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Aeroplane Design Study

STOL Airliner (A71)

Part 2 — DETAIL DESIGN FEATURES

by D. HOWE

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SUMMARY

This report is concerned with a description of the detail design features of the A71 project study. This aircraft is an airliner designed for operation off single 2000 ft long runways. The overall description of the design and its aerodynamic characteristics are contained in Part I of the report (Ref.1).

The detail design of the structure and systems is conventional in most respects. The need to provide a long stroke undercarriage for STOL operations incurred a large weight penalty and it is concluded that further work is necessary to establish acceptable requirements for this type of undercarriage. A separate investigation (Ref.3) has shown that the aircraft does not meet its stipulated design objectives due to an inability to cope with engine failure and gusting cross wind conditions. A study to investigate the potential of the cross-coupling of adjacent powerplants to mitigate engine failure control problems suggests that the weight penalty is not justified (Ref.4).

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1. INTRODUCTION

The subject of the 1971 design study was an STOL airliner, designated the A71. The basic configuration and operating conditions of the aircraft are described in Part 1 of this report (Ref.1). This second part is concerned with a description of the detail design work undertaken by the sixteen students who participated in the study. Appendix A lists their individual responsibilities. Some more general comments on certain aspects of the investigation are included.

The aircraft has a design weight of 115,000 lbs and is intended for all weather operations off single 2000 ft long runways. It is powered by four underwing mounted RB410 high bypass ratio fan engines, individually rated at 14500 lb static thrust. Landing on to the short runway implies a 7½° glide path with an approach speed of just under 80 knots corresponding to a maximum landing weight of 100000 lbs. This can only be achieved by developing an effective lift coefficient in excess of 3 if the wing loading is to be kept to a tolerably high value for passenger comfort in cruising flight. A combination of wide chord double slotted flaps and engine mounted thrust deflectors is used to turn the exhaust efflux and give the necessary amount of powered lift. Leading edge flaps are incorporated to assist in the process. A general impression of the layout of the aircraft can be gathered by reference to Figure 1, which is the key structural drawing. The design features a swept, high mounted wing with a high tailplane and a long undercarriage which retracts forward into wing fairings. Up to 120 passengers can be carried over a still air, zero reserves, range of 1500 n. miles.

An augmenter flap version of the aircraft is also being investigated (Ref.2), as are some of the lowspeed control and stability characteristics of the externally blown flap design (Ref.3).

2. DESCRIPTION OF THE STRUCTURAL DESIGN

Figure 1 indicates the location of the main structural components in the airframe. The construction uses conventional light alloys for the most part with high grade steels for the undercarriage units and certain other local details.

2.1 Fuselage

The nominal fuselage frame pitch of 20 ins was determined by pressure cabin crack propagation considerations. The minimum shell thickness of 0.048 ins occurs over the forward portion of the fuselage. Elsewhere the L72 skins vary up to a maximum of 0.1 ins in the region of the two wing attachment frames. The skins are stiffened by L71 zed section stringers which are placed at a pitch of from 2.5 ins to 6 ins round the circumference of the section.

The larger values of pitch occur in the forward region and are associated with skin buckling at loads below the proof condition. Stringer geometry varies considerably. In the more lightly loaded regions a depth of 1.0 in is associated with a thickness of 0.028 ins and a free flange width of 0.3 ins. The corresponding dimensions over the centre fuselage are 1.5 ins, 0.064 ins and 0.42 ins respectively. The stringers are continuous past the standard frames and are cleated to them, but they are interrupted at and connected to the substantial pick up frames. The basic standard frame design is a 4 ins deep L71 lipped channel section pressing connected to the shell by a pressed angle through which the stringers pass. The flange width and thickness of the channel vary between 0.75 ins and 1.0 in and 0.028 ins and 0.056 ins respectively.

Both of the heavily loaded wing pick up frames are of similar design. A pair of light alloy channel section forgings is joined by side plates to make up the basic box section. In each case one of the forged channels continues into the wing section to attach to the outer face of one of the spar webs. The overall depth of the channels varies between 6.8 ins and 10 ins round the fuselage cross section with the web thickness being between 0.2 ins and 0.4 ins and a 0.6 ins thick flange. Side plate thickness lies between 0.1 ins and 0.2 ins. The basic fuselage shell is cut away to allow the wing box to pass across it. The end load carrying material thus removed is made good by a pair of side longerons placed below the wing. These are L65 extrusions with a lipped, acute angle cross section of some 4 ins depth and 0.35 ins thickness.

The fin front spar joins the fuselage in a sloping half frame, the lower ends of which terminate at a vertical fuselage bulkhead. The upper part of the sloping frame is forged integrally with the spar root and is a channel section with a 1.5 ins deep flange and maximum thickness of 0.35 ins. The web of the vertical bulkhead consists of an assembly of sandwich panels which have an end grain balsa core and light alloy facings. The fin rear spar is continued into a complete sloping frame. The aft end of the pressure shell is closed by a 0.022 ins thick L72 domed bulkhead of relatively small diameter. It is located aft of the ventral access door and stairs and has both radial and circumferential crack stoppers. The nose undercarriage is attached to the lower bulkhead portion of frame 150 ins. The leg trunnion fittings are housed in bearings contained in a pair of forged light alloy brackets. They lie primarily in the vertical direction but have side webs to transmit lateral loads. Fore and aft loading is taken back to the fuselage shell by two tubular vee bracing struts.

The windscreen panels are mounted in a built up framework of L65 extrusions. The main forward facing windows are installed from the outside to facilitate replacement. They consist of an outer 0.075 ins thick glass, a 1.19 ins vinyl layer and an inner 0.54 ins thick chemcor glass. The direct vision panels are located to either side of the front windows and are of similar design except that the inner glass is only 0.27 ins thick. A 0.9 ins thick double ply stretched acrylic material is used for the side cockpit windows. The passenger window transparencies have two separate 0.15 ins thick glasses separated by a 0.4 in air gap. The cutouts for them are reinforced by a continuous longitudinal 0.064 ins thick L71 doubler which is reduxed to the basic shell. The skins around the cutouts for the baggage and passenger side doors are also reinforced by reduxed doubler plates. However in these cases a series of laminations is used to bring the total local thicknesses to maximum values of 0.3 ins and 0.21 ins respectively. In addition the edges are supported by 4.8 ins deep longitudinal channels. The baggage door itself is hinged at three points along its upper edge and is locked in place by three shoot bolts along the bottom edge and three more on each side. The construction of this door is based on 4.8 ins deep channel members of 0.072 ins thickness. They are located at a 20 in orthogonal spacing and covered by inner and outer L71 skins. The ventral access door is within the pressurised part of the cabin. It is a built up box construction of 5 ins depth. The main internal members are 0.22 ins thick pressed channels arranged in a 5 in pitch orthogonal layout. It is hinged at two points on the front edge and located in place by six shoot bolts. Two of these are placed on the fore and aft centreline and the others two on each side. These latter also incorporate hooked lugs to ensure pressure tightness.

The standard lateral floor beams are 4.5 ins deep I sections made up of 0.064 ins thick L71 webs with 0.75 ins L65 extruded angles placed back to back for the booms. They are reinforced in the centreline region by an additional 2.5 ins deep, 0.064 ins thick L71 channel placed under the lower booms of the I. Forged brackets are used to connect the beams to the frames. In the case of the two wing pick up frames the floor beams are of special design as they react frame as well as floor loads. In these cases they consist of a pair of back to back forged channel members which are supported off the base of the frames by tubular struts. The longitudinal beams use double 0.056 ins thick webs which terminate at the top in the L65 extruded seat rails. The double webs are connected by a channel across their lower edges.

2.2 Wing

The most important stressing cases for the inner wing are associated with flap deflection but various combinations of weight and centre of gravity position are critical in different local areas. Over the outer wing the most severe case is rolling and pitching with 1.67g normal manoeuvre at the design diving speed and gross weight. Provision of adequate torsional stiffness to prevent flutter dominated the design of the skins. In order to alleviate this as much as possible the structural chord of the wing box makes full use of the available planform. Thus over the greater part of the span within the outer engine locations the box is of two cell construction with spars at 15%, 30% and 60% of the chord. The forward cell could not be provided within the fuselage, in the region of the undercarriage fairing and outboard of the engines. Over the inner, basically two cell region, the ribs are placed parallel to the flight direction at a pitch of between 17 ins and 26 ins. Over the outer wing they are perpendicular to the rear spar at a typical pitch of 23 ins.

The covers of the structural box are integrally machined panels in D.T.D. 5020 forged alloy. Basic skin thickness varies considerably from a maximum of 0.60 ins over the lower surface at the root to 0.074 ins adjacent to the tip. The stiffener pitch is approximately 3 ins on the upper surface but as much as 8.6 ins on the lower surface at the root. Stiffener height and thickness decrease from root values of 1.70 ins and 0.17 ins respectively to 0.95 ins and 0.05 ins outboard. Access to the integral fuel tanks is through stress carrying panels in the bottom covers except in the undercarriage bay where small upper surface panels have had to be provided. The skins are thickened locally at the rib stations. The stiffeners are run into these chordwise bands which also act as booms for the standard ribs. The latter are basically 0.048 ins thick L71 pressed channel members with lightening holes. The spars are built up with plate webs of varying thickness and extruded angle section booms. Vertical stiffeners are placed along them at 4 ins pitch.

