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THE COLLEGE OF AERONAUTICS
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AEROPLANE DESIGN STUDIES
CONVENTIONAL AND V.T.O.L. FREIGHTER AIRCRAFT

(Academic Years 1959 and 1961)

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SUMMARY

During the second year of their course in the Department of Aircraft Design, students have the option of working as a member of a team engaged in a design study. The subjects for the studies are chosen to represent the current interests of the industry and include unusual features considered to be worthy of investigation. Examples of these design studies are the F-59 freighter and its derivative the F-61, V.T.O.L. freighter. In a conventional role these designs are intended to carry a payload of up to 77000 lb., over 800 nautical miles range, using four turboprop engines. V.T.O.L. capability is given to the F-61 design by the addition of two wing pods, each of which houses 22 lift engines. The application of boundary layer control in the form of blown ailerons and flaps has been investigated for the F-59 design. Both aircraft have been designed in detail.

The major conclusion of the studies is that the application of V.T.O.L. to large freight aircraft is feasible, but further detailed work is necessary to resolve some flutter and noise problems.

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1. Introduction

The design studies discussed in this report were undertaken jointly by the staff and students of the Department of Aircraft Design. In the final year of their course the students have the opportunity to become members of a team engaged in the detailed study of a project aircraft, and are given individual responsibility for a structural, mechanical or system component. The staff prepare a new design each year for this purpose, the subject being chosen to be representative of the problems currently faced by industry. The design is made as realistic as is possible in the time available, and the opportunity is taken to incorporate unusual features in order that an assessment of them may be made. The studies thus constitute a valuable form of research and the students encounter problems similar to those which they will meet in industry and the services.

During the 1959-60 academic year the students worked on a large freighter aircraft capable of lifting low or high density payloads of up to 34 tons maximum. This design, designated the F-59, was powered by four Rolls Royce Tyne propeller turbine engines. Subsequently, in 1961-62, the design was reconsidered, modified in certain respects and given vertical take off and landing capability. The new design is known as the F-61.

Appendix A lists the allocation of components for these two design studies.

2. Philosophy of large V.T.O.L. freighter aircraft

Although there are many potential applications of V.T.O.L. to aircraft operations, at the present time the associated problems impose considerable restrictions. Possibly the most significant difficulties are those which result from noise and cost. Noise is an especially serious problem when the lifting system utilises a high induced vertical velocity, that is when the disc loading is high, and it is accentuated by increase in aircraft size. A high cost results from the greater complexity of this type of vehicle and it reflects both upon the first cost and the depreciation rate. Frequently the fuel consumption is relatively high and this implies large operating expenditure. On the other hand there are savings in aerodrome facilities and, possibly, fuel reserves which can partially offset these effects. Tentative estimates have indicated that the use of direct lift engines to give V.T.O.L. capability to a conventional design approximately doubles the first cost.

One particular type of aircraft where V.T.O.L. has significant advantages and where the cost may be acceptable, is the military freighter. There is an obvious need for a tactical freighter intended to support V.T.O.L. strike aircraft. This would have to be capable of operation in forward military areas and a high noise level during take off and landing could be very embarrassing. This is an extremely serious problem and if a sufficiently large helicopter could be produced, perhaps of about 40 to 45 tons gross weight, it might well prove to be the best solution. At present, however, design thought is centered around the application of lift or deflected thrust engines to otherwise conventional fixed wing designs. There is also a requirement, although possibly a less obvious one, for a large strategic military freighter. There have been occasions in recent years when the necessity has arisen for the transportation of troops and heavy equipment to remote areas. Conventional strategic freighters are excellent for this purpose providing that adequate aerodrome facilities are available, but this is not always the case. Air dropping of troops and equipment is a possibility, but it is somewhat restricted in its scope especially with regard to very heavy items. The availability of a fleet of V.T.O.L. strategic freighters requiring the minimum of ground preparation would be invaluable in these conditions. Such an aircraft would have a gross weight of about 100 tons and a payload of about 35 tons. V.T.O.L. operations would be infrequent and would not justify the aircraft being used in this role alone. It is therefore desirable for the aircraft to be capable of operating conventionally with the minimum of penalty resulting from its ability to convert to V.T.O.L. Restricted civil operations with this type of aircraft may be envisaged as, for example, the transport of heavy mining equipment to remote areas.

The obvious solution to this problem is to equip a conventional aircraft with direct lift engines arranged in a number of readily attachable pods. These pods would need to be self-contained, require the minimum of time and special equipment for attachment, and be sufficiently compact to be transported by the aircraft as payload. Pods could be stored at strategic locations throughout the world to be attached to aircraft as and when necessary. This self-contained pod unit would have the advantage of simplifying maintenance and reducing the number of basic aircraft required. The V.T.O.L. noise level would be extremely high but could be tolerated since personnel would wear protective gear. The number of individual lift engines required is substantial and the method of engine control used needs careful consideration.

3.0 Description of the aircraft

3.1 The F-59 conventional freighter

It is convenient to begin by describing the F.59 design since the F.61 V.T.O.L. aircraft is a direct derivative from it. A general impression of the aircraft can be gained from Figure 1, a photograph of a model and Figure 3, the general arrangement. The aircraft is intended to operate in both tactical and strategic military roles, but is also suitable as a car ferry. The freighthold height is 11.0 feet and the floor width 14.0 feet over the greater part of the 100 feet length, the gross volume being about 14,000 cubic feet. The maximum payload of 77,000 lb. can be loaded either through a nose door or a rear ramp type door designed to meet air dropping requirements. When arranged for air dropping the door clearance height of 10.3 feet caters for a 10 ton truck. The large floor width enables either two rows of cars or heavy earth moving machinery to be carried. The freighthold can be pressurised for flights up to a maximum altitude of 33,000 ft.

Special features are incorporated in the design to give versatility for civil and tactical military operations. The bogie main undercarriage uses large, low pressure tyres which are housed in fuselage blisters and protrude into the freighthold but do not decrease the floor width. At the maximum take off weight of 200,000 lb. the runway load classification number is 25. In addition boundary layer control in the form of blowing over the slotted flaps and drooped ailerons enables good low speed performance to be achieved. The approach speed is 95 knots at the maximum landing weight of 190,000 lb. and 80 knots at a weight of 130,000 lb. Under normal conditions both landing and take off require less than 2000 ft. of runway length. The air required for the boundary layer control on the ailerons is obtained from a pair of auxiliary power units housed in the undercarriage blisters. These are also used for starting the propulsion engines and generating auxiliary power. Air is tapped from the main engines for the flap blowing which is primarily used for landing when the power loss is acceptable.

When carrying the maximum payload the still air range is 800 nautical miles at 300 knots true airspeed. The maximum range of 4600 nautical miles is achieved with 22,400 lb. of payload. Typical loads are shown in Figure 5.

3.2 The F.61 freighter with V.T.O.L. capability

The major external differences between this design and its predecessor can be seen by reference to Figures 2 and 4. The addition of a pair of wing mounted pods provides the means of achieving V.T.O.L. Each pod carries 22 lift engines of 8000 lb. nominal thrust. In view of the more specialised application of this later design, the nose loading door is deleted and the geometry of the cockpit revised. Provision for the pods implies a reduction of 18.0 feet in the flap span and this is offset by replacing the slotted flaps by ones of Fowler type. Boundary layer control is not retained and only one auxiliary power unit is installed. The approach speed at a weight of 190,000 lb. is 112 knots and the aircraft requires 6000 ft. of runway length for normal operations in the conventional configuration. The fuselage blisters are somewhat larger as the intrusion of the wheel bay into the pressurised region is eliminated and, in consequence, a small but beneficial increase in track obtained. The actual undercarriage layout is unusual in that a 'reverse scooter' configuration is used to facilitate stowage and mounting off the fuselage. The improved nose shape more than offsets the extra drag due to the blisters.

The addition of the wing pods to the aircraft enables the all up weight to be increased to 250,000 lb. without increasing the maximum static wing bending moment. Some 44,000 lb. of this additional 50,000 lb. is accounted for by the pods themselves. The V.T.O.L. design criterion, is the ability of the aircraft to lift 75,000 lb. of payload over 400 nautical miles range, with the take off and landing from a site at 5000 ft. altitude and an ambient temperature of I.S.A. plus 15°C. When the pods are fitted, the aircraft can be operated conventionally to carry 77,000 lb. over 900 nautical miles range, or 25,000 lb. over 3500 nautical miles. An overload fuel tank in the freighthold enables 5000 nautical mile ferry range to be achieved, or alternatively the pods can be carried in the freighthold when a range of 3000 nautical miles is possible with a take off weight of 200,000 lb.

4.0 Performance and control

The increase in weight required to enable the F-61 design to be fitted with lift engine pods is almost exactly equal to the saving achieved by deletion of the boundary layer control system used for the F-59. As a result of this the basic performance of the two aircraft is almost identical.

4.1 Conventional configuration

The level flight performance and the range-payload variations are shown in Figure 6 and 8. A maximum true airspeed of 368 knots occurs at an altitude of 26,000 ft. when the aircraft weight is the minimum flight condition of 110,000 lb. When the flight weight is 190,000 lb. a maximum level speed of 335 knots is achieved at 12,000 ft. The normal cruising speed is 230 knots equivalent airspeed, flight being between 20,000 feet and 25,000 feet altitude, but cruise at a constant 310 knots true airspeed enables up to 20% extra range to be achieved for low values of payload.

A maximum tolerable cruise C_L of 0.65 has been assumed. In standard atmospheric conditions the take off distance to 50 ft. height is 3,600 feet for a weight of 200,000 lb. The corresponding landing distance at 190,000 lb. is 3,800 feet, and at 130,000 lb. it is 2,900 feet. Use of reverse thrust reduces these figures to approximately 2,500 feet and 1,700 feet respectively.

Conventional trailing edge control surfaces are used.

4.2 V.T.O.L. configuration

In this case the nominal minimum flight weight is 160,000 lb. and the maximum level speed achieved is 322 knots at 17,000 feet altitude. As is shown in Figure 7 the equivalent speed for 240,000 lb. weight is 302 knots at 8,000 feet altitude. A summary of the range-payload characteristics is given in Figure 9. The normal cruising speed is 225 knots equivalent airspeed, the height varying from 15,000 feet to 20,000 feet. In the V.T.O.L. case the lift engines are assumed to be used for a total of 3 minutes, although take off, climb and transition can be accomplished in less than 1 minute, and provision is therefore made for the case of an aborted approach. In I.S.A. plus 15°C and 5,000 feet altitute conditions, water injection is used to boost the thrust to a minimum of 1.25 times the aircraft weight. When sufficient water for two minutes operation is carried the range decrement is approximately 200 nautical miles relative to operation in a standard atmosphere. A conventional take off and landing enables the range to be increased by approximately 400 nautical miles at any given payload. The take off run to 50 feet height at 250,000 lb. weight is 5,400 feet and landing from 50 feet at 240,000 lb. requires 5,000 feet of runway unless reverse thrust is used when the distance is reduced to 3,400 feet.

During V.T.O.L. operation and in the transition phase control is obtained solely from the lift engines. Of the minimum of 25% excess thrust some 10% is used for vertical acceleration and the other 15% is available for control. The 44 lift engines are operated in four groups, port and starboard and fore and aft about the aircraft centre of gravity. Differential use of the group throttle fore and aft gives pitch control, and port and starboard gives roll control. The exhaust nozzles of the engines can be rotated about a horizontal lateral axis and differential movement of this facility provides yaw control. Since the lift engine pods are located well outboard of the centreline and are of considerable length in themselves no auxiliary control air nozzles are necessary. During transition the attitude of the aircraft in pitch is automatically stabilised at approximately three degrees below the stall, and the flaps are set at the take off position. As forward speed is increased the lift engine thrust is progressively reduced automatically until the full weight can be sustained by the wings. When the transition is complete the normal trailing edge controls, which are interconnected with the lift engine controls, become effective. The lift engines are then stopped, the pod fairing doors closed and the aircraft proceeds in a conventional manner.

5.0 Detail specification of the aircraft

A detailed specification of the two aircraft is given in Appendix B. Together with the weight breakdown to be found in Table 1 and certain load distributions this appendix represents the initial information given to the students. Table 1 includes both predicted weights and also weights estimated from the detail design work completed on the F-61 project.

6.0 Description of structure

The structures of the two aircraft are similar and hence it is sufficient to describe that of the F-61 V.T.O.L. design.

The basic structure of the aircraft was designed to have a given safe life when subjected to a chosen set of operations. These are summarised in Appendix B paragraph 5.2 and cover conventional and V.T.O.L. operational and training flights totalling 20,000 hours. In addition fail safe features have been incorporated where possible and emphasis given to the need for ease of inspection. In the event of a failure of a component which is readily inspected a residual strength of at least 66% of the ultimate has been ensured. Where a failure is not readily seen the residual ultimate strength is at least 83% of the ultimate.

The greater part of the airframe is of conventional light alloy construction. Copper based alloys have been preferred to ensure good crack and stress corrosion properties. The main sheet material used is L 72 with L 73 where necessary. L 65 is used for extrusions and forgings and T 63 for tubes. S 97 has been used for steel components.

A general layout of the main structural members is shown in Figure 10.

6.1 Fuselage

The basic fuselage structure is conventional in that it uses skins stiffened by stringers and is designed to remain unbuckled up to proof conditions. The frame and stringer pitches are approximately 20 inches and 5 inches respectively.

Forward of the wing the primary stresses arise from pressurisation loads which are especially severe on the large radius of curvature lower skin. The greatest bending stress of 7300 p.s.i. occurs during a three point landing and compares with a hoop stress of 12000 p.s.i. The Zed section stringers are intercostal between the frames and act only as crack stoppers and local stiffeners. They are bonded to the skins. Stiff frames are necessary because of the high freightloads and they react a substantial portion of the pressure load. Built of back to back channel construction, they incorporate a braced framework below floor level.

Bending stresses are much higher in the locality of the wing attachments, the maximum tensile stress being 35,000 p.s.i. during a landing approach with 40° of flap and forward centre of gravity. Figure 11 shows that in this region the Zed stringers are continuous, the frames being castellated to allow them to pass through. Between the front and rear spar frames the stringers are machined and pass through the wing box where necessary. Each frame has a crack stopper strip redux bonded to the skin beneath the stringers. Forged sections are introduced into the built up frames at the wing pick-up and the chine. Above the chine the skin thickness is 16G, and below it is 14G, the longitudinal joints being lap and the circumferential ones butted at the major frames.

