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CRANFIELD

AEROPLANE DESIGN STUDIES.

TURBINE AND PURE JET POWERED GENERAL PURPOSE TRANSPORT AIRCRAFT

by

D. Howe

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Aeroplane Design Studies

Propeller Turbine and Pure Jet Powered General Purpose Transport Aircraft

(Academic Years 1963 and 1965)

- by -

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SUMMARY

The recent interest in the air bus conception of air travel is reflected in the aircraft chosen for study by the students in the Department of Aircraft Design during the 1963 and 1965 academic years.

The first study was based upon the use of four propeller turbine engines to power an aircraft capable of carrying up to 40,000 lb. of payload over short stage lengths. Emphasis was placed on the need for operations with mixed passenger and freight loads and the fuselage layout incorporates two decks, the lower one of which is designed as a freighthold with nose loading doors.

The second study was similar except that four wing mounted pure jet engines replaced the propeller turbines of the earlier design. The cruising speed is thus some 50 per cent higher with a Mach number limitation of 0.8. The two deck fuselage layout is retained, but with a rear loading door for the freighthold, and the wing has 28^{o} of leading edge sweepback.

An initial economic comparison of the two aircraft revealed that when the aircraft are operated over 250 n. mile stage lengths the direct operating costs of the propeller turbine powered design are some 20 per cent less than those of the pure jet version. This is mainly due to the much lower first cost of the simpler aircraft.

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1. Introduction

Recently considerable thought has been given to means of providing low cost air transport. This has lead to the proposals for 'air bus' types of aircraft which include the very large subsonic jet designs. Most of these are intended for use on existing high density routes and little attention has been given to meeting the needs of relatively underdeveloped areas. Although the present volume of air traffic in these regions of the world is small in comparison with that in economically developed areas the introduction of a suitable type of aircraft could be expected to generate a substantial increase in local demand, as occurred throughout the world when railways were first built. It is suggested that the current designs for large civil aircraft are basically unsuited to this type of operation primarily because of their sophistication and the airport facilities required for their operation.

The design study chosen for investigation by the students in the Department of Aircraft Design during the 1963-64 academic year represented an attempt to meet this unfulfilled requirement for an aircraft for use in underdeveloped areas. Known as the GP63, the design was powered by four Rolls-Royce Dart Mk. 542 turboprop engines. Considerable emphasis was placed on simplicity in both the choice of basic configuration and the detail design. Operation off poorly prepared runways 4500 feet long was catered for. Provision was made for the carrying of mixed payloads of both passengers and freight in a capacious, pressurised double deck fuselage.

By way of comparison the design chosen for study during the 1965-66 academic year, although based upon a somewhat similar requirement, differed in that the turboprop engines were replaced by four Rolls Royce Spey Junior Mk. 550 bypass turbojets. In order to take full advantage of the benefits conferred by this change of powerplant it was necessary to accept an increased complexity in the design. Consequently the resulting aircraft bears some resemblance to the commonly accepted form of airbus.

A general arrangement drawing of the GP63 project is shown in Figure 1, whilst that of the later GP65 design is in Figure 2. Photographs of models of the two aircraft appear in Figures 3 and 4 respectively.

Appendix A lists the students who were concerned in the work on the two project aircraft.

2. Configuration and Performance of the Aircraft

2.1 The GP63

The propeller turbine powered GP63 project has a fuselage capable of carrying passengers and large, bulky freightloads at one and the same time. This is achieved by using a pressurised double deck layout. Both decks can be used for passengers and the maximum capacity with a seat pitch of 34 inches is 183. However the lower deck is primarily intended as a freighthold and independent external access is provided to the 99 seats on the upper deck. As a freighthold the lower deck has a clear space 63.7 feet long which is

6.5 feet high and 6.5 feet wide at the floor level. Loading of this deck is through a hinged nose door located below the cockpit, and by a rear door on the port side. The normal height of the freight floor above ground datum is 4.5 feet. A freight load of 40,000 lb. may be carried in the absence of passengers.

The normal design all up weight of the aircraft is 110,000lb. This weight may be varied to suit different operating conditions and in particular provision is made for overloading to a maximum of 132,000 lb. for operations off long runways. In this condition both maximum payload and fuel load may be carried. The design runway load classification number at the normal take off weight is 35.

The wing is basically unswept and has a constant chord between the outermost engine nacelles. Externally hinged double slotted flaps are used. The aspect ratio is nominally nine and the wing loading at 110,000 lb. weight is 74.4 lb. per sq. ft. The need to keep the freighthold clear of obstruction implies that the centre wing box structure must be passed above the freighthold roof. Thus whilst a mid wing layout is used, the effect is to divide the upper deck into two cabins. These cabins are connected by a service passage, 6.0 feet in height. A layout of the cabin and freighthold is shown in Figure 5.

The main undercarriage is somewhat unusual for this type of aircraft in that it is mounted from the wing just outboard of the inner engine nacelle. It retracts sideways and outwards so that the wheels lie behind the outer engines.

The basic performance specification for the GP63 was that it should be able to carry a 40,000 lb. freightload over two separate 250 n. mile stage lengths with reserve fuel for 100 n. mile diversion and 30 minutes stand off. In this condition the required length of runway was not to exceed 4500 feet. Predictions indicate that the aircraft can achieve this performance with a take off weight of 106,000 lb. For operations off a 3000 feet long runway a payload of 25,000 lb. can be carried under similar conditions, the take off weight being 90,200 lb. The variation of range with payload for three datum take off weight conditions is shown in Figure 7. The normal cruising speed is 237 knots E.A.S. In short range operation the cruise altitude does not exceed 12,000 feet, but the cabin is pressurised to a differential of 5.6 p.s.i. to cater for longer flights.

Maximum level speed is 315 knots T.A.S. at 15,000 feet altitude and the minimum flying weight of 60,000 lb. Speed performance is illustrated in Figure 9. The design diving speed is 300 knots E.A.S. The unstick speed at 110,000 lb. take off weight is 110 knots and the approach speed at the maximum landing weight of 105,000 lb. is 105 knots.

A detailed specification of the geometry, weight and aerodynamic characteristics of the GP63 is given in Appendix B. Table 1 includes a predicted component weight allocation for the design.

2.2 The GP65

The use of bypass turbojet engines for the GP65 enables the cruising speed to be increased to an estimated value of 360 knots E.A.S. which is some 50 per cent greater than that of the GP63. At higher altitudes the limiting cruise Mach number of 0.8 introduces a speed restriction. As would be expected the major change in the layout is in the wing geometry. A leading edge sweepback of 28^{o} is associated with an aspect ratio of eight and a root chord thickness of 13 per cent. At the normal take off weight of 127,000 lb. the wing loading is 79.3 lb. per sq. ft. Variable gap double slotted flaps are incorporated in the design of the wing. These are unswept over the central portion of the span.

Underwing pod mounting is used for the four engines. They are arranged in pairs, each pair being suspended on a single pylon located approximately 35 per cent out along the span.

The fuselage arrangement is very similar to the one proposed for the GP63. Certain detail changes have nevertheless been made. The nose shape is more slender for reasons of critical Mach number, and the nose loading door is replaced by a rear ramp door of the type preferred for military aircraft as it is suitable for air dropping operations. This arrangement does introduce a complication in that it is necessary to have a subsidiary door to enable the required loading headroom to be obtained. The lower fuselage cross section has been modified to give an increased floor width of 7.5 feet which allows standard 7 feet 4 inch pallets to be carried. Small changes in the layout have resulted in the freighthold length being increased to 65 feet and the maximum passenger capacity to 190. Of this number 106 are accommodated on the upper deck. The true double-bubble cross section used for the GP63 is replaced by a flat sided configuration by way of comparison.

A bogie undercarriage arrangement is used, the legs being mounted off the sides of the fuselage. When the wheels are retracted they lie in two blisters located on the lower fuselage sides as is shown in the fuselage layout drawing, Figure 6. The runway load classification number at the design weight is 35.

Provision is made for the overloading of the aircraft to a maximum weight of 150,000 lb. when this is deemed to be desirable.

The payload-range performance requirement is identical to that used as a basis for the GP63 study. It has been estimated that when the aircraft takes off at 120,000 lb. weight it can carry 40,000 lb. of payload over two 250 n. mile stages with the necessary fuel reserves. Figure 8 gives the payload range performance for three datum take off weights and is directly comparable with Figure 7 for the GP63. The normal cruising altitude is in the 20,000 ft. to 25,000 ft. region and a 7 p.s.i. cabin pressure differential is required to cater for the longer range flights.

The design diving speed limitation is 450 knots E.A.S. or, at higher altitudes, Mach 0.9. When the aircraft is flying at a typical cruise weight of 90,000 lb. at 17,000 ft. altitude it can achieve 520 knots T.A.S. This is shown in Figure 10. The low speed characteristics of the design give an unstick speed of 120 knots at 127,000 lb. take off weight, and an approach speed of 115 knots at the maximum landing weight of 120,000 lb.

A more detailed description of the geometry and other characteristics of the design is given in Appendix B. The predicted component weight breakdown appears in Table 1.

3. Description of the Structure of the GP63

The short range type of operation envisaged for the aircraft implies a severe fatigue problem which results directly from the large number of landings to be expected during the total life. For design purposes it was assumed that a life of 40,000 hours spread over a fifteen year period could be made up of 100,000 flights.

Copper based light alloys were preferred throughout the structure. Wherever possible fabricated components using L72 or L73 sheet have been used, with forgings and extrusions in L65.

The locations of the main members of the structure are shown in Figure II.

3.1 Fuselage

The deep cross section of the fuselage has a double bubble configuration with the intersection of the two circles at the roof line of the freighthold. Over the greater part of the length of the fuselage the cross section is constant and is approximately 17.3 ft. deep. As would be expected, in view of this relatively great depth, the pressurisation loads play a significant part in the determination of the skin thicknesses. This is especially true of the forward 40 feet of the fuselage length. The worst vertical bending and shear loads over the remainder of the length occur as a result of ground operations. Forward of the wing dynamic braking is critical, and gives rise to a factored vertical bending moment of $2,85 \times 10^6$ lb. ft. and a shear force of 1.5×10^5 lb. Aft of the wing the two point high drag landing case gives a factored bending moment of 6.75×10^6 lb. ft. and a shear force of 2.55×10^5 lb. The critical lateral loads on the front part of the aircraft occur in a three point landing with sideload, but on the aft portion the overswing in yaw resulting from rudder application is most severe.

3.1.1 Shell

A basic frame pitch of 17 inches is used throughout the fuselage. This was chosen as being within the limit set by consideration of crack propagation in the L72 skin, and it enabled windows to be located between every other frame to coincide with the nominal seat spacing of 34 inches. Apart from the forward 12 feet of the nose of the fuselage all skin and stringer joints use mushroom head rivets. To avoid the need for spin dimpling the nose skins are 18G thick. In the local region of the wing attachment the skin thickness is 14G, but elsewhere the upper portion of the section is in 20G with 18G and 16G for the sides and bottom of the lower shell respectively.

Zed section stringers, 1.25 inches deep and 18G thick are used since they are preferable from the point of view of inspection and corrosion. Over the greater length of the upper deck they are intercostal. Where they are required to be continuous the stringers are passed through holes cut in the webs of the 4 inches deep, pressed channel section frames, and are joggled over the frame flange. The minimum stringer pitch of 3 inches occurs over the bottom of the fuselage, and a pitch of 4.5 inches is used on the sides of the lower deck. Throughout the length of the top deck 6 inch pitch is adequate.

Longitudinal skin joints are made on special inverted top hat section stringers. Continuity of stringer loads at the intersection with the wing pick up frames is achieved by means of a 14G skin reinforcing finger plate. The pressure shell is closed at the rear end by a membrane bulkhead, assembled by rivetting together a number of separate gores. A forging is used at this position to react the kink loads at the floor joint. The maximum design stress in the fuselage structure is 44,000 p.s.i.

3.1.2 Floors

The passenger floor is located 6 inches above the intersection of the cross section radii, which is made at a 'Y' section extrusion. The kink loads are reacted by deep horizontal beams located along the sides of the fuselage. These in turn are supported by the lateral floor beams. Although the skin hoop stress due to the design pressure differential of 5.6 p.s.i. is not permitted to exceed 12,000 p.s.i. some relaxation is accepted in the design of the cross beams. This is justified on the grounds of their redundancy and the fact that they do not, themselves, directly contain the pressure. Extruded seat rails are located on the top of the 4.5 inches deep intercostal fore and aft floor beams. End grain balsa floor panels faced in 26G L72 are placed between the rails.

The upper floor line coincides with the neutral axis of the fuselage in vertical bending. The freight floor, on the other hand, is a long way removed from the neutral axis and it was found to be necessary to construct it in short sections longitudinally to avoid unduly high compressive stresses being developed in the upper fuselage skin. It is supported by full depth frame webs below the floor line and seat rails similar to those used on the top deck are built in. The central area of the floor, which supports the freight loads, is fabricated from a 20G L72 corrugated sandwich of 0.75 inches depth. The top surface is covered by a replaceable 0.25 inch thick layer of plywood or other material. The sides of the floor use L72 surfaced end grain balsa panels similar to those employed for the passenger floor above.

3.1.3 Doors and Windows

The large nose loading door is designed to react only the local inertia and pressure loads. It is constructed in one piece to minimise the length of the pressure seals required, to simplify actuation and to enable a good structural design to be achieved. Two simple hinges located on the starboard side are used and as these are of necessity outside the skin line they are housed in small fairings. The door is operated by means of a long screw jack driven by a hydraulic motor. Locks are provided along the horizontal top surface of the door and round the aft face of it. The upper locks are illustrated in Figure 13 and are, in reality, toggle operated hooks which lift the door into place. A microswitch sequence system controls the hydraulic jacks used to rotate the lock bars. Inflatable pressure seals are placed on the fuselage for the top joint and on the door for the rear joint.

Access to the rear of the freighthold is through a 6.5 ft. square side door. This is split into two portions, each hinged to the upper edge member. Only one half is used when passengers are carried on the lower deck. Two separate lock systems are incorporated for reasons of safety, each being sufficient to withstand normal loads. Inflatable pressure seals are provided. In the region of this door the frame pitch is reduced to 12 inches, primarily to support the locks.

The passenger windows have two load carrying acrylic panes, which are 14 inches in diameter.

3.1.4 Attachments

The unpressurised three spar wing box passes through the fuselage. Shear attachments are made between each of the spars and adjacent frames. The front and rear spar frames pass in front of and behind the wing box, respectively, and so are unbroken. The centre spar frame terminates at the skin surfaces of the box, continuity being provided by diaphragms and booms inside the wing. Each of the frames has a local forged section adjacent to the joint with the wing which consists of numerous bolts. Reaction of the torque at the fuselage side is assisted by the provision of longeron members. The intersection of the wing box with the kink region of the fuselage results in a difficult geometric path for these longerons and the design of the root rib is complicated. The 'Y' shaped kink extrusions pass through holes in the webs of the spar frames.

The two spar tailplane box also passes across the fuselage. It is connected to two special frames built up from plate webs and extruded angle booms. Each of the four connections employs a single pin with a tongue to react the load as a fail safe measure. The fin is built into the same pair of frames by forged fittings.

The frame immediately aft of the rear spar station is used to support the innermost of the flap hinges. A skin doubler plate is provided to assist in the diffusion of the local loads.

3.2 Wing

The wing box structure is continuous from tip to tip, although a large cut out is required in the lower surface for stowage of the main undercarriage. Between the outer pair of engine nacelles there are three spars located at 10.7 per cent, 34.5 per cent and 69 per cent of the chord. The cut outs for the undercarriage extend 12 feet inboard from these nacelles but are limited to the rear cell. Outboard only the front and rear spars are retained, and the latter is kinked forward to a 55 per cent chord position in the region of the aileron. The maximum factored shear force of 1.5×10^5 lb. occurs during a two point landing at the design vertical velocity. However the maximum bending moment of 3.15×10^6 lb. ft. arises during a 2.5g manoeuvre at speed V_c with the centre of gravity on the forward limit and a weight of 90,200 lb. Fatigue considerations limit the maximum working stress in the skin box to approximately 75 per cent of the static design value. The ground-air-ground cycle was found to account for some 70 per cent of the total damage.

3.2.1 Structural box

The distributed flange box structure is based on the use of zed section stringers reduxed bonded to tapered skins. Redux bonding was chosen rather than rivets to eliminate the need for spin dimpling of the skins and to reduce the sealing problem resulting from the use of the box as an integral fuel tank. The skin-stringer assembly is supported by ribs which have a pitch varying from 17.5 inches to 32.5 inches over the span, although 24 inches is a typical value. These variations are necessary to suit hinge locations and othe datum points. The L72 skin has a thickness which varies from 0.2 inches at the root to 0.1 inches at the outer nacelle and 18G at the tip. There are four planks across the chord. Between the nacelles the skins are chemically etched to obtain the requisite taper and provide local lands for the spar connections. The high torques which occur inboard of the undercarriage main attachment require these connections to be bolted. A basic stringer pitch of 3 inches is used across the span. Near to the root the stringers on the top surface are 1.25 inches deep by 0.1 inches thick L65 extrusions, whilst those on the lower surface are rolled in 14G L72. Towards the tip 18G stringers of reduced depth suffice.

