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# REPORT OF THE PROJECT DESIGN OF THE CRANFIELD A-90 SHORT HAUL 500-SEAT AIRLINER PROJECT

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ABSTRACT

This report describes the conceptual and detail design of the A-90 Short-haul 500 seat airliner project. It started with a market investigation which then led to the specification of the aircraft.

The author performed a conceptual design process, to derive the configuration - a twin-engined jet transport with a swept wing, shoulder mounted to a large double-bubble fuselage. Aerodynamic, mass and geometric work was then performed prior to the start of the main design programme in October 1990.

The main programme involved 23 MSc students and 5 members of staff and lasted for 8 months. Each student was given responsibility for the detail design of a major component such as outer wing, fuel system, etc.

This work is described together with the final design that emerged. This description is aided by the reproduction of numerous engineering drawings.

The work was complemented by extra studies, performed by 15 Flight Dynamics students.

The report then discusses the final configuration of the A-90.

The project showed the potential of meeting mass, cost and airport requirements. It should exceed the range requirements and carry 620 passengers for 1700 n miles, 500 for 2260 n miles or 345 for 3500 n miles.

The design showed considerable flexibility and could be relatively easily developed to carry some 1000 passengers.

Investigations were performed of several applications of new technology, including variable camber flaps, fibre optic flight controls, "all electric" systems and modern materials. They all looked feasible, and should be investigated further. The main concern was the provision of bleed air and secondary power following the loss of one engine, on such a large aircraft. Careful system design overcame this problem.

The A-90 project proved again the validity of Cranfield's group design project as a powerful means of educating design students.

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# REPORT OF THE CONCEPTUAL DESIGN AND DESIGN DEVELOPEMENT OF THE CRANFIELD A-90 500-SEAT SHORT HAUL AIRLINER

## 1. INTRODUCTION

The A-90 project was initiated to satisfy requirements of two organisations. Guinness Peat Aviation (G.P.A.) wanted a realistic investigation of a large short-range airliner design. They felt that this was one possible means of alleviating the chronic and worsening congestion at many of the World's airports. Cranfield Institute of Technology performs annual group design projects as major constituents of its M.Sc. course in Aerospace Vehicle Design. It is always monitoring the aerospace world so that it may choose relevant civil, military or spacecraft topics for its group projects.

A former Cranfield Air Transport Engineering student took up employment with GPA and proposed what became the A-90 project as a means of satisfying the requirements of both organisations. This report will describe the entire 18-month process of conceptual design and design development. It will show the final aircraft configuration, discuss its' strengths and weaknesses and propose areas for further work.

## 2. THE CRANFIELD GROUP DESIGN PROJECT METHOD

The College of Aeronautics at Cranfield Institute of Technology has a practical approach to the teaching of aircraft design. Students will only be awarded an M.Sc. degree if they have proved that they have the ability to produce workable, realistic designs in which all of the major problems have been addressed. This ability is assessed by means of annual group projects in which relevant aircraft types are studied, in this case the A-90 airliner. These group projects are unique by virtue of the amount of preparatory work done by staff before work is started by the students. All other known design projects start with the students being given the aircraft requirements. Those students then have to perform a conceptual design, which leaves little time available for detailed design. With the Cranfield method, this work is done by the author, thus enabling the students to start much further down the design evolution process. They thus have an opportunity really to get to grips with the detail design problems, and become much more experienced and employable in the process.

The design project accounts for 50% of the M.Sc. assessment. Students are also required to complete individual research theses as the remaining 50% of their assessments. These cover a wide range of activities from structural testing, computer modelling, mechanical system research, to conceptual design. Results of these activities are often fed into the teaching programme and future design projects. References 1 and 2 are typical examples of individual conceptual designs of 1000 and 1500 seat aircraft respectively, which gave useful background information for the A-90.

A conceptual design study was performed for the A-90 by the author, as described later in this report. This process determined the basic shape of the aircraft together with weight, aerodynamic and loading information. This work is summarised in the project specification, shown as appendix 1 of this report. The specification was presented to each student at the start of the academic year. Twenty three students were then allocated the resonsibility for the detailed design of a major part of the aircraft. These responsibilities took the form of a major structural component, such as the forward fuselage, a flying control surface or a mechanical system such as fuel, environmental control, propulsion, landing gear or the active control system. Each student was expected to act as designer, stressman and draughtsman for his or her component.

The project was managed to an exacting eight month programme by means of the weekly project meetings where students reported on progress, received advice and instructions for subsequent work, from the staff project team. The most important role of the meetings, however, was that of a forum where design compromises were resolved and students gained an appreciation of the problems being encountered on other parts of the aircraft. Table 1 shows staff and student responsibilities.

The programme ended in May 1991 with the submission of voluminous project theses containing detailed drawings and calculations. It has been estimated that at least 20,000 man-hours were spent on the programme, which produced some excellent design work and gave the students considerable design experience.

The knowledge gained during lectures, project meetings and discussions with members of staff, was augmented by several valuable visits.

No design programme would be complete without a visit to a company operating the type of aircraft being designed. A visit was therefore made to Britannia Airways' maintenance hangar where minute examinations were made of Boeing 737 and 767 aircraft which were undergoing maintenance. Individual students visited factories which were particularly relevant to their design specialisations.

The A-90 project was also used as the basis of research projects by 15 students attending the Flight Mechanics M.Sc. course.

The design programme was completed by the assessment of the M.Sc. theses and their results synthesised into this report.

Figure 1. shows a chart summarising the timescales of the various project activities.

## 3. MARKET INVESTIGATION

The most important part of any design process is to get the requirements right! The first stage was to examine the main transport aircraft in use, or projected, together with suitable powerplants. The leading parameters are summarised in table 2 for aircraft and table 3 for engines. This information provided a useful database for subsequent analyses.

The main aircraft manufacturers perform extensive market surveys and publish their results. The author used a 1990 Airbus Industry survey (ref. 3), a 1988 Airbus paper (ref. 4) and a Boeing 1990 survey (ref. 5) as the basis of his investigations. Other useful comments were taken from references 6 and 7.

These reports studied current markets and made projections up to the year 2005 or 2008, but ignored the Eastern Bloc. They estimated Revenue passenger miles (RPM) growth at 5.5% per year and cargo at 7%. Fig. 2 is extracted from ref. 5 and shows that RPMs will be more than double 1990 values. Fig. 3 shows available seat (ASM) mile growth. Extra ASMs will also be required from new aircraft because many of today's aircraft will have to be retired.

Ref. 3 stated that Airport/Air Traffic Control capacity will put a physical limit on the expansion of aircraft movement growth. It showed that 24 European, 59 North American and 12-15 Asian airports will be frequency-limited by AD 2000. These are big airports that handle 55% of all passenger movements. These problems may be reduced by:

i) Increasing aircraft load factors
ii) Increasing aircraft utilisation
iii) New airports and/or extra runways
iv) Improved ATC
v) Larger aircraft

Ref. 3 states that "Larger aircraft are the only viable short-term solution to ease congestion problems."

This view is echoed by Sir Ralph Robbins of Rolls-Royce in ref 6:

"The ATC situation, congestion, staffing problems, and increasing air traffic all point to reduced growth in frequency and increased aircraft size."

Fig. 4 shows Boeing's projections of aircraft seat number categories expected to be required to meet the A.S.M. growth.

The above projections were made before the Persian Gulf Crisis, but the 1991 Boeing Report (ref.7) expected the market fluctuation caused by the war to be short-lived. It did, however, down-grade the average growth rates to 5.2% for passengers and 6.5% for cargo. Fig. 5 shows the short-term nature of reduced growth in the recessions of the mid '70s and early '80s and was used as evidence for the short-term effects of the Gulf-war recession.

The next stage in the study was to quantify the required numbers of large aircraft. Table 4 summarises the results of the surveys, for aircraft larger than 70 seats. It can be seen that there is some discrepancy between figures, but some of this is due to inconsistent definitions of aircraft size.

The later Airbus survey (AIRBUS 1) estimates the need for about 5000 wide-body aircraft, whilst the earlier Airbus and Boeing quoted about 4000. Even the lower figure would give sales of more than $400 billion at 1990 values. These aircraft would be those in current production, developments, or committed programs such as the A340 or 777.

The next question to be addressed was the proportion of short/medium range aircraft. Refs. 4 and 5 gave aircraft numbers in this category of 3000 and 2000, respectively. These would be passenger/COMBI aircraft, to which may be added a number of cargo aircraft. The next stage in the investigation was to determine aircraft required seat numbers. Ref. 5 showed that about 800 aircraft would have more than 350 seats. Reference 3 shows that the <u>average</u> number of seats across the whole jet fleet will increase by 38% over the study time-frame. It seemed reasonable to apply this growth rate to current short/medium widebodies. In all-tourist layout, the DC10-10 and A300 have capacities of 380 and 375, respectively. Their replacements would therefore have a capacity of some 520 seats (using the above factor). The Boeing 747-400 has an all-tourist capacity of some 570 seats and is being used by a Far-Eastern Airline, with average block times of 1.25 hours. This is obviously non-optimum use of such a long-range aircraft, but it shows the requirement for a 500+ seat short-haul aircraft. Several press articles have been written showing Airbus and Boeing suggestions as to how they can achieve stretches of their products to reach 450-500 seats. The case for 500 seats therefore seemed to be strong.

The next major requirement to be determined was the range. Fig. 6 shows a useful plot of range and capacities, based on mixed-class seating. The average short range is 2000 n. miles (as reflected in Ref. 8), whilst medium range is about 4,400 n. miles. A 500-seat aircraft with a 4,400 n. mile range would be very large and could lead to airport compatibility problems. It would also be in direct competition with A330 and 777 derivatives.

The more recent Boeing report (ref. 9) showed that some 64% of the growth in RPMs would be less than 2500 miles.

It was decided to take the more radical approach of aiming for a 2000 n. mile 500 seater. This could replace DC10-10 and A300 aircraft over most of their operations and meet growth generated by such aircraft as the 757, 767, and A321s. Discussions with a senior British Airways representative suggested there was a marked requirement for a 3,500 n.m. range for Trans-Atlantic or trans U.S.A. routes. The A-90 aircraft requirements therefore included provisions for fuel volume for such a range, although there would have to be some reduction in payload, to limit the aircraft size.

The strong predicted growth in cargo led to the requirement for carriage of standard containers above and below the main deck in cargo or COMBI versions of the aircraft. A less important suggestion was to make the aircraft compatible with military cargo operations, providing that this would not detract from civil operations.

## 4. THE AIRCRAFT SPECIFICATION

### 4.1 Derivation

Paragraph 3, above, shows the process by which the aircraft capacity and range were determined. Ref. 8 formed the basis for much of the remainder of the specification. This was felt to be appropriate because it was based on the Association of European Airlines requirements for future short/medium haul aircraft. The main change was to alter the field lengths. The AEA requirements had been:

i) Take off distance to be 5,500 ft. at an altitude of 2000 and temperature of 15A + 15°C

ii) Landing distance of 5000 ft. at an altitude of 2000 ft.

These figures were based on what would have been a relatively small aircraft of some 200 seats, but this was thought to be too severe for a 500 seat aircraft. The figures for some relevant short/medium range aircraft were:

| | DC 10-10 | A330 | A321 |
|---|---|---|---|
| Take off, ISA, S.L. | 9800 ft. | 8300 ft. | 8545 ft. |
| Landing, ISA, S.L. | 5820 ft. | 5650 ft. | 5120 ft. |

It was decided that the A330 distances would be the closest match to the proposed aircraft, and these were used as a target.

Comparison with existing aircraft suggested a high-speed cruise of M = 0.86 and an airframe life of 100,000 hours with an average flight duration of 1.67 hours.

It was envisaged that the aircraft would use state-of-the-art materials and technology. The operational flexibility required for a short/medium range airliner with possible civil/military cargo derivations prompted the decision to specify the use of variable camber wing flaps to optimise lift/drag ratios over a wide lift coefficient range. It was further decided to use the wing aerofoil and variable-camber (V-C) flaps being developed at Cranfield on an independent research programme. This had the advantage of making use of good data from the computational fluid dynamics work on the aerofoil The variable-camber research programme would benefit from ideas generated in the A-90 application. One of the benefits of the V-C system was its ability to be easily adapted to the use of "active control" of surfaces, for wing mass reduction.

The initial assumption of the use of such a system, plus the use of aluminum/lithium alloys for the majority of the airframe, and composite materials for the tail and flying surfaces, led to the following assumed mass savings, relative to conventional aircraft:

| Component | Mass Saving |
|---|---|
| Fuselage | 8% |
| Wing | 25% |
| Nacelle | 25% |
| Tail | 25% |
| Undercarriage | 5% (Carbon Brakes) |

4.2 Summary of the Specification

4.2.1 Interior Layout

500 single-class passengers at 34" pitch with comfort standards at least as good as those of the Boeing 727.

One attendant's seat per 35 passengers with sufficient galley space per passenger of $0.025m^2$. One toilet per 50 passengers.

Two-person flight deck.

4.2.2 Cargo

Baggage space should be determined by assuming 4 cu. ft. per seat with additional cargo space of 4 cu. ft. per seat. It should be possible to carry LD3 and LD7 containers under the main floor. There should be an optional main-deck cargo door.

4.2.3 Performance

i) Passenger and bag payload range shall be approximately 2000 nautical miles with FAR reserves.

ii) The maximum design cruise speed will be not less that 340 KT. CAS.

iii) Maximum cruise altitude should be at least 39,000 ft.

iv) It must be possible to maintain an altitude of 15,000 ft. after the failure of a single engine following a 30 minute flight at ISA + $10^{\circ}C$.

v) Maximum certified maximum all up mass takeoff is distance 8300 ft. at ISA sea level conditions.

vi) The FAR landing distance at maximum landing mass should not exceed 5650 ft. at ISA sea level conditions.

vii) Runway loading should not exceed an LCN of 65 at ramp mass.

## 5. A-90 CONCEPTUAL DESIGN

This was performed by the author prior to the start of the main design phase by the full student/staff team in October 1990. The conceptual design stage followed the sequence shown in fig. 7, starting with the specification and ending with the aircraft configuration in near-final form, ready for more detailed design by the students. The main stages of the conceptual design were as shown below:

### 5.1 Parametric Study

This was a preliminary design process in which the specification was used to drive a logical decision-making process. This was guided by simple empirical performance prediction methods and information from the empirical data base. The process is shown in full in appendix B of this report. The performance requirements were:

i) Landing Field Performance
ii) Take-off performance
iii) Second-segment climb
iv) Missed approach
v) Cruise
vi) 15,000 ft. cieling following a single engine failure

The designs which had to satisfy these requirements were taken from a matrix of possible twin-jet configurations with the following variables:

a) Wing loading between 90 and 130 $lb/Ft^2$ at take off
b) Thrust loading between 0.2 and 0.35
c) Wing aspect ratios between 6 and 10

The optimum design to meet the requirements was determined by use of fig. B10, which is reproduced in a simpler form as fig. 8 of the main text of this report.

The features of this design were:

| | |
|---|---|
| Max. wing loading | = 119.31b/ |
| Max. thrust loading | = 0.308 |
| Wing aspect ratio | = 9.0 |
| $CL_{max}$ - take-off | = 1.8 |
| $CL_{max}$ - landing | = 2.5 |
| ratio of landing to take-off mass | = 0.83 |
| Cruise lift coefficient | = 0.5 |
| opt. cruise lift/drag ratio | = 18.3 |
| Max. cruise altitude | = 40,500 ft. = 12.34 KM. |
| Economical Mach No. | = 0.82 |
| Max. cruise Mach No. | = 0.86 |

It must be stressed that those figures were based on necessarily simple design methods. They did, however, provide a good start to the design process, which was checked and modified during subsequent design stages, as more information became available.

The requirements for the aircraft were expressed in terms of lbs/feet/mile units as they are what the air transport industry uses. The parametric study used similar units, because it was based on ref. 9, which uses them. Units were changed to S.I. at this stage of the programme, because of the requirements of the European education system.

5.2 Initial Wing Configuration

The parametric study, above, gave target values of wing loading, aspect ratio, and cruise lift coefficient. These, and, the specification requirements were used as input values during the use of the College of Aeronautics ADROIT computer program. This is a relatively simple Expert System which performs the following tasks:

i) It chooses an aerofoil suitable for cruise conditions form a limited range of "open- literature" supercritical aerofoil sections.

ii) It calculates 3-dimensional drag-rise Mach numbers for a matrix of t hickness/chord ratios and sweep angles, based on the chosen aerofoil section.

iii) It models the spanwise airload distributions with user-defined or default taper ratios and twist. It then indicates sweep angles that may lead to tip-stall

iv) It gives an indication of unacceptable sweep angles for flap effectiveness.

v) It performs simple checks of bending and torsional stiffness for the matrix of combinations of aspect ratio and sweep

vi) It estimates the wing weight of each alternative

vii) The above stages are then used to eliminate unacceptable designs in terms of tip-stall, flaps, and stiffness. The remaining design options are then assessed by weight.

This program is described more fully in ref. 10.

The program run for the A-90 project chose the RAE 9515 aerofoil as the basis of the wing design. The valid range of wing quarter-chord sweep was 20° to 40°, with corresponding thickness-chord ratios between 9.74% and 10.58% respectively. These values, together with the wing weight variations were plotted on figure 9. All of these configurations satisfied the tip-stall, flap and stiffness criteria.

Fig. 9 shows that that the slope of the wing weight curve increased more rapidly after 30°, so this was taken as the chosen value, together with an average thickness/chord ratio of 10.1%. These values, together with the assumed taper ratio enabled the construction of the first wing plan form.

The wing design process was then held at this stage, because work was required on the fuselage and general configuration before more detailed wing design work could be done.

5.3 Initial Fuselage Configuration

The cross-sections of current aircraft were examined and it was decided to use a double-bubble fuselage, with a lower-lobe of similar width to the Boeing 747, with an upper lobe of similar width to the Airbus A320. It was felt that this would give a reasonable fuselage length/diameter ratio (which was later confirmed as being correct).

The requirement for 500 passengers with an average seat pitch of 0.86 M (34 inches) was then investigated. The aircraft was to be short-haul with relatively brief flights, so it was decided to reduce the economy seat pitch below this value and offer a 2-class aircraft with a total of 500 seats. Statistical study suggested that 75% of passengers would be economy class, and it was decided that they would occupy the lower deck. Business-class would occupy most of the upper deck.

A Cranfield-developed computer program was then used to optimise the fuselage cross-sections. It took the numbers of seats and numbers abreast for each deck, together with aisle width, and calculated the minimum cross-section shape to accommodate them. It further calculated the passenger door requirements from airworthiness considerations and made allowances for them in fuselage length calculations.

Fuselage cross-section and plan forms were then drawn, based on program out-puts. It was found possible to accommodate 620 passengers in an alternative, all-economy 0.76 (30 inch) seat-pitch arrangement. The doors gave a safety exit limit of 650 passengers.

Fig. 10 shows the cross-section. It was chosen so that two 8 x 8 ft. or even 8 x 10 ft. containers could be fitted-side by side on the main deck, with a 6-abreast upper deck and two LD3 containers below the main deck.

The flight deck was placed at the front of the upper-deck, which blended with the main deck to give a nose shape with adequate pilot vision.

Other fuselage design choices were postponed until the overall aircraft configuration had been decided -- see below.

5.4 Aircraft Configuration Layout Choice

The first configuration choices were made during the parametric study. They were that twin turbo-fan engines would be used. Those were considered to be the most cost-effective solution for a high-subsonic speed airliner.

### 5.4.1 Engine Position

The choice of wing-mounted podded engines was made for the following main reasons:

i) Engine position was relatively close to the aircrafts' fore-and-aft centre of gravity and gave payload and fuel loading flexibility.

ii) Wing weight saving due to inertial bending relief from the engines

iii) Simple fuel feed from wing fuel tanks to the engines

iv) Relatively easy engine maintenance access

v) Avoidance of weight penalties and potential acoustic fatigue problems associated with fuselage-mounted engines

It was felt that these advantages out-weighed the disadvantages, compared to those of fuselage-mounted engines, of interior noise, interference with wing high-lift systems and yaw control following engine failure.

### 5.4.2 Vertical Wing Position

The next major decision was the choice of vertical wing positions, and this is where the A-90 differs most from comparable aircraft.

The original choice was between high and low wing, because of the problem of providing wing bending carry-through structure in the fuselage. The first choice was a high-wing, but advice from an industrial designer modified this to a mid/high wing. Fig. 10 shows how this was achieved. The wing structure passes through the fuselage at the intersection of the upper and lower fuselage lobes. There is a clearance of more than 8 ft. between the wing lower surface and main-deck floor for uninterrupted loading of 8 ft. containers. The upper deck is partially divided by the upper-surface of the wing, but there is sufficient space for emergency transit between each half of the deck and access to the over-wing exits.

This arrangement thus combines the low interference drag of a mid-wing and the structural efficiency of a high-wing.

Other advantages of this layout were:

i) Good ground-clearance for the underwing pods of the 10 ft. + diameter engines. (This was the primary reason for this choice.)

ii) The fuselage is closer to the ground because of less severe engine clearance problems. This eases cargo loading, passenger loading, and emergency passenger evacuation. The low fuselage facilitates the conversion of the aircraft of a military transport role, with loading ramps.

iii) Easier access for fuselage maintenance, lavatory servicing, and galley replenishment.

iv) Main-deck passenger vision is improved, except directly next to engines.

The disadvantages of this layout, relative to the more usual low-wing layout were:

i) The ditching properties are not as good. This would be an extremely rare event, and the upper-deck over-wing exits should alleviate or eliminate this problem.

ii) The high-wing arrangement leads to fuselage-mounted main landing gears. Those are installed in fuselage blisters, with added weight and drag. Such a big aircraft, even with a low wing, however, would still require one or two fuselage main-legs.

5.4.3 Tail Configuration

The mid/high wing location made a fuselage mounted tailplane unattractive due to downwash. A high T-tail was chosen and mounted in such a position as to minimise deep stall problems. This arrangement led to the advantage of increasing the tailplane moment-arm, thus reducing tailplane size. The tailplane also acts as an end-plate, and increases fin effectiveness. The disadvantages of this choice are those of increased fin and rear fuselage loads due to asymmetric tailplane lift, and maintenance access to a fin some 18 metres (60 ft) above the ground!

The latter problem was reduced by designing an internal maintenance ladder forward of the fin front spar, where the width was some 0.8M (2 ft 6") at the intersection with the tailplane.

5.4.4 Landing Gear Configuration Choice

A tricycle landing-gear was chosen, for the usual reasons. The main units were to be mounted on the low fuselage, because of the use of a mid/high wing. It was thought that multi wheel bogies would be required, and that more than two main legs, would be required, because of the aircraft's large size.

The sizing of wheels and tyres could not be done in advance of the aircraft weight estimate. This, and the disposition of the gear legs, was determined at a later stage.

5.5 Weight Estimates

Sufficient configuration information was available to perform an initial weight estimate. The basic shape of the aircraft had been determined, although the physical size of the wing and flying surfaces could not be known until the weight was known. This required an iterative approach in which an aircraft weight was estimated and then checked progressively by another Cranfield-developed computer program. This was based on a component build-up method utilising empirical methods (ref. 11). Table 5 shows a typical result for one of the A-90 program runs.

The program was used several times, as the design evolved. This was because initial estimates used simple fuel-burn calculation and drag estimates. These were refined together with control-surface sizes and this affected the aircraft weight. The program made allowances for the weight savings expected from advanced technology from the requirements of paragraph 4.1 above.

The final weight estimate was used with the output of the parametric study to determine the definitive engine thrust and wing area requirements.

Maximum all-up mass was 211075KG (465,000 lb) and as maximum wing loading was to be 583 KG/M$^2$, wing area became 362 sq. m. or 3900 Ft$^2$. A thrust/weight ratio of 0.308 led to a thrust requirement of 63.7 KN (143,220 lbf) from both engines, giving an individual engine sea level static thrust of 31.85 KN (71,600 lbf). Examination of available engine data suggested that the Rolls-Royce Trent 800 series engine would be a suitable candidate. This decision was reinforced by the fact that Rolls Royce P.L.C. have always been extremely helpful during the course of Cranfield projects. They have supplied detailed installed performance and installation data. In addition, they have supplied bleed pressures, flow rates and temperatures, so necessary in the detail design stages of the environmental control system.

### 5.6 Drag and Initial Cruise Estimates

Initial drag estimates were made with a computer program based on the simple method of ref. 12. More refined estimates were later made with Cranfield's DELTA program, which was based on a Lockheed method. This was augmented by extra drag for the blisters and the results used to get a better estimate for cruise lift/drag ratios. This, combined with better engine information, gave a check of cruise performance which modified fuel burn and weight estimates, as explained above.

The aerodynamic output of this process gave the cruise drag polar as shown in appendix A.

### 5.7 Aircraft Configuration Development

The fin and tailplane sizes were initially determined by using tail and fin volume coefficients. More elaborate stability and control calculations were performed later.

Component centre of gravity locations were estimated and synthesised to obtain whole aircraft C.G.s. Some components were then "juggled" to give an acceptable C.G. range.

The spanwise location of the engines were determined by comparison with modern twin airliners. This led to placement at 35% of the semi-span from the centre-line. The position of engine nacelles forward and below the wing was determined from published wing-tunnel tests by the Lockheed Aircraft Company.

## 5.8 Undercarriage Layout

The location of the landing-gears could be determined because engine and CG locations were known and the weight estimates gave the starting-point in wheel and tyre selection.

Ref. 12 was used to estimate single-wheel loads for groups of wheels. It was decided to use four main landing-gear legs, each with a 4-wheel bogie. These would retract simply into relatively small fuselage bulges. Calculations showed that standard Boeing 747 tyres could be used. They were 1.24 in dia. (49") and 0.43 m. width (16 in). Pressure was 13.79 bar (198 P.S.I.). It was found that the same tyres could be used in the nose unit, to reduce airline spares inventory.

Cranfield graphical layout methods were used to determine suitable locations for main and nose legs at all CG locations. This necessitated a slight increase of the rear fuselage up-sweep for clearance purposes. Fig. 11 shows the fuselage arrangement, together with the landing gears.

## 5.9 Take-off, Landing Performance and Flap Design

Initial take-off and landing performance requirements were important parts of the parametric study. These specified a $CL_{max}$ in take-off configuration of 1.8 and 2.5 in landing. One of the aircraft requirements was to use the Cranfield-developed variable-camber wing configuration. This used a supercritical section, similar to that chosen by the ADROIT wing program. The Cranfield 2-Dimensional wing data was converted to 3-dimensions using ref. 12 and it was found that the V-C wing gave adequate take-off performance with:

Leading-edge flap - 17% wing chord, $+6^{\circ}$ deflection
Trailing-edge flap - 35% wing chord, $+12^{\circ}$ deflection

These devices were split into 5 spanwise sections on each wing. All 5 could be used for manoeuvre load control and gust-load alleviation, whilst three inboard sections performed the flap function, and the outbound two provided roll control. (See Appendix A for the drawings.)

The inboard flaps are fitted with an auxiliary single-slotted flap to augment lift up to the $C_L$ of 2.5 required for landing.

The flaps may also be used in cruise with small deflections to optimise lift/drag ratios over a wide lift coefficient range. These devices could enable the wing to be used, with little modifications, in a 1000 passenger stretched aircraft or a military cargo version with air-drop capabilities.

It was decided not to build-in twist on the wing, as the V-C flaps could be used to eliminate tip stall.

More detailed take-off calculations were performed during the main design phase and performance was shown to be adequate.

## 5.10 Stability and Control Calculations

Extensive use was made of the MITCHELL stability computer program, developed by Cranfield from the method of ref. 13. This program uses aircraft geometry and weights information as input information. It calculates aerodynamic derivatives and inertias, then calculates longitudinal and lateral static and dynamic stability response for the aircraft.

The derivatives were used to manually check:

i) Elevator angle to trim
ii) Crosswind capability
iii) Fin stall
iv) Roll power

The aircraft originally had level 2 short period oscillation performance and Dutch roll performance. The design was modified but a yaw damper will be required. The rudder chord was increased to meet cross-wind requirements. The outstanding problem was aileron power in a sideslip. The dihedral was modified, but there was still a requirement to augment roll control with spoilers.

## 5.11 Performance of Conceptual Configuration

The modifications produced by the Stability and Control analyses led to the final configuration of the conceptual design phase. This was used for performance checks and led to the payload range curve shown in appendix A. It can be seen that the aircraft exceeded its requirements.

It was very difficult to estimate aircraft costs at such an early design stage, but two attempts were made. Ref. 14 has a plot of aircraft cost versus take-off wt. for jet transport aircraft. This predicted the A-90 to cost $80 M in 1989 dollars.

More recent data were used for current and projected aircraft and were plotted on fig. 12. Curves were drawn for maximum all-up weight and empty weight and predicted A-90 costs as $82 M and $92 M respectively in 1990 values.

A reasonable estimate was $85 M. Subsequent analyses were performed using more detailed information.

## 5.12 Aircraft General Arrangement

Fig. 13 shows the general arrangement drawing of the aircraft design after the conceptual design stage, immediately before the inception of the main design programme. Appendix A shows contemporary drawings of the fuselage wing and tail surfaces.

5.13 Loading Actions Preliminary Information

The Cranfield group design method requires the provision of considerable amounts of loading-actions information prior to the inception of the main design programme.

This is fully shown in appendix A, but will be summarised here. It was based on hand calculations, data-sheets and outputs from several of the computer programs that were used in the conceptual design process. The main loading information was:

i) Aircraft detailed geometry
ii) Undercarriage information
iii) Powerplant information
i) Masses, centres of gravity and inertias
v) Lift, drag and pitching moment data
vi) Stability and control derivations
vii) Mass targets
viii) Reliability targets
ix) Wing, tail and fuselage airload distributions
x) Wing, tail and fuselage inertial distributions
xi) The main design work programme.

## 6. THE MAIN DESIGN PROGRAMME

The design project method is summarised in para. 2 of this report and its major activities shown in fig. 1. Table 1 shows the names of students and staff of the project design team, and their responsibilities. A chronological description of activities follows below. Appendix C contains the minutes of a typical weekly design meeting to give an insight into this part of the design programme.

### 6.1 CAD Modelling

The development of an overall computer-aided design aircraft model was an early priority. It was to act as an electronic data base, provide a reference for interfaces, and help integration and visualisation.

A group of 4 or 5 students used the information provided in appendix A to produce individual "wire-frame" models of the wing, fuselage, tail unit and engine nacelles. These were synthesised into one complete model within two weeks of the start of the programme. The UNIGRAPHICS CAD system was used on a Cranfield VAX computer. This model was subsequently used to provide section "cuts" for the definition of fuselage frames, wing ribs, etc.

The next stage was to model the doors, windows and fairings on the fuselage. The model was then surfaced to produce coloured, shaded images as shown in figs. 14 and 15 of the whole aircraft, fig. 16 of the fuselage and fig. 17 of the engine pod. The shading high-lights the blending between the fuselage upper and lower lobes.

The CAD model was used as the basis of aerodynamic panelling method prediction of pressure distributions. CAD was also used in the production of detailed engineering drawings, as described later.

Fig. 18 shows a CAD drawing of the aircraft, showing the fuselage interior configuration of November 1990.

6.2 Loading Calculations - Structures

Table 6 indicates the loading tasks that were to be performed by all of the students. The aim was to take the preparatory information in appendix A and use it to determine the aerodynamic and inertia forces that would be exerted on the aircraft during a wide range of flight and ground cases. Those were determined during phase 1 by students working in small teams. They used loading actions course materials and produced computer programs to analyse hundreds of loading cases. An important input into this process was a revised inertial estimate as shown in table 6. These loads were then transformed into shear force, bending moment and torque diagrams for critical cases. These cases were then superimposed on SF, BM, and torque envelopes for each student's component. Fig. 19 shows the draft shear force envelope for the wing. This was subsequently modified by the use of the active control variable camber devices.

The loading process was a time-consuming and occasionally frustrating exercise, but it was the only way to get realistic structural requirements. Work is currently under-way to provide general-purpose computer programs to minimise this work. Sample hand calculations, however, will be required to ensure that students understand the calculation process.

6.3 Loading Calculations - Systems and Equipment

These calculations were more diverse than those for the structures, being more individual tasks.

The landing gear group checked take-off and landing performance, tyre sizes and ground loading cases.

Fuel usage calculations followed from aircraft performance work and suitable fuel tankage was determined in terms of volume and centre-of-gravity locations. It was found that the use of a fin fuel tank would considerably improve C.G. control. Fuel tank pressure loads were determined.

The use of a centre-wing fuel tank would give a range of 3,500 n. miles with a payload of some 350 passengers. It was found that the specified landing mass of 175,000 KG was too low to give operational flexibility at high payloads. It was increased to 185,000 KG but gave reduced landing performance. Engine and pylon loads were calculated for airborne and landing cases.

Flight deck and flying control system tasks included wind screen loading due to pressure and bird-strike, and flying control system loads.

The remaining system calculations concerned cooling, anti-ice, pressurization and electrical power loading requirements.

## 6.4 Design Development

Much preliminary work was performed in parallel with the loading work described above. The design proceeded in an integrated manner, but it is convenient to describe work in terms of the aircraft major components:

### 6.4.1 Wing

The wing spar positions were chosen to give good support to the large-chord leading and trailing-edge flaps. The wing span of 57 m (187 ft) was too large to meet the 155 ft. requirement of short-haul gates at many airports. Several wing-fold mechanisms were investigated with the fold being made inboard of the roll-control flaps. Structural optimisation calculations were performed for the configurations of the skin-stringer panels. The deployment of sliding variable-camber flaps led to severe problems with the swept hinge lines. Much work was done with drawings, CAD and even 3-dimensional cardboard models. A visit to Brittania Airways Boeing 767 maintenance hangar prompted a possible solution, but a more extensive change was adopted.

Fig. 20 illustrates various stages in the flap deployment, normal to the hinge line. The flap deployment was changed from the original configuration, which needed a 12.5$^{\circ}$ take-off setting and 37% chord extension, moving about a large-radius arc with sliding contact with the wing skin. It was decided to cantilever the rear upper wing skin panel from the rear spar and slide the smaller radius flap upper surface underneath the wing skin. This concept had greater rotation and smaller extension than the original scheme, for similar performance. A nested, slotted auxiliary flap was necessary for the landing performance.

Suitable fuel tank arrangements were made and tank rib boundaries defined. Fault Tree analyses were performed to maximise system safety. Engine attachments were schemed, as were pylon/wing and wing/fuselage attachments. Investigations were made into using the engine intake lip as a pre-cooler for the environmental control system, but this idea was rejected in favour of a electro - impulse de-icing system.

### 6.4.2 Fuselage

Local modifications were made to the fuselage at the wing intersection to ease attachment. Nose and rear fuselage pressure bulkheads were defined. Standard fuselage frame pitches were determined in conjunction with practically-optimised skins and stringers. Major frames were located at positions suitable for attachment of the nose and main landing gears, attachment of the wing, fin and auxiliary power unit.

Extensive use was made of Finite Element structural analysis to refine the structure.

The flight deck windows and surrounds were checked for vision and then designed. The avionics fit was determined and storage designed. The electrical power system runs were defined and APU chosen. It was decided not to have a hydraulic system, but to use electrical power. It was decided to use fibre-optical signalling and routes were determined.

There was just enough engine bleed air available for the ECS system in the event of a single engine failure, but insufficient remained for hot air anti-icing.

Interior arrangements were checked and final door sizes and positions were determined.

6.4.3 Tail Unit

Fin and tailplane spar locations were determined, as were fin/fuselage and fin/tailplane attachments. Work was done with Cranfield's COALA laminate analysis program to optimise the composite materials of these components. It was decided to have a two-section rudder.

6.4.4 Landing Gear

Several landing gear retraction schemes were investigated and drawn and the best chosen for further study. The decision was made primarily on the basis of the weights estimated for the alternatives. Shock-absorber oleo design was performed with the aid of a landing simulation computer model.

## 7. DESCRIPTION OF THE FINAL DESIGN

Figure 13 shows a general arrangement drawing of the aircraft and table 8 summarises its leading dimensions. This section will describe the major components of the aircraft, aided by copies of some of the two hundred engineering drawings that were produced by the students.

### 7.1 The Wing Group

A modest ¼ chord sweepback of 30°, combined with an advanced aerofoil section enabled an efficient cruise mach number of 0.86 to be achieved. Fig. 21 shows the arrangement of th fuel system in the wing and illustrates the main wing structure. The main box is a two spar arrangement with integrally machined skin stringer panels constructed from aluminium lithium alloys. The outer wing panel has an optional fold mechanism so that the A-90 folding wing span is less than that of the DC-10 to facilitate the use of current short haul airport terminals.

The very large turbo fan engines are attached to the wing by means of the pylons illustrated in fig. 22. This arrangement inevitably led to significant structural problems, which were solved by the partial use of very high grade steel components.

The engine pod and engine mounts were fully designed, as was the fire extinguishing system, shown in fig. 23.

The trailing - edge variable camber flaps perform several functions. The inner three segments per wing are used symmetrically in much the same way as conventional flaps, but the skin connection between the flaps and wing is always smooth, thus allowing the optimisation of lift/drag ratios throughout the flight. The flaps can be used in cruise with small deflections and can provide gust load alleviation and manoeuvre load control, in conjunction with the outer flaps. The flaps however do not provide enought lift for landing so nested auxilliary slotted flaps are used. Fig. 24 shows the inner flap scheme and fig. 25 shows the structural arrangement of the main flaps.

The outer two trailing-edge flap segments also provide high lift, but they act assymetrically to give roll control, augmented by spoilers. It was necessary to provide auxiliary slotted flap segments to give negative deflections. The construction is shown in figure 26. Drooped leading edge variable camber flaps have also been designed (fig. 27).

## 7.2 The Fuselage Group

The double bubble fuselage permits twin aisle 10 abreast seating on the main desk and six abreast seating in the upper decks to a total of 620 seats in all tourist or 500 seats in a mixed seating arrangement. Figure 28 shows a typical cross section which highlights the spacious cabin, capable of carrying two 8ft x 8ft containers across the main deck. Standard LD 3 containers may be carried under the main deck. This fuselage permits easy development of civil or military cargo versions.

Figs 29 to 31 show drawings of forward, centre and rear fuselage sections. All the main structural items were designed and stressed. The construction is of a semi-monocoque fuselage shell using aluminium lithium alloys.

Fig. 32 shows the distribution system for the cabin environmental control system, which is the semi-recirculating type.

## 7.3 The Tail Group

The aircraft utilised a trimming high TEE tailplane and elevator combination mounted some 18 metres from the ground!

The tailplane is of skin stringer construction, pivotted to the top of the fin.

The elevator is made from carbon fibre honey comb sandwich panels and actuated by faired, external actuators as shown in fig. 33.

The large fin was also designed with carbon fibre reinforced plastic construction. It formed the walls of the integral fin fuel tank which is used to optimise the aircraft centre of gravity location.

## 7.4 The Systems Group

Mention has already been made of the fuel system, environmental control and powerplant installations. Other systems were designed in some detail:-

- i) Nose landing gear (fig. 34)
- ii) Main landing gear (fig. 35)
- iii) Anti-icing system
- iv) Flight deck layout and avionics installations
- v) Flight control system, utilising fibre-optic signalling. Fig 36 shows a schematic of the system
- vi) The secondary power system was unusual in being almost totally electro-mechanical in operation, to reduce the weight and maintenance cost of hydraulic systems. Fig. 37 shows a schematic of the electrial system.

## 8. DISCUSSION

### 8.1 Mass

The initial mass targets were set by the use of semi-empirical prediction methods. The main phase of the design project produced stressed scheme drawings for many of the major components. These were used to give a good mass estimate of those components, and the rest of the aircraft, by comparison. These estimates are shown in table 9 and compared with component targets. Several points are worthy of comment:-

i) The wing group was some 3 tonnes heavier than the target. This was largely due to the complexity of the variable camber device, and conservative structural design of the flap structures.

ii) The hydraulics were largely eliminated except for a couple of local areas. The electrical system was lighter than predicted, but the actuators were included in the structure allowances for the flying control surfaces.

iii) The system components were less detailed in their design than the structure, and may have been under-estimated.

iv) Some items, such as the furnishings were not designed, so the target values were assumed to be correct.

v) The Manufacturers Equipped Mass was estimated to be some 5 tonnes lighter than the target, but the uncertainties mentioned above led to the decision to increase the MEM tolerance to 7.6% rather than the 2% required by the Association of European Airlines. This left the all-up mass unchanged.

### 8.2 Performance

Performance checks were made by the powerplant installation designer who produced a more accurate payload-range curve based on a better drag estimate than that of appendix A. This is shown as fig. 38 and indicates that the aircraft would exceed the specification requirements, giving a 500-passenger range of 2260 N. MILES, rather than the required value of 2000 N miles.

The economical cruise Mech No. was predicted to be 0.83 with high speed at 0.86. The optimum performance over the 2000 mm range was cruise at M = 0.81 at 37,000 ft altitude.

It was possible to meet the specificed all up mass takeoff field length of 8300 ft at ISA conditions, but more power would increase climb gradient after the failure of one of the very large engines.

The increase in the maximum landing mass meant that the landing field length increased to 7750 ft. This is still reasonable performance, but the specified performance could be achieved by the use of more powerful auxilliary flaps.

The aircraft meets the runway LCN requirement of 65 and exceeds the internal space requirements for passengers.

Trans-Atlantic or trans continental flights of 3,500 n miles should be possible with 345 passengers.

8.3 Cost Estimates

The very simple empirical method shown earlier estimated that aircraft first cost to be 85 M US Dollars (1990).

More detailed estimates were made using the method of ref. 14. This included development and production costs and gave figures of:-

$67 M US per aircraft for 1000 aircraft produced
$80 M US per aircraft for 500 aircraft produced

This compares with figures quoted during a visti to the Boeing Factory of $64-89 M for a Boeing 767 and $106 - 126 M for the Boeing 777.

The A-90 is likely to be between those aircraft in capability, so the estimate seems reasonable, given the uncertainty in data, particularly for engines and avionics.

Estimates of Direct Operating costs will be made in the near future.

8.4 General Points

The basic aircraft concept seems sound and the design shows the promise of meeting its requirements. It's mass and performance are generally adequate, and the wing fold, LCN and turning circle are such that it could use conventional short-haul terminals. The 3,500 n m range means that Trans Atlantic or trans USA flights are possible with approximately 350 passengers. The aircraft would be particularly suitable for Pacific rim operations where 620 single class passengers could be carried up to 1700 n miles.

New technology has been incorporated in several important areas, to achieve this performance:-

i) Powerplant

The new technology Trent engine offers excellent fuel economy and noise characteristics. The very large size of these engines led to the novel mid shoulder wing arrangement mentioned earlier. This will minimise Foriegn Object damage to the engines and high lift systems

ii) Variable Camber Flaps

These have the potential of optimising cruise lift/drag and producing performance improvements that our simple drag programs were unable to quantify. They led to formidable engineering problems when practical deployment schemes were investigated. Suitable methods were found, but the extension geometry had to be modified. The variable camber flaps (V-C) allowed the attainment of a wide range of cruise and climb lift coefficients with the fuselage largely horizontal. This has drag and passenger comfort advantages, not mentioning easing flight attendants problems with meal trolleys! The V-C flaps, linked with a sophisticated active control flight control system, could provide gust and manoeuvre load alleviation and prevent tip stall without built-in washout.

One of the students proposed the alternative arrangement shown in fig. 39 which incorporates a kinked wing. It would be much easier to engineer the unswept inner V-C flaps for use in cruise lift control. Conventional slotted flaps could then be used to augment take-off and landing performance.

iii) Advanced Systems

620 passenders and a large crew posed serious problems for the design of the environmental control system. The twin engined high bypass engine arrangement had distinct airlow supply problems in the event of a single engine failure. This was solved by using all the engine air for the ECS system. This left nothing for hot air anti-icing, so an electro impulse, de-icing system was design. The student designing the secondary power system decided to eliminate the mass and maintenance problems of the hydraulic system. Careful power scheduling meant that the engine and APU electrical power was always adequate. Some students suggested local eletrically powered hydraulic systems to supply activator power.

Considerable work was done on the design of the optically signalled flight control system, with significant potential benefits. Reliability calculations showed adequate systems integrity to meet safety requirements.

iv) Materials

The majority of the airframe was designed to be constructed from aluminium lithium alloy, with most of the flying control surfaces and the entire tail unit of carbon fibre composite materials.

Adequate design computer programs were available to give confidence that these designs were sound. These features mirror current practice in modern transport aircraft design.

v) Validation of the Aircraft Flight Dynamics

The A-90 project was considered to be a good subject for teaching and research in the 1990/1991 Cranfield Flight Dynamics MSc course. Fifteen students were given the responsibility for computer simulation of the aircraft, each at a different part of the flight profile. They produced six degree of freedom models of the aircraft. Ref. 15 describes the work done in the critical landing configuration. Part of the phugoid response simulation is shown in fig. 40.

The author's original calculations had shown that the aircraft should meet civil aircraft Stability and Central criteria. The students' simulations were checked against the stringent military transport requirements of Defence Standard 00-970 and also found to be satisfactory. Those of ref 15 showed level 1 performance in the critical landing phase.

The Flight Dynamics students were excited about the simulation of such a realistic and challenging project. They interacted well with the Aircraft Design students and therefore increased to project team to some 40 students and 7 staff. It is hoped to further increase student and staff participation by the inclusion of aerodynamics, avionics, air transport and applied psychology students. This raises the spectre of a project with some 90 students and 15 staff, with a manpower expenditure of some 50,000 hours! The project management task will be formidable.

vi) Future Development Potential of the A-90

The fuselage cross-section was chosen so that a stretch in capacity to 1000 passengers would be relatively easy to achieve. The variable camber devices have the potentil of providing much of the extra lift required in cruise, but some wing area increase would probably be required. Field performance would be problematical with twin engines on such a large aircraft and 3 or 4 engines would be better. This would help the air-supply problem mentioned earlier.

It would be quite easy to modify the existing design into a civil or military cargo aircraft.

It would be possible to fit 12 standard 8 ft x 8 ft x 20 ft containers on the main deck. These would have the capability of carrying some 70 tonnes of cargo, which is more than the current payload limit of 56 tonnes. There is additional cargo volume on the upper deck and in the LD3 containers of the lower deck. It can thus be seen that cargo volume is not a problem.

Research work is required into the emergency evacuation, ditching and impact on airports of such large high aircraft. It is hoped that these issues will be addressed by groups of Cranfield students.

vii) The A-90 Project as a Teaching Exercise

The project provided a realistic environment in which students learned how to design practical components, work as a team and present their results orally, and in written theses. The theses contained some 200 engineering drawings, produced by traditional and CAD methods. Some 40 theses have been published, giving some 6000 pages of description and analysis.

Students have been given "hands-on" experience of the use of many modern computer techniques, such as CAD, Finite Element Analysis, Composite materials analysis as well as a wide range of dedicated analysis programs. They have researched up to date aeronautical technologies such as fibre-optics, all-electric aircraft, and advanced materials. These activities will provide information of use to other members of the aerospace community.

Students were drawn from many countries in the world, indeed the only continent not represented was South America.

These students will reach senior positions within their countries and, hopefully, benefit aerospace activities throughout the world.

## 9. CONCLUSIONS

i) A case has been made for the development of 500 seat class, short haul airliners.

ii) The A-90 project aircraft has been designed in considerable detail and has the potential of meeting mass, cost and airport requirements. It should exceed the range target of 2000 n miles with 500 passengers or carry 620 passengers 1700 n miles or 345 passengers for 3500 n miles.

iii) The novel shoulder wing arrangement gives good engine clearance and has considerable flexibility for civil or military cargo operations. Ditching characteristics should be adequate, but research is required in terms of emergency evacuation.

iv) The twin engine arrangement is feasible on such a large aircraft, but leads to potential problems with the provision of bleed air and secondary power. These were resolved by careful system design.

v) Practical schemes were produced for the deployment of variable camber flaps. They offered aerodynamic benefits and increased operational flexibility at the expense of increased complexity. Their effectiveness was increased by using them for gust and manoeuvre load alleviation, using fibre optics signalling. These designs should be continued and attempts made to further quantify their mass, aerodynamic and direct operating cost characteristics.

vi) The fuselage cross section was chosen so that it could be stretched to accomodate some 1000 passengers. It is likely that 3 or 4 engines would then be required.

vii) The project fulfilled its primary aim of giving a realistic design environment for the education of some 40 MSc students.