There are a number of special ribs which are machined from D.T.D.5020 forged billets. Included in these are the fuselage side ribs, undercarriage and engine mounting ribs, aileron and flap support ribs and fuel tank end ribs. With the exception of the channel sections tank end ribs these are all of I section. In the case of the undercarriage ribs the web thickness has a maximum value of 0.8 ins and the vertical stiffeners are 0.36 ins thick. The undercarriage mounting lugs are forged integrally with the ribs and incorporate four split bearing housings. The flap track support ribs have an overall width of 1.4 ins, a flange depth of from 0.042 ins to 0.37 ins and a web thickness of 0.05 ins. Vertical stiffeners on the webs are pitched at 7.2 ins across the chord. The engine mounting ribs are similar and each one incorporates three lugs on its lower surface for attachment of the pylon structure. The tank ribs are 0.6 ins wide and have a 0.05 ins thick web supported by 0.18 ins thick vertical stiffeners placed at 5 ins pitch. The outer tank ribs are connected to the tip, surge tank region which is of built up box construction. The extreme wing tip is in glass fibre reinforced plastic.

2.2.1 Ailerons

Each aileron is a single surface which is hinged to the wing at two points and operated by a single tandem actuator located at the inner hinge.

2.2.2 Leading edge

The greater part of the leading edge is occupied by high lift devices. The original intention was to use full span Kruger flaps, the section within the outboard engines being of 15% chord width and that outboard 30%. However the region of the leading edge inboard of the engines was found to be interrupted by the undercarriage fairing in such a way that only very short lengths of flap could be used. Because of this the design was modified to incorporate slats in this region. The slats move out in line of flight and hence use the space available more efficiently than the flaps which are hinged perpendicularly to the leading edge. Between the pairs of engines a single piece flap is used whilst the wider chord outer portion is in two pieces on each side of the aircraft. There are two operating hinge points on each piece. The layout of a typical attachment point is shown in Figure 2. The lower edges of the flap units fold up to lie within the main flap sections for retraction and the top lips of the units are flexible to enable a smooth contour to be achieved in both extended and retracted positions. When extended the maximum factored load on the inner section is 5020 lbs and the corresponding total and the outer sections is 10350 lbs.

As can be seen from Figure 2 the operation of the units is by means of ball screw actuators. Levers and rods connect to the retractable lower edges whilst the flexible upper lips are controlled by tension limited cable systems. The lip material is a glass fibre reinforced plastic.

The basic construction of the flap consists of a 0.75 ins deep light alloy honeycomb sandwich, on the outside of which is a 0.12 in deep chordwise corrugation and outer skin. The corrugations serve as passages for the de-icing hot air. Both the outer skin and that on the inside of the sandwich are 0.018 ins thick L71. The corrugations and the other skin of the sandwich are 0.015 ins thick. In the region of the attachment loads these are increased to 0.048 ins and 0.036 ins respectively. The retractable lower edges are connected to the main flap by piano hinges. They are assemblies of relatively short light alloy cast units. The main flap operating levers are part of the flap structure. They are tee section L65 forgings with a web thickness of 0.2 ins and a 0.7 ins square upper boom.

The wing leading edge shroud skins are carried on two types of rib. Most of them are 0.036 in L72 channel pressings but where the flap attachments are made machined ribs are employed. These are of I section in L65 with 0.06 ins thick webs and 1 in wide by 0.25 in deep booms. The actuator and hinge bosses are integral.

2.2.3 Trailing edge flaps

The double slotted trailing edge flaps extend to a maximum deflection of 20° on the front segment and an additional 20° on the aft segment. The aft segment in particular moves down into the exhaust efflux from the powerplants. The establishment of the flap design speeds necessitated a modified interpretation of the requirements. A large contribution of the total lift with flaps deflected, and hence a large part of the flap load, was found to be dependent upon the setting of the engine thrust deflectors.

In order to restrict the flap loads to an acceptable level it was decided to consider the movement of the thrust deflectors from the cruise to the low speed, high lift condition, as being equivalent to an additional gated flap position. On this basis the flap design speed was found to be 176 kts when the thrust deflectors are set to cruise, but this is reduced to 131 kts in the complete low speed configuration. The total factored load on the front flap segment was estimated to be 29000 lbs per side whilst the corresponding figure for the aft segment is 16,900 lbs.

The flaps are constructed in three spanwise sections on each side of the aircraft. Each section is supported at two track actuator stations from the wing rear spar. As can be seen from Figure 3 the tracks are suspended just below the wing profile. The aft segment initially moves back along short subsidiary tracks and subsequently the complete assembly moves out on the main tracks. Ball screw actuators are placed just above each track and are attached to the aft segment of the flap. The two segments are linked together by an extension of the rear roller carriage. The actuators are driven by cross shafts through bevel gear boxes.

Each main track is an S99 forging of I cross section. It is 2.4 ins deep and 2.3 ins wide and has 0.2 ins and 0.4 ins thick web and booms respectively. The front end is connected to the bottom face of the wing spar and the aft end is shaped to allow the rear roller carriage to move round to give the correct flap angle. The subsidiary track is a 1.4 ins deep by 0.5 ins wide S99 forging of rectangular cross section. The forward roller carriage is some 16 ins deep overall and consists of three separate machined L65 units. These are the trunnion fitting, which is attached to the ribs of the flap, the suspension arms and the roller assembly. Separate rollers which move along the web of the I section track give side location. The rear roller carriage is a single piece L65 forging. It is connected to the front segment of the flap, but has the link back to the nose of the aft segment.

The forward flap segments use a skin-stringer type of construction. The 1 in deep zed section stringers have 0.6 ins wide flanges and are 0.028 ins thick. They are pitched at 3.6 ins across the chord. The pitch of the 0.028 ins thick L72 pressed channel section ribs varies between 5 ins and 11 ins. At the roller carriage attachment stations the ribs are machined channel components in L65. Web thickness is 0.2 ins. There is a single plate spar with drawn angle section booms. The aft flap segment is built-up with honeycomb sandwich skin panels due to the severe acoustic environment. The core is 0.82 ins deep light alloy and the L72 facings are 0.022 ins thick. The single spar has a 0.064 ins thick L72 web with tee section extruded booms. The nose shape is 0.036 ins thick sheet.

2.3 Tailplane

The maximum up load on the high mounted tailplane is 47920 lbs factored. This occurs when the aircraft pitches nose down from 2.5g to 1g at aft centre of gravity, high altitude and speed V_A. The ultimate download has a maximum value of 102,050 lbs in a similar pitching case at forward centre of gravity and sea level with the flaps deployed at their design speed.

The tailplane is hinged at the top of the fin on a chordwise station near to the elevator hingeline. It is varied in incidence by means of a ball screw actuator which acts at a point well forward on the chord. The construction is based on the use of a single spar which is located as far aft as possible consistent with elevator nose clearance. The whole of the cross section forward of the spar is structural in that it contributes both to the bending and torsional properties of the tailplane. The L73 skins vary in thickness from 0.104 ins at the root to 0.036 ins near to the tip. The pivot loads are reacted in two closely spaced machined ribs and there are no stringers between them. Outboard of the pivot ribs the zed section stringers are placed at 2.5 ins pitch. The depth of 1.0 ins inboard drops to 0.85 ins outboard. The corresponding thickness variation is 0.064 ins to 0.022 ins.

The pivot ribs are of I section L65 and have web thicknesses of between 0.1 ins and 0.2 ins. Vertical stiffeners are placed at 5 ins pitch. Overall boom width is 4.8 ins and thickness is in the range of 0.2 ins to 0.5 ins. The pivot lugs are separate bolted on units in S99. Basic rib pitch increases from 13 ins inboard to 30 ins outboard, with the ribs placed normal to the rear spar. There are two other machined ribs on each side of the tailplane. They provide attachment points for the elevator hinges and actuators. In these cases the cross section of the ribs varies from an I section of 2.0 ins width at the rear spar to a channel section forward. The webs have a maximum thickness of 0.16 ins and are supported by integral vertical stiffeners with a mean pitch of 15 ins. Boom thicknesses vary between 0.65 ins and 0.9 ins. All the other ribs are pressed channels and the spar is built up from a plate web and extruded angle booms.

2.3.1 Elevator

The elevator is designed in four separate sections, two on each side of the aircraft. Each section is supported by a pair of hinges mounted off the tailplane rear spar. In each case the inboard hinge is also used to mount a tandem hydraulic actuator. Construction is generally similar to that of the rudder.

2.4 Fin

The fin is of two spar construction. The tailplane pivot is positioned at the upper extremity of the rear spar and the actuator mounting bracket is in the leading edge.