The spars are built up from tapered plate webs and angle boom extrusions. The front and rear spar web thicknesses vary from 0.3 inches at the root to 0.08 inches at the tip. The centre spar web tapers from 0.2 inches to 0.15 inches thickness. Load carrying access panels for the integral tanks are located in the bottom surface and in the outer wing it was found to be necessary to locate these between every rib. The standard ribs are fabricated from channel section pressings in 16G L72.

Special ribs are required at a number of stations. The root rib is built up of 10G plate reinforced by vertical zed stiffeners. At the main undercarriage pick-up the web of the rib is 0.15 inches thick in the forward cell and 0.2 inches thick aft. A rib web thickness of 0.15 inches is necessary at the point where the centre spar terminates.

A production joint is incorporated on the aircraft centreline.

3.2.2 Leading and Trailing Edges

Both the leading edge and the flap and aileron shrouds are detachable, being bolted to the main box. They are fabricated in short lengths to reduce the possibility of bending end loads being induced in them.

3.2.3 Engine Mountings

The four engines are mounted off the front of the main wing box by means of a braced tubular structure. Rivetting is preferred to welding for the joints. The T60 tubes used vary in diameter from $\frac{7}{8}$ inch to 2.0 inch and in thickness from 22G to 17G.

3.2.4 Flaps

The flaps are constructed in two sections on each side of the aircraft. The innermost of the sections is some 27 feet in span and parallel in chord, whilst the tapered outer portion has a span of 9 feet. Four hinges are used to support the long span and two the short one. A double slotted configuration is used in conjunction with a simple hinge located 0.806 chords aft and 0.212 chords below the wing leading edge. Tracks and rollers are thereby eliminated albeit at the expense of a drag penalty.

Both the main flap and the nose vane have a three cell torsion box construction with intercostal plate ribs. The normal spacing of the ribs is 12 inches and alternate ones are in 18G and continuous across the main flap to the vane. The 22G skins are supported by 20G angle stringers placed at 3 inches pitch.

End loads on the flap sections are reacted at the innermost and outermost hinges for the inner and outer flap sections respectively. With the exception of the innermost one the hinges are supported off wing ribs by triangular structures of steel tubes. A similar arrangement is used to carry the flaps on the hinges. The hinge at the junction of the two flap portions serves both parts. The flaps are actuated by synchronised hydraulic jacks located at each of the hinge positions.

At the flap design speed of 180 knots and with 50^{o} flap the factored resultant load is 43,000 lb. on each side.

3.2.5 Ailerons

Each aileron is divided into two sections of approximately equal span. The two parts are connected by torque links which incorporate a spherical bearing at the apex. Tabs are located on each part. One of these is a combined geared and trim tab and the other, on the inboard section, is a spring tab. They are operated by screw jacks, the latter through a torsion bar. The critical strength design case was found to be when the aileron was deflected through an angle of 16^{o} during a normal manoeuvre of 1.67g at speed V_A. The corresponding factored aileron load is 9400 lb. per side. In the absence of tab and balance effects the unfactored moment is 6700 lb.ft.

Each part of the aileron and each tab has three hinges, the centre one of which is used as the datum. The aileron outer hinges incorporate swinging links and self-aligning bearings. The aileron has a spar located just behind the hinge line and a subsidiary curved spar aft also serves as a shroud for the tab. The skins are 22G thick and the spar and rib webs vary from 18G to 22G. The tabs have 24G nose skins, 26G aft skins and a 20G spar web. Back to back channel section plate hinges are employed for both the control surface and tab. The wing hinge brackets have flanged plate webs reinforced by angle booms. Restricted space behind the wing rear spar dictates the use of a round nose on the aileron and the mass balancing is by three discrete weights on each section. These are located on arms which are cantilevered from the aileron ribs and which pass through the web of the wing rear spar.

3.3.1 Tailplane

The tailplane design case is a factored download of 42,000 lb. This occurs when the aircraft is flying at the flap design speed of 180 knots in a pitching manoeuvre to 2g with the centre of gravity forward and the flaps set at 50^{o}. The maximum upload is some 70 per cent of this value.

A two spar configuration is used for the primary structure with the leading edge contributing to the torsional stiffness outboard of the fuselage sides. The skin thickness varies from 14G at the root to 22G at the tip in three steps and is determined by strength rather than stiffness. L73 sheet is employed for both the skin and the zed section stringers. These stringers are 1.1 inches deep and 20G thick, and are spaced at a typical pitch of 2.7 inches across the chord. A skin doubler is located in the root rear spar region to cater for constraint stresses.

The spars are placed at 15 per cent and 46 per cent of the chord and are fabricated from plate webs and extruded angle booms. The web thickness varies from 12G at the root to 16G at the tip in two steps. Ribs are located at a pitch which increases from 19 inches at the root to 25 inches outboard. The centre box ribs are built up as braced structures using channel sections with angle boom members. The leading edge ribs are simple pressings.

3.3.2 Elevator

In common with the ailerons the elevators are split into two sections on each side of the aircraft. Although the two sections are connected by a universal joint located on the hinge line there is no connection port to starboard. The cross connection was omitted as spring tabs are used to assist in the operation of the elevators. Unlike the aileron the elevator incorporates an aerodynamic balance with a 30 per cent set back hinge. The maximum elevator load of 40,000 lbs. occurs in a pitch to 2.5g at speed V_A.

Two hinges are used for each section of the elevator and each tab has five hinges. Once section carries a trim tab and the other the spring tab. The critical torsion case was found to arise when the setting of the two tabs is in the opposite sense.

The elevator structure has two spars. The main spar is forward of the hinge line and is built up from 20G web and angle booms. The rear spar acts as a tab shroud and is a 22G channel section pressing. Holes in the top skin are provided for access to the hinges. The 22G pressed ribs are placed at 7 to 8 inches pitch. The skins, which are also in 22G, are further supported by a pair of spanwise intercostals positioned between the spars. The leading edge skin is 20G and the end ribs are 16G thick.

The tabs use 26G skins and ribs and they are operated at a tab hinge position which coincides with the main elevator datum hinge. A spring box is incorporated in the spring tab circuit as is illustrated in Figure 13. The other tab hinges are provided with self-aligning bearings.

The elevator hinge fittings are of back to back channel design. The wing supporting brackets are fabricated from back to back 22G channel pressings supplemented by 18G angle booms. Aerodynamic sealing is obtained by placing a rubberised fabric curtain between the aileron and wing. A series of discrete mass balance weights are attached to the nose ribs.

3.4.1 Fin

The two spar construction of the fin is similar to that of the tailplane. Overswing of the aircraft in yaw subsequent to instantaneous deflection of the rudder at V_c gives the maximum factored side load of 44,600 lb. and the corresponding root bending moment of 4×10^5 lb. ft.

The spars are located at 13.5 per cent and 47.5 per cent of the chord and are built up from 18G webs and light angle booms. The 16G skins are reinforced over the lower one third of the span by 16G zed section stringers. Above this 18G angle stiffeners are used. The 22G pressed ribs are positioned at a typical pitch of 18 inches.

3.4.2 Rudder

The one piece rudder is connected to the fin by three hinges. The main spar is located forward of the hinge line as in the case of the elevators. Trim and spring tabs occupy approximately equal parts of the span. The upper, trim tab, is hinged in four places whilst there are three hinges on the spring tab.

3.5 Undercarriage

A deliberate attempt was made to keep the undercarriage mechanically simple. The use of a bogie layout for the main gear was excluded on these grounds and common tyres are used on the nose and main wheel units.

3.5.1 Main Undercarriage

Basically the main undercarriage consists of a cantilever leg which carries twin wheels on a single axle. Each wheel has two tyres. The top of the leg is in the form of a vee shaped yoke, the arms of which terminate at the retraction hinge line. The leg is braced laterally by a side stay which folds during retraction to enable the whole unit to hinge outwards and up into the wing.

The axle is rotated through 90^o during retraction so that the wheels occupy the space behind the outer engines. This is illustrated in Figure 14 which is a general arrangement drawing.

The liquid spring shock absorber has a stroke of 12 inches and a relatively high proof reaction factor of 2.15. Undercarriage design loads are therefore rather large, and when these are associated with the very long leg the result is a heavy unit. The factored design loads are 170,000 lb. vertically in a three point landing, 102,000 lb. fore and aft in a high drag condition and 51,500 lb. sideways during turning and swinging.

The vee yoke is a steel casting in DTD 666. The two arms are inward facing channels reinforced by internal webs and having a typical wall thickness of 0.6 inches. A mechanical dog clutch is used to lock the lower leg assembly to the casting when the unit is in both the extended and retracted positions. It is automatically disengaged during retraction by the first motion of the side stay and similarly re-engaged by the last motion. The design of this is shown in Figure 13. The component parts are forged in S99B steel and automatic centring is included to ensure correct engagement of the dogs. The leg is rotated by means of a special jack, which operates on an arm forged in L65. The estimated time for complete retraction is 12 seconds.

Unlocking of the sidestay is carried out by the initial motion of main retraction jack. The components for it are forged in S96. The uplock is operated hydraulically but has a manual override for emergency extension of the leg. The wide wheel spacing combined with the high turning and swinging side load imposes a severe torque on the leg and two pairs of forged S99 torque links are required. The wheels are chill cast in L53 light alloy and each houses three pairs of disc brakes.

3.5.2 Nose Undercarriage

The layout of the nose undercarriage unit was greatly influenced by a desire to retract it aft into the main fuselage rather than forward into the nose loading door. Retraction into the door was ruled out because of the pressure sealing problem, but in the event the rearwards retraction chosen was found to introduce ground clearance problems as well as additional drag due to the blister fairing required. The size of this fairing was minimised by rotating the wheels through 90^{o} during retraction. This involves virtually no penalty as it is achieved by appropriate choice of geometry for the steering mechanism. The nosewheel bay is unpressurised. The factored vertical and side loads of 95,000 lb and 38,000 lb. respectively both occur in a three point landing, but the maximum drag load of 57,000 lb. arises in the high drag case.

Steel is used throughout the nose unit, the majority of the components being forged in S99. Side loads are reacted by the trunnion fitting at the top of the leg, which is also the retraction hinge. It is supported by fore and aft webs positioned between the freight floor and the adjacent lower fuselage frame. The down lock is located centrally at the bottom of this frame and reacts the drag loads. Cross beams brace the frame back to the fore and aft webs. The twin wheels are mounted on a live axle. An earthing rod is used in conjunction with non-conducting tyres to preserve the commonality with the main tyres.

4. Description of the Systems of the GP63

In order to minimise service maintenance on the aircraft the design of the airframe systems was kept as conventional and simple as possible.

4.1 Flying Control System

Complete manual operation of the flying control surfaces is proposed with the assistance of the spring and geared tabs. Cables are used for the main control runs which are located below the upper floor and behind the rear spar of the wing. Automatic tensioners are incorporated. In the locality of the control column and the control surfaces the system uses levers and push-pull rods. The trim tabs are operated through cable and chain circuits.

4.2 Fuel System

All the fuel is contained in the integral wing tanks. These tanks are located very close to the fore and centre of gravity and manual selection is adequate for control of fuel usage. Electrically driven booster pumps feed the fuel to the engines.

4.3 De-icing System

The wing leading edge is de-iced by hot air tapped off the engine compressors. Electric de-icing is used on the leading edges of the tailplane and fin.

4.4 Air Conditioning and Pressurisation System

The form of air conditioning system installed depends very largely upon the use made of a particular aircraft. When the operation is limited to short ranges over normal terrain the maximum cruise altitude can be restricted to 10,000 ft. or less and pressurisation is not necessary. For this type of operation the complete elimination of the pressurisation system greatly eases the servicing problem and prolongs the life of the fuselage structure. When flight at higher altitudes is implied, either by longer stage lengths or operation in mountainous country, pressurisation up to the maximum differential of 5.6 p.s.i. is necessary.

The pressurisation system uses air bled from the engine compressors.

5. Description of the Structure of the GP65

The overall structural problems of the GP65 design are similar to those of the GP63, but are aggravated by the increased cabin differential pressure of 7 p.s.i. and the 50 per cent higher design diving speed. As in the previous case the design life of 40,000 hours is associated with 100,000 individual flights. The comparatively high intensity of structural loading has resulted in the much greater use of forged and machined components. Copper based alloys are used both for these and the sheet metal parts.

Figure 12 shows the configuration of the main structural members. A model of the structure is illustrated in Figures 19 and 20.

5.1 Fuselage

One of the major differences in the configuration of the GP65 fuselage as compared with that of the GP63 is the use of nominally flat sides to connect the circular arcs of the two decks. These flat sides and the remainder of the upper part of the section are designed almost entirely by the pressurisation loads. Freight loads were found to be critical for the lower deck frames. The maximum factored vertical shear force of 3×10^5 lb. results from a three point landing at the design weight. However, the most severe up gust case of 3.4g gives the critical bending moment of 6×10^6 lb. ft., this being associated with a shear force of 2×10^5 lb.

5.1.1 Shell

The shell is constructed from L72 skins reinforced by rolled zed section stringers and supported by frames located at a maximum pitch of 20 inches. The minimum skin thickness of 18G is dictated by the need to cut countersink for $^5/_{32}$ inch diameter rivets. These L69 rivets are of special design and have reduced heads to improve fatigue properties. Their estimated design tensile strength is only 30 lbs. The skin thickness on the flat sides and lower part of the cross section is 16G apart from the wing intersection region where it is increased to 14G. The upper deck skin is 16G in this area. No hoop tension stresses exceed 12,000 p.s.i. at the normal pressure differential.

The 1.5 inch deep L73 stringers are continuous through all but the heavy attachment frames, where skin reinforcing finger plates of 14G are used to give load continuity. Over the curved portion of the upper deck the stringers are pitched at 6.0 inches. Their thickness is the same as that of the local skin. Along the flat sides and below the freight floor the pitch is 4.5 inches and the thickness 14G. The pitch used on the lower curved sides decreases from 6.0 inches over the nose to 4.5 inches along the centre and rear portions of the fuselage. Stringer thickness also varies from 18G to 16G.

Circumferential skin joints are made at frames, each skin panel being wrapped round three frame pitches along the parallel portion of the fuselage. The lap longitudinal joints occur at the points of geometry change round the section. The panels are arranged longitudinally in regions of double curvature. The standard pressed frames have holes cut in their webs to allow the stringers to be threaded through. The frame flanges are not cut, the stringers being joggled over them and cleated. The maximum factored design stress due to the 3.4g gust case is 50,000 p.s.i.

5.1.2 Floors

The passenger floor is geometrically similar to that of the GP63. The construction is also similar with the L72 faced end grain balsa panels supported on the lateral tie beams. Extruded L65 seat rails, which allow the seat pitch to be varied in one inch increments are placed in the floor. They are easily replaceable in the event of their becoming damaged. Each of the two longitudinal rows of seats has a pair of rails which are 20.75 inches apart.

The freight floor of the GP65 is 92 inches wide so that 7.33 ft. wide standard pallets can be accommodated. This is 8 inches more than the width in the GP63. The seat rails are identical to those used on the upper deck, and are incorporated in the floor. As the frames are pitched at 20 inches a nominal 20 inch squre grid of lashing points is provided by locating a fifth seat rail on the centreline of the aircraft. Roller tracks may be attached to the seat rails if this is required. The floor structure consists of a mesh of longitudinal and lateral beams, the former being intercostal apart from the continuous seat rails. Top hat section struts support the lateral beams from the frames. The beams are typically 4 inches deep with plate webs and extruded angle booms. The floor panels are fabricated from 0.75 inches deep honeycomb sandwich. Each lashing point is designed to cater for 10,000 lbs.for and aft, 5,000 lbs. lateral and 6,700 lbs. vertical load.

5.1.3 Doors and Windows

The main ramp freight door can be used in the horizontal position for truck loading or air dropping. Height clearance in this case is achieved by opening the subsidiary rear doors and folding aft the lower portion of the pressure bulkhead which is located at the rear of the freight bay as may be seen in Figure 6. This apparently complex arrangement was evolved after consideration of various schemes. These included clam shell doors and the concept of presurising most of the tail cone to eliminate the folding bulkhead. A change of the external shape of the rear fuselage to completely avoid the necessity for additional doors would have aggravated the flow problem associated with the already bluff rear body.

The freight door itself is hinged on the aft face of a major frame which is also designed to cater for the load arising when the aircraft is propped for loading. This frame is built up and has a forging across the bottom and 16G plate webs with extruded booms elsewhere. Box sections are used to form the longitudinal edges of the door cutout and to carry the locking pins. There are ten of these on each side. The boxes are supported by frames constructed from two 14G channel pressings placed back to back. The locks are operated in sequence from the front to the aft end, and each pin is tapered to cater for 0.2 inches lateral or vertical misalignment. The door itself uses an 'egg box' type of construction of plate webs supporting the honeycomb top surface and 16G zed stringer-skin lower surface. The hinged pressure bulkhead also uses 0.75 inches deep honeycomb sandwich and when in place it is supported by the rear horizontal door.

The rear passenger doors are close to the freight door and there is only one clear frame pitch between them. The high local skin shears which result from the load diffusion round these adjacent cutouts are catered for by skin doubler plates. The frames around the passenger doors are of box section and are built up from pairs of 14G channels connected by capping plates.