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TABLE 1

THE A-90 DESIGN TEAM

STUDENTS

| | |
|---|---|
| Nose Fuselage | J. O |
| Centre Fuselage | R.P. Jonkers |
| Rear Fuselage | W.Z.B. Wan Omar |
| Tail Fuselage | T. Askar |
| Fin | P.D. Friar |
| Rudder | J. Eiblmeier |
| Tailplane | I.P. Miller |
| Elevator | J.F.L.L. Grenier |
| Nose Undercarriage | P.J. Hopgood |
| Flight Deck | I-H. Tsay |
| Main Undercarriage | S.G. Gentles |
| Environmental Control | W-Y. Wang |
| Flight Control | C. Carré |
| Secondary Power System | B.J.M.L. Hubin |
| Inner Wing | W. Kuntjoro |
| Outer Wing | M.J. Stoltz |
| Inboard Variable-Camber Rear Flaps | L. Larrive |
| Outboard Variable-Camber Flaps | J.G.N. Landry |
| Wing Spoilers | L. Art |
| Leading Edge Flaps | A.P.F. Charles |
| Fuel System | D.H. Atton |
| Engine Pylons | J.J. Remacha |
| Powerplant/Performance | R. Van Den Berg |

STAFF

| | |
|---|---|
| Dr. J.P. Fielding | Project Director - up to Jan 1991 |
| Prof. D. Howe | Project Director - after Jan 1991 |
| Mr. J. Jamieson | Computer-Aided Design |
| Dr. R.I. Jones | Secretary and Systems Design |
| Mr. J.B. Young | Structures and Fatigue |

Also contributions from:

| | |
|---|---|
| Prof. J.L. Stollery | Aerodynamics |
| Dr. K. Garry | Aerodynamics |
| Mr. R. Golding | Air Transport and Avionics |
| Mr. A.F. Taylor | Safety and Fuel Systems |

TABLE 2 - LEADING PARTICULARS OF CURRENT OF PROJECTED LARGE AIRLINERS

| PARAMETER/AIRCRAFT | 747-400 | 777 | MDII | A330 | DC10-10 | A300-600 | A321 |
|---|---|---|---|---|---|---|---|
| All Up Wt. $W_G$(lb) | 873,000 | 550,000 | 605,500 | 460,500 | 440,000 | 376,000 | 181,200 |
| Landing Wt $W_L$(lb) | 630,000 | | 430,000 | 382,500 | 363,500 | 309,000 | 161,000 |
| Empty Wt.(lb) | 394,000 | | 277,000 | 255,150 | 243,000 | 190,000 | 100,800 |
| Engine Thrust (lb f) | 4x58,000 | 2x75,000 | 3x65,000 | 2x68,000 | 3x40,000 | 2x61,000 | 2x29,000 |
| T/W | 0.266 | 0.273 | 0.322 | 0.294 | 0.272 | 0.324 | 0.32 |
| Wing Span (ft) | 211 | 197/150 | 169.5 | 192.5 | 155 | 147 | 111 |
| 1/4 Chord Sweep (Deg) | 37.5 | | 35 | 30 | 35 | 28 | 25 |
| Wing Area ($Ft^2$) | 5650 | 4480 | 3648 | 3892 | 3550 | 2800 | 1320 |
| Wing Aspect Ratio | 7.88 | 8.66 | 7.88 | 9.52 | 6.79 | 7.72 | 9.35 |
| $W_G/S$ | 155 | 123 | 166 | 118 | 124 | 134 | 137.5 |
| Max. Passengers | 570 | 500 | 405 | 440 | 380 | 375 | 179 |
| Max. Payload (lb) | 140,800 | | 122,500 | 105,300 | 92,000 | 96,500 | 51,300 |
| Range at Max.Payload(nm) | 6950 | 4-4500/ 375Pax | 6000 M. | 3750 | 2950 | 3340 | 1750 |
| Max. Op. Mach No. | 0.92 | | 0.87 | 0.86 | 0.88 | 0.82 | 0.82 |
| Econ. Mach No. | | | 0.82 | 0.82 | | | |
| App. Speed (Kt) | 153 | | 148 | 137 | | 136 | 140 |
| Fuselage Dia. Ft. | 21 | 20.33 | | 18.5 | | 18.5 | |
| $W_L/W_G$ | 0.72 | | 0.71 | 0.83 | 0.825 | 0.82 | 0.89 |
| T.O. Field ISA/SL | 10,900 | | 10,600 | 8300 | 9800 | 7500 | 8545 |
| Landing (Ft.) | 7000 | | 6450 | 5650 | 5800 | 5100 | 5150 |

TABLE 3 - LARGE CIVIL ENGINE LEADING CHARACTERISTICS

| Parameter/Engine | Rolls-Royce Trent 871 | Pratt & Witney 4084 | General Electric GE-90B1 | GECF6-80 E1A/3 |
|---|---|---|---|---|
| Sea Level S.Thrust | 74,900 lb | 84,000 lb | 86,800 lb | 72,000 lb |
| S.F.C.(T.O.)lb/lb/hr | | | 0.278 | |
| Diameter (in) | 110 | 112 | 158 | 110 |
| Length (in) | 172 | 192 | 200 | 171 |
| Dry Weight | | 13,700 lb | | 10,726 lb |

TABLE 4 - SUMMARY OF AIRLINER FUTURE REQUIREMENTS

| Parameter | Airbus (1) (Ref. 3) | Airbus (2) (Ref. 4) | Boeing Ref. 5) |
|---|---|---|---|
| Projected Date | 2008 | 2005 | 2005 |
| Projected Fleet | 11136 | 7840 | 9935 |
| % of 240-350 Pass | 28% | - | 14% |
| % of 350 + Pass | 45% | 54% | 39% |
| Long Range 240 + Pass | - | 14% | 25% |
| Percent <130 Seats | 14% | - | 8% |

TABLE 5 - MASS COMPUTER PROGRAM PRINT-OUT (Not the final result)

```
Aircraft:  A90-9

Fuselage        :     31554
Wing            :     17923
Tail unit       :      2221
Undercarriage   :      7853
Nacelle(s)      :      2635
Pylons          :      2411
-------------------------------
STRUCTURE GROUP:      64597 kg

Engine(s)          :     14182
Lift jet(s)        :         0
Engine accessories:       1033
-------------------------------
PROPULSION GROUP  :      15215 kg

Fuel system                              :       1215
Separate tanks                           :          0
Flight controls                          :       1551
Hydraulics and Pneumatics                :       1411
Electrics                                :       3350
Radio, Radar and Navigation equipment    :       1726
Anti-ice or De-ice                       :        830
Fire extinguishing                       :        620
Auxiliary power unit (APU)               :        230
-----------------------------------------------------
SYSTEMS GROUP                            :      10934 kg

Pressurisation and Air Conditioning :       2079
Paint                               :        180
Furnishings                         :      18900
Armour protection                   :          0
-----------------------------------------------------
MISCELLANEOUS GROUP                 :      21159 kg

EMPTY MASS = 111905 kg

Service items  :      2250
Crew           :      1800
-----------------------------------------------------
AIRCRAFT PREPARED for SERVICE MASS:    115955 kg

Passengers     :      45000
Cargo          :          0
Fuel           :      45889
Stores         :          0
------------------------------------------
ALL UP MASS (or gross mass) = 206844 kg
```

TABLE 6 - LOADING GROUPS - A-90

LONGITUDINAL (SYMMETRIC PITCHING CASES) TAILPLANE LOADS (ALL-PHASE 1)

- Tailplane S.F., B.M. and Torque diagrams
- Overall longitudinal balance. SF and BM
- Fuselage torque diagrams

LATERAL (ASYMMETRIC FLIGHT CASES) FIN AND RUDDER LOADS (ALL-PHASE 1)

- Lateral Fin and Rudder balance - Fin SF, SM and Torque
- Rudder control loads, SF, BM and Torque
- Spoiler and pylon loads

WING GROUP (SYMMETRIC SURFACES CASES) WING, V-C DEVICE LOADS

- N-V and gust diagrams, spanwise loads, wing SF, BM and Torque, Pitch and Roll Cases
- T/E Flap speeds, loads, SF, BM and Torque
- L/E Flaps loads SF, BM and Torque

LANDING GEAR (GROUND LOAD CASES) LOADS AND LATERAL GROUND BALANCE

- Main gear loads
- Nose gear loads
- Field performance

SYSTEMS GROUP

- Engine loads, performance checks
- Fuel usage, CG and tank pressures
- Flying control loads, cockpit area, tailplane control loads
- Cockpit Transparency loads
- Power and ECS requirements
- Initial interior layouts

CAD GROUP

- Check specification drawings
- Construct models of major components
- Synthesise models

TABLE 7 - MASS, CENTRE OF GRAVITY AND INERTIA ANALYSIS PROGRAM FOR AIRCRAFT

Filename - A90
Description of file - A90 Airliner Mass Analaysis
Mission that was run - All Up Mass Fwd CG

| C G Envelope Limits | | Criteria |
|---|---|---|
| Maximum Mass (kg) | | 220000 |
| Minimum Mass (kg) | | 110000 |
| Fwd C G Pos @ Min Mass | (mm) | 26565 |
| Aft C G Pos @ Min Mass | (mm) | 27835 |
| Fwd C G Pos @ Max Mass | (mm) | 26565 |
| Aft C G Pos @ Max Mass | (mm) | 27835 |
| Normal C G Position | (mm) | 27200 |

| Ref | Description | MASS (kg) | XPOS (mm) | YPOS (mm) | ZPOS (mm) | IXX (kg m2) | IYY (kg m2) | IZZ (kg m2) |
|---|---|---|---|---|---|---|---|---|
| 1000 | Structure | 53631.000 | 28298 | 0 | 1250 | 2858975 | 10099946 | 12435151 |
| 2000 | Landing Gear | 7855.000 | 25303 | 0 | -3400 | 243310 | 888421 | 836300 |
| 3000 | Powerplant | 17609.000 | 22714 | 0 | -321 | 1792705 | 456597 | 2185692 |
| 4000 | Systems | 11285.000 | 29976 | 0 | -724 | 709162 | 624945 | 1157791 |
| 5000 | Equipment | 27575.000 | 26390 | 0 | 684 | 297131 | 923141 | 1164055 |
| 6000 | Avionic Fit | 1120.000 | 7200 | 0 | 2000 | 1278 | 430659 | 429381 |
| | Operating Empty Mass | 119075.000 | 26793 | 0 | 400 | 5902562 | 13423709 | 18208369 |
| 7100 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7200 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7300 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7400 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7500 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7600 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Basic Operating Mass | 119075.000 | 26793 | 0 | 400 | 5902562 | 13423709 | 18208369 |
| 8100 | Passengers | 47500.000 | 25669 | 0 | 869 | 215260 | 7543314 | 7541804 |
| 8200 | Cargo | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8300 | Unused | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Zero Fuel Mass | 166575.000 | 26473 | 0 | 533 | 6117822 | 20967023 | 25750173 |
| 9100 | Wing Fuel | 43706.000 | 27468 | 0 | 2353 | 5259237 | 314285 | 5396861 |
| 9200 | Fuselage Fuel | 794.000 | 53350 | 0 | 6310 | 22966 | 583503 | 560537 |
| | Total Gross Mass | 211075.000 | 26780 | 0 | 932 | 11400026 | 21864810 | 31707570 |
| | Corrected Total Inertia Due to Self Inertia | 211075.000 | 26780 | 0 | 932 | 11970027 | 22958051 | 33292949 |

TABLE 8 - A-90 LEADING DIMENSIONS AND MASSES

| | | |
|---|---|---|
| Wing Span | 57M | (187ft) |
| Wing Span-Folded | 40M | (131ft) |
| Gross Area | $361.95M^2$ | $(3896ft^2)$ |
| ¼ Chord Sweep | 30.0° | |
| Aspect Ratio | 8.98 | |
| Supercritial Aerofoil t/c = 14% Root, 10.2% MAC, 8% TIP | | |
| Anhedral | 3.0° | |
| Overall Fuselage Length | 59.3M | (194.5ft) |
| Max. Width | 6.56M | (21.5ft) |
| Height to Tailplane | 18M | (59ft) |
| Passenger Capacity (Mixed) | 500 | |
| Passenger Capacity (All Tourist) | 620 | |
| Powerplant | RR Trent 800 series | |
| All-up Mass | 211075 KG | (466,923lb) |
| Normal Fuel Mass | 44500 KG | (98,018lb) |

TABLE 9 - A-90 COMPONENT MASS ESTIMATES AND TARGETS

| COMPONENT | EST.MASS (KG) | TARGET |
|---|---|---|
| Wing Group-Structure (inc. actuators) | 20790 | 17920 |
| Fuselage Structure | 28315 | 31554 |
| Fin and Rudder (inc. actuators | 1934 | 1200 |
| Tailplane & Elevators (inc. actuators | 1180 | 1020 |
| Undercarriage | 8420 | 7855 |
| Pylons | 2160 | 2100 |
| STRUCTURE | 62799 | 61649 |
| ENGINES, POWERPLANT STRUCT & ACCESS | 14008 | 15509 |
| Fuel System | 1324 | 1215 |
| Flying Control System | 1395 | 1551 |
| Hydraulics | 32 | 1411 |
| Electrical System | 1680 | 3350 |
| APU | 260 | 230 |
| Inst. & Avionics | 1100 | 1120 |
| De-ice | 397 | 830 |
| Fire Protection | 80 | 620 |
| Furnishings | 7100 | 7100 |
| Environmental Control System | 1423 | 2078 |
| Paint | 180 | 180 |
| SYSTEMS & EQUIPMENT | 14971 | 19685 |
| Manuf Equipped Mass | 91778 | 96843 |
| MEM Tolerance | 7002 | 1937 |
| Crew & Provisions | 3690 | 3690 |
| Seats, Emergency Equipmentt Pax Service | 11800 | 11800 |
| Nom OEM | 114270 | 114270 |
| 2% Mid Life | 2285 | 2285 |
| Pallets & Containers | 2520 | 2520 |
| OPERATING EMPTY MASS | 119075 | 119075 |
| 500 Passengers and Baggage | 47500 | 47500 |
| Fuel at Above Payload | 44500 | 44500 |
| MAX ALL UP MASS | 211075 | 211075 |

## FIG. 1 A-90 PROGRAMME TIMESCALE

Key: ▒ Staff (part-time) ▓ Students & Staff

| TASK | 1990 J | F | M | A | M | J | J | A | S | O | N | D | 1991 J | F | M | A | M | J | J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PREPARATION** | | | | | | | | | | | | | | | | | | | |
| Information Gathering | ▒ | ▒ | | | | | | | | | | | | | | | | | |
| Market Investigations and Spec. Derivation | | | | | ▒ | | | | | | | | | | | | | | |
| Parametric Study | | | | | | ▒ | | | | | | | | | | | | | |
| Conceptual Design | | | | | | | ▒ | ▒ | ▒ | | | | | | | | | | |
| **THE MAIN DESIGN PROGRAMME** | | | | | | | | | | | | | | | | | | | |
| CAD Modelling | | | | | | | | | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | | | | |
| Structures Loading CALCS | | | | | | | | | | ▓ | ▓ | ▓ | | | | | | | |
| Systems Loading CALCS | | | | | | | | | | ▓ | ▓ | ▓ | | | | | | | |
| Scheme Drawings | | | | | | | | | | | ▓ | ▓ | ▓ | ▓ | | | | | |
| Structural Design & Analysis | | | | | | | | | | | ▓ | ▓ | ▓ | ▓ | ▓ | | | | |
| System Design and Analysis | | | | | | | | | | | ▓ | ▓ | ▓ | ▓ | ▓ | | | | |
| Weight Estimation | | | | | | | | | | | ▓ | | | | ▓ | | | | |
| Fatigue or Reliability CALCS | | | | | | | | | | | | | ▓ | ▓ | ▓ | | | | |
| Final Drawings | | | | | | | | | | | | | | | ▓ | ▓ | | | |
| Thesis Write Up and Typing | | | | | | | | | | | ▓ | ▓ | | | | ▓ | | | |
| Thesis Hand-In | | | | | | | | | | | | | | | | | | | |
| **ASSESSMENT AND REPORTING** | | | | | | | | | | | | | | | | | | | |
| Thesis Assessment | | | | | | | | | | | | | | | | | ▒ | ▒ | ▒ |
| A90 Project Report | | | | | | | | | | | | | | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |

## World Air Travel Forecast

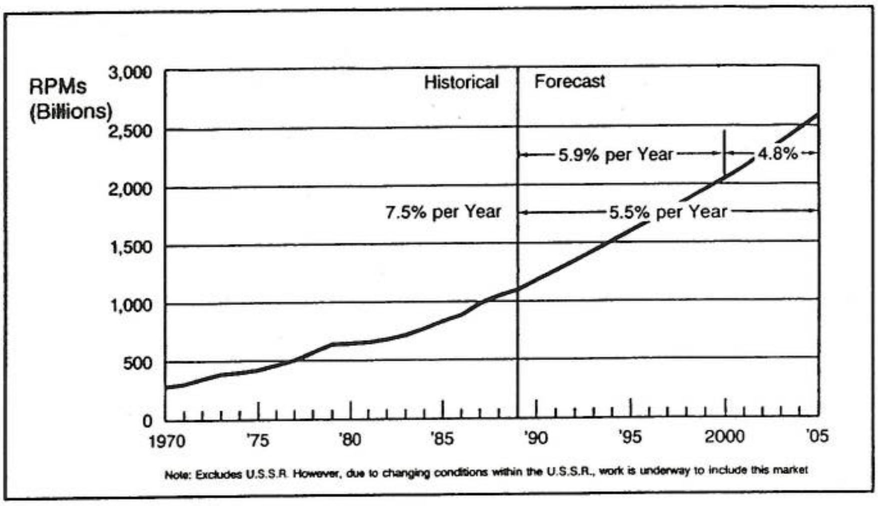



FIG. 2 (COURTESY BOEING COMMERCIAL AIRPLANE Co)

## World Capacity Requirement

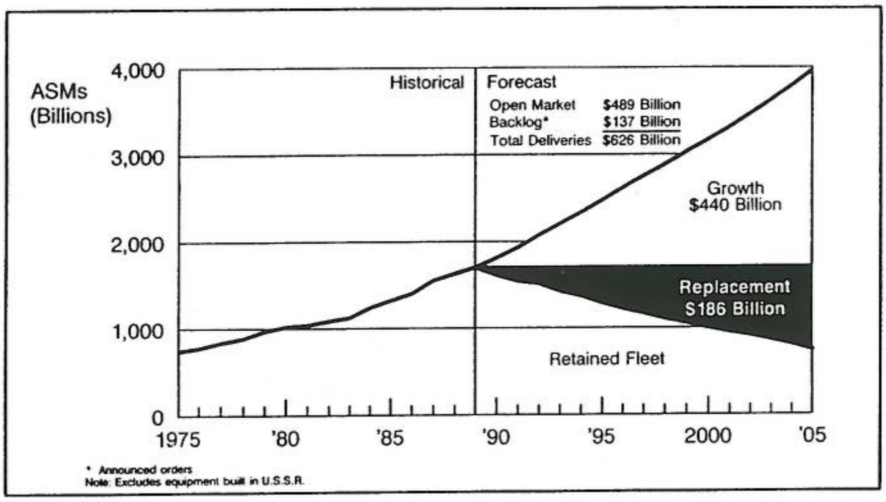



FIG. 3 (COURTESY BOEING)

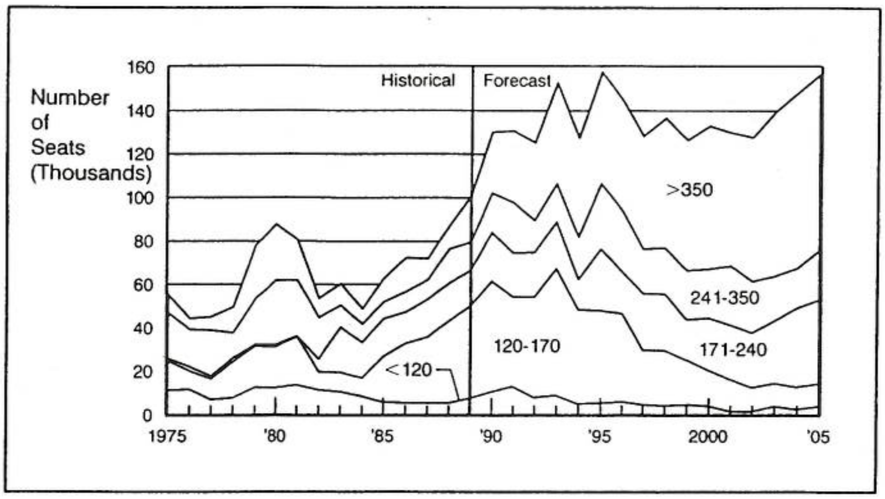



FIG. 4 SEAT REQUIREMENTS
(COURTESY BOEING)

World Air Travel Growth—RPMs

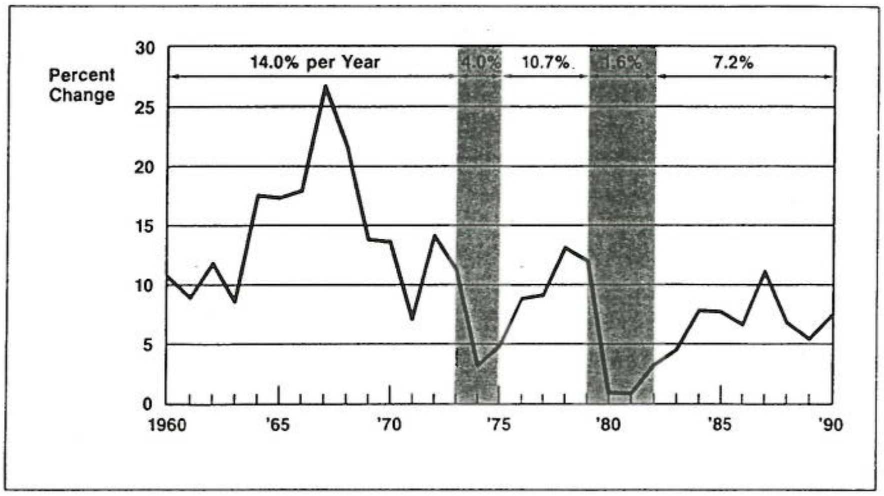



FIG. 5 (COURTESY BOEING)

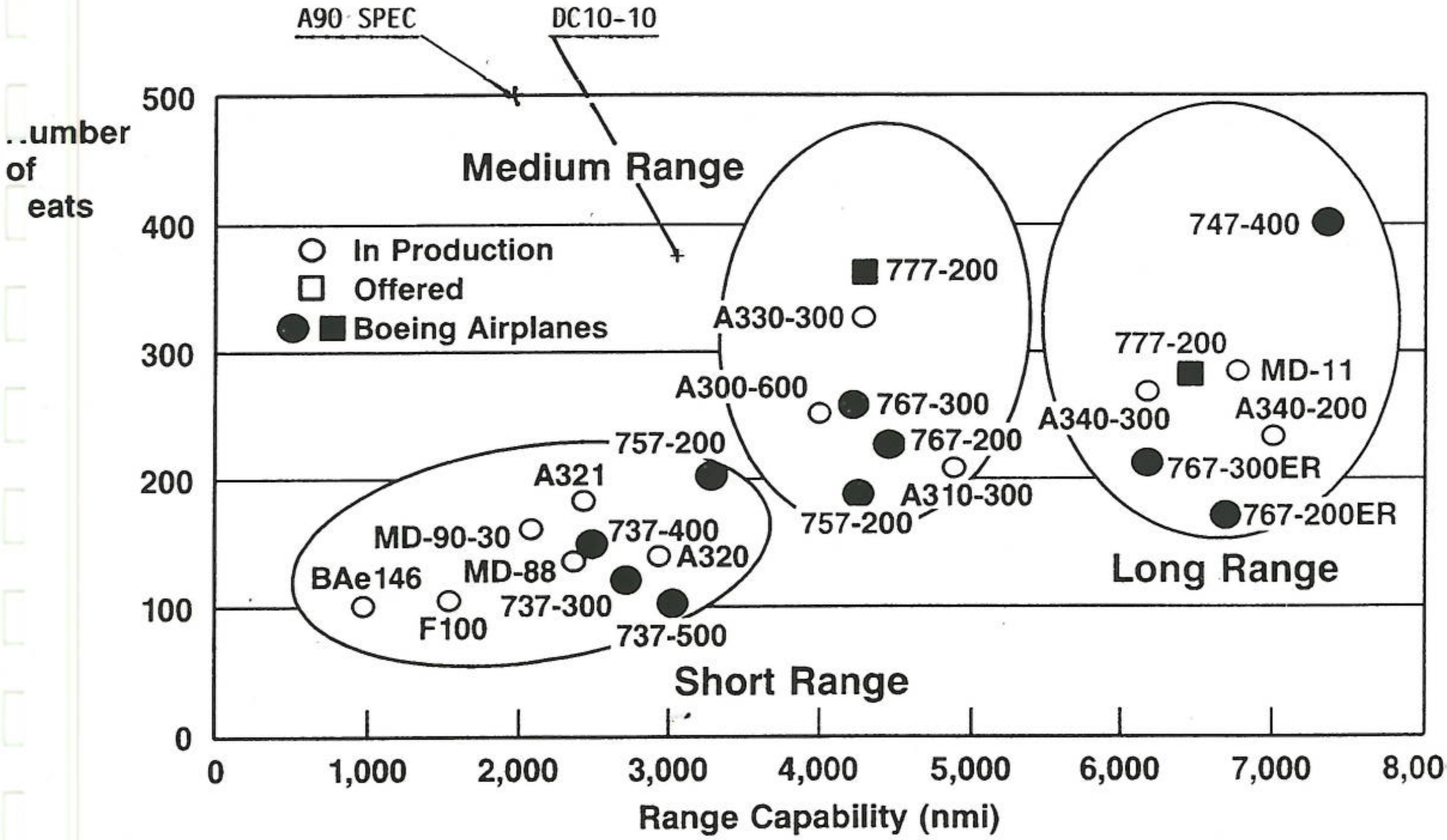
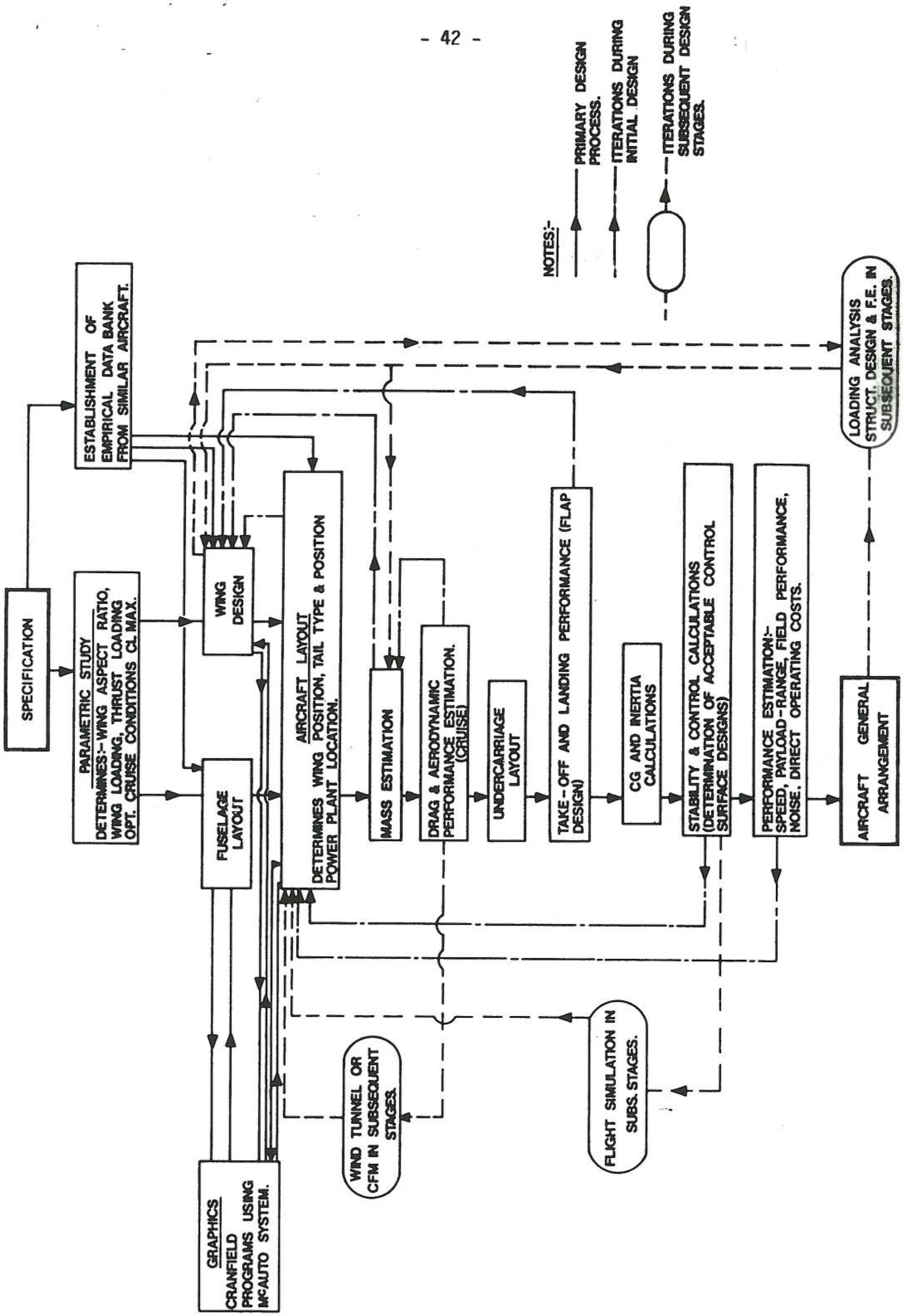



FIG. 6 (COURTESY BOEING)




MAJOR STAGES IN AN AIRLINER INITIAL DESIGN PROCESS

FIG. 7

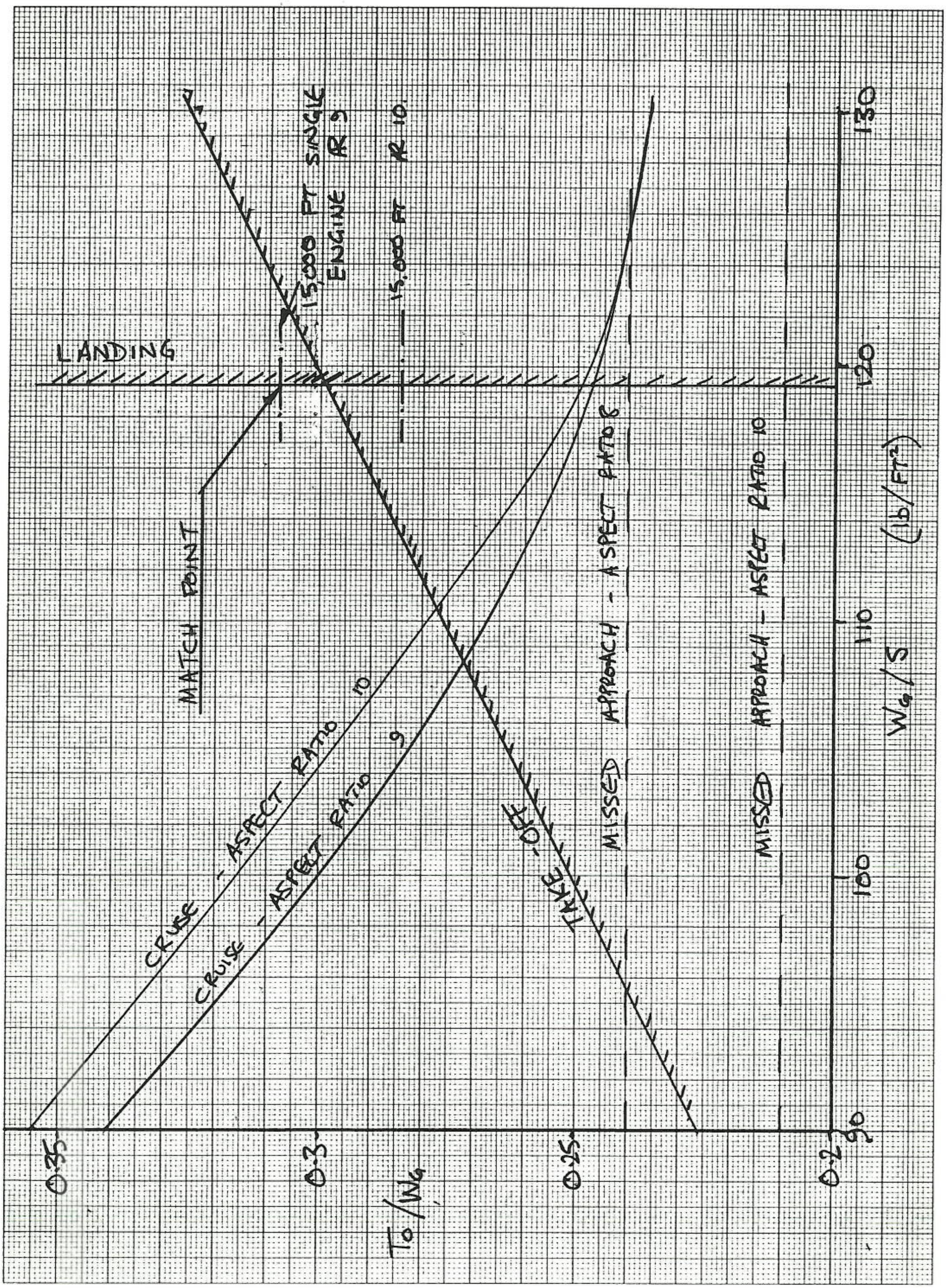



FIG. 8 PARAMETRIC STUDY RESULTS (SIMPLIFIED)

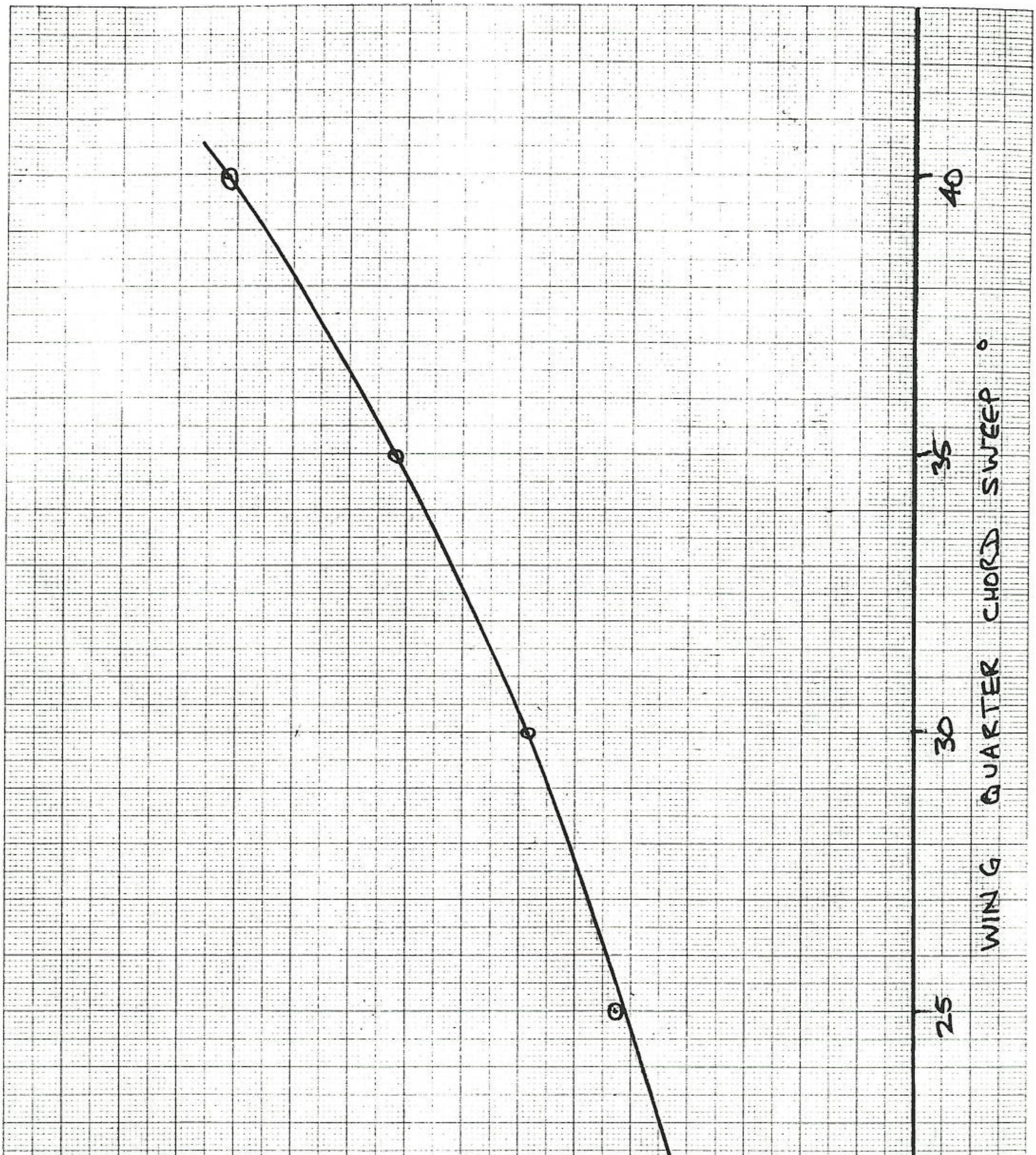



FIG. 9 EFFECT OF WING SWEEP ON MASS

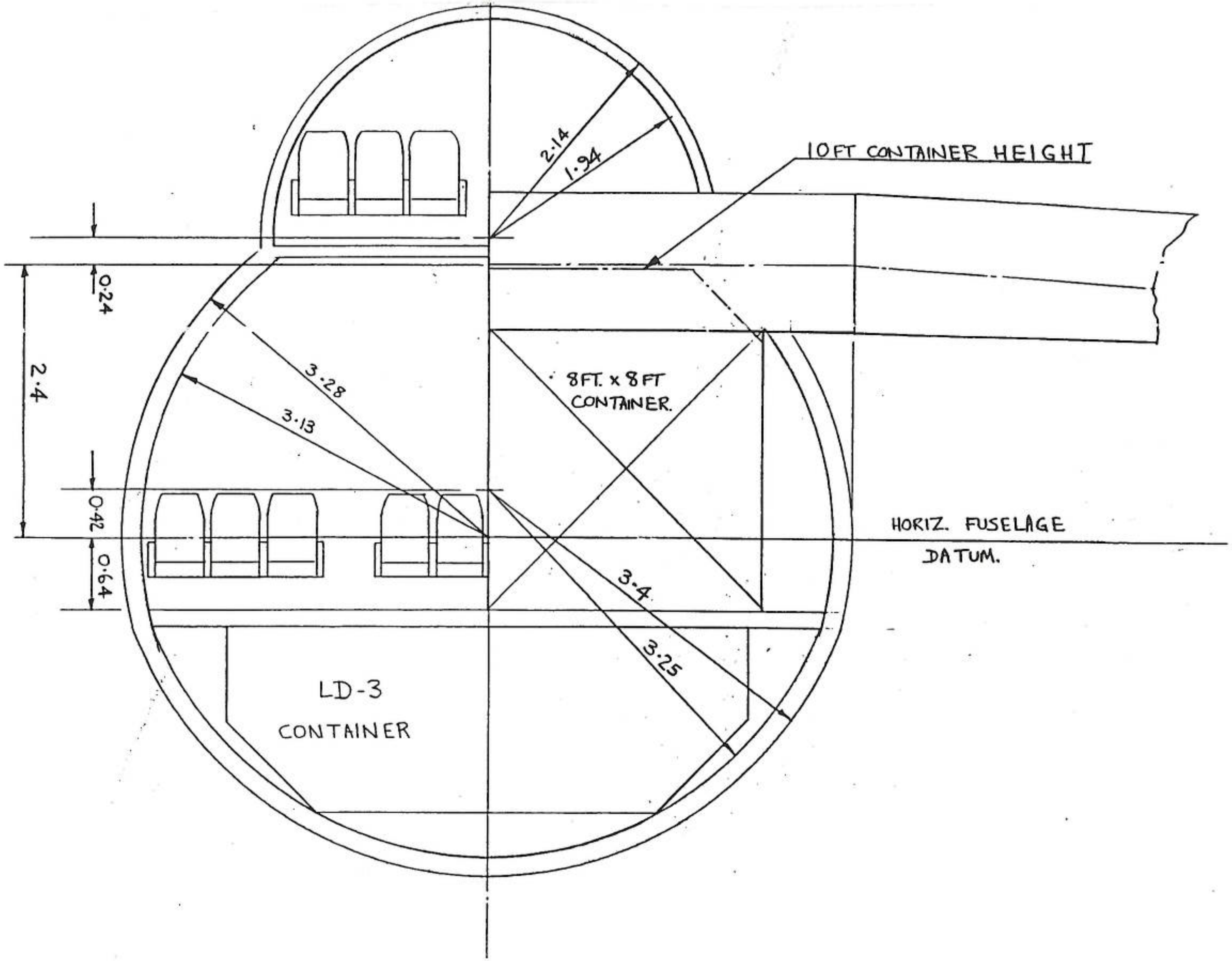



FIG. 10 FUSELAGE CROSS SECTION (METRES)

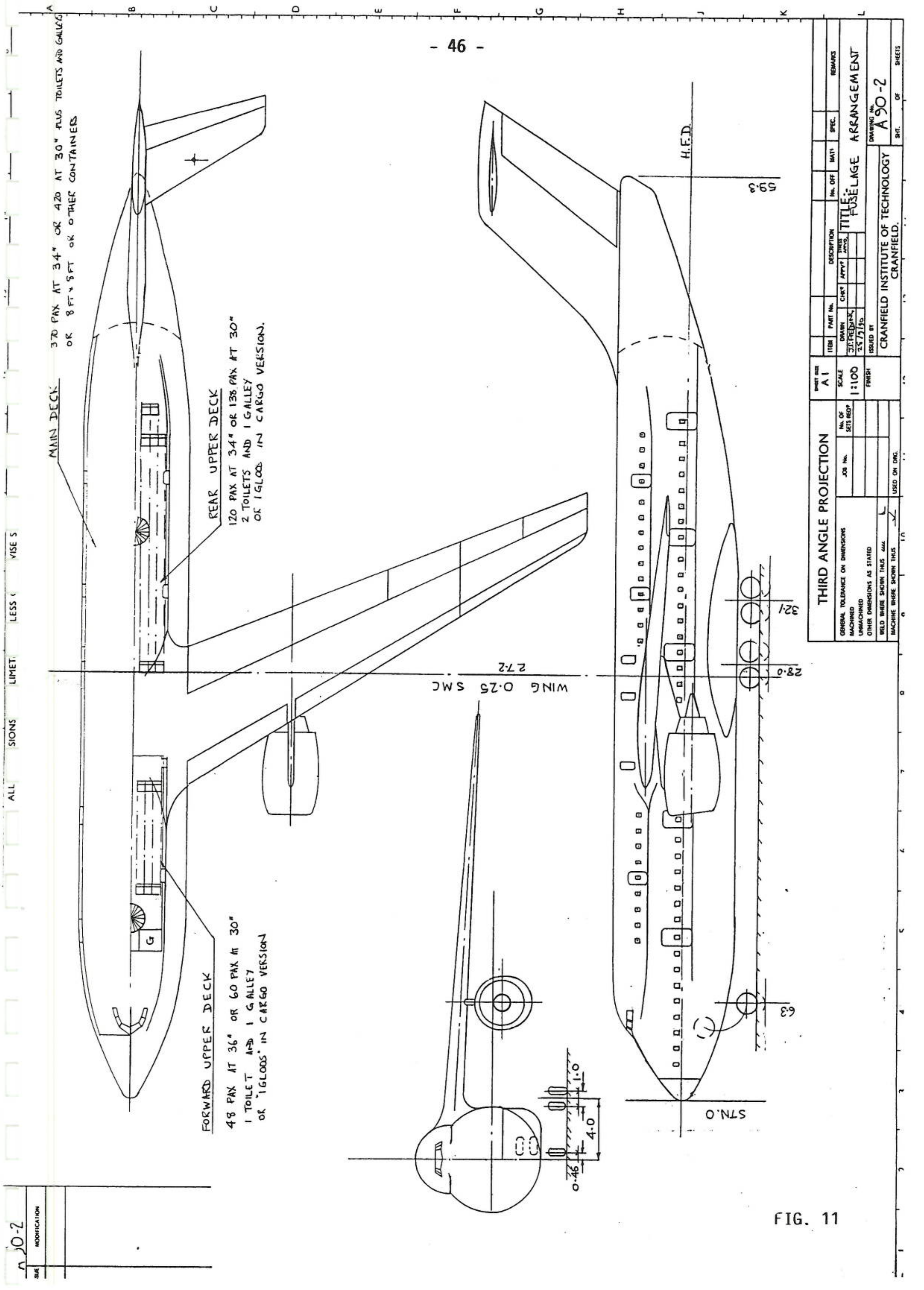

THIRD ANGLE PROJECTION
TITLE: FUSELAGE ARRANGEMENT
CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD.
DRAWING No. A90-2
SCALE 1:100
SHEET SIZE A1
DRAWN J.T. FIELDING 25/7/90
MAIN DECK
370 PAX AT 34" OR 420 AT 30" PLUS TOILETS AND GALLEYS
OR 8FT × 8FT OR OTHER CONTAINERS
REAR UPPER DECK
120 PAX AT 34" OR 138 PAX AT 30"
2 TOILETS AND 1 GALLEY
OR 1 GLOOS IN CARGO VERSION.
FORWARD UPPER DECK
48 PAX AT 36" OR 60 PAX AT 30"
1 TOILET AND 1 GALLEY
OR 'IGLOOS' IN CARGO VERSION
WING 0.25 SMC
27.2
H.F.D.
59.3
32.1
28.0
6.3
STN.0
1.0
4.0
0.46
G

FIG. 11

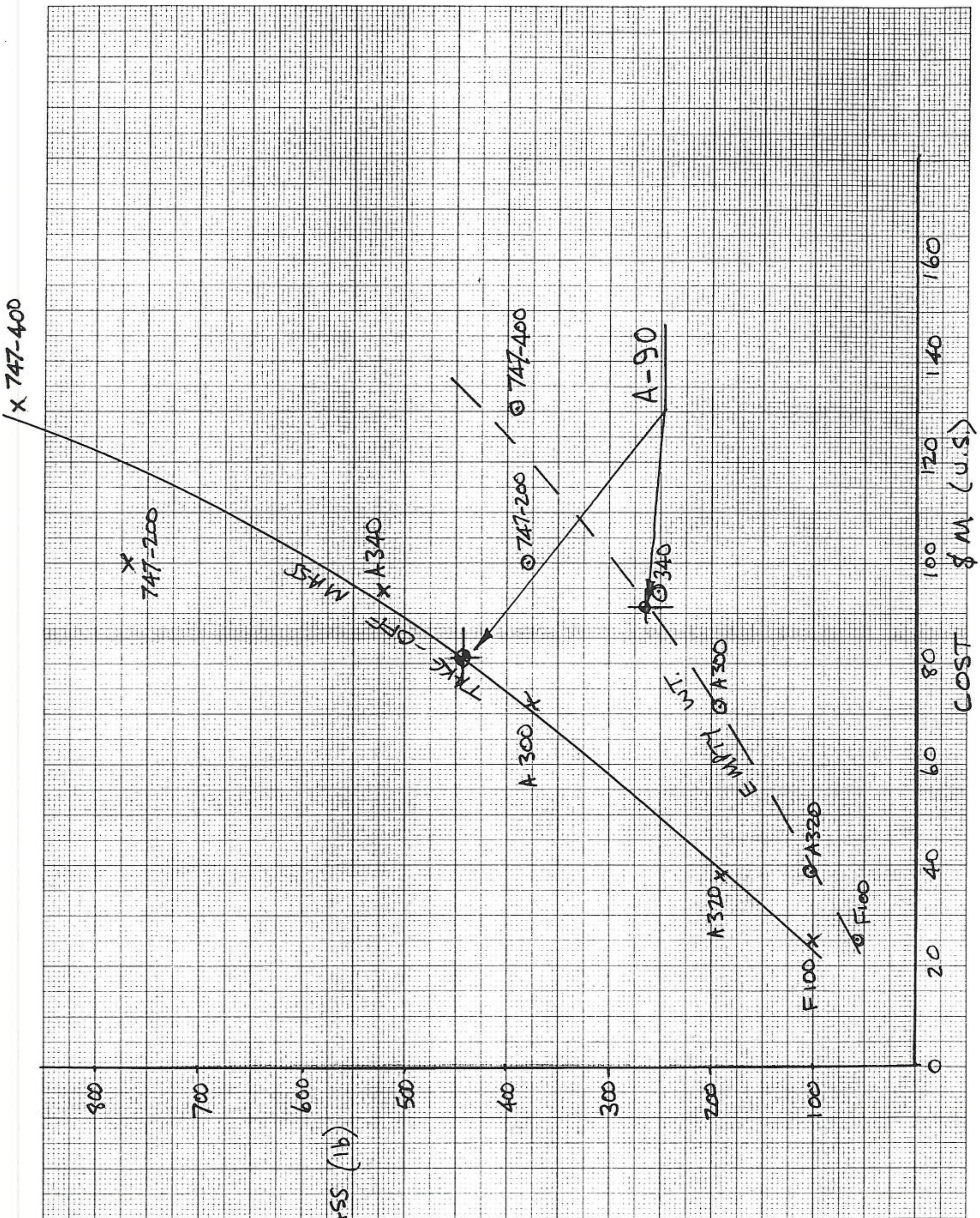

MASS (lb)
COST $M (U.S.)
800
700
600
500
400
300
200
100
0
20
40
60
80
100
120
140
160
747-400
747-200
A340
A300
A320
F100
340
A-90
TAKE-OFF MASS
EMPTY WT.