All the fin bending moments are passed into the fuselage through the attachments of the two spars to the appropriate frames. The torsional stiffness required to prevent flutter was a major consideration in the design. The maximum factored load of 90900 lbs occurs when the rudder is deflected instantaneously at high altitude and the design diving speed. It is associated with a substantial tailplane rolling moment.

The covers are integrally machined in D.T.D. 5020 with a stiffener pitch of 8.5 ins. The basic skin thickness varies between 0.13 ins and 0.25 ins, but it is further increased locally along the rib stations where the stiffeners are run out. The ribs are placed in line of flight to give some supplementation to the torsional stiffness of the skins. Rib pitch varies between 12 ins and 20 ins. The root rib has a curved web and locally completes the fuselage pressure shell. In this case the L72 web is 0.064 ins thick and stiffening is provided by the fuselage frames attached to it. The booms are 1.5 ins deep drawn angles in 0.08 in thick L72. At the rear the booms are connected to the spars through forged L65 angle fittings. The standard ribs are of braced tubular construction using 1.0 ins diameter by 0.022 ins thick L63 with L65 machined end fittings and 2 ins wide by 0.75 ins deep channel section boom members in 0.064 in thick L72.

The rudder sections are hinged to the rear spar at four points, two of which incorporate actuators. The simple hinge brackets are triangular shaped components with I cross section members being 0.125 ins thick webs. They are L65 forgings. On the other hand the hinges which also incorporate actuator mountings consist of pairs of back to back triangular L65 machinings. The actuators themselves pass through the rear spar and are supported on 3 ins deep channel members which run diagonally between pairs of adjacent ribs.

The front spar is built-up with a 0.13 ins thick plate web and 2 ins by 2.5 ins by 0.064 ins thick back to back drawn angle booms. A single angle member runs spanwise along the centre of the web as a stiffener and crack stopper. The rear spar web is 0.25 in thick and has 2.0 ins wide booms, but is otherwise similar. The tailplane pivot fitting is an S99 forging in the form of a tee section in side elevation. It is connected across the webs of the fin rear spar and uppermost rib. The pivot lugs are outside the nominal skin line, but within the bullet fairing. The pin is 2.0 ins in diameter and rotates in a reinforced PTFE bearing. The tailplane actuator is fitted on a pair of 3 ins deep channel beams which cross from the spar to the leading edge.

2.4.1 Rudder

The rudder is divided into two sections, each of which is approximately equally effective. There are two hinges on each part of which the lower one incorporates the actuator fittings. The total maximum factored load of 20,000 lbs arises when the rudder is deflected at the design diving speed.

Structurally both sections are similar. The single spar has a 0.08 ins thick web and 0.5 ins square back to back angle booms. The 0.05 in thick L72 pressed channel ribs are placed at between 22 ins and 32 ins pitch. Hinge fittings are L65 machinings. The skins are 0.5 ins deep honeycomb sandwich panels with 0.015 ins thick L72 faceplates. The trailing edge member and curved nose use moulded fibreglass reinforced plastic.

2.5 Undercarriage

The nosewheel undercarriage is unusual in that it has an exceptionally long stroke shock absorber unit and all three wheel assemblies can be steered for cross wind landing.

2.5.1 Main undercarriage

In spite of the high wing layout of the aircraft the main undercarriage is supported off the wing rear spar. It is therefore unusually long and has an extended length of some 15 ft. Whilst this does enable a long stroke shock absorber to be employed it inevitably results in penalties of weight and retraction complexity. The actual stroke of 3.5 ft corresponds to a maximum ultimate reaction factor of 2.3 associated with an ultimate vertical impact velocity of 21.6 ft/sec. As has been previously mentioned this high impact velocity is a direct consequence of the steep 7.5 degree approach angle and an assumed incomplete flare. The design ultimate loads for the main undercarriage unit are 130,000 lbs vertically in the two point landing case at 100,000 lbs weight, 57,500 lbs horizontally in a high drag landing and 40,500 lbs laterally in the turning and swinging case. The four wheel bogie unit can be steered up to 20 degrees in either direction.

Extensive use is made of maraging steels in order to keep the weight to within acceptable limits. The main leg is an elaborate forging which incorporates the outer tube of the oleo-pneumatic shock absorber at its lower end. The upper end is a tapered I section which terminates in the side trunnion mountings. Maraging steel is also used for the torque links, the inner tube of the shock absorber, and the steering ring which is located at the lower end of the fixed tube. Twin jacks are used for the steering action. The bogie beam is a tubular maraging steel forging with separate S99 stub axles.

Two methods of retraction were considered. In both cases the leg rotated forwards and upwards about its main attachment point and the wheels were housed in a faired forward extension of the wing section. In one case the drag strut attached to the lower boom of the front spar and for retraction was unlocked at this point which was then moved upwards and forwards along a track. In the alternative system, which was adopted for the design, the top drag strut attachment is similarly located but the strut is folded at two hinges for retraction. Each of these hinges is locked by hydraulic jacks which also provide the overall retraction effort. This arrangement is complex but necessary to enable the strut to be accommodated in the space available. The three basic components of the strut are all maraging steel forgings. The lower portion is a uniform I section and the upper part is similar but of much greater width. The central section is more complex but is effectively a tapered member with channel section edges connected by a web. A large cutout in the web is necessary to enable one of the retraction jacks to pass through it.

2.5.2 Nose undercarriage

The twin wheel nose undercarriage is also a relatively long unit, and has a stroke of 2.85 ft. It is located in the front fuselage and is pivotted at a point which is some 1.7 ft below its upper extremity. The retraction motion is forwards into a bay below the pilots floor. The critical design case was found to be a high drag landing when the ultimate loads reach 62,000 lbs vertically and 65,000 lbs fore and aft. The vertical load has a maximum value of 76,000 lbs in a three point landing corresponding to an ultimate reaction factor of 2.28.

The greater part of the assembly is manufactured as high grade steel forgings to specification 300M. The main casing is a cruciform shape with an I section cross beam having the mounting trunnions at its extremities. The sliding tube of the oleo pneumatic shock absorber is forged integrally with the solid axle and the magnesium wheels are of the split type for tyre assembly. Drag loads are reacted in the down lock fitting which takes the form of a pin passing through a pair of lugs. The fixed lug is attached to the mounting bulkhead at station 150. The pin is hydraulically disengaged but it is spring loaded to the down locked position. A pivotted guard is incorporated in the design of the lugs to prevent the pin from entering the locked position unless the leg is down. The up lock is located on the roof of the wheel bay. It consists of a spring loaded hook and locking pawl which engage with a fixed pin placed on the front of the leg casing.

Space limitations dictated the use of a rack and pinion steering gear. These components were designed in S99 to give 60 degrees steering angle in either direction. The wheels can be fully castored. The use of a rack and pinion was found to be heavy in this application. The torque links are also forged in S99. The retraction jack attaches to a lug positioned on the cruciform cross beam.

3. POWERPLANT INSTALLATION

Little work was done on the engine installation as such since it was assumed that the units would be supplied as complete assemblies for attachment to the wing pick up points. However it was realised that the consequences of an engine failure are extremely critical with the type of high lift system used and the possibility of cross coupling the fans of adjacent power plants has been investigated.

3.1 Engine fan cross-coupling

This part of the study was undertaken as a special investigation by Webb (Ref.4). The RB410 is designed with the fan driven through a 3:1 reduction gearbox. In order to provide an offtake for the cross connection of adjacent powerplants it is suggested that the final output of the reduction gear should include a pair of bevel wheels. These would provide a power offtake rated at approximately 6000 H.P. at 10,500 rev/min and positioned to enable a drive to be taken up the pylon to the wing. It is anticipated that this would introduce a weight penalty of approximately 40 lbs on each engine. Right angle transfer gearboxes would be located in the wing leading edge immediately above the pylon. Space is available for these as there are no high lift devices in these positions. Adjacent transfer gearboxes would be connected to one another by means of a shaft with self-aligning couplings at its ends. Provision for this has been made in the design of the leading edge structure.

A layout of the proposed transfer gearbox and details of the shafting are shown in Figure 4. Since the main power transfer requirement only occurs in emergency conditions the life rating has been selected as 40 hours at 6000 H.P. This corresponds to 10^{-4} of the aircraft life and although it is low it is anticipated that emergency uses would be recorded in the aircraft log book and gearbox replacement made if it became necessary. In order to cater for the balancing of power between adjacent fans during normal operation the transfer system has been designed for full aircraft life operation at 10^{-2} of the design maximum power.

The bevel wheels in the transfer box are spiral gears with 32 teeth on a 10 in pitch circle diameter. The material used is casehardened steel S107. The gear shafts are machined in S99, and the shell of the box is a magnesium alloy casting. In order to minimise the weight penalty of the cross connection it is essential to use the highest possible rotational speed. In view of this the cross shaft is designed to run at a speed above its critical whirling condition. It is a 1.875 ins outside diameter, 0.156 ins thick T60 tube. Apart from the end connections it is supported in six intermediate bearings. These are simple ball races mounted in rubber blocks to provide damping of the whirling modes during run up and normal operation. The limit on rotational speed was found to be due to the bearings both in the transfer box and along the cross shaft. To make full use of the available capacity in this respect the box journal bearings are roller races and there are separate hydrostatic thrust bearings.