The pilots' windscreen panels are fabricated from an acrylic-vinyl sandwich. Acrylic is preferred to glass because the better bird impact resistance and lower weight are considered to compensate for the increased cost. Electric gold film de-icing is provided. The passengers windows also use acrylic for the transparencies, which are duplicated in each window. Windows are located between all frames except in the wing region, and are 11 inches in diameter.

5.1.4 Attachments

The main wing box passes unbroken through the fuselage, above the freight-hold roof. It is attached at three frame stations. Multiple bolted joints transmit the shear from the front and rear spars to the frames. These joints can be readily inspected by removal of the cabin trim. The frames are built up from plate webs with machined extruded booms and forgings in the actual attachment region. Aft of the rear spar of the main box there is a subsidiary spar. This is attached by a single pin located on the intersection of spar and frame neutral axes. Longerons extend forward from the subsidiary spar station to the front spar and line up with the wing root kink rib. They assist in the distribution of the wing torques into the fuselage.

The main undercarriage units are attached to the fuselage aft of the wing. The connection consists of a braced structure built on to the side of the fuselage within the undercarriage blister. The main hinge attachment transmits vertical loads into the fuselage through a substantial forged fitting which forms the lower part of a fuselage frame. This fitting is continuous across the section below the floor and extends approximately half way up the sides of the lower deck. Drag and side loads are reacted primarily at a lower connection on the leg which also serves as a down lock. This point is also on the forged frame, and together with the main hinge fitting it is braced to the fuselage side by forged L65 struts. These form a triangulated drag structure. The upper strut is 3.1 inches square and the lower one 3.4 inches square. This structure serves to locally react moments due to the drag loads as well as transmit the load itself to a diffusion member on the fuselage skin. It is bolted to the fuselage and pick up forging.

The nosewheel is attached to the front face of the forward freight hold bulkhead.

5.1.5 Assembly of fuselage

The fuselage is built in three basic sections. The centre fuselage complete with the wing between the engine ribs is one unit, the wing box being used as a base on to which the fuselage frames, skins, and floors are assembled. The nose and rear sections are added to this assembly. Systems can be installed to the powerplants before the outer wing panels are joined on, thereby reducing the floor space required during the construction of the aircraft.

5.2 Wing

The wing structure is basically a two spar single cell construction across the whole span. It is swept back at approximately 24°. The front spar is located at a constant 15 per cent of the chord outboard of the fuselage side. The rear spar is placed at 55 per cent of the chord at the fuselage side and 60 per cent at the engine mounting rib which is approximately one third out along the span. This 60 per cent location is then maintained constant to the tip. Because the trailing edge is unswept over the inner wing, the local rear spar sweep is only 16°. A short, unswept, subsidiary spar runs from the rear spar kink to the fuselage side where it is attached by a single pin. The main box is continuous and unswept across the fuselage width. It is attached to two spar frames by bolted joints.

The wing design case occurs when the aircraft encounters a 50 ft/sec. vertical gust when flying at the cruising speed of 350 knots E.A.S. and a typical weight of 100,000 lb. The corresponding normal acceleration is 3.4g.

The maximum factored shear force and bending moment are 174,000 lb. and 4.3×10^6 lb. ft. respectively. The maximum stress developed is 49,000 p.s.i., which compares with the normal 1g level of 8500 p.s.i. Torsional stiffness is critical in the design of the outer wing structure.

5.2.1 Structural Box

The wing box is constructed from integrally machined panels which are supported on plate spar webs. Over the central portion of the wing there are four spanwise planks, but outboard of the engine rib this is reduced to three and then to two planks. A production joint is incorporated in the design of the engine rib, and the skin planks are also joined on the aircraft centreline. The upper surface planks are in D.T.D.5020 alloy and the lower ones are in S4ST4. At the root the 0.3 inches thick skins are reinforced by 2 inches deep by 0.45 inches wide stringers, placed at 5 inches pitch. The first three of these dimensions are reduced to 0.1 inches, 1.25 inches and 0.2 inches respectively at the tip.

The L73 spar webs are 10G thick and are split along their spanwise centreline. The joint is made on a Tee section extrusion. The webs are attached to the skins by angle section extrusions and stiffened by vertical top hat members placed on the face opposite the tee section. Web joints occur at the root and engine kink ribs.

The wing box structure is used as an integral fuel tank. Access holes are placed in the lower skin and the covers are designed to be load carrying. Tank ends coincide with the substantial kink and hinge ribs.

The rib pitch varies from 30 inches to 33 inches over the span. The ribs are placed normal to the subsidiary spar over the centre wing and normal to the rear spar outboard. The root tank rib is a single channel section forging which has 1.4 inches deep by 0.4 inches wide vertical stiffeners and a web thickness of 0.1 inches.

The engine kink rib is built up from an L65 forging and plate web with booms. The forging is located in the forward part of the section and includes the local front spar web and the three engine mounting pylon pick up points. Two inches deep by 0.5 inches wide stiffeners are placed at 5.0 inches pitch along the forged part of the rib. Flap and aileron hinge ribs are built up from 14G plate with extruded angle booms and vertical 18G top hat stiffeners. At these ribs the stringers are run into a thicker local skin to cater for the two load paths. Other, intermediate ribs require only a 20G web and 16G rolled angle booms which are placed on the inside of the stringers.

5.2.2 Leading and Trailing Edges

The leading edge is fabricated in 6 ft. long sections. The 20G plate ribs are placed normal to the front spar at approximately 10 inches pitch. The skin is chemically etched from a basic thickness of 0.2 inches to provide 0.12 inches deep by 1.25 inches wide chordwise ducts for the de-icing hot air.

Rivetted zed section stringers, 1.65 inches deep and 14G thick are used to stabilise the 10G trailing edge skins. They are supported by rib extensions which incorporate the hinge brackets. The latter are connected to the main ribs by cleats placed inside the structural box.

5.2.3 Engine Mountings

Each pair of engines is suspended from the wing on a pylon structure. The pylon has a sweepback of 62°. The two spars are built up from plate webs and extruded booms and the skins are supported by ribs placed parallel to the line of flight. The front pylon spar is attached at the upper end to two lugs on the forward face of the wing front spar, which at this section is integral with the engine mounting kink rib. The pylon rear spar has a single point attachment on this rib, about mid way between the wing spars. At their lower ends the pylon spars are built into a fore and aft titanium beam which acts as a spine for the engine pod structure. The spine is extended downwards as a titanium bulkhead which acts as a fire wall between the two engines. Two L65 forged cross ribs extend from the spine and the engines are suspended from their extremities. Each engine has a third attachment point on the spine. The remainder of the pod structure is essentially fairing and access doors. The former forms the upper surface of the pod. It is an L72 skin supported on five cross ribs and the intake ring, all of which are assembled to the spine. The access doors complete the lower surface. Exhaust shrouds are attached to the rear end of the spine.

5.2.4 Flaps

The double slotted flaps are also built in two parts on each side of the aircraft. The division is at the engine mounting kink rib where the trailing edge sweepback changes. The inner flap has a span of 15.5 ft. and is unswept. The main flap and vane chords are constant at 41 inches and 13.7 inches respectively. The outer flap is swept back at 23° and has a span of 19 ft. Three hinges are provided on the inner flap and two on the outer.

The hinge system is located below the wing surface and the geometry is arranged so that near optimum slot widths are maintained throughout the range of flap deflection. This is achieved by the simple linkage system illustrated in Figure 15. The use of rollers and tracks is avoided. An adjustment link is incorporated in the mechanism which is assembled from L65 forgings with Teflon-glass bearings at the pivots. The outer flap moves around a conical surface and the hinge bearings are spherical and inclined at 23° so that the linkage lies in the line of flight when in the retracted position. Each portion of the flap is operated by two hydraulic jacks which are located at the outer-most hinge positions. The jack mountings on the outer flap are arranged to allow for the 7° of lateral motion which occurs during deflection of the flap.

The inner main flap structure is provided with 20G skins in L72 with the exception of the lower rear half of the chord. In this region honeycomb sandwich is used to cater for the effects of acoustic loading from the engines and debris damage. The two spars are placed 7 inches and 23 inches aft of the flap leading edge and are 16G pressed channels in L73. There is an auxiliary 18G spar 36 inches back and the trailing edge member is in full depth honeycomb sandwich. The ribs between spars at the hinge positions are integral with the forged hinge links. Elsewhere the ribs are 20G thick and placed at 9 inches pitch.

The vane is constructed with a 4.5 inch diameter, 0.2 inches thick L62 tubular leading edge spar member. The trailing edge is faired with full depth honeycomb sandwich panels. The outer flap construction is similar, the ribs being placed in the flight direction.

The trailing edge shroud is of mixed construction. The actual slot lip of the upper surface and deflector on the lower surface use honeycomb sandwich panels with extruded edge members. Elsewhere the skin is of conventional form in 18G thick L72.

5.2.5 Ailerons

The ailerons on each side of the aircraft are split into two parts of approximately equal area. Each part is operated by a single irreversible electro-hydraulic power control unit. As the power control units are directly connected to the control surfaces it is not considered necessary to provide mass balance. There are two hinges on each section of the aileron, the inner one being used as the datum to react side loads. Ease of access dictated a location for the power control units away from the hinges.

The inner portions of the aileron have a span of 7.7 ft. The rib pitch is 8.5 inches between hinges and 11.0 inches along the overhangs. The main spar is located 1.2 inches behind the hinge line and is a pressed 18G channel is L73. The skins are 20G, hinge ribs 22G, and other ribs 24G thick. The outer portions have a span of 9.75 ft. and a rib pitch of 9.5 inches between hinges. Otherwise they are similar to the inner portions. The two sections are not interconnected except through the control signalling system.

5.3.1 Tailplane

The tailplane structure is a two spar, two cell box apart from the centre portion across the fuselage where the leading edge is discontinued. The design case for strength arises in a 2.5g manoeuvre at speed V_D when the down tail load corresponding to forward centre of gravity is 68,000 lb. factored. The same manoeuvre at speed V_A with an aft centre of gravity results in the maximum factored up load of 53,000 lb. The skin thickness of 14G, however, is determined by the torsional stiffness requirement. This is due to the small chord of the structural box, which is itself a result of the use of a large elevator. The front spar is located at 12.5 per cent and the rear spar at 52.5 per cent of the chord.

The skin is supported by rivetted zed section stringers which are 1.6 inches deep and 16G thick. These are pitched at 4.5 inches across the root and 6.0 inches outboard. The skin-stringer assembly is joined at the root kink rib. Redux bonded skin reinforcing plates with fingers for the bolted attachments are used for this. Outboard of the kink rib the front spar is swept at 27° and the rear spar at 22°. The spars are fabricated from plate webs of 14G and 16G and extruded angle booms. The root kink rib has a 20G plate web reinforced by 0.7 inches deep 18G vertical top hat section stiffeners. The rolled angle section booms are attached directly to the skin reinforcing plate.

Over the centre box the rib pitch is 18 inches, and outboard it varies from 22 inches to 27 inches. Elevator hinge ribs have a 20G web with angle booms which are located below the stringers and cleated to them. The web is stiffened by vertical angles. The 14G leading edge skin is supported by plate ribs placed at an average pitch of 8 inches.

Both the tailplane and fin spars pick up on the same fuselage frames. This is achieved by inclining the fin rear spar bulkhead so that it is in line with the spar, and attaching the tailplane rear spar to it by means of two triangular forgings. This bulkhead is effectively the rear extremity of the fuselage structure and is supported at the lower edge by a roof which runs over the rear loading door.

5.3.2 Elevator

The elevator is divided into two sections on either side of the fuselage and each part is operated by a single power control unit. The layout is generally similar to the ailerons with two hinges on each portion. The 22G skins are supported by ribs placed at 5.0 inches pitch on the inner section and 6.5 inches pitch on the outer section. The ribs are 22G thick and redux bonded to the skins. The main spars are located 2 per cent of the tailplane chord behind the hingeline and are constructed with 22G webs and 16G angle booms.

5.4.1 Fin

The fin is generally similar to the tailplane in construction with the spars located at 10 per cent and 51 per cent of the chord. These positions were determined by the use of common attachment frames for the fin and tailplane. The fin is designed by strength rather than stiffness, the critical loads being those which occur during overswing in yaw following rudder application.

5.4.2 Rudder

The rudder is divided into three portions of approximately equal area, each of which is operated by a single power control unit. The constructional details are similar to those of the elevator.

5.5 Undercarriage

The main undercarriage has a bogie configuration. It is mounted on the side of the fuselage and retracts aft into fuselage blisters. Twin wheels are used on the nose unit which retracts forwards into a well under the forward passenger stairs.

5.5.1 Main Undercarriage

The liquid spring shock absorber has a stroke of 10 inches. The maximum reaction factor is 2.42 and the initial inflation pressure is 2000 p.s.i. A two point landing at the design descent velocity results in the maximum factored vertical load of 212,000 lbs. The drag and side loads are 127,000 lbs. and 86,000 lbs respectively. These arise in a high drag landing and ground turning and swinging respectively.

The leg is an S99 steel forging which is connected to the fuselage at the upper end by trunnions in split cap bearings. The down lock is also on the main leg and consists of a hydraulically operated taper pin which is designed to transmit both drag and side loads. The bogie beam is an S99 forging and is hollow with separate axles for the four wheels. Multidisc brakes are housed in each wheel. The brake torques are reacted by a compensating link system located both above and below the bogie beam.

The fairing structure is a simple extension from the local frames. The uplock is placed in the fairing structure roof and the doors are split into two lengthwise sections. Retraction is by means of a jack connected across the top of the main leg and the fuselage mounting structure.

5.5.2 Nose Undercarriage

The factored nosewheel design loads are 105,000 lb. vertically, 26,000 lb. sideways, and 63,000 lb. in the drag direction. The drag load occurs in a high drag landing, but the others arise in a design three point landing.

The cantilever leg carries the twin wheels on a live axle. The loads are transmitted to the fuselage at the bulkhead at the front end of the freight-hold. A 'Y' shaped yoke at the top of the leg is supported by a forged fitting at the base of the bulkhead and it is braced to the sides of the wheel bay by a folding drag stay.

6. Description of the Installations and Systems of the GP65

6.1 Flight Deck

The crew gain access to the flight deck from the forward end of the upper passenger cabin. The forward passenger stairs also terminate at this point.

A suggested layout for the flight deck is shown in Figure 16. Provision is made for the operation of the aircraft by either two or three crew members. It is considered that in most cases of short range operation only two crew will be employed. The majority of the engine and systems instruments and controls are located on the panel provided for the third crew member. Essential ones are repeated on the main panel, a suggested arrangement for which is shown in Figure 17. The seats for the first and second pilots are mounted on rails which enable them to be moved rearwards and outwards for ease of access. The second pilot's seat is also able to rotate so that he can turn round and operate controls on the auxiliary panel. The seat for the third crew member can be rotated, but it is otherwise fixed.

6.2 Engine Installation

Each engine pod is approximately 14 feet long and 4 feet in diameter. The engines themselves are connected to the mounting structure by two forward trunnions and a rear suspension. The engine mountings are designed by the crash case except for the downwards load which is a maximum in the 3.4g normal gust case.

Engine removal is downwards through the large lower door which is in fact most of the lower pod surface. Local access holes are provided in the door for normal servicing.

All accessories are located on the lower portion of the engine. Pipes are control runs pass along the wing leading edge and down the leading edge of the pylon into the engine bay. The exhaust shrouds are faired to provide a bullet between the adjacent jet pipes with a 20^{o} taper angle. Thrust reversers and silencers may be fitted if they are required.

Auxiliary power is supplied through a low pressure air driven constant speed unit. This may be run on the ground either from an external air supply or from an auxiliary power unit located in the fuselage tail cone. The systems may therefore be operated without running the main powerplants and the constant speed unit can also be used to start the engines.

The twin engine pod installation was chosen for a number of reasons. Pod skin friction drag is reduced by approximately 30 per cent and the pylon to wing interference drag is also reduced. Engine control systems are more compact, and hence lighter, and the fin and rudder size is reduced due to the smaller offset in an engine failure case. Certain disadvantages must be set against these however. There is an interference drag between the two pods, especially in the intake and exhaust regions. The torsional relieving moment experienced by the wing only occurs well inboard and there is a maintenance accessibility difficulty associated with the need to keep all engines identical. The concept does enable the four small powerplants to be readily replaced by two large ones.

6.3 Power Supplies

Electrical power is supplied by four 22.5 KVA 400 cycles alternators, one on each engine. They are used in pairs in a duplicated system. Apart from providing power for the general services, the electrical system also supplies the flying control power units.

A duplicated 4000 p.s.i. system is used for the supply of hydraulic power. The two systems are used together when demand is a maximum and each one is supplied by two of the four pumps. The system provides power for operation of the brakes and the flap, ramp door and undercarriage jacks. The flap jacks are synchronised by flow control with an electrical signalling back up. The main ramp door jacks are provided with a manual lock for the intermediate, horizontal, door position to cater for the case of loss of pressure.