FIG. 12

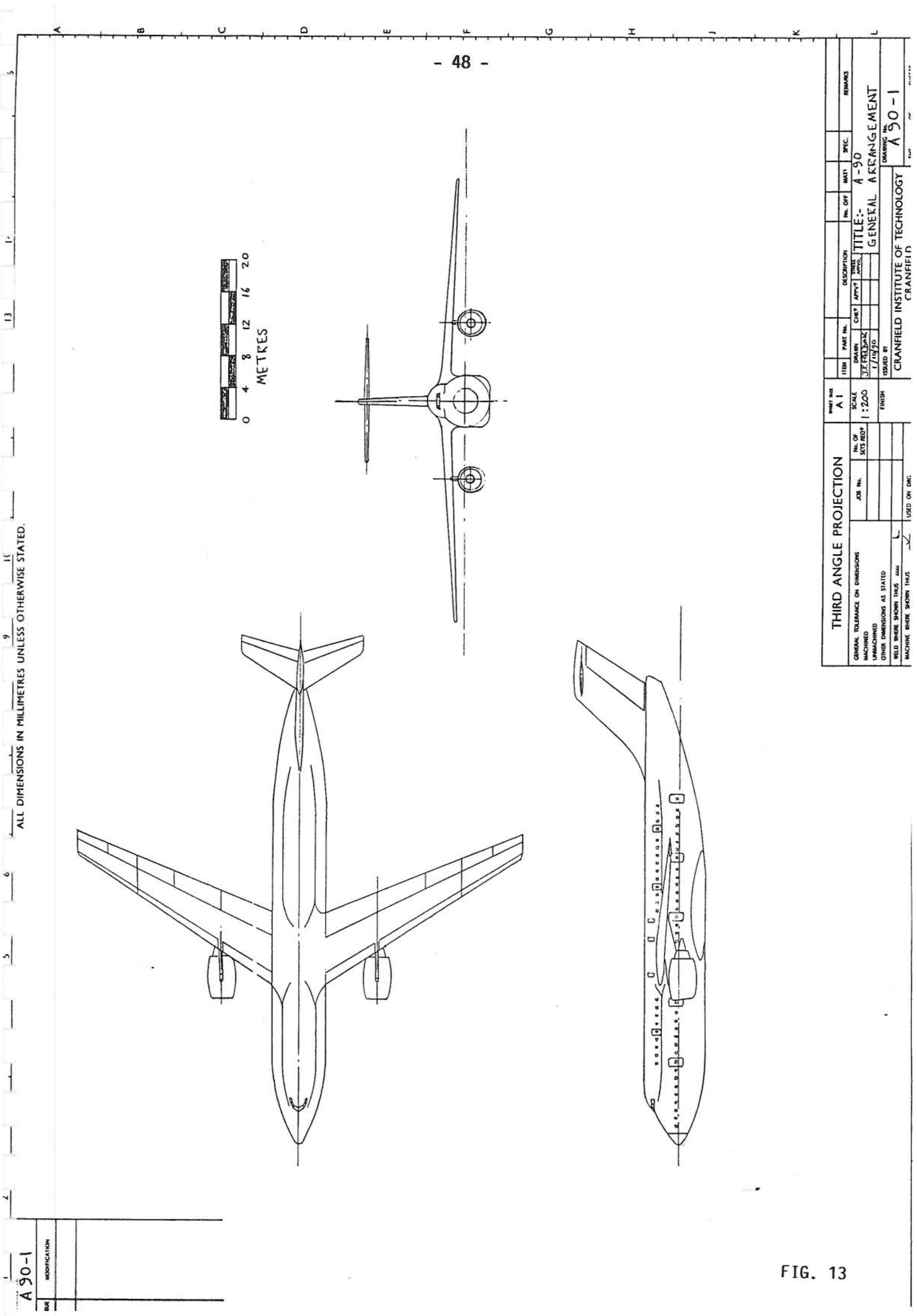

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED.
0 4 8 12 16 20
METRES
THIRD ANGLE PROJECTION
GENERAL TOLERANCE ON DIMENSIONS
MACHINED
UNMACHINED
OTHER DIMENSIONS AS STATED
SHEET SIZE A1
SCALE 1:200
DRAWN J.P. FIELDING 1/10/90
TITLE:- A-90
GENERAL ARRANGEMENT
DRAWING No. A 90-1
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD
A 90-1
MODIFICATION

FIG. 13

FIG. 14

FIG. 15

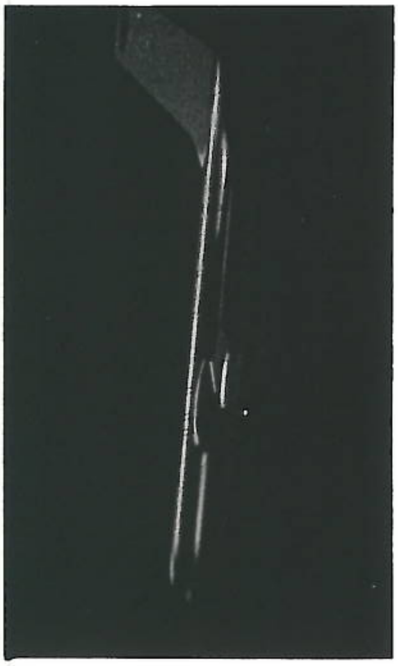


FIG. 16

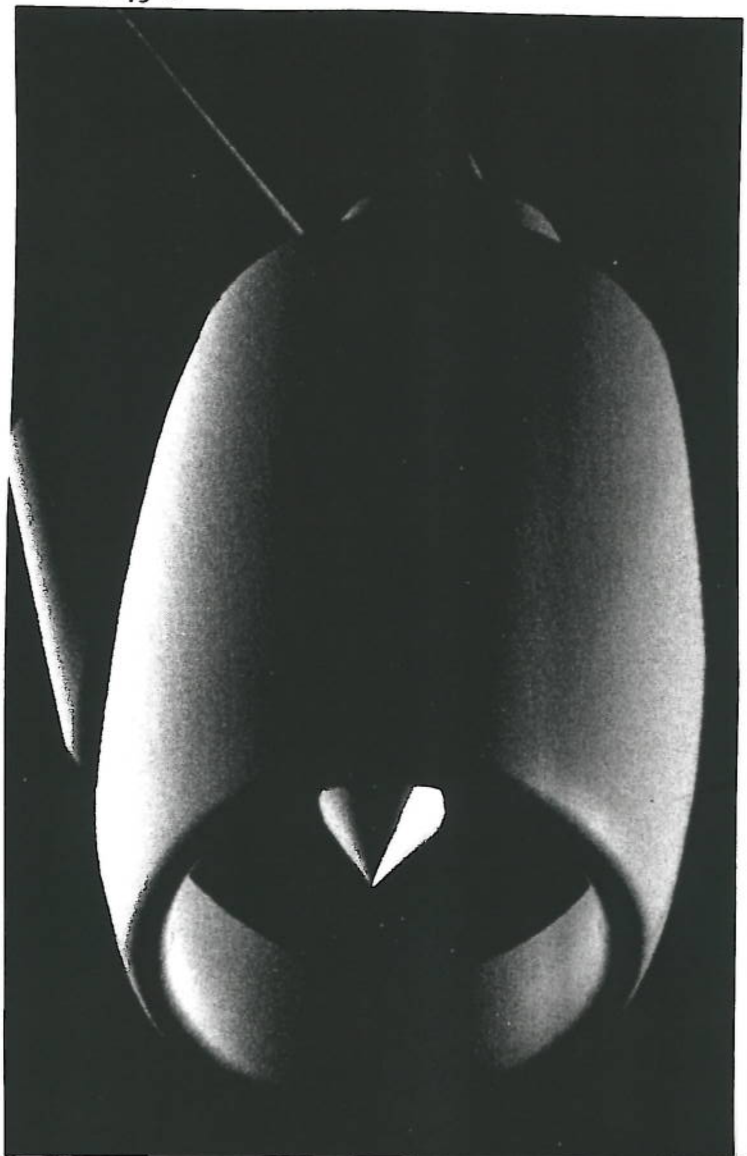


FIG. 17

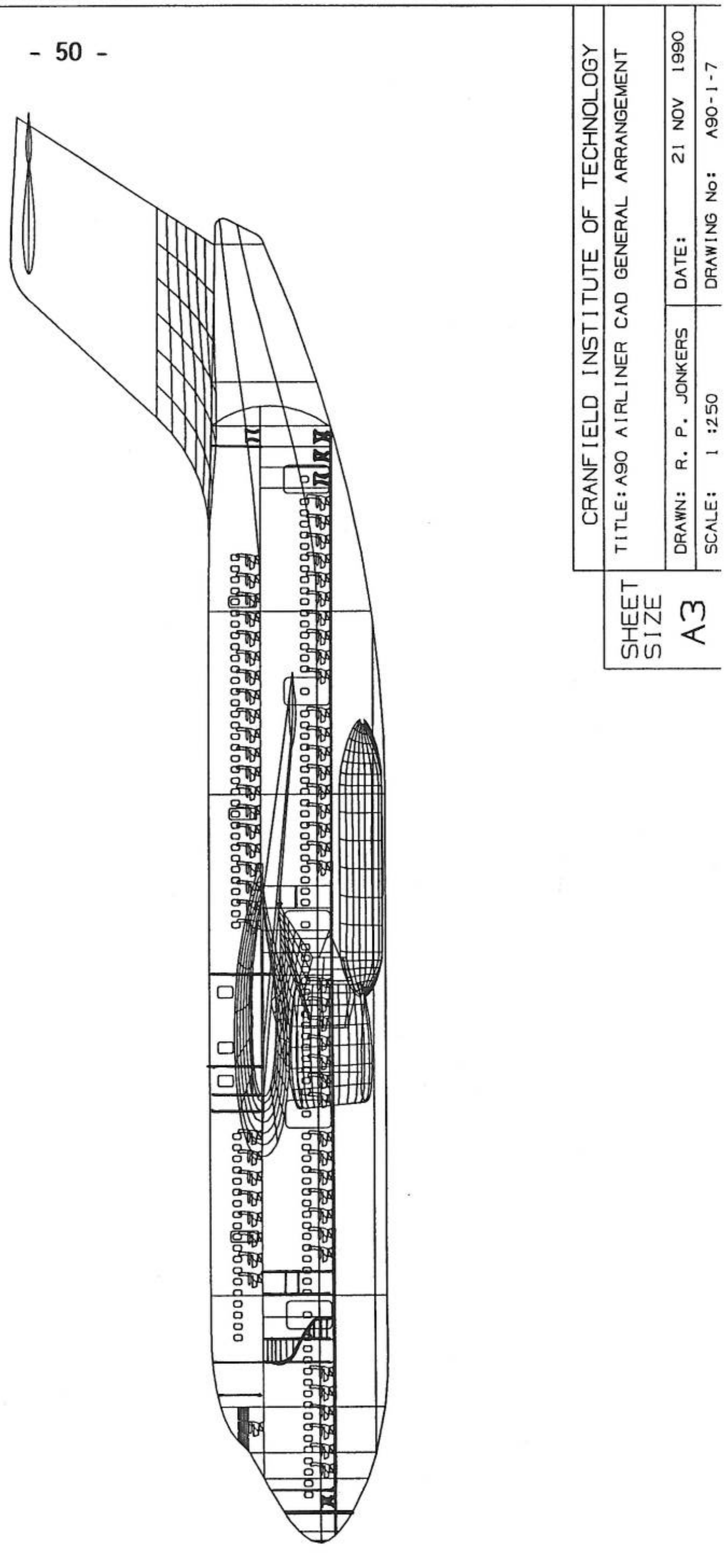

CRANFIELD INSTITUTE OF TECHNOLOGY
TITLE: A90 AIRLINER CAD GENERAL ARRANGEMENT
SHEET SIZE
A3
DRAWN: R. P. JONKERS
DATE: 21 NOV 1990
SCALE: 1 :250
DRAWING No: A90-1-7

FIG. 18

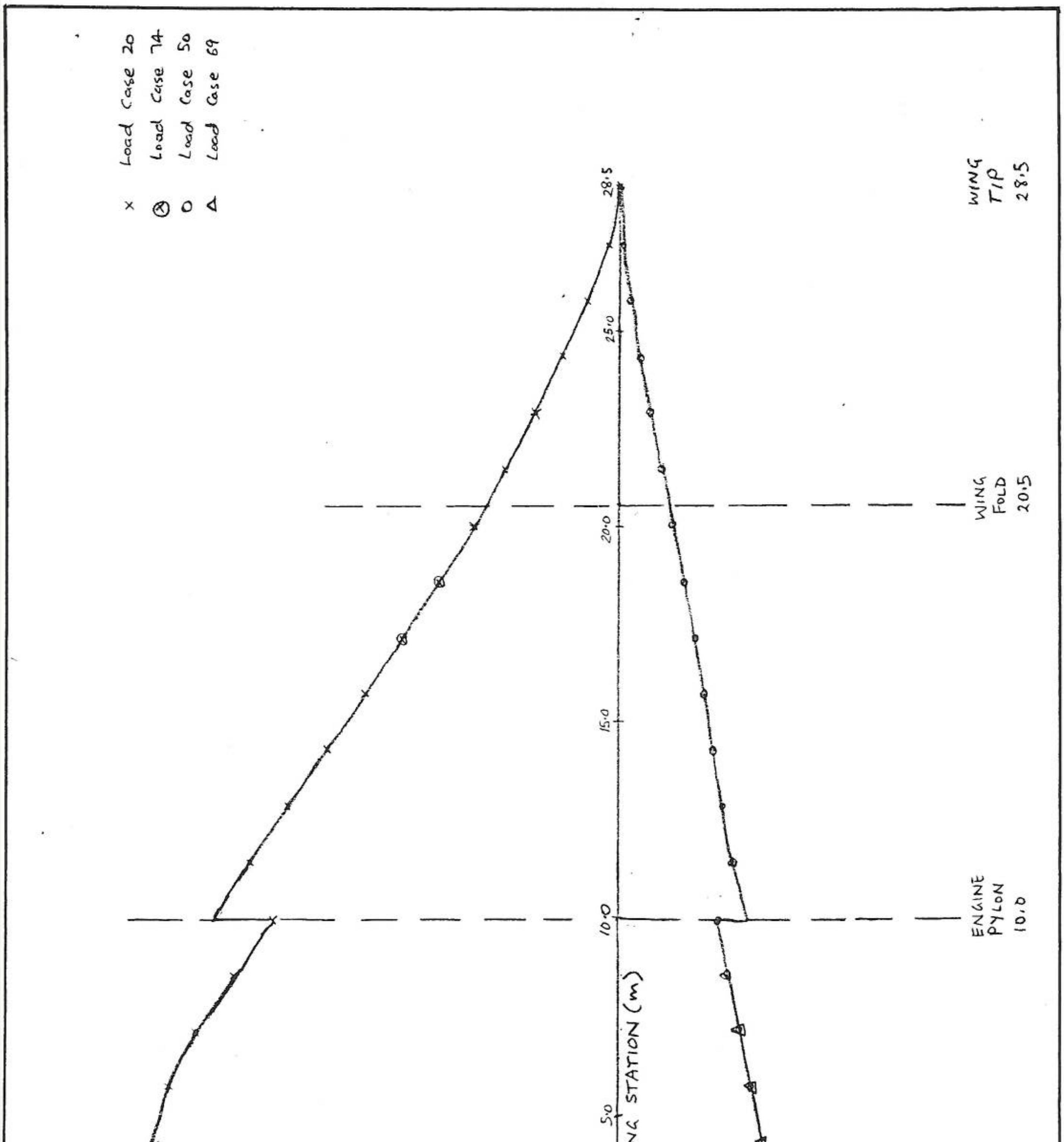

A90 WING SPANWISE SHEAR FORCE DIAGRAM
× Load Case 20
⊗ Load Case 74
o Load Case 50
Δ Load Case 69
SHEAR FORCE (MN)
+ve up
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
WING STATION (m)
5.0
10.0
15.0
20.0
25.0
28.5
FUSELAGE CENTRE LINE 0.0
WING ROOT 3.28
ENGINE PYLON 10.0
WING FOLD 20.5
WING TIP 28.5

FIG. 19

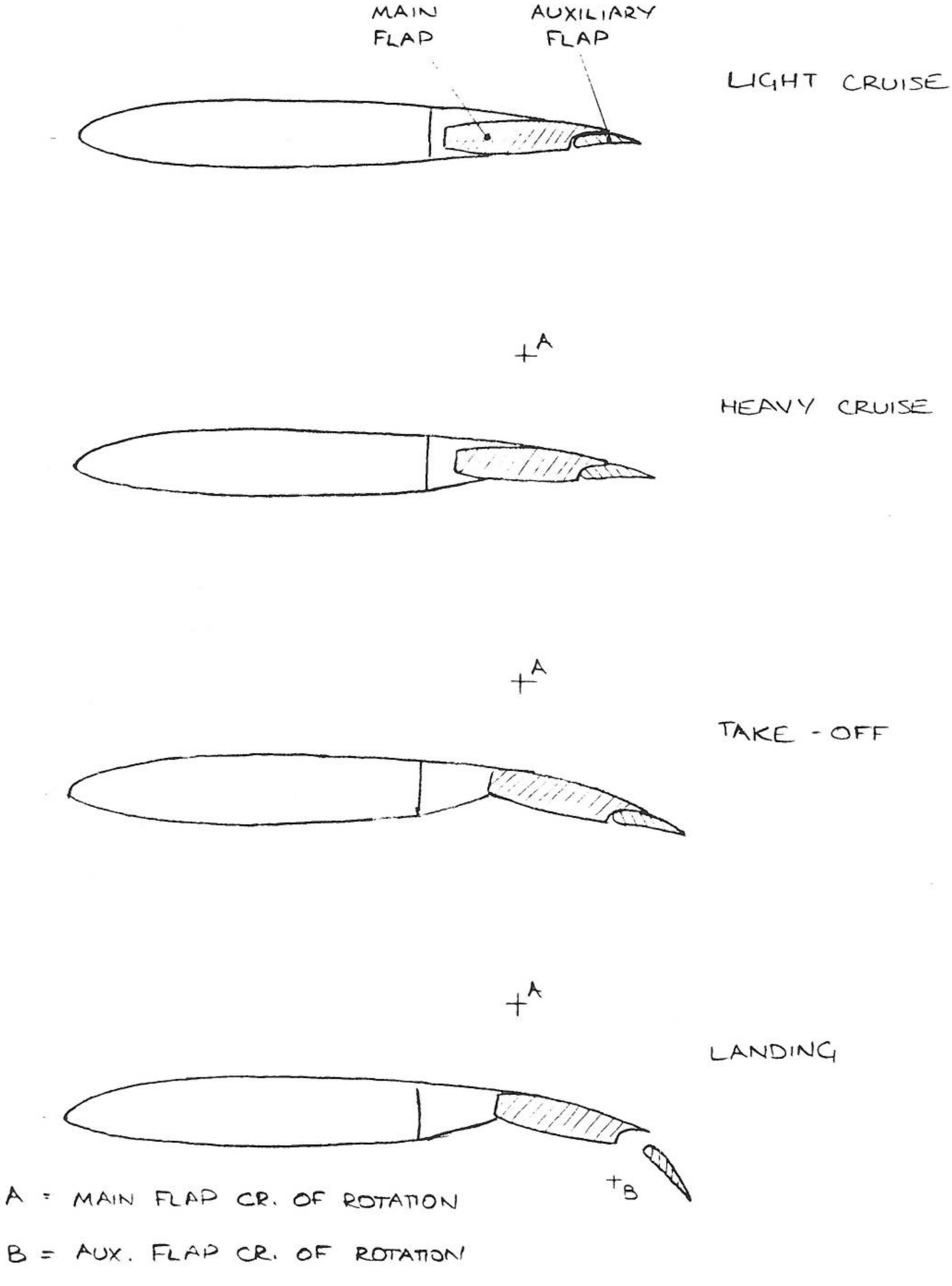
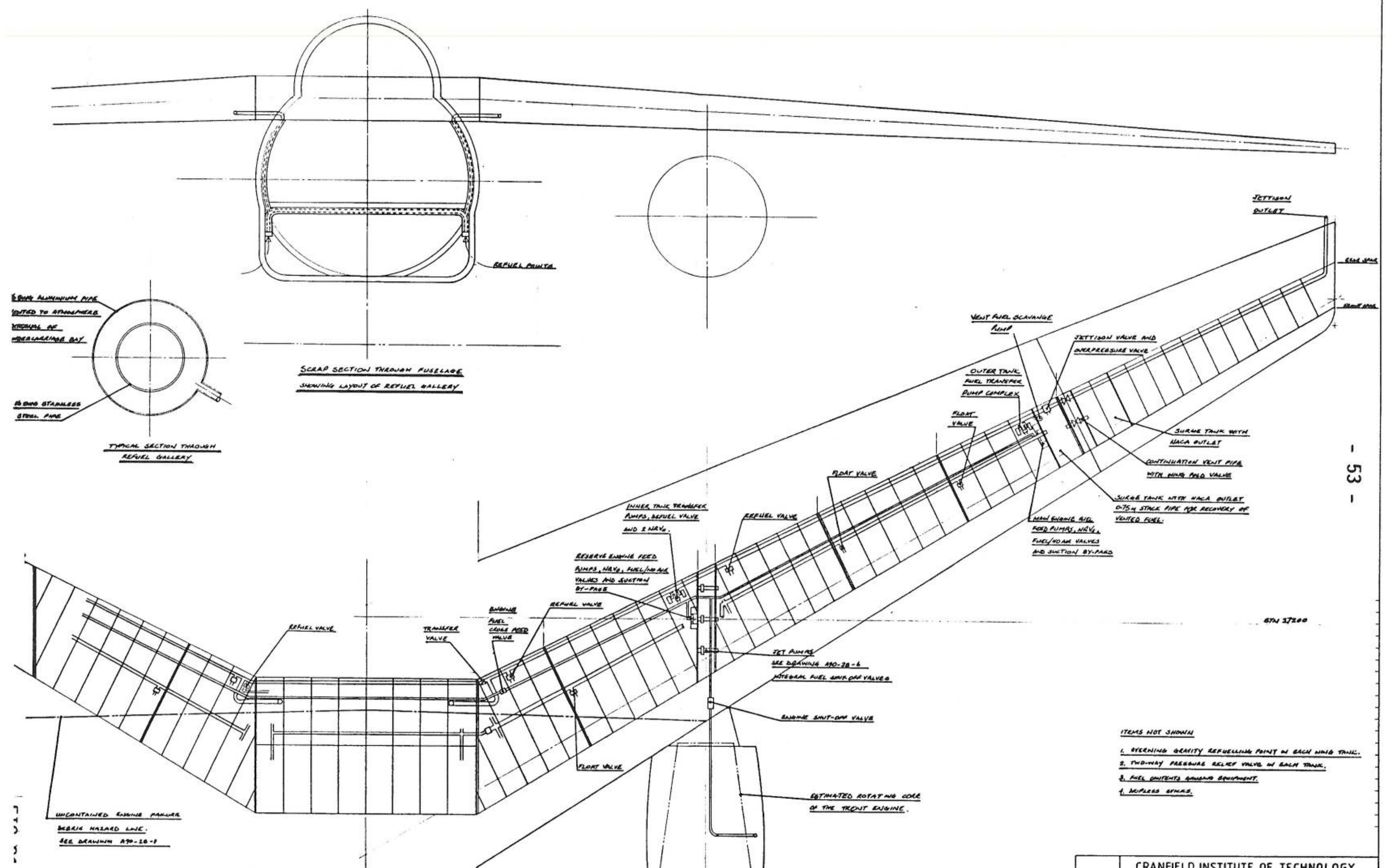

MAIN FLAP
AUXILIARY FLAP
LIGHT CRUISE
A
HEAVY CRUISE
A
TAKE - OFF
A
LANDING
B
A = MAIN FLAP CR. OF ROTATION
B = AUX. FLAP CR. OF ROTATION

FIG. 20




| | | |
|---|---|---|
| SHEET SIZE | CRANFIELD INSTITUTE OF TECHNOLOGY | |
| A1 | TITLE: A90 AIRLINER PROJECT<br>FUEL SYSTEM — COMPONENT LAYOUT | |
| | DRAWN: D.H. ATTON | DATE: 10 MARCH 1991 |
| | SCALE: 1:50 | DRAWING No: A90-28-3 |

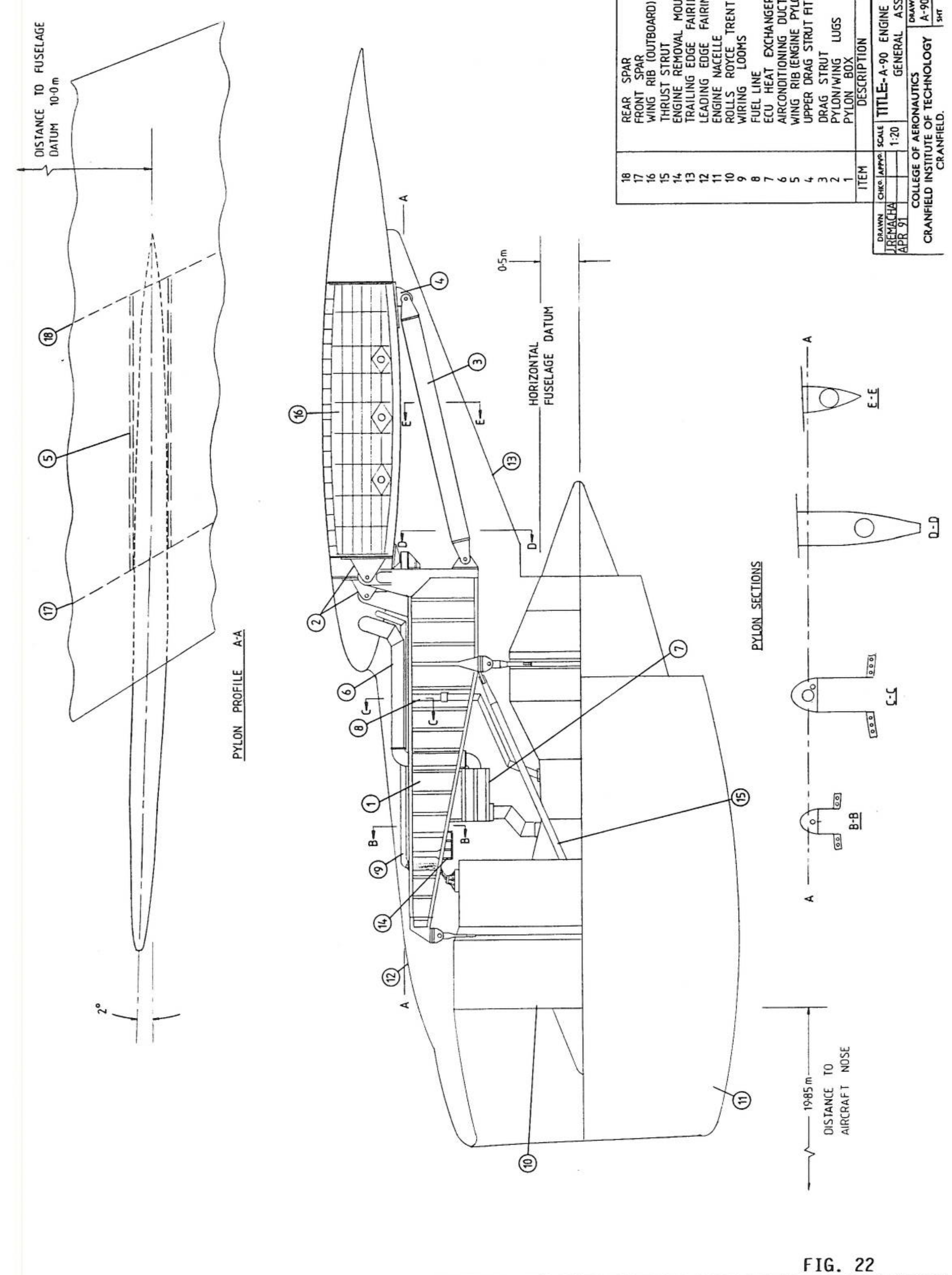

DISTANCE TO FUSELAGE DATUM 10·0 m
2°
PYLON PROFILE A-A
HORIZONTAL FUSELAGE DATUM
0·5 m
19·85 m
DISTANCE TO AIRCRAFT NOSE
PYLON SECTIONS
B-B
C-C
D-D
E-E
18 REAR SPAR
17 FRONT SPAR
16 WING RIB (OUTBOARD)
15 THRUST STRUT
14 ENGINE REMOVAL MOUNT
13 TRAILING EDGE FAIRING
12 LEADING EDGE FAIRING
11 ENGINE NACELLE
10 ROLLS ROYCE TRENT - 800
9 WIRING LOOMS
8 FUEL LINE
7 ECU HEAT EXCHANGER
6 AIRCONDITIONING DUCT
5 WING RIB (ENGINE PYLON) A-90-EP-
4 UPPER DRAG STRUT FITTING A-90-EP-
3 DRAG STRUT A-90-EP-
2 PYLON/WING LUGS A-90-EP-
1 PYLON BOX A-90-EP-
ITEM DESCRIPTION DRAWING
DRAWN J.REMACHA APR 91
CHKD. APPVD.
SCALE 1:20
TITLE:- A-90 ENGINE PYLON GENERAL ASSEMBLY
COLLEGE OF AERONAUTICS
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD.
DRAWING No. A-90-EP-1
SHT 1 OF 1 SHEET

FIG. 22

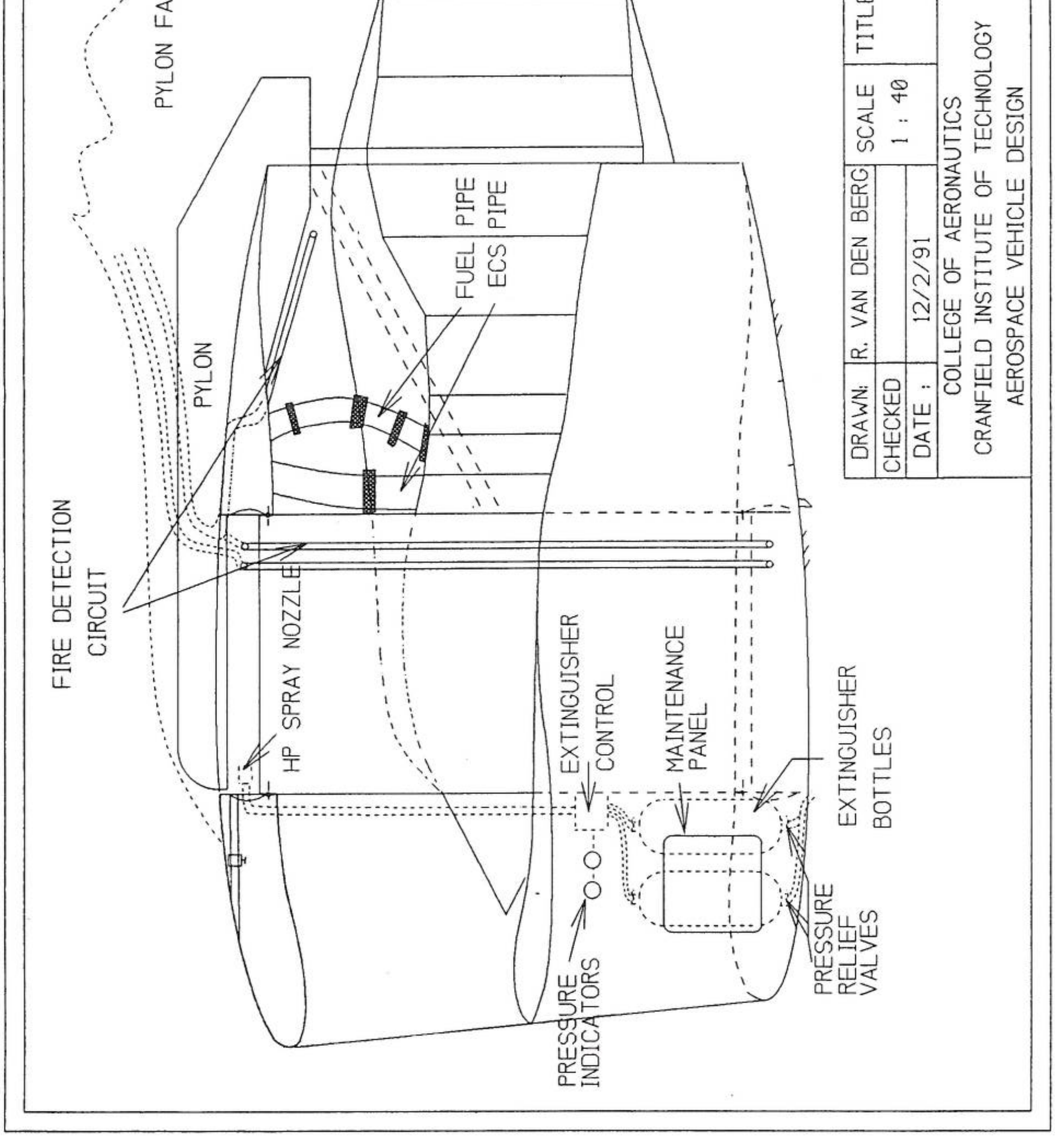
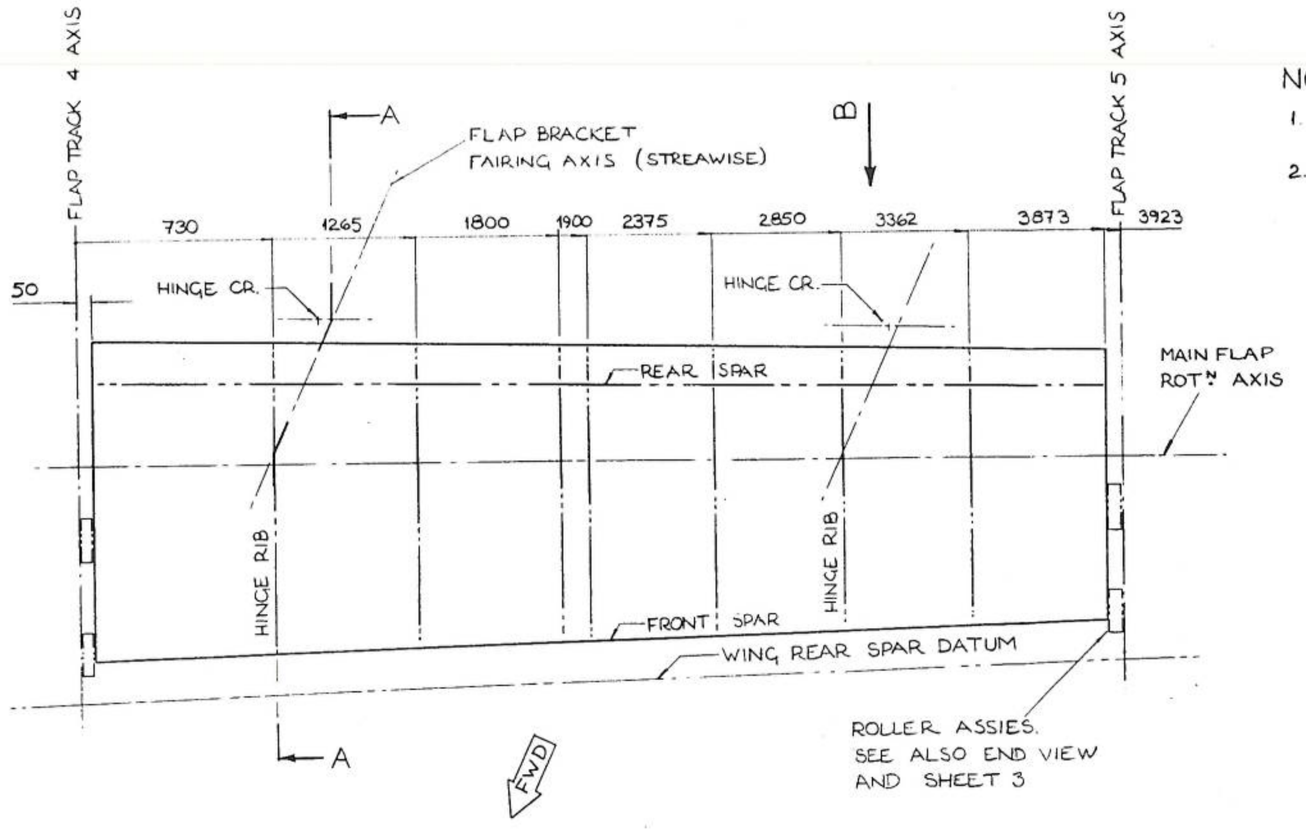
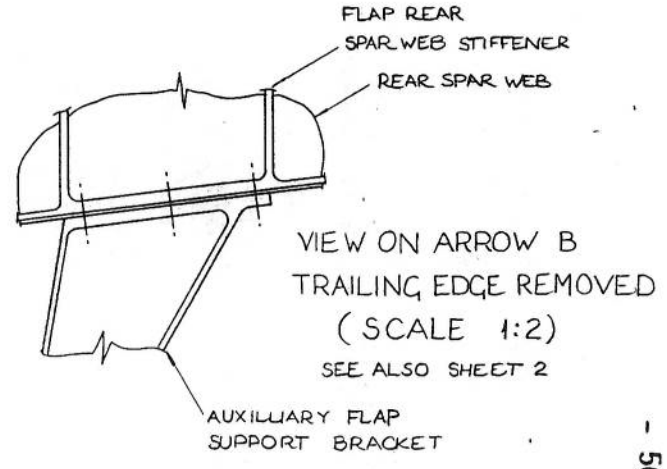

PYLON FAIRING
PYLON
FIRE DETECTION CIRCUIT
HP SPRAY NOZZLE
FUEL PIPE
ECS PIPE
EXTINGUISHER CONTROL
MAINTENANCE PANEL
EXTINGUISHER BOTTLES
PRESSURE INDICATORS
PRESSURE RELIEF VALVES
DRAWN: R. VAN DEN BERG
CHECKED
DATE : 12/2/91
SCALE 1 : 40
TITLE : ENGINE FIRE SYSTEMS
COLLEGE OF AERONAUTICS
CRANFIELD INSTITUTE OF TECHNOLOGY
AEROSPACE VEHICLE DESIGN
DRAWING NUMBER : A90-EF-1
SHT , 2 OF 2

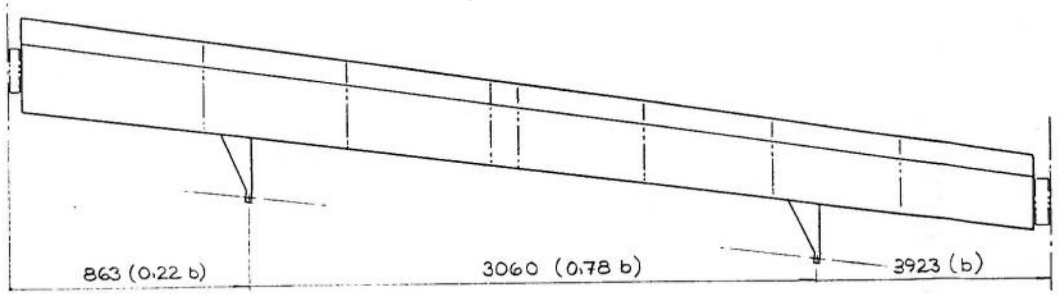
FIG. 23

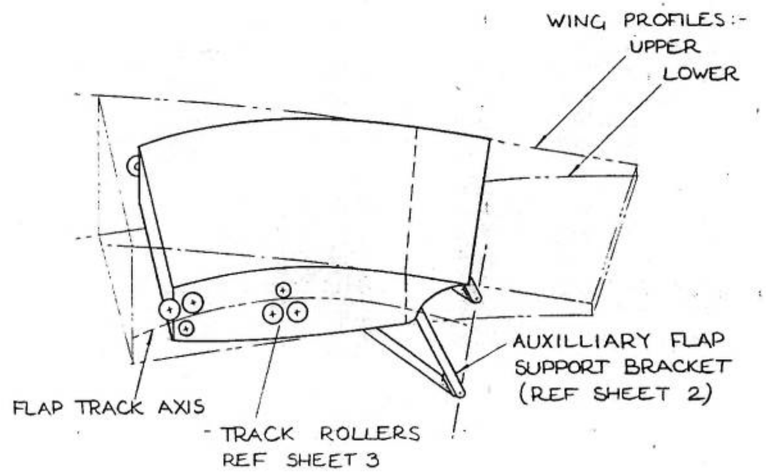
NOTES

1. SEE SHEET 2 FOR HINGE RIB DETAILS, AUXILLIARY FLAP SUPPORT BRACKET DETAILS AND STRINGER ARRANGEMENT
2. SEE SHEET 3 FOR END RIB DETAILS AND DETAILS OF TRACK ROLLERS



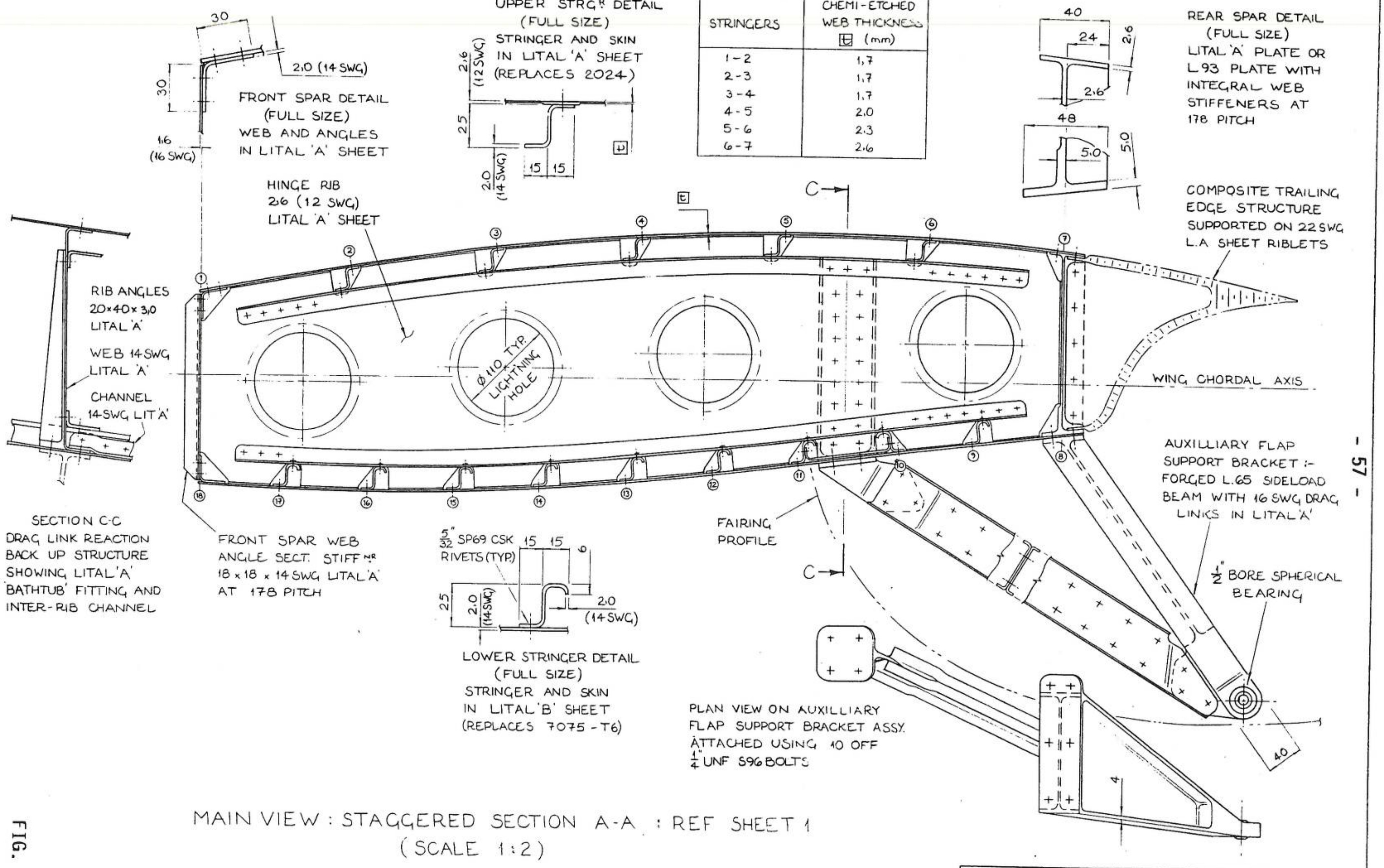




| DRAWN<br>L. LARRIVE | TITLE :<br>MAIN FLAP ASSY |
|---|---|
| SCALES : MAIN VIEWS 1:10 , DETAIL 1:2 | |
| DRG Nº: A90-IBF-04 | SHT 1 OF 3 SHTS. |

FIG. 24




| STRINGERS | CHEMI-ETCHED WEB THICKNESS ⊞ (mm) |
|---|---|
| 1 - 2 | 1,7 |
| 2 - 3 | 1,7 |
| 3 - 4 | 1,7 |
| 4 - 5 | 2,0 |
| 5 - 6 | 2,3 |
| 6 - 7 | 2,6 |

| DRAWN L. LARRIVE | TITLE : MAIN FLAP ASSY. |
|---|---|
| SCALES : MAIN VIEW 1:2 , DETAILS FULLSIZE | |
| DRG Nº : A90-IBF-04 | SHT 2 OF 3 SHTS. |

FIG. 25

| # | NOMENCLATURE | DWG/PART # |
|---|---|---|
| 1 | AA TRAILING EDGE SKINS AND CORE | A90-A-02/1 |
| 2 | AA MAIN SKIN PANELS | A90-A-02/6 |
| 3 | AA NOSE SKIN PANELS | A90-A-02/7 |
| 4 | AA FRONT SPAR | A90-A-03/1 |
| 5 | AA ACTUATOR/HINGE RIBS | A90-A-01/1 |
| 6 | AA MID-SPAN RIB | A90-A-01/2 |
| 7 | AA HINGES NOSE RIBS | A90-A-01/3 |
| 8 | AA INTERMEDIATE NOSE RIBS | A90-A-01/4 |
| 9 | AA END RIBS | A90-A-01/5 |
| 10 | AA HINGE ACCESS PANEL | A90-A-02/2 |
| 11 | AA No 3 HINGE MAIN FLAP BRACKETS | A90-A-02/3L&R |
| 12 | AA No 3 HINGE SUPPORT ARMS | A90-A-02/4L&R |
| 13 | AA No 3 HINGE AILERON SPAR FITTING | A90-A-02/5L&R |
| 14 | AA No 2 HINGE MAIN FLAP BRACKETS | A90-A-05/1L&R |
| 15 | AA No 2 HINGE SUPPORT ARM | A90-A-05/2 |
| 16 | AA No2 HINGE AILERON SPAR FITTING | A90-A-05/3 |
| 17 | AA ACTUATOR HINGE AILERON FITTING | A90-A-04/1L&R |
| 18 | AA ACTUATOR HINGE SUPPORT ARM | A90-A-04/2L&R |
| 19 | AA ACTUATOR MOTOR FLAP FITTING | A90-A-01/1L&R |
| 20 | AA ACTUATION MECHANISM | A90-A-01 |
| 21 | MF SKIN PANELS | A90-A-06/4 |
| 22 | MF FRONT SPAR | A90-A-07/3 |
| 23 | MF TRACK RIBS | A90-A-06/5 |
| 24 | MF DOUBLE TRACKS | A90-A-06/2 |
| 25 | MF TRACK DIFFUSION PLATE | A90-A-06/1 |
| 26 | MF TRACK FWD CARRIAGES SUPPORTS | A90-A-07/2 |
| 27 | MF TRACK ROLLER CARRIAGES | A90-A-07/1 |
| 28 | MF MIDDLE CARRIAGE SUPPORT | A90-A-01/6 |
| 29 | MF ACTUATION MECHANISM | A90-A-01/7 |
| 30 | WING REAR SPAR | A88-OW |

Notes: A. The abbreviations AA and MF refer to Auxiliary Aileron and Main Flap Respectively.

