfe =  1801   context:  minimization step
fstart =  0.8203125E-04      gstart =  0.0000000E+00
pstart =  0.8203125E-04      lstart =  0.8203125E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1211260E+01      vscale =  0.1000000E+01

nfe =  1851   context:  minimization step
fstart =  0.3320313E-04      gstart =  0.0000000E+00
pstart =  0.3320313E-04      lstart =  0.3320313E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.4921939E+00      vscale =  0.1000000E+01

nfe =  1901   context:  minimization step
fstart =  0.3320313E-04      gstart =  0.0000000E+00
pstart =  0.3320313E-04      lstart =  0.3320313E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1827387E+01      vscale =  0.1000000E+01

nfe =  1951   context:  minimization step
fstart =  0.3320313E-04      gstart =  0.0000000E+00
pstart =  0.3320313E-04      lstart =  0.3320313E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1827387E+01      vscale =  0.1000000E+01

nfe =  1980   context:  changing to central differences
fdatum =  0.3320313E-04 gdatum =  0.0000000E+00 rtol =  0.1000000E-01

nfe =  2001   context:  changing to central differences
fdatum =  0.3320313E-04 gdatum =  0.0000000E+00 rtol =  0.1000000E-01

nfe =  2051   context:  minimization step
fstart =  0.3320313E-04      gstart =  0.0000000E+00
pstart =  0.3320313E-04      lstart =  0.3320313E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.5599248E+00      vscale =  0.1000000E+01

nfe =  2101   context:  minimization step
fstart =  0.3320313E-04      gstart =  0.0000000E+00
pstart =  0.3320313E-04      lstart =  0.3320313E-04
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.5599248E+00      vscale =  0.1000000E+01
```

```
nfe =  2151   context:  minimization step
fstart =  0.3320313E-04     gstart =  0.0000000E+00
pstart =  0.3320313E-04     lstart =  0.3320313E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.5599248E+00     vscale =  0.1000000E+01

nfe =  2201   context:  minimization step
fstart =  0.3320313E-04     gstart =  0.0000000E+00
pstart =  0.3320313E-04     lstart =  0.3320313E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.5599248E+00     vscale =  0.1000000E+01

nfe =  2251   context:  minimization step
fstart =  0.3320313E-04     gstart =  0.0000000E+00
pstart =  0.3320313E-04     lstart =  0.3320313E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.5599248E+00     vscale =  0.1000000E+01

nfe =  2301   context:  minimization step
fstart =  0.1074219E-04     gstart =  0.0000000E+00
pstart =  0.1074219E-04     lstart =  0.1074219E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1641856E+00     vscale =  0.1000000E+01

nfe =  2351   context:  minimization step
fstart =  0.1074219E-04     gstart =  0.0000000E+00
pstart =  0.1074219E-04     lstart =  0.1074219E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1641856E+00     vscale =  0.1000000E+01

nfe =  2401   context:  minimization step
fstart =  0.1074219E-04     gstart =  0.0000000E+00
pstart =  0.1074219E-04     lstart =  0.1074219E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1641856E+00     vscale =  0.1000000E+01

nfe =  2451   context:  minimization step
fstart =  0.1074219E-04     gstart =  0.0000000E+00
pstart =  0.1074219E-04     lstart =  0.1074219E-04
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1641856E+00     vscale =  0.1000000E+01

nfe =  2501   context:  minimization step
fstart =  0.7812500E-05     gstart =  0.0000000E+00
pstart =  0.7812500E-05     lstart =  0.7812500E-05
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1983449E-01     vscale =  0.1000000E+01

nfe =  2551   context:  minimization step
fstart =  0.7812500E-05     gstart =  0.0000000E+00
pstart =  0.7812500E-05     lstart =  0.7812500E-05
nu     =  0.0000000E+00     numax  =    infinite
unrmxs =  0.0000000E+00     rtol   =  0.1000000E-01
vnormx =  0.1983449E-01     vscale =  0.1000000E+01

nfe =  2601   context:  minimization step
fstart =  0.7812500E-05     gstart =  0.0000000E+00
pstart =  0.7812500E-05     lstart =  0.7812500E-05
```

```
nu      =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1983449E-01      vscale =  0.1000000E+01

nfe =  2651   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1983449E-01      vscale =  0.1000000E+01

nfe =  2701   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1983449E-01      vscale =  0.1000000E+01

nfe =  2751   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01

nfe =  2801   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01

nfe =  2851   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01

nfe =  2901   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01

nfe =  2951   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01

nfe =  3001   context:  minimization step
fstart =  0.7812500E-05      gstart =  0.0000000E+00
pstart =  0.7812500E-05      lstart =  0.7812500E-05
nu     =  0.0000000E+00      numax  =    infinite
unrmxs =  0.0000000E+00      rtol   =  0.1000000E-01
vnormx =  0.1531897E+00      vscale =  0.1000000E+01
```

FIG.B.6 FILE RQPMIN.REP (EXAMPLE)

FILE RQPMIN.RES (EXAMPLE)

Program RQPMIN Version 1.0 for Multics

ANALYSIS OF INPUT FILE DATA AND CONTROL PARAMETERS

Input file: RQPMIN.DAT
Output file: RQPMIN.RES

Variable data

Number of variables = 23

Index	Status	Scale	Starting value	Lower bound	Upper bound
1	1	0.1000000E+02	0.4800000E+01	0.4000000E+01	0.5300000E+01
2	1	0.1000000E+01	0.2250000E+01	0.1700000E+01	0.3000000E+01
3	1	0.1000000E+00	0.1750000E+01	0.1000000E+01	0.3000000E+01
4	1	0.1000000E+00	0.7000000E+01	0.6000000E+01	0.9000000E+01
5	1	0.1000000E-01	0.5500000E+01	0.5000000E+01	0.7000000E+01
6	1	0.1000000E+00	0.8000000E+01	0.7500000E+01	0.9500000E+01
7	1	0.1000000E+00	0.1500000E+01	0.1000000E+01	0.2000000E+01
8	1	0.1000000E+00	0.6500000E+01	0.6000000E+01	0.7000000E+01
9	1	0.1000000E+00	0.6900000E+01	0.4000000E+01	0.7500000E+01
10	1	0.1000000E+00	0.3500000E+01	0.1000000E+01	0.6500000E+01
11	1	0.1000000E+00	0.1950000E+01	0.1000000E+01	0.2000000E+01
12	1	0.1000000E+01	0.1000000E+01	0.8000000E+00	0.1500000E+01
13	1	0.1000000E+02	0.1590000E+01	0.1450000E+01	0.1650000E+01
14	1	0.1000000E+00	0.3500000E+01	0.2500000E+01	0.4000000E+01
15	1	0.1000000E+00	0.3000000E+01	0.2500000E+01	0.4000000E+01
16	1	0.1000000E+00	0.5500000E+01	0.5000000E+01	0.7000000E+01
17	1	0.1000000E+00	0.3500000E+01	0.3000000E+01	0.5500000E+01
18	1	0.1000000E+00	0.2000000E+01	0.1500000E+01	0.6000000E+01
19	1	0.1000000E+00	0.2500000E+01	0.2000000E+01	0.7000000E+01
20	1	0.1000000E+00	0.3500000E+01	0.3000000E+01	0.7000000E+01
21	1	0.1000000E+00	0.1800000E+01	0.9999999E-01	0.2500000E+01
22	1	0.1000000E+00	0.1500000E+01	0.9999999E-01	0.2500000E+01
23	1	0.1000000E+00	0.1000000E+01	0.9999999E-01	0.2500000E+01

Problem function data

Number of constraints = 15

Index	Status	Type	Scale	Index	Status	Type	Scale
1	0	0	0.1000000E+04	2	1	0	0.1000000E+04
3	1	0	0.1000000E+02	4	1	0	0.1000000E-01
5	-1	0	0.1000000E+01	6	-1	0	0.1000000E+01
7	-1	0	0.1000000E+01	8	-1	0	0.1000000E+02
9	-1	0	0.1000000E+02	10	-1	0	0.1000000E+03
11	-1	0	0.1000000E+01	12	-1	0	0.1000000E+01