6.4 Flying Control System

All the flying controls are power operated by electro-hydraulic units located adjacent to the surfaces. There is no provision for aerodynamic or mass balance. The two sides of the ram actuators are connected through a damping valve and there is a mechanical lock in the neutral position. The flying control surfaces are all split, the elevators and ailerons into four sections and the rudder into three. Each section carries an approximately equal share of the control effort and is operated by a single actuator. In the event of a failure of a unit the surface returns to neutral by virtue of aerodynamic forces, pressures on either side of the ram being equalised through the damping valve. The mechanical lock then operates.

The maximum rates of application of the controls are 25 deg/sec. for the elevator, 30 deg/sec. for the ailerons and 18 deg/sec. for the rudder. Artificial feel is provided by a single electrically driven three axis unit. Mechanical signalling is employed and breakout struts are incorporated on the valves to restrict circuit loads. Cables with automatic tensioners are used for the long control runs in the fuselage and wing. Push-pull rods provide the connection between the control column and rudder pedals and the feel unit. They are also used at the aft end of the fuselage and in the fin and rudder. The fuselage cable runs are under the floor and over the wing box whilst those in the wing are behind the rear spar.

6.5 Fuel System

The fuel system is designed to carry a total of 49,900 lbs., which is equivalent to 6250 gallons of AVTUR or AVTAG. The aircraft centre of gravity is controlled by tank sequencing, although in practice this only requires a correct order of selection in most operational cases. Provision is made for 7 seconds of flight in negative 'g' conditions.

There are nine integral tanks, four in each of the wings and one in the centre section. The centre section tank is only used for extreme long range operation. The tank capacities have been chosen so that no part filling of tanks is necessary for any of the basic roles of the aircraft. Tank walls coincide with spars and major ribs.

The feed system uses A.C. electrically operated booster pumps which have a standard capacity of 1200 gallons per hour. These are fitted in isolating chambers and duplicated in critical tanks. The location of the tanks relative to the engines is such that gravity feed alone enables full flow to the engines to be achieved up to an altitude in excess of 7500 feet.

Vent galleries connect each of the tanks to a wing tip surge tank which can be drained through transfer pumps. Jettison pipes are provided which exhaust at the wing trailing edge between the flaps and ailerons. Refuelling at a maximum rate of 350 gallons per minute at two couplings enables the tanks to be filled from normal reserves level in 16.5 minutes. The complete system is shown diagrammatically in Figure 18. As far as is possible all the feed pipes are run in the tanks and explosion suppression capsules are installed. Fuel content is measured by capacitance gauges supplemented by flowmeters.

Access is gained to the tanks through 18 inches by 12 inches elliptical holes in the wing lower surface. Only one hole is necessary in the two pairs of inner tanks, but the outer pairs of tanks require two and six respectively. This is due to the small depth of the outboard wing.

6.6 De-icing System

Wing leading edge de-icing uses hot air tapped from the 7th and 12th engine compressor stages. The ducts pass up the pylon leading edge into the wing. Electric de-icing is provided on the engine air intakes and tail surfaces.

6.7 Air Conditioning and Pressurisation System

Engine bleed air is also used for the pressurisation system. Tapping is made at the same compressor stages as the de-icing air but separate ducting is used.

7. Special Investigations Associated with Design Studies

Certain of the students carried out special investigations associated with the project aircraft in addition to being responsible for the detail design of one of the major components.

7.1 Aileron-Tab Flutter of GP63

The wing-aileron-spring tab flutter characteristics of the GP63 were investigated by Williams[1]. Particular emphasis was placed on the influence of the aileron and tab mass balance. Cases considered were as follows:-

1) Fully mass balanced as designed.
2) Mass balances reduced to 75 per cent of design values.
3) Zero mass balance.

The problem was treated both as a simple aileron-tab binary and also coupled with the wing fundamental torsion-second bending overtone and first overtone torsion-fourth overtone bending. These wing modes were chosen as being those having frequencies close to the aileron-tab frequency.

The study showed that no flutter occurred in the flight speed range of the aircraft. Flutter was predicted to occur at 445 knots with zero mass balance.

7.2 Fuselage cross section configuration

As has been previously noted the fuselage cross sectional configurations of the two project aircraft differed. The GP63 design was based on a true double-bubble geometry whilst the GP65 has nominally flat sides. The two concepts have been compared by Holmes[2]. The investigation includes subsidiary design variations on both schemes. All comparisons were based on the use of the GP65 loading and dimensions.

The more significant results found are:-

1) In a double-bubble arrangement the standard frames weigh 8.3 lbs. less than in the flat sided case. Of this saving some 5 lbs. is in the upper bubble and 1.3 lbs. is due to the shorter cross tie.

2) The wing-fuselage intersection is more complex with the double-bubble arrangement. The spar frames are slightly heavier, 4 lb. each, and additional weight is incurred in the rib and longeron design. The extent of this is dependent upon the detail arrangement.

3) The weight of the skin side panels is lightest with the double-bubble geometry. Some 5 lbs. per frame pitch can be saved relative to the flat sided configuration, although 2 lbs. of this are recoverable by introducing short frames intermediate between the normal ones. Honeycomb sandwich was found to offer no significant advantage.

The aggregate of these effects over the 65 ft. length of the freighthold reveals that the double-bubble geometry fuselage is 265 lbs. lighter. Table 3 gives the breakdown of this figure. Some further small weight gain could possibly be made by using a flat side locally over the wing intersection, the fuselage geometry change being masked in the wing fillet Production problems would also be less in this case.

7.3 Optimisation of the root spar positions of the GP65

The root planform geometry of the wing of the GP65 was chosen so that the inner flaps are unswept. The chord length at the fuselage side is sufficiently great to enable a variety of spar configurations to be chosen. Ewins[3] has compared a number of these alternatives on a weight basis.

The initial design concept for the inner wing structure employed a single cell, two spar box in conjunction with an auxiliary spar. This arrangement was chosen to minimise the loss of upper cabin length caused by passing the main wing box across the fuselage, and at the same time to provide a spanwise support for the flaps. As the design developed the main box was increased in width and the need for the auxiliary spar became less apparent. It also became feasible to restrict the fuel tankage to forward of the rear spar proper.

The variation of weight with change in position of the rear of the two box spars was investigated initially. The weight considered included all the main structure bounded by the front and auxiliary spars and the engine kink ribs. The position of the aft spar of the box was varied from 43 per cent to 78 per cent of the chord at the fuselage side. The structure weight was estimated to vary correspondingly from 6665 lbs to 6030 lbs with a minimum of 5900 lbs when the spar location is at 66 per cent. The compromised position proposed for the actual design is 55 per cent. Elimination of the auxiliary spar results in a saving of weight of some 80 lbs for the optimum spar position and somewhat more for aft locations.

The second phase of the investigation considered the case of a three spar, two cell box where the central spar position was varied. The front and rear spar locations were fixed at 15 per cent and 60 per cent of the fuselage side chord for reasons of overall geometry. It was found that the weight was insensitive to change of centre spar position in the range 30 per cent to 50 per cent, and that the total structural weight was approximately equal to that of the three spar single cell box configuration actually used. The centre spar position would be chosen by consideration of fuel tankage, fuselage attachment frames or local pickups. Whilst the use of a two spar box saves 80 to 100 lbs. in weight, the two cell construction is preferable from the fail safe aspect.

8. Unusual Features of the Designs

8.1 The undercarriage of the GP63

The undercarriage of the GP63 is unusual for an aircraft of 110,000 lb. design weight in that it retracts sideways and outwards, the axle assembly being rotated through 90° at the same time. The length of the main leg necessitated by the relatively high wing precludes a simple fore and aft retraction geometry, and the arrangement adopted was chosen as an alternative to fuselage side mounting.

The advantages of the arrangement are the lighter fuselage structure and a reduction in drag due to the elimination of fuselage fairing blisters. However the undercarriage itself is much heavier than a fuselage mounted one would be, as can be seen by the comparison between the GP63 and GP65 weights in Table I, and there is a substantial wing structure weight penalty due to the heavy concentrated loads and the cut out in the lower skin. On balance there is little doubt that the fuselage mounting arranged for the undercarriage is preferable for an aircraft of the size and configuration of the GP63.

8.2 Twin podded engine installation of the GP65

The advantages and disadvantages of the twin podded arrangement relative to the conventional single pod configuration are discussed in paragraph 6.2. It is questionable as to whether the twin pod arrangement confers any real overall advantage in view of the difficulties experienced in the design of the installation. It would seem that in most designs it is preferable to retain individual engine mounting. In certain special design circumstances it might be that the advantages of the twin pod are sufficiently important for it to be adopted.

The detail drawings were used to estimate the weight of the pylon and pod structure. The weight of each pylon below the wing and above the pod spine is 190 lb., and the weight of each pod structure is 540 lb., exclusive of doors and fairings.

9. Economic Assessment of the GP63 and GP65

An initial economic assessment of the two design studies has been carried out by Pickford[4]. It has been estimated that the equipped first costs of the aircraft for delivery in 1969 would be £714,000 for the GP63 and £1,488,000 for the GP65. The low cost of the first study is a reflection of the simple, unsophisticated design, combined with the use of relatively low cost powerplants.

On the basis of operation over stage lengths of 250 n. miles the GP63 was predicted to have a direct operating cost some 20 per cent less than that of the GP65. This advantage is largely a direct result of the lower first cost and the implied lower spares, insurance, interest and amortisation costs.

Using the BEA method of cost evaluation[5] the GP63 has an estimated cost of 215 pence per aircraft mile, and the corresponding figure for the GP65 is 263 pence. The costs per seat mile are naturally dependent upon the number of passengers carried. The assumption that all the seats are occupied results in costs of 1.15 pence and 1.44 pence per seat mile for the GP63 and GP65 respectively. However these figures should not be compared with the corresponding ones for other types of aircraft flying on 250 n. mile stage lengths since the full passenger load can only be carried with an absolute minimum of furnishings and equipment. The freight costs of 10.75 pence and 13.15 pence per capacity short ton mile are probably more representative.

10. Conclusions

As a result of the design studies of the GP63 and GP65 general purposes transport aircraft and the special investigations associated with them it is possible to come to certain conclusions.

1) The two deck pressurised fuselage arrangement with flat sides used for the GP65 implies a substantial and unacceptable weight penalty. The best compromise solution appears to be the use of curved sides with a local flattening in the region of the wing intersection.

2) A two spar single cell box was found to give the lightest wing structure in the root region of the GP65. The penalty associated with the addition of a third spar is some 0.6 per cent of the wing weight, and it is insensitive to the chordwise location of this centre spar.

3) The long, sideways retracting undercarriage configuration used for the GP63 gives rise to unacceptable weight penalties. For an aircraft of this size and configuration the fuselage side mounted arrangement is preferable.

4) No special advantages were found for the use of the twin podded engine installation incorporated in the GP65. In the majority of designs the conventional single pod layout would seem to be preferable.

5) When the aircraft are operated over 250 n. mile stages the direct operating costs of the GP63 propeller turbine design are some 20 per cent less than those of the pure jet GP65. This is mainly due to the much lower first cost of the simpler aircraft.

References

1. Williams, D.A. — An investigation of the aileron-tab flutter of the GP63 design project. College of Aeronautics Thesis June 1964

2. Homes, K. — An investigation of alternative fuselage construction methods for the GP65 aircraft. College of Aeronautics Thesis June and October 1966

3. Ewins, P.D. — Spar optimisation in the stub wing of the GP65 aircraft. College of Aeronautics Thesis June and October 1966

4. Pickford, G.A. — Economic comparison of the 1963 and 1965 design projects. College of Aeronautics Technical Essay June 1966

5. B.E.A. 'A' Costs Estimation Method, Issue No. 9 British European Airways, October 1965

TABLE 1

Weight Breakdown of the Designs

Component	GP63		GP65	
	Weight lb.	%	Weight lb.	%
Wings	9850	8.95	14050	11.0
Fuselage	11100	10.1	13800	10.9
Tailplane	1530	1.39	1810	1.4
Fin	560	0.51	710	0.6
Main Undercarriage	4260	3.87	4380	3.4
Nose Undercarriage	530	0.48	620	0.5
Nacelles	1600	1.45	-	-
Engine Pylons	-	-	600	0.5
Total Structure	29430	26.7	35970	28.3
Engines	6300	5.82	8132	6.4
Cowlings, mountings, etc.	800	0.73	1418	1.1
Jet pipes and nozzles	160	0.15	1680	1.3
Propellers	2600	2.36	-	-
Total Power Plant	9860	8.97	11230	8.8
Fuel system	1800	1.63	2000	1.6
Flying Controls	800	0.73	1330	1.0
Power supplies (electrics and hydraulics)	3000	2.73	3300	2.6
Auxiliary power unit	-	-	450	0.4
De-icing	800	0.73	900	0.7
Air conditioning and pressurisation	800	0.73	1150	0.9
Fire protection	500	0.45	80	0.1
Total Systems	7700	7.01	9210	7.3
Instruments and automatic control	400	0.36	440	0.35
Radio and Radar	1000	0.91	1000	0.8
Furnishings, etc.	-	-	440	0.35
Total Equipment	1400	1.27	1880	1.5
Crew	560	0.51	560	0.4
Removable and consumable items	240	0.22	250	0.2
Basic Operating Empty Weight	49190	44.7	59100	46.5

TABLE 2

Typical Operating Weight Configurations of the Designs

	Weight Configuration	Normal A.U.W. Max. Freight Load lb.	Normal A.U.W. passengers lb.	Normal A.U.W. Freight, max. fuel lb.	Low weight case, Freight lb.	Overload weight case Freight lb.
GP63	Basic operating weight	49190	49190	49190	49190	49190
	Furnishings and seats	1000	4760	1000	1000	1000
	Payload	40000	36240	18000	25000	40000
	Fuel	19810	19810	41810	16810	41810
	Take off weight	110000	110000	110000	92000	132000
GP65	Basic operating weight	59100	59100	59100	59100	59100
	Furnishings and seats	1000	4760	1000	1000	1000
	Payload	40000	36240	17000	25000	40000
	Fuel	26900	26900	49900	19900	49900
	Take off weight	127000	127000	127000	105000	150000

TABLE 3

Comparison of Weights of Flat and Curved Sided Fuselages

(Based on 65 ft. Typical length of GP65 fuselage)

Component	No. off	Weight for each unit of :-		Total weight difference - lb.
		Curved Side	Flat Side	
Side panels (inc. frames)	40	62.3	70.6	-332
Longerons	2 sets	31.5	22.5	+ 18
Heavy frames	4	95.5	92	+ 14
Pressure rib	2	20	0	+ 40
Kink rib	2	59	61.5	- 5
			Total	-265 lb.

Appendix A

Allocation of components for GP63 study

Bedford, R.	Front fuselage structure and doors.
Beenham, D.A.J.	Nose undercarriage.
Goodman, G.N.	Fin and rudder structure.
Horsfall, J.P.	Wing flap structure and hinges.
Hughes, P.T.	Elevator structure and operation.
Lord, B.	Main undercarriage.
Minchin, R.W.H.	Centre fuselage structure.
Oldale, P.H.	Rear fuselage structure.
Or-Hof, I.	Tailplane structure.
Parry-Jones, G.	Centre wing structure.
Singh, G.	Aileron structure and operation.
Williams, D.A.	Outer wing structure and engine mounting.

Allocation of components for GP65 study

Baston, D.W.	Rear fuselage structure and doors.
Batstone, K.J.E.	Landing gear.
Bower, B.E.	Control and hydraulic systems.
Ewins, P.D.	Wing structure.
Hamilton, T.A.P.	Engine installation and mounting pylon.
Hey, J.M.	Front fuselage structure and cockpit arrangement.
Holmes, K.	Centre fuselage structure.
Sachdeva, J.N.	Fuel system.
Watterson, T.P.H.	Empennage structure.
Zaghloul, M.W.	Wing flap mechanism and flap and aileron structure.

Appendix B

SPECIFICATION OF AIRCRAFT

1.0 Geometry

1.1 Wing

	GP63	GP65	
Gross Area	1480	1600	sq. ft.
Span	115	113	ft.
Aspect Ratio	8.94	8.0	
Leading edge sweepback	-	28^{o}	
Sweep of 0.69 chord line	0^{o}	-	
Trailing edge sweepback inboard of 0.354 semispan	-	0^{o}	
outboard of 0.354 semispan	-	20^{o}	approx.
Root Chord (centreline)	14.0	24.3	ft.
Chord at 0.354 semispan	-	14.35	ft.
Chord at 0.548 semispan	14.0	-	ft.
Tip Chord	9.0	8.5	ft.
Standard Mean Chord	12.87	14.16	ft.
Aerofoil Sections, Root	NACA 65_3-118	NACA 66_1-213	
Tip	NACA 65-112	NACA 66-210	
Wing-body angle (centreline chord to body datum)	$+3^{o}$	$+1.5^{o}$	
Dihedral, lg flight at design weight	0^{o}	0^{o}	
Location of 0.25 S.M.C. aft of fuselage nose	46.2	55.4	ft.
Location of 0.69 chord aft of 0.25 S.M.C.	6.4	-	
Location of root trailing edge aft of 0.25 S.M.C.	-	8.6	ft.

1.2 Trailing Edge Flaps

	GP63	GP65
Type: Double slotted	Fixed slot	Variable slot
Overall flap chord/wing chord	0.31	0.3
Subsidiary flap chord/overall flap chord	0.8	0.8
Take off flap setting	35^{o}	$15^{o} + 15^{o}$
Landing flap setting	65^{o}	$30^{o} + 30^{o}$
Inboard end of flap from aircraft centreline	6.0	6.0 ft.
Outboard end of flap from aircraft centreline	42.0	41.0 ft.