The total weight of the two transfer boxes, cross connecting shaft and pylon shafts on each side of the aircraft is estimated to be about 420 lbs. With the penalty introduced in the engine modification this results in a total weight of 1000 lbs, or 0.87 per cent of the all up weight, for the complete installation. The drive power rating is approximately equivalent to half of the normal fan power.

4. SYSTEMS AND INSTALLATIONS

4.1 Fuel System

The layout of the fuel system is very simple. Basically there is a single integral tank on each side of the aircraft. It is located between the two main wing spars and the total fuel capacity is 28,000 lbs. Under conditions of high lateral acceleration each tank is divided into two by means of the automatic closing of inertially loaded clack valves. In this way the fuel pressure loads experienced by the tank end ribs are kept to a level which is tolerable to the structure.

The anhedral of the wing is used to cause the fuel to gravitate towards the tips. From there it is fed to the engine delivery lines by triplicated A.C. booster pumps. One of the three pumps in each assembly is mounted high in the tank to cater for negative 'g' conditions. The tanks are vented from a number of points along their length into a 2.5 ins diameter gallery which terminates in the wing tip surge tanks. Fuel which collects in the surge tanks is returned to the main tanks by means of jet pumps. The maximum differential vent pressure is controlled to 2 lb/sq in.

The aircraft is refuelled at points on the inner wings in the region of the undercarriage bays. With a maximum refuelling rate of 300 galls/min it is possible to refuel in as little as six minutes. The booster pumps are used for defuelling through the same lines. Fuel can be jettisoned through retractable pipes located below the ailerons.

Holes are provided in the lower surface of the wing structure for tank inspection, except in the main undercarriage bay where it has been necessary to use two small upper surface access panels.

4.2 Air Conditioning and Pressurisation Systems

A schematic drawing of the air conditioning system is shown in Figure 5. The air supply can be derived from either the high or intermediate engine compressor tappings, the auxiliary power unit, or an external ground supply. In the normal case when engine tapped air is employed the hot air is first passed through a primary heat exchanger in which the cooling source is ram air. The resulting warm air is then available either for mixing or for further cooling in the first stage of a turbine cold air unit. A second heat exchanger is located between this and the second stage turbine. The hot air turbine is used to keep the air moving in the associated ducting. An appropriate mixture of cold, warm and hot air is passed through a water separator before entering the cabin distribution ducts. These extend from a cross ducting at the front spar station into two longitudinal systems which are placed along the cabin sidewalls. Extraction is through floor level grills.

The pressure control system maintains the cabin altitude at 8000 ft for aircraft altitudes up to 38,000 ft which is significantly above the normal cruise level. Crew and passenger air temperature can be regulated between 60°F and 80°F for ambient temperatures between -45°F and 100°F. Basic control of the pressure, temperature and humidity is automatic, but manual override is provided.

4.3 Flying Control System

A fully powered system is used for the operation of the flying control services. As can be seen by reference to Figure 6 the primary surfaces are subdivided in various ways. The elevator has a total of four independent sections, the rudder two and each aileron is a single unit. A tandem hydraulic actuator unit is used to operate each of the sections. The total hinge moments under the most severe conditions were estimated to be 22500 lb ft for the elevators, 18,350 lb ft for the rudders and 11,000 lb ft for the ailerons. Each part of a given tandem actuator is supplied by an independent hydraulic circuit and there is provision for a back up from the general services hydraulic circuit in an emergency.

The tailplane adjustment is essentially used for trimming and in this case the operation is by means of a single irreversible ball screw actuator. This is hydraulically powered.

Push rods and cables are provided for signalling of pilot or autopilot demands to the surface actuators. Force limiting devices are located between the pilots controls and the hydraulic-pneumatic artificial fuel unit. This latter item incorporates variable gearing in conjunction with 'q' feel. The design of the actuator units includes special provision for the overriding of a jammed valve.

4.4 Ice Protection System

The location and nature of the components of the ice protection system can be seen from Figure 7. A combination of energy sources is used to de-ice the various parts of the aircraft.

The proximity of the main powerplants is used to advantage in the wing region where hot air de-icing is used for most items. The air is taken from the engine compressors at the same points as that used as the supply to the air conditioning system. In those parts of the wing span where the leading edge is of fixed geometry the ducts are arranged to allow the de-icing air to flow aft from the leading edge on both the upper and lower surfaces. Chordwise corrugations on the inside of the double skin act as the local distribution ducts. A similar system is used for the nose of the undercarriage fairing. The Kruger flaps are de-iced by air passed into them through a fixed pipe which coincides with the flap hinge point. Again a corrugated surface is employed to distribute the air. The more complex geometry of the leading edge slats has dictated the use of electrical de-icing in this case.

Hot air passed through appropriately shaped ducting is also used for the protection of the engine intake annulus and central bullet. Electric heating using a gold film is incorporated in the design of the windscreen. Both the horizontal and vertical surfaces of the tailplane are provided with electric deicing along the leading edges.

Warning of icing conditions is given to both pilots by means of simple probes which are located within their normal fields of vision. A pneumatic ice detector is included in the system so that the ice protection devices are automatically activated in icing conditions. Many of the components of the hot air deicing system are common with those of the air conditioning system.

4.5 Avionics

The basic avionics system has been designed for Category II operation, but there is also full provision for Category IIIB units to be installed.

The primary navigation aids consist of duplicated VOR/DME equipment. Provision is made for an area navigation system using a moving map display as this is thought to be essential for short range STOL flights. ADF is also provided, mainly as a back up to the VOR/DME and area navigation systems. The more important controls for the navigation system are located on the glare shield for easy access and monitoring by the crew.

The complete flight control system includes the following items:-

a) An autopilot system with dual flight computers. Only the first pilot's flight computer is used to give autopilot demand signals.

b) A flight director which receives information from the triplicated radio altimeters, vertical reference gyro, navigation systems and flight computer. A paravisual display located on the glare shield gives information on the flight course and a similar device is used for ground roll guidance.

There are three communication systems. These may all be VHF units, or alternatively one may be replaced by an HF set. Controls for the communications are located on the central pedestal between the pilots.

The displays associated with the avionics system are placed on the main instrument panel. The location of the aerials is shown in Figure 8. All the other avionics units are installed on a special rack which is located on the starboard side of the flight crew cabin, behind the second pilot.

4.6 Cockpit Layout and Instruments

It was considered that the systems of the aircraft are too complex for it to be operated by two flight crew members and therefore the layout of the flight deck is based on the assumption that there will be a crew of three. Two of these are pilots and the third is a systems specialist. The overall layout of the cockpit is shown in Figure 9. The emphasis has been placed on minimising the workload of the crew, especially during the critical phases of take off and landing.

The two pilots are located in the conventional position. The windscreen area is large to facilitate lookout, especially by the systems specialist who is placed on the port side of the aircraft behind the command pilot. His seat is located more or less centrally, and it is on a turntable so that he can also monitor the main instrument panel and central controls. Standard crew seats are used, the pilots' ones being mounted on tracks for fore and aft adjustment. The controls are of the wheel type with the control column itself being offset to the side of the cockpit. The adjustable pendant rudder pedals are interconnected by a torque tube. Toe pedals are provided for brake operation.

The flight instruments have been specifically chosen in the context of STOL operation. The layout of the main panel is shown in Figure 10. It extends across the width of the cockpit and is used to display the basic flight and avionic information to the two pilots. Engine instruments are not duplicated but they are placed centrally within easy vision of all three crew members. The glareshield above the panel is used to mount various navigation control units and three paravisual displays for flight and ground guidance. A subsidiary panel is located in the roof above the windscreen. The instruments and controls on this panel have been chosen to be those to which reference is not normally necessary in flight. The system specialist panel is confined to the display and controls for the aircraft systems. This is illustrated in Figure 11.

A central pedestal is placed between the pilots, below the engine instruments. It serves as a mounting for the engine, trim and communication system controls. None of these is duplicated.

An elaborate visual and audio warning system is provided. The master warning indications require particular identification by reference to a subsidiary panel.

5. DISCUSSION AND CONCLUSIONS

5.1 Discussion

In most respects the detail design of the A71 is conventional. The most significant problems are naturally associated with the short field landing and take off requirements. These have an indirect effect on some aspects of the structural design, but the low speed control problems are by far the most significant.

5.1.1 Effect of STOL requirement on structural design

There are two aspects of this worthy of mention. Firstly the STOL performance is partly obtained by low wing loading and partly by using deflected thrust. The former implies large wing and stabilising surfaces and the latter extensive high lift devices, some of which must operate in the engine exhaust flows. The large wing surface coupled with the relatively narrow structural box forced by the high lift system results in the wing torsional stiffness considerations being very important. The trailing edge flaps have to be designed to work in a severe acoustic environment. Both of these effects imply a weight penalty relative to a more conventional design and the available evidence suggests that the total wing weight penalty is likely to be some 2 per cent to 3 per cent of the all up weight.