Aft of the rear spar the freighthold roof forms a torsion box with the upper skin thus compensating for the large cutouts required for the rear loading doors. The twin fin layout has the effect of minimising the torsional loads which occur during yawed flight. Box booms transfer the longitudinal bending loads past the edges of the door cutouts, and the stringer pitch is reduced to 2.5 inches locally. Although they do not contribute to the longitudinal bending strength, the doors do transmit pressurisation and local loads laterally across the fuselage section. The maximum stress in the box booms is 40,000 p.s.i. compression. A pressure bulkhead is located aft of the door section and it also transmits the forward tailplane pick-up loads into the fuselage. This bulkhead is shallow and uses a plate web reinforced on one side by vertical top hat stiffeners and on the other by horizontal corrugations. The fuselage terminates at a plate bulkhead which carries the rear tailplane pick-ups. L 71 is used to skin the whole of the rear fuselage because of the high maximum design loads.

The construction of the freight floor is illustrated in Figure 12. The floor is supported by two deep and three shallow longitudinal beams which rest on the frames. The deep beams coincide with the most severe vehicle loads and at their rear they terminate at the hinges for the main loading door. The floor itself consists of honeycomb panels which extend for three frame pitches and are not joined together. A 2.5g manoeuvre is the critical floor and frame design case, axle loads up to 21.5 tons being catered for. The forward end of the freight floor is connected to the nosewheel bulkhead which is of corrugated construction.

The pressure shell is completed at the forward end by the lower part of the nosewheel bulkhead and a curved floor under the crew compartment, the nosewheel bay being unpressurised. A complex machined extrusion acts as a chine member below the crew floor. Stiffness is the criterion for the L 65 forged windscreen frames which are assembled as pairs of back to back units. The pilot has 28° of downward vision over the nose through the glass-vynal-toughened glass sandwich windscreen panels. A rubber pressure seal is trapped between the vynal and the frame, and a gold film element deposited between the outer glass and vynal is used for demisting. An Echo E 190 radar unit is mounted in the extreme nose. The fibreglass radome is 5 feet in diameter and 1.3 inches thick.

The design of the wing-fuselage joint is such that both structures are unbroken. The lower wing skin is also the local freighthold roof and reacts fuselage pressure loads, whilst the fuselage stringers pass through the wing box which is an integral fuel tank. The booms of the three fuselage frames located coincident with the wing spars are attached to the spar webs. A single cell box positioned below the freight floor transmits the main undercarriage loads into the fuselage and as it is aft of the wing it requires two additional special frames. Landing with high drag and the turning and swinging cases design these two frames and the box.

As is shown in Figure 13, the tailplane attachment uses four swinging links to react vertical shear loads without introducing constraints. Drag and side loads are taken through locating blocks and pegs which are mounted at the centreline and give vertical freedom.

There are two rear loading doors, the aft one of which hinges up into the fuselage to give loading and dropping clearances, as is indicated in Figure 4. The forward one is an extension of the freight floor and the most severe loads arise when it is open. During normal flight both doors are locked to the fuselage by pins located on transverse beams. In the case of the forward door the locking pins are given a lead-in and are hydraulically operated in sequence from the forward end. Internal pressure is reacted by the outer skin and longitudinal stiffness is provided by braced webs to which the hinges are attached. A pair of double stroke jacks located approximately two thirds of the door length aft of the hinges raise and lower the door. There are three positions; closed, horizontal for air dropping, and fully open for loading and propping the fuselage. When the door is in the closed position the hinge gap is sealed by a flexible diaphragm.

6.2 Wing

The wing structure inboard of the pod is designed by a combination of conventional and V.T.O.L. loading cases. The maximum compression stress of 47,000 p.s.i. on the upper surface occurs in a 2.5g manoeuvre at an equivalent airspeed of 280 knots, with an aircraft weight of 187,000 lb. of which only 5,200 lb. is fuel. On the lower surface dynamic braking at 250,000 lb. weight causes the maximum compression stress whilst the most severe torque arises when the two rearmost lift engines fail together. Aileron loads are critical for outer wing torques.

The fatigue strength of the wing at a section 10 feet out from the centreline has been evaluated.[1] Table 2 summarises the results obtained by applying the method developed by Raithby[2] and using the aircraft roles specified in Appendix B. The estimated mean safe life of 30,000 hours gives a factor of 1.5 on the required life, the lower wing skin having been designed to have an ultimate stress level 79% of the L 72 material U.T.S. The upper wing surface has a mean safe life of 39,000 hours, the tensile damage being caused by taxying loads. V.T.O.L. operations cause severe damage, and the assumed roles limit V.T.O.L. flight time to 22.5% of the total. Purely conventional operation would enable the ultimate stress level to be raised to approximately 87% of the material U.T.S., since 44.5% of the damage occurs in V.T.O.L. operation. Assuming that the wing box weighs half of the gross wing weight the penalty for V.T.O.L. operation is about 5% of the wing weight, or approximately 1100 lb.

The presence of the large pod inertia well outboard on the wing also gives rise to unusual flutter characteristics. A preliminary investigation[3] has shown that a problem exists when the wing stiffness is that obtained in meeting strength requirements. This stiffness is substantially greater than that specified by the normal criteria. The major effect of the pod is to reduce the fundamental torsion frequency of the wing to a value 25% of that of the wing without pods, but the bending frequency is reduced by much less.

If it is assumed that the structural damping is 3% flutter is predicted to occur at speeds above 200 knots E.A.S., which is well below the design diving speed. Increase of wing stiffness is not an obvious solution to this difficulty due to the unusual ratio of torsional and bending frequencies, nor is it likely to be possible to change the pod position on the wing chord. Spanwise movement of the pod or, preferably, the addition of fins to provide aerodynamic damping may be the solution.

Inboard of the pod centreline the main wing box is of two cell design, the centre spar terminating at this point. The box is continuous over the top of the fuselage, the fuselage loads being transmitted through it by continuous stringers.

Although the use of three webs gives rise to a 10% web weight penalty relative to a single cell box, their use is justified by the extra margin of safety which is achieved. The spar positions were determined by the geometry restrictions imposed by the lift engines and the desirability of containing all the fuel in integral tanks in the wing box. The actual locations are at 15%, 34%, and 54% of the chord at the root. By choosing the wing dihedral to be 1°54' it was possible to have a straight upper wing surface. The lower surface changes direction gradually across the fuselage.

Tapered rolled skins reinforced by extruded Zed section stringers are used. The stringers are attached by rivets, this method being chosen to ensure good fail safe behaviour. The flanges of the stringers are reduced in width at outboard locations so that the optimum area is obtained without change in depth. The skin thickness at the root is 0.31 inches on the upper and 0.27 inches on the lower surface and it reduces to 0.212 inches and 0.192 inches respectively at the lift pod station. Outboard of this section there is an abrupt change to 10G and 12G respectively, and the stringers are drawn rather than extruded. Although the number of skin joints is reduced to a minimum by using 25 feet x 10 feet size sheets, there is a spanwise joint along the centre spar. Each spar web is divided horizontally to give improved fail safe properties, buckling being prevented by vertical stiffeners. The small extruded booms are split either side of the web, each half being designed to take 80% of the total load.

Ribs are located at approximately 24 inches pitch and the standard ones are of built-up plate construction with booms passing below the stringers and cleated to the skin. Flap and aileron loads are taken directly into the skin by rib boom extensions. The 15 feet wide centre section is bounded by two forged light alloy ribs which connect the three spar web fittings to the fuselage frames. These ribs act also as tank ends and their booms are connected directly to the skins. Both the spar booms and stringers are interrupted at these two stations, continuity being provided by flanges forged onto the rib booms. Connections are made by Hi-Shear pins located in close fitting tapered holes.

At the wing to fuselage junction the fuselage stringers are cleated to the front and rear spar webs and a fuel seal is provided in the cleat. In the design of the three spar frames and attachments, it was found to be more economical to use a large safe life factor than to arrange for any two to take all of the load. Inspection of the centre web and fuel tanks is achieved through holes placed in the rear web, selected ribs and the upper wing box skin. All the cover plates are load carrying.

Tank sealing at the front and rear spar to skin joints is by means of chords trapped in the joint. Elsewhere sealing strip in bead form and sprayed on sealing compound is used.

The leading edge is detachable and made in four feet long sections. Spigots on the leading edge rib engage in holes on the front spar web and bolts are used for the skin attachment. A thermal deicing duct is incorporated in the front 12% of the upper and 10% of the lower skins.

The V.T.O.L. pod is attached at four points, three of which are on the front spar and the fourth on the rear spar. The two outer front spar attachments carry a total of only 20% of the vertical load. Each connection is by a single pin designed to have a large life factor. The front centre pickup extends 3.5 inches below the wing profile to simplify the pod connection procedure, and is faired when the pod is not carried.

Nacelles

Each propulsion engine is mounted off extensions to three wing ribs. The centre rib reacts vertical loads only and the two outer ones carry the main engine trunnion mounts. The pod itself is a fairing structure and is easily removable for servicing.

Flaps

The Fowler flaps use a NACA 23012 section which is modified at the nose and trailing edge to enable a compact retracted installation to be achieved. The trailing edge modification consists of superimposing the extreme 5% of the basic wing depth on to the flap trailing edge. The design of the mechanism is such that the most severe loading case occurs when the aircraft is parked tail into a 60 m.p.h. wind. Stiffness is the major criterion, the skin and fairing deflections being held to 0.1 inches and flap track deflections to 0.75 inches.

Structurally the flaps are built in segments so that wing bending restraints are minimised. As can be seen in Figure 14 these segments are joined to one another by a sliding and universal joint at the front spar and a sliding, swivel joint near to the trailing edge. The gap between the segments is not sealed, but is minimised by virtue of the geometry chosen. Much of the flap is constructed from 22G, L 72 alloy, although 18G and 16G are used for the front spar and ribs respectively. The segment connecting joints are fabricated in S 80.

The noses of the flap segments are attached to track beams and links. The track beams carry hardened steel rollers which run in the steel tracks built into the wing trailing edge ribs. They provide fore and aft flap motion and are operated by chains and sprockets from the hydraulic flap motors. Each one consists of a pair of L 65 forgings placed back to back. Rotary motion is imparted to the flap by the forged L 65 links which are operated by S 96 cam rods. The cam rods are manufactured in steel to obtain adequate stiffness within the restricted space available.

The wing trailing edge fairings are constructed in short lengths from 20G L 72 alloy, and are attached to the rear spar independently of the flap tracks.

Ailerons

Each aileron is split into two sections, and the parts are connected by a torque tube with universal joints. There are three hinges on each section. Hydraulic boosters are located at the pair of hinges either side of the torque tube so that a booster failure can be tolerated with minimum penalty to the structure. The aileron hinge line is above the section datum as this facilitates the nose fairing design. It is made possible by using differential movements. The main aileron spar is located just behind the hinge line and acts as the centre web in a two cell torque box, the nose box being discontinued in the region of the hinges. The 18G nose and 24G main box skins are supported by closely spaced ribs and intercostal stiffeners.

Because the aileron hinge line is well behind the wing rear spar it is possible to use concentrated balance masses carried on long arms. A sealed aerodynamic balance is used.

The aileron hinge brackets attach to the rear spar and are constructed from a pair of back to back L 65 forgings as a fail safe measure.

6.3 Tailplane and Elevator

The maximum tail load of 58,500 lb. occurs during a conventional landing approach with full flap at an aircraft weight of 240,000 lb. This case is slightly more severe than a 2.5g pitching manoeuvre, and the outer 40% of the tailplane span is designed by asymmetric flight fin and rudder loads. The basic structure uses a two spar box with the nose cell contributing to torsional strength. Optimisation calculations led to the rib pitch being chosen as 12 inches at the root increasing to 15 inches at the tip. Zed section stringers reinforce the L 72 skins which taper from 0.1 inches thickness at the root to 0.05 inches thickness outboard. The stringers are made from 20G L 73 alloy and have a spacing of 3.4 inches inboard decreasing to 2.5 inches outboard. The booms of the plate ribs pass inside the stringers, the rib webs being castellated to form a skin attachment. Each stringer is cleated to the rib. The main tailplane fuselage attachment ribs are of box section. Plate webs are used for the spars which have L 65 extruded booms of varying cross section. The maximum design stress level in the tailplane structure is 25,000 p.s.i. and the normal working level 14,000 p.s.i.

The four swinging links which connect the tailplane to the fuselage and the locating blocks are L 65 forgings. The innermost of the five hinges on each half of the elevator is used as a datum and is incorporated in the rear spar link attachment. The link attachments are also L 65 forgings.

The elevator uses a sealed round nose balance and is similar to the aileron in construction.

Fin and Rudder

The interchangeable twin fins and rudders are attached to the outer ends of the tailplane as can be seen from Figure 13. The design load of 30,000 lb. arises when the aircraft is oscillated in yaw by sinusoidal application of rudder angle. Each fin is connected to the extremities of the two tailplane spars by four pins. These pins are positioned on the fin centreline and at the top and bottom tailplane spar booms. In the region of the attachments the fin spar webs and skins have doubler plates to which the machined pick-up fittings are fixed. A spigot on the fin front spar engages the tailplane fitting to provide an alternative load path in the event of a pin or lug failure. The load distribution which occurs if a rear spar pick-up fitting fails is tolerable as the majority of the load is carried by the front spar. The front spar position is dictated indirectly by the location of the forward tailplane to fuselage connection and it is at 24% of the chord. The rear spar is at 65% of the chord as this is the most suitable position for the elevator and rudder.

A stiffened 16G L 72 plate web is used in the construction of the front spar, which has back to back L 72 extruded angle booms. The rear spar is similar, but requires only single angle booms. The 20G L 72 alloy skins are stabilised by Zed section intercostals and plate ribs.

Each rudder has four hinges, the one located at the tailplane being used as a datum and operating point. The hinge fittings are designed to provide alternative load paths in the event of a failure. The rudder is similar to the aileron in construction and has a rib pitch of 9 inches.

6.4 Main undercarriage

Each of the four wheel bogie units retracts forward into a blister on the side of the fuselage. The proof reaction factor is two. Because of the narrow track the greatest loads occur when the aircraft is turning on the ground. When the aircraft weight is 250,000 lb, the maximum vertical reaction of 175,500 lb. is associated with a side load of 87,500 lb. Exceptionally heavy loads have to be transmitted by the bogie beam because of the unusual 'reverse scooter' layout shown in Figure 15. The main leg is attached to the rear axle and it incorporates a sliding tube and antislamming fluid damper. A liquid spring shock absorber is located between the centre of the bogie beam and the main leg, a measure of drag damping being achieved by virtue of its angle of inclination to the ground line. In order to be sure of rapid extension of the shock absorber in V.T.O.L. operations it is inflated to 2000 p.s.i. and it has a maximum working pressure of 48,000 p.s.i.