1.3 Ailerons

Type: Round nose	Sealed, geared and spring tab	-
Aileron chord aft of hinge/wing cord	0.3	0.3
Balance chord/aileron chord aft of hinge	0	0
Tab chord/aileron chord aft of hinge	0.2	-
Movement of aileron	$\pm 16^{o}$	$\pm 20^{o}$
Inboard end of aileron from aircraft centreline	42.3	42.0 ft.
Outboard end of aileron from aircraft centreline	57.5	56.5 ft.

1.4 Tailplane

Gross area	435	400 sq.ft.
Span	47	40 ft.
Aspect ratio	5.08	4.0
Leading edge sweepback	-	28^{o}
Sweep of 0.6 chord line	0^{o}	-
Root chord (Centreline)	11.5	12.5 ft.
Tip chord	7.0	7.5 ft.

1.4 Tailplane continued	GP63	GP65
Aerofoil section	NACA 64-012	NACA 66-012
Tail setting angle (centreline chord to body datum)	0^{o}	0^{o}
Vertical location of tailplane above fuselage datum	5.0	4.5 ft.
Tail volume coefficient	1.2	0.89
Dihedral	0^{o}	0^{o}
Distance of centreline chord leading edge aft of fuselage nose	-	97.5 ft.
Distance of centreline 0.6 chord aft of fuselage nose	101.0	- ft.
1.5 Elevators		
Type	Nose balance and spring tab	Round nose
Elevator chord aft of hinge/tailplane chord	0.4	0.4
Balance chord/elevator chord aft of hinge	0.17	0
Tab chord/elevator chord aft of hinge	0.18	-
Movement of elevator:- Up	25^{o}	22^{o}
Down	12^{o}	15^{o}
Inboard end of elevator from aircraft centreline at hinge	4.0	4.2 ft.
1.6 Fin		
Nominal area above rudder root chord	186	220 sq. ft.
Height above rudder root chord	16.0	18.0 ft.
Aspect ratio (based on above dimensions)	1.37	1.47
Chord at rudder root	12.5	16.5 ft.
Tip chord	7.0	8.0 ft.
Height of rudder root chord above fuselage datum	8.0	8.0 ft.
Leading edge sweepback	-	36^{o}

1.6 Fin	GP63	GP65	
Sweepback of 0.6 chord line	0^{o}	-	
Aerofoil section	NACA 64-012	NACA 66-010	
Distance of leading edge at rudder root aft of fuselage nose	-	99.3	ft.
Distance of 0.6 chord line aft of fuselage nose	104.6	-	ft.
1.7 Rudder			
Type:	Nose balance and tab	Round nose	
Rudder chord aft of hinge/fin chord	0.4	0.4	
Balance chord/rudder chord aft of hinge	0.3	0	
Tab chord/rudder chord aft of hinge	0.22	-	
Movement of rudder	$\pm 20^{o}$	$\pm 20^{o}$	
1.8 Fuselage			
Overall length	100	116	ft.
Maximum depth	17.4	17.4	ft.
Diameter of upper cabin section (external)	5.55	5.55	ft.
Diameter of lower cabin section (external)	5.25	5.55	ft.
1.9 Undercarriage			
Type:	Nosewheel	Nosewheel	
Wheelbase	37.55	42.5	ft.
Track to centre of main leg	40.6	13.0	ft.
Design vertical velocity (proof)	10	10	ft/sec
Main Undercarriage Units			
Type:	Single axle	Bogie	

Main Undercarriage Units continued	GP63	GP65	
Number of tyres per unit	4	4	
Tyre size	30 x 9	34 x 9	
Tyre pressure	150	150	p.s.i.
Inner tyres local track	1.40	1.50	ft.
Outer tyres local track	3.10	-	ft.
Bogie wheelbase	-	3.60	ft.
Maximum tyre closure	0.46	0.53	ft.
Location of axle (centre of bogie) aft of fuselage nose	50.75	59.0	f'

Nosewheel Unit

Type:	Single axle	Single axle	
Number of tyres	2	2	
Tyre size	30 x 9	34 x 9	ins
Tyre pressure	90	100	p.s.i.
Track	1.70	1.65	ft.

2.0 Powerplant

Type:	Dart 542	Spey Junior	
Number of engines	4	4	
Propeller diameter	14	-	ft.
Number of propeller blades	4	-	
Propeller polar moment of intertia	15000	-	lb.ft.
Auxiliary power unit, located below tailplane	Palouste IV	Palouste IV	

2.1 Power Plant Geometry

	GP63	GP65	
Installation type:	Separate Wing Nacelles	Twin Wing pods	
Centreline of inboard engine from aircraft centreline	16.0	18.5	ft.
Centreline of outboard engine from aircraft centreline	31.5	22.5	ft.
Distance of engine (propeller) centreline below body datum	0.5	5.0	ft.
External maximum diameter of nacelle (pod)	3.6	4.0	ft.
Location of front face of engine intake from fuselage nose	38.0	42.2	ft.
Location of forward face of pod from engine intake	-	1.0	ft.
Pod length	-	14.0	ft.
Sweepback of engine support pylon	-	63^{o}	
Pylon cord	-	8.5	ft.
Pylon aerofoil section	-	RAE 103	

3.0 Weights, Centres of Gravity and Moments of Inertia

3.1 Weights

Normal design all up weight	110,000	127,000	lb.
Maximum landing weight	105,000	120,000	lb.
Overload maximum weight	132,000	150,000	lb.
Maximum landing weight	60,000	63,000	lb.
Basic operating empty weight (including crew)	49,190	59,100	lb.
Maximum payload (freight)	40,000	40,000	lb.
Maximum normal fuel load (wing tanks)	41,810	49,900	lb.
Maximum overload fuel (special fuselage tankage)	66,810	74,900	lb.
Weight breakdown	Table 1	Table 1	
Weight allocation for various roles	Table 2	Table 2	

3.2 Centre of Gravity position at basic operating empty weight

	GP63	GP65	
Undercarriage retracted : aft of fuselage nose	47.3	55.3	ft.
below fuselage datum	-	0.6	ft.
Allowable centre of gravity range, aft of fuselage nose	45.5 to 48.7	53.5 to 57.0	ft.

3.3 Typical Moments of Inertia

		GP63	GP65	
Basic operating empty weight:-	Pitch	21	26	lb.ftx10^{-6}
	Roll	23	27	"
	Yaw	43	53	"
Normal design weight, full passenger load:-	Pitch	39	46	"
	Roll	43	50	"
	Yaw	80	94	"
Normal design weight, typical maximum freightload:-	Pitch	39	46	"
	Roll	55	50	"
	Yaw	80	94	"
Normal design weight, full fuel and freight:-	Pitch	30	35	"
	Roll	55	63	"
	Yaw	83	97	"

4.0 Aerodynamic Information (Low speed values)

4.1 Lift characteristics

		GP63	GP65
Maximum aircraft lift coefficient:-	Basic wing	1.32	1.45
	Flaps at take off setting	2.20	2.15
	Flaps at landing setting and ailerons drooped 20°	2.77	-
	Flaps at landing setting	2.57	2.55
	Approach lift coefficient	1.70	1.65

	GP63	GP65
4.1 Lift characteristics continued		
Slope of wing-body lift curve, a_1	5.17	4.6 per rad
Wing no lift angle	-1.5°	-1.5°
Slope of lift curve due to aileron deflection, a_2(2-dimensional)	3.0	2.6 per rad
Slope of tailplane lift curve, a_{1_T}	4.26	3.7 per rad
Slope of lift curve due to elevator deflection, a_{2_T}	2.6	2.6 per rad
Slope of fin lift curve, isolated, a_{1_F}	2.17	2.0 per rad
Slope of fin lift curve with body effect, $a_{1_{BT}}$	-	3.9 per rad
Slope of lift curve due to rudder deflection, a_{2_F}	1.03	1.4 per rad
Downwash at tailplane, ϵ/C_L (fuselage datum level)	4.25°	4.6°
4.2 Drag characteristics		
Zero lift drag coefficients, C_{DO}:- Cruise Mach Number and altitude	0.020	0.019
:- Landing configuration at sea level	0.081	0.120
Induced drag coefficient, KC_L^2 :- Cruise Mach Number and altitude	$0.041C_L^2$	$0.044C_L^2$
:- Landing configuration at sea level	$0.045C_L^2$	$0.052C_L^2$
4.3 Moment characteristics		
Pitching moment coefficient at zero lift, (clean)	-0.069	-0.070
Increment due to flaps at take off setting	-0.40	-0.34
Increment due to flaps at landing setting	-0.60	-0.45
Location of wing-body aerodynamic centre aft of fuselage nose	47.08	54.9 ft.
Location of tailplane aerodynamic centre aft of fuselage nose	97.65	104.65 ft.
Location of fin aerodynamic centre aft of fuselage nose	100.63	108.1 ft.

4.4 Control Hinge Moment characteristics	GP63	GP65
Slope of aileron hinge moment curve due to wing incidence, b_1	-0.36	-0.38 per rad
Slope of aileron hinge moment curve due to aileron deflection, b_2	-0.35^{*}	-0.67 per rad
Slope of aileron hinge moment curve due to aileron tab deflection, b_3	-0.24 (geared) -0.32 (spring)	- "
Slope of elevator hinge moment curve due to tailplane incidence, b_{1_T}	-0.24	-0.39 "
Slope of elevator hinge moment curve due to elevator deflection, b_{2_T}	-0.058^{*}	-0.60 "
Slope of elevator hinge moment curve due to elevator tab deflection, b_{3_T}	-0.3	- "
Slope of rudder hinge moment curve due to fin incidence, b_{1_F}	-0.36	-0.36 "
Slope of rudder hinge moment curve due to rudder deflection, b_{2_F}	-0.023^{*}	-0.57 "
Slope of rudder hinge moment curve due to rudder tab deflection, b_{3_F}	-0.36	- "

4.5 Control and stability derivatives		
Rolling moment coefficient due to aileron deflection, ℓ_ξ	-0.181	-0.14
Rolling moment coefficient due to rolling, ℓ_p	-0.588	-0.47
Rolling moment coefficient due to sideslip, ℓ_v	$-0.008C_L - 0.053$	$-0.15C_L + 0.08$
Rolling moment coefficient due to yawing, ℓ_r	$0.21C_L + 0.034$	$0.21C_L + 0.04$
Side force coefficient due to sideslip, y_v	-0.2	-0.2
Yawing moment coefficient due to sideslip, n_v	0.056	0.15
Yawing moment coefficient due to yawing, n_r	$-0.015C_L^2 - 0.163$	$-0.014C_L^2 + 0.23$
Tailplane rolling moment coefficient due to sideslip, K	0.15	0.15 per rad

* Effective values of b_2 with tab operative.