The second important structural consideration is concerned with the undercarriage. The A71 has been designed to meet a severe design vertical velocity of 18 ft/sec. This was chosen because of the steep descent path and incomplete flare, and effectively allows for the aircraft to be flown straight into the runway. A detailed study of this problem is required to establish what are the true requirements. It must not be forgotten that the nature of the high lift system is such as to couple vertical and forward speed control on the approach although properly arranged it can operate as a direct lift system. All that can be said with certainty at the present time is that the value of 18 ft/sec used represents a likely upper limit. Once this value has been accepted it became necessary to use a very long stroke undercarriage to keep the design vertical deceleration to a tolerable value of around two. It was not possible to accommodate the main units in fuselage side fairings and therefore in spite of the wing being located across the top of the fuselage it was necessary to mount the undercarriage from it. The resulting long, heavy undercarriage is further complicated by the provision of bogie steering for cross wind landing. In the turn the undercarriage adversely influences the wing design by virtue of the volume required for stowage. In this case the study suggests a weight penalty of at least 2 per cent of the all up weight and the importance of accurately assessing the design vertical velocity requirement is obvious.

5.1.2 Low Speed Control, Stability and Performance

The low speed flight performance of the aircraft is the most critical area of the overall design. For this reason a special study was undertaken by Ward (Ref.2). The main results of this may be summarised as follows:-

a) The aircraft cannot successfully complete a take off in 2000 ft when an engine fails, in spite of the nominal thrust/weight ratio of 0.5. The reason for this is that it is not possible to climb away on three engines after a failure subsequent to the decision speed, due to the high effective induced drag. Calculation suggests that an installed thrust/weight ratio in excess of 0.6 is necessary to overcome this difficulty.

b) An outer engine failure on the approach results in severe rolling and yawing moment which it is not possible to control by the surfaces provided in the design. Cross-coupling of the adjacent fans is beneficial if the engine failure is due to a faulty gas generator which can be isolated. However the weight penalty of doing this is nearly 1 per cent of the all up weight and it does not help in the case of a fan failure. The value of cross-coupling must therefore be seriously questioned in this application. A more satisfactory solution would appear to be the increasing of control power by some means to cope with engine failure. Alternatively an augmentor wing or internally blown flap fed with engine bleed air fed from common ducting is a possible solution to the problem.

c) The control power is insufficient to cope with the intensity of cross wind gusting conditions likely to be encountered in some operations. This also implies a need to increase control power.

5.2 Conclusions

a) It is desirable to establish accurately the undercarriage design requirements for STOL aircraft due to the significant weight penalty which can result from the need to use long stroke units. The requirements are likely to vary according to the type of STOL system used.

b) As designed the A71 does not meet the requirements for operation off 2000 ft long runways. There are two main reasons for this. Firstly there is inadequate thrust to cater for an engine failure at take off. Secondly there is inadequate control power to cope with engine failure and gusting cross wind conditions on the landing approach.

REFERENCES

1.	HOWE, D and WARD, R.E.	Aeroplane Design Study, STOL Airliner (A71) Part 1 - Configuration description and data. July 1972
2.	VAN TWISK, J.	Design study of STOL transport using internally blown flaps. Cranfield Institute of Technology, M.Sc. Thesis 1972
3.	WARD, R.E.	A71 STOL Airliner, Low speed lift and control investigation. Cranfield (unpublished) June 1972
4.	WEBB, J.	Feasibility study for cross-coupled fans on the A71 project aircraft. Cranfield March 1972.

APPENDIX A

Students engaged in the A71 design study

Bryan, J.M.	Fin structure
Dodd, G.R.	Flying control system
Fews, F.C.	Centre fuselage structure
Hempsall, R.P.	Rear fuselage structure
McLoughlin, P.	Fuel system
Manders, C.	Main undercarriage
Marshall, G.W.	Trailing edge flaps
Mileshkin, N.	Air conditioning, pressurisation and ice protection systems
Newman, P.C.	Outer wing structure and ailerons
Oswald, D.C.	Cockpit layout and avionics
Petherbridge, P.	Leading edge high lift systems
Punj, V.K.	Forward fuselage structure
Van Twisk, J.	Rudder
Van Zyl, R.W.	Nose undercarriage
Watterson, T.A.	Tailplane structure and elevators
Wersby, J.	Inner wing structure