B. Upper Skin Panels Removed for Clarity.

C. Flap Tracks and Auxiliary Aileron Hinges are numbered 1 to 3 from the fold line going outboard.

D. Flap Track Carriages are shown in details in A90-A-14.

E. The Flap Track Carriages Support Fittings are identical on number 1 and 3 tracks as those on number 2.

F. Metallic components are protected from galvanic actions by use of Glass Cloth and Titanium Sleeves inserted in bolt holes.

G. The Main Flap Assembly Nomex Core is HRH 10-3/16-6.0(5); thickness of 10 mm in forward and rear torsion boxes.

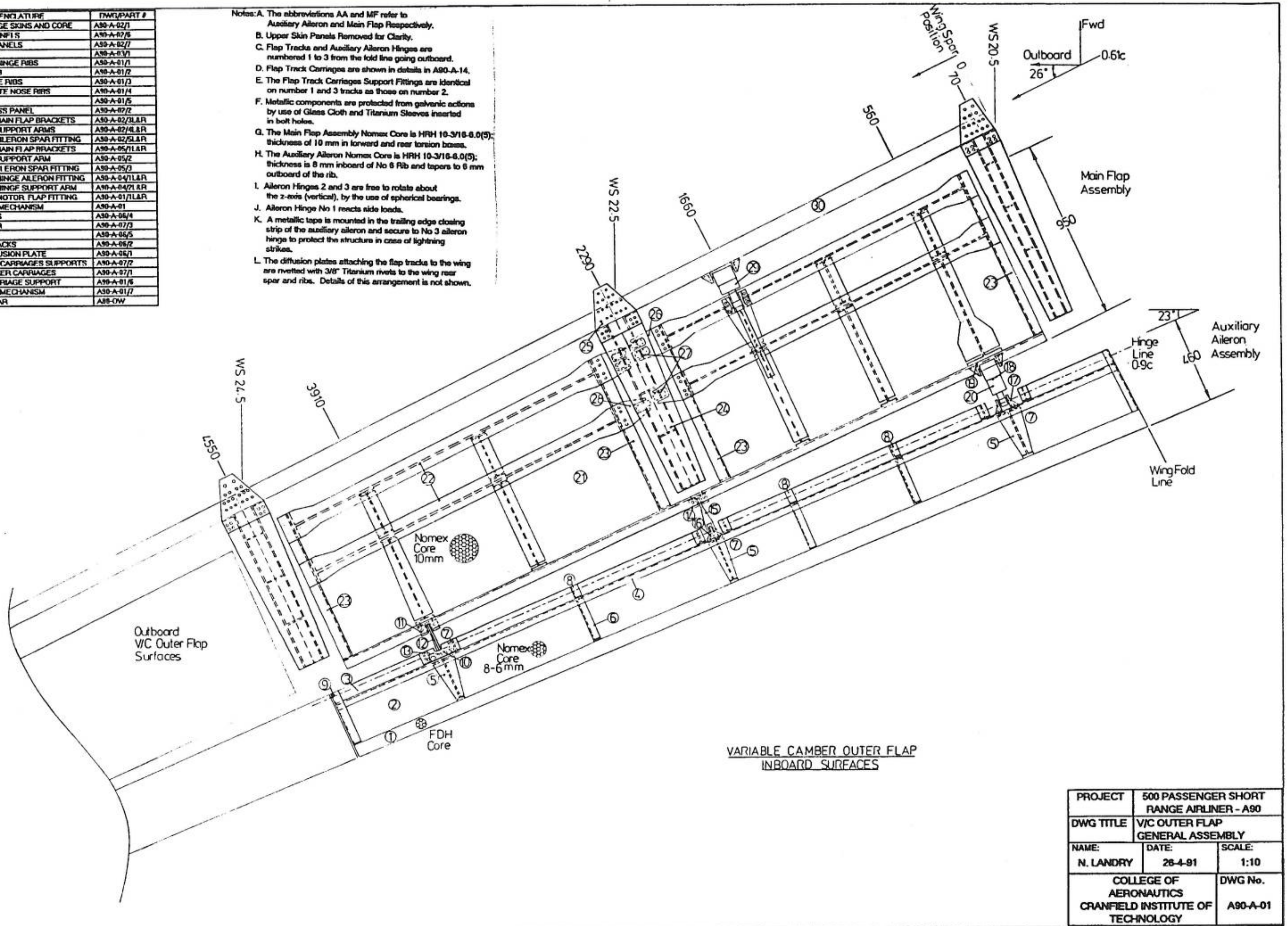
H. The Auxiliary Aileron Nomex Core is HRH 10-3/16-6.0(5); thickness is 8 mm inboard of No 6 Rib and tapers to 6 mm outboard of the rib.

I. Aileron Hinges 2 and 3 are free to rotate about the z-axis (vertical), by the use of spherical bearings.

J. Aileron Hinge No 1 reacts side loads.

K. A metallic tape is mounted in the trailing edge closing strip of the auxiliary aileron and secure to No 3 aileron hinge to protect the structure in case of lightning strikes.

L. The diffusion plates attaching the flap tracks to the wing are rivetted with 3/8" Titanium rivets to the wing rear spar and ribs. Details of this arrangement is not shown.




| | | | |
|---|---|---|---|
| PROJECT | 500 PASSENGER SHORT RANGE AIRLINER - A90 | | |
| DWG TITLE | V/C OUTER FLAP GENERAL ASSEMBLY | | |
| NAME: N. LANDRY | DATE: 26-4-91 | SCALE: 1:10 | |
| COLLEGE OF AERONAUTICS CRANFIELD INSTITUTE OF TECHNOLOGY | | DWG No. A90-A-01 | |

FIG. 26

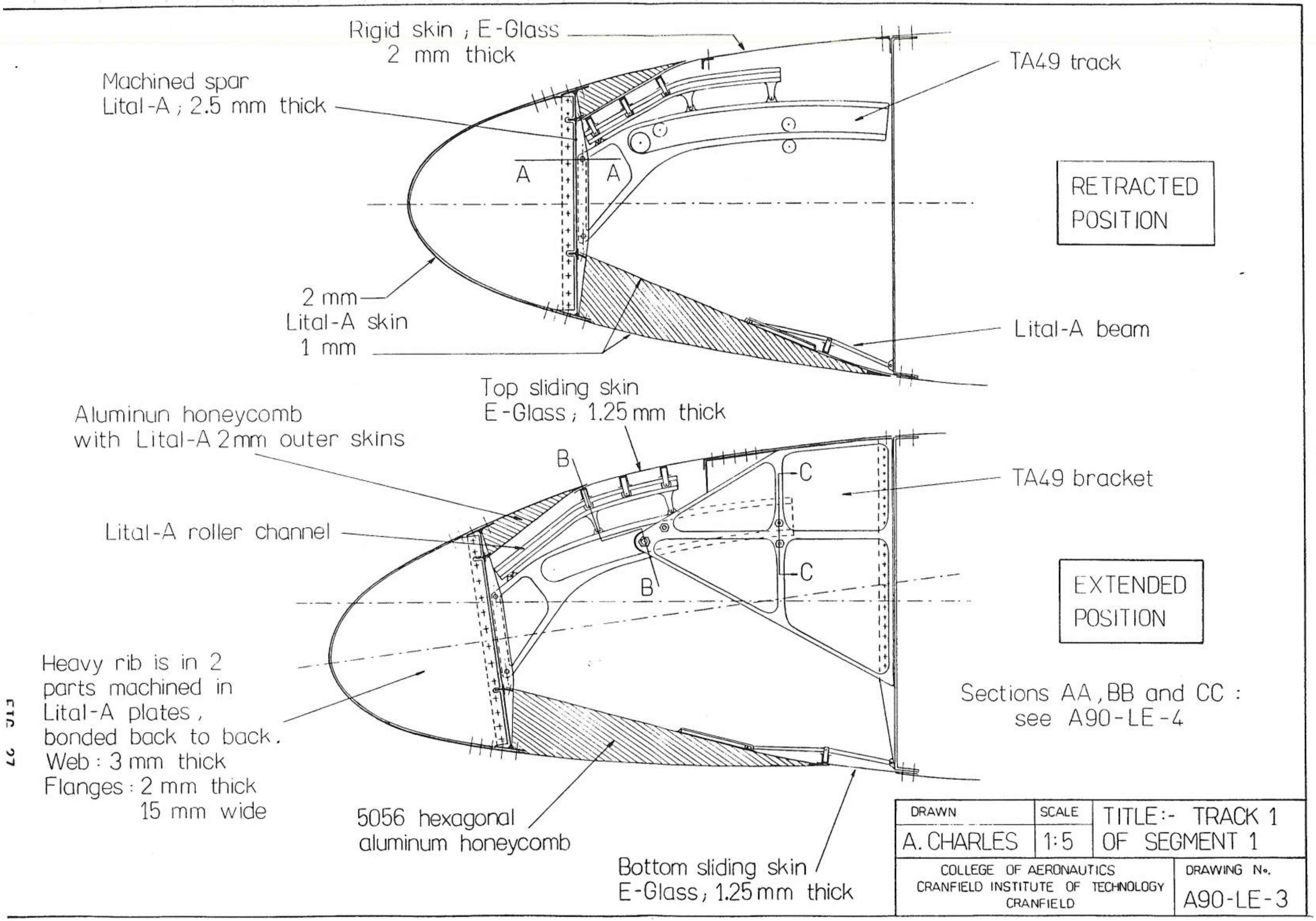
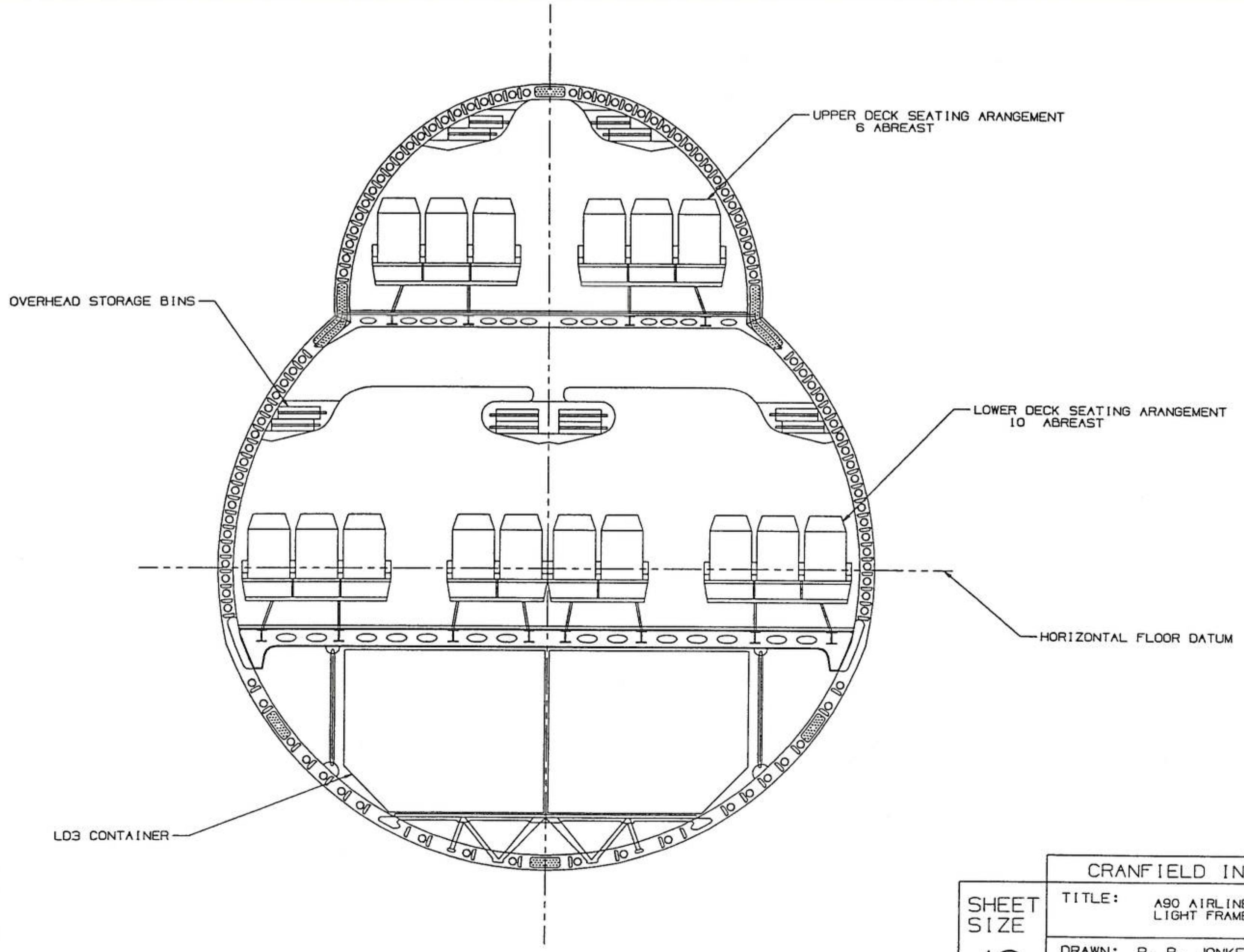

Rigid skin ; E-Glass
2 mm thick
Machined spar
Lital-A ; 2.5 mm thick
TA49 track
A A
RETRACTED
POSITION
2 mm
Lital-A skin
1 mm
Lital-A beam
Top sliding skin
E-Glass ; 1.25 mm thick
Aluminun honeycomb
with Lital-A 2mm outer skins
B
B
C
C
TA49 bracket
Lital-A roller channel
EXTENDED
POSITION
Heavy rib is in 2
parts machined in
Lital-A plates ,
bonded back to back.
Web : 3 mm thick
Flanges : 2 mm thick
15 mm wide
Sections AA , BB and CC :
see A90-LE-4
5056 hexagonal
aluminum honeycomb
Bottom sliding skin
E-Glass ; 1.25 mm thick
DRAWN
A. CHARLES
SCALE
1:5
TITLE:- TRACK 1
OF SEGMENT 1
COLLEGE OF AERONAUTICS
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD
DRAWING No.
A90-LE-3

FIG. 27

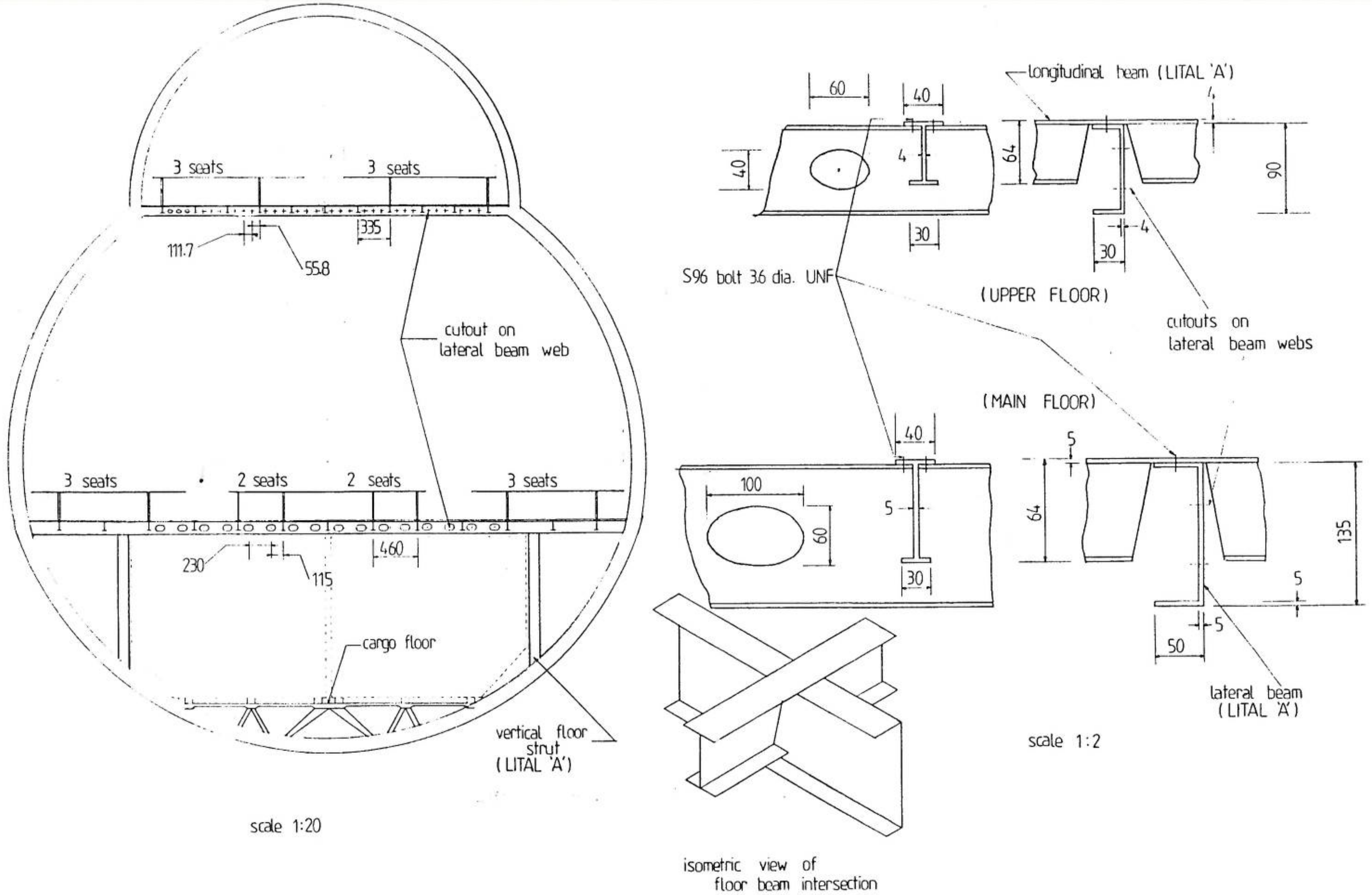



PASSENGER SECTION FRAME

| | | | |
|---|---|---|---|
| SHEET SIZE | CRANFIELD INSTITUTE OF TECHNOLOGY | | |
| | TITLE: A90 AIRLINER CENTRE FUSELAGE LIGHT FRAME AT PASSENGER SECTION | | |
| A3 | DRAWN: R. P. JONKERS | DATE: 6 FEB 1991 | |
| | SCALE: 1 : 40 | DRAWING No: A90-CF-2-5 | |

FIG. 28

All Dimensions in mm




| CRANFIELD INSTITUTE OF TECHNOLOGY | |
|---|---|
| Title : Passenger Cabin Floor Beams | |
| Drawn : J. O | Drawing No.: A90-NF-2 |

FIG. 29

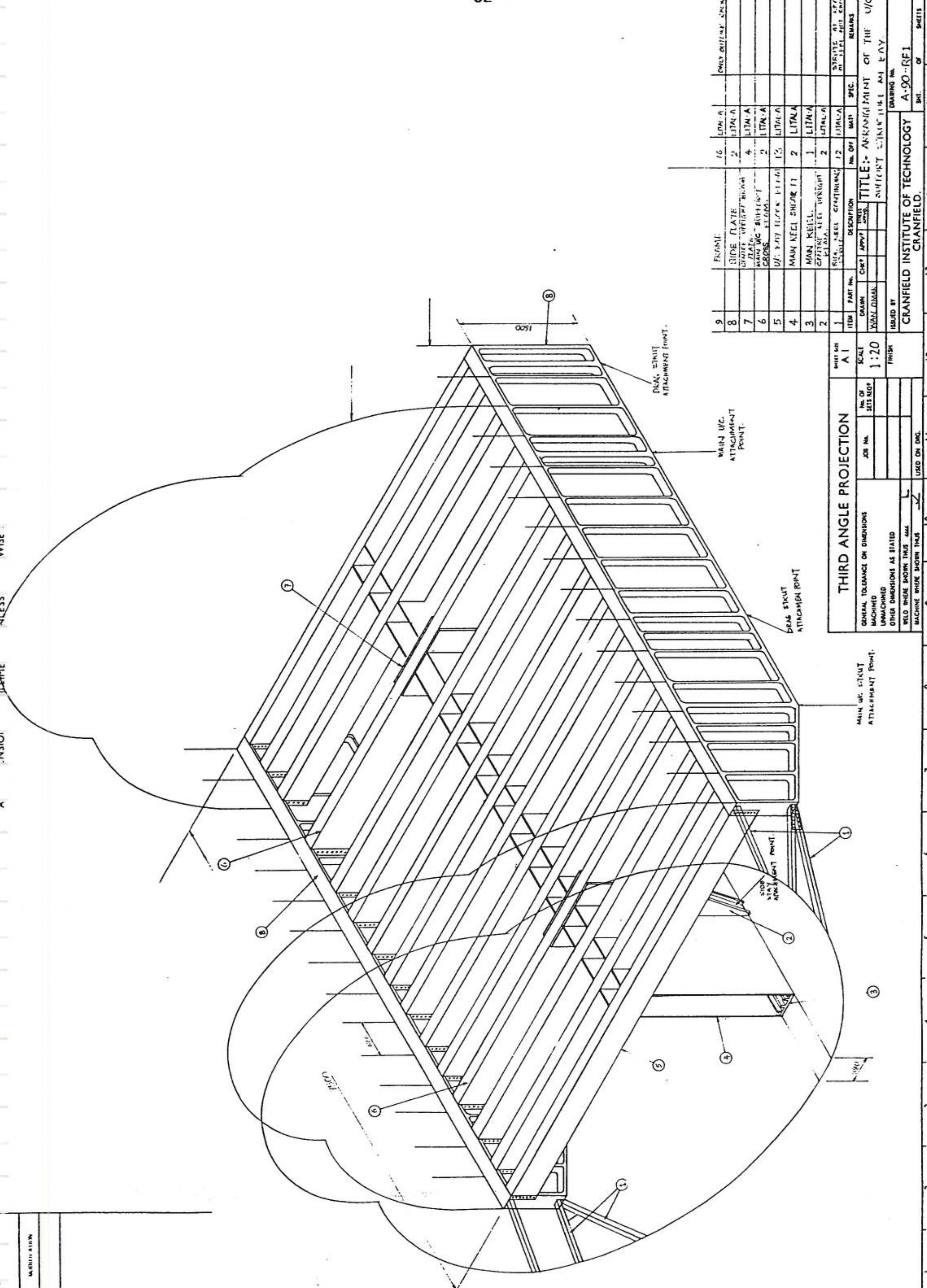

THIRD ANGLE PROJECTION
SCALE 1:20
TITLE:- ARRANGEMENT OF THE U/C SUPPORT STRUCTURE AT BAY
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD.
A-90-RF1
MAIN U/C ATTACHMENT POINT.
DRAG STRUT ATTACHMENT POINT
MAIN U/C STRUT ATTACHMENT POINT.

FIG. 30

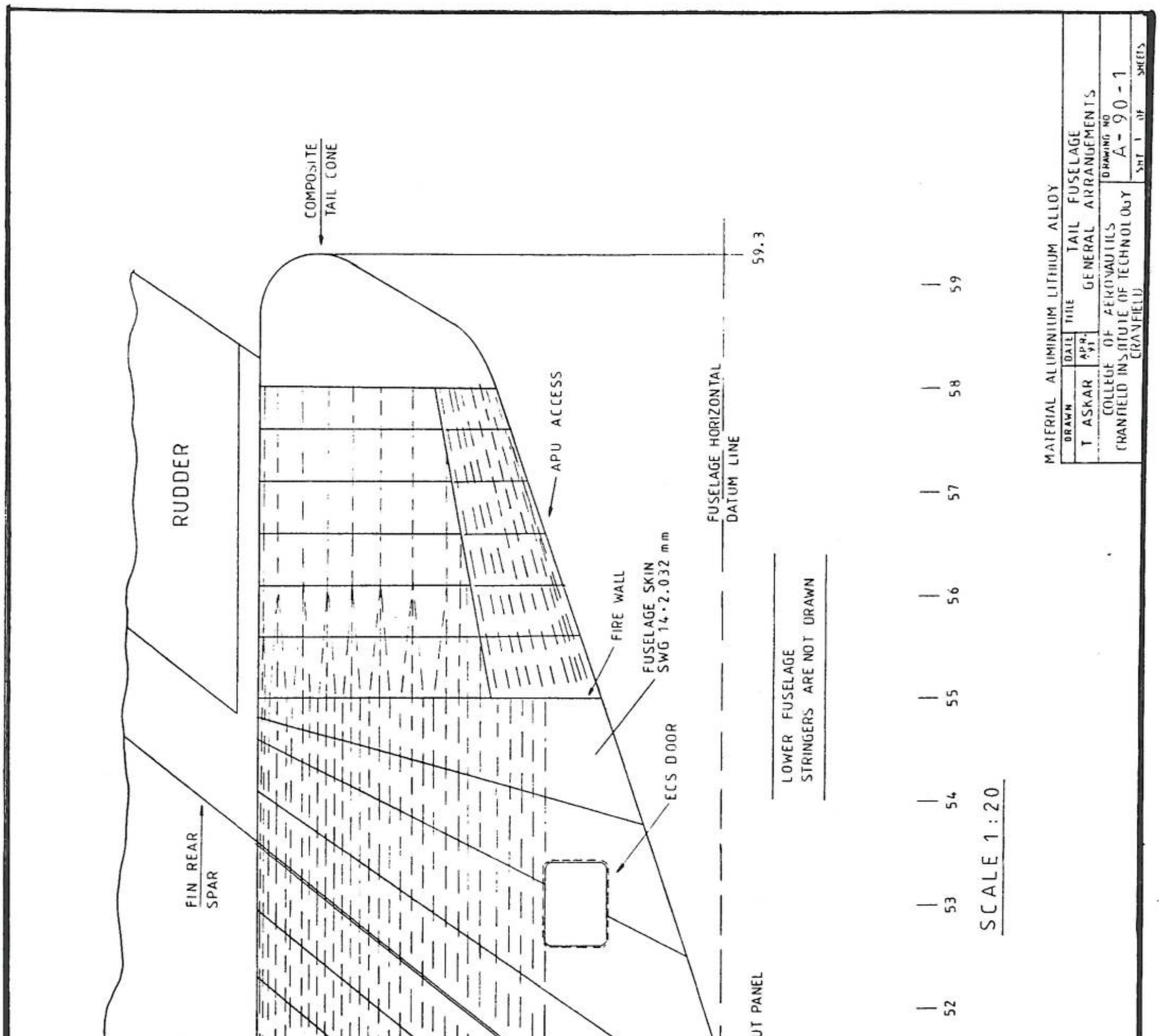

COMPOSITE TAIL CONE
59.3
RUDDER
APU ACCESS
FUSELAGE HORIZONTAL DATUM LINE
FIRE WALL
FUSELAGE SKIN SWG 14·2.032 mm
LOWER FUSELAGE STRINGERS ARE NOT DRAWN
FIN REAR SPAR
ECS DOOR
SCALE 1:20
BLOW OUT PANEL
FIN FRONT SPAR
FIN REAR SPAR PICK UP FRAME A·90·6
HALF CIRCULAR FRAME A-90-4
TAIL FUSELAGE DRAIN
MAIN FIN FRONT SPAR PICK UP FRAME AND REAR PRESSURE BHD FRAME
A-90-5
UPPER DECK
CURVED REAR PRESSURE BHD
A-90-2
LOWER DECK
47
48
49
50
51
52
53
54
55
56
57
58
59
FUSELAGE STATION FROM THE NOSE IN METERS
MATERIAL ALUMINIUM LITHIUM ALLOY
DRAWN
DATE
TITLE
T ASKAR
TAIL FUSELAGE GENERAL ARRANGEMENTS
COLLEGE OF AERONAUTICS CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD
DRAWING NO
A-90-1

FIG. 31

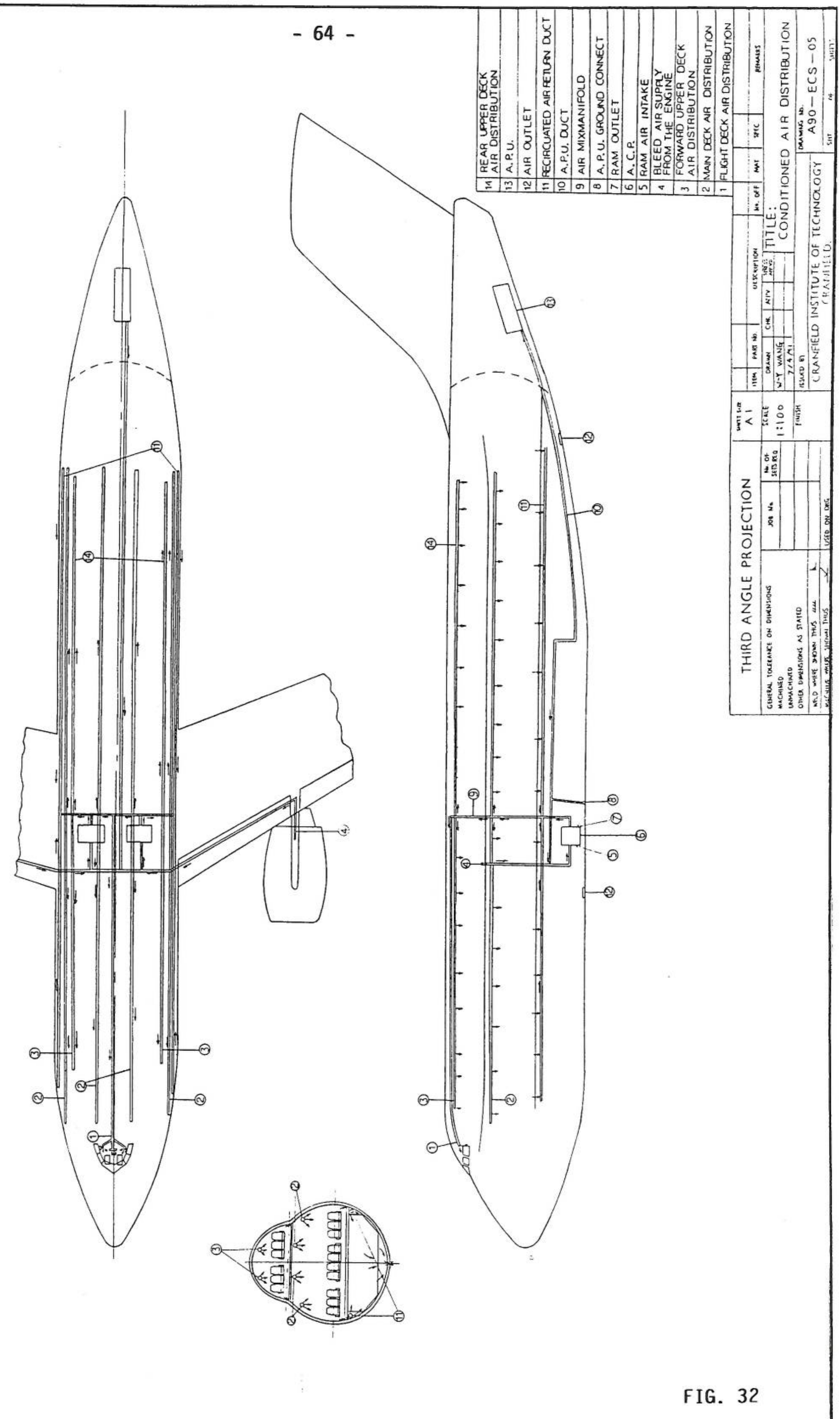
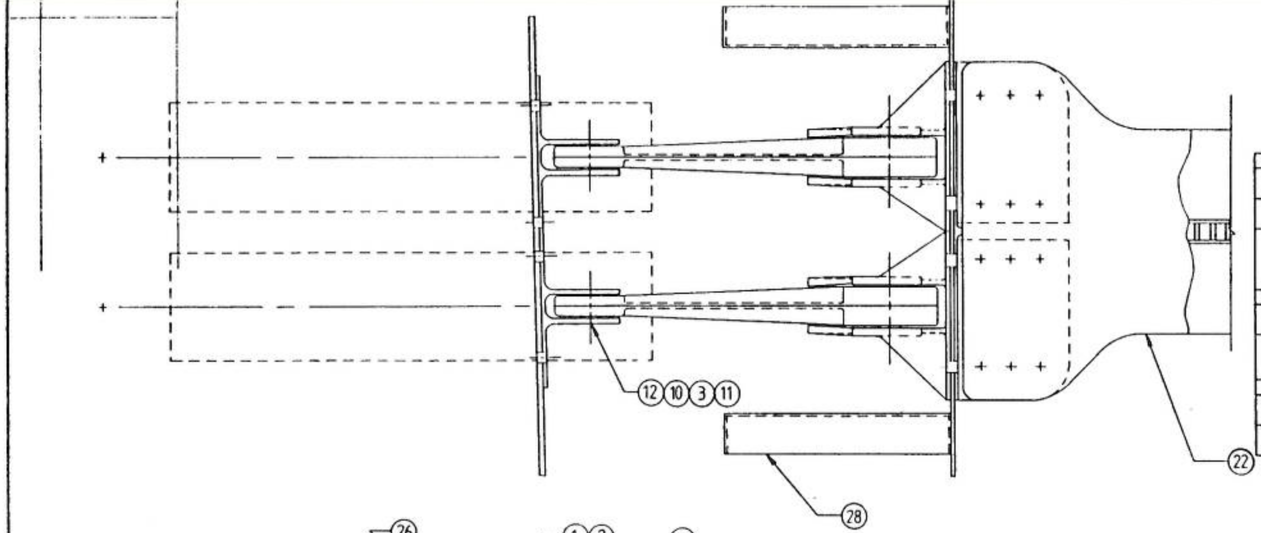
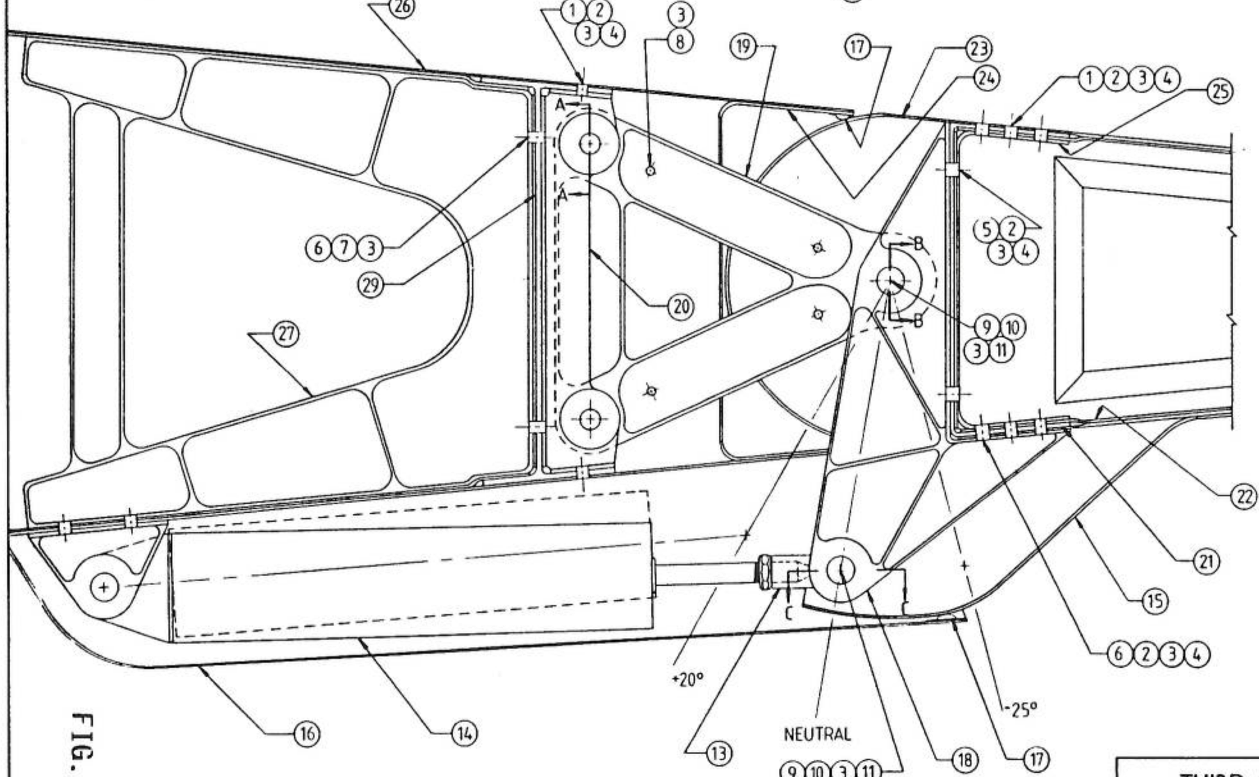
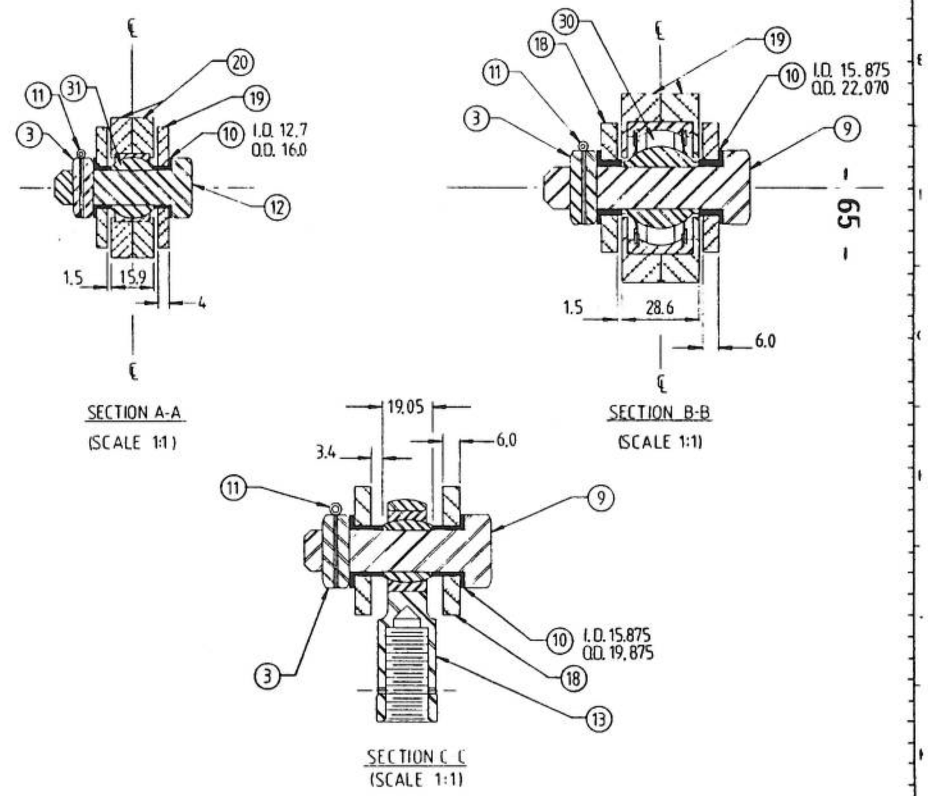

14 REAR UPPER DECK AIR DISTRIBUTION
13 A.P.U.
12 AIR OUTLET
11 RECIRCULATED AIR RETURN DUCT
10 A.P.U. DUCT
9 AIR MIXMANIFOLD
8 A.P.U. GROUND CONNECT
7 RAM OUTLET
6 A.C.P.
5 RAM AIR INTAKE
4 BLEED AIR SUPPLY FROM THE ENGINE
3 FORWARD UPPER DECK AIR DISTRIBUTION
2 MAIN DECK AIR DISTRIBUTION
1 FLIGHT DECK AIR DISTRIBUTION
THIRD ANGLE PROJECTION
SHEET SIZE A1
SCALE 1:100
DRAWN W-Y WANG 7/4/91
TITLE: CONDITIONED AIR DISTRIBUTION
CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD.
DRAWING NO. A90-ECS-05

FIG. 32




| ITEM | DESCRIPTION |
|---|---|
| 1 | 5/16" DIA S99 Mushroom Head Bolts. |
| 2 | TA49 Titanium Sleeve. |
| 3 | Slotted Pinned Nut. |
| 4 | Fasteners Installed with wet Ploysulphide Sealant. |
| 5 | 3/8" DIA S99 Bolts. |
| 6 | 5/16" DIA S99 Bolts. |
| 7 | S99 Bushings. |
| 8 | 1/4" DIA S99 Bolts. |
| 9 | 5/8" DIA S99 Hinge Pin Bolts. |
| 10 | S80 Bushings. |
| 11 | Split Pin. |
| 12 | 1/2" DIA S99 Bolts. |
| 13 | FAFNIR REF20W20M - 10 Spherical Bearing. |
| 14 | Hydraulic Actuators (2) as Possible Alternative to Electro-Magnetic Type. |
| 15 | Rotating Aft Actuator Fairing (Kevlar). Fairing longitudinal centreline normal to hinge line. |
| 16 | Fixed Forward Actuator Fairing (Kevlar) Fairing longitudinal centreline normal to hinge line. |
| 17 | Rubber Seal. Bounded between tailplane skin and shroud. |
| 18 | Elevator Actuator-Hinge Fitting. TA48 Machined Forging. Refer to Forging Note (1) of DWG A90-E-04 Sheet 1 of 3. |
| 19 | Elevator Actuator-Hinge Support Arms (Left and Right) (Two Pairs). TA48 Machined Forging. Refer to Forging Note (1) of DWG A90-E-04 Sheet 1 of 3. |
| 20 | Actuator-Hinge Tailplane Fitting. TA48 Machined Forging. Refer to Forging Note (1) of DWG A90-E-04 Sheet 1 of 3. |
| 21 | Elevator Main Spar. |
| 22 | Actuator-Hinge Rib. |

NOMENCLATURE

| ITEM | DESCRIPTION |
|---|---|
| 23 | Lower and Upper Elevator Skins. Lap joint at leading edge not shown (Refer to A90-E-03). |
| 24 | Kevlar Shroud. Bounded to tailplane skins. |
| 25 | Elevator Backing Plates. TA10 Titanium Sheet (2.5mm thick.). Not Detailed, but similar to one shown on A90-E-04 Sheet 3 of 3. |
| 26 | Tailplane Skin. |
| 27 | Tailplane Backing Plate (Schematic Only) |
| 28 | Dimpled Nose Ribs (Both). [90ud/45ud/-45ud/90ud/45w*/45w]s Dimpled for access to hinge pin bolts. |
| 29 | Tailplane Rear Spar. |
| 30 | Roller Bearing. FAFNIR GDSRP10 FS464 |
| 31 | Spherical Bearing. FAFNIR BSH16ATC32ZM-8 (Z Wide Series) |

THIRD ANGLE PROJECTION

| GENERAL TOLERANCE ON DIMENSIONS | JOB No. | No. OF SETS REQ'D | SHEET SIZE A1 |
|---|---|---|---|
| MACHINED | | | SCALE 1:2 |
| UNMACHINED | | | |
| OTHER DIMENSIONS AS STATED | | | FINISH |
| WELD WHERE SHOWN THUS | | | |
| MACHINE WHERE SHOWN THUS | USED ON DRG. | | |

| ITEM | PART No. | DESCRIPTION | No. OFF | MAT'L | SPEC. | REMARKS |
|---|---|---|---|---|---|---|

DRAWN: L. GRENIER | CHK'D | APPV'D | STRESS APPVD.

TITLE:- ELEVATOR ACTUATOR-HINGE

ISSUED BY: CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD.