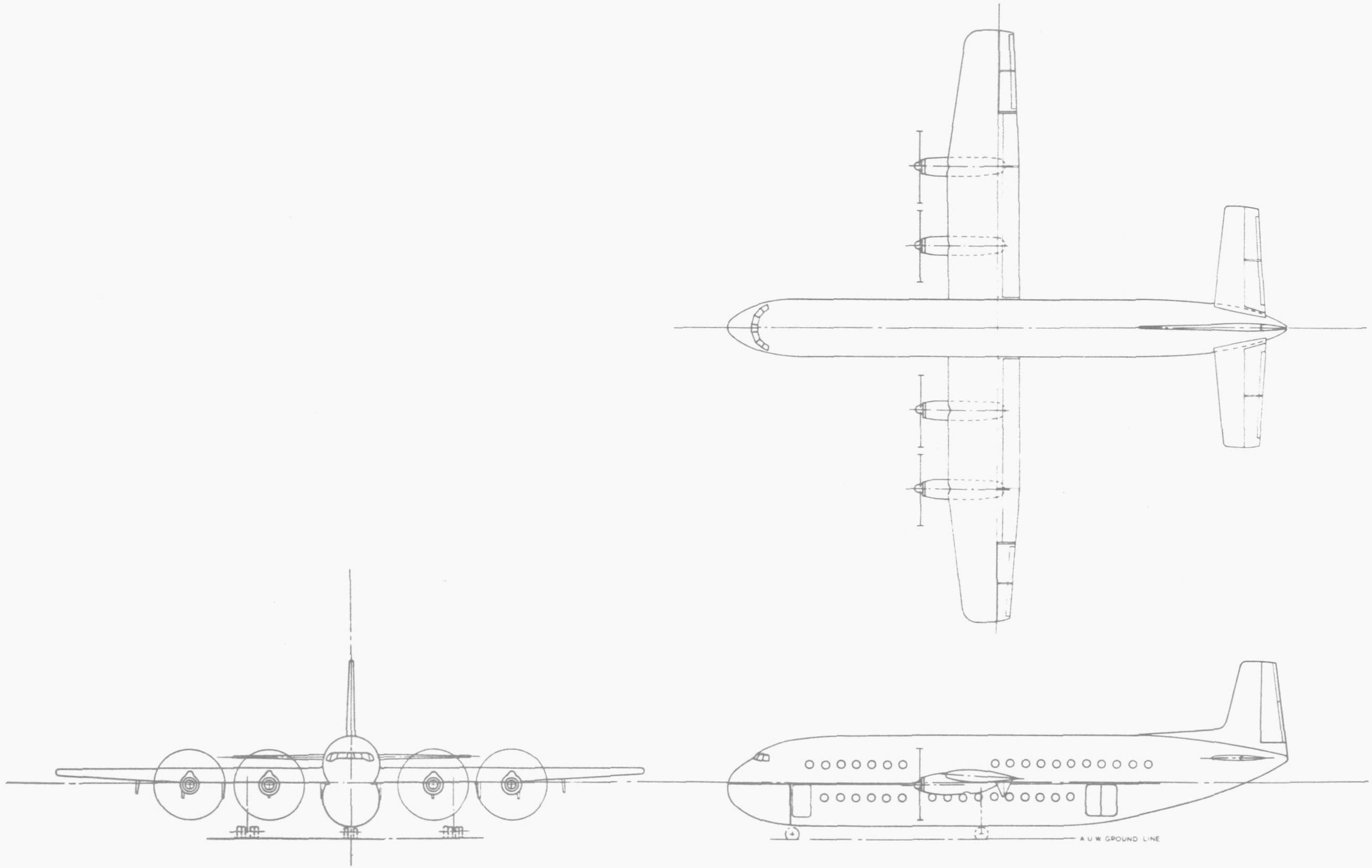


FIG. 1 GENERAL ARRANGEMENT OF THE GP 63

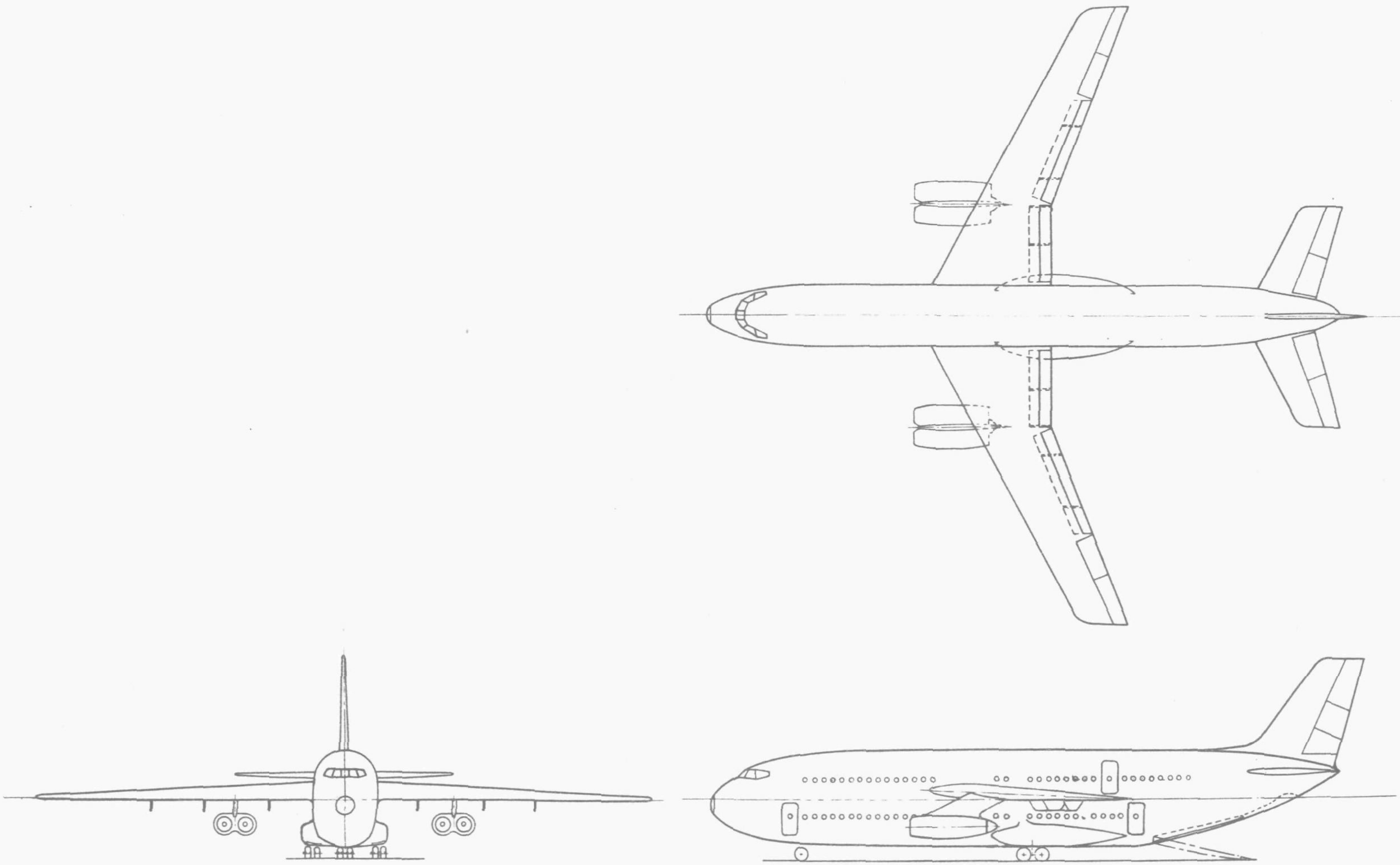


FIG. 2 GENERAL ARRANGEMENT OF THE GP 65

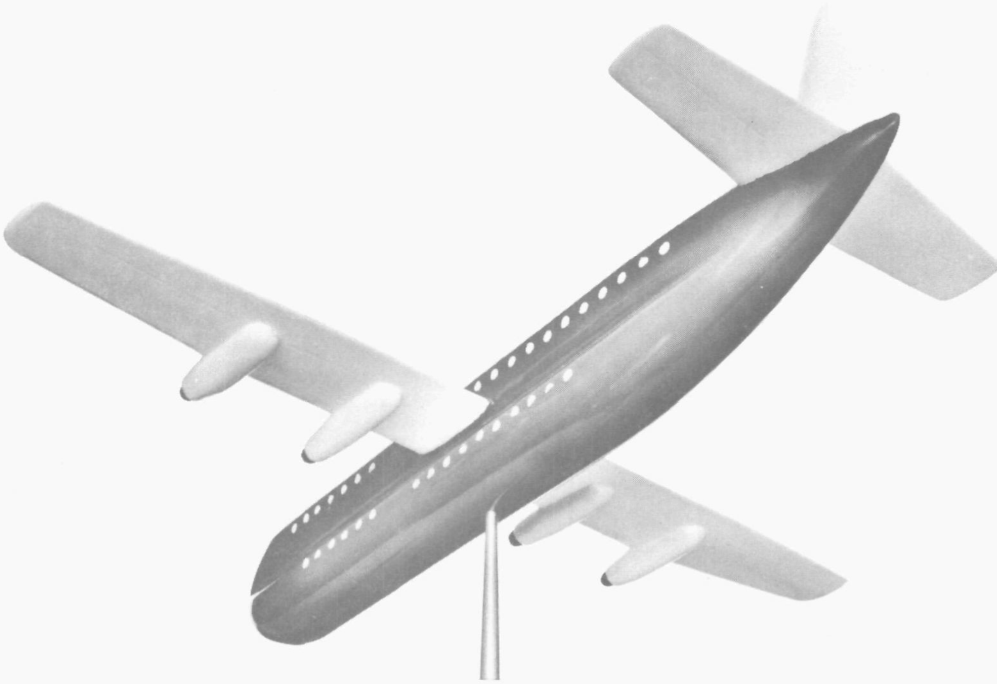


FIG. 3 MODEL OF THE GP63

FIG. 4 MODEL OF THE GP65

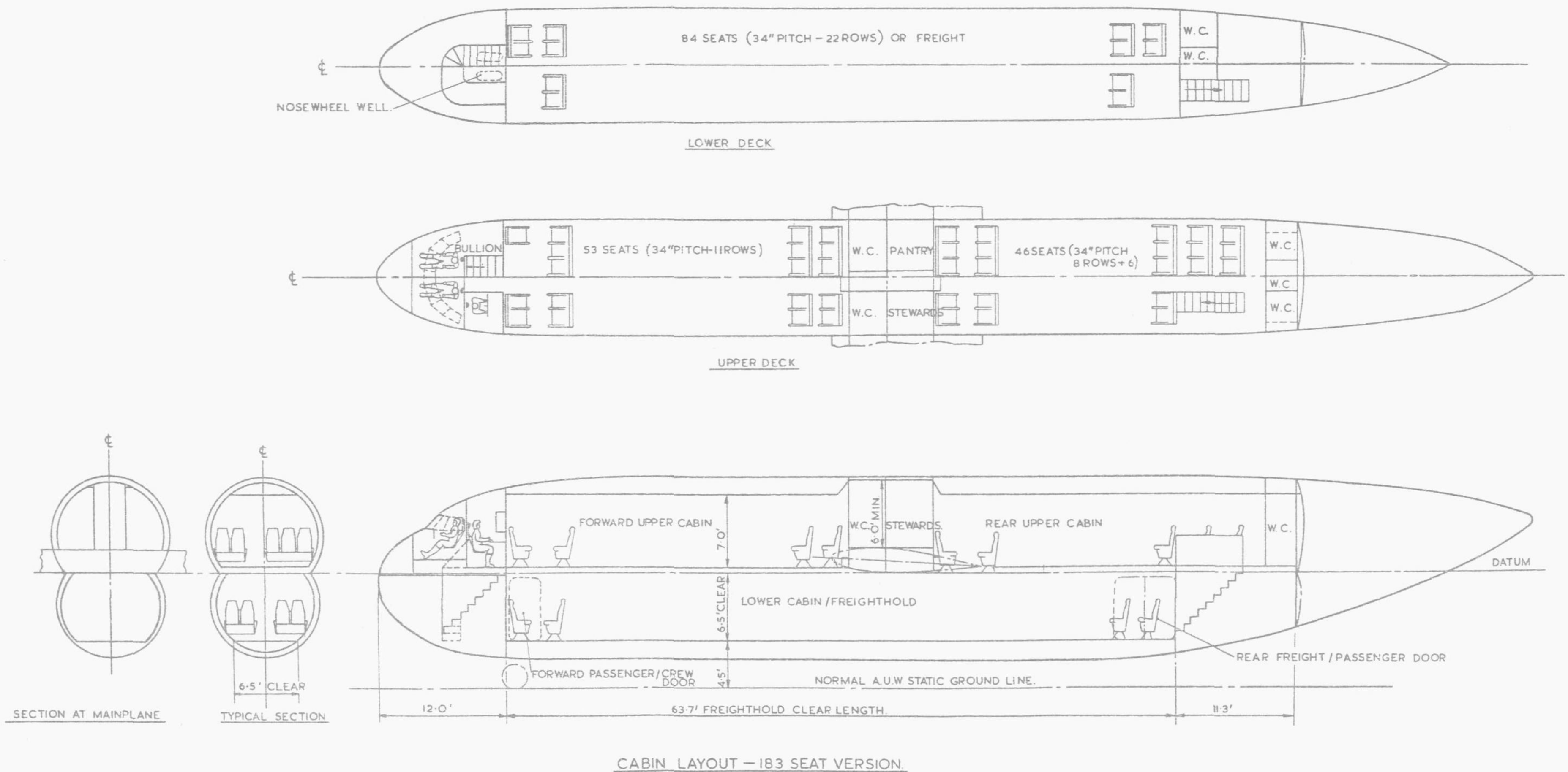


FIG. 5 FUSELAGE LAYOUT OF THE GP 63

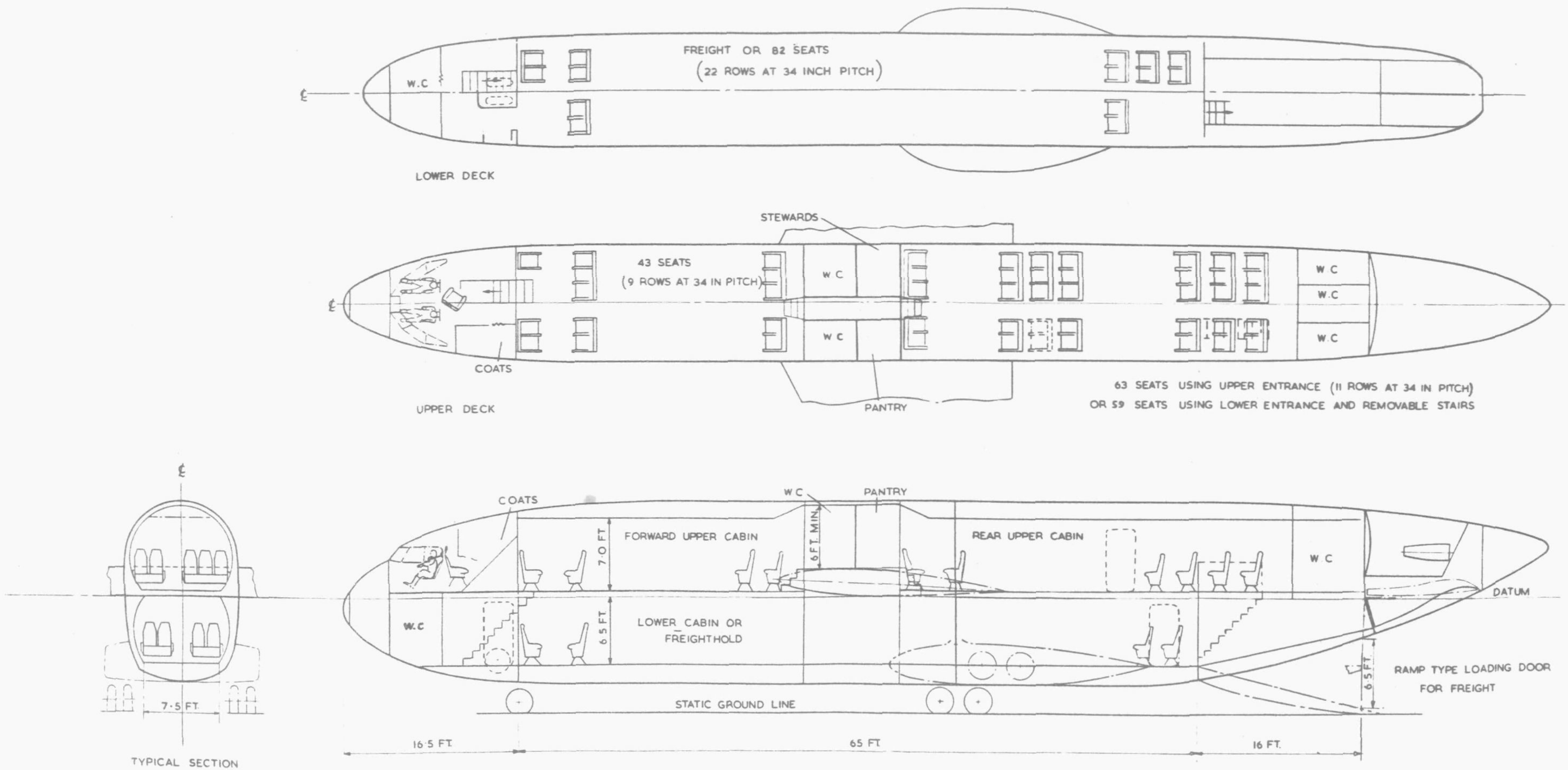


FIG. 6 FUSELAGE LAYOUT OF THE GP 65

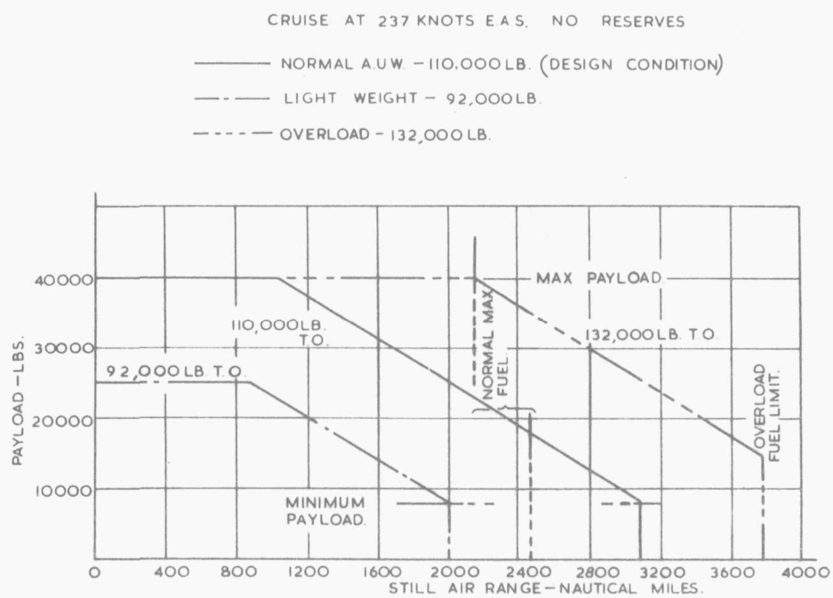


FIG. 7 PAYLOAD – RANGE PERFORMANCE OF THE GP 63

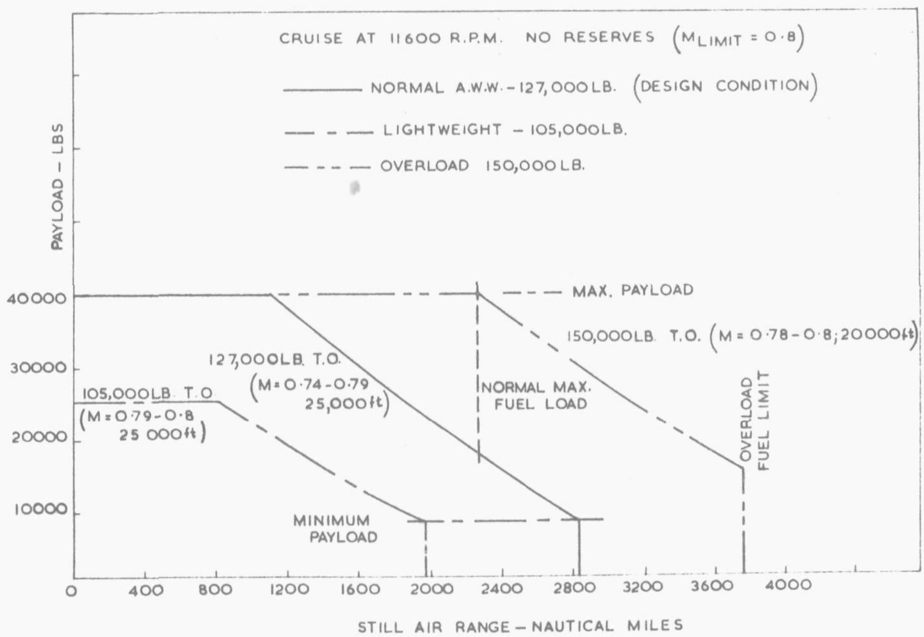


FIG. 8 PAYLOAD – RANGE PERFORMANCE OF THE GP 65