Both the main leg and bogie beam are forged of S 99. The wheel assembly is such that a tyre change can be made without removal of the steel brake discs. The undercarriage is attached to the airframe on two forged L 65 brackets mounted to the top of the undercarriage box beam. The downlock acts as a drag strut and transmits loads through the beam to the fuselage. The design of the major components is such that they are identical on both port and starboard units.

Nose undercarriage

The nose undercarriage is a twin wheel telescopic unit which retracts into the unpressurised region below the pilot's floor. Its layout is shown in Figure 16. Closure of the shock absorber is limited by the small clearance of 2 feet between the bottom of the fuselage and the static ground line. The unit can be steered to an angle of ± 70° and it can also castor so that the aircraft can be turned about a point 15 feet outside one of the main undercarriage units. The greatest loads arise as the result of dynamic braking, the vertical reaction being 97,700 lb. The liquid spring shock absorber has a working pressure range from 2,000 p.s.i. to 45,000 p.s.i. and it acts as the sliding tube. The large wheels and small clearance force the steering mechanism to the top of the leg and the steering torque is transmitted to the axle by a tube and links. The axle is live and is used with detachable rim wheels.

The main leg is attached by means of a forged light alloy sidestrut and trunnion fitting which transmits vertical and side loads to the freighthold forward pressure bulkhead. Drag loads are taken through the downlock directly into the freight floor. The nose wheel doors fold upwards after the unit has been lowered to give adequate ground clearance.

7.0 Description of systems

The major difference between the two aircraft as far as the systems are concerned is the boundary layer control installation of the F-59 design. This is discussed separately, but otherwise the description of the F-61 systems is adequate.

7.1 Pressurisation and air conditioning system

The air conditioning system is of conventional design and uses air tapped from the compressors of the propulsion engines for the purpose of pressurisation.

7.2 Flying control system

A fully powered system is implied by the need to integrate the conventional flying controls with those used during V.T.O.L. operation. Each of the main control surfaces is operated by hydraulic boosters and those on the ailerons and elevators are duplicated so that adequate control power is available in the event of a failure. In the case of the rudders, which are interconnected, the hinge moments are low enough for manual reversion to be acceptable in emergency. Hydraulic actuators are also used to rotate the lift engine nozzles to give yaw control, and the flaps are operated by a hydraulic motor driving through a lay shaft and chain and sprocket mechanism.

7.3 Fuel system

The fuel system is an atmospherically vented, booster pump type. The fuel is carried in fourteen integral wing tanks which occupy virtually all of the wing interspar space. Provision is made for the carriage of an overload fuel tank in the freighthold. Each tank has two submerged booster pumps fitted into isolating chambers. They can be individually controlled from the flight deck.

Figure 17 is a layout of the system. The fuel from the pumps feeds into a main transfer gallery which is located along the face of the front spar. Non return valves in this gallery prevent fuel from being fed into a damaged tank and transfer valves are incorporated to ensure that in normal conditions the fuel is used from the inboard tanks first. Refuelling and de-fuelling are accomplished through two connections located at shoulder height in the undercarriage blisters. Each of these feeds one half of the system, but a cross feed valve is provided. Provision is made for jettisoning the fuel from the wing tips, and venting also takes place in this region. A collector tank which feeds back into the main system is located at the upper end of the venting gallery. The system includes a capsule type explosion suppression device.

The lift engines require a very high fuel flow rate and this is obtained from an air turbine driven pump which feeds directly into the pod through a quick release connection. The total effective capacity of the normal system is 1725 cubic feet, or 86,250 lb of AVTUR. Overload tank capacity is 24,200 lb.

7.4 Boundary layer control of ailerons and flaps of F-59 design

The boundary layer control consists of blowing from the flap and aileron shrouds over the surfaces. Although there are two separate systems they are basically similar. The compressed air for flap blowing is taken from the compressors of the Tyne propulsion engines and ducted to a central reservoir. The individual flaps are supplied from the reservoir through balanced gate valves. All the main ducts and the reservoir are located in the wing leading edge. In the case of the aileron system the air is supplied by the auxiliary power units which are located in the undercarriage blisters. The ducting is installed in the trailing edge fairing behind the rear spar. Each section of the aileron or flap is supplied by a single branch from the main duct. This branch divides into a number of smaller circular pipes and finally terminates in a series of discrete nozzles along the shroud.

The design of the flap and aileron structures is dominated by the high temperature and noise environment. Experiments[4] conducted on a representative jet flap structure indicate that the upper surface of the flap is cooled by the entrainment of cold air drawn through the gap between the shroud and flap. The actual surface temperatures recorded were less than 50% of the gas temperature, and this would give 170°C for the F-59 surfaces. Using this information the flap and aileron upper surfaces have been designed to use bonded light alloy honeycomb panels, with insulation applied locally. This form of construction was chosen as the best solution to the acoustic problem. Internally both flaps and ailerons use braced ribs and spars to minimise thermal stresses.

An analysis of the weight penalty due to the boundary layer control installation indicates that the improved low speed performance is only obtained at the expense of a reduction in payload and range of 3% and 1% respectively. The overall advantage must be considered to be marginal.

8.0 V.T.O.L. pods

The V.T.O.L. pods are designed as self contained units. A gantry mounted on the wing is used to raise the pod from a ground trolley and the pod to wing connection consists of four pins. Apart from the structural attachment it is necessary to connect the electrical control cables and the fuel and starting supplies. The 22 lift engines contained in each pod are carried in two rows of 11 as is shown in Figure 18. The pod structure uses an egg-box arrangement which is based on a deep central beam and two side beams. These beams are unbroken along the length of the pod and are connected by vertical bulkheads located between each pair of engines. Torsional stiffness is obtained by joining the outer top and bottom spar booms with two horizontal skins. Large reinforced holes in these two skins provide clearance for the engine intakes and exhausts. All of the four pod attachments are mounted on the spars. The central front and rear points transmit both vertical and lateral loads and the two outer ones vertical and fore and aft loads. L 72 alloy is used for all the webs and skins and L 65 extrusions and forgings are used for the spar booms and pick-ups respectively. The pick-up fittings straddle the spar booms and are attached to the webs by S 96 tapered bolts. Fibreglass fairings complete the nose and tail shape.

All the pod services are located on the outside faces of the outer beams and are covered by large hinged fairing doors. Each engine is mounted at three points but all the necessary adjustment and locking is carried out on one of these which is positioned on an outer beam. Individual engines can be changed by lowering them out through the bottom of the pod. No primary structure extends below the level of the exhaust nozzles, the pod shape being completed by large doors which, like those over the intakes, use a double skin construction with a full depth honeycomb core. Cascades are used to turn the airflow into the intakes when the aircraft is in the transition phase. These are hinged so that they lie flat across the top of the engines when not in use. Both the doors and cascades are operated by hydraulic jacks.

There are two ways of starting the lift engines. The complete system is outlined in Figure 19. In normal operation the main propulsion engines are started first, either from the auxiliary power unit or from a ground supply. Air is tapped from the compressors of these engines and used to start a master pair of lift engines in each pod. The master engines are accelerated to full power and additional air is taken from them to enable the remainder of the lift engines to be started in two stages. Should the master engines become inoperative two adjacent engines can be used as a standby. When the aircraft is flying an alternative starting procedure can be adopted. Either the master or standby engines can be started by wind-milling and to facilitate this the appropriate pod intake doors are designed to act as an air scoop.

The pod fuel supply pumps are of the air driven turbine type and are located in the two outermost wing tanks. Each pod has a duplicated supply with automatic cross feed in the event of a failure. The 2 inches diameter flexible pipes use quick release couplings. A total loss oil system is installed to provide engine lubrication. This system is pneumatically pressurised by air bled from the master or standby lift engines. The oil for each engine is contained in a small reservoir of 0.5 lb. capacity which is sufficient for one complete V.T.O.L. cycle. A four gallon replenishment tank enables up to four V.T.O.L. cycles to be carried out independently of ground facilities. Fire protection is provided by a methyl bromide system which has 3.5 lb. of extinguishant for each engine. The total weight of this system is 250 lb. in each pod. Provision is made for water injection by the inclusion of a 3,000 lb. capacity tank below the wing structure.

9.0 Conclusions

A number of unusual features have been investigated in the F-59 and F-61 project studies.

a) Undercarriage layout of F-61 design.

The 'reverse scooter' layout used was chosen to enable a simple retraction mechanism and a good structural configuration to be achieved. However, the loads on the bogie beam are very high and it is not possible to claim a definite gain relative to a unit of more conventional layout.

b) Boundary layer control on F-59 design.

The overall advantage of the system was found to be marginal as the improved low speed performance was very largely offset by the significant losses in payload and range.

c) V.T.O.L. pods on F-61 design.

The design study shows the feasibility of using direct lift engines on a strategic freighter aircraft to give it V.T.O.L. capability. The special problems involved are those of wing fatigue life and flutter, and noise. The flutter problem has not been fully resolved and the noise aspect requires extensive investigation.

10. References

1.	Chaney, J.M.	Design of centre wing for 1961 design project F-61. College of Aeronautics Thesis June 1962.
2.	Raithby, K. D.	A method of estimating the permissible fatigue life of the wing structure of a transport aircraft. Journal of the Royal Aeronautical Society, Vol.65, No.611, Nov. 1961.
3.	Momirski, M.	An aeroelastic investigation of the wing of the F-61 design project with reference to the influence of the V.T.O.L. pods. College of Aeronautics Thesis June 1962.
4.	Davey, A.E.	Design of jet flap for 1958 design project. College of Aeronautics Thesis June 1960.

TABLE 1A

WEIGHT BREAKDOWNS

COMPONENT	Predicted Weights - lb & % of 200,000 lb.				Estimated Weight-lb F-61
	F-59		F-61		
Wings	23,000	11.5	23,000	11.5	22,000
Fuselage	28,000	14.0	27,100	13.55	27,800
Tail	4,000	2.0	4,250	2.13	4,120
Main undercarriage	8,000	4.0	8,100	4.05	8,400
Nose undercarriage	1,000	0.5	1,050	0.52	1,520
Nacelles	1,500	0.75	1,500	0.75	-
Structure	65,500	32.75	65,000	32.5	
Engines	8,700		8,700		
Cowlings, mountings	2,200		2,200		
Propellers	4,500		4,500		
Jet pipes	600		600		
Power Plant	16,000	8.0	16,000	8.0	
Fuel system	2,500		2,700		
Flying controls	1,500		2,500		
Power supplies, services	6,500		6,500		
De-icing	1,100		1,100		
Fire protection	1,000		1,000		
Instruments	600		600		
Radio & Radar	1,000		1,000		
Seats & Furnishings	1,500		1,500		
Air conditioning, Oxygen	2,800		2,700		
Auxiliary power units	1,200		600		
Boundary layer control	800		-		
Systems, etc.	20,500	10.25	20,200	10.1	

TABLE 1B

WEIGHT BREAKDOWNS

COMPONENT	Predicted Weights - lb & % of 200,000 lb				Estimated Weight-lb F-61
	F-59		F-61		
Structure	65,500	32.75	65,000	32.5	
Power Plant	16,000	8.0	16,000	8.0	
Systems	20,500	10.25	20,200	10.1	
Basic Weight	102,000	51.0	101,200	50.6	
Freight Gear	2,000		2,000		
Water, oil, etc.	600		600		
Crew & baggage	1,000		1,000		
Operating Weight	105,600	52.8	104,800	52.4	
Payload (maximum)	77,000	38.5	77,000	38.5	
Fuel with above	17,400	8.7	18,200	9.1	
A.U.W.	200,000	100	200,000	100	
Fuel (maximum)	72,000	36.0	77,000	38.5	
Payload with above	22,400	11.2	18,200	9.1	
A.U.W.	200,000	100	200,000	100	
Pod Structure			8,800	4.4	9,120
Lift engines			26,400	13.2	
Additional fuel and starting systems			4,000	2.0	
Additional flying controls			4,000	2.0	
Additional fire protection			800	0.4	600
Pod weight			44,000	22.0	
Basic weight with Pods			145,200	72.6	
Operating weight with Pods			148,800	74.2	
Payload (maximum)			77,000	38.5	
Fuel with above			24,200	12.1	
A.U.W.			250,000	125	
Fuel (maximum)			77,000	38.5	
Payload with above			24,200	12.1	
A.U.W.			250,000	125	

TABLE 2

WING FATIGUE ANALYSIS

(Ref. 1)

Role	V.T.O.L. Training	V.T.O.L.	V.T. Off Con. Land Operational	Conventional Training	Conventional Operational	Conventional Operational
Total Hours	400	100	4,000	700	2,800	12,000
Hours per flight	0.25	0.25	2	1	1	10
T.O. Weight - lb	180,000	240,000	250,000	130,000	187,000	200,000
Max. Altitude - ft.	1,000	1,000	15,000	5,000	5,000	20,000
% Gust Damage	0	23.6	15.3	85.5	72	82
% Ground-Air-Ground Damage	100	76.4	84.7	14.5	28	18
Damage per flight x 10^6	14.2	145	107	3.5	53.5	179
Damage per hour x 10^6	57	580	53	3.5	53.5	17.9
Safe Life, hours/role	17,600	1,710	18,800	350,000	18,700	56,000
Total Damage/role	0.023	0.058	0.212	0.002	0.150	0.215
Mean Safe Life (Lower surface) 30,200 hours (Factor 1.5)						
Safe Life, hours/role (Upper surface)*	3,040	5,840	14,400	56,800	56,000	46,200
Mean Safe Life (Upper surface) 39,000 hours						

* V.T.O.L. taxying assumed to be 20% of conventional distance

APPENDIX A

Allocation of components for F-59 Study

Armstrong, K.W.	Landing gear
Deakin, M.J.	Fuselage tail cone
Harrison, J.T.	Rear fuselage and loading door
Hill, G.D.	Outer wing structure
Hollis, F.M.	Engine and auxiliary power unit installation
Marsh, C.J.	Flaps, ailerons and boundary layer control
Massingham, R.E.	Fin and rudder structure
Nair S.K.	Tailplane and elevator structure
Torkington, C.	Front loading doors
Twigger, M.J.	Inner wing structure
Welbourne, E.R.	Front fuselage structure
Wilson,Q.	Centre fuselage structure

Allocation of components for F-61 study

Bamford, B.	Outer wing structure
Chaney, J.M.	Inner wing structure
Hewson, P.	Fuselage tail cone
Hillsdon, R.H.	Fuel system and lift engine installation
Hunter, J.C.	Main undercarriage and attachments
King, R.S.	Fuselage nose structure and freightfloor
Minion, R.J.	Lift engine pod structure
Mishra, D.S.	Aileron structure and mechanism
Momirski, M.	Tailplane and elevator structure
Murray, R.	Centre fuselage, wing and undercarriage frames
Riddett, R.C.	Fin and rudder structure
Smith, S.J.	Flap mechanism and structure
Stott, J.C.P.	Rear fuselage and loading door
Sykes D.R.	Nose undercarriage

APPENDIX B

Specification of Aircraft

1.0 Powerplants

1.1 Propulsion engines

Type: 4 Rolls Royce Tyne 11

Propellers: 16 ft dia., four blade.
Polar moment of inertia 30,000 lb. ft.^{2}

1.2 Lift engines

Type: 44 ducted fan units of 8,000 lb. nominal thrust

Length	3.4 ft.
Diameter	3.4 ft.
Weight, bare	600 lb.