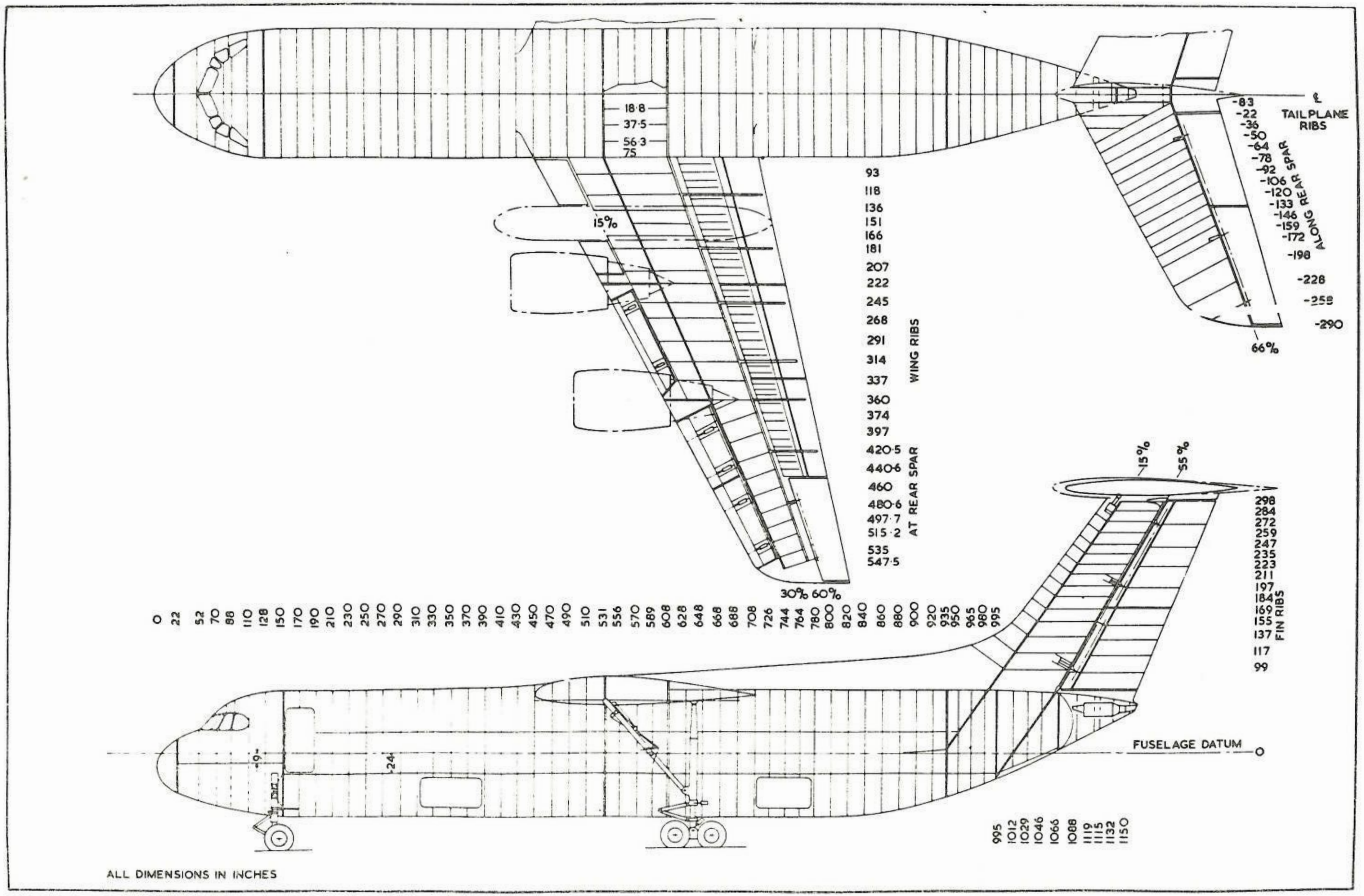


FIG. 1. KEY STRUCTURAL DRAWING

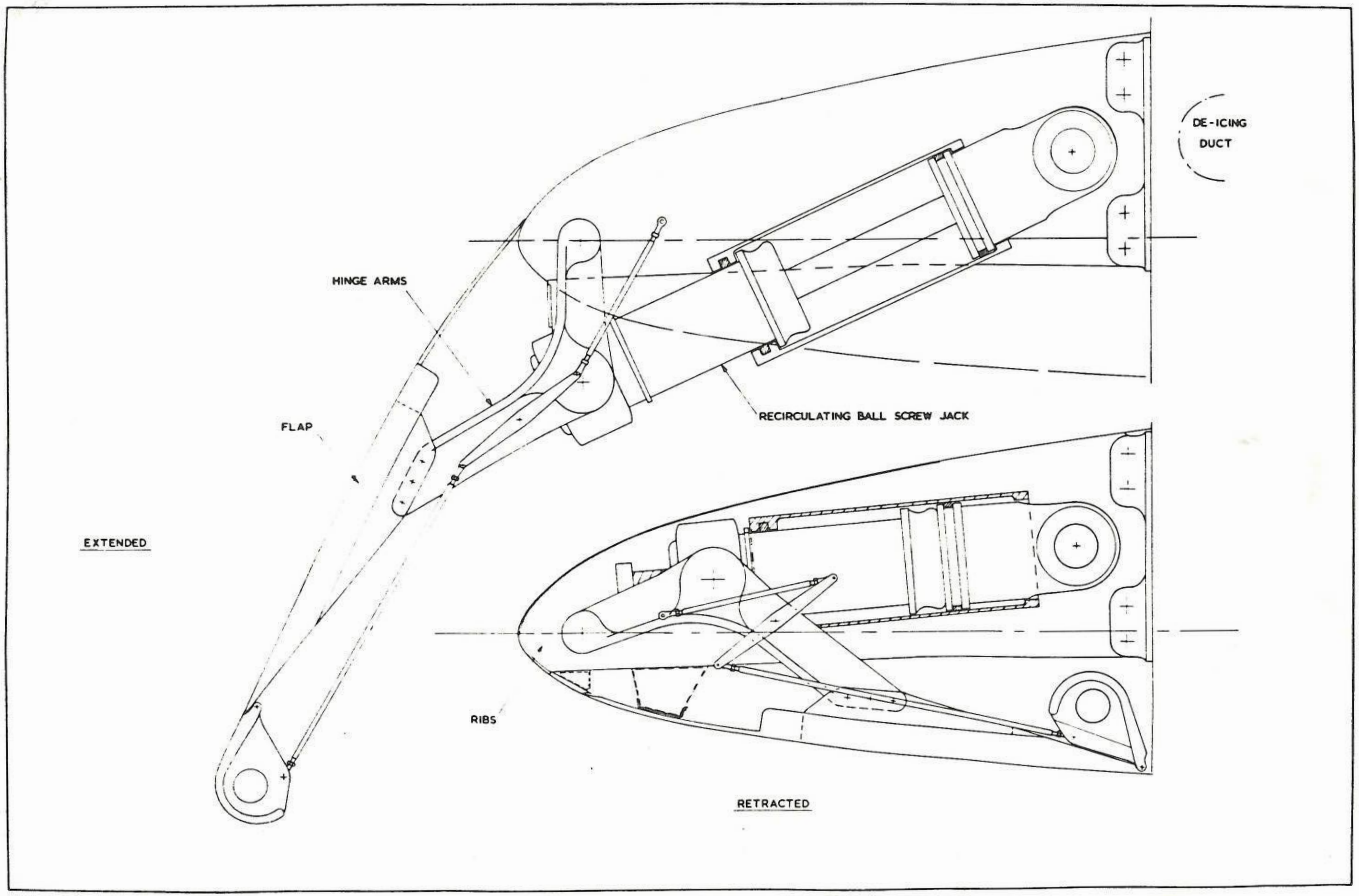


FIG. 2 LEADING EDGE FLAPS (CROSS SECTION)

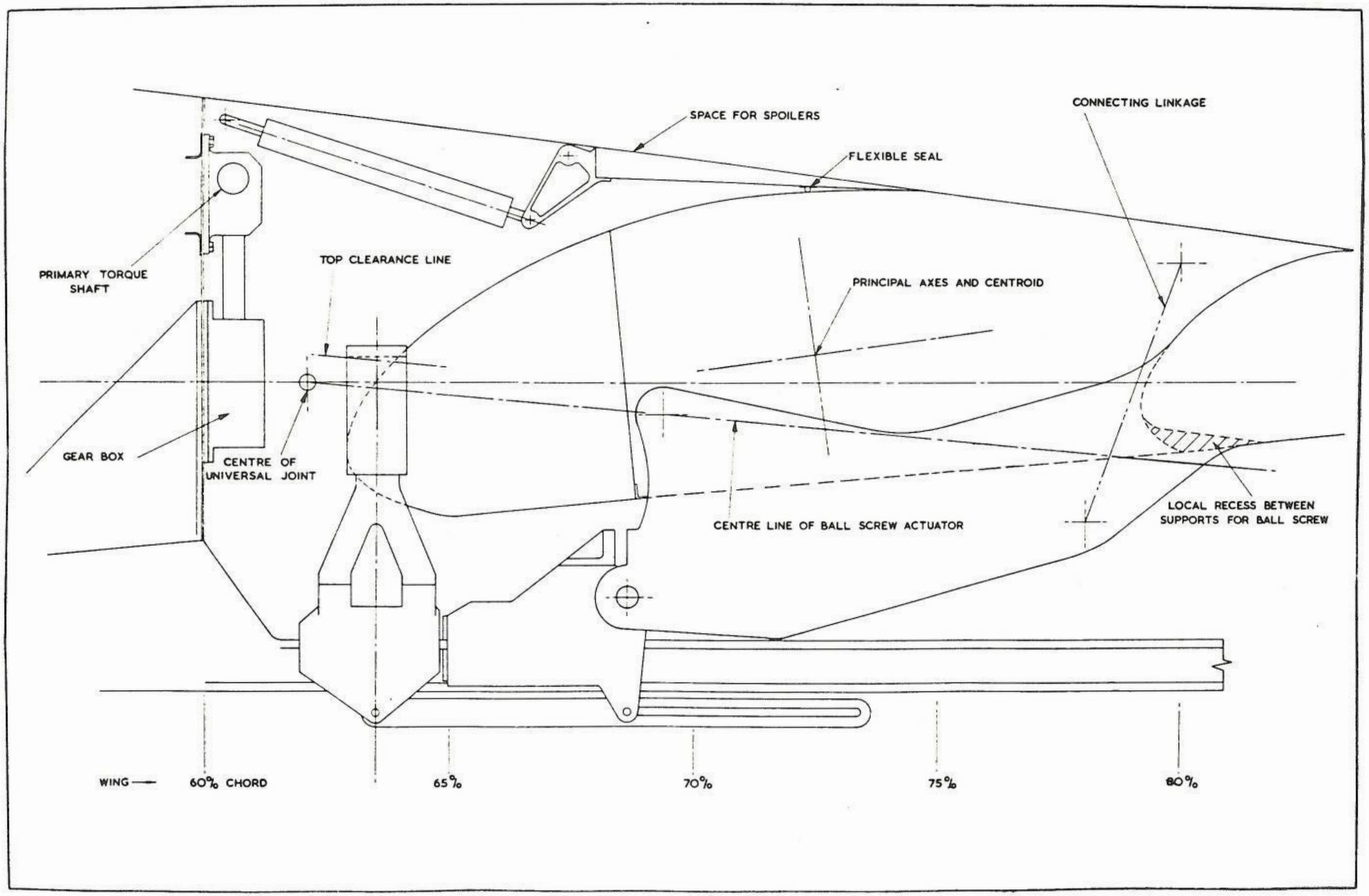


FIG 3 TRAILING EDGE FLAPS (CROSS SECTION)