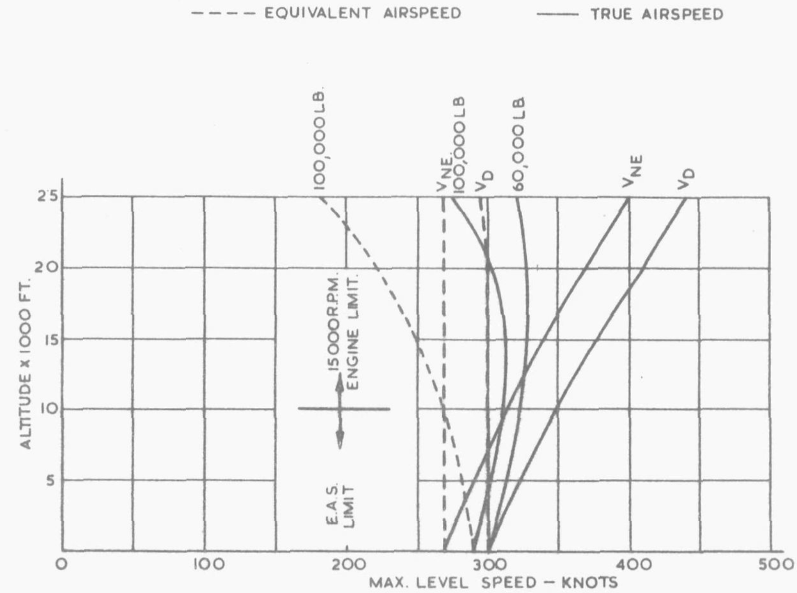


FIG. 9 LEVEL SPEED PERFORMANCE OF THE GP 63

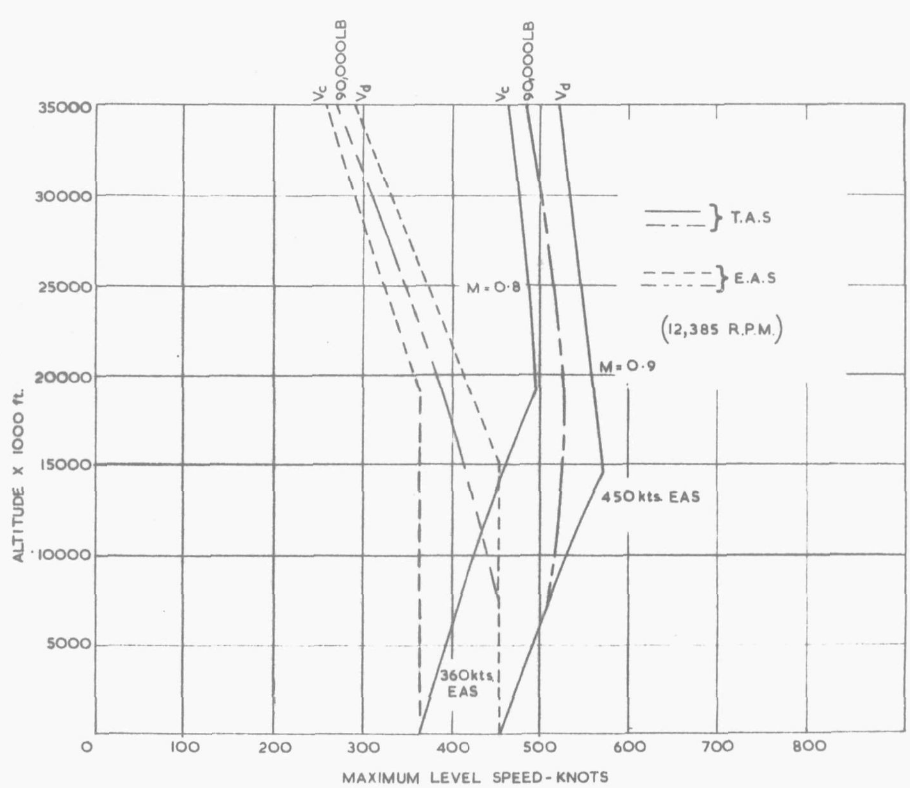


FIG. 10 LEVEL SPEED PERFORMANCE OF THE GP 65

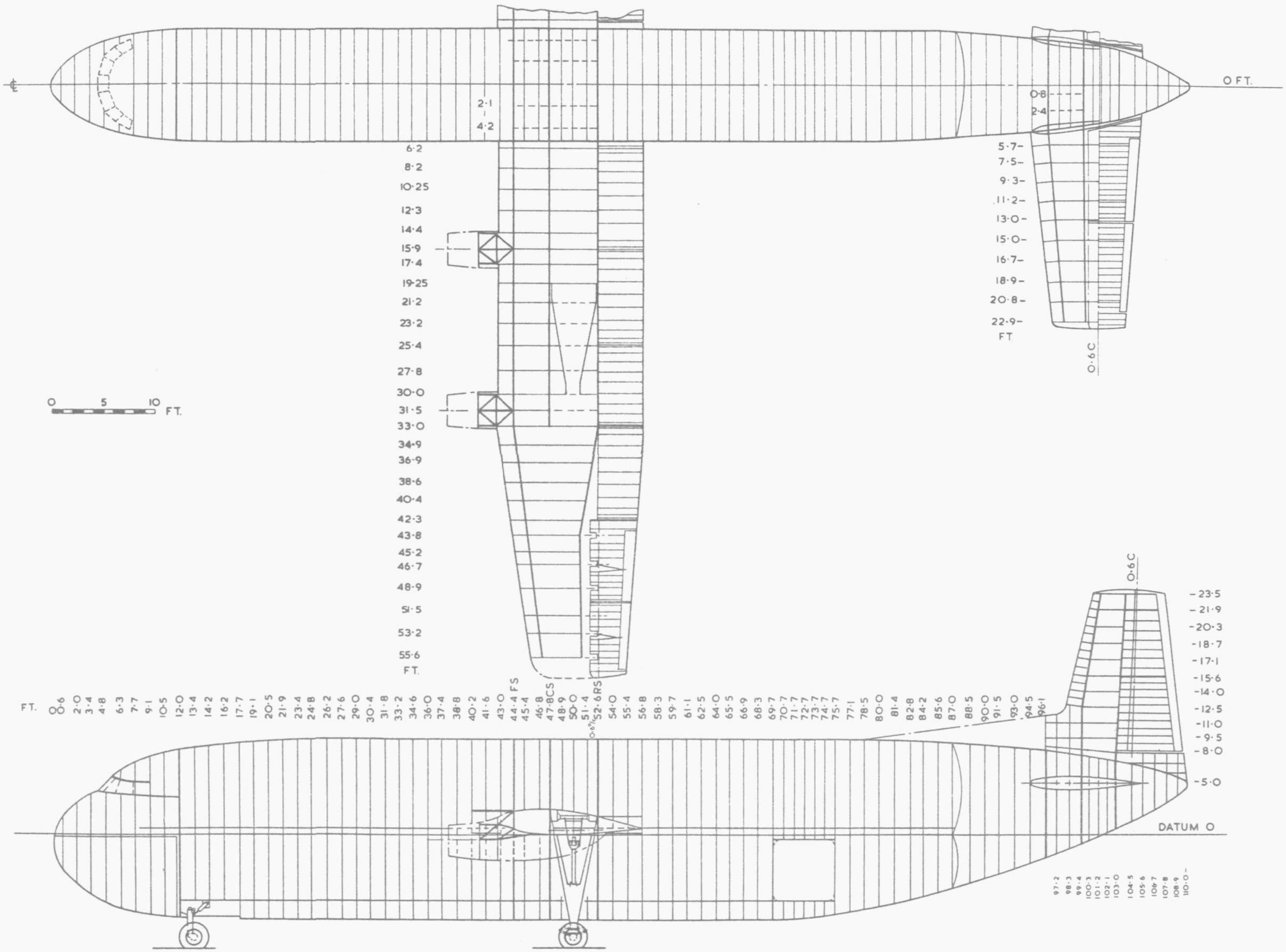


FIG. 11 STRUCTURAL LAYOUT OF THE GP63

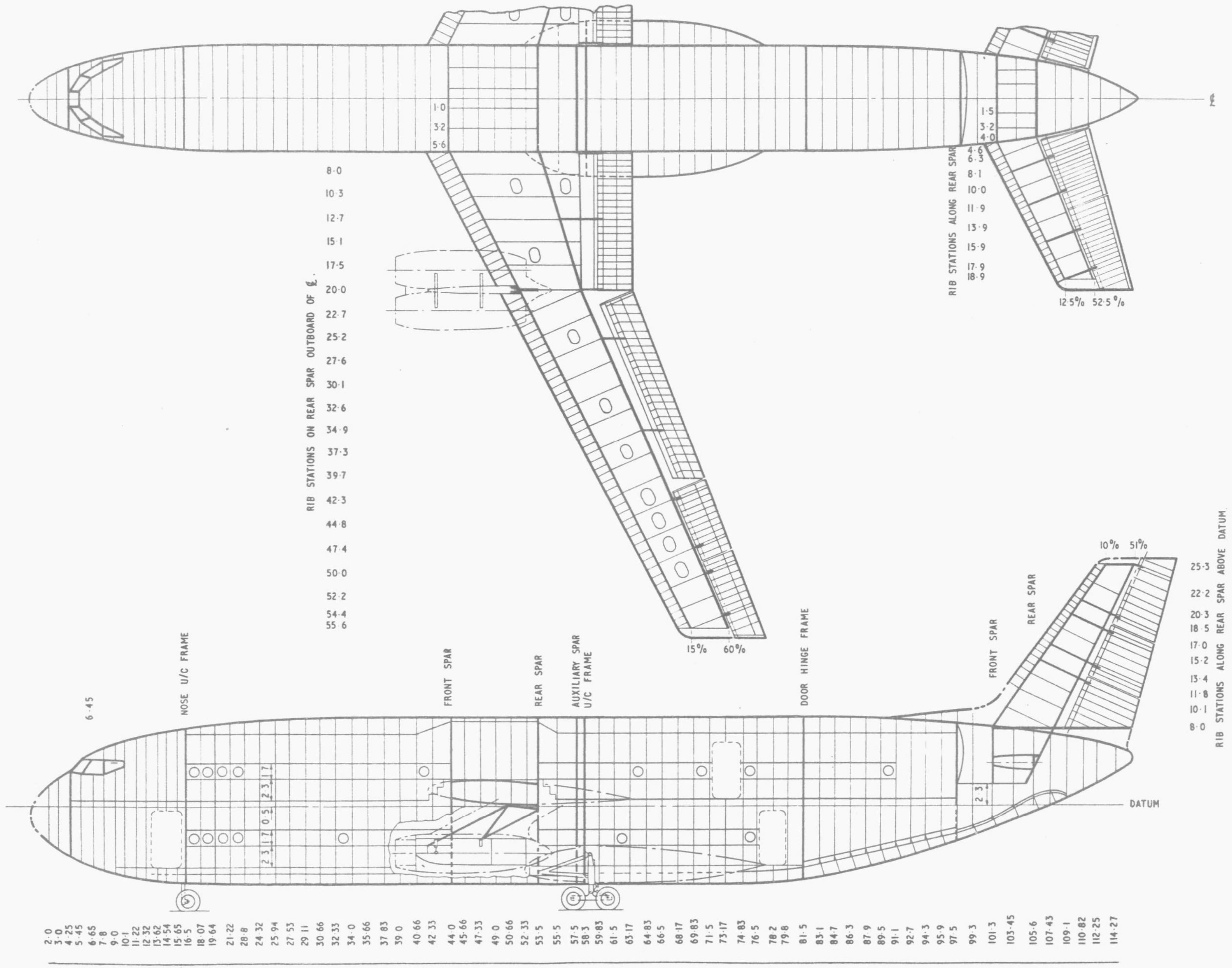


FIG. 12 STRUCTURAL LAYOUT OF THE GP 65

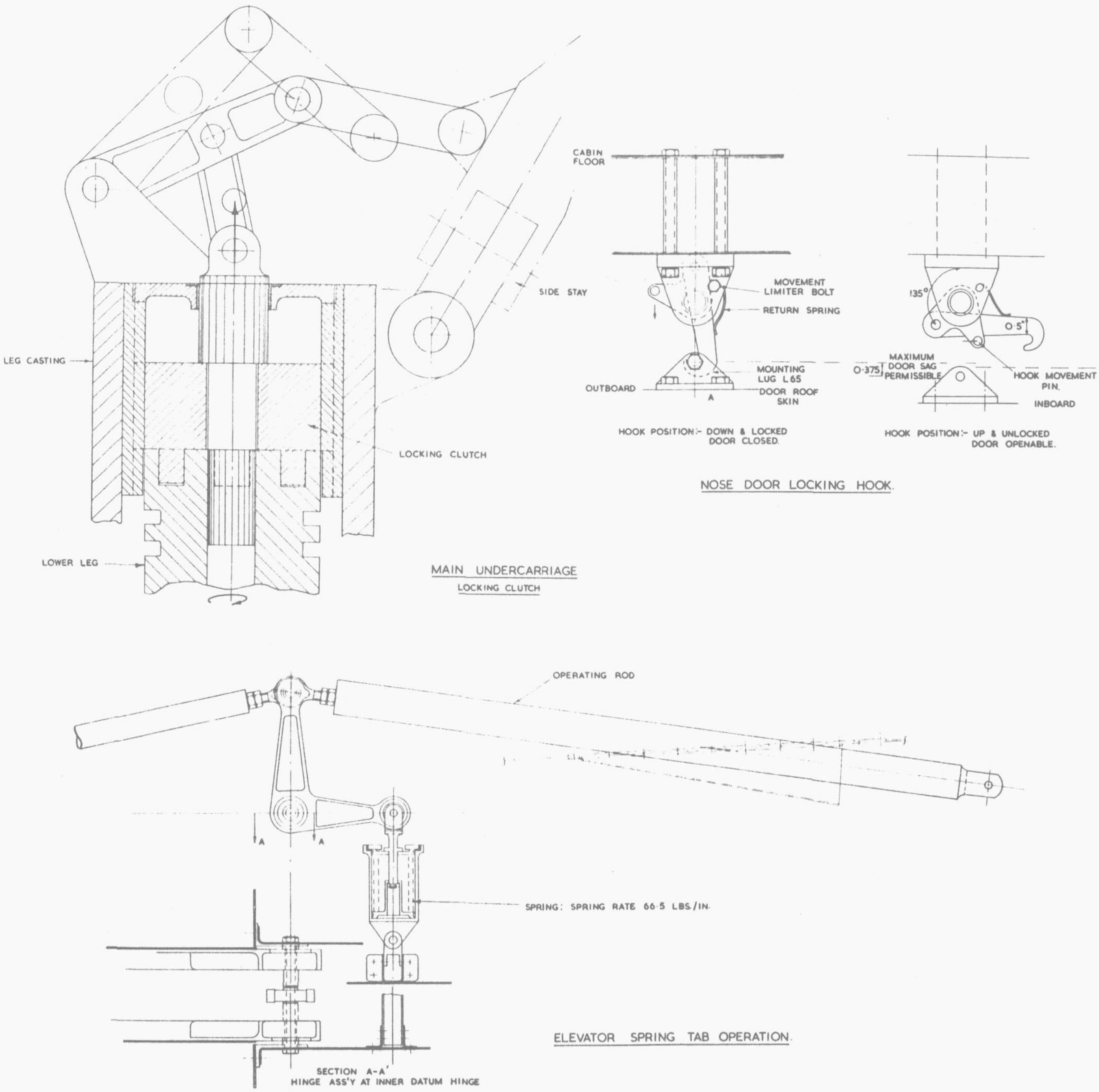


FIG. 13 SPECIAL MECHANICAL FEATURES OF THE GP63

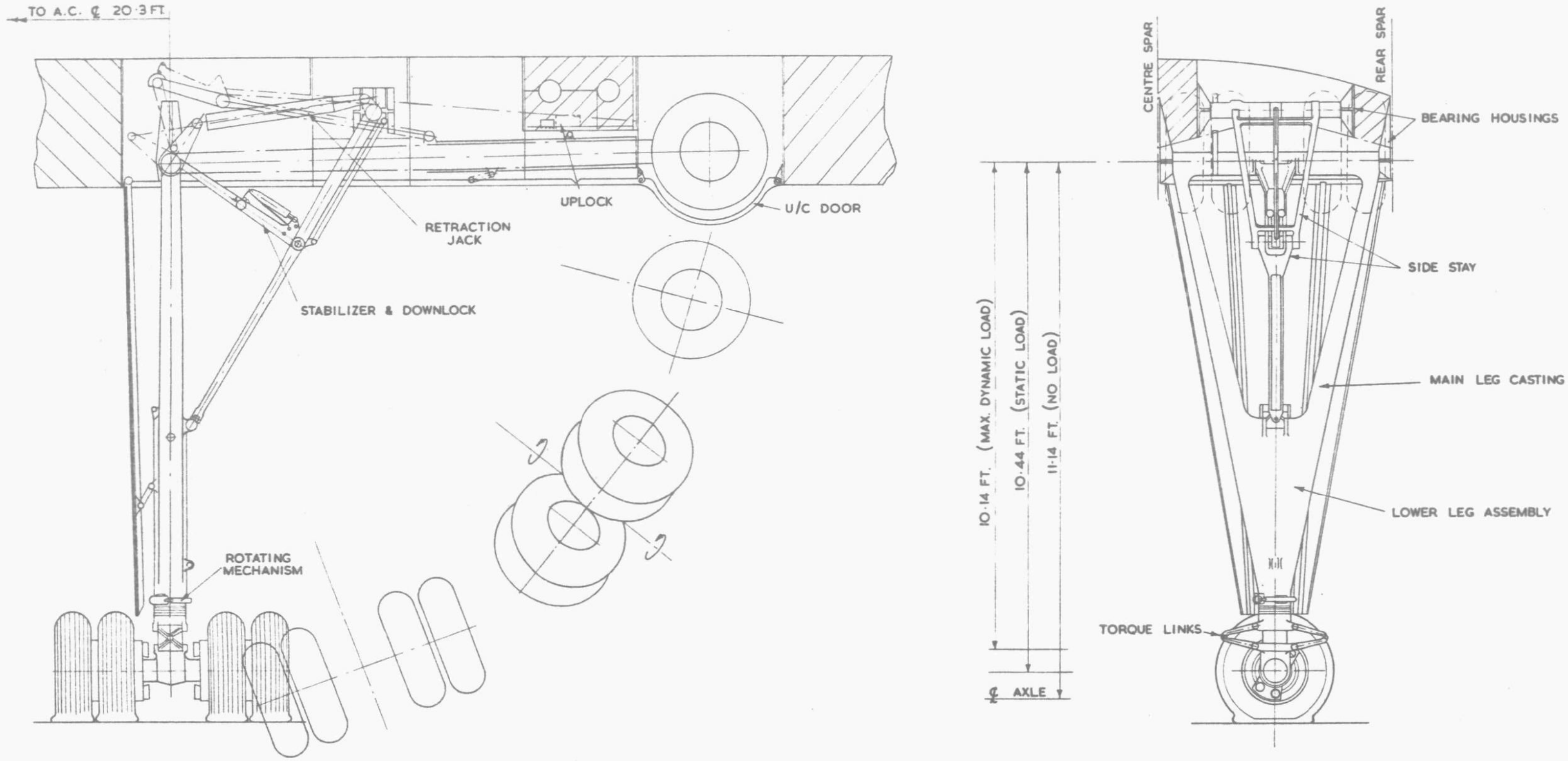
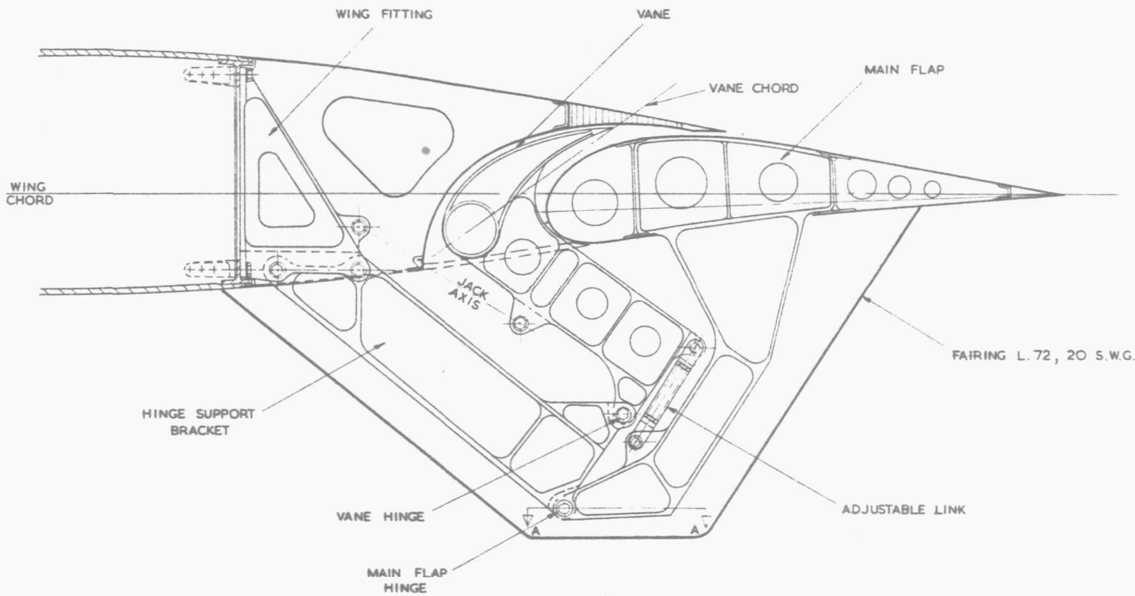
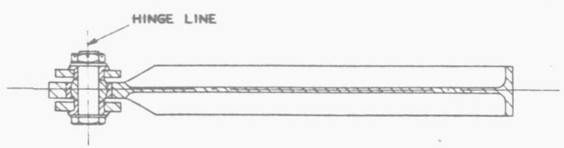
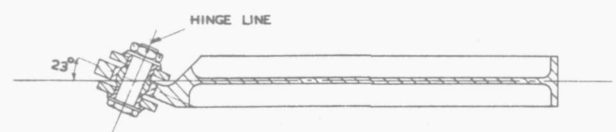