1.3 Auxiliary power unit

Type: Turbomeca Palouste IV.
Located in undercarriage fairing

2.0 Geometry

2.1 Wing

Gross area	2,200 sq. ft.
Span	148.3 ft.
Aspect ratio	10.0
Sweepback on 0.25c line	3.5° approx.
Sweepback on 0.70c line	0°
Root chord	19.8 ft.
Tip chord	9.9 ft
Standard mean chord	14.83 ft.
Aerofoil section:	Root NACA 64_3418 (modified) 18% thickness ratio. Tip NACA 64_1212 (Modified) 12% thickness ratio.

Straight generators between root and tip, modification consists of eliminating reverse curvature at trailing edge.

Wing - body angle (centreline chord to body datum)	3°
Dihedral	1° 54'
Location of 0.25 S.M.C. forward of 0.7c line	7.05 ft.

2.2 Flaps

Type: F-59 Slotted; F-61 Fowler

Take off deflection		20°
Landing deflection:	F-59	60°
	F-61	40°
Flap chord/Wing chord		0.3
Inboard end of flap from aircraft centreline		8.5 ft.
Outboard end of flap from aircraft centreline	F-59	52.0 ft.
	F-61	43.2 ft.

2.3 Ailerons

Type: Sealed nose balance, differential movement.

Movement	20° up 12° down
Aileron chord/Wing chord - aft of hinge line	0.25
Balance chord/Aileron chord	0.20
Inboard end of aileron from aircraft centreline	52.5 ft
Aileron extends to wing tip	

2.4 Propulsion engine nacelles

Inboard nacelle centreline to aircraft centreline	18.0 ft
Outboard nacelle centreline to aircraft centreline	34.5 ft
Maximum nacelle diameter	4.0 ft
Front face of intake from leading edge of wing	11.5ft
Propeller datum above fuselage floor datum - inboard	10.6 ft
outboard	11.1 ft

2.5 Lift engine pods

Pod centreline to aircraft centreline	47.9 ft
Pod overall length	64.2 ft
Maximum width of pod	9.0 ft
Maximum depth of pod	6.0 ft
Distance of pod nose forward of wing 0.7 c	37.85 ft

2.6 Tailplane

Gross area	675 sq. ft.
Span (to fin centreline)	52.0 ft
Aspect ratio	4.0
Root chord (aircraft centreline)	15.0 ft
Tip chord (fin centreline)	11.0 ft
Standard mean chord	13.0 ft
Sweepback of 0.65c line (elevator hinge)	0°
Aerofoil section:- NACA 64012 (modified) 12% thickness ratio	
Tail setting angle (centreline chord to fuselage datum)	-0.5°
Tail volume coefficient	1.43
Dihedral	0°

2.7 Elevator

Type: Round nose balance, sealed

Movement	22° up and down
Elevator chord/Tailplane chord - aft of hingeline	0.35
Balance chord/Elevator chord	0.20

2.8 Fins

Type: Twin end plates

Area (each fin)	190 sq ft
Height (overall)	17.3 ft
Aspect ratio	1.57
Chord	11.0 ft
Fin centreline to aircraft centreline	26.0 ft
Height of fin tip above tailplane	10.8 ft

Aerofoil section: NACA 64012 (modified) 12% thickness ratio

2.9 Rudder

Type:	Round nose balance, sealed, differential control	
Movement		20° inboard 25° outboard
Rudder chord/Fin chord - aft of hinge line		0.35
Balance chord/Rudder chord		0.2
Rudder height		17 ft

2.10 Fuselage

Length	F-59	137.5 ft
	F-61	142.7 ft
Maximum height		16.2 ft
Maximum width		18.0ft
Distance of 0.25 S.M.C. aft of nose:-	F-61	63.0 ft.
Distance of nose forward of section datum (freighthold) front face):-	F-61	16.0 ft
Length of freighthold		99.8 ft
Doors:	4 doors 6 ft high x 3 ft wide (the rear doors are for paratroop dropping and incorporate a step and windshield)	
Windows:	16 inches diameter	

2.11 Undercarriage

Type:	Nosewheel	
Wheelbase (to centre of bogie) :-	F-59	47.0 ft
	F-61	52.0 ft
Track (to centre of bogie) :-	F-59	20.5 ft
	F-61	22.4 ft
Design Vertical Velocity (proof) at 200,000 lb (F-61 figure reduced for higher weights to keep absorbed energy constant)		12 ft/sec
Main undercarriage units, (4 wheel bogie)		
Bogie track		3.0 ft
Bogie wheelbase		5.5 ft
Tyres:	58 inches diameter x 21 inches width	
Tyre pressure:	200,000 lb.	60 p.s.i.
	250,000 lb.	76 p.s.i.
Static tyre closure (200,000 lb.)		5 inches
Maximum tyre closure		10 inches
Centre of bogie wheelbase aft of 0.25 S.M.C.		4.1 ft
Bogie rear axle stroke		1.75 ft
Max. proof reaction factor		2
Nosewheel unit, (twin wheels):-		
Track		1.8 ft
Tyres:-	42 inches diameter x 13.5 inches width	
Tyre pressure:-	200,000 lb.	70 p.s.i.
	250,000 lb.	89 p.s.i.
Static tyre closure (200,000 lb.)		3.5 inches
Max. tyre closure		7.0 inches

3.0 Weights, centres of gravity and moments of inertia

3.1 Conventional configuration

Maximum take off weight	200,000 lb
Maximum landing weight	190,000 lb
Minimum landing weight	110,000 lb
Design operating weight (zero fuel and payload)	104,800 lb
Maximum payload	77,000 lb
Maximum fuel load (wing tanks)	77,000 lb

Centre of gravity position (zero fuel and payload)
a) Undercarriage extended 1.27 ft fwd of 0.25 S.M.C.
7.5 ft above floor datum

b) Undercarriage retracted 1.39 ft fwd of 0.25 S.M.C.
7.83 ft above floor datum

Allowable centre of gravity range 0.12 to 0.32 S.M.C.

3.2 V.T.O.L. Configuration

Maximum take off weight	250,000 lb
Maximum landing weight	240,000 lb
Minimum landing weight	155,000 lb
Design operating weight (zero fuel and payload)	148,800 lb
Maximum payload	77,000 lb
Maximum fuel load (in wing tanks)	77,000 lb
Maximum overload of fuel (in wing and freighthold for ferry role)	101,200 lb

Centre of gravity position (zero fuel and payload)
a) Undercarriage extended 0.63 ft fwd of 0.25 S.M.C.
7.5 ft above floor datum

b) Undercarriage retracted 0.71 ft fwd of 0.25 S.M.C.
7.83 ft above floor datum

Allowable centre of gravity range is as for the conventional configuration.

3.3 Moments of inertia

These are sensitive to both fuel and payload distribution. Likely extremes about axes passing through the appropriate centre of gravity are:-

Conventional configuration:-
Pitch:- 10^8 lb ft^2 at design operating weight to 1.6×10^8 lb ft^2 with max. payload

Roll:- 0.75×10^8 lb ft^2 at operating weight to 2.0×10^8 lb ft^2 with max. fuel

Yaw:- 1.65×10^8 lb ft^2 at operating weight to 3.0×10^8 lb ft^2 with max. fuel or payload

V.T.O.L. configuration:-
Pitch:- 1.15×10^8 lb ft^2 at operating weight to 1.75×10^8 lb ft^2 with max. payload

Roll:- 1.8×10^8 lb ft^2 at operating weight to 3.1×10^8 lb ft^2 with max. fuel

Yaw:- 2.75×10^8 lb ft^2 at operating weight to 4.4×10^8 lb ft with max. payload

4.0 Aerodynamic data

4.1 General information :- F-59

Maximum lift coefficients (untrimmed)	
Basic wing (no flaps)	1.65
Flaps at 20° (no blowing)	2.45
Flaps at 60° (no blowing)	2.85
Ailerons drooped at 45° and blown, flaps 20° unblown	3.2
Ailerons drooped at 45° and blown, flaps 60° unblown	3.6
Ailerons drooped at 45° and blown, flaps 60° blown	4.15
Zero lift drag at 100 ft/sec (D_{100})	630 lb

Drag polar (cruise) $C_D = 0.0241 + 0.0382\ C_L{}^2$

Increment in D_{100}:-	due to undercarriage down	500 lb
	due to flaps at 20°	260 lb
	due to flaps at 60°	1,910 lb
	due to drooped ailerons at 45°	500 lb

Pitch moment coefficient at zero lift, C_{M_o}

(flaps up, ailerons normal)		-0.06
Increment due to:-	flaps at 20°, unblown	-0.07
	flaps at 20°, blown	-0.10
	flaps at 60°, unblown	-0.24
	flaps at 60°, blown	-0.35
	ailerons at 45° blown	-0.16

Location of wing-body aerodynamic centre (mean position).	0.265 S.M.C.

Flap and aileron blowing (blowing from shroud)

Ailerons:

Supply from the output of the two auxiliary power units, the ailerons being fed from a common reservoir.
The total mass flow is 11 lb/se at 45 p.s.i. and 400°K at the blowing slot. Ejection velocity is 1580 ft/se ($M = 1.2$) ($C\mu = 0.03$).

Flaps

20° flap position for take off, engines at 15,250 r.p.m. The engine bleed is 3% of mass flow giving a total of 6.5 lb/sec at 200 p.s.i. and 670°K. Ejection velocity is 2670 ft/sec ($M = 1.6$) ($C\mu = 0.013$). Engine power loss is equivalent to a 10°C rise in ambient temperature, that is, approximately 500 H.P. per engine

60° flap position for landing, engines at 13,500 r.p.m. The engine bleed is 8% of mass flow giving a total of 17 lb/sec at 173 p.s.i. and 630°K. Ejection velocity is 2470 ft/sec ($M = 1.5$) ($C\mu = 0.03$). The power loss is approximately 1130 H.P. per engine

4.2 General information:- F-61

Maximum lift coefficients (untrimmed)	
Basic wing	1.65
Flaps at 20° (take off)	2.13
Flaps at 40° (landing)	2.67
Zero lift drag at 100 ft/sec (D_{100})	
Conventional configuration	600 lb
V.T.O.L. configuration	715 lb

Drag polar:- Conventional configuration at cruise:

$$C_D = 0.0229 + 0.0367{C_L}^2$$

at landing:

$$C_D = 0.0389 + 0.0414{C_L}^2$$

V. T. O. L. configuration at cruise:

$$C_D = 0.0273 + 0.0367{C_L}^2$$

at landing:

$$C_D = 0.0433 + 0.0414{C_L}^2$$

Pitching moment coefficient at zero lift, C_{M_0} (flaps up)	-0.070
Increment due to V. T. O. L. pods	-0.003
Increment due to flaps at 20°	-0.266
Increment due to flaps at 40°	-0.570
Location of wing-body aerodynamic centre (mean position)	-0.265 S. M. C.
Wing no lift angle	-2.0°

4.3 Derivatives (cruising conditions)

Slope of wing-body lift curve a_1	5.2/rad
Slope of aileron hinge moment curve due to wing incidence, b_1	-0.18/rad
Slope of aileron hinge moment curve due to aileron angle, b_2	-0.43/rad
Slope of tailplane lift curve a_{1T}	4.1/rad
Slope of lift curve due to elevator angle, a_{2T}	3.1/rad
Slope of elevator hinge moment curve due to tailplane incidence, b_{1T}	-0.23/rad
Slope of elevator hinge moment curve due to elevator angle, b_{2T}	-0.42/rad
Slope of fin and rudder lift curve, a_{1F}	2.0/rad
Slope of lift curve due to rudder angle, a_{2F}	1.55/rad
Slope of rudder hinge moment curve due to fin incidence, b_{1F}	-0.08/rad
Slope of rudder hinge moment curve due to rudder angle, b_{2F}	-0.23/rad
Downwash at tailplane, ϵ	$3.5C_L{}^{\circ}$
Rolling moment coefficient due to aileron angle, l_ξ	-0.175/rad
Rolling moment coefficient due to rolling, l_p	-0.54
Rolling moment coefficient due to rolling, l_v	-0.10
Increment in l_v due to V. T. O. L. pods l_r	- 0.03
Rolling moment coefficient due to yawing, l_r $0.15C_L$	+ 0.035
Yawing moment coefficient due to sideslip, n_v	0.085
Increment in n_v due to V. T. O. L. pods	-0.1
Yawing moment coefficient due to yawing, n_r	-0.18
Tailplane rolling moment coefficient due to sideslip, K	0.15/rad

4.4 Stalling speeds:- F-61

Weight	130,000 lb.	flaps 40°	73 knots E.A.S.
	190,000 lb.	flaps 40°	96 knots E.A.S.
	200,000 lb.	flaps 20°	113 knots E.A.S.
	240,000 lb.	flaps 40°	108 knots E.A.S.
	250,000 lb.	flaps 20°	126 knots E.A.S.

5.0 Loading requirements

The F-59 aircraft is designed to meet both British civil airworthiness and military requirements, but the F-61 is intended only for military applications.

5.1 Design envelope

The maximum unfactored normal acceleration is 2.5g and the design flight speeds are :-

V_C	280 knots E.A.S.
V_D	350 knots E.A.S.
V_E	245 knots E.A.S.

5.2 Aircraft life and load frequencies

The following details apply specifically to the F-61 military design

A total design life of 20,000 hours, broken down into separate flights:-
400 hours in a V.T.O.L. training role, 15 minute flights up to 1,000 ft altitude and at 180,000 lb weight.
100 hours in an operational V.T.O.L. role, as above, but at 240,000 lb.
4,000 hours in an operational vertical take off, conventional landing role, each flight of 2 hours duration at altitudes up to 15,000 feet, taking off at 250,000 lb.
700 hours in a conventional training role, one hour flights up to 5,000 feet at 130,000 lb.
2,800 hours in a conventional operational role, as above but at 187,000 lb.
12,000 hours in a conventional operational role, ten hour flights up to 20,000 feet altitude and taking off at 200,000 lb.