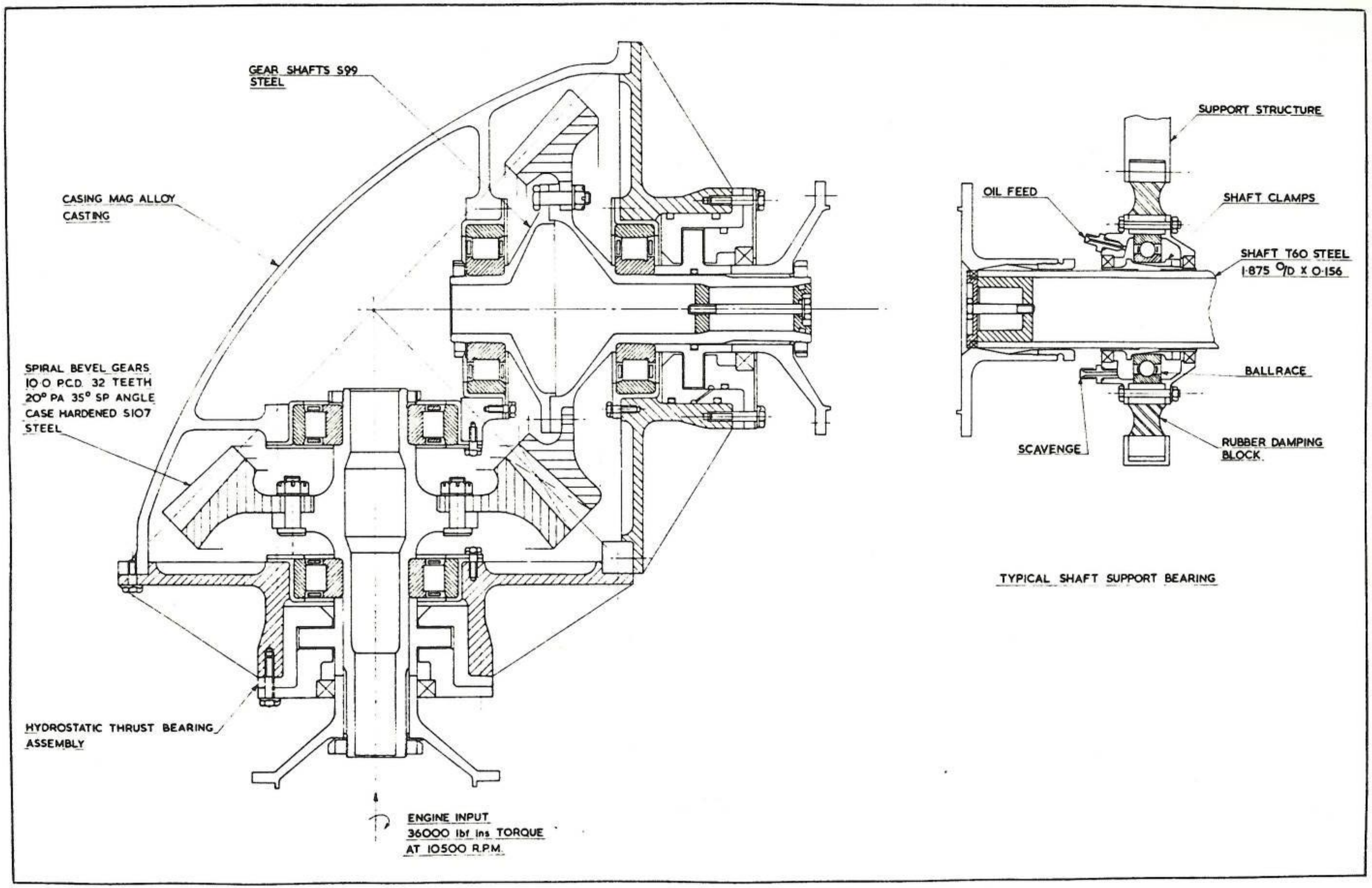


FIG. 4. ENGINE CROSS-COUPLING TRANSFER GEARBOX

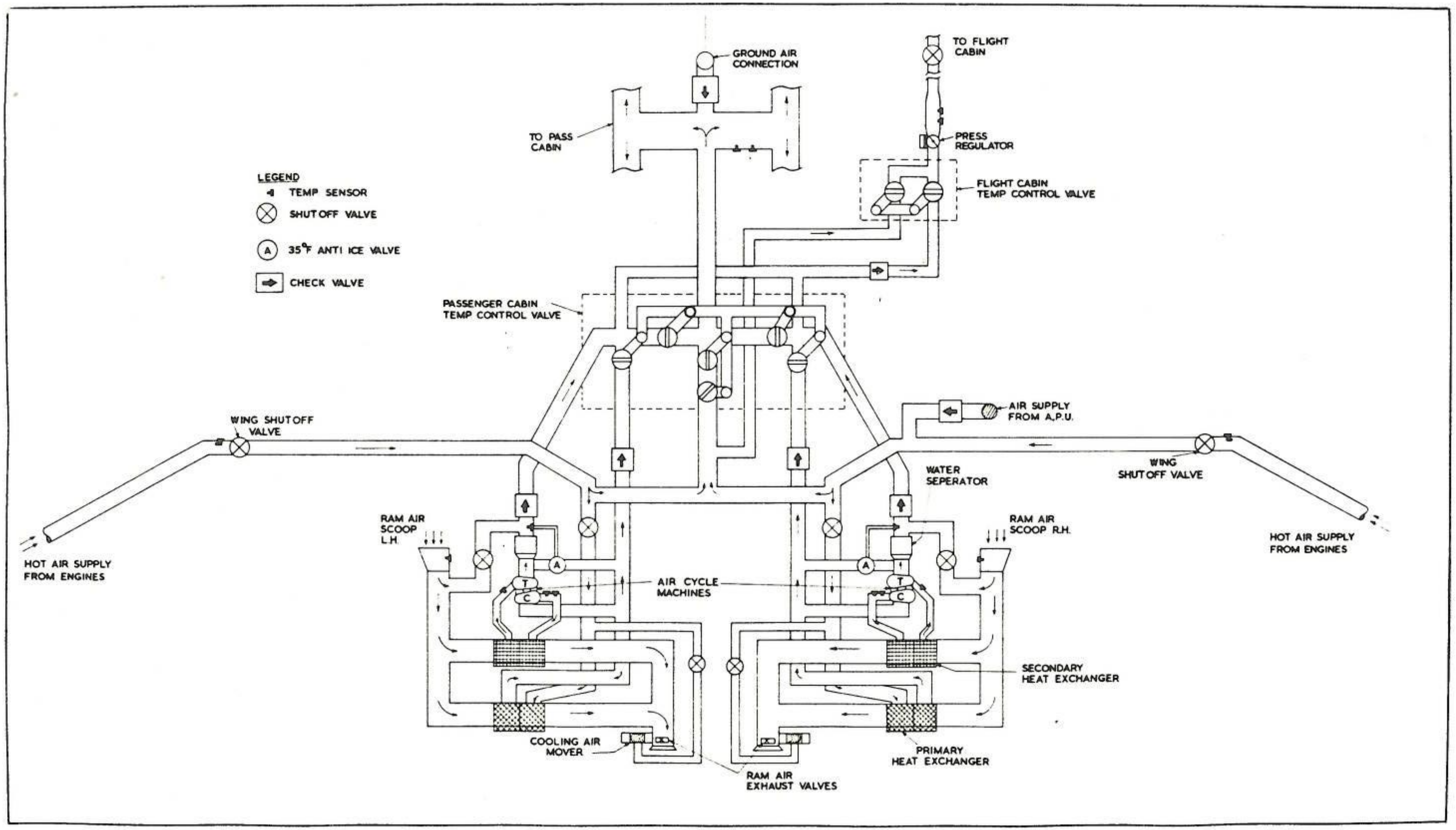


FIG. 5. AIR CONDITIONING SYSTEM SCHEMATIC DIAGRAM