DRAWING No. A90-E-05

SHT. 1 OF 3 SHEETS

FIG. 33

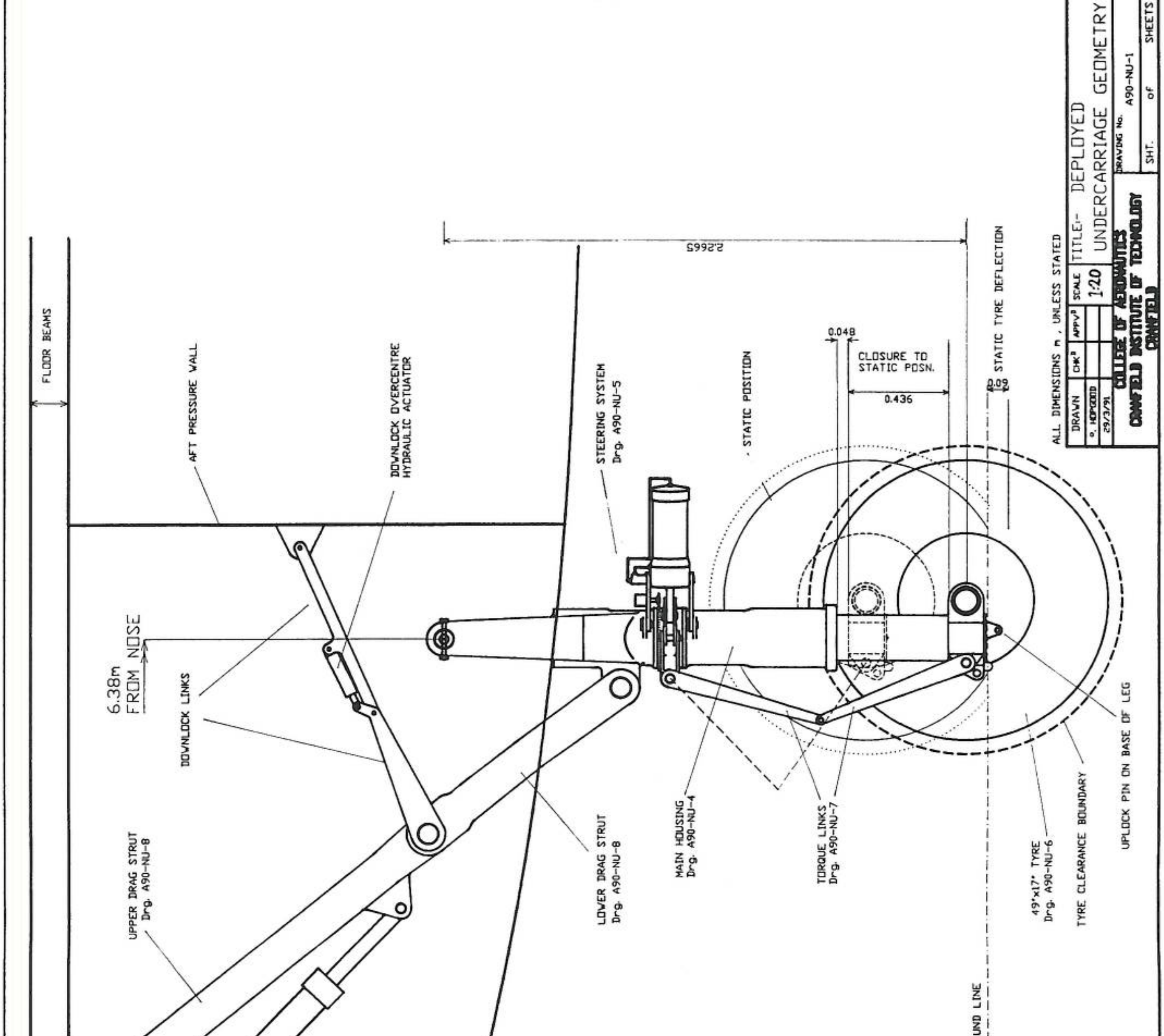
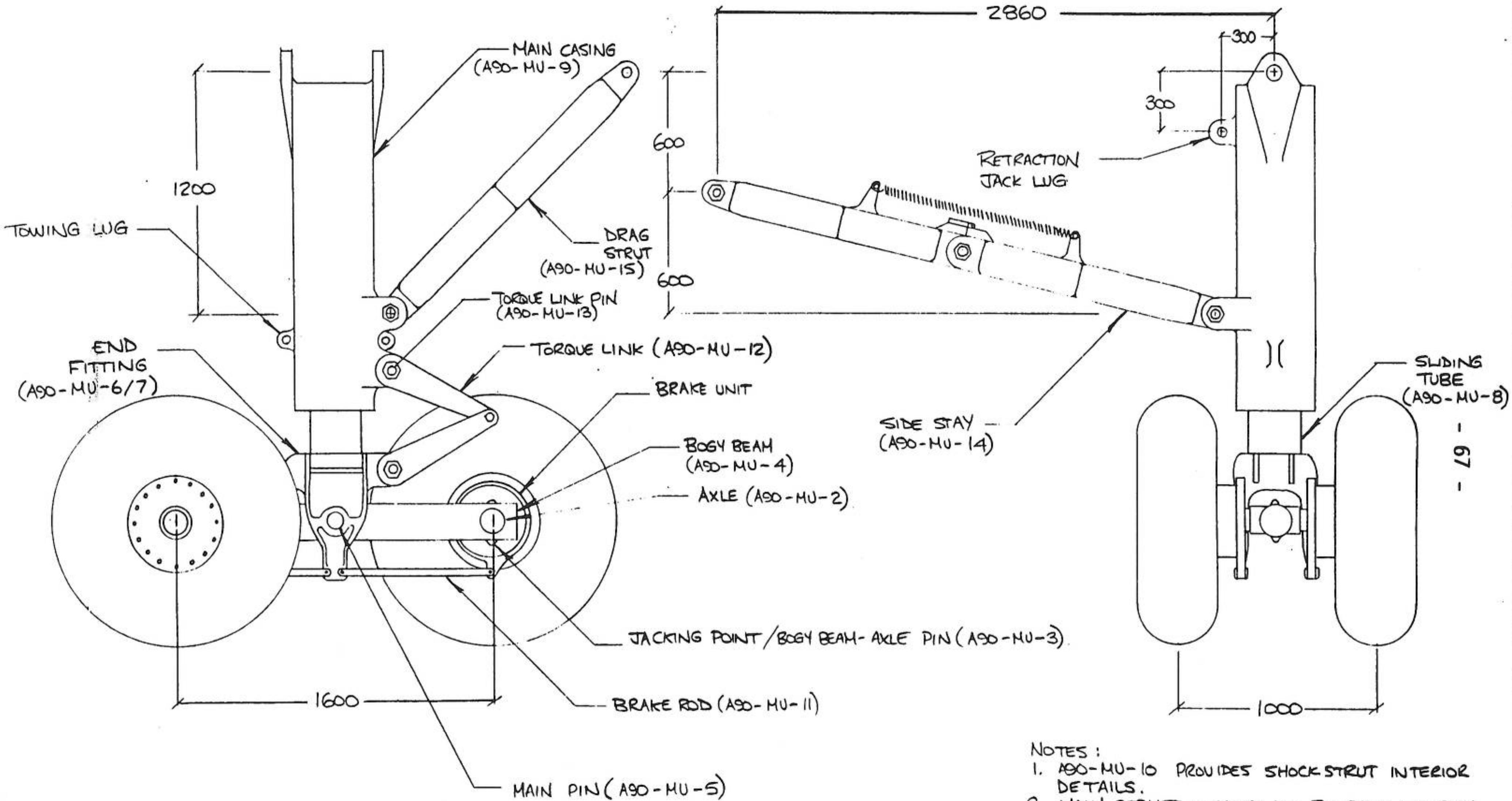

FLOOR BEAMS
AFT PRESSURE WALL
DOWNLOCK OVERCENTRE HYDRAULIC ACTUATOR
STEERING SYSTEM Drg. A90-NU-5
STATIC POSITION
CLOSURE TO STATIC POSN.
0.048
0.436
0.09
STATIC TYRE DEFLECTION
2.2665
6.38m FROM NOSE
DOWNLOCK LINKS
UPPER DRAG STRUT Drg. A90-NU-8
LOWER DRAG STRUT Drg. A90-NU-8
MAIN HOUSING Drg. A90-NU-4
TORQUE LINKS Drg. A90-NU-7
49"x17" TYRE Drg. A90-NU-6
TYRE CLEARANCE BOUNDARY
UPLOCK PIN ON BASE OF LEG
STATIC GROUND LINE
HYDRAULIC RETRACTION JACK
UPLOCK
FUSELAGE CENTRELINE SECTION
FORWARD PRESSURE WALL
RETRACTION JACK AND UPLOCK SUPPORT ATTACHED TO FLOOR AND FRONT PRESSURE WALL STRUCTURE
ALL DIMENSIONS m, UNLESS STATED
DRAWN
CHK'D
APP'D
SCALE 1:20
TITLE:- DEPLOYED UNDERCARRIAGE GEOMETRY
COLLEGE OF AERONAUTICS
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD
DRAWING No. A90-NU-1
SHT. of SHEETS

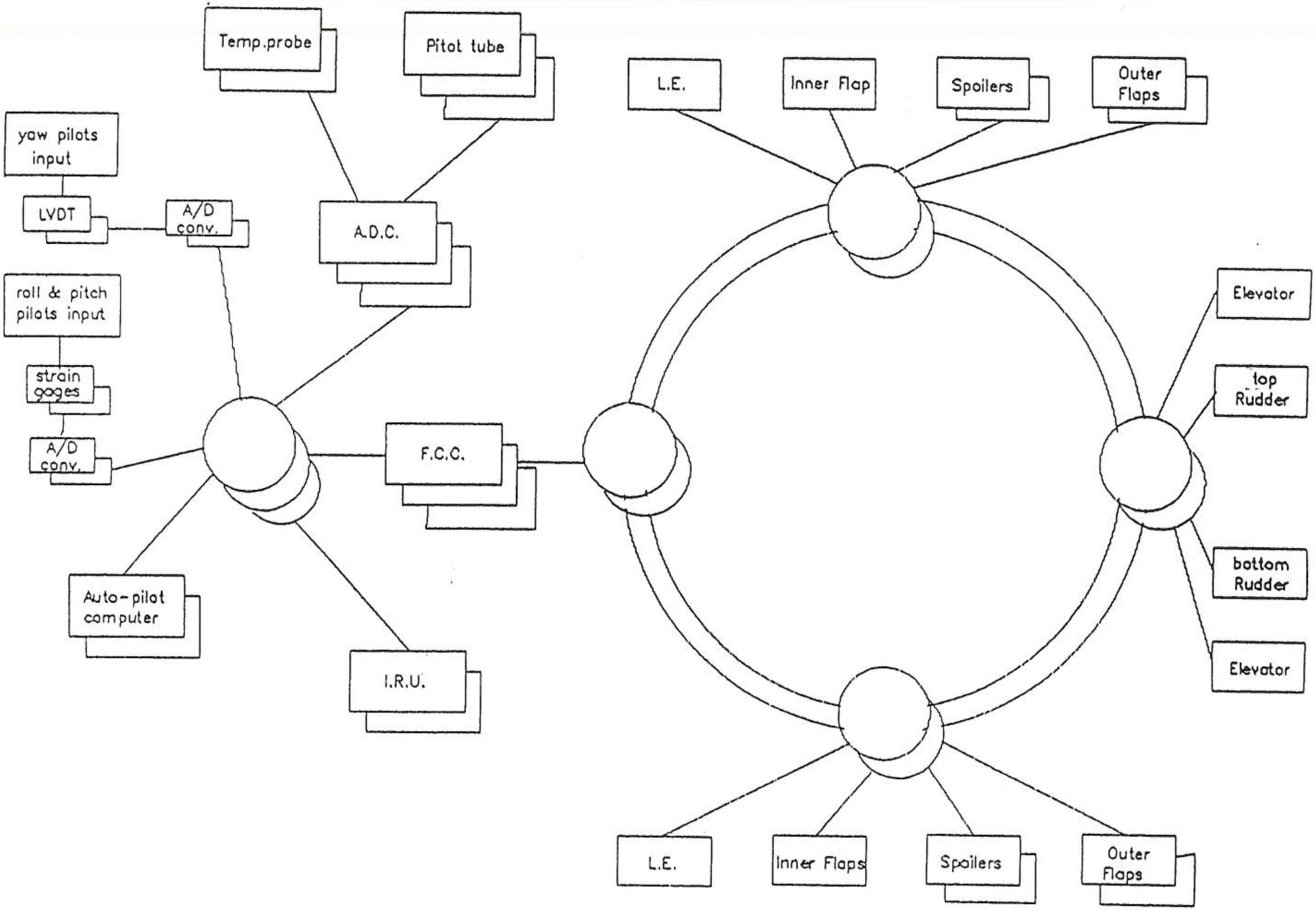
FIG. 34




NOTES:
1. A90-MU-10 PROVIDES SHOCK STRUT INTERIOR DETAILS.
2. MAIN STRUTS LOCATED AT FS 28.0 AND 32.1. LATERAL LOCATION – 3.4 M OUTBOARD OF FUSE ℄.

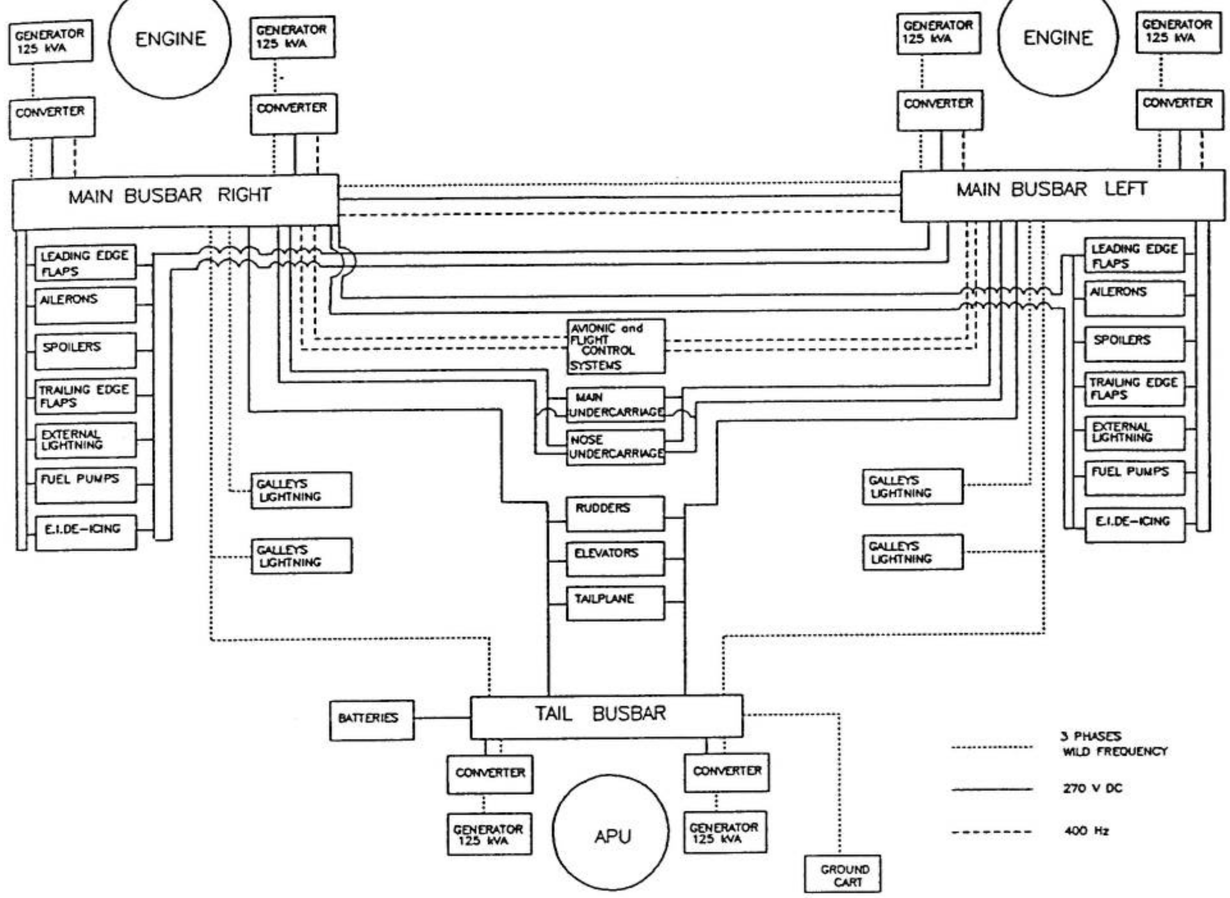
| SHEET SIZE | CRANFIELD INSTITUTE OF TECHNOLOGY | |
|---|---|---|
| | TITLE: GENERAL ARRANGEMENT – MAIN U/C – A90 | |
| A3 | DRAWN: S. GENTLES | DATE: 26 FEB 1991 |
| | SCALE: 1:20 | DRAWING No: A90-MU-1 |

FIG. 35




'LOCAL STAR BASED' TOPOLOGY

FIG. 36



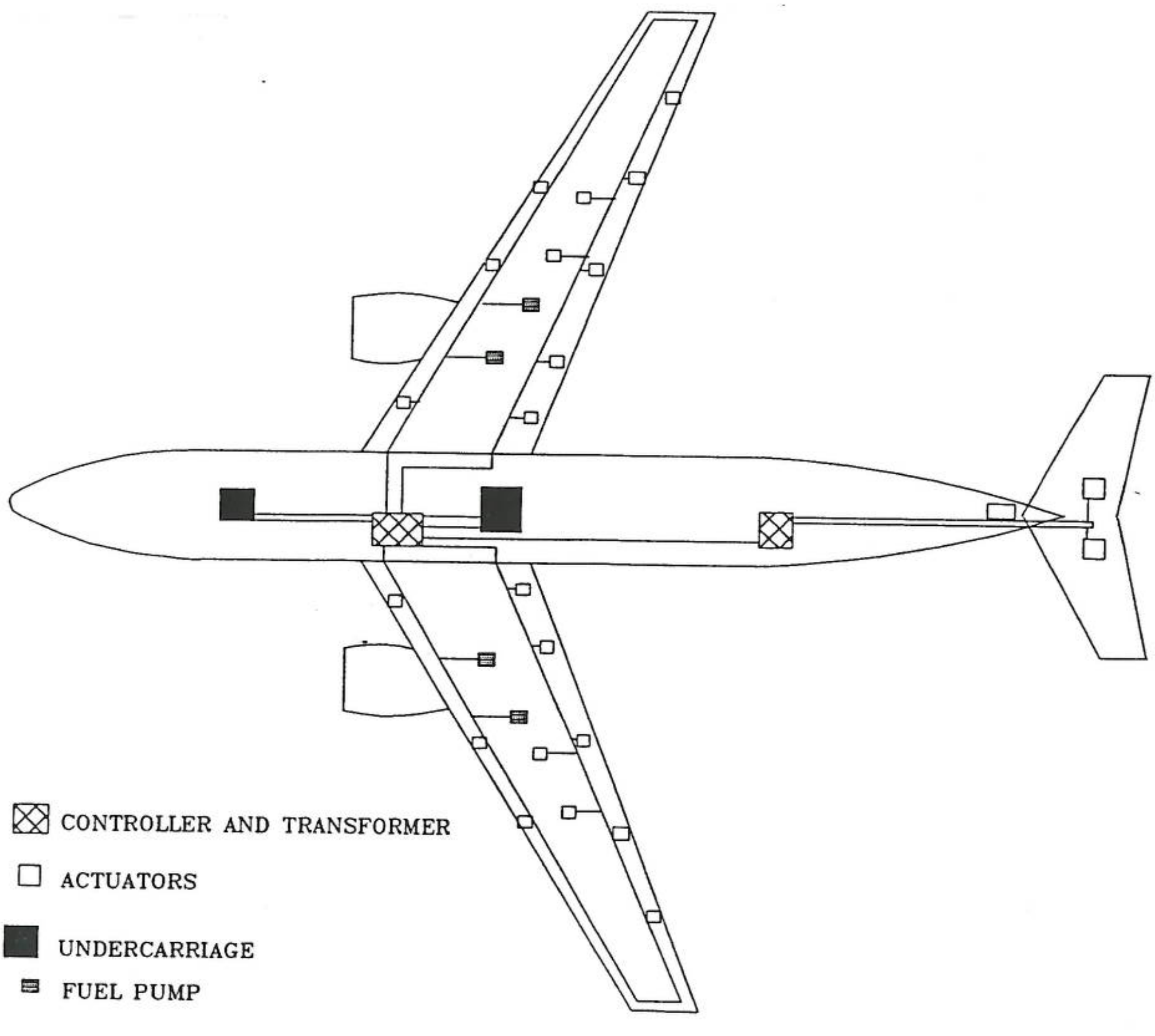




FIG. 37 ELECTRICAL POWER SYSTEM

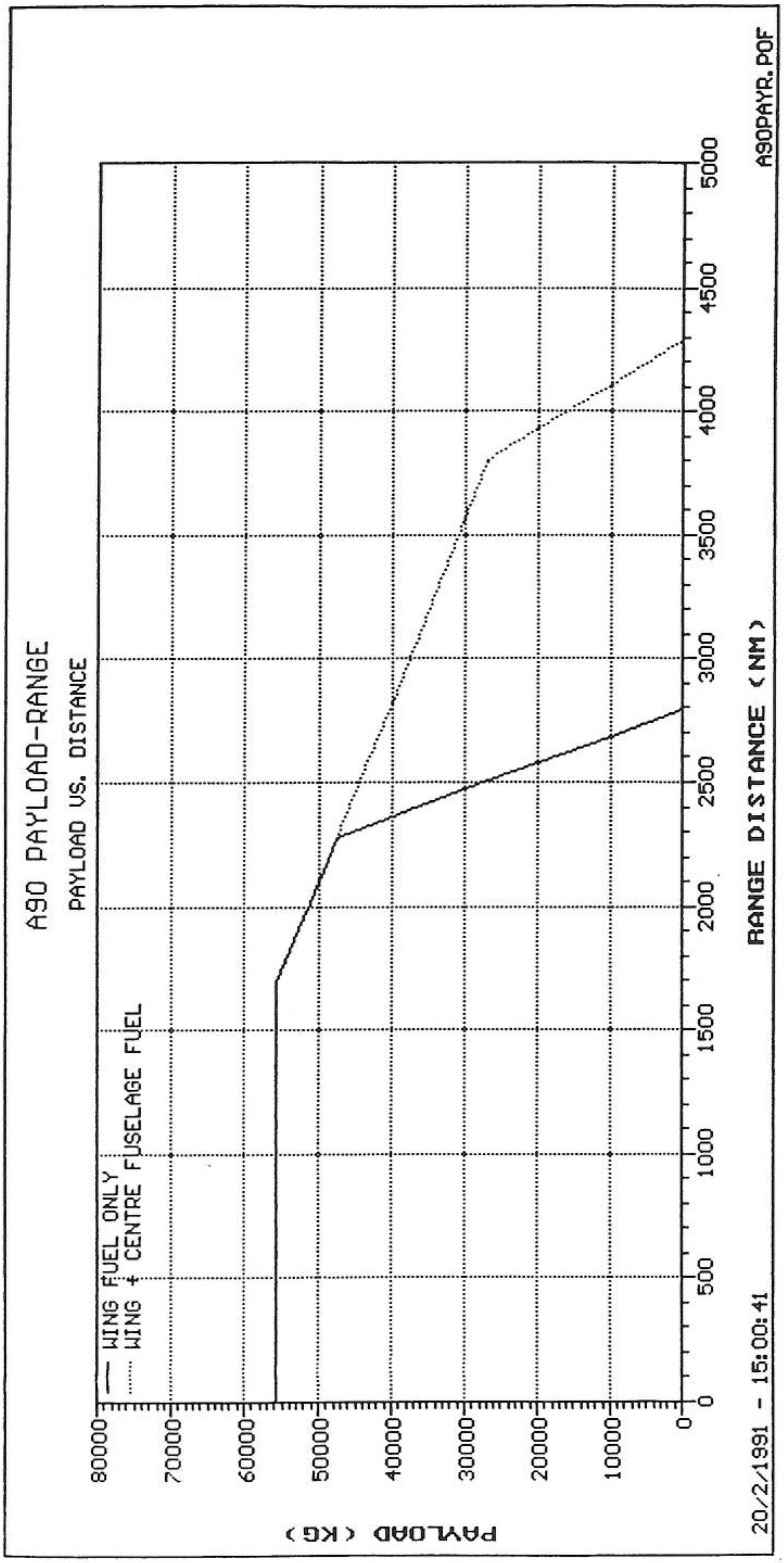

A90 PAYLOAD-RANGE
PAYLOAD VS. DISTANCE
WING FUEL ONLY
WING + CENTRE FUSELAGE FUEL
PAYLOAD (KG)
80000
70000
60000
50000
40000
30000
20000
10000
0
RANGE DISTANCE (NM)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
A90PAYR.POF
20/2/1991 - 15:00:41

FIG. 38

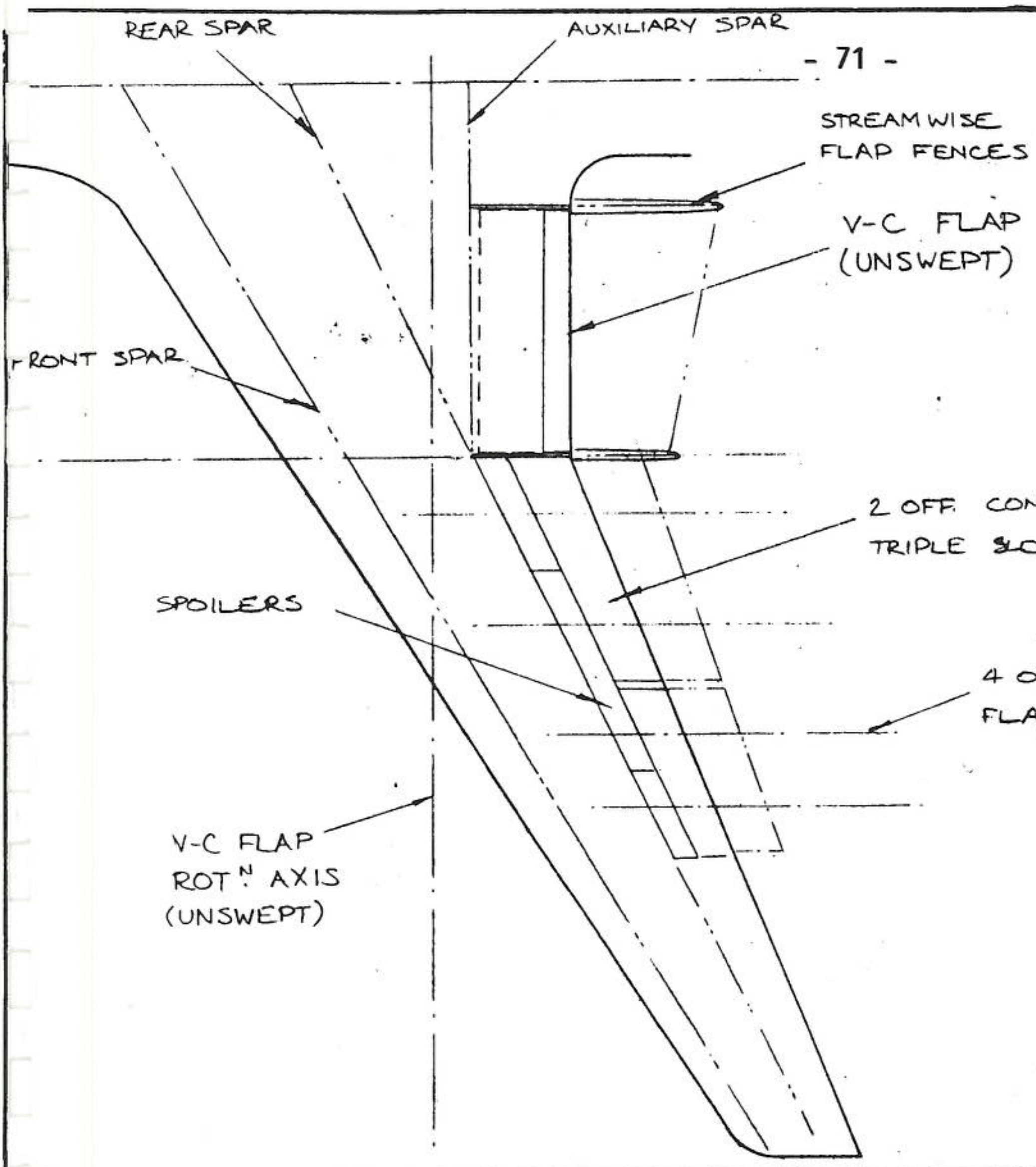



FIG. 39

APPLICATION OF AN UNSWEP
V-C FLAP WITH CONICAL UPPE
SURFACE TO THE SWEPT WING
OF A TRANSPORT AIRCRAFT

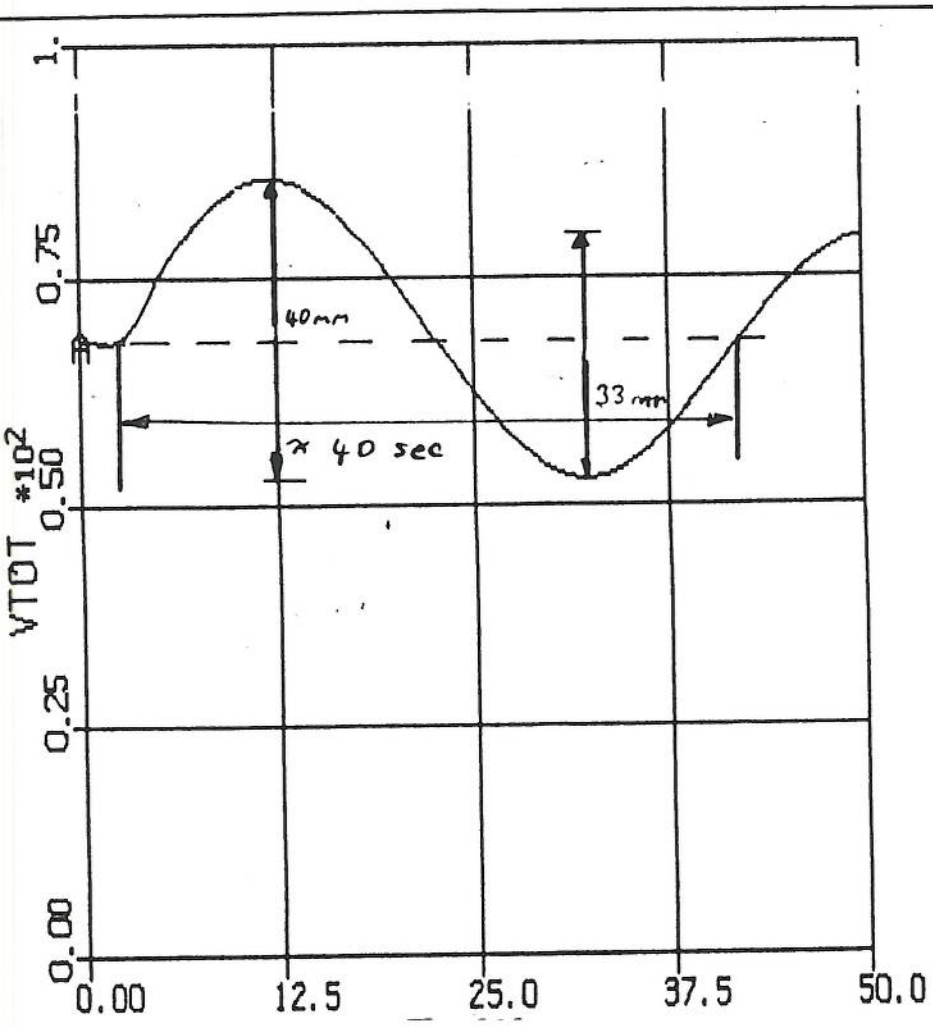



FIG. 40

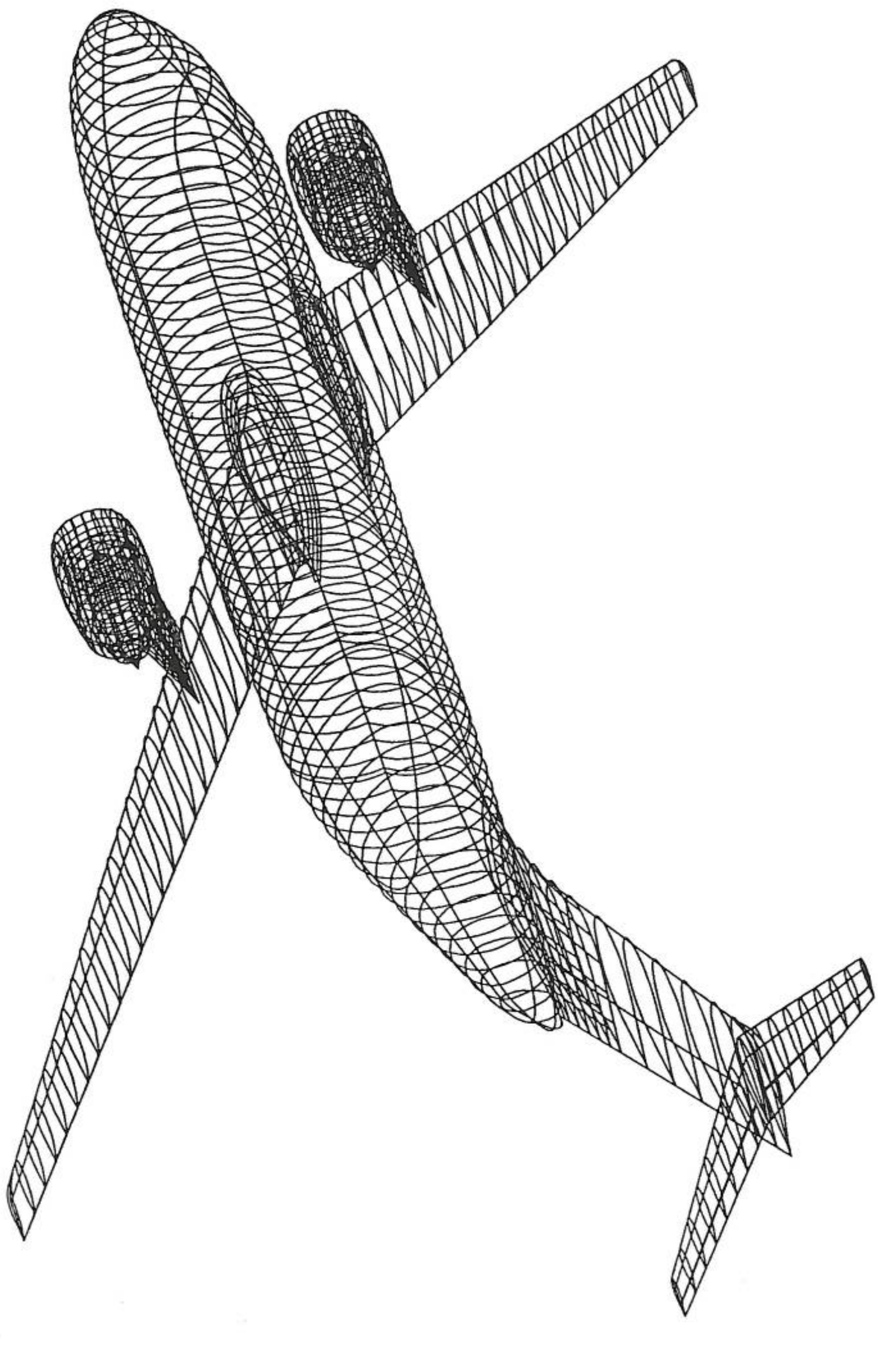
PHUGOID RESPONSE
LANDING CONFIGURATION

APPENDIX A

PROJECT SPECIFICATION

## CONTENTS

FIGURES



CRANFIELD INSTITUTE OF TECHNOLOGY

TITLE: A90 AIRLINER CAD ISOMETRIC SECTIONS

SHEET SIZE A3

DRAWN: R. P. JONKERS | DATE: 21 NOV 1990

SCALE: 1 : 200 | DRAWING No: A90-4-4

## 1. Introduction

Aircraft Manufacturers must be constantly aware of future trends in Air Transport Requirements. Many current market surveys show a compound growth in passenger miles of 7% PA over the next 20 years. This implies a growth factor of about three out of already overcrowded airports! A partial solution will be to use much larger aircraft at similar frequencies to today's aircraft. Investigations suggest that a 500 seat short haul aircraft would be suitable. A specification was drawn up, based on that of ref. 1. The main changes were to make field lengths compatible with Trister/A330 aircraft and a range slightly greater than for the A321 for the baseline aircraft. Growth potential to a range of 3500m miles should be provided. The wing should allow use of short haul gates at current airports.

## 2. Specification

### 2.1 Interior Layout

#### Capacity

500 single class passengers at 34" pitch with comfort standards at least as good as those of the Boeing 727.

One attendants' seat per 35 passengers with sufficient galley space per passenger of $0.025m^2$.

One toilet per 50 passengers.

The flight deck shall be designed for a two-man crew.

#### Cargo

Baggage space should be determined by assuming 4 $ft^3$ per seat minimum. Cargo space should be an additional 4 $ft^3$ per seat. Cargo doors should be the same height as the bin interior height and be located so that loading can be accomplished without a mechanical loading system.

It should be possible to carry LD3 and LD7 containers and pallets under the main floor. There should be an optional door for a cargo version.

2.2 Performance

i) Passenger and bag payload range shall be approximately 2000 nautical miles with FAR reserves.

ii) The maximum design cruise speed will be not less than 340 kt. CAS

iii) Maximum cruise altitude should be at least 39000 ft.

iv) Maximum certificated runway for maximum all up mass takeoff is 8300 ft at ISA sea level conditions.

v) The FAR landing distance at maximum landing mass should not exceed 5650 ft at ISA sea level conditions.

vi) Runway loading should not exceed an LCN of 65 at ramp mass.

2.3 General

The major design objectives are to include minimum seat-mile costs with maximum passenger comfort. It is expected that the aircraft will use the latest aerodynamic systems and material technology consistent with maximum service life, reliability and maintainability.

3. Configuration and Design Requirements

The aircraft will use state-of-the-art materials, at the discretion of the students concerned. It is envisaged that the majority of the airframe will be constructed of aluminium-lithium alloys with extensive use of composite materials in flying surfaces. The assumed mass savings associated with these materials are:-

| Components | Mass Saving Rel. to Conventional |
|---|---|
| Fuselage | 8% |
| Wing | 25% |
| Nacelle | 25% |
| Tail | 25% |
| Undercarriage | 5% |
| Pylon | 0% |

This should produce considerable weight savings and produce a smaller and lighter aircraft to meet the specification, with obvious fuel saving benefits. Figure A90-1 shows a general arrangement drawing of the aircraft, the major points of which are discussed below:-

3.1 Wing - (Figure 3)

A modest sweepback combined with a supercritical wing section enable Mach numbers in the region of 0.86 to be achieved. The aspect ratio is 8.98 and there is sufficient fuel tankage at spec. payload for a range of some 2000 miles with reserves. The high aspect ratio improves fuel burn and airfield performance. Variable camber flaps, low wing loading, leading edge devices and the high aspect ratio give moderate field performance. The V-C flaps improve cruise efficiency, provide growth potential and are used for gust and manoeuvre alleviation.

3.2 Fuselage - (Figure 2)

The double-bubble fuselage permits twin-aisle, 10-abreast seating on the main deck, six on upper deck. Passenger baggage is stored under the cabin floor. The seating arrangements are as in the specification but an alternative layout accommodates 620 passengers at 30" seat pitch. Figure 4 shows a typical cabin interior. A quick-change version can accomodate twin rows of 8ft x 8ft containers. The high wing would permit easy development of an air-dropping military version.

3.3 Powerplant

The choice of twin large-diameter engines led to the adoption of a high wing with 2 pod-mounted Trent powerplants. The high wing improves lift and engine clearance and provides a lower fuselage for ease of loading, maintenance and emergency evacuation. Ditching evacuation would be by overwing exits from the upper deck.

3.4 Tail Unit

The aircraft utilises an all-moving high-tee tail. Trim is obtained by tailplane movement whilst control is provided by the elevators. This powerful arrangement is necessary to trim out the large pitching moments produced by the wing high lift devices.

3.5 Landing Gear

Four - wheel Bogie units are mounted on each leg. Four main units retract into fuselage blisters, whilst the nose unit retracts forward.

3.6 Design Requirements

The aircraft is to be designed to meet JAR requirements at the normal take-off mass of 211075 kg. The design value of cruise speed $V_C$ is 193M/S EAS or M = 0.86 whichever is the lesser. The corresponding values of the design diving speed $V_D$ = 213M/S EAS and M = 0.91 and these values are shown in Fig. 5.

The airframe life is to be 100,000 hours with average flight duration of 1.67 hours without major repairs. The cabin differential pressure of 0.6 bar ensures that the cabin altitude need never exceed 2.1 km. The range performance depends on the flight pattern used and is summarised in Fig. 6. The payload - range diagram is shown as Fig.23.

The undercarriage design vertical velocity of descent is 3.05m/s. The aircraft mass associated with particular flight patterns for fatigue loading purposes must be calculated as appropriate.

Where appropriate the design of components should allow for the reliability requirements shown in Table 3.

## 4. Geometry

### 4.1. Wing (see Fig.3)

| | | |
|---|---|---|
| Gross area | | 361.95$m^2$ |
| Span | | 57m |
| Aspect ratio | | 8.976 |
| Root chord (centreline) | | 9.7m |
| Leading edge sweepback | (Approx) | 32.5 ° |
| Sweep of 0.25c line | | 30 ° |
| Standard mean chord $\bar{c}$ | | 6.35 |

Aerofoil Section:- V-C Aerofoil.

root 14% thickness supercritical

MAC 10.2% thickness supercritical

tip 8% thickness supercritical

(see Figure 3)

| | |
|---|---|
| Wing body setting angle, rel. to chord line | 0.0 ° |
| Anhedral on 0.25c line | 3.0 ° |
| Location of 0.25 $\bar{c}$ aft of nose | 27.2m |
| Location of 0.25 $\bar{c}$ line, at centreline above datum. | 2.4m |

4.2 Outer Variable Camber Trailing Flaps (see Fig.3)

| | |
|---|---|
| Flap chord/wing chord | 35% |
| Movement | +9°<br>-3.5° |
| Inboard end of flap group from aircraft centreline | 20.5m |
| Outboard end from aircraft centreline | 28.5m |

4.3 Inner Variable Camber Trailing Flaps (see Fig.3)

Type:- VC with nested single - slotted flap

| | |
|---|---|
| Flap chord/wing chord | 0.35 |
| Take off flap angle | 12° |
| Landing flap angle | 12° +35° Aux Flap |
| Inboard end of flap groupfrom $C_L$ | 3.28m |
| Outboard end of flap from $C_L$ | 20.5m |
| Wing chord flap extended/wing chord (Inc. L.E.) | 1.40 |
| Aux chord/wing chord | 0.15 |

4.4 Wing Leading Edge VC Devices (see Fig.3)

| | |
|---|---|
| Chord/wing chord | 0.17 |
| Deflection relative to horiz. | -6° |
| Inboard end relative to aircraft $C_L$ | 3.28m |
| Outboard end relative to aircraft $C_L$ | 28.5m |

4.5 Tailplane (see Fig.3)

| | |
|---|---|
| Gross area | $60.16m^2$ |
| Span | 16.0m |
| Aspect ratio | 4.255 |
| Root chord (centreline) | 5.2m |
| Tip chord (nominal) | 2.32m |
| Sweepback of leading edge, approx. | 32° |
| Sweep of 0.25 c line | 27.5° |
| Aerofoil section:- NACA 63A010 | |
| 10% thickness symmetrical | |
| (see Fig.3) | |
| Dihedral | 0° |
| Movement | +8° <br> -13° |
| Location of apex line aft of fuselage nose | 56.85m |
| Vertical location above fuselage datum | 12.7m |

4.6 Elevator (see Fig.3)

| | |
|---|---|
| Type:- Round nose | |
| Elevator chord/tailplane chord | 0.30 |
| Movement | +20° <br> -25° |

4.7 <u>Fin</u> (see Fig.3)

| | |
|---|---|
| Nominal area | 79.65m$^2$ |
| Nominal height above fuselage datum | 13.5m |
| Aspect ratio, based on nominal area | 1.017 |
| Aspect ratio, effective | 1.444 |
| Root chord | 10.1 |
| Tip chord (nominal) | 7.6 |
| Sweepback of leading edge | 43.0$^\circ$ |

Aerofoil section:- 12% thickness symmetrical

NACA 64, - 012 (see Fig.3)

| | |
|---|---|
| Distance of intersection of leading edge with fuselage top, aft of fuselage nose. | 48.07m |

4.8 <u>Rudder</u> (see Fig.3)

Type:- Round nose

| | |
|---|---|
| Rudder chord/fin chord | 0.37 |
| Height of rudder root at trailing edge, above datum | 4.7m |
| Height of rudder tip at trailing edge above datum | 12.1m |
| Movement | $\pm 20^\circ$ |

4.9 <u>Fuselage</u> (see Fig.2)

| | |
|---|---|
| Overall length | 59.3m |
| Maximum width | 6.56m |
| Maximum height | 7.76m |
| Internal width of cabin (Main Deck) | 6.26m |
| Length of main cabin | 47.8m |

4.10 Undercarriage (see Fig.2)

Type:- Nosewheel with four main legs

| | |
|---|---|
| Wheelbase, to centre of main leg group | 23.75m |

Main undercarriage units

Four wheel Bogie, sideways retracting

Tyres: 1.24m diameter by 0.43m wide

| | |
|---|---|
| Tyre pressure | 13.79 Bar |
| Static tyre closure | 0.114m |
| Maximum tyre closure | 0.27m |
| Centre of wheel group aft of fuselage nose | 20.05m |
| Bogie Wheel Base | 1.7m |
| Wheel Track | 1.0m |

Nose undercarriage

Twin wheels, forward retracting

Tyres 1.24m diameter x 0.43m wide

| | |
|---|---|
| Tyre pressure | 12.41 Bar |
| Wheel track | 0.9m |
| Location of leg aft of fuselage nose | 6.3m |

5. Powerplants

Type: Rolls Royce Trent bypass turbojet

| | |
|---|---|
| Sea level static rating kN | 333.6 |

Installation: 2 underslung wing pods

| | |
|---|---|
| Distance of engine centreline below datum at front face | 0.5m |
| Distance of engine centreline from aircraft centreline at front face | 10.0m |
| Location of engine front face aft of fuselage nose | 19.85m |
| Maximum pod diameter | 3.7m |
| Total length of pod | 8.0m |
| Angle of pod datum (nose in) | $2.0^\circ$ |
| Sweepback of pylon leading edge relative to fuselage datum | $6.2^\circ$ |
| Sweepback of pylon trailing edge relative to fuselage datum | $15^\circ$ |
| Inclination of pylon to vertical | 0.0 |
| Pylon chord at engine centreline (projected) | 19.0m |
| Pylon chord at wing datum | 6.0m |

Pylon aerofoil section Symmetrical 9% thickness at 50%c

Auxilliary power unit type: - TO BE DETERMINED

| | |
|---|---|
| APU datum above fuselage datum | 3.5m |
| APU C G aft of fuselage nose | 58.0m |

## 6. Masses, Centres of Gravity and Moments of Inertia

| | |
|---|---|
| Design normal take off mass | 211,075KG |
| Design maximum landing mass | 175,000KG |
| Manufacturers Equipped mass | 96,843KG |
| Operating empty mass | 119,075KG |
| Maximum payload | 55,800KG |
| Maximum fuel load (inc. wing c/sect) | 65,000KG |

Mass breakdown - see Table 1

Centre of gravity at O.E.M. relative to 0.25 $\bar{c}$ and HFD

(U/C extended) 0.413m fwd, 0.402m above

Centres of gravity range in flight 0.15-0.35$\bar{c}$

Moment of inertia - see Table 2.

## 7. Aerodynamic Information

### 7.1 Lift Characteristics

Maximum lift coefficient:-

| | |
|---|---|
| Basic wing | 1.20 |
| + VC Devices at take-off setting | 1.8 |
| + VC Devices at landing setting | 2.5 |

Slope of wing-body lift curve

Basic

See Fig.8

Flaps deployed

7.2 Drag Characteristics

Drag Polar:-

Cruise condition M = 0.86 and 12,000 m

$C_D = 0.02 + 0.047\ C_L{}^2$

Take-off at sea level, undercarriage and flaps extended

$C_D = 0.0488 + 0.047\ C_L{}^2 + 0.053\quad C_L{}^2$

Landing at sea level, undercarriage and flaps extended

$C_D = 0.0948 + 0.047\ C_L{}^2 + 0.053\quad C_L{}^2$

Where $C_L$ is increment in $C_L$ due to flap deflection.

7.3 Pitching Moment Characteristics (low speed)

Pitching moment coefficient at zero lift

| | | |
|---|---|---|
| Wing alone, $C_{M_O}$ | | -0.06 |
| Increment due to body | $C_{M_O}$ | -0.015 |

Pitching moment increment due to flaps:-

| | |
|---|---|
| Take off setting, $C_{M_O}$ | -0.09 |
| Landing setting, $C_{M_O}$ | -0.17 |

Location of overall wing-body aero centre

| | |
|---|---|
| % S.M.C., whole aircraft | 20.3% |
| includes:- | |
| (Forward shift due to basic fuselage) | 5.6% |
| (Forward shift due to Nacelles) | 7.0% |

Spanwise variation of basic wing aero centre Fig.9

## 7.4 Control and Stabiliser Characteristics

| | |
|---|---|
| Location of mean tailplane aero centre aft of fuselage nose | 60.0m |
| Spanwise variation of tailplane aero centre - see Fig.10 | |
| Location of mean fin aero centre aft of fuselage nose | 54.2m |
| Rolling moment coefficient due to aileron, $L_\xi$ - see Fig. 12 | |
| Aileron hinge moment coefficient due to wing incidence, $b_1$ | to be |
| Aileron hinge moment coefficient due to aileron angle, $b_2$ | determined |
| Slope of tailplane lift curve variation with M, $a_{1T}$ - - see Fig.8 | |
| Elevator lift curve slope, - see Fig.8 | |
| Elevator hinge moment coefficient due to tailplane angle, $b_{1T}$ | to be deter- |
| Elevator hinge moment coefficient due to elevator angle, $b_{2T}$ | mined |
| Slope of fin lift curve variation with M, a1F - see Fig.8 | |
| Rudder lift curve slope, - see Fig.8 | |
| Rudder hinge moment coefficient due to fin angle, $b_{1F}$ | to be |
| Rudder hinge moment coefficient due to rudder angle, $b_{2F}$ | determined |
| Yawing moment coefficient due to rudder, $N_\zeta$, approx. | -0.11 |

7.5 Stability Characteristics

Downwash at tailplane - see Fig. 13

Rolling moment coefficient due to:-

Rolling moment, $L_p$ - see Fig. 12

| | | |
|---|---|---|
| Sideslip, $L_v$ | (Low speed) | -0.19 |
| | (Cruise) | -0.15 |

Yawing, $L_r$ - see Fig. 12

Yawing moment coefficient due to:

| | |
|---|---|
| Sideslip, $N_v$, tail off | -0.109 |
| $N_v$, overall | 0.193 |
| Yawing, $N_r$ | 0.14 |

Tailplane rolling moment coefficient due to sideslip, $K_\beta$ - see Ref. 2.

(Note: All derivatives are based on the reference areas and dimensions quoted in paragraph 4. Hinge moment coefficients are based on control surface chord and area aft of the hinge line. All angular measurements are in radians unless otherwise stated)

8. Load Distribution

8.1 Aerodynamic Loads

The wing spanwise load distribution due to incidence, VC devices and tailplane load distribution due to both incidence and elevator deflection are given in Figs. 14-16. Whilst the corresponding information for the fin and rudder is to be found in Fig.17. Fig.18 shows a typical lift distribution along the fuselage. The shape of the distribution is dependent upon incidence and the diagram given is a means for initial loading calculations.