The main undercarriage design caters for two applications of turning and swinging loads and two applications of braked taxying loads per conventional flight, each at 50% of the maximum design condition. The nosewheel design caters for one application of dynamic braking to full design load and four applications of braked turning at 20% of the maximum design condition for each conventional flight. Each V.T.O.L. flight is considered to apply 50% of the maximum load.

5.3 Freightloads (Unfactored)

The freighthold is designed to meet the following typical loading conditions:-

a) 3 armoured personnel carriers, totalling 76,500 lb with axle loads on the main floor beams and the vertical centre of gravity 4.0 feet above the floor.

b) 3 ten ton trucks, totalling 76,500 lb with axle loads on the main floor beams and the vertical centre of gravity 4.5 feet above the floor.

c) 2 lift engine pods, totalling 44,000 lb.

d) 2 units of heavy earth moving equipment weighing 75,000 lb, with the load on the main floor beams uniformly distributed over lenghts 4 feet to 24 feet either side of the aircraft centre of gravity. Vertical centre of gravity 3 feet above the floor.

e) A load of 77,000 lb uniformly distributed over the whole floor with a vertical centre of gravity up to 4 feet above the floor.

f) 3 heavy dropping platforms totalling 66,000 lb. A mean load of 125 lb/sq ft over the centre 8 feet of the floor width, with the vertical centre of gravity 3 feet above the floor.

g) Local loads of up 1,000 lb on an area 4 inches square anywhere on the floor.

During loading at the rear the ramp loads are either 37,500 lb distributed over the length of the door on the main beams, or 14,500 lb at the centre, also on the main beams.

In the case of air dropping, the door is designed to cater for the weight of either one ten ton truck or one heavy dropping platform standing on the door. The dropping of a ten ton truck is limited to the case of a single vehicle located at the aircraft centre of gravity immediately prior to the drop.

5.4 Pitching acceleration

The design values are :-

Speed V_A :- Pitching acceleration $\frac{166}{V_A}$ rad/sec^2 (V_A ft/sec E.A.S.)

V_C :- 0.35 rad/sec^2

V_D :- 0.225 rad/sec^2

5.5 Roll rates

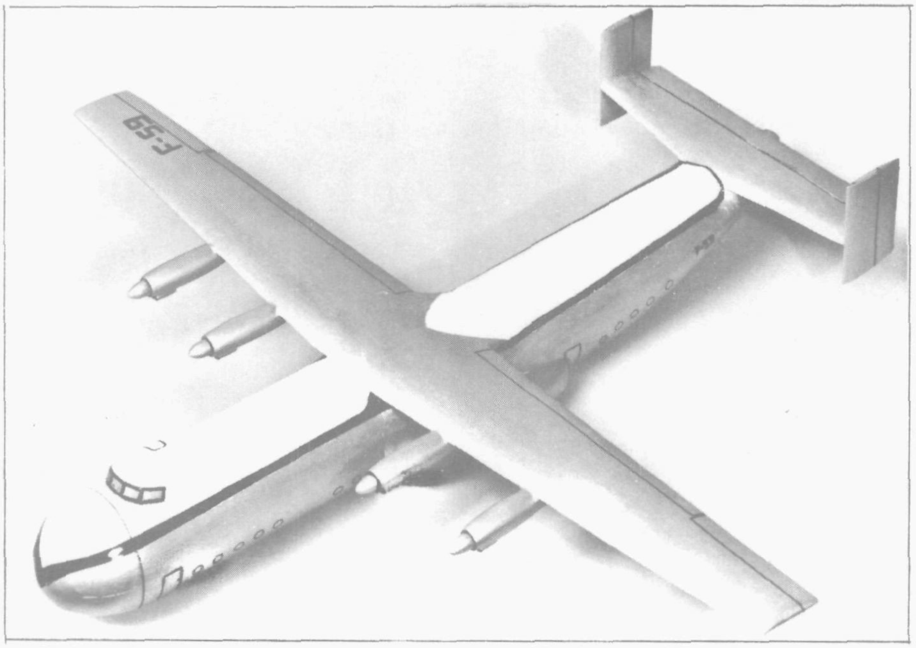
Low speed (136 ft/sec) Roll rate 9.6 degrees/sec (angle limit)
High speed (V_D) 7.0 degrees/sec

5.6 Cabin pressurisation

The maximum cabin differential pressure is 7 p.s.i., which allows a cabin altitude of 8,000 feet to be maintained for all cases except the extreme long range cruise. In this case the cabin altitude reaches a maximum of 10,000 feet.

5.7 Design brake torque

A static brake torque of 14,000 lb ft per brake is assumed. The energy absorption is 9.6×10^6 lb ft per brake on 8 brakes in normal conditions.



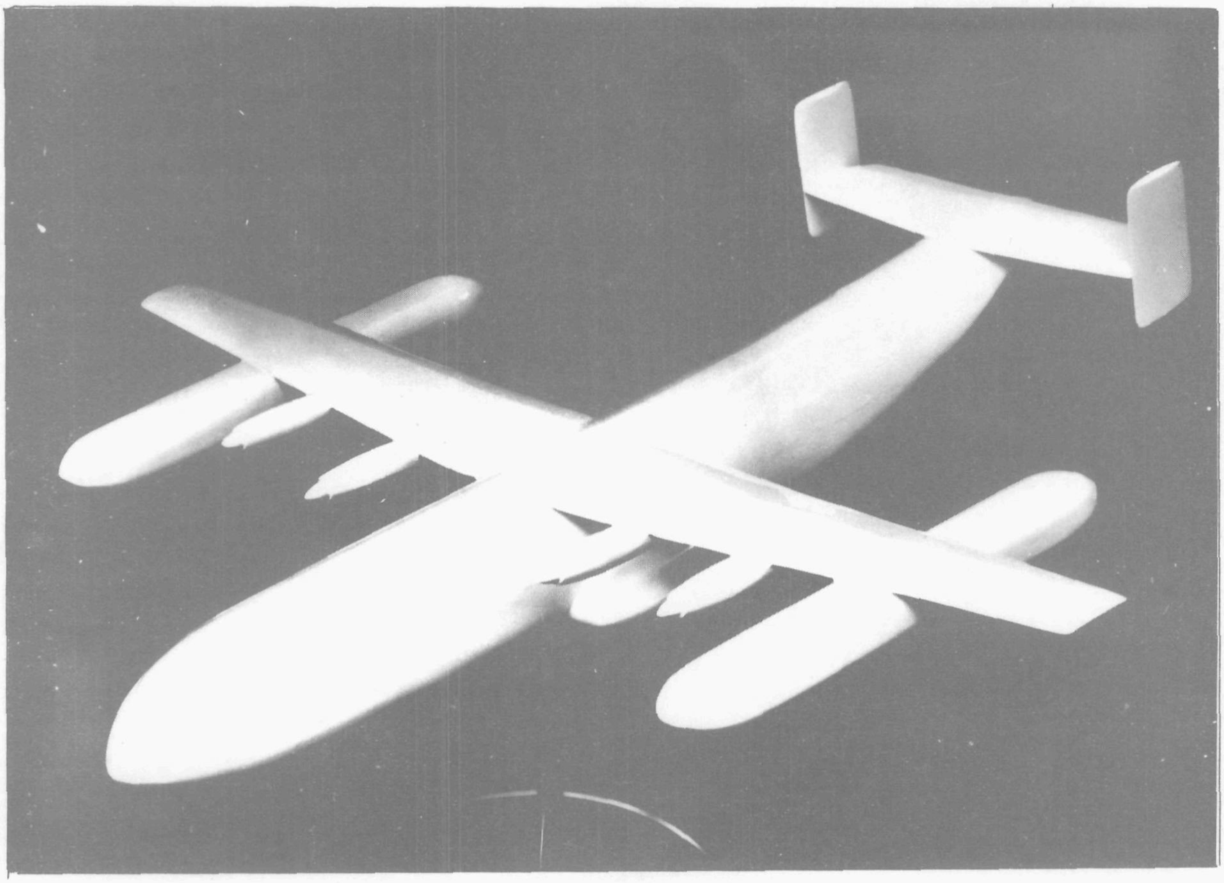


FIG. 1. MODEL OF F-59 DESIGN

FIG. 2. MODEL OF F-61 DESIGN

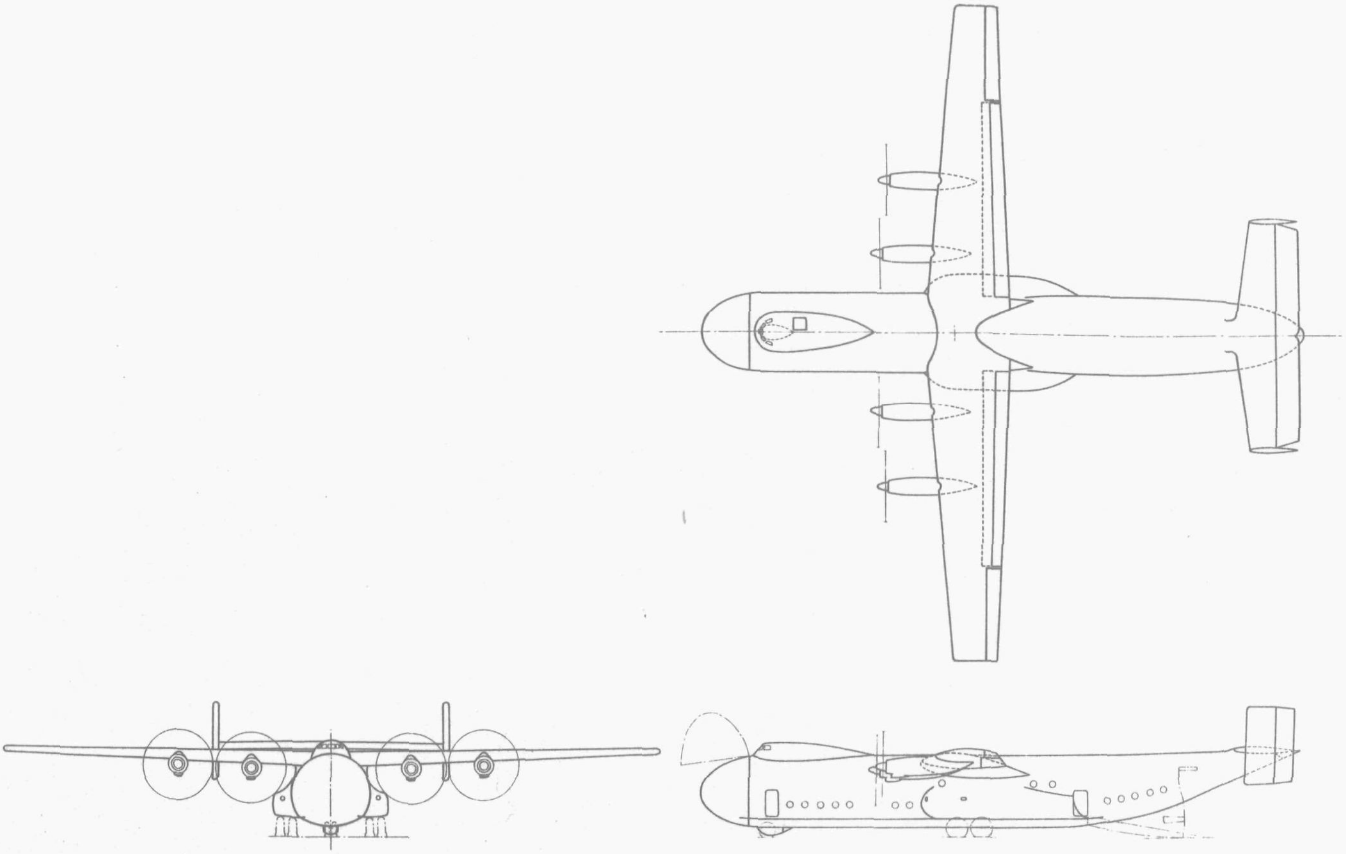


FIG. 3. GENERAL ARRANGEMENT OF THE F-59 DESIGN

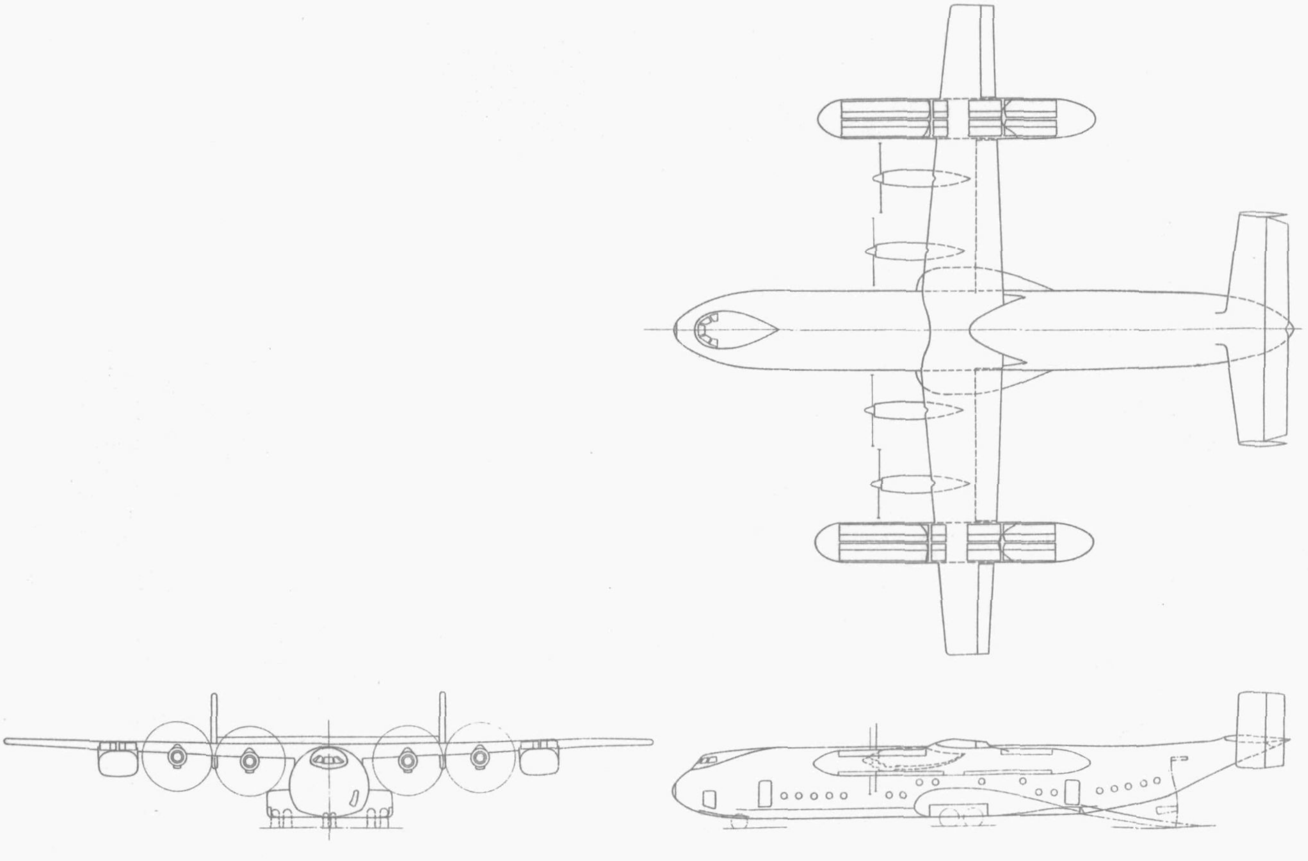
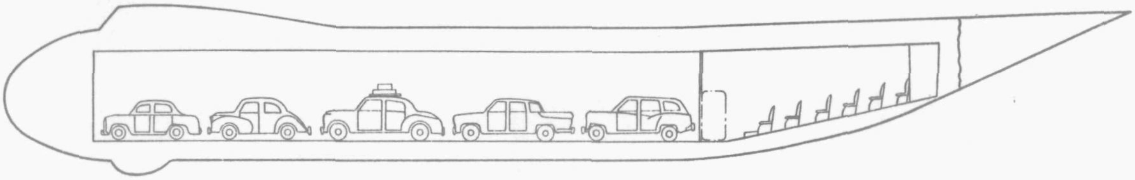
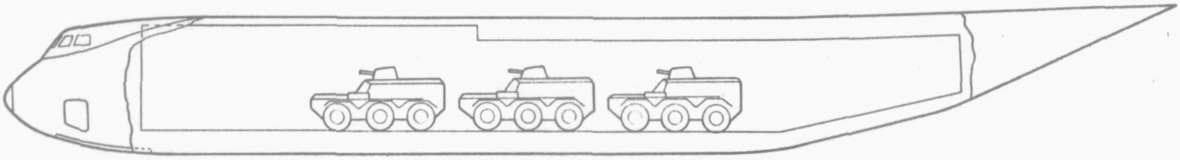