FIG. 14 LAYOUT OF THE UNDERCARRIAGE OF THE GP 63





SECTION A-A
SHOWING THE HINGE LINE DIRECTION
IN THE "INNER FLAP"



SECTION A-A
SHOWING THE HINGE LINE DIRECTION
ON THE "OUTER FLAP"

FIG. 15 FLAP MECHANISM OF THE GP 65

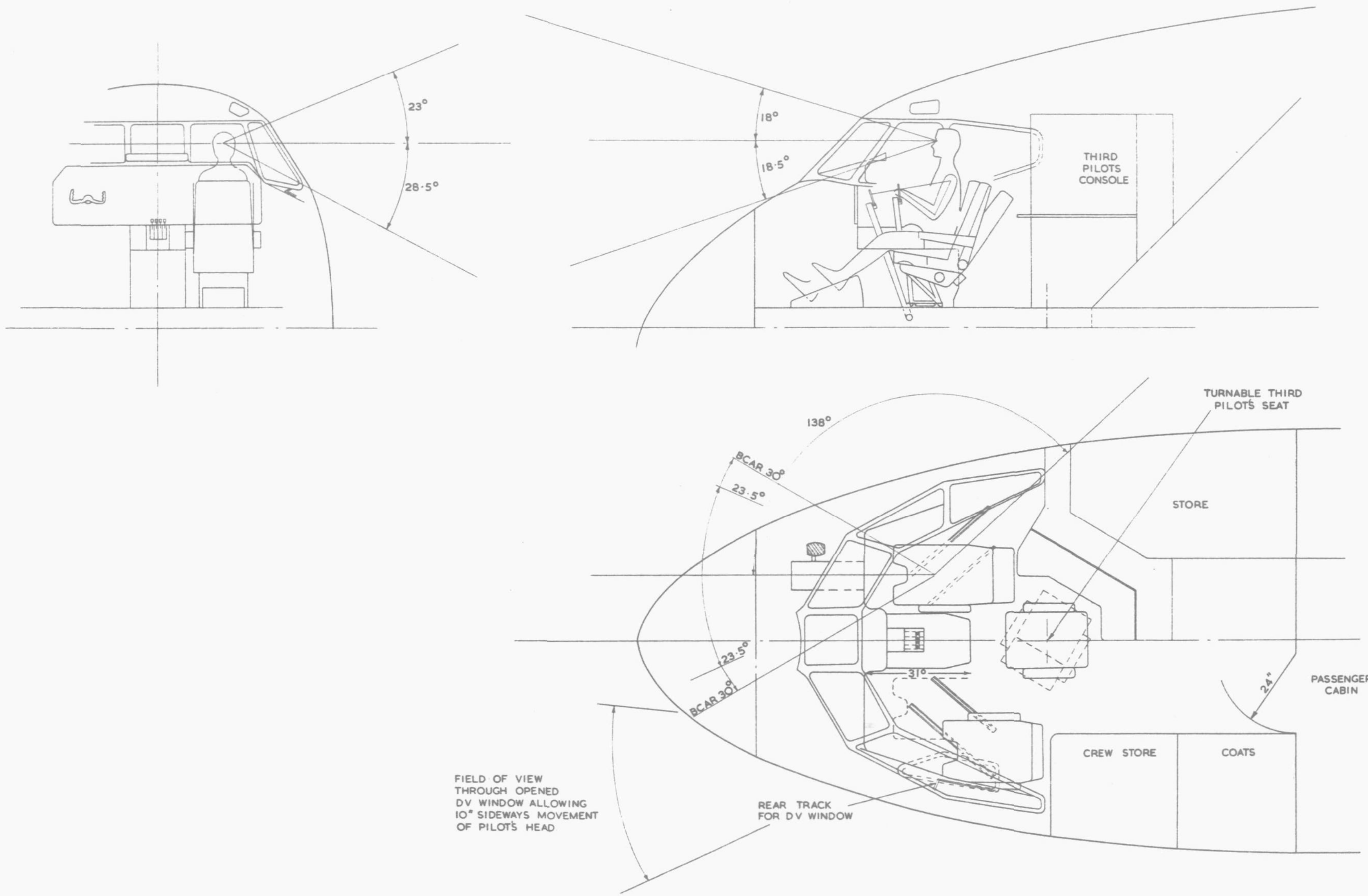


FIG. 16 FLIGHT DECK LAYOUT OF THE GP 65

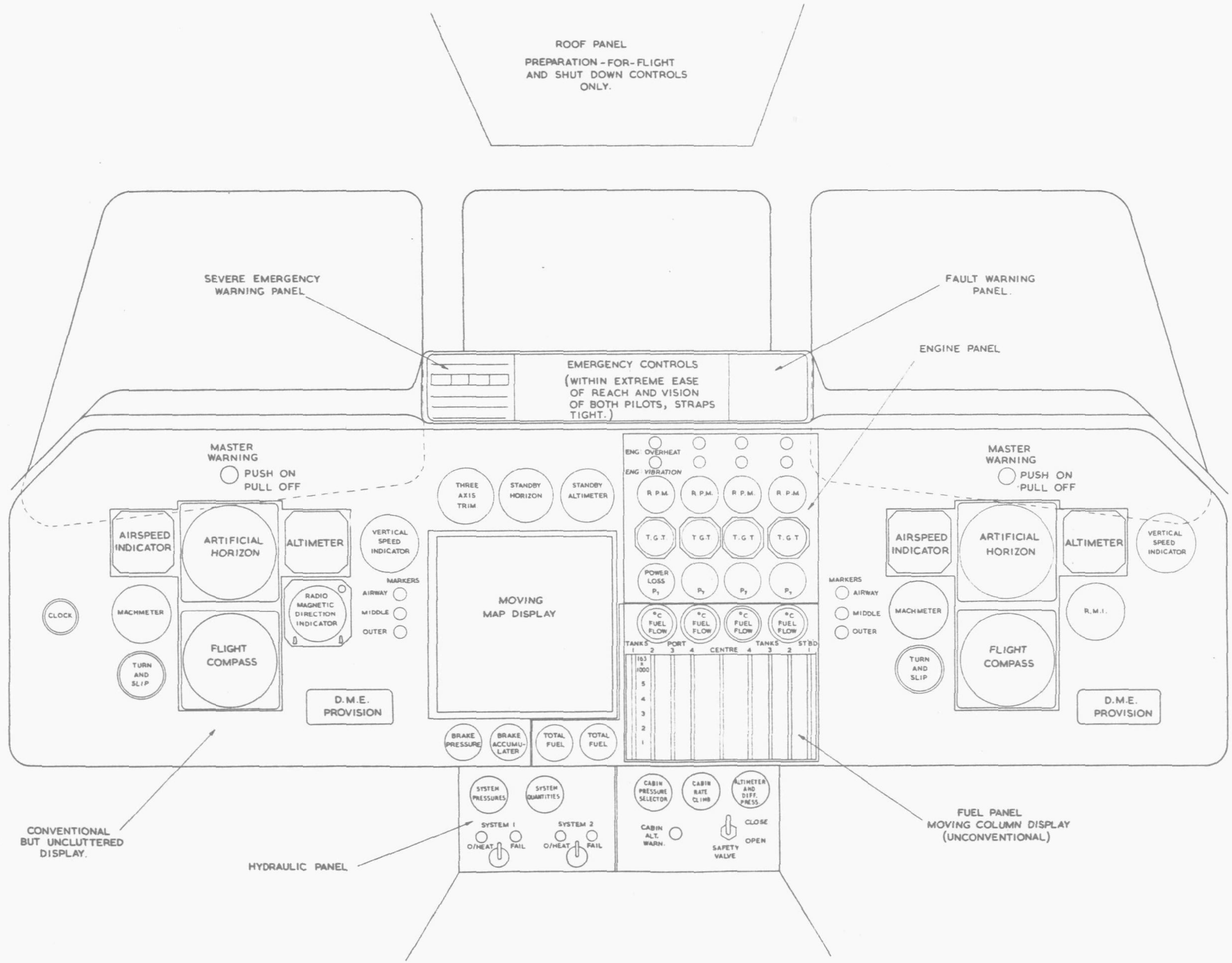


FIG. 17 INSTRUMENT PANEL ARRANGEMENT OF THE GP 65

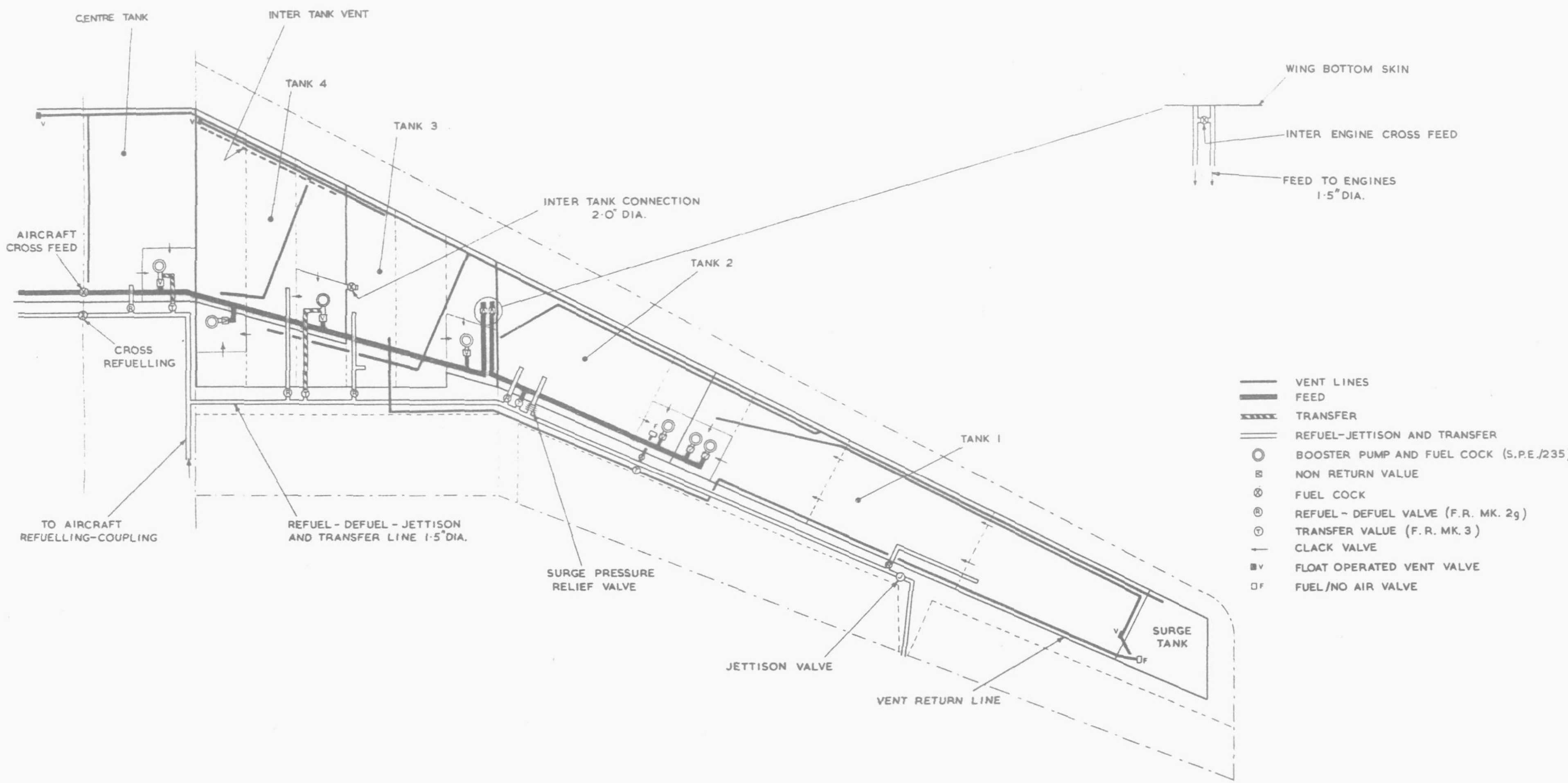


FIG. 18 FUEL SYSTEM OF THE GP 65

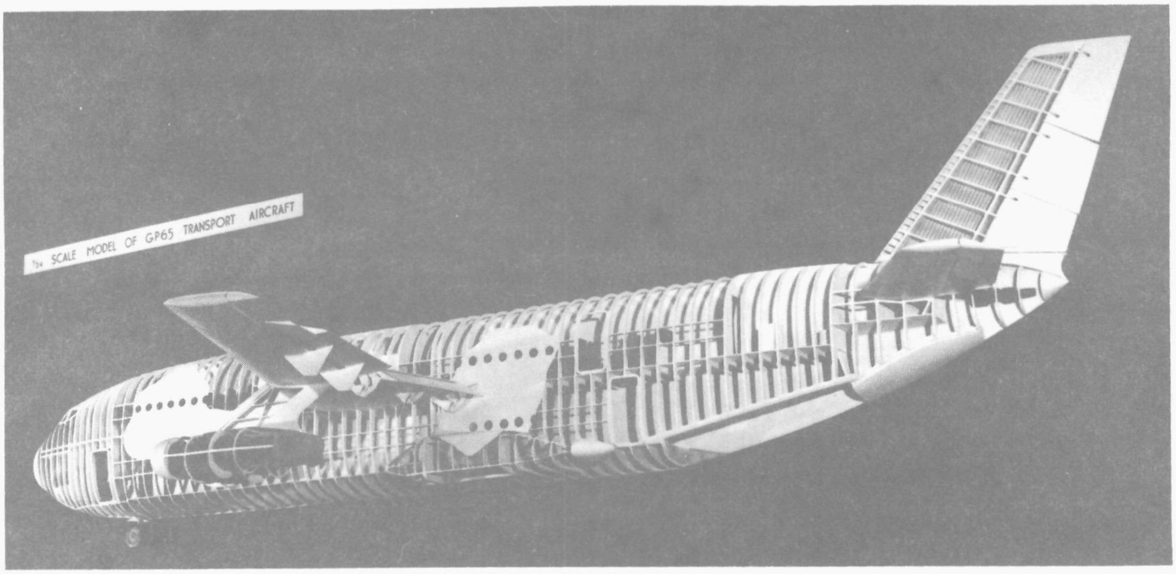


FIG. 19 STRUCTURAL MODEL OF THE GP65

FIG. 20 STRUCTURAL MODEL OF THE GP65