Chordwise load distributions vary substantially with Mach number and lift coefficient. The curves given should only be used for local design of the various components and not for overall balance calculations. Typical wing chordwise loading due to incidence is shown in ref. 3, whilst distributions due to flaps, control surface, are to be determined from supercritical data. The chordwise loading on the tailplane and rudder may be derived from DES 8714/5.

8.2 INERTIA LOADS

Inertia distributions are shown in figs. 19-22

## 9. References

1. Short-medium range aircraft AEA requirements, Dec 1989 association of European Airlines.

2. ARC 14969
Assymetric Tailplane Loads Due to Sideslip.
W. Braun CP 119.

3. V-C Aerodynamics - see A McKinnon or S H Macci - PhD Students.

TABLE 1 MASS BREAKDOWN

| COMPONENTS | MASS KG | % AUM |
|---|---|---|
| WING (INC. AUXIL. SURFACE STRUCTURE) | 17920 | 8.51 |
| FUSELAGE | 31554 | 14.98 |
| FIN (INC. RUDDER) | 1200 | 0.57 |
| TAILPLANE (INC. ELEVATOR) | 1020 | 0.48 |
| MAIN UNDERCARRIAGE | 6285 | 2.98 |
| NOSE UNDERCARRIAGE | 1570 | 0.75 |
| PYLONS | 2100 | 1.00 |
| STRUCTURE | 61649 | 29.2 |
| ENGINES<br>POWERPLANT STRUCTURE & ACCESSORIES | 15509 | 7.35 |
| POWERPLANT | 15509 | 7.35 |
| FUEL SYSTEM | 1215 | 0.58 |
| FLYING CONTROL SYSTEM | 1551 | 0.74 |
| HYDRAULICS | 1411 | 0.67 |
| ELECTRICAL SYSTEM | 3350 | 1.59 |
| A.P.U. | 230 | 0.11 |
| INST. AND AVIONICS | 1120 | 0.53 |
| DE-ICE | 830 | 0.39 |
| FIRE PROTECTION | 620 | 0.29 |
| FURNISHINGS (FIXED) | 7100 | 3.37 |
| ENVIRONMENTAL CONTROL SYSTEM | 2078 | 0.98 |
| PAINT | 180 | 0.09 |

| | | |
|---|---|---|
| SYSTEMS | 19685 | 9.33 |
| MANUF.EQUIPPED MASS | 96843 | 45.68 |
| MEM TOLERANCE | 1937 | 0.9 |
| CREW AND PROVISIONS | 3690 | 1.74 |
| SEATS, EMERG.EQUIP,PAX SERVICE | 11800 | 5.6 |
| NOM. O.E.M | 114270 | |
| 2% MID LIFE | 2285 | 1.08 |
| PALLETS & CONT | 2520 | 1.19 |
| OPERATING EMPTY MASS | 119075 | 56.41 |
| 500 PASSENGERS AND BAGGAGE | 47500 | 22.5 |
| FUEL AT ABOVE PAYLOAD | 44500 | 21.08 |
| MAX ALL UP MASS | 211075 | 100.00 |

TABLE 2 MOMENTS OF INERTIA

| CONFIGURATION | MOMENT OF INERTIA $10^3$ KG-$M^2$ | | |
|---|---|---|---|
| | PITCH | ROLL | YAW |
| Operating Empty mass 119075 kg | 10,404 | 5,903 | 15,217 |
| Increment due to 44,500 kg of fuel | 194 | 5,563 | 5,400 |
| Increment due to passenger and baggage 47,500 kg | 2,402 | 134 | 1,573 |

NOTE

These figures have been calculated relative to the intersection of the wing quarter standard mean chord and the horizontal fuselage datums. Allowances should be made for changes due to centres of gravity being different from this point.

TABLE 3 DELAY RATE TARGETS FOR INDIVIDUAL SYSTEMS

| ATA CHAPTER NO. | DESCRIPTION | DELAY RATE |
|---|---|---|
| 21 | Air Conditioning | 0.12 |
| 22 | Auto. Flight | 0.03 |
| 23 | Communications | 0.03 |
| 24 | Elec. Power | 0.10 |
| 25 | Furnishings | 0.06 |
| 26 | Fire Protection | 0.05 |
| 27 | Flying Controls | 0.32 |
| 28 | Fuel System | 0.10 |
| 29 | Hyd. Power | 0.18 |
| 30 | Ice Protection | 0.01 |
| 31 | Instruments | 0.02 |
| 32 | Landing Gear | 0.41 |
| 33 | Lights | 0.07 |
| 34 | Navigation | 0.15 |
| 35 | Oxygen | 0.01 |
| 38 | Water/Waste | 0.02 |
| 49 | A.P.U. | 0.09 |
| 52 - 57 | Structures | 0.24 |
| 71 - 80 | Powerplant Systems | 0.86 |
| TOTAL | | 2.87 |

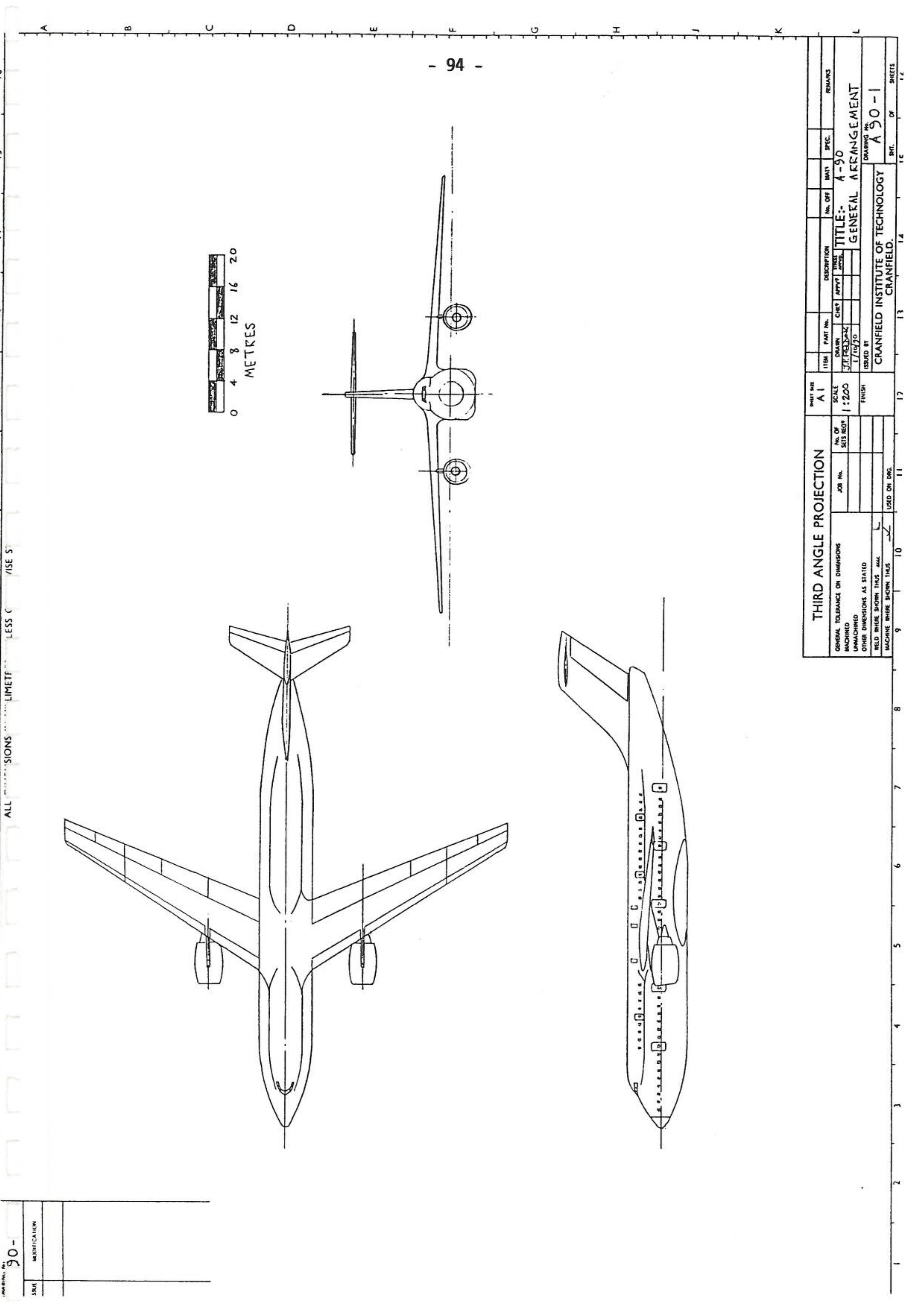
$$\text{Delay Rate} = \frac{\text{No. of delays > 15 min + cancellations}}{\text{100 departures}}$$

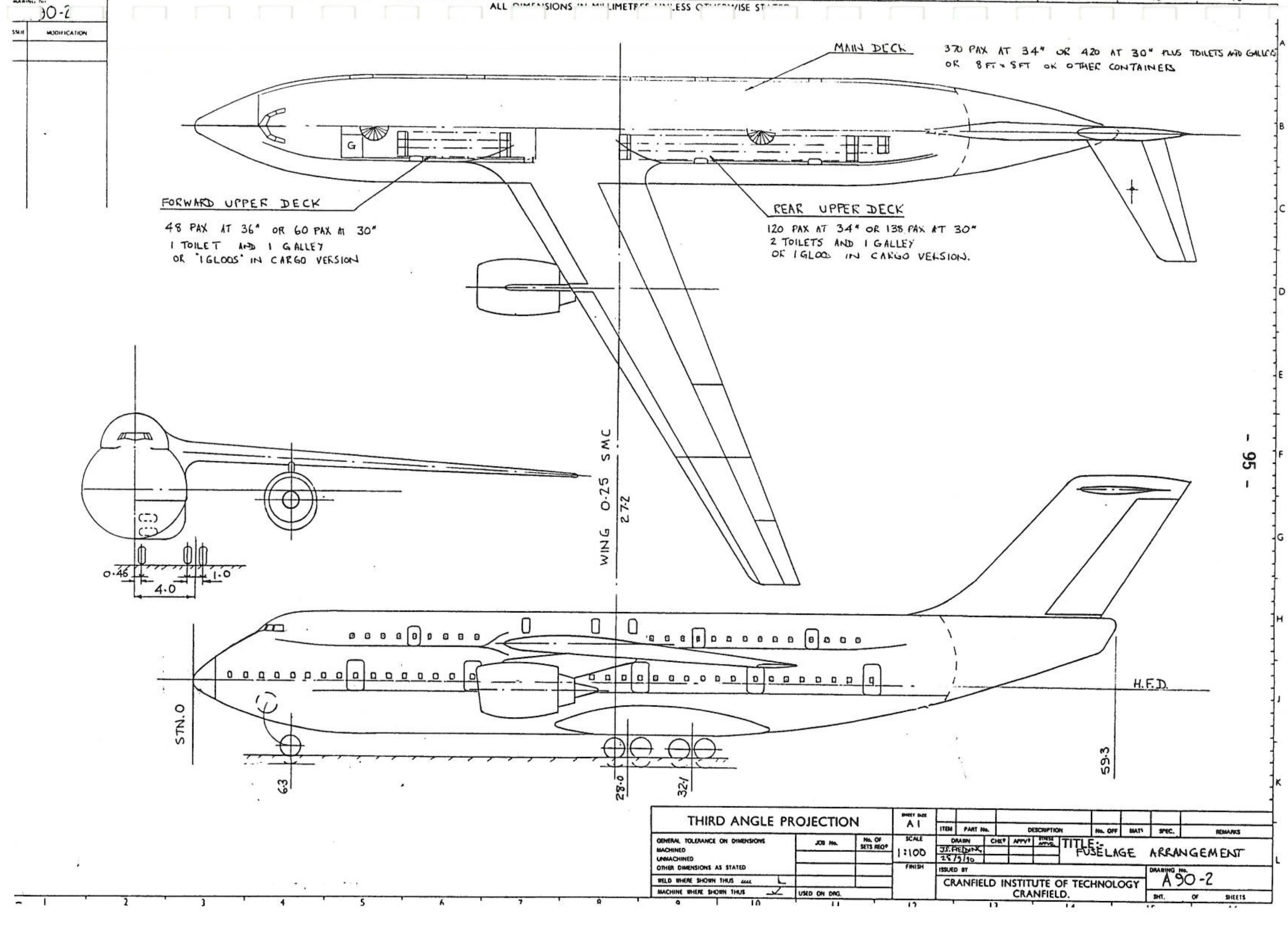
TABLE 4 COMPONENT C G LOCATIONS

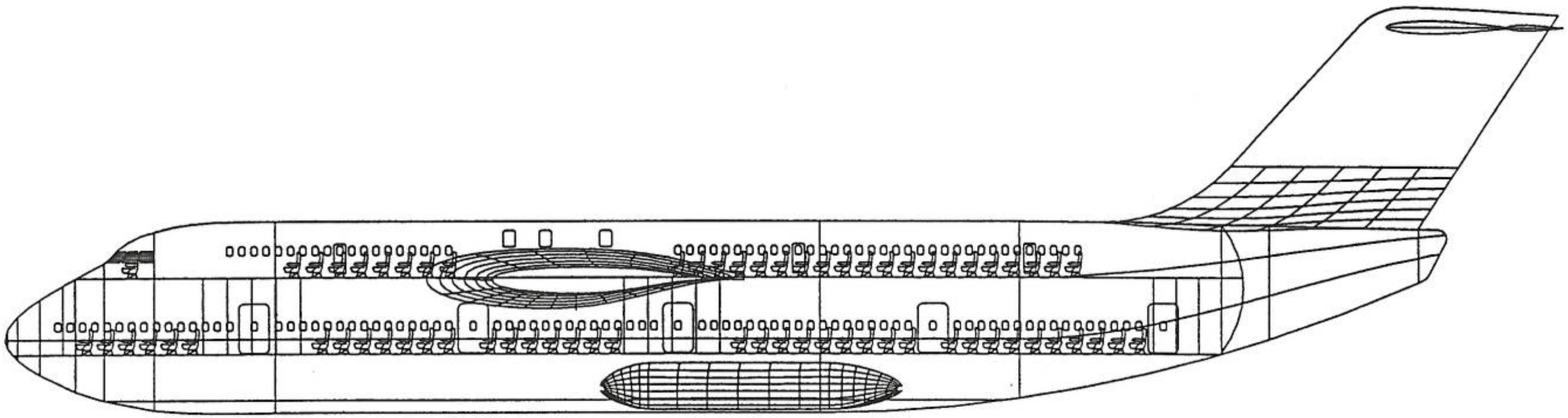
Distances are relative to the intersection of the 0.25 SMC and HFD

POSITIVE AFT AND UP

| ITEM | | MASS KG | X (M) | Y (M) | Z (M) |
|---|---|---|---|---|---|
| WING | C | 3580 | -3.2 | 1.8 | 2.5 |
| | 01 | 4400 | -2.2 | 5.3 | 2.45 |
| | 02 | 4020 | -0.35 | 9 | 2.4 |
| | 03 | 3400 | 2.6 | 14.4 | 2.3 |
| | 04 | 2520 | 6.3 | 21.4 | 2.2 |
| FUSELAGE | F1 | 6554 | -19 | | - |
| | F2 | 12000 | 6 | | - |
| | F3 | 8000 | 9.5 | 1.5 | - |
| | F4 | 5000 | 22 | | - |
| FURNISHINGS | | | | | |
| (FIXED) | 1 | 3550 | -6 | 0 | 1.5 |
| | 2 | 3550 | 8 | 0 | 1.5 |
| TAILPLANE | | 1020 | 33 | 3.5 | 12.5 |
| FIN | | 1200 | 28 | - | 8 |
| NOSE U/C | DOWN | 1570 | -21.1 | - | -3 |
| MAIN U/C | DOWN | 6285 | 2.9 | 3.9 | -3.5 |
| PYLONS | | 2100 | 3 | 10 | 1.0 |
| ENGINES & COWLS | | 15509 | -5.5 | 10 | -0.5 |
| FUEL SYS | | 1215 | 0 | 12 | 2.3 |
| FLYING CONT | | 1551 | 12 | 10 | 2.5 |
| HYD & PNEU | | 1411 | 0 | 4 | -2.5 |
| ELECT SYS | | 3350 | 0 | 4 | -2.5 |
| AVIONICS & INST | | 1120 | -20 | - | 2 |
| ANTI & DE-ICE | | 830 | 2 | 12 | 1 |
| FIRE EXT | | 620 | -7 | 10 | 1 |
| APU | | 230 | 30.8 | - | 3.5 |
| PAINT | | 180 | 0 | 0 | 0 |
| ECS | | 2078 | 4 | 4 | -2.5 |
| MEW ALLOWANCE | | 1930 | 0 | 10 | 1 |
| SERVICE ITEMS | | 2250 | 0 | 1.5 | 1 |
| CREW | | 1440 | 0 | 1.5 | 1 |
| PAX SERVICE | | | | | |
| SEATS, EMERG EQIPT | | 11800 | -1 | 1.5 | 1 |
| MID LIFE ALLOW | | 2280 | 0 | 10 | 0 |
| PALLETS & CONT | | 2520 | -7 | 1.5 | -2 |


0 4 8 12 16 20
METRES
THIRD ANGLE PROJECTION
SHEET SIZE A1
SCALE 1:200
DRAWN J.T.FIELDING 1/10/90
TITLE:- A-90
GENERAL ARRANGEMENT
DRAWING No. A 90 - 1
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD.
GENERAL TOLERANCE ON DIMENSIONS
MACHINED
UNMACHINED
OTHER DIMENSIONS AS STATED
WELD WHERE SHOWN THUS
MACHINE WHERE SHOWN THUS
USED ON DRG.
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
MODIFICATION


ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
MAIN DECK
370 PAX AT 34" OR 420 AT 30" PLUS TOILETS AND GALLEYS
OR 8FT × 8FT OR OTHER CONTAINERS
FORWARD UPPER DECK
48 PAX AT 36" OR 60 PAX AT 30"
1 TOILET AND 1 GALLEY
OR 'IGLOOS' IN CARGO VERSION
REAR UPPER DECK
120 PAX AT 34" OR 138 PAX AT 30"
2 TOILETS AND 1 GALLEY
OR IGLOO IN CARGO VERSION.
G
WING 0.25 SMC
27.2
0.46
4.0
1.0
STN.0
6.3
28.0
32.1
59.3
H.F.D.
THIRD ANGLE PROJECTION
GENERAL TOLERANCE ON DIMENSIONS
MACHINED
UNMACHINED
OTHER DIMENSIONS AS STATED
WELD WHERE SHOWN THUS
MACHINE WHERE SHOWN THUS
JOB No.
No. OF SETS REQ'D
USED ON DRG.
SHEET SIZE A1
SCALE 1:100
FINISH
ITEM
PART No.
DESCRIPTION
No. OFF
MAT'L
SPEC.
REMARKS
DRAWN J.S. FIELDING 25/9/90
CHK'D
APPV'D
STRESS APPVD.
TITLE:- FUSELAGE ARRANGEMENT
ISSUED BY
CRANFIELD INSTITUTE OF TECHNOLOGY
CRANFIELD.
DRAWING No. A90-2
SHT. OF SHEETS
ISSUE
MODIFICATION



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|---|---|---|---|
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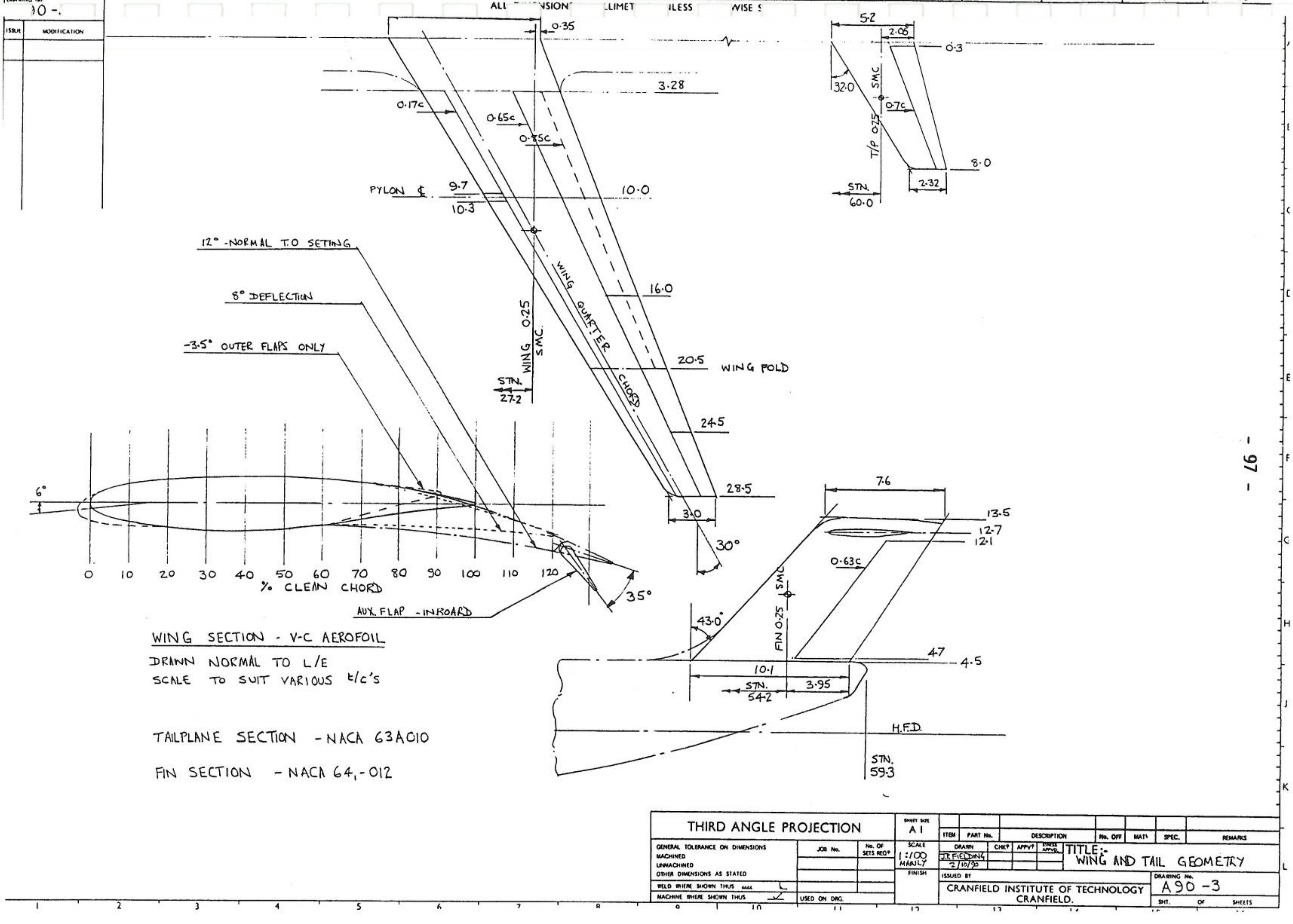
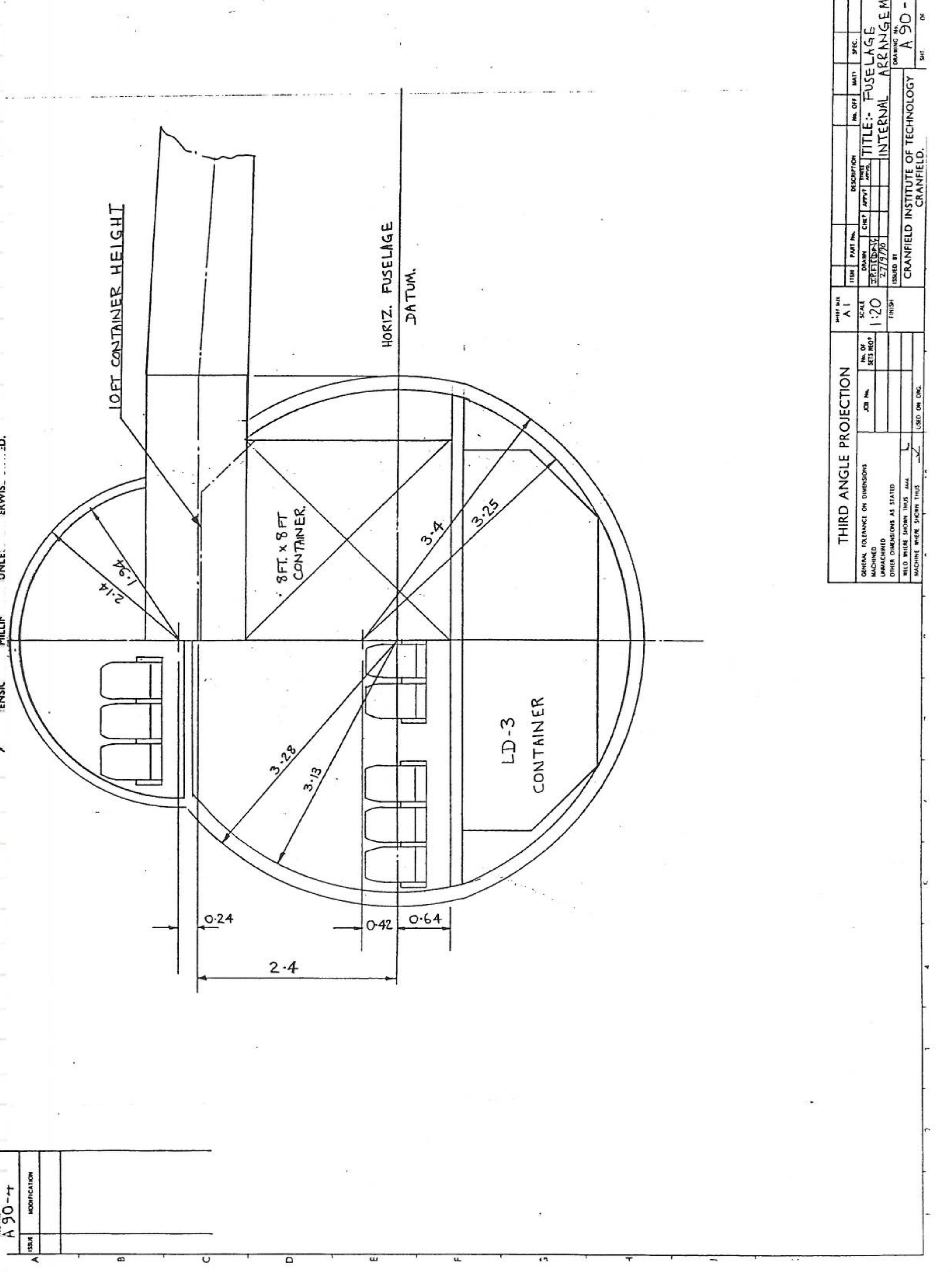
| | DRAWN: R. P. JONKERS | DATE: | 21 NOV 1990 |
| | SCALE: 1 : 50 | DRAWING No: | A90-1-7 |


ALL DIMENSIONS ... MILLIMET... UNLESS ... OTHERWISE S...
ISSUE
MODIFICATION
0.35
3.28
0.17c
0.65c
0.85c
PYLON ℄
9.7
10.3
10.0
12° - NORMAL T.O SETTING
8° DEFLECTION
-3.5° OUTER FLAPS ONLY
WING QUARTER CHORD
WING 0.25 SMC
STN. 27.2
16.0
20.5
WING FOLD
24.5
28.5
3.0
30°
6°
0 10 20 30 40 50 60 70 80 90 100 110 120
% CLEAN CHORD
35°
AUX. FLAP - INBOARD
WING SECTION - V-C AEROFOIL
DRAWN NORMAL TO L/E
SCALE TO SUIT VARIOUS t/c's
TAILPLANE SECTION - NACA 63A010
FIN SECTION - NACA 64,-012
5.2
2.05
0.3
32.0
SMC
0.7c
T/P 0.25
8.0
2.32
STN. 60.0
7.6
13.5
12.7
12.1
0.63c
SMC
FIN 0.25
43.0°
4.7
4.5
10.1
STN. 54.2
3.95
H.F.D.
STN. 59.3
THIRD ANGLE PROJECTION
GENERAL TOLERANCE ON DIMENSIONS
MACHINED
UNMACHINED
OTHER DIMENSIONS AS STATED
WELD WHERE SHOWN THUS
MACHINE WHERE SHOWN THUS
JOB No.
No. OF SETS REQ'D
USED ON DRG.
SHEET SIZE A1
SCALE 1:100 MAINLY
FINISH
ITEM
PART No.
DESCRIPTION
No. OFF
MAT'L
SPEC.
REMARKS
DRAWN J.R. FIELDING 2/10/90
CHK'D
APPV'D
STRESS APPVD.
ISSUED BY
TITLE:- WING AND TAIL GEOMETRY
CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD.
DRAWING No. A90 -3
SHT. OF SHEETS


10FT CONTAINER HEIGHT
HORIZ. FUSELAGE DATUM.
8FT. x 8FT CONTAINER
LD-3 CONTAINER
2·14
1·94
3·4
3·25
3·28
3·13
0·24
0·42
0·64
2·4
THIRD ANGLE PROJECTION
SCALE 1:20
SHEET SIZE A1
TITLE:- FUSELAGE INTERNAL ARRANGEMENTS
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DRAWING No. A 90-4
CRANFIELD INSTITUTE OF TECHNOLOGY CRANFIELD.
A 90-4

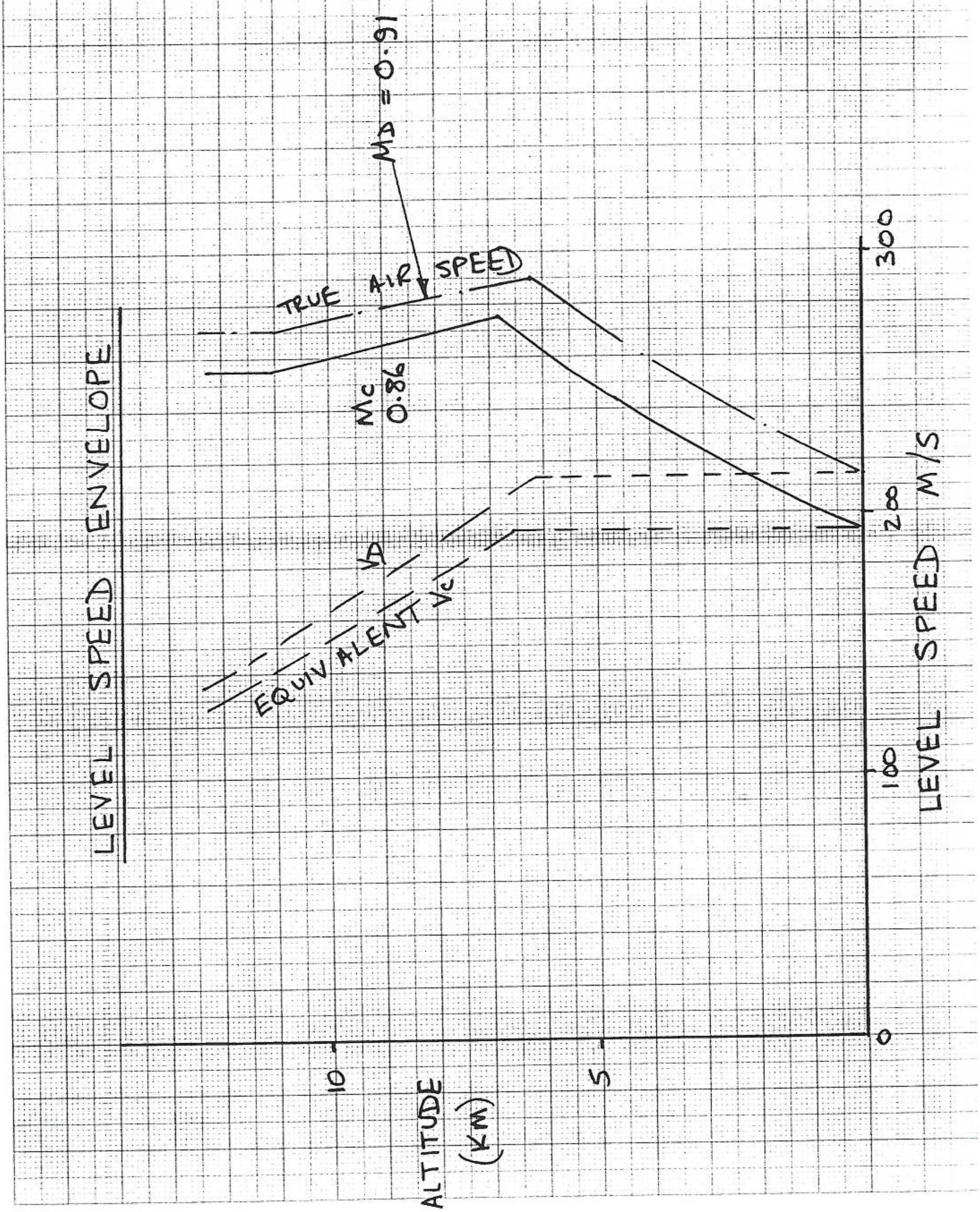

LEVEL SPEED ENVELOPE
TRUE AIR SPEED
$M_D = 0.91$
$M_C$ 0.86
$V_A$
EQUIVALENT $V_C$
ALTITUDE (KM)
0
5
10
100
200
300
LEVEL SPEED M/S

FIG. 5

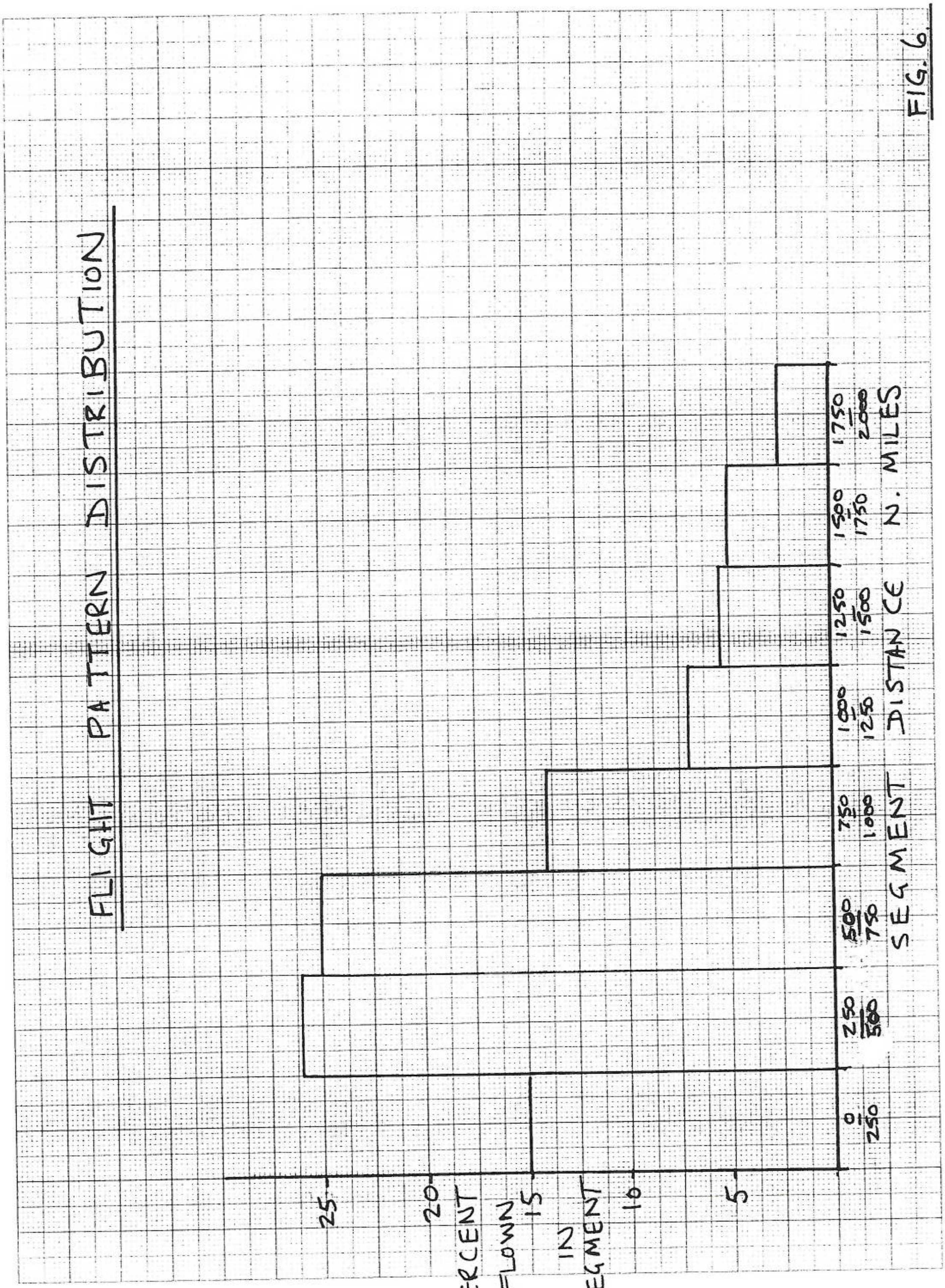

FLIGHT PATTERN DISTRIBUTION
PERCENT FLOWN IN SEGMENT
25
20
15
10
5
0 – 250
250 – 500
500 – 750
750 – 1,000
1000 – 1250
1250 – 1500
1500 – 1750
1750 – 2000
SEGMENT DISTANCE N. MILES

FIG. 6

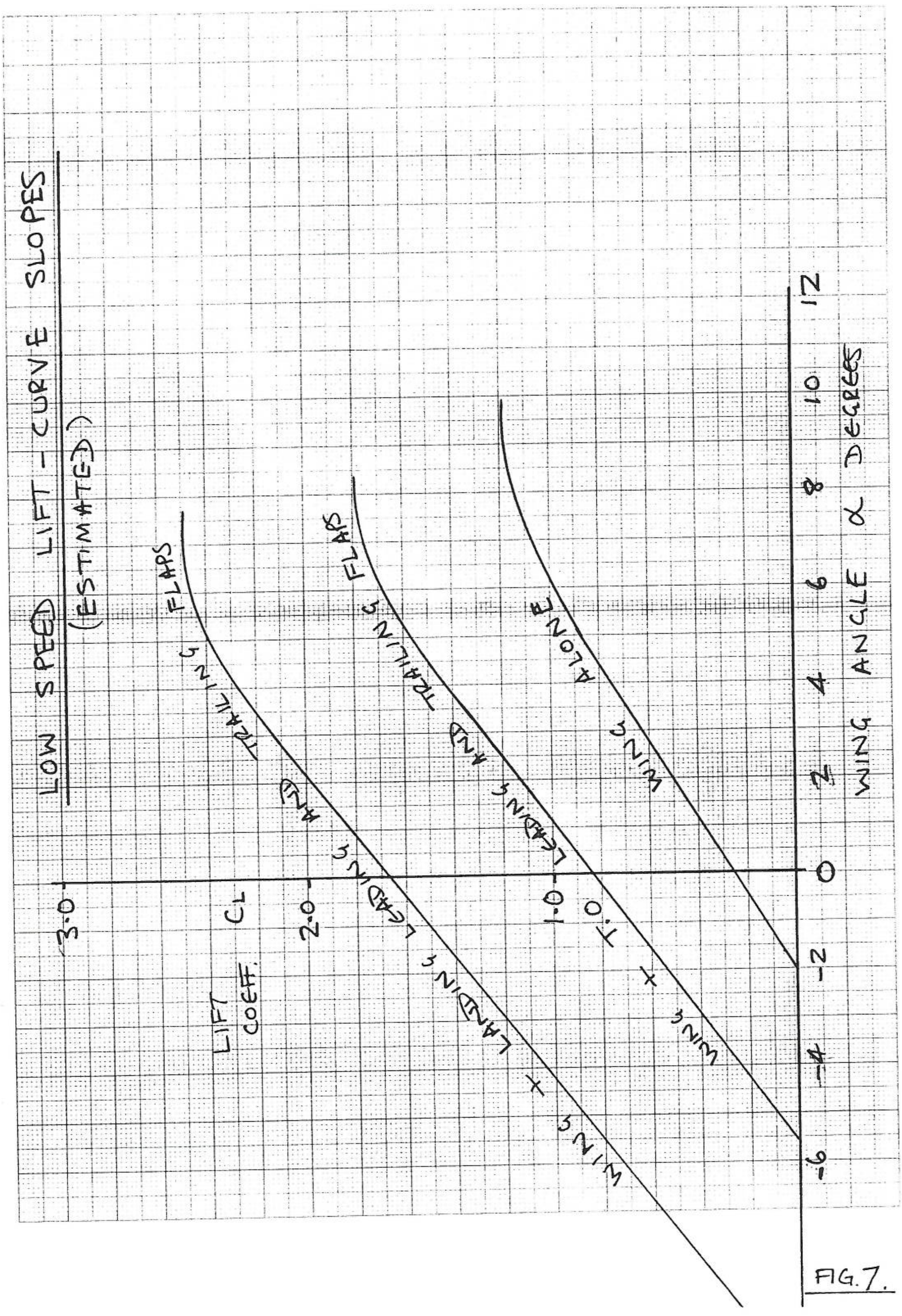

LOW SPEED LIFT - CURVE SLOPES
(ESTIMATED)
LIFT COEFF. $C_L$
3.0
2.0
1.0
WING ALONE
WING + L.E. AND TRAILING FLAPS
WING + LANDING AND TRAILING FLAPS
-6
-4
-2
0
2
4
6
8
10
12
WING ANGLE α DEGREES

FIG. 7.

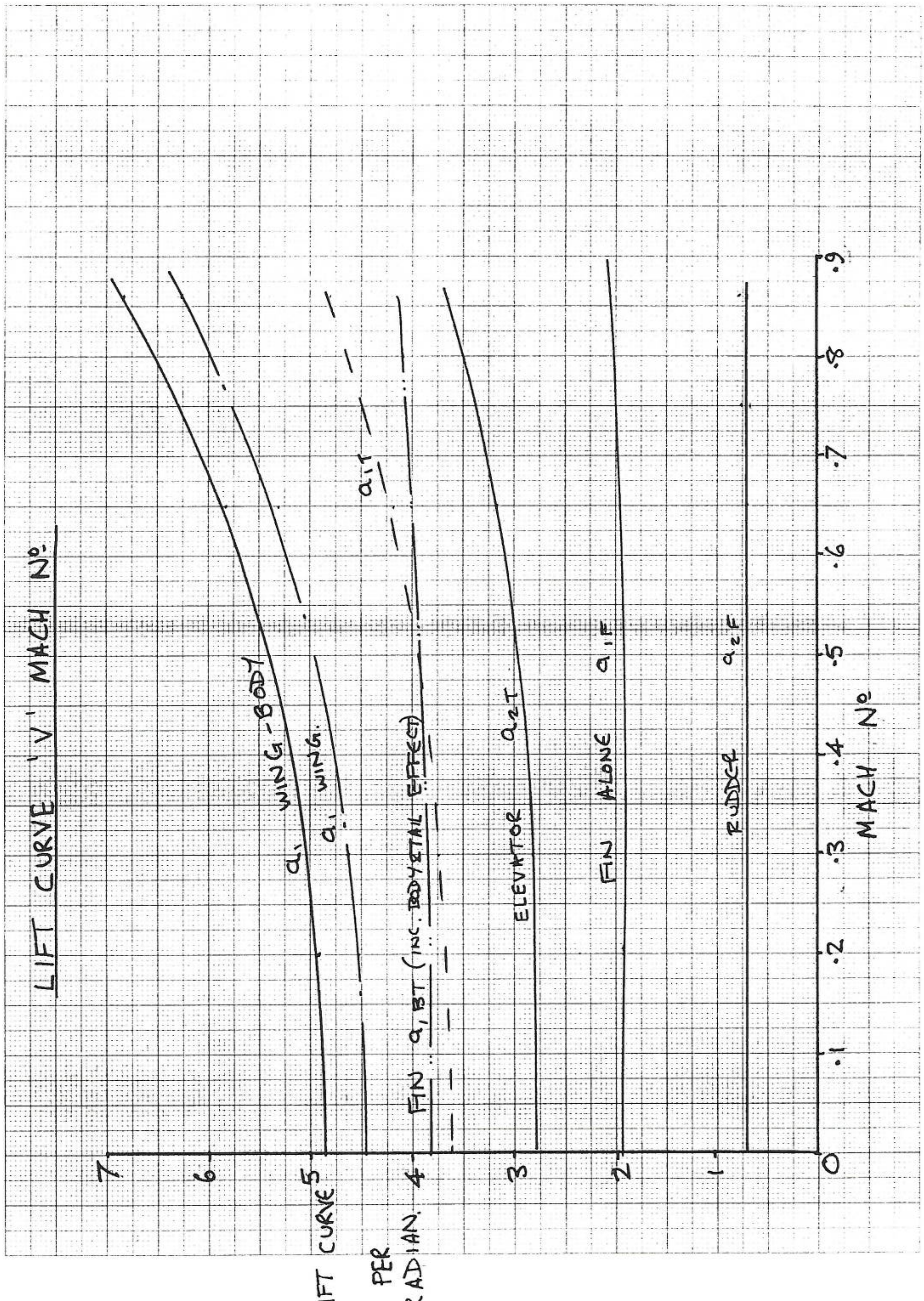

LIFT CURVE 'V' MACH Nº
$a_1$ WING-BODY
$a_1$ WING.
$a_{1T}$
FIN $a_{1BT}$ (INC. BODY+TAIL EFFECT)
ELEVATOR $a_{2T}$
FIN ALONE $a_{1F}$
RUDDER $a_{2F}$
MACH Nº
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
LIFT CURVE PER RADIAN

FIG. 8.