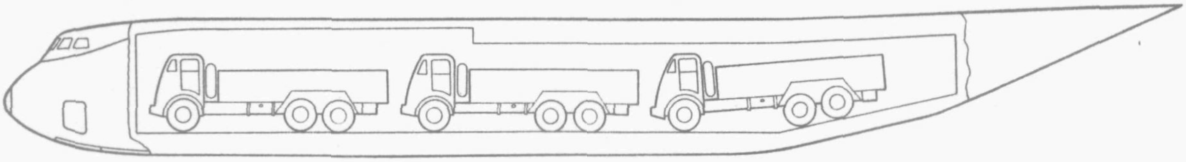
FIG. 4. GENERAL ARRANGEMENT OF THE F-61 DESIGN



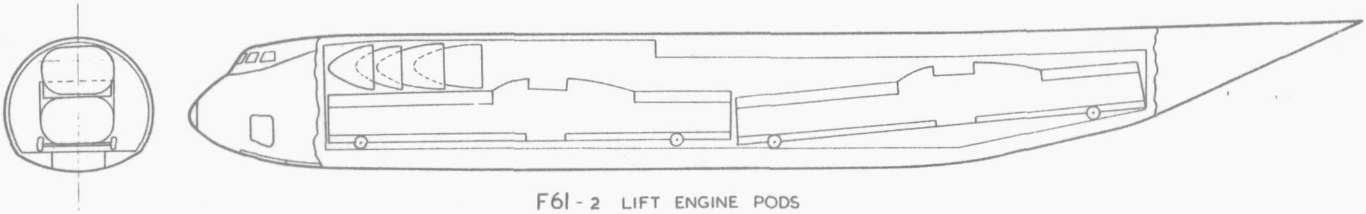
F59 - VEHICLE FERRY, 10 CARS.



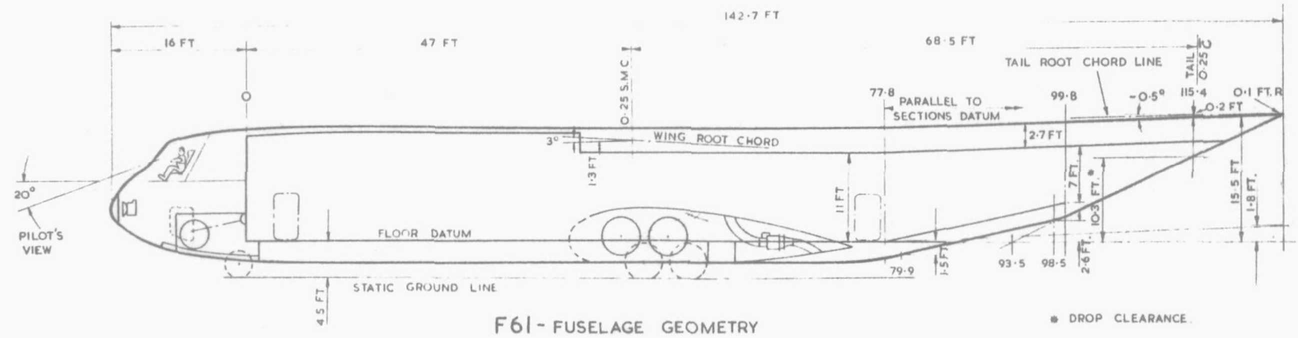
F61 - 3 ARMOURED PERSONNEL CARRIERS. CASE A



F61 - 3 TEN TON TRUCKS. CASE B

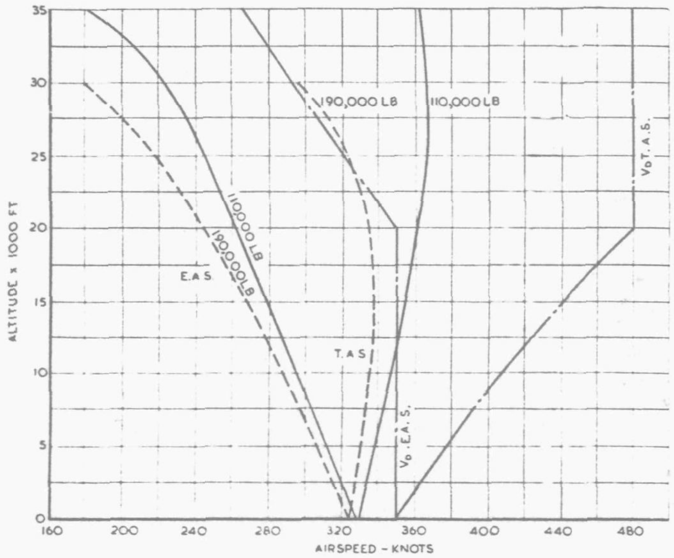


F61 - 2 LIFT ENGINE PODS



F61 - FUSELAGE GEOMETRY

FIG. 5. TYPICAL FREIGHT LOADS

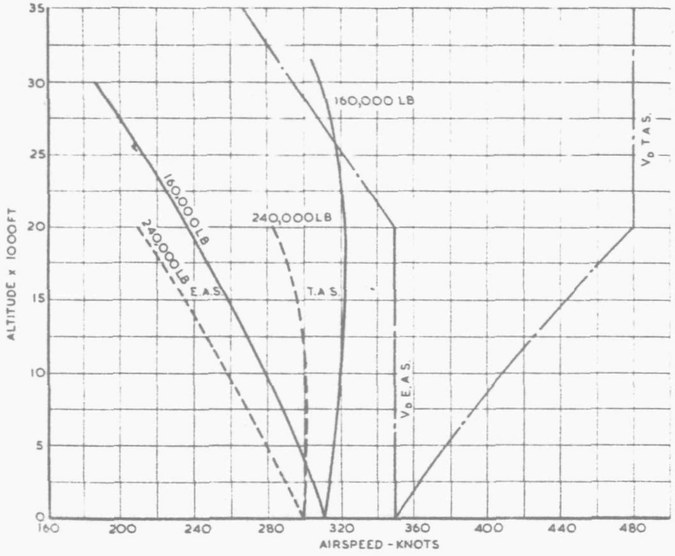


LEVEL FLIGHT PERFORMANCE

CONVENTIONAL AIRCRAFT CONFIGURATION

ENGINES:- MAX CONTINUOUS 14,100 R.P.M.

FIG. 6.



LEVEL FLIGHT PERFORMANCE

V.T.O.L. CONFIGURATION

ENGINES:- MAX CONTINUOUS

FIG. 7.

PAYLOAD RANGE DIAGRAM

AIRCRAFT IN CONVENTIONAL CONFIGURATION

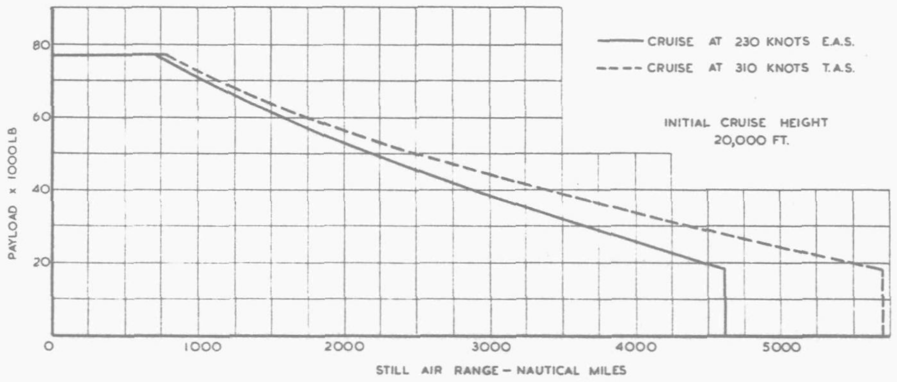


FIG. 8.

PAYLOAD RANGE DIAGRAM

AIRCRAFT IN V.T.O.L. CONFIGURATION

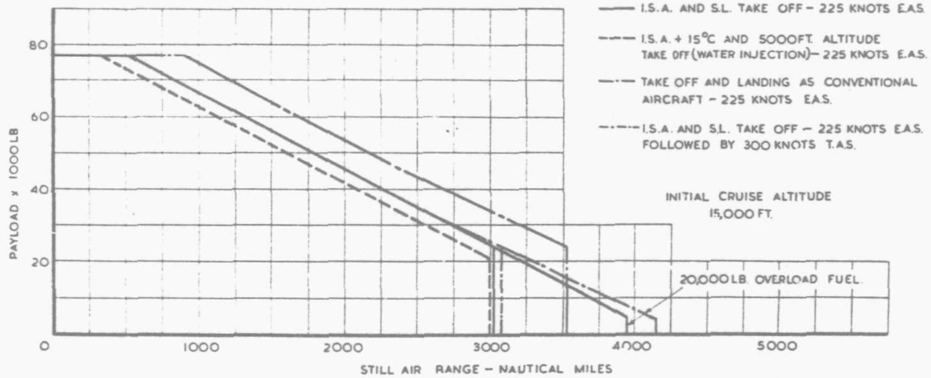
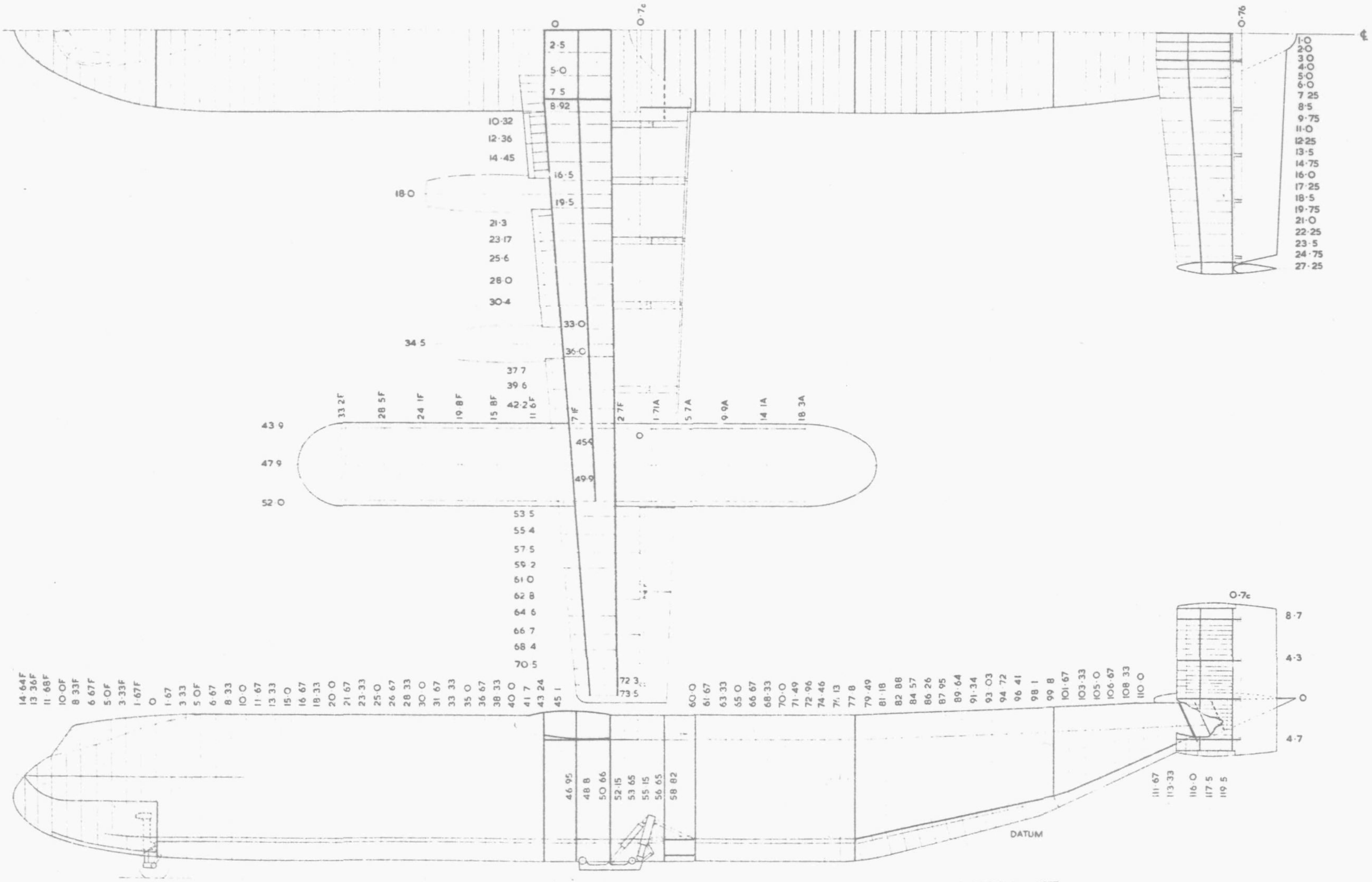


FIG. 9.



ALL STATIONS IN FEET

FIG. 10. KEY DRAWING OF F-61 STRUCTURE

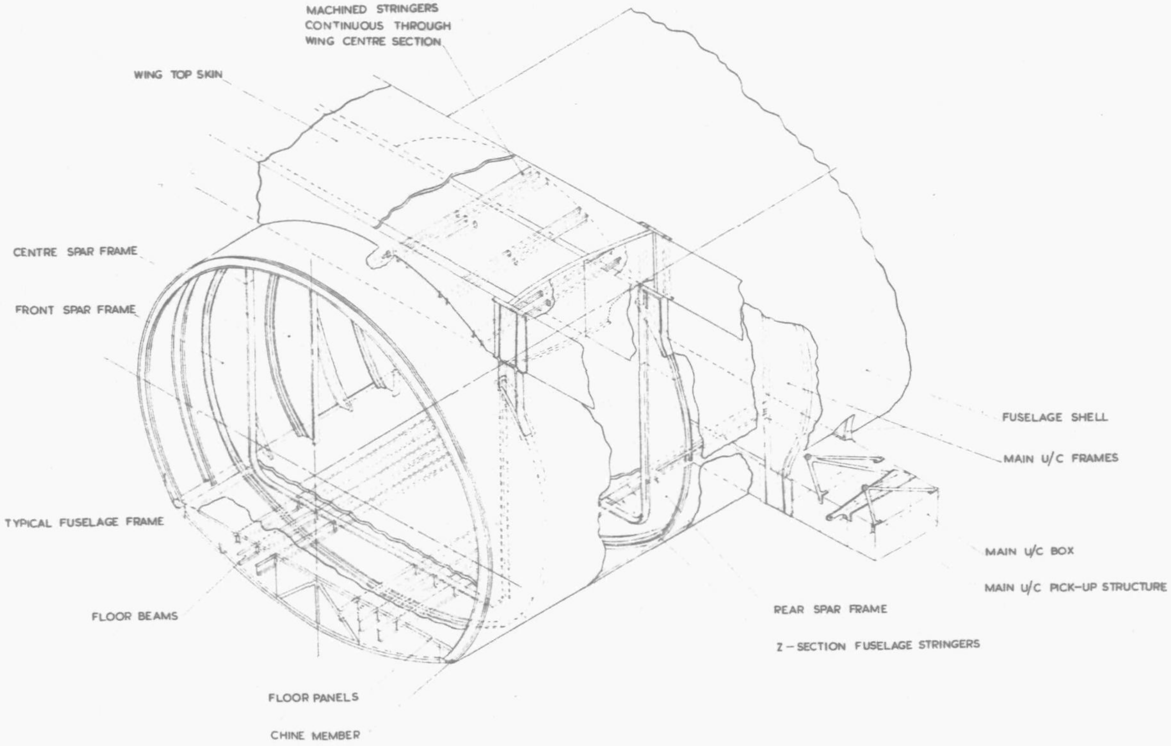
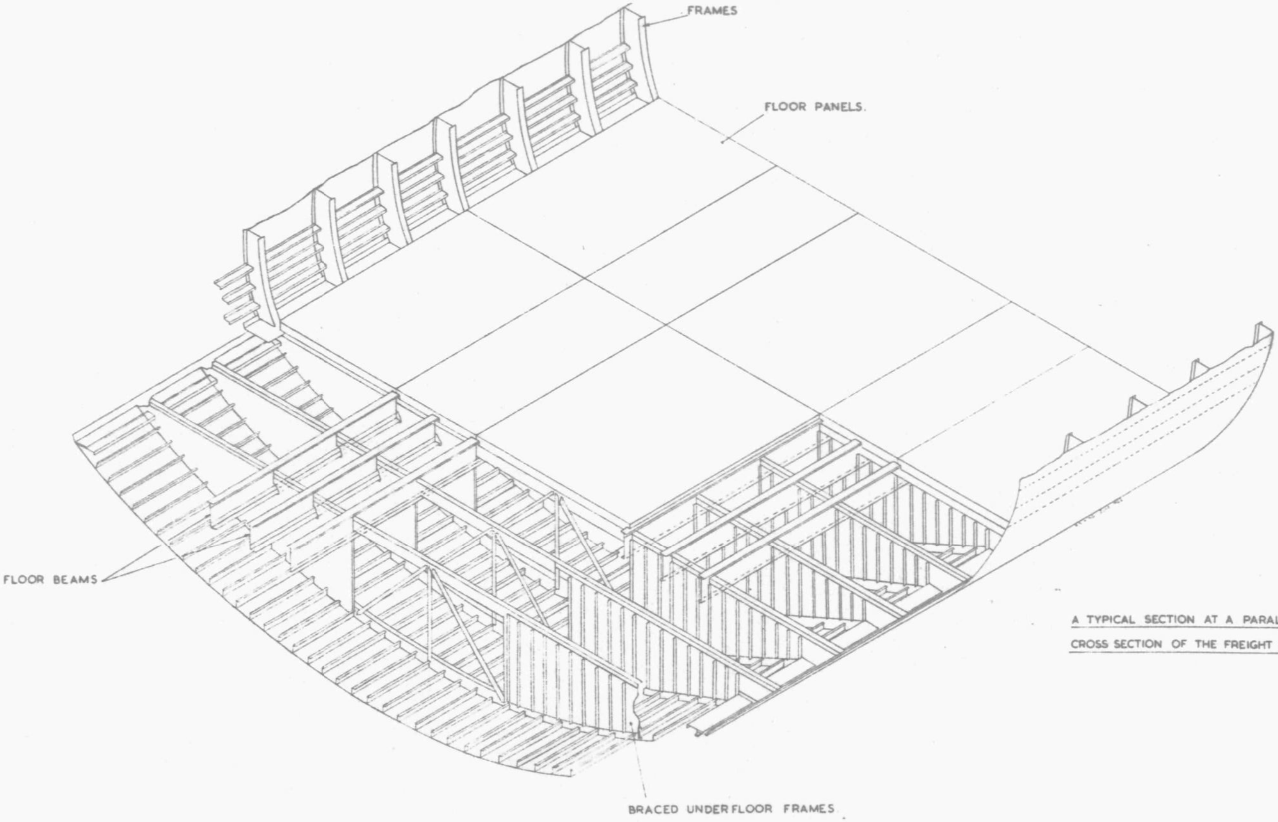


FIG. 11. FUSELAGE-WING INTERSECTION STRUCTURE



A TYPICAL SECTION AT A PARALLEL CROSS SECTION OF THE FREIGHT HOLD.