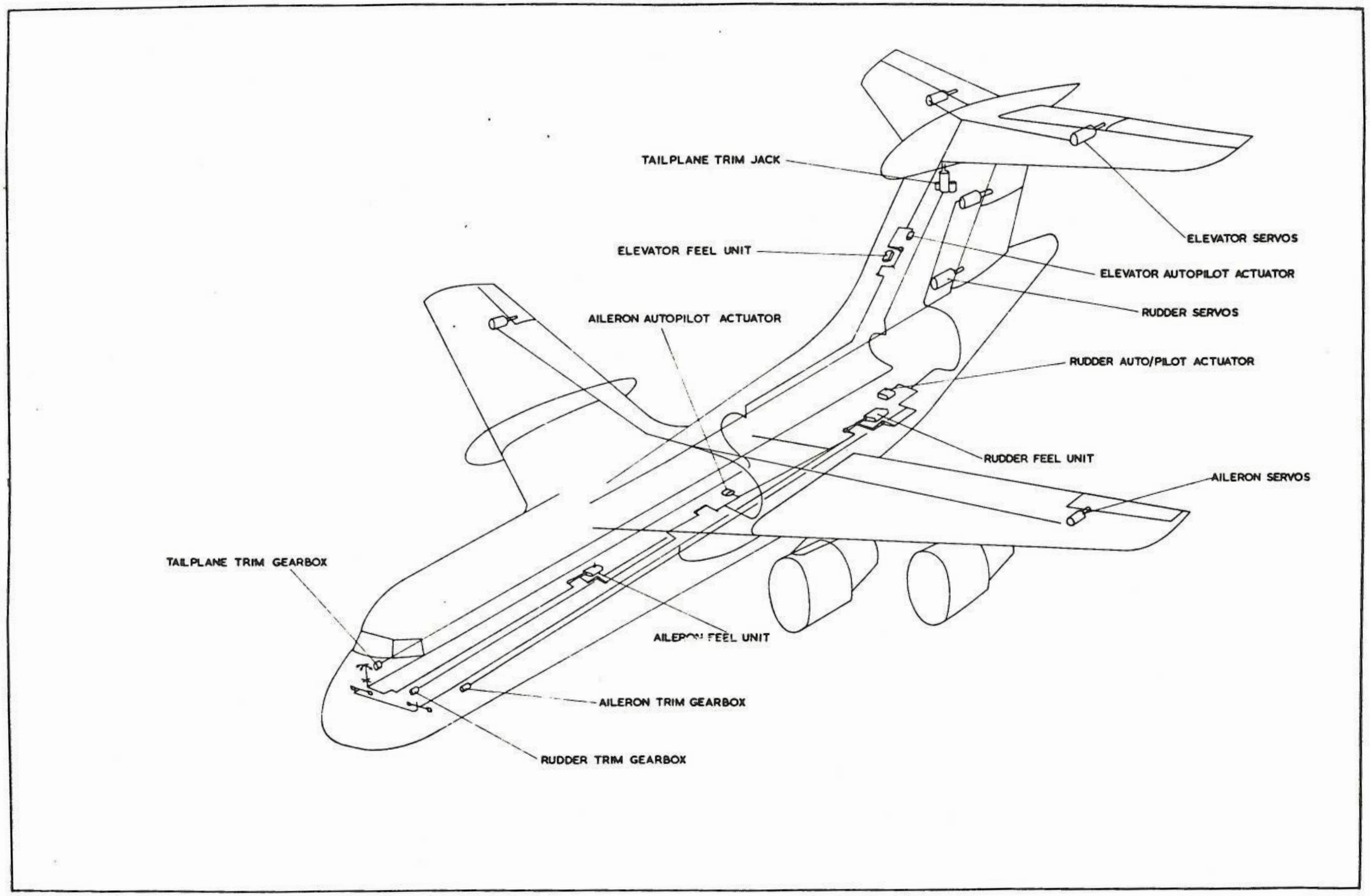


FIG 6 FLYING CONTROL SYSTEM LAYOUT

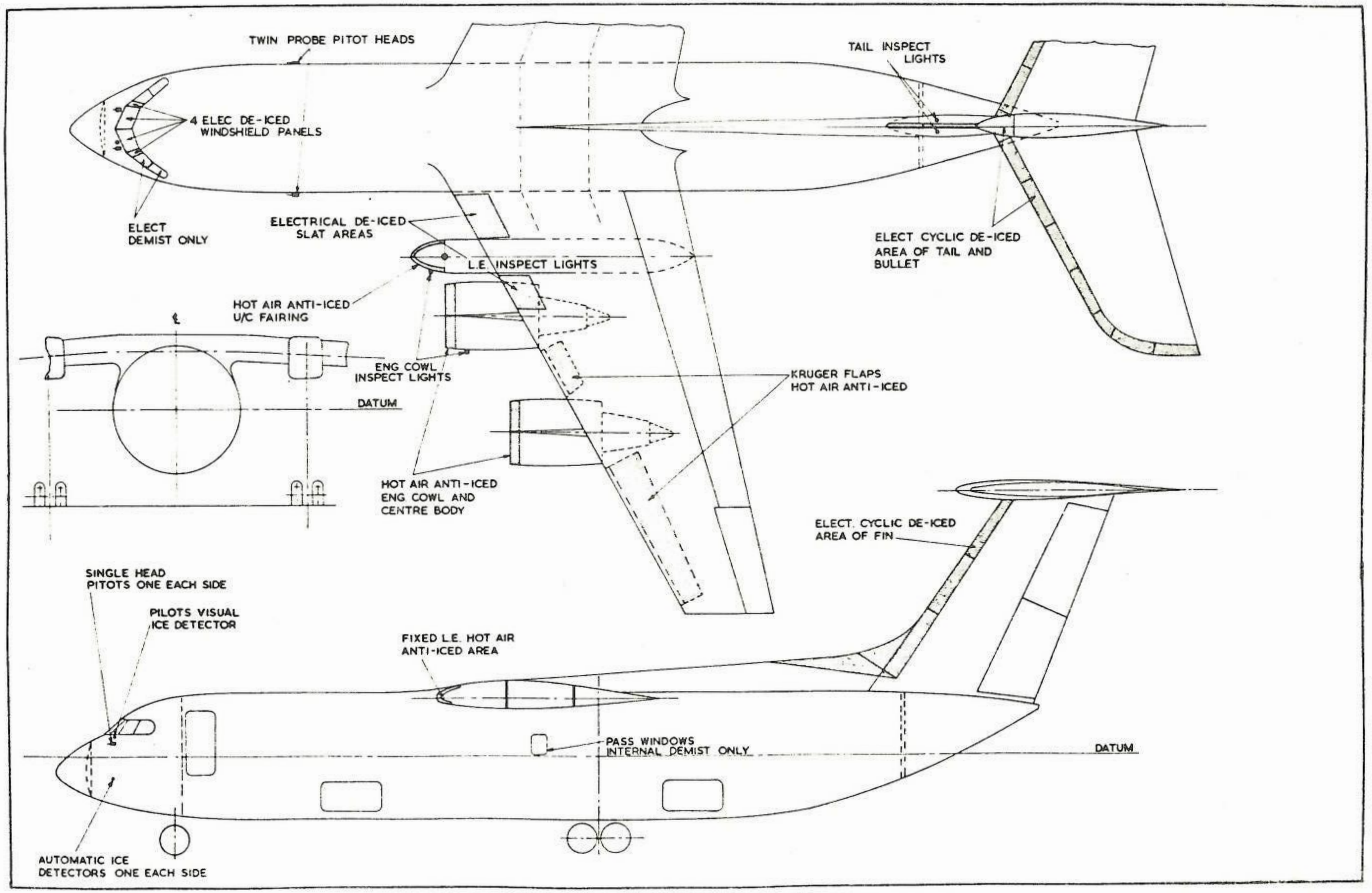


FIG. 7. ICE PROTECTION SYSTEM LAYOUT

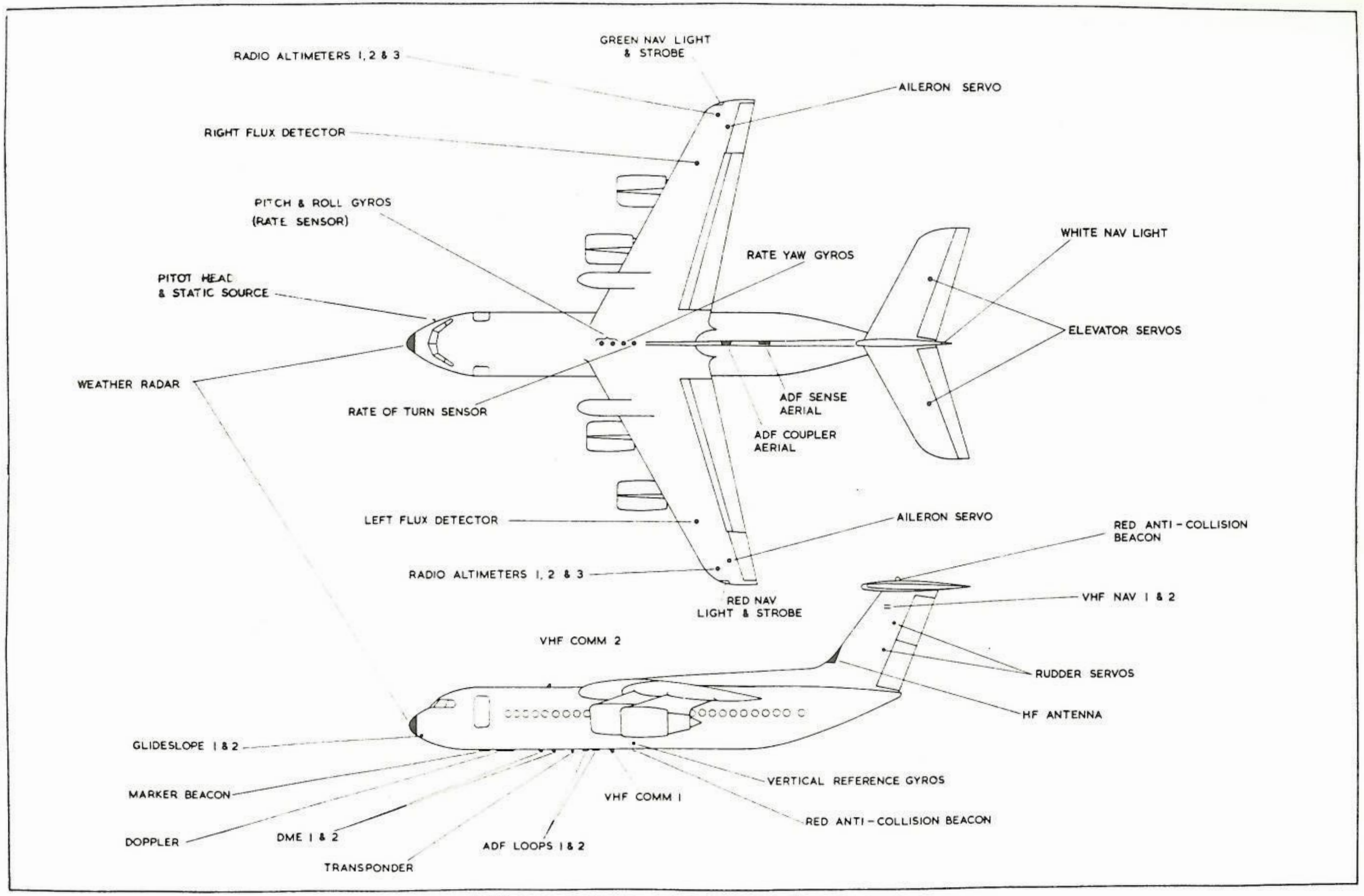


FIG. 8 AERIAL LOCATIONS