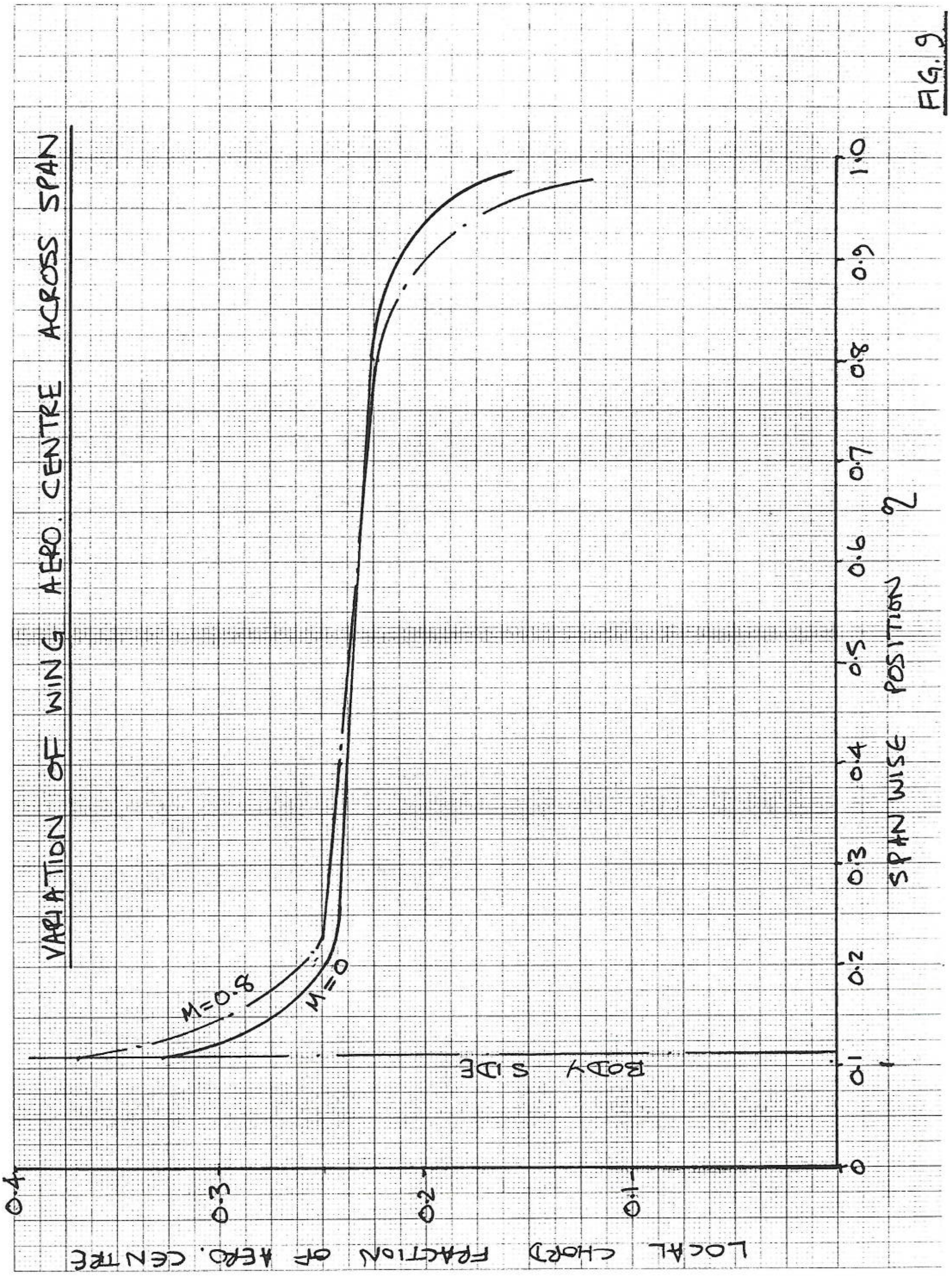

VARIATION OF WING AERO. CENTRE ACROSS SPAN
M=0.8
M=0
BODY SIDE
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
SPANWISE POSITION η
0 0.1 0.2 0.3 0.4
LOCAL CHORD FRACTION OF AERO. CENTRE

FIG. 9

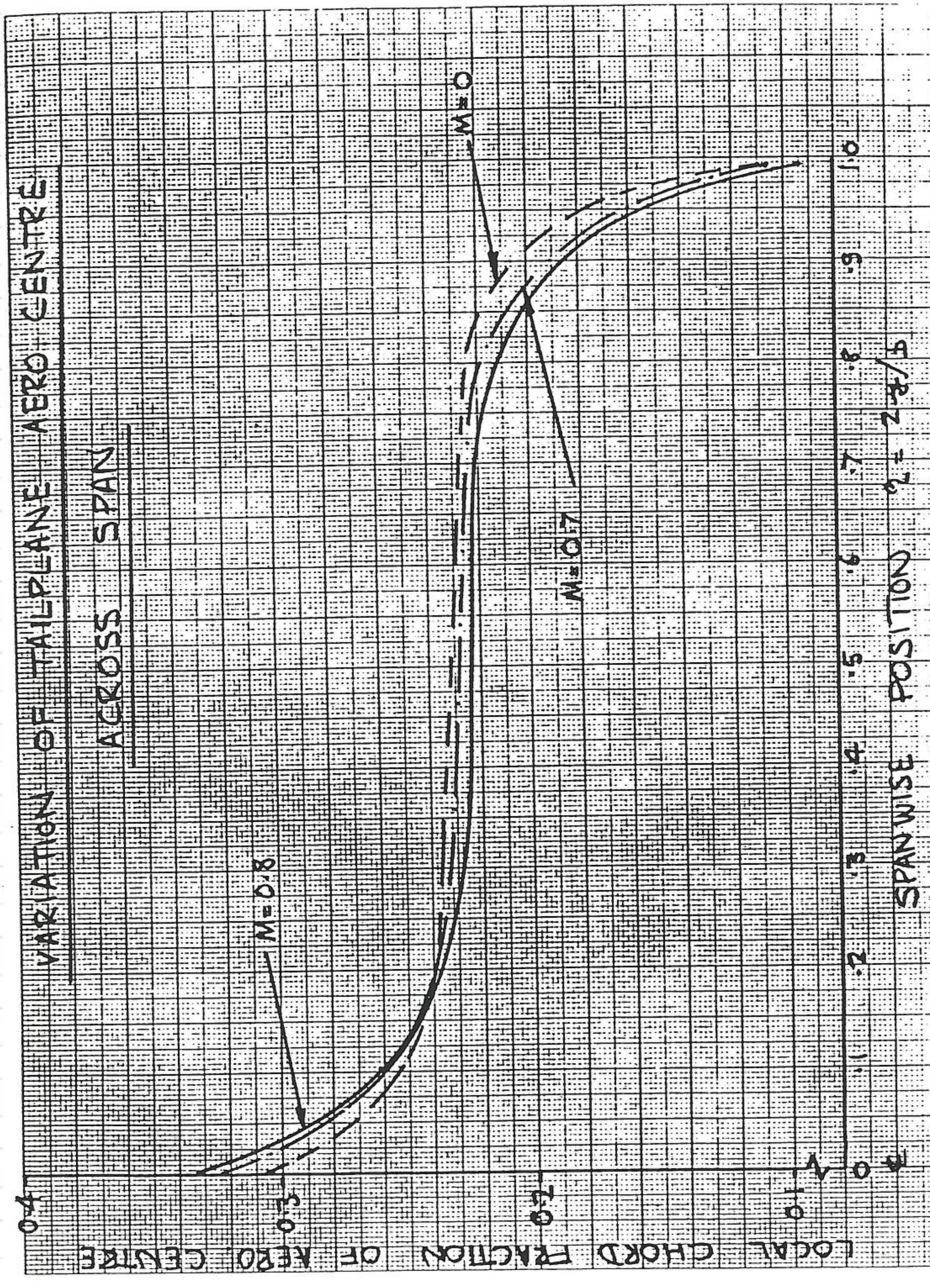

VARIATION OF TAILPLANE AERO CENTRE
ACROSS SPAN
M=0.8
M=0.7
M=0
LOCAL CHORD FRACTION OF AERO CENTRE
0.4
0.3
0.2
0.1
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
SPANWISE POSITION η = 2y/b

FIG. 10

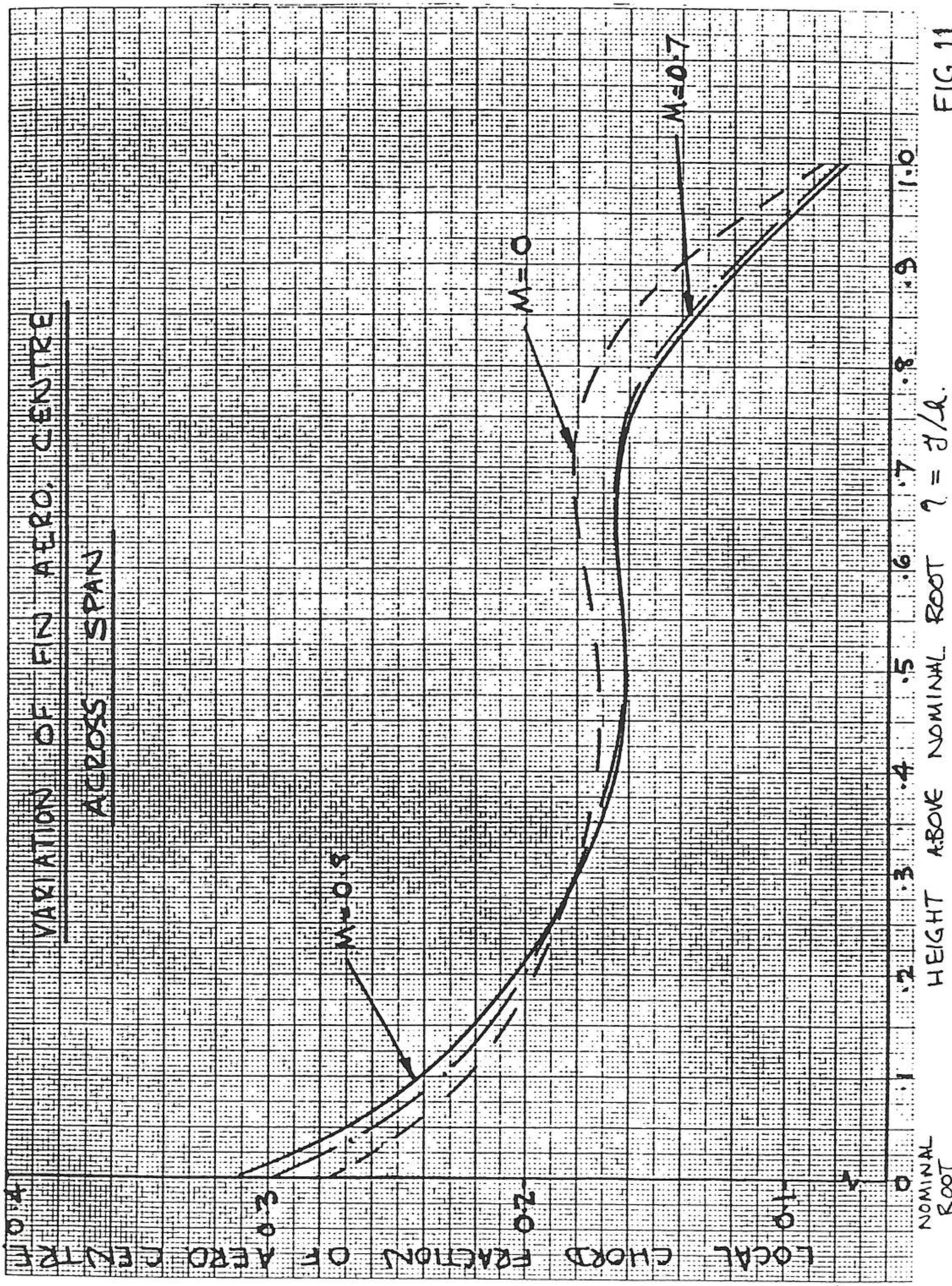

VARIATION OF FIN AERO. CENTRE
ACROSS SPAN
LOCAL CHORD FRACTION OF AERO CENTRE
0.4
0.3
0.2
0.1
0
M=0.8
M=0
M=0.7
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
NOMINAL ROOT
HEIGHT ABOVE NOMINAL ROOT η = y/l

FIG. 11

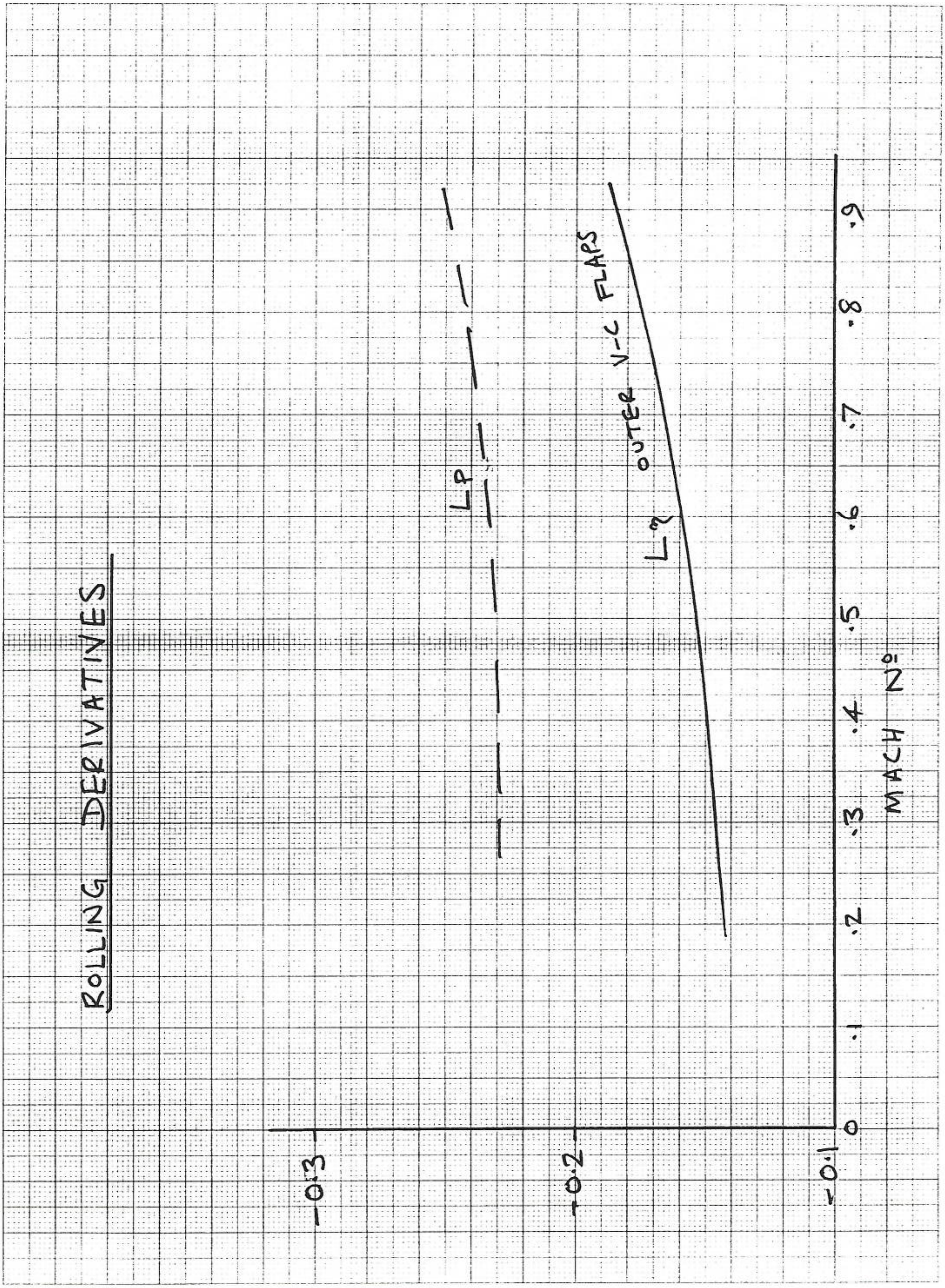

ROLLING DERIVATIVES
LP
Lr
OUTER V-C FLAPS
MACH Nº
-0.3
-0.2
-0.1
0
.1
.2
.3
.4
.5
.6
.7
.8
.9

FIG. 12.

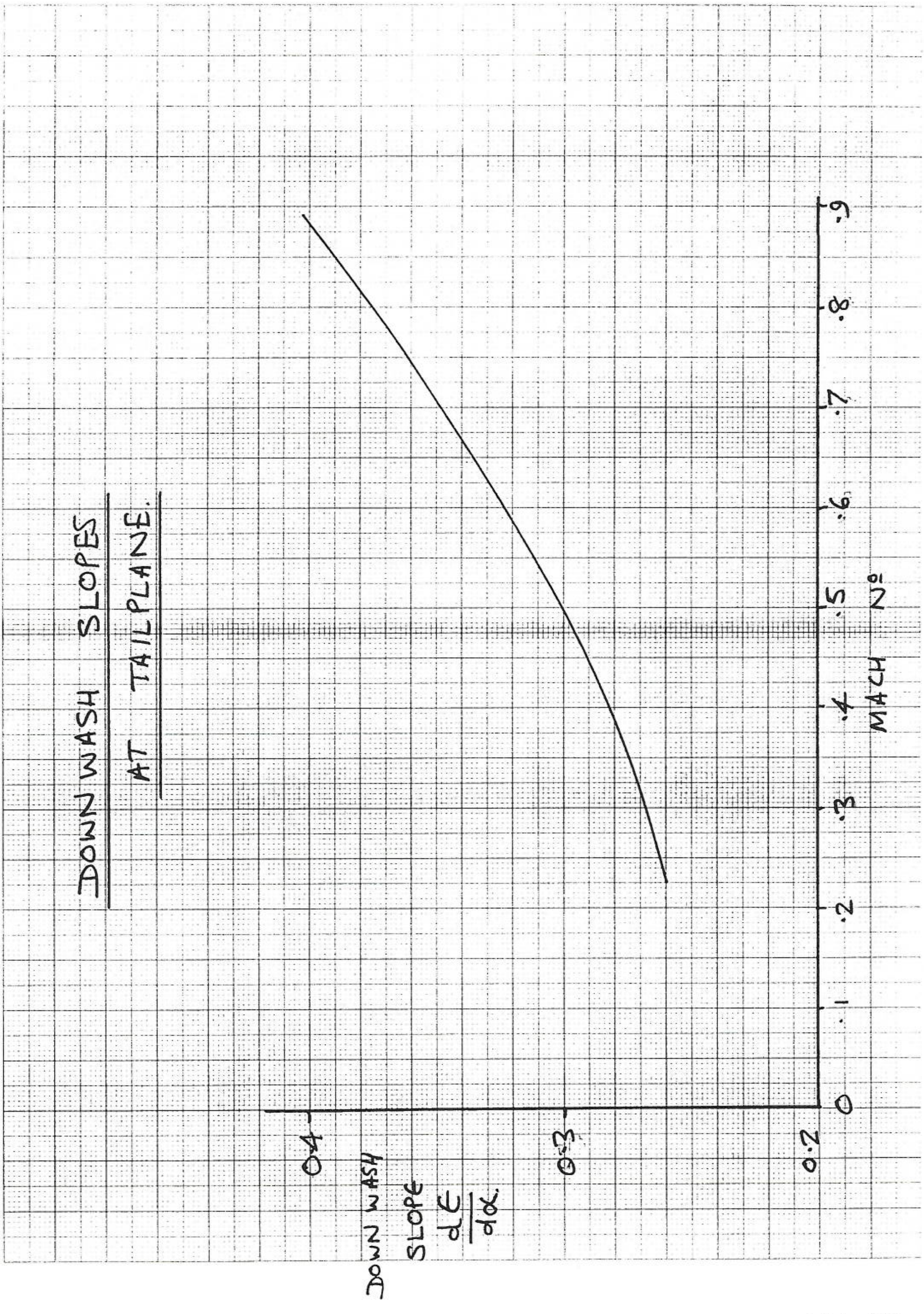

DOWNWASH SLOPES
AT TAILPLANE.
MACH No
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
0.2
0.3
0.4
DOWNWASH SLOPE
$\frac{d\epsilon}{d\alpha}$

FIG. 13

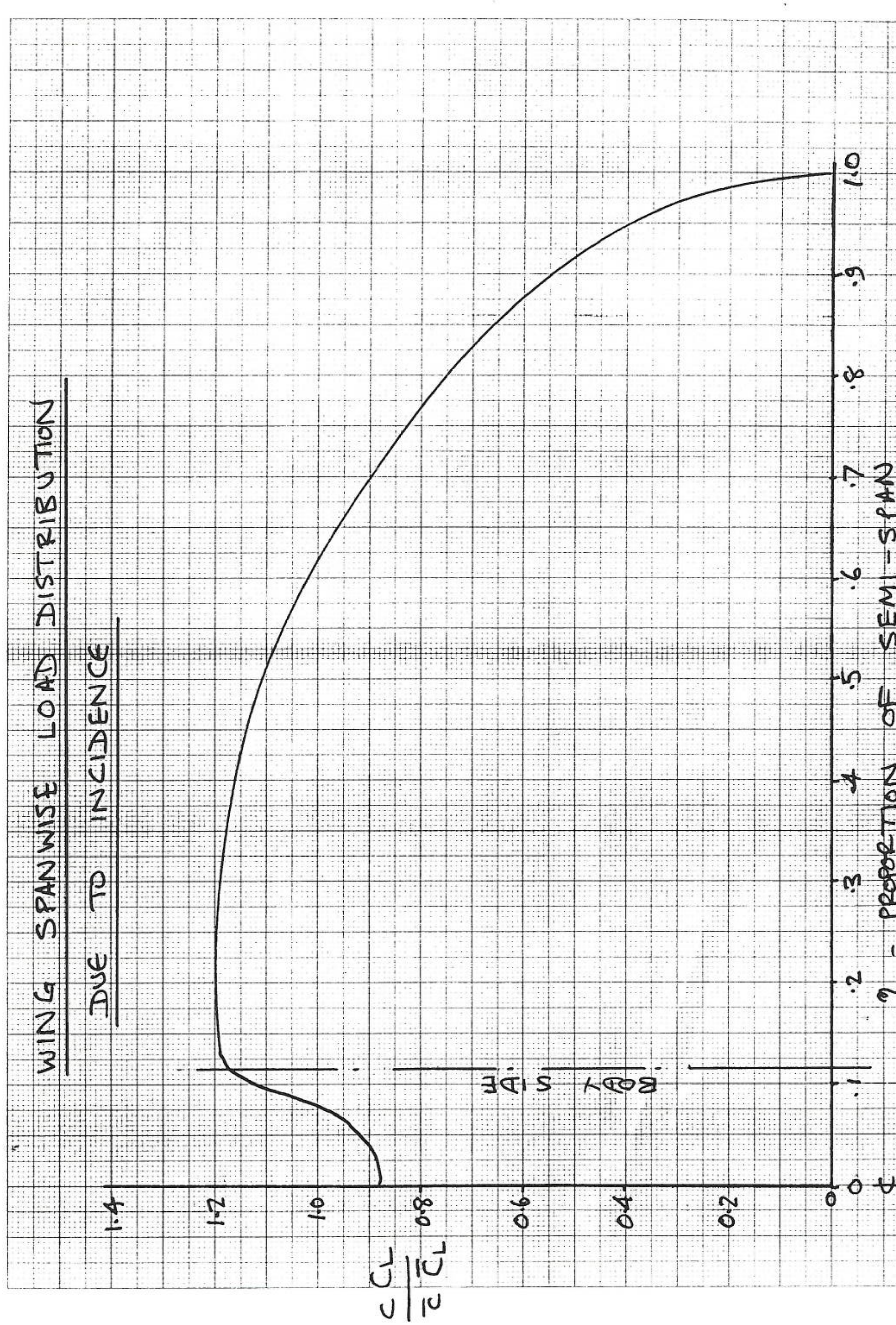

WING SPANWISE LOAD DISTRIBUTION
DUE TO INCIDENCE
$\frac{c\,C_L}{\bar{c}\,\bar{C}_L}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
℄
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
BODY SIDE
η - PROPORTION OF SEMI-SPAN

FIG. 14

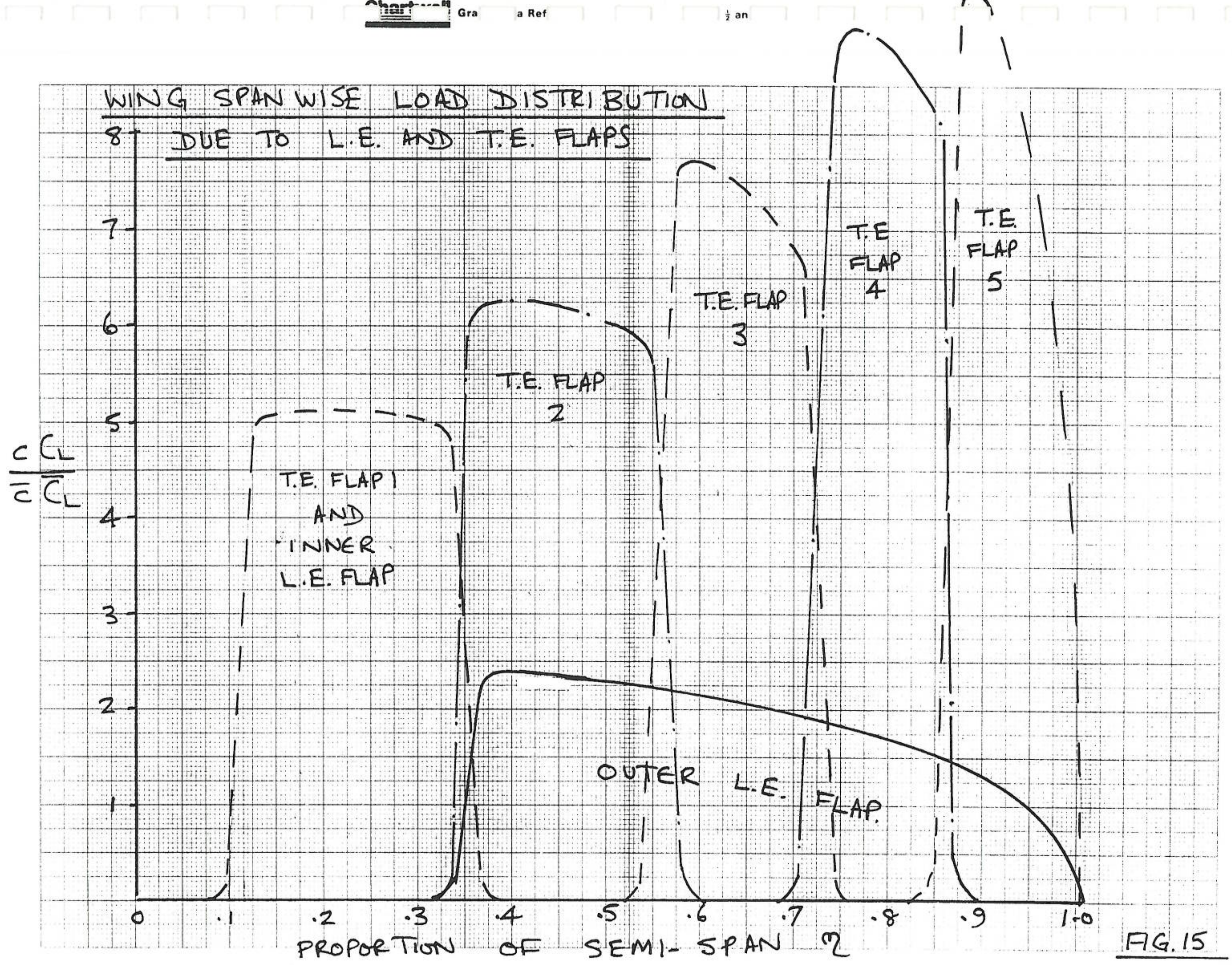
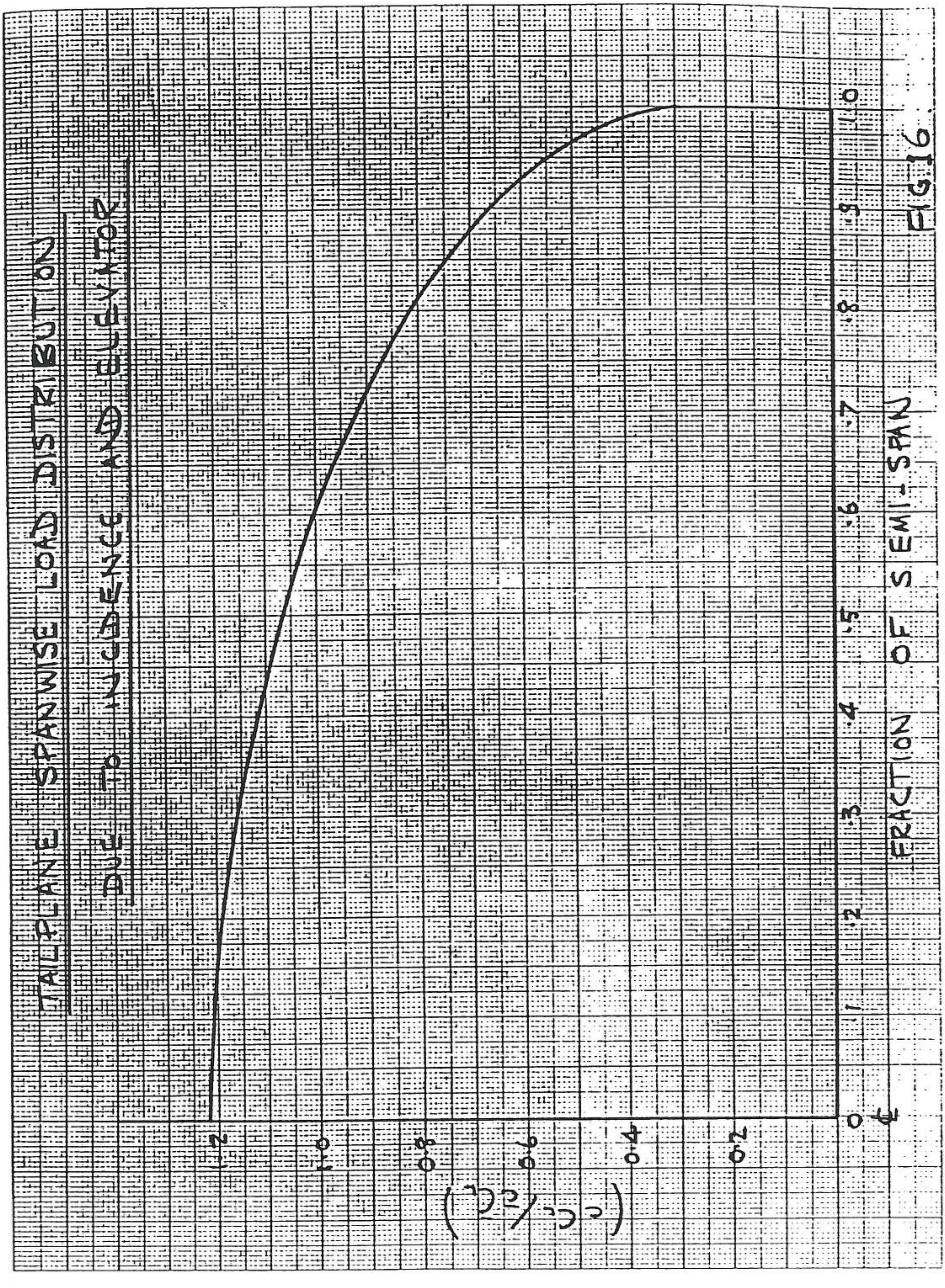

WING SPAN WISE LOAD DISTRIBUTION
DUE TO L.E. AND T.E. FLAPS
$\frac{c\,C_L}{\bar{c}\,\bar{C}_L}$
8
7
6
5
4
3
2
1
0
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
PROPORTION OF SEMI-SPAN η
T.E. FLAP 1 AND INNER L.E. FLAP
T.E. FLAP 2
T.E. FLAP 3
T.E FLAP 4
T.E. FLAP 5
OUTER L.E. FLAP

FIG. 15


TAILPLANE SPANWISE LOAD DISTRIBUTION
DUE TO INCIDENCE AND ELEVATOR
FIG.16
FRACTION OF SEMI-SPAN
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
1.2 1.0 0.8 0.6 0.4 0.2
(c c_L / c̄ C_L)

FIN AND RUDDER SPANWISE AIRLOAD DISTRIBUTION DUE TO INCIDENCE

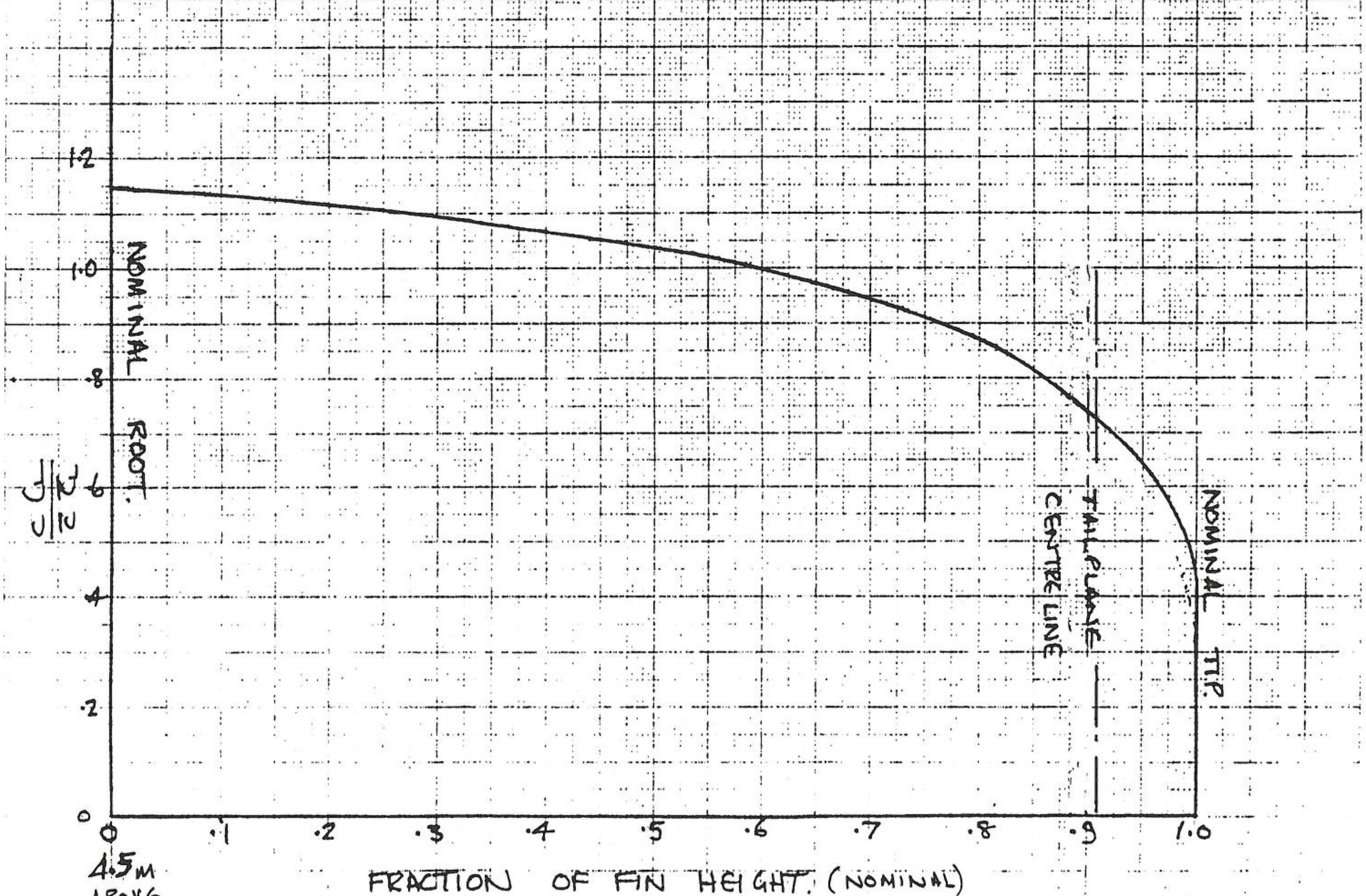
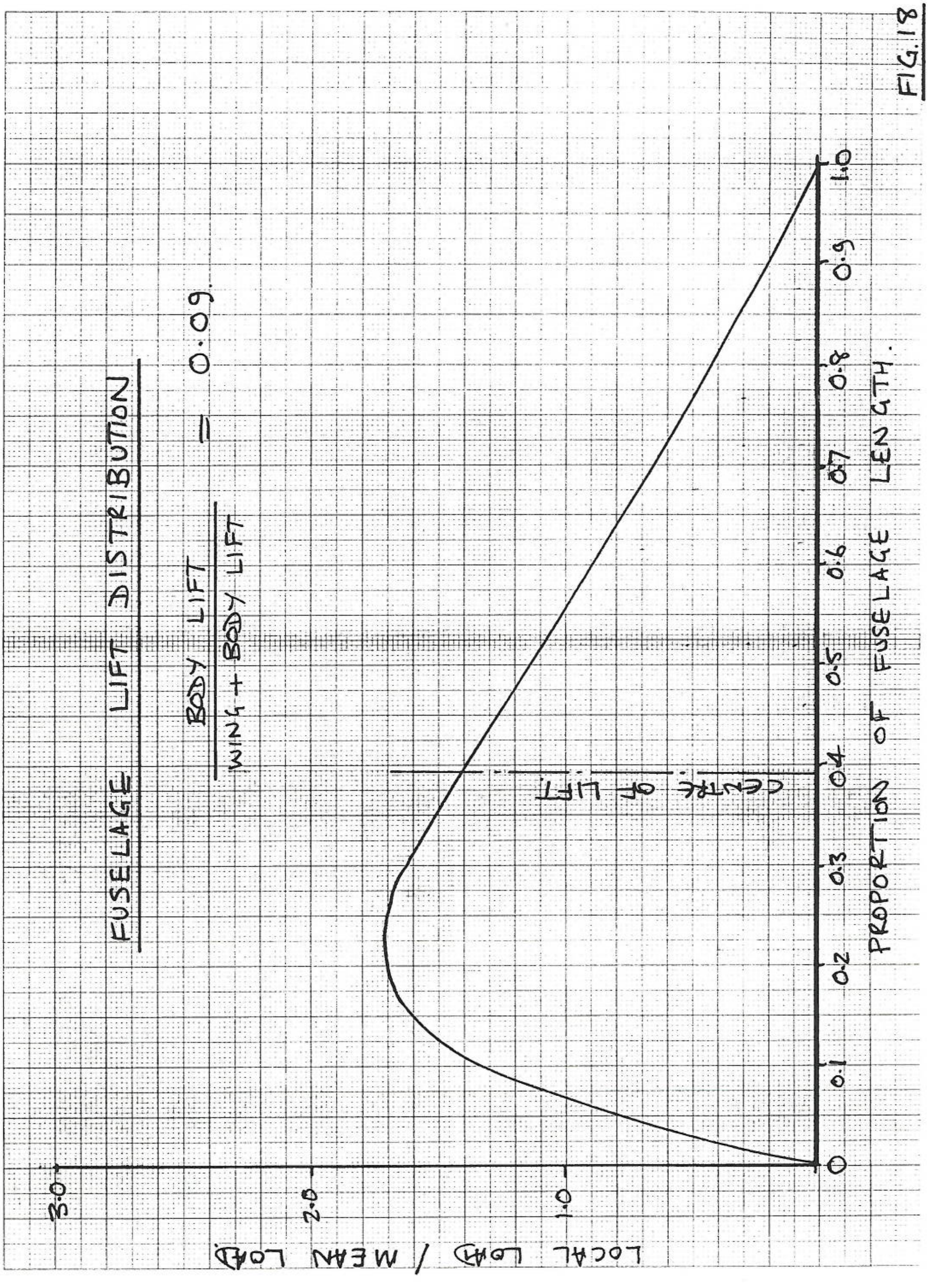



FIG. 17


FUSELAGE LIFT DISTRIBUTION
BODY LIFT / WING + BODY LIFT = 0.09
CENTRE OF LIFT
LOCAL LOAD / MEAN LOAD
3.0
2.0
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
PROPORTION OF FUSELAGE LENGTH.
FIG. 18

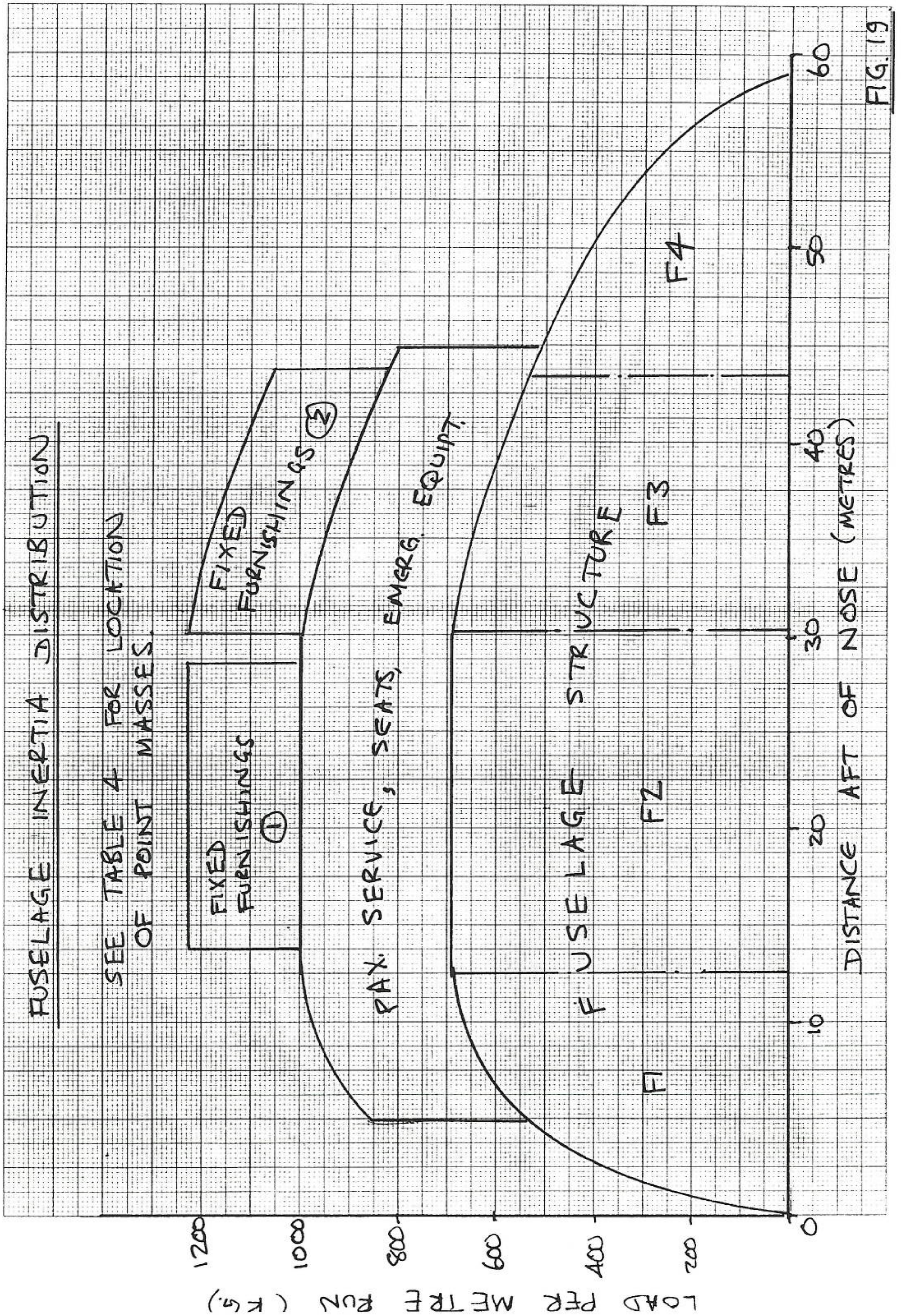

FUSELAGE INERTIA DISTRIBUTION
SEE TABLE 4 FOR LOCATION
OF POINT MASSES.
FIXED
FURNISHINGS
1
FIXED
FURNISHINGS 2
PAX. SERVICE, SEATS, EMERG. EQUIPT.
FUSELAGE STRUCTURE
F1
F2
F3
F4
0
10
20
30
40
50
60
DISTANCE AFT OF NOSE (METRES)
200
400
600
800
1000
1200
LOAD PER METRE RUN (KG.)