FIG. 12. FREIGHT FLOOR STRUCTURE

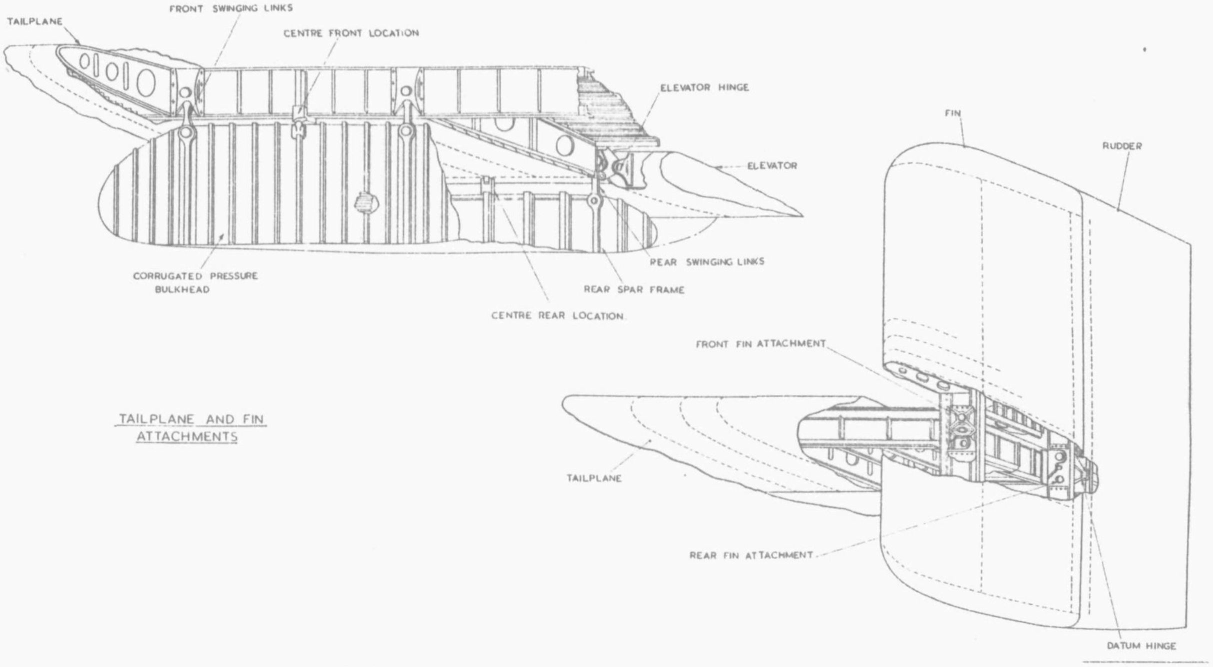


FIG. 13. TAILPLANE AND FIN ATTACHMENTS

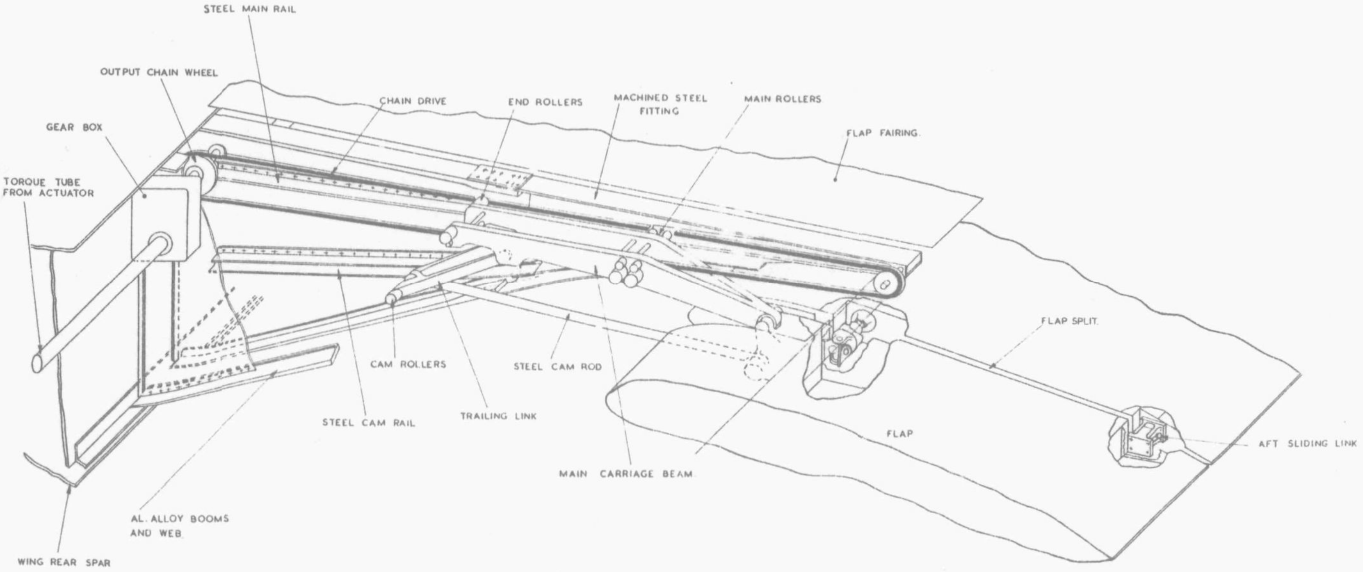


FIG. 14. FLAP MECHANISM

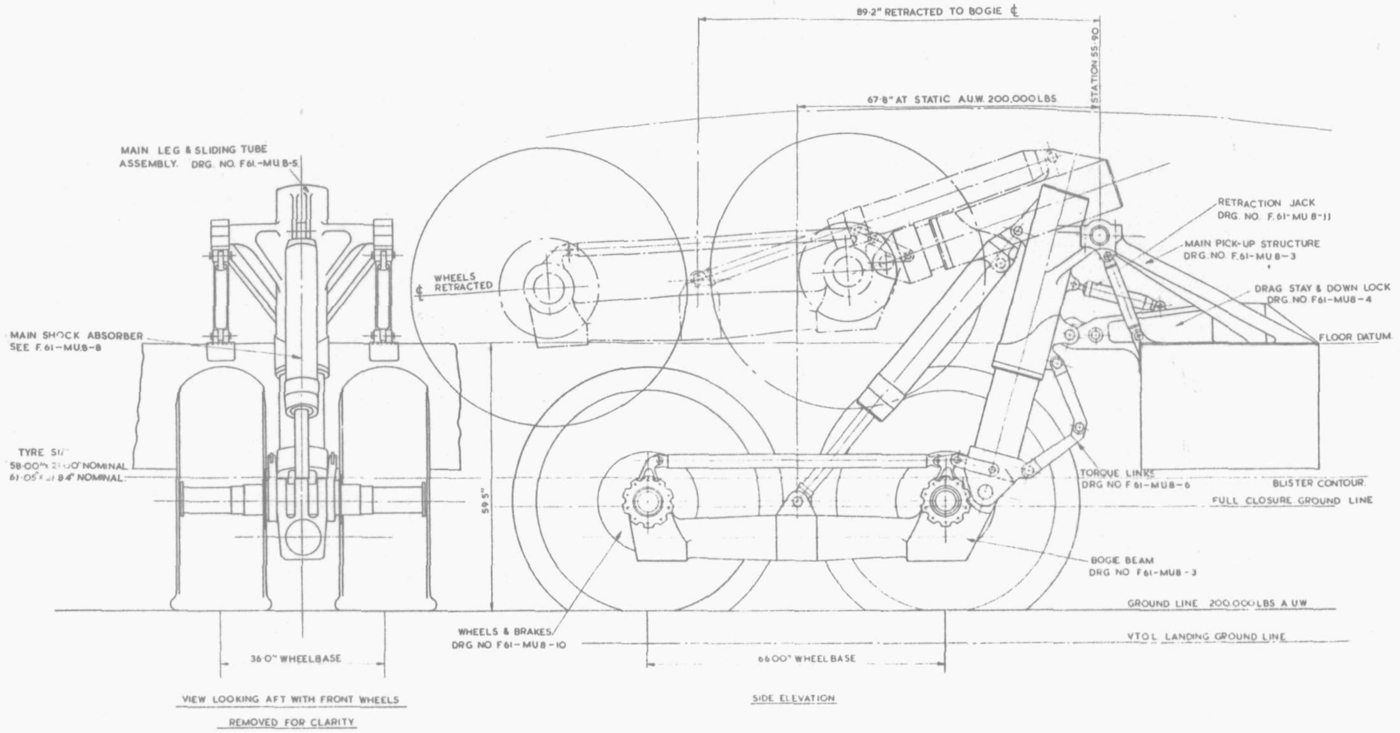


FIG. 15. MAIN UNDERCARRIAGE LAYOUT

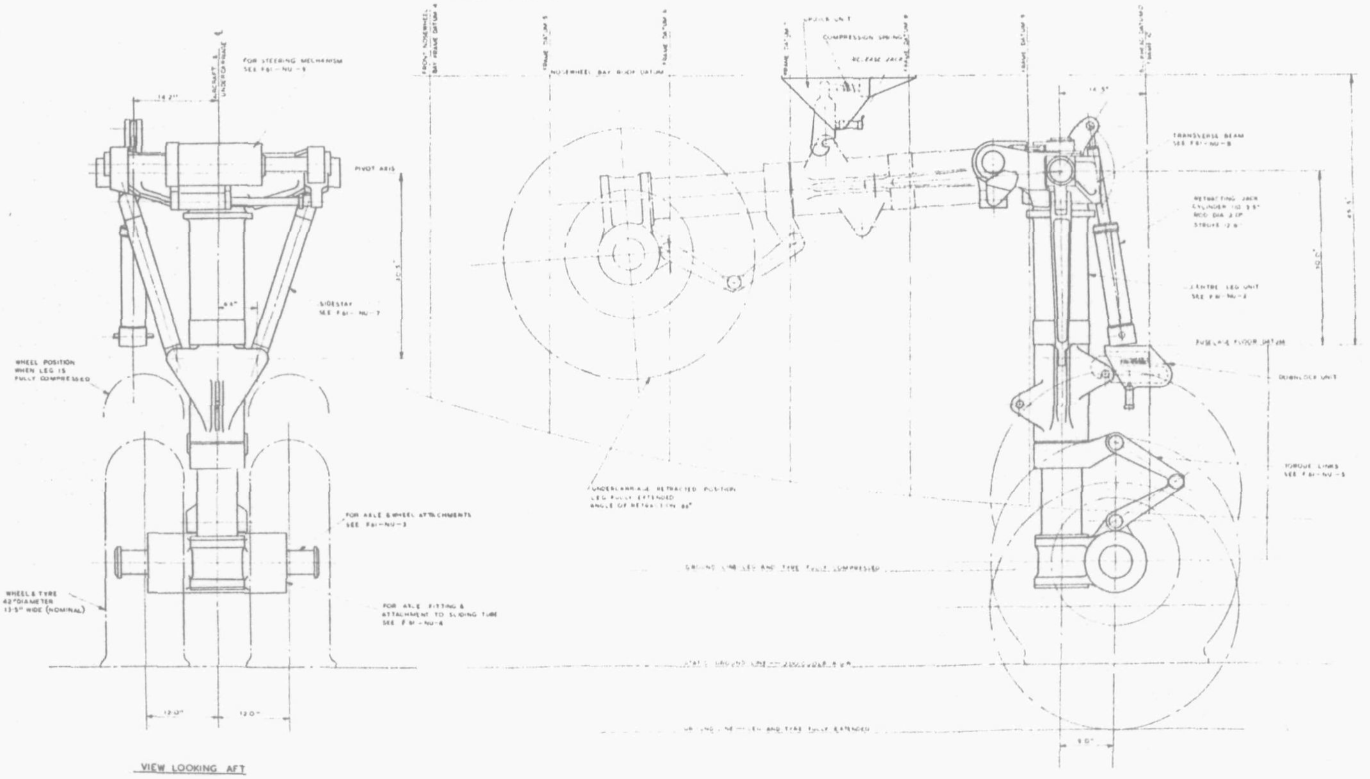


FIG. 16. NOSE UNDERCARRIAGE LAYOUT

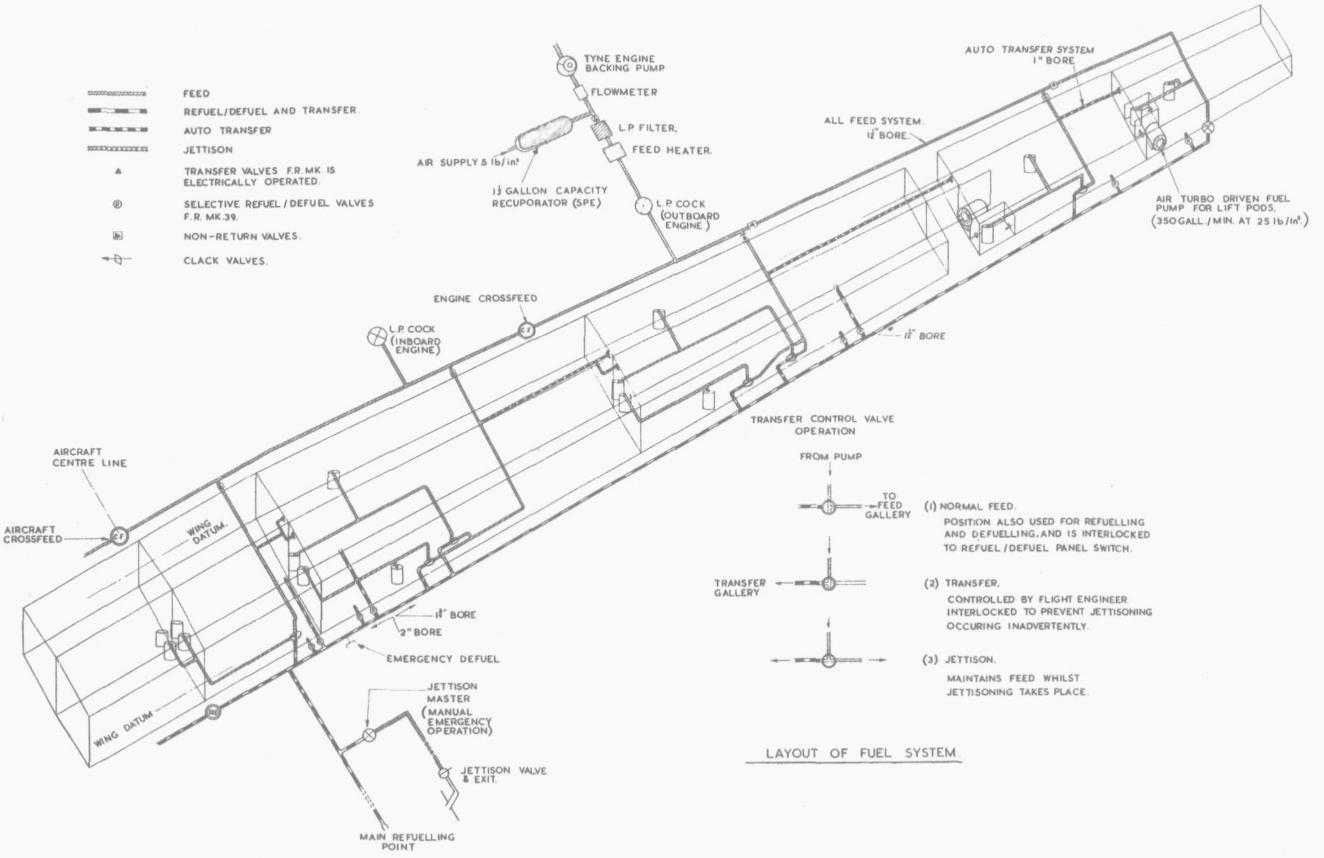


FIG. 17. FUEL SYSTEM ARRANGEMENT

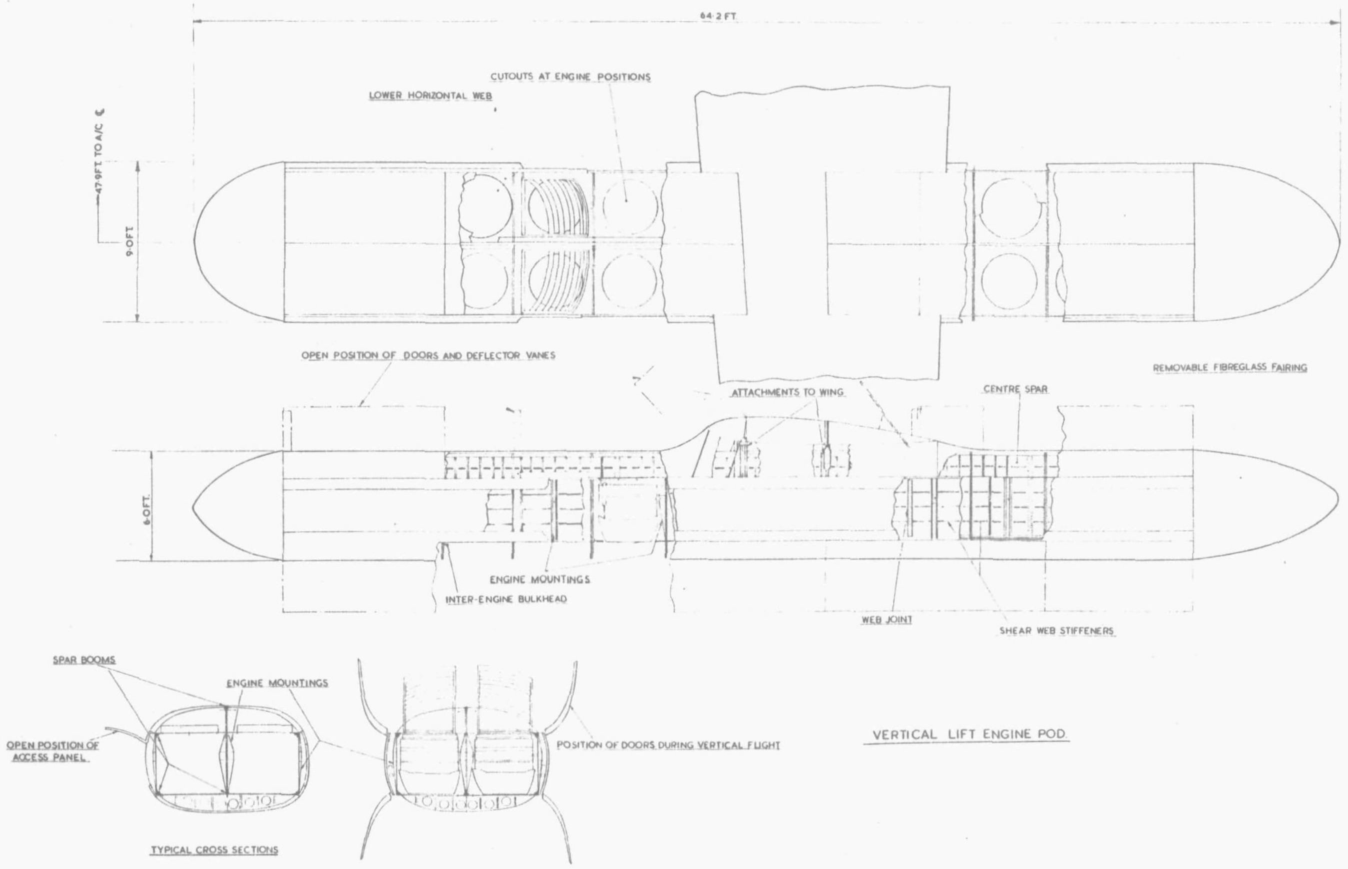


FIG. 18. V.T.O.L. POD STRUCTURE AND INSTALLATION

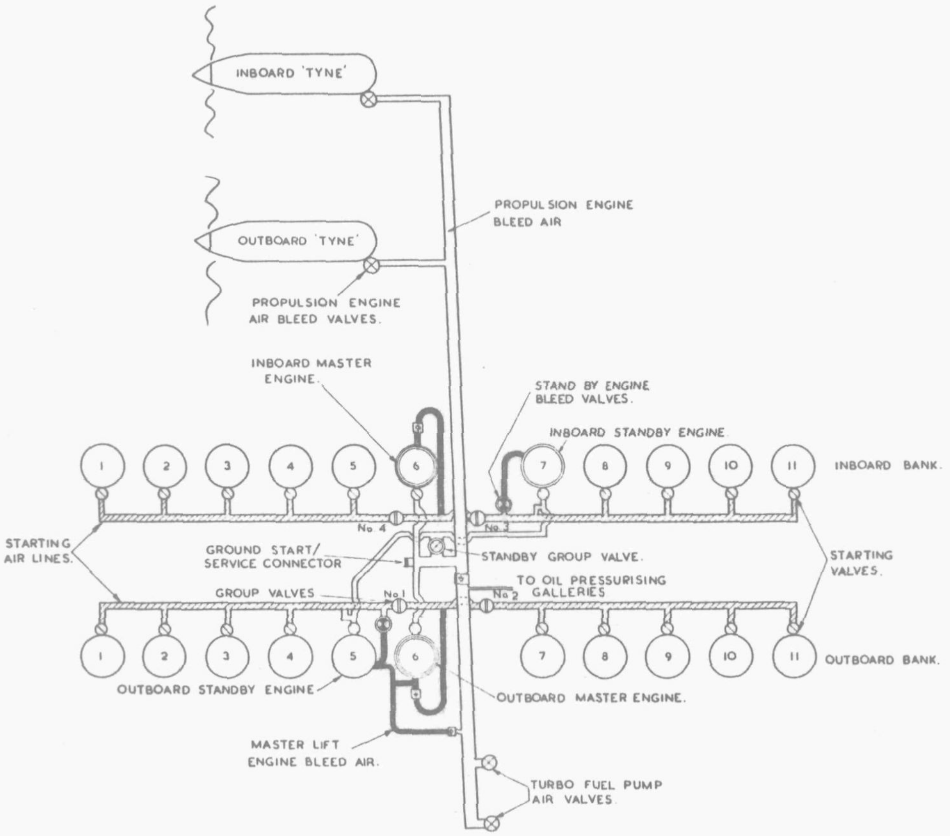


FIG. 19. V.T.O.L. ENGINES STARTING SYSTEM