```
   13        -1         0      0.1000000E+02            14        -1         0      0.1000000E+01
   15        -1         0      0.1000000E+03            16        -1         0      0.1000000E+03

objective is function     1                  problem number =      0


Control parameters
------------------

nfemax =  6000     nimax  =  1000     nsmax   =    20
nsetc  =     4     nsetcf =     8     nsetv   =     4     nsetvf =     8
ofreq  =    20     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   =  0.1000000E-05     xtolu  =  0.1000000E-05     xtolv  =  0.1000000E-05     gtol   =  0.1000000E-02
rtol   =  0.1000000E+00     omegar =  0.1000000E+00     rpmax  =  0.2000000E+00
umin   =  0.1000000E-05     vminf  =  0.1000000E-02     vminc  =  0.1000000E-05     ctol   =  0.1000000E-02
umax   =  0.1000000E+00     vmax   =  0.1000000E+00     omega  =  0.1000000E+00     mu     =  0.1000000E-03
bdtol  =  0.1000000E+00     lmtol  =  0.1000000E+00     mtol   =  0.5000000E+00     cmax   =  0.1000000E-01
subtol =  0.1000000E-02     qrtol  =  0.1000000E+02     bfstol =  0.1000000E-05     diftol =  0.5000000E-03
ztol   =  0.1000000E-29


End of input data
-----------------
```

```
Program  RQPMIN  Version 1.0  for Multics

STARTING POINT


free variables
--------------

 1  0.4800000E+01  2  0.2250000E+01  3  0.1750000E+01  4  0.7000000E+01  5  0.5500000E+01  6  0.8000000E+01  7  0.1500000E+01
 8  0.6500000E+01  9  0.6900000E+01 10  0.3500000E+01 11  0.1950000E+01 12  0.1000000E+01 13  0.1590000E+01 14  0.3500000E+01
15  0.3000000E+01 16  0.5500000E+01 17  0.3500000E+01 18  0.2000000E+01 19  0.2500000E+01 20  0.3500000E+01 21  0.1800000E+01
22  0.1500000E+01 23  0.1000000E+01

objective function
------------------

f(x) =  0.7687110E-01

equality constraints
--------------------

 2 -0.7117456E-01  3  0.1654613E+00  4 -0.1595744E+02

inactive inequality constraints
-------------------------------

 5  0.0000000E+00  6  0.0000000E+00  7  0.0000000E+00  8  0.0000000E+00  9  0.0000000E+00 10  0.0000000E+00 11  0.0000000E+00
12  0.0000000E+00 13 -0.1900890E+00 14  0.0000000E+00 15  0.0000000E+00 16  0.0000000E+00
```

```
Program  RQPMIN  Version 1.0  for Multics

end of iteration number     1
------------------------------

end of a successful feasiblity step
number of calls made to user function so far =    384


free variables
--------------

 9  0.6282863E+01  2  0.2183770E+01 22  0.2319816E+01  4  0.7000000E+01  5  0.5500000E+01  6  0.8000000E+01  7  0.1500000E+01
 8  0.6500000E+01 13  0.1490000E+01 10  0.3500000E+01 11  0.1950000E+01 12  0.1020303E+01  1  0.4800000E+01 14  0.3500000E+01
15  0.3000000E+01 16  0.5500000E+01 17  0.3500000E+01 18  0.2000000E+01 19  0.2500000E+01 20  0.3500000E+01 21  0.1800000E+01
 3  0.1750000E+01 23  0.1000000E+01


objective function
------------------

f(x) =   0.8238672E-01


equality constraints
--------------------

 2 -0.2872559E-02  3  0.0000000E+00  4  0.0000000E+00


inactive inequality constraints
-------------------------------

 5  0.0000000E+00  6  0.0000000E+00  7  0.0000000E+00  8  0.0000000E+00  9  0.0000000E+00 10  0.0000000E+00 11  0.0000000E+00
12  0.0000000E+00 13 -0.8509903E-01 14  0.0000000E+00 15  0.0000000E+00 16  0.0000000E+00


Lagrange multiplier estimates
-----------------------------

 2 -0.1974652E+01  3 -0.8841621E+01  4  0.3434189E-02


Partial derivatives of Lagrangian function
------------------------------------------

 9  0.0000000E+00  2  0.2235174E-07 22  0.0000000E+00  4 -0.3778851E+00  5  0.2601584E+00  6 -0.9015981E-01  7  0.1140804E+00
 8 -0.6770915E-02 13  0.0000000E+00 10  0.5955356E-01 11  0.0000000E+00 12 -0.3337691E+01  1  0.3964853E+00 14  0.5695159E-01
15 -0.6075500E+00 16  0.0000000E+00 17  0.0000000E+00 18  0.0000000E+00 19 -0.2756414E+00 20 -0.9205107E-03 21 -0.7001794E-02
 3  0.5426603E-01 23 -0.2723749E-01


Norms of active constraint gradients
```

```
------------------------------------
 2  0.8721253E+00   3  0.1835393E+00   4   0.2095903E+02

convergence criteria
--------------------

pdatum =  0.8805902E-01      ldatum =  0.8805902E-01      gdatum =  0.8251593E-05
nu     =  0.0000000E+00      numax  =    infinite
unormx =  0.1819177E-01      unormd =  0.1819177E-01      rtol   =  0.1000000E+00      xtolu  =  0.1000000E-05
vnormx =  0.0000000E+00      vnorm  =  0.0000000E+00      xtolv  =  0.1000000E-05      grdldn =  0.3337691E+01
nde    =     0     ndef =     16     ndec =      0     ncalls =     32     nfuncs =     16
```

```
Program  RQPMIN  Version 1.0  for Multics


end of iteration number    21
-----------------------------

end of a successful minimization step
number of calls made to user function so far =  1284


free variables
--------------

 9  0.6102759E+01 12  0.9784333E+00  2  0.2510374E+01  4  0.7104773E+01  5  0.5478871E+01  6  0.8042237E+01  7  0.1465887E+01
 8  0.6504935E+01 13  0.1490000E+01 10  0.3494123E+01 11  0.1950000E+01 15  0.3057489E+01  1  0.4808097E+01 14  0.3519954E+01
22  0.2396934E+01 16  0.5500000E+01 17  0.3500000E+01 18  0.2000000E+01 19  0.2582041E+01 20  0.3561501E+01 21  0.1881082E+01
 3  0.1723517E+01 23  0.1098158E+01


objective function
------------------

f(x) =  0.4396484E-01


equality constraints
--------------------

 2  0.0000000E+00  3  0.0000000E+00  4  0.0000000E+00


inactive inequality constraints
-------------------------------

 5  0.0000000E+00  6  0.0000000E+00  7  0.0000000E+00  8  0.0000000E+00  9  0.0000000E+00 10 -0.2379150E-01 11  0.0000000E+00
12  0.0000000E+00 13 -0.2633068E+00 14  0.0000000E+00 15  0.0000000E+00 16  0.0000000E+00


Lagrange multiplier estimates
-----------------------------

 2 -0.1286424E+01  3 -0.2850596E+01  4  0.1783821E-02


Partial derivatives of Lagrangian function
------------------------------------------

 9  0.3725290E-08 12 -0.1266599E-06  2  0.9313226E-08  4 -0.3036075E+00  5  0.1099281E+00  6 -0.1162216E+00  7  0.1202660E+00
 8 -0.2218770E-01 13  0.0000000E+00 10  0.2353009E-01 11  0.0000000E+00 15 -0.2678590E+00  1 -0.2102944E-01 14 -0.4595029E-01
22 -0.2262942E+00 16  0.0000000E+00 17  0.0000000E+00 18  0.0000000E+00 19 -0.1864487E+00 20 -0.1499209E+00 21 -0.2225640E+00
 3  0.7589392E-01 23 -0.2778975E+00


Norms of active constraint gradients
```

```
-------------------------------------
 2  0.2105031E+01  3  0.1835393E+00  4  0.2095903E+02

convergence criteria
--------------------

pdatum =  0.4396484E-01     ldatum =  0.4396484E-01     gdatum =  0.0000000E+00
nu     =  0.0000000E+00     numax  =    infinite
unormx =  0.0000000E+00     unormd =  0.0000000E+00     rtol   =  0.1000000E-01     xtolu  =  0.1000000E-05
vnormx =  0.2451765E+03     vnorm  =  0.1000000E+00     xtolv  =  0.1000000E-05     grdldn =  0.3036075E+00
nde    =     0      ndef =    52      ndec =      0      ncalls =   140      nfuncs =    88
```

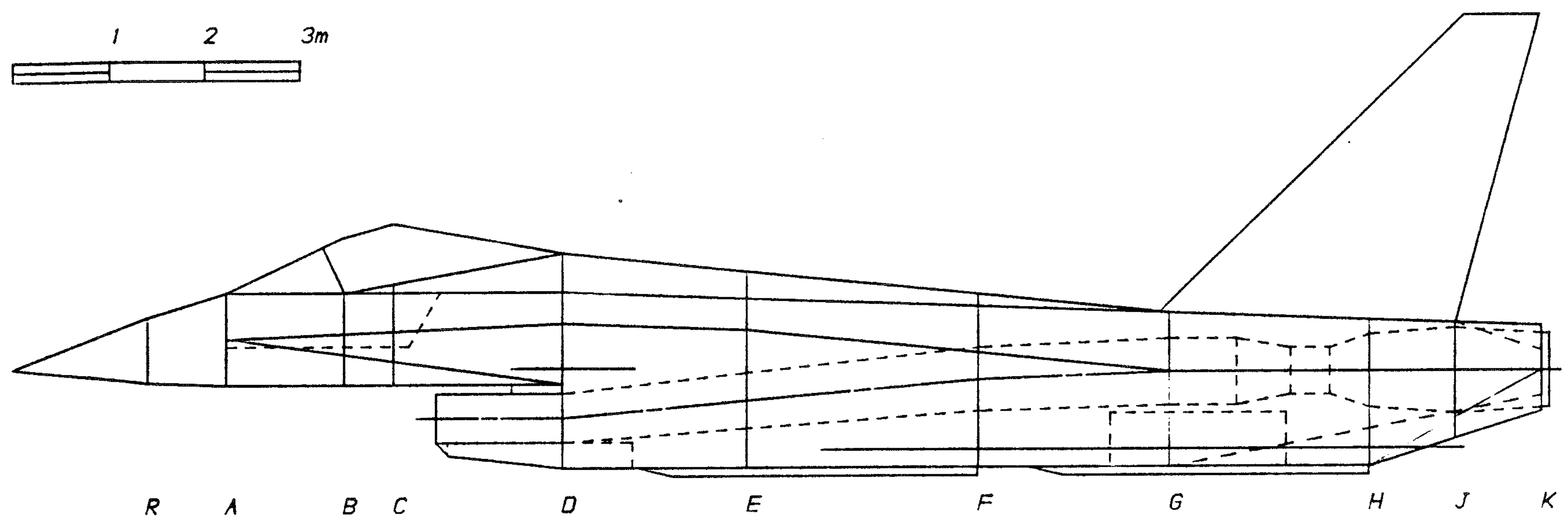
```
Program  RQPMIN  Version 1.0  for Multics

end of iteration number    40
------------------------------

CONVERGENCE DETECTED  [ Code B ]      after  3014 calls to user routine


free variables
--------------

 9  0.6038560E+01 12  0.9704377E+00  2  0.2626156E+01  4  0.7128222E+01  5  0.5472294E+01  6  0.8049045E+01  7  0.1456873E+01
 8  0.6505495E+01 13  0.1490000E+01 10  0.3492853E+01 11  0.1950000E+01 15  0.3094276E+01  1  0.4820598E+01 14  0.3501284E+01
22  0.2417047E+01 16  0.5500000E+01 17  0.3500000E+01 18  0.2000000E+01 19  0.2597090E+01 20  0.3575066E+01 21  0.1900921E+01
 3  0.1717444E+01 23  0.1122819E+01

objective function
------------------

f(x) =  0.7812500E-05

equality constraints
--------------------

 2  0.0000000E+00  3  0.0000000E+00  4  0.0000000E+00

inactive inequality constraints
-------------------------------

 5  0.0000000E+00  6  0.0000000E+00  7  0.0000000E+00  8  0.0000000E+00  9  0.0000000E+00 10 -0.3904327E-01 11  0.0000000E+00
12  0.0000000E+00 13 -0.2966129E+00 14  0.0000000E+00 15  0.0000000E+00 16  0.0000000E+00

Lagrange multiplier estimates
-----------------------------

 2 -0.1082802E-01  3 -0.2242368E+00  4  0.9968863E-03

Partial derivatives of Lagrangian function
------------------------------------------

 9 -0.1862645E-08 12  0.3259629E-08  2  0.1862645E-08  4  0.1143275E-01  5 -0.8473374E-02  6  0.1958389E-01  7  0.1141088E-01
 8  0.1666294E-01 13  0.0000000E+00 10  0.1610405E-01 11  0.0000000E+00 15 -0.2303545E-01  1  0.2783218E-01 14  0.1588955E-01
22  0.2849254E-01 16  0.0000000E+00 17  0.0000000E+00 18  0.0000000E+00 19  0.1074327E-01 20  0.2445468E-01 21  0.2881999E-01
 3  0.1387538E-01 23  0.2829222E-01
```

```
Norms of active constraint gradients
-----------------------------------
 2  0.2105031E+01  3  0.1835393E+00  4  0.2095903E+02

convergence criteria
--------------------

pdatum =  0.7812500E-05     ldatum =  0.7812500E-05     gdatum =  0.0000000E+00
nu     =  0.0000000E+00     numax  =     infinite
unormx =  0.0000000E+00     unormd =  0.0000000E+00     rtol   =  0.1000000E-01     xtolu  =  0.1000000E-05
vnormx =  0.1531897E+00     vnorm  =  0.1000000E+00     xtolv  =  0.1000000E-05     grdldn =  0.2881999E-01
nde    =     0      ndef =    81     ndec =    22     ncalls =   242      nfuncs =   139
```

FIG.B.7 FILE RQPMIN.RES (EXAMPLE)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION

(SIDE VIEW)



DESIGN SYNTHESIS
FOR
CANARD-DELTA COMBAT AIRCRAFT
BY, V.C.SERGHIDES
1985/87
COLLEGE OF AERONAUTICS
CRANFIELD INSTITUTE OF TECHNOLOGY

FIG.B.8 INITIAL FILE FOR007.DAT (EXAMPLE)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(LOWER PLAN VIEW)

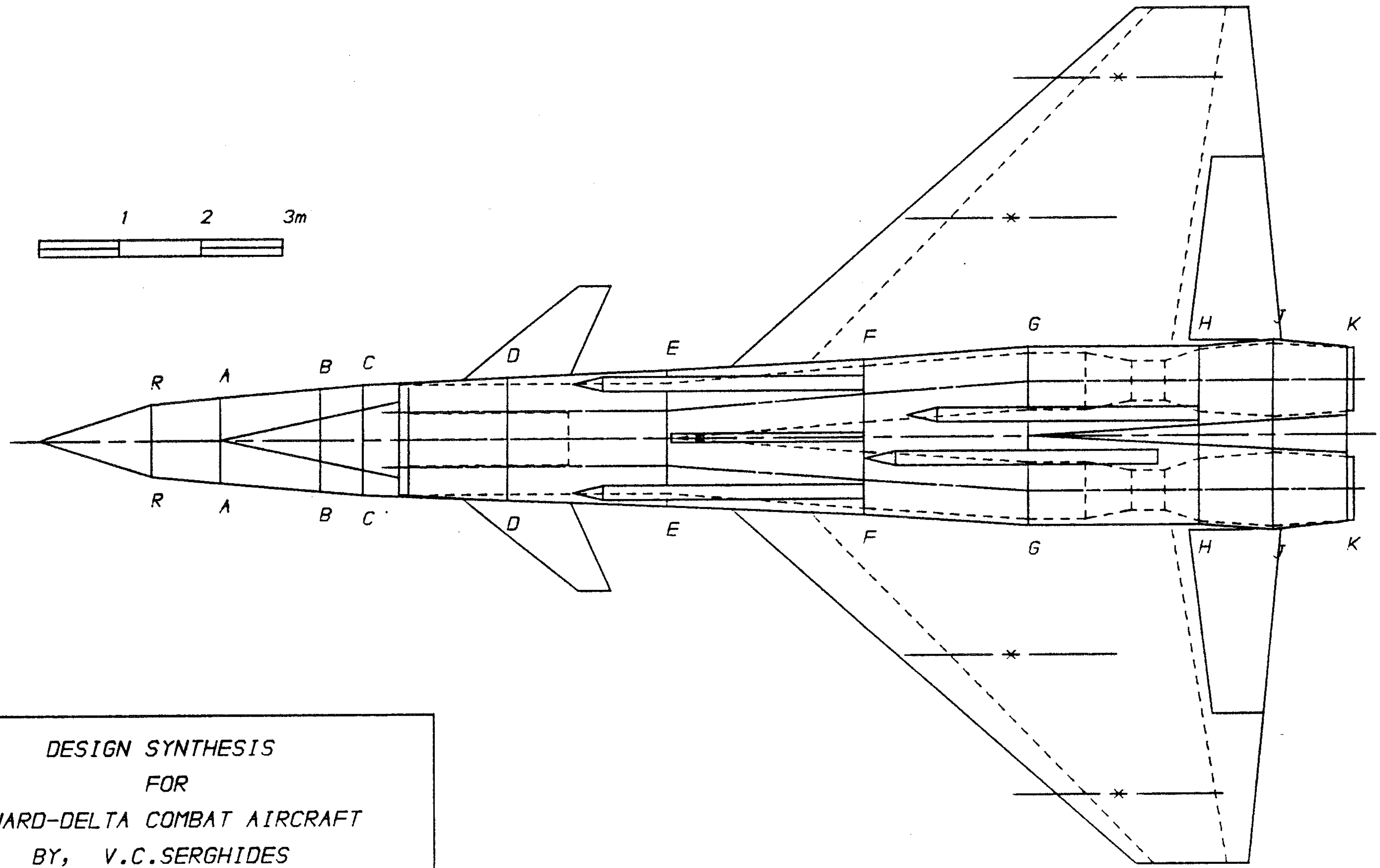


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FIG.B.8 (.....CONTINUED)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(UPPER PLAN VIEW)

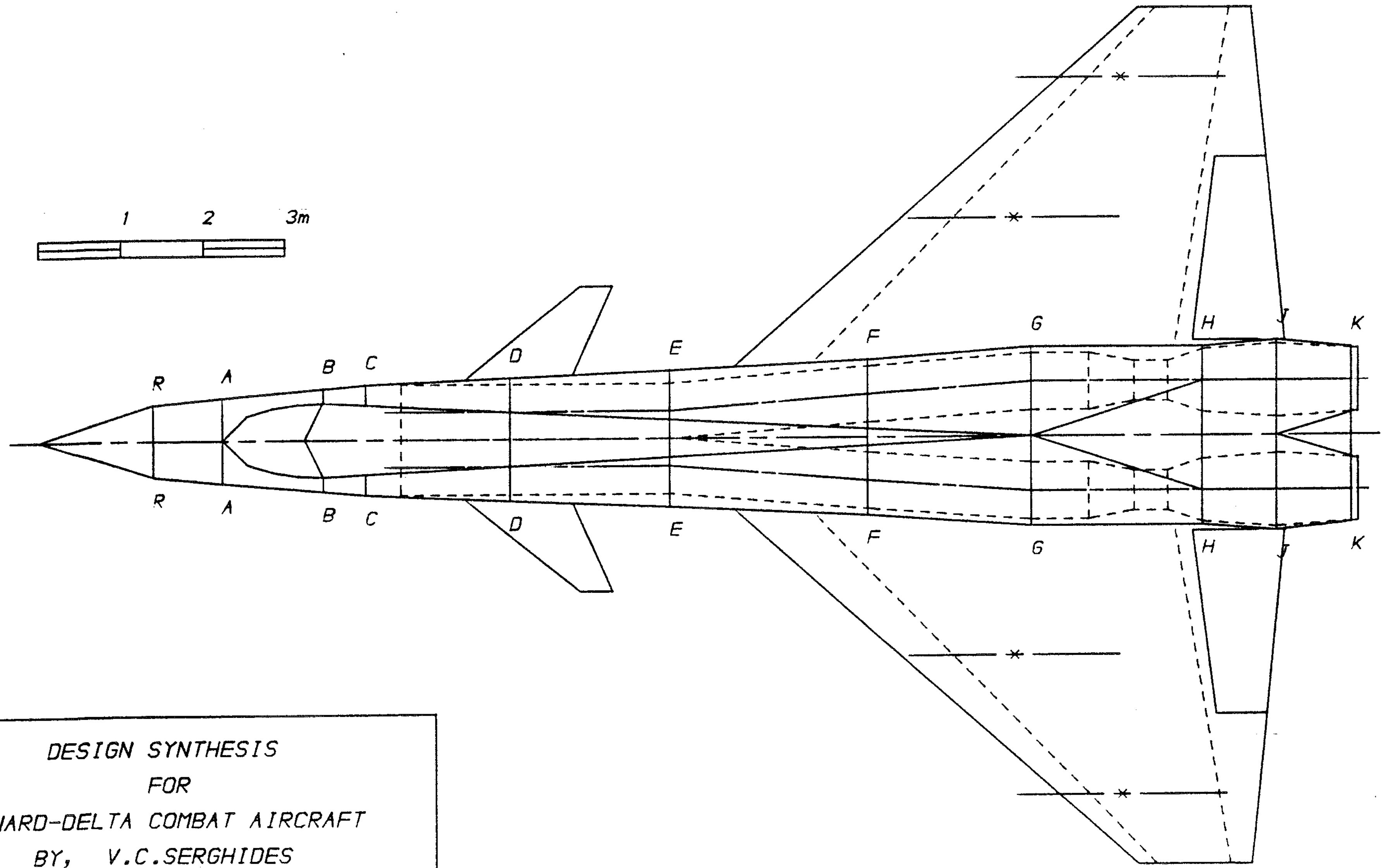

FIG.B.8 (.....CONTINUED)

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COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(SIDE VIEW)

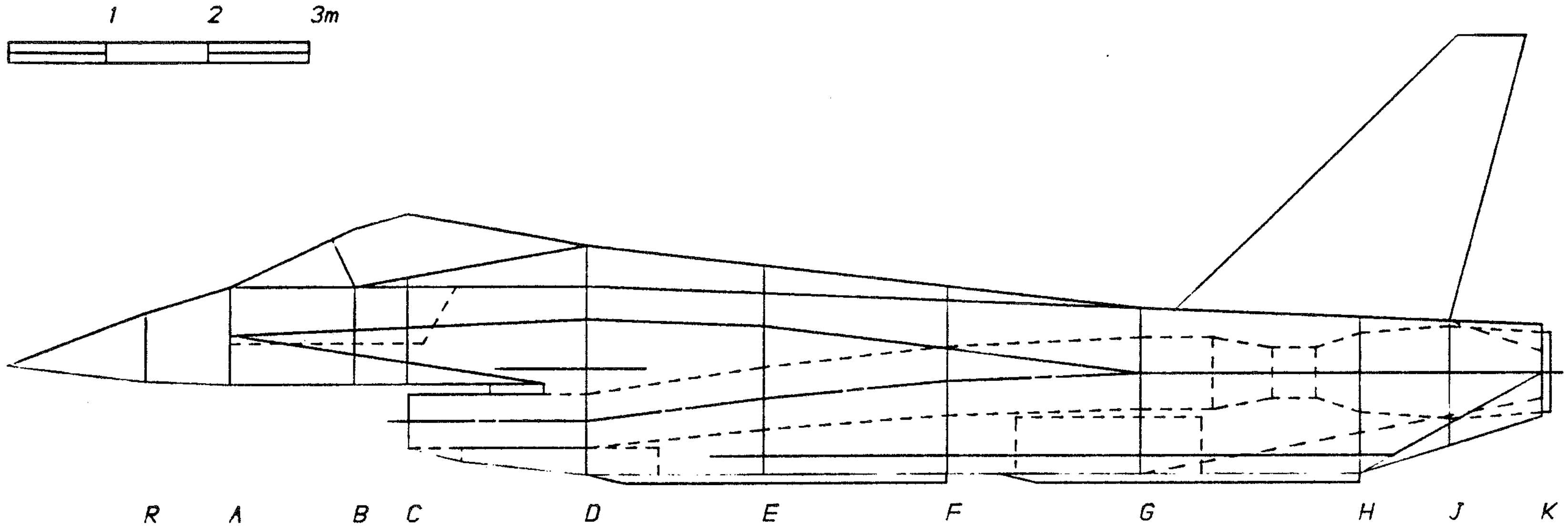

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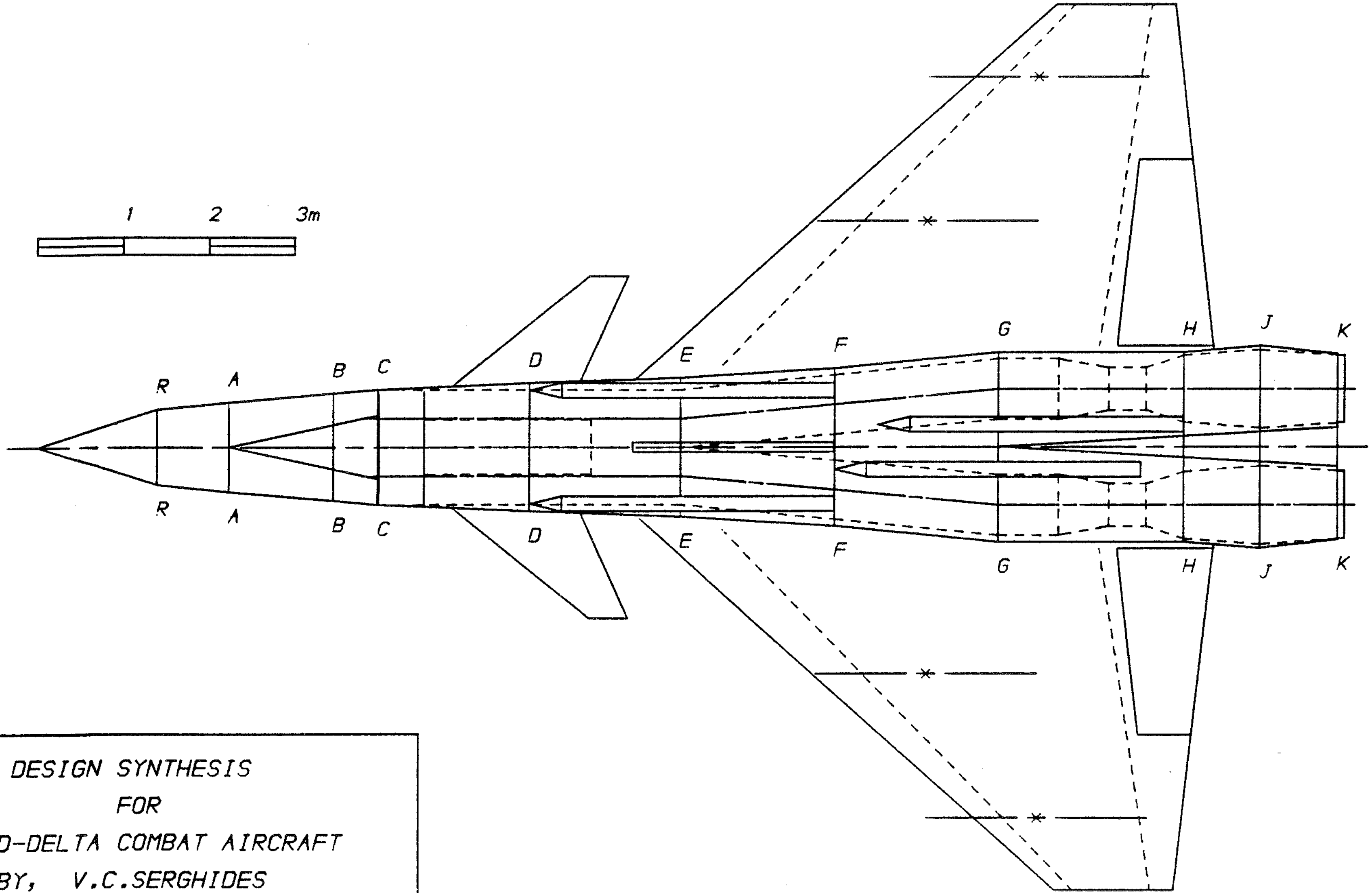
FIG.B.9 INTERMEDIATE FILE FOR007.DAT (EXAMPLE)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION

(LOWER PLAN VIEW)



DESIGN SYNTHESIS

FOR

CANARD-DELTA COMBAT AIRCRAFT

BY, V.C.SERGHIDES

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FIG.B.9 (.....CONTINUED)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(UPPER PLAN VIEW)

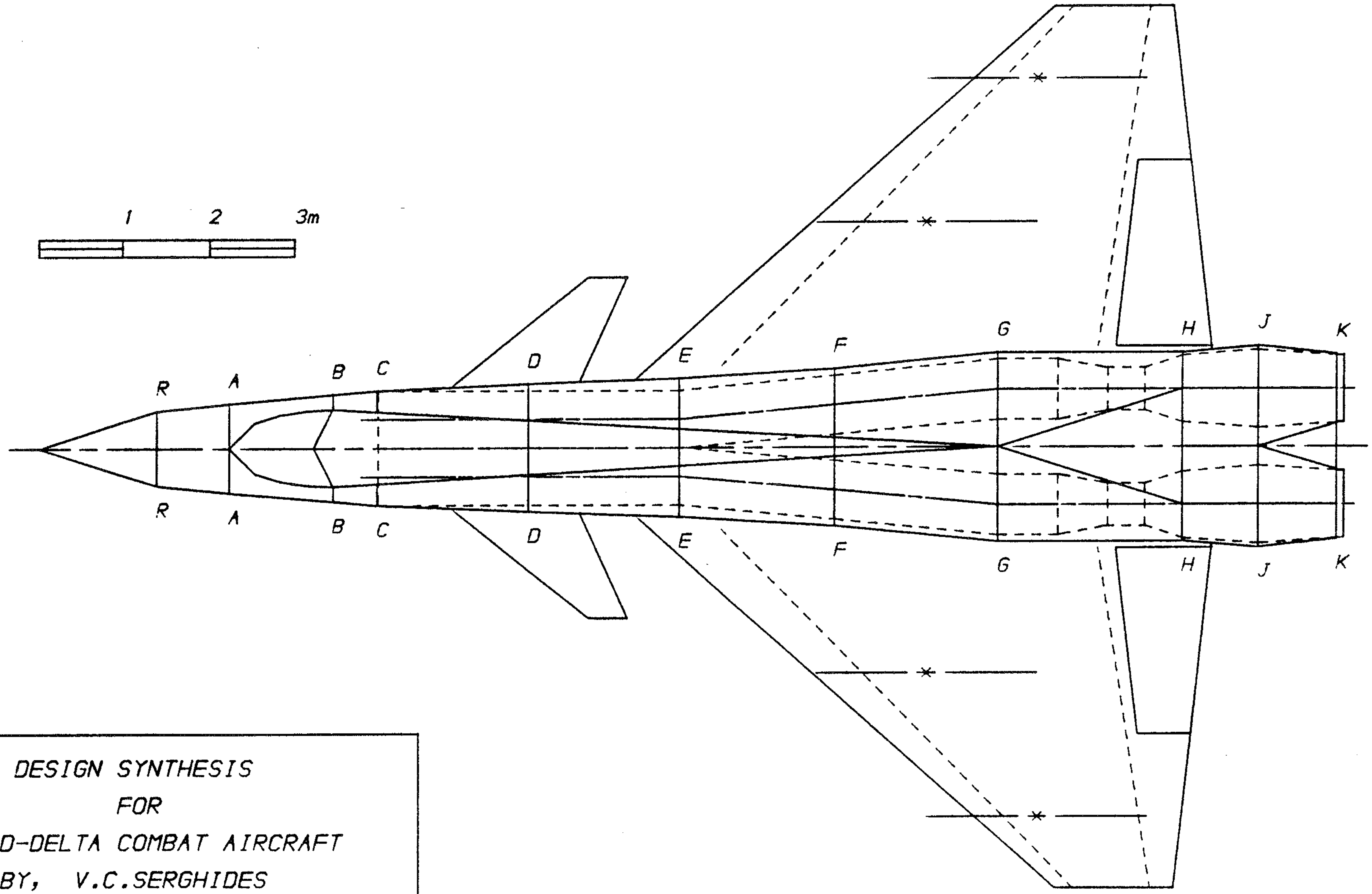

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FIG.B.9 (.....CONTINUED)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(SIDE VIEW)

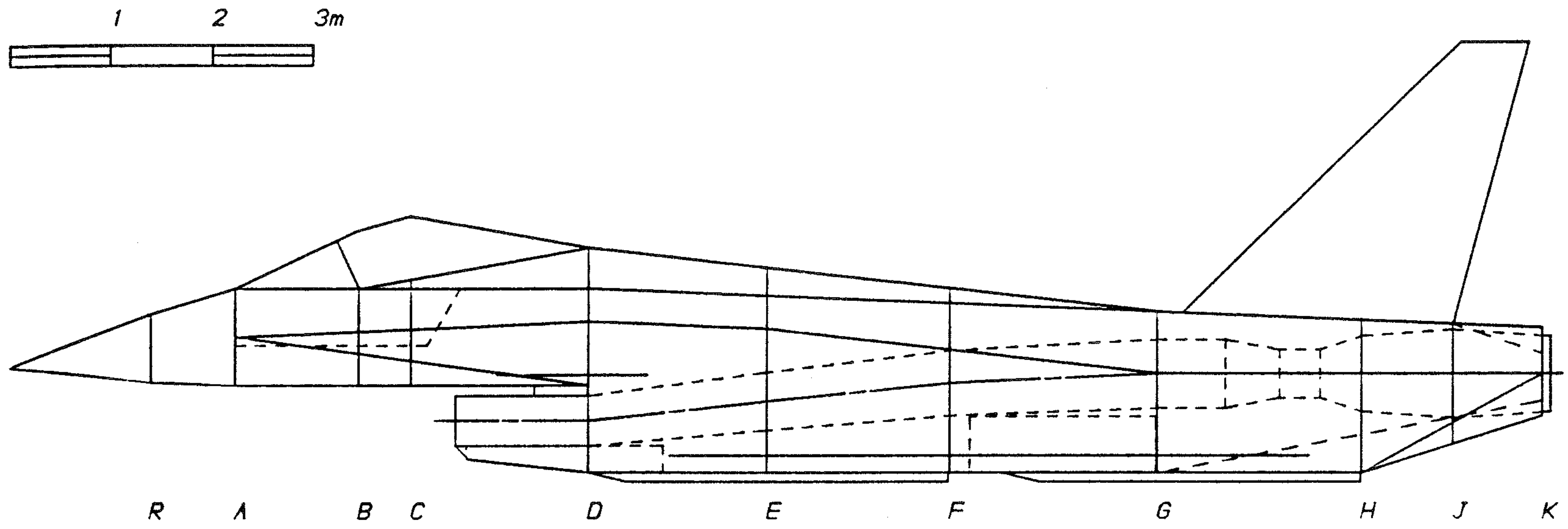

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FIG.B.10 FINAL FILE FOR007.DAT (EXAMPLE)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(LOWER PLAN VIEW)

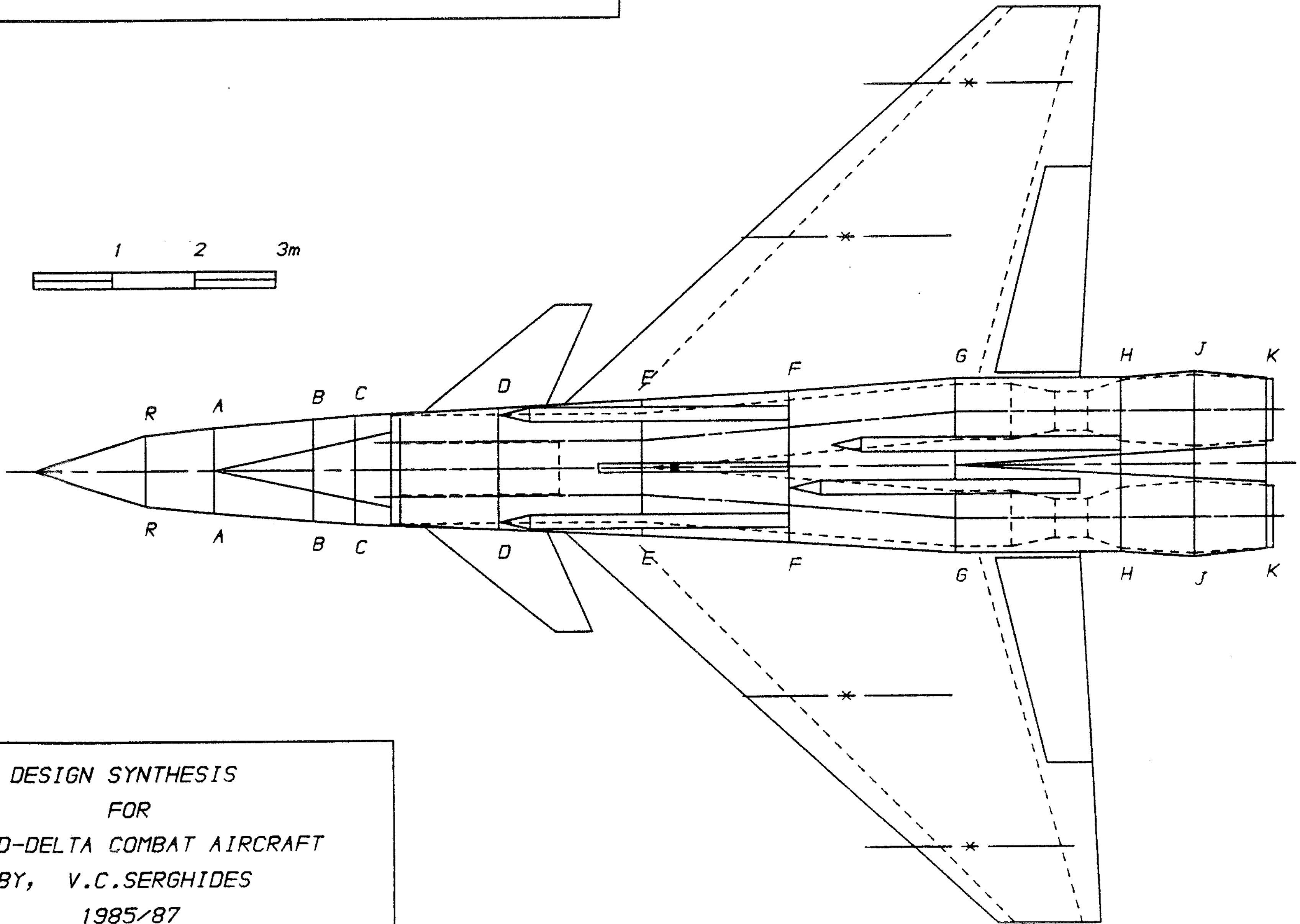

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FIG.B.10 (.....CONTINUED)

COMPUTER GENERATED IMAGE OF THE SYNTHESIZED CONFIGURATION
(UPPER PLAN VIEW)

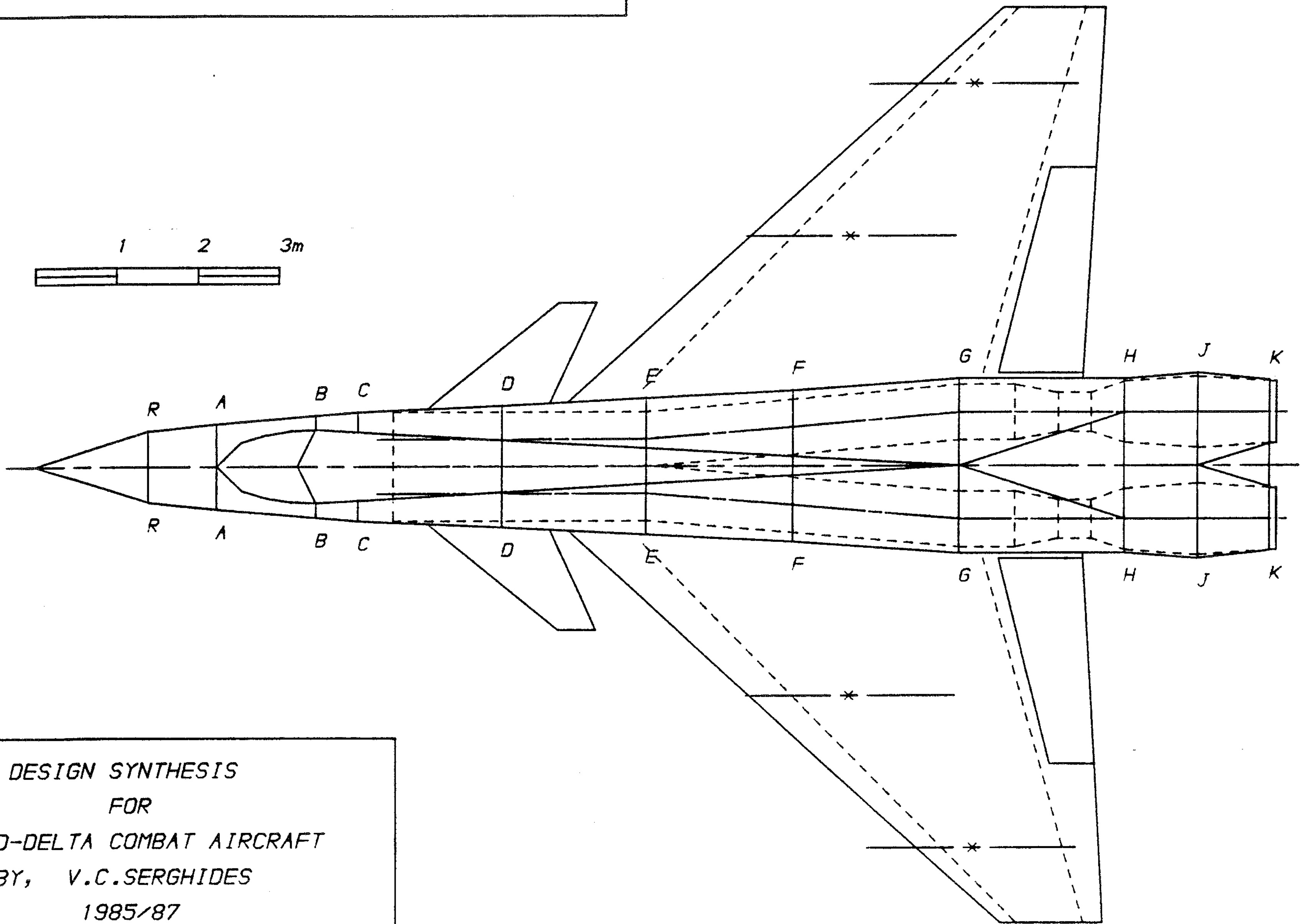

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FIG.B.10 (.....CONTINUED)