FIG. 19

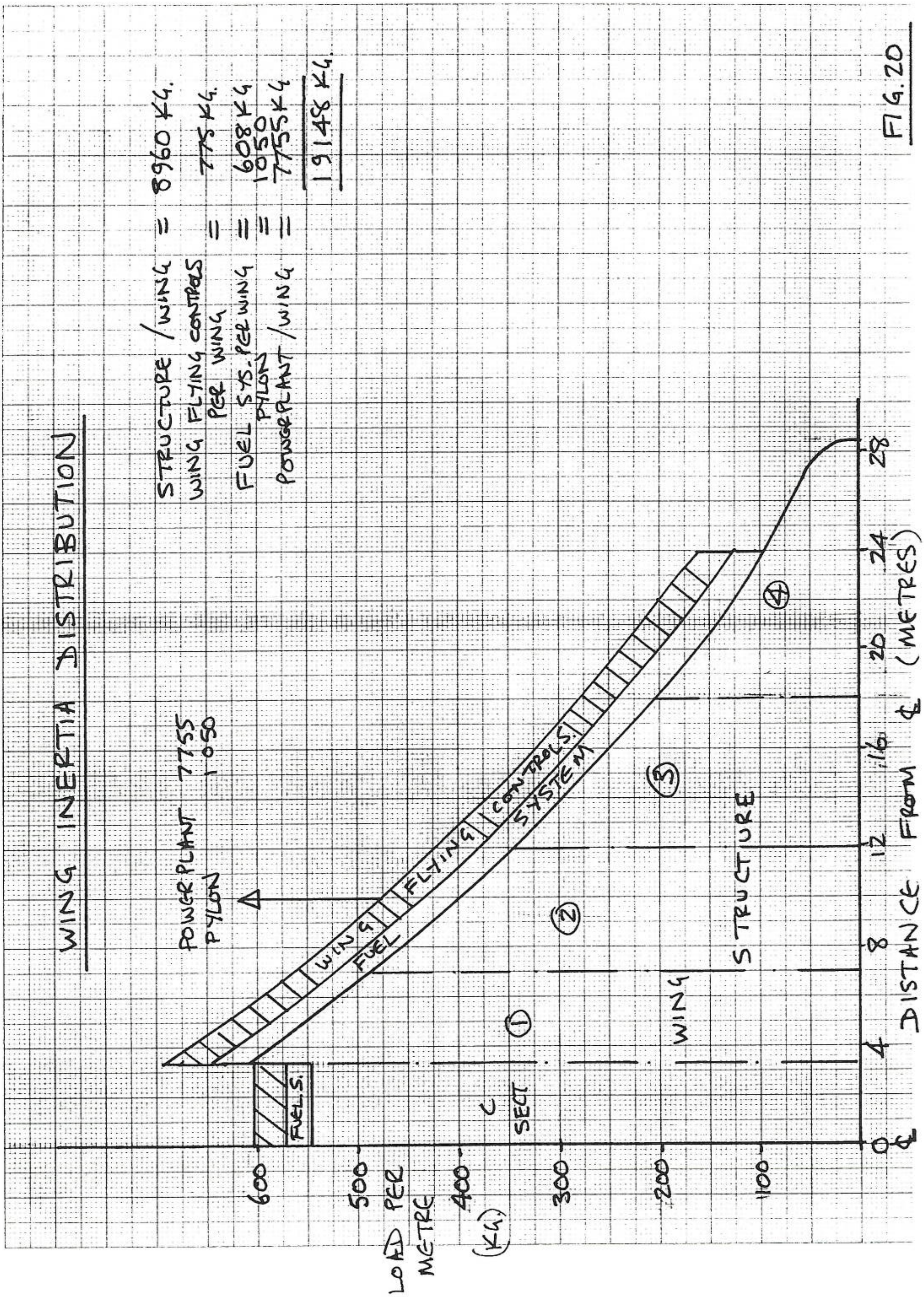

WING INERTIA DISTRIBUTION
STRUCTURE /WING = 8960 KG.
WING FLYING CONTROLS PER WING = 775 KG.
FUEL SYS. PER WING = 608 KG
PYLON = 1050
POWERPLANT /WING = 7755 KG
19148 KG.
POWERPLANT 7755
PYLON 1050
FUEL S.
℄ SECT
WING FUEL
WING FLYING CONTROLS SYSTEM
WING STRUCTURE
1
2
3
4
0 ℄
4
8
12
16
20
24
28
DISTANCE FROM ℄ (METRES)
600
500
400
300
200
100
LOAD PER METRE (KG)

FIG. 20

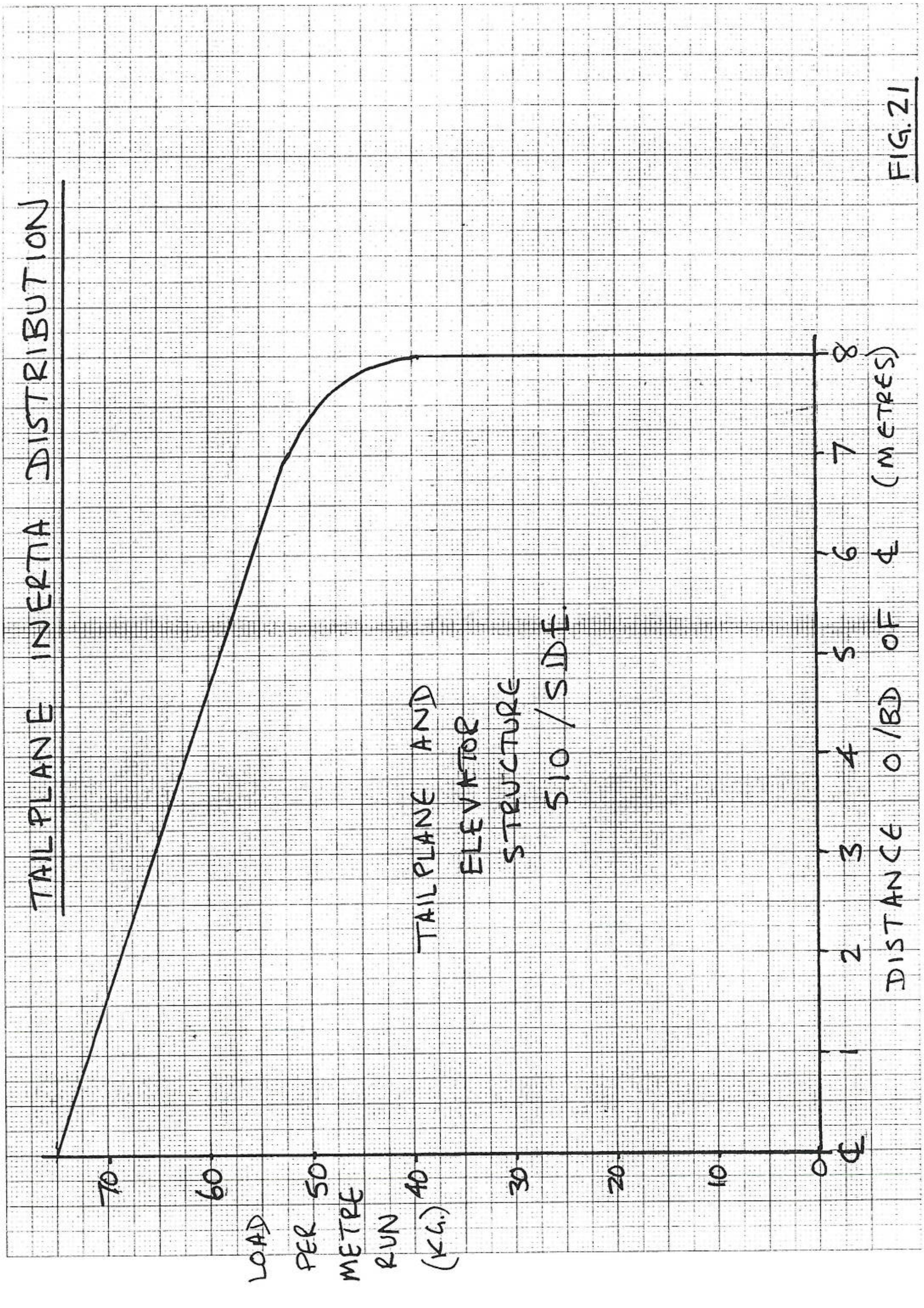

TAILPLANE INERTIA DISTRIBUTION
TAILPLANE AND
ELEVATOR
STRUCTURE
510 / SIDE
LOAD
PER
METRE
RUN
(KG.)
70
60
50
40
30
20
10
0
℄
1
2
3
4
5
6
7
8
DISTANCE O/BD OF ℄ (METRES)

FIG. 21

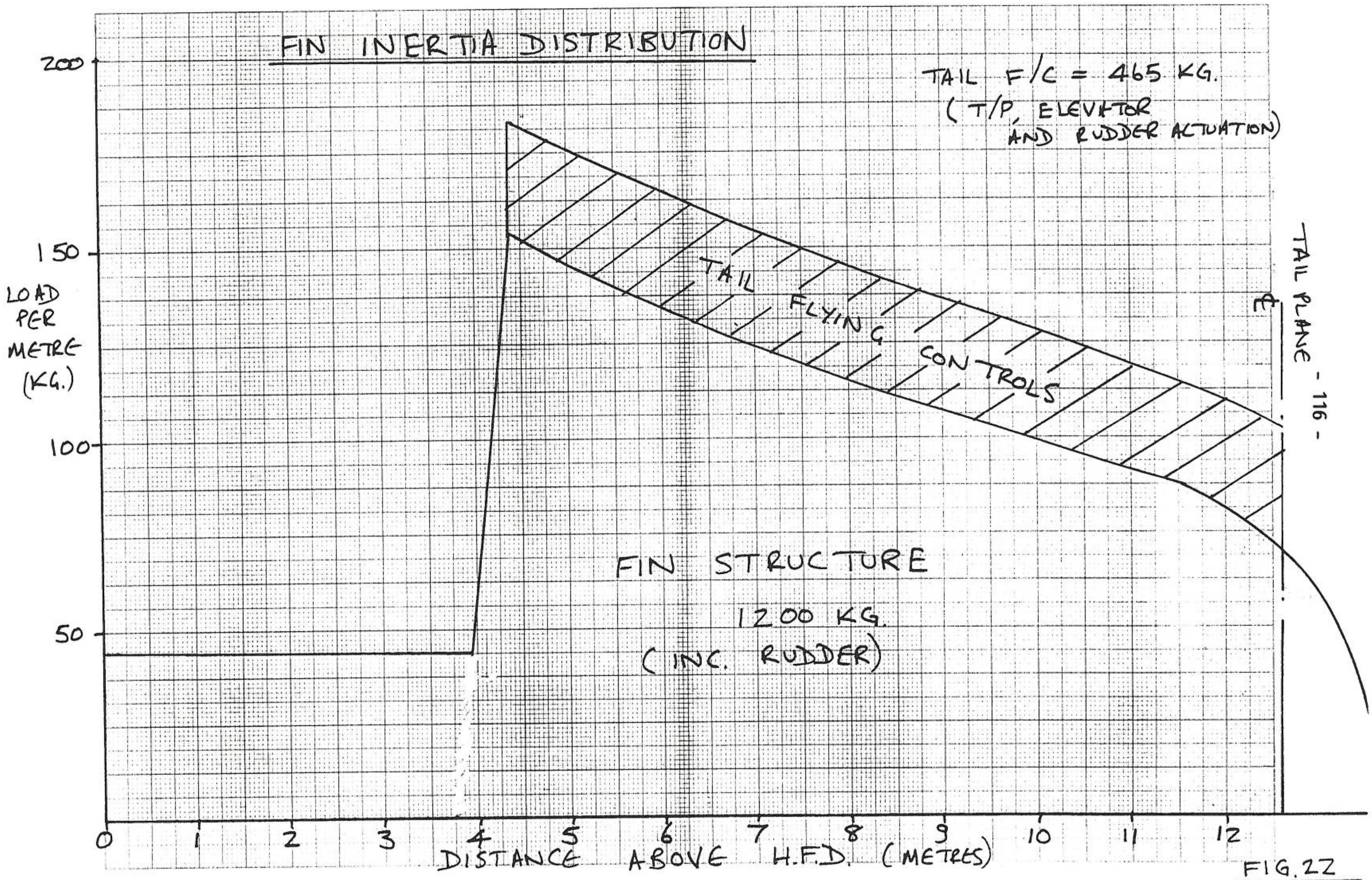

FIN INERTIA DISTRIBUTION
TAIL F/C = 465 KG.
( T/P, ELEVATOR AND RUDDER ACTUATION)
TAIL PLANE
℄
TAIL FLYING CONTROLS
FIN STRUCTURE
1200 KG.
(INC. RUDDER)
200
150
100
50
LOAD PER METRE (KG.)
0
1
2
3
4
5
6
7
8
9
10
11
12
DISTANCE ABOVE H.F.D. (METRES)

FIG. 22

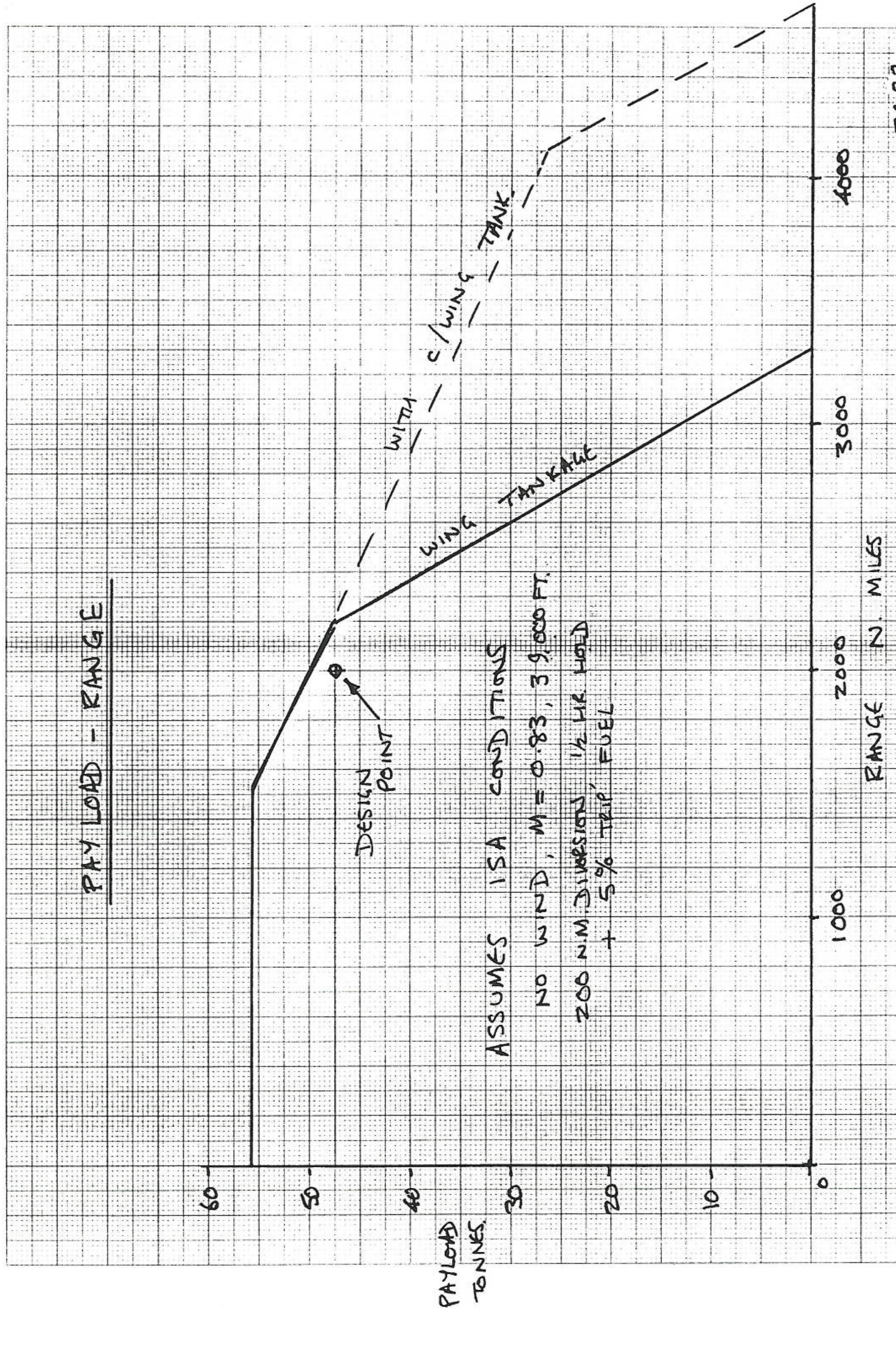

PAYLOAD - RANGE
ASSUMES ISA CONDITIONS
NO WIND, M = 0.83, 39,000 FT.
200 N.M. DIVERSION 1/2 HR. HOLD
+ 5% 'TRIP' FUEL
DESIGN POINT
WING TANKAGE
WITH C/WING TANK
RANGE N. MILES
0
1000
2000
3000
4000
PAYLOAD TONNES
10
20
30
40
50
60

FIG. 23

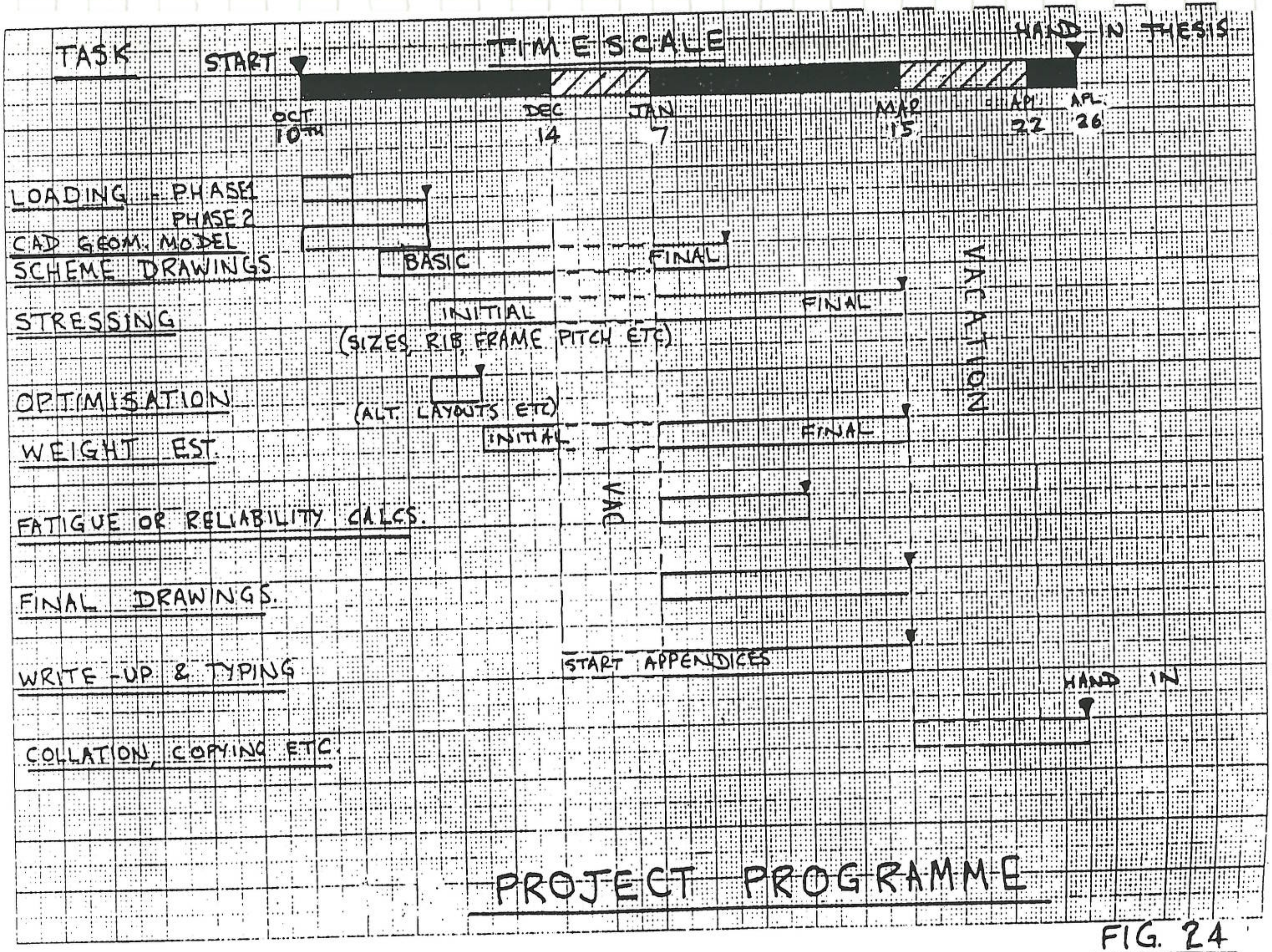

TASK
START
TIMESCALE
HAND IN THESIS
OCT 10TH
DEC 14
JAN 7
MAR 15
APL 22
APL 26
LOADING - PHASE 1
PHASE 2
CAD GEOM. MODEL
SCHEME DRAWINGS
BASIC
FINAL
STRESSING
INITIAL
FINAL
(SIZES, RIB, FRAME PITCH ETC)
OPTIMISATION
(ALT. LAYOUTS ETC)
WEIGHT EST.
INITIAL
FINAL
FATIGUE OR RELIABILITY CALCS.
VAC
VACATION
FINAL DRAWINGS.
WRITE-UP & TYPING
START APPENDICES
HAND IN
COLLATION, COPYING ETC.
PROJECT PROGRAMME

FIG. 24

APPENDIX B

PARAMETRIC STUDY

1. Introduction

The parametric study was based on the method by LOFTLIN (Ref. 9). This was an initial attempt to determine basic aircraft parameters such as wing loading, thrust/weight ratio, wing aspect ratio, take-off and landing left coefficients, and cruise lift/drag ratios. This method relies heavily on empirical data and cannot be safely used for aircraft which are not of the conventional subsonic transport type. The method uses knots, lb, and feet units, which were converted to SI units at the end of the study. The method starts with a large design space and then excludes designs that cannot satisfy landing and take-off distances, second segment climb or missed-approach requirements. It then goes on to examine cruise performance. An extra requirement that came from the aircraft specification was the 15,000 ft. cieling after a single engine failure.

2. Landing Field Distance

Fig. B1 shows an empirical plot of the relationship between approach speed and FAR landing field length. The required value of 5650 ft. gave $V_A^2 = 19{,}000$, therefore $= 138$ Kts.

Having this value, fig. B2 was used to determine the wing-loading parameter. This process required the estimation of the approach lift coefficient. The variable camber flaps required by the specification could be expected to produce a landing $CL_{max}$ of 2.5. The approach lift coefficient was found from:

$$CL_A = CL_{max}/1.3^2 = 1.48$$

This follows because stall speed, $V_S$ occurs at $CL_{max}$ and approach speed, $V_A = 1.3\ V_S$. This value and the approach speed on fig. B2 gave the

landing parameter $\sqrt{\dfrac{W_L/S}{\sigma}} = 9.95$

at I.S.A., S.L., $\sigma = 1$, therefore $W_L/S = 99 lb/ft^2$.

The parametric study was carried-out in terms of gross-weight, $W_G$, so a relationship between that and the landing weight ($W_L$) had to be determined. Study of comparable-range aircraft indicated that $\dfrac{W_L}{W_G} = 0.83$

this then gave the value to satisfy landing requirements as

$$\frac{W_G}{S} = \frac{W_L}{S} \times \frac{1}{0.83} = 119.3\ lb/ft^2$$

This was the landing boundary shown on fig. B10.

3. Take-off Field Length

Using fig. B3 with a length of 8300 ft. gave

$$\frac{W_G/S}{\delta\, CL_T(T_O/W_G)} = 220$$

Assuming $CL_T$ = 1.8 (max. lift coeff. in T.O. configuration)

$$\delta = 1 \text{ (I.S.A., S.L.)}$$

$$\frac{W_G/S}{T_O/W_G} = 220 \times 1.8 = 396$$

Using this value, and a suitable range of wing loadings gave:

| | | | | | |
|---|---|---|---|---|---|
| $W_G/S$ (lbf/ft$^2$) | 90 | 100 | 110 | 120 | 130 |
| $T_O/W_G$ | 0.227 | .252 | .28 | .303 | .328 |

These were plotted as the take-off boundary on fig. B10.

4. Second Segment Climb

This is the part of the take-off between 35 and 400 ft. altitude at $V_2$. Airworthiness requirements state that in the event of an engine failure during this period a twin-engined aircraft must sustain a 2.4% climb with flaps in take-off setting and undercarriage retracted. Two engines were chosen as the most economic solution, consistent with safety.

We need to find $CL_2$ which is the lift coefficient associated with $V_2$. As $V_2$ is 1.2 times the stalling speed

$$CL_2 = 1.8/1.44 = \underline{1.25}$$

Using fig. B4 for twin-engined aircraft with this value of $CL_2$ we obtain the following $T_O/W_G$ ratios for a range of aspect ratios:

| | | | |
|---|---|---|---|
| Aspect ratio | 6 | 8 | 10 |
| $T_O/W_G$ | 0.29 | 0.24 | 0.21 |

These values are included as second segment boundaries in fig. B.10.

5. Missed Approach

This must be considered in relation to the landing manoeuvre. This occurs when the aircraft is on final landing approach but does not land for any reason. Power is applied and the aircraft circles, usually to try another landing. Airworthiness authorities require the installation of sufficient thrust to enable adequate climb gradients with the aircraft in approach configuration. This would include approach slats and flaps and undercarriage. Fig. B5 shows empirical figures of required $T_O/W_G$ for various aspect ratios and engine requirements.

With $CL_A$ = 1.48 from para. 2 we obtain:

| | | | |
|---|---|---|---|
| Aspect ratio | 6 | 8 | 10 |
| $T_O/W_L$ | 0.34 | 0.29 | 0.25 |
| $T_O/W_G$(as $W_L/W_G$ = 0.83) | 0.28 | 0.24 | 0.21 |

These values are included in fig. B10 as missed approach boundaries.

6. Cruise Performance

The optimisation of cruise performances is a complex operation in which engine performance and aircraft lift/drag ratios are matched. Fig. B6 gives a chart to obtain an initial estimate of the maximum lift/drag ratio. We need to know the parameters:

$$\pi d^2/4S \text{ amd } \ell/d$$

Initial fuselage layout work, assuming a multiple circular arc cross-section with main deck ten-abreast seating yielded:

d = 23 ft.
From initial fuselage layout drawings
l/d = 8.3

An initial wing area of 4200 $ft^2$ was assumed (based on the Boeing 777). Using fig. B6 with the above figures gave:

| Aspect Ratio | $L/D_{max}$ | $CL_m$ | $CDO_{REF}$ |
|---|---|---|---|
| 7 | 16.7 | 0.55 | 0.017 |
| 9 | 18.9 | 0.64 | 0.017 |
| 10 | 20 | 0.67 | 0.017 |

Fib. B6 was based on a reference aircraft flying at a given Reynolds Number very similar to the study aircraft, and was therefore valid.

It was thought that flying at $L/D_{max}$ would be optimistic and have high cruise $C_L$, therefore a value of 0.97 $L/D_{max}$ would be used. Using this value in fig. B7 gave a $\bar{C}_L$ value of 0.78. Applying this factor to the $CL_{ms}$, above, the following values were produced:

| Aspect ratio | L/D | $CL_{max}$ (Cruise) |
|---|---|---|
| 7 | 16.2 | 0.429 |
| 9 | 18.3 | 0.499 |
| 10 | 19.4 | 0.52 |

These values were associated with different combinations of cruise altitude and wing loading as shown in Fig. B8. They were checked for a cruise Mach No. of 0.82 (economical).

| Aspect Ratio | L/D | CL | $C_L M^2$ | $W_g/S(lb/ft^2)$ | $h.(x10^{-3}ft)$ |
|---|---|---|---|---|---|
| 7 | 16.2 | .429 | .288 | 90 | 37.5 |
| | | | | 100 | 33 |
| | | | | 110 | 31 |
| | | | | 120 | 29 |
| 9 | 18.3 | .499 | .336 | 90 | 41 |
| | | | | 100 | 36.5 |
| | | | | 110 | 35 |
| | | | | 120 | 32.6 |
| 10 | 19.4 | .52 | .35 | 90 | 41.5 |
| | | | | 100 | 38 |
| | | | | 110 | 36 |
| | | | | 120 | 34 |

The next step was to check the thrust/weight ratios associated with these wing loadings. Ref. 9 gave

$$T_O/W_g = \frac{1}{(T_C/T_O)\ (L/D)_{max}}$$

where $T_c/T_o$ was a measure of thrust decay with Altitude and Mach No. Fig. B9 shows generalised curves for a modern high compression-ratio turbofan with a bypass ratio of 4.5, which should be a suitable class of engine for the A-90. Using fig. B9 we obtained the following values of $T_c/T_o$ and therefore the $T_oW_g$:

| Aspect Ratio | $W_g/S(lb/ft^2)$ | $T_c/T_o$ | $T_oW_g$: |
|---|---|---|---|
| 7 | 90 | .195 | .316 |
| | 100 | .235 | .26 |
| | 110 | .25 | .247 |
| | 120 | .26 | .237 |
| 9 | 90 | .16 | .341 |
| | 100 | .205 | .267 |
| | 110 | .215 | .25 |
| | 120 | .23 | .238 |
| 10 | 90 | .145 | .355 |
| | 100 | .185 | .279 |
| | 110 | .205 | .251 |
| | 120 | .22 | .234 |

These were plotted as cruise boundaries on fig. B10.

The specification called for a cruise altitude of "at least 39,000 ft." Cruise altitudes of 39,000, 40,000, and 41,000 ft. were cross-plotted from the cruise curves and drawn on figure B10.

7. Cieling with one engine inoperative

The parameters on fig. B10 were pointing towards a wing loading of about 120 $lb/ft^2$ but no clear aspect ratio had emerged. It was decided to check the average value of 9 and a reduced Mach number of 0.65 for this requirement.

This produced a lift coefficient of 0.355, which gave the lift coefficient ratio = 

$$\frac{0.355}{0.64} = .56$$

(Fig. B7 then gave a normalised lift/drag ratio of 0.86)

Therefore at 15,000 ft. L/D = $(L/D_{max})$ x 0.86

$$T_o/W_g = \frac{1}{(T_C/T_O)\ (L/D)} = \underline{16.25}$$

where $T_C/T_O$ = 0.4 from modern engine (max continuous)

$$= \frac{1}{0.4 \times 16.25} = 0.154$$

This is based on both engines working, therefore the single engine case = 0.308. A similar check for a wing with an aspect ratio of 10 gave a value of 0.284. This was the final parameter inserted onto fig. B10. This figure does not include the effect of windmilling or yaw drag, which will have to be checked later.

## 8. Arrival at the Match Point

Fig. B10 shows the design space available when all 6 performance parameters are satisfied. For a good, lightweight design we needed to maximise wing loading and minimise thrust loading, indeed, to be as close as possible to the bottom right-hand corner of the graph.

The main intersection is that of the take-off and landing boundaries at W/S = 119.3 $lb/ft^2$ and $T_o/W_g$ = 0.301. This is more than adequate for both the second segment climb and missed approach for all of the considered aspect ratios. There seems to be more than enough thrust for cruise, but this will leave a margin for possibly increased thrust lapse with high-bypass engines. The maximum cruise altitude is adequate, at between 40,000 and 41,000 ft.

The deciding factor on wing aspect ratio was the single engine failure cieling. The minimum suitable aspect ratio was 9, which gave a $T_o/W_g$ of 0.308, which was chosen as the final value.

Summerising the match point and its implicit parameters:

| | |
|---|---|
| Max. Wing Loading | $W_G/S$ = 119.3 $lb/ft^2$ = 583 $KG/M^2$ |
| Max. Thrust Loading | $T_O/W_G$ = 0.308 |
| Wing Aspect Ratio | AR = 9.0 |
| $CL_{max}$-take-off | = 1.8 |
| $CL_{max}$- landing | = 2.5 |
| $W_L$/WG | = 0.83 |
| Opt. Cruise $C_L$ | = 0.5 |

L/D cruise = 18.3

Max. cruise alt = 40,500 ft. = 12.34 km.

M economical = 0.82
$M_c$ = 0.86
$M_D$ = 0.92

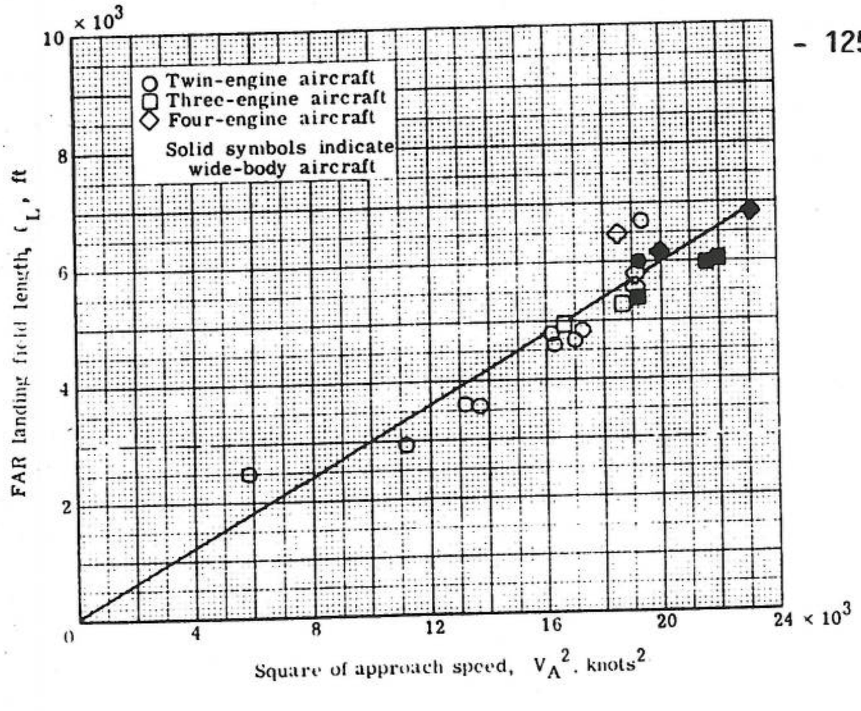



FIG. B1 LANDING LENGTH

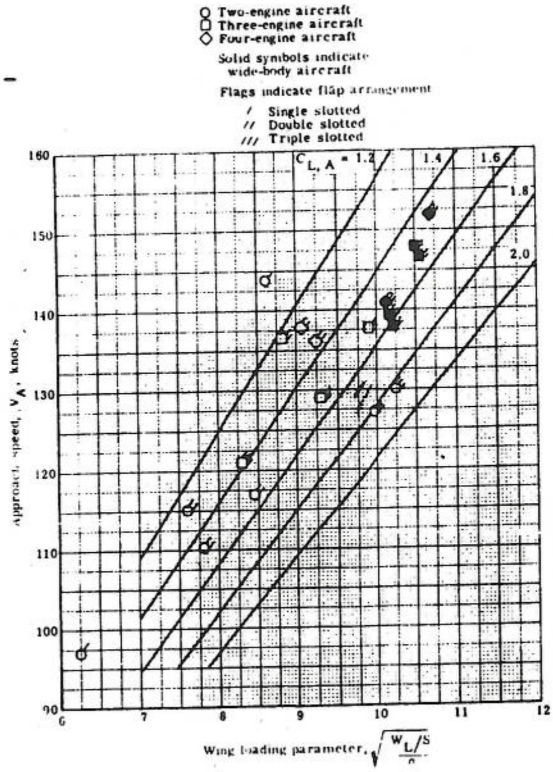



FIG. B2 APPROACH SPEED

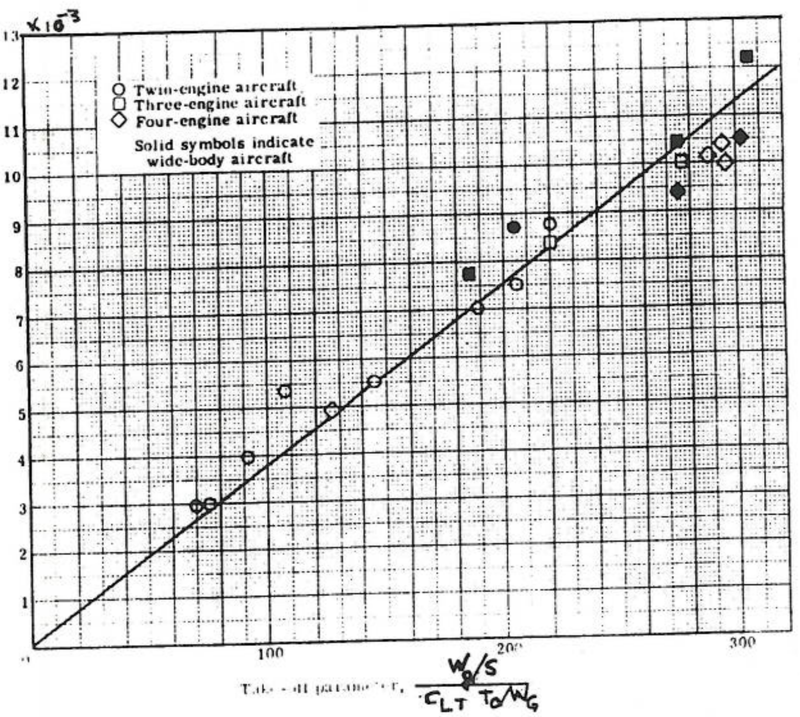



FIG. B3 TAKE OFF LENGTH

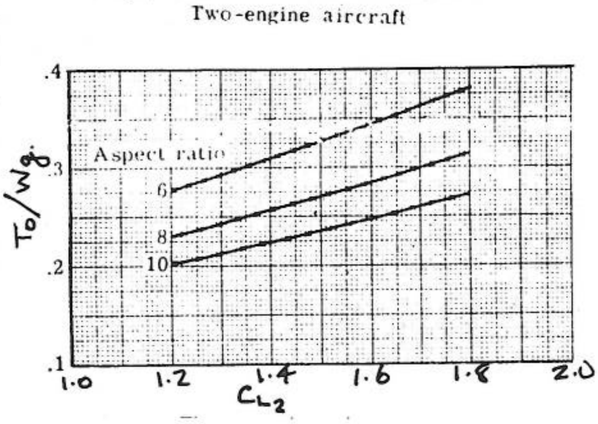



FIG. B4 SECOND SEGMENT CLIMB

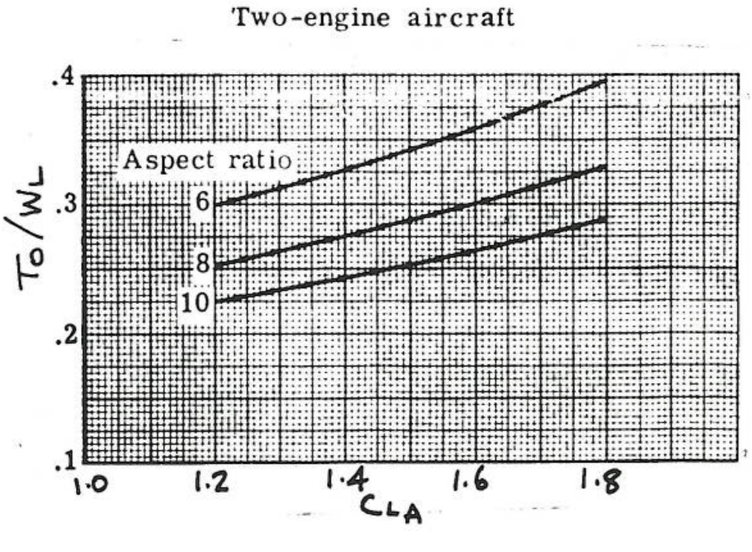



FIG. B5 MISSED APPROACH

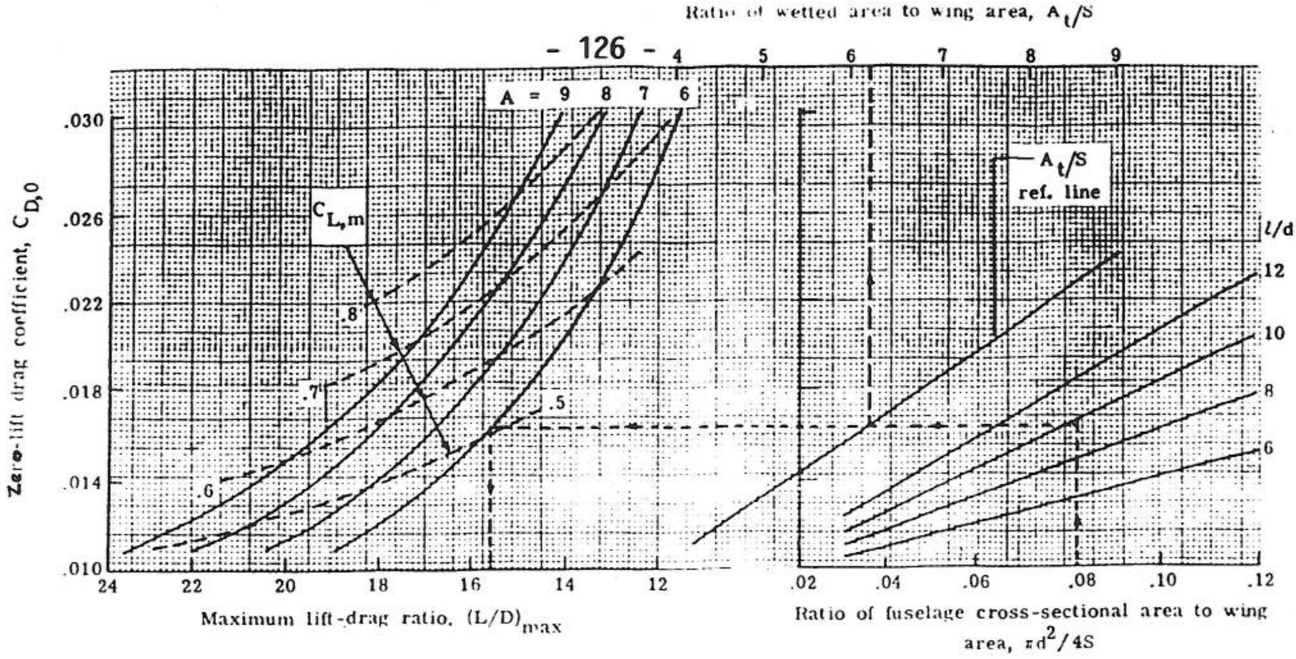



FIG. B6 LIFT-DRAG

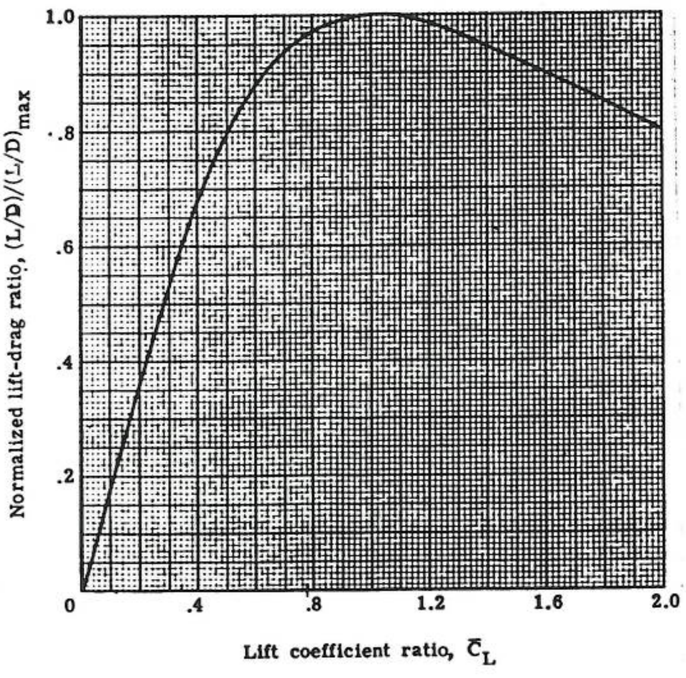



FIG. B7 NORMALISED L/D

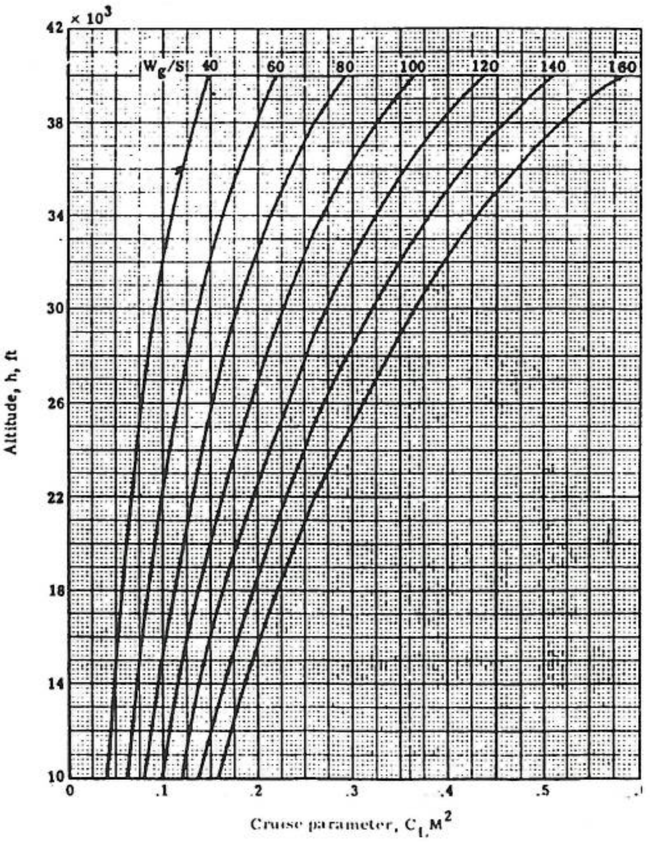



FIG. B8 CRUISE MATCH

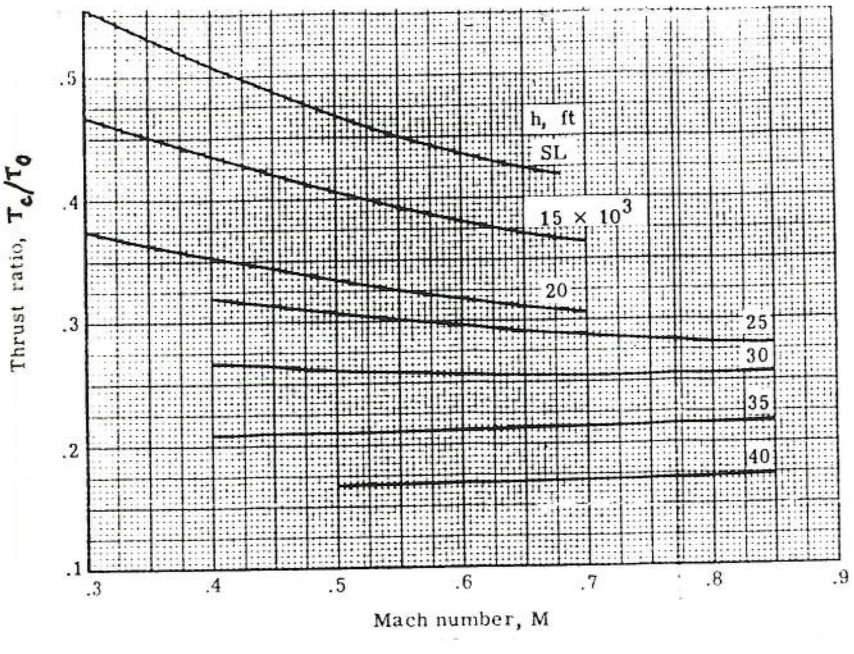



FIG. B9 THRUST RATIOS

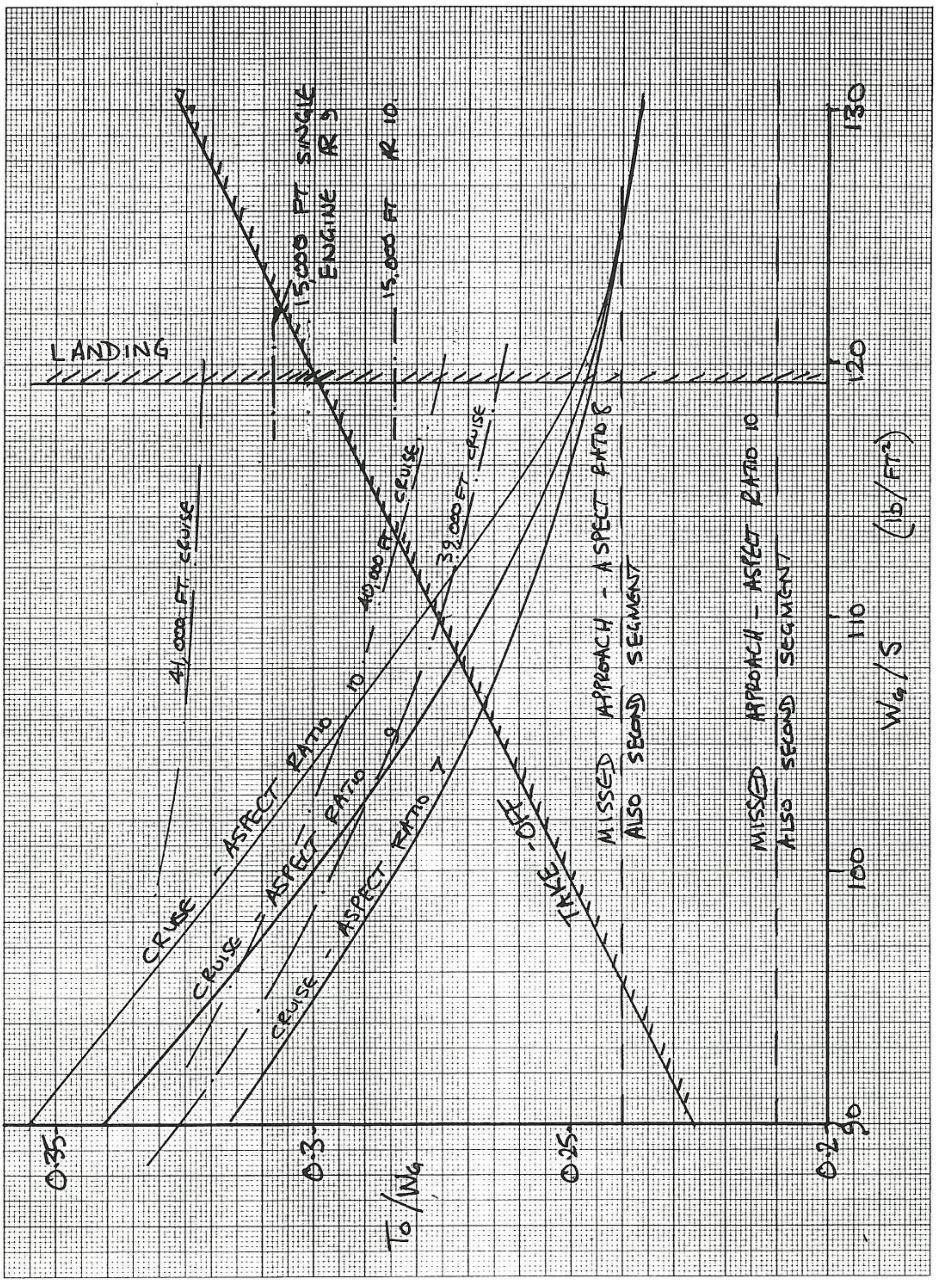

LANDING
15,000 FT SINGLE ENGINE AR 9
15,000 FT AR 10
41,000 FT. CRUISE
40,000 FT CRUISE
39,000 FT CRUISE
CRUISE - ASPECT RATIO 10
CRUISE - ASPECT RATIO 9
CRUISE - ASPECT RATIO 7
TAKE-OFF
MISSED APPROACH - ASPECT RATIO 8
ALSO SECOND SEGMENT
MISSED APPROACH - ASPECT RATIO 10
ALSO SECOND SEGMENT
0.35
0.3
0.25
0.2
To/Wg
90
100
110
120
130
Wg/S (lb/FT²)

FIG. B10

APPENDIX C

A-90 AVD Project Meeting No.10

13 Decemvber 1990

Present: Professor A J Troughton
Professor D Howe
Dr J P Fielding
Mr J B Young
Mr A Clegg
Dr R I Jones
All AVD Students

Apologies: Mr R Jamieson

L E Flaps (Charles)

Present scheme for slat tracts does not encroach on wing box. Assuming use of 7 segments for L E devices.

Outer U/C Flaps (Landry)

Further considered advanctages of 'auxilary aileron' allowing shorter tracks etc. This is to be option used.

Inner U/C Flaps (Larrive)

Defined segmentation of inner flaps and further looked at contruction/motion.

Outer Wing (Stolz)

Drawing of arrangement of ribs shown and considering mechanism for wing fold.

Inner Wing (Kuntjoro)

Sketch of rib positions for inner wing based on flap track and pylon positions.

Secondary Power System (Hubin)

Based on the hinge moments for the elevator and rudder, powers required, for actuation are very large.

Environmental Control (Wang)

Approximated duct diameters for wing L E area at around 160 mm.

Flight Control System (Carré)

Tabulation of loading modifed by allieviation in gust and manoeuvre cases produced.

<u>Flight Deck</u> (Tsay)

Drawing of initial layout of flight deck shown. Now to being looking at avionics.

<u>Main Gear</u> (Gentles)

Weights of drag struts in three design options estimated and looked at construction of oleo.

<u>Nose Gear</u> (Hopgood)

Looked at detailed design of shock-strut and sizing of bay for nose gear.

<u>Centre Fuselage</u> (Omar)

Drawing of possible side member construction to take main gear loads shown.

<u>Tail Fuselage</u> (Askar)

Drawing of possible side member construction to take main gear loads shown.

<u>Fin</u> (Friar)

Further considered composite design methods.

<u>Rudder</u> (Eiblmeier)

Drawing of hinge positions and rudder rib layout shown.

<u>Tailplane</u> (Miller)

Having been supplied with elevator hinge positions, rib layout chosen and now looking at required lay-up for composite skins.

<u>Elevator</u> (Grenier)

Sketch of layout using 2 actuators, one either side of a hinge enclosed within the tailplane. Will look at putting actuators outside structure.

<u>Interior Layout</u> (Baha)

Sketched possibilities for side, nose and tail cargo doors.

<u>Nose Fuselage</u> (O)

Continuing to optimise stringer/skin panels for nose fuselage area.

<u>Pylons</u> (Remacha)

Looked at engine pylon support with requirements. Chosen two ribs in line-of-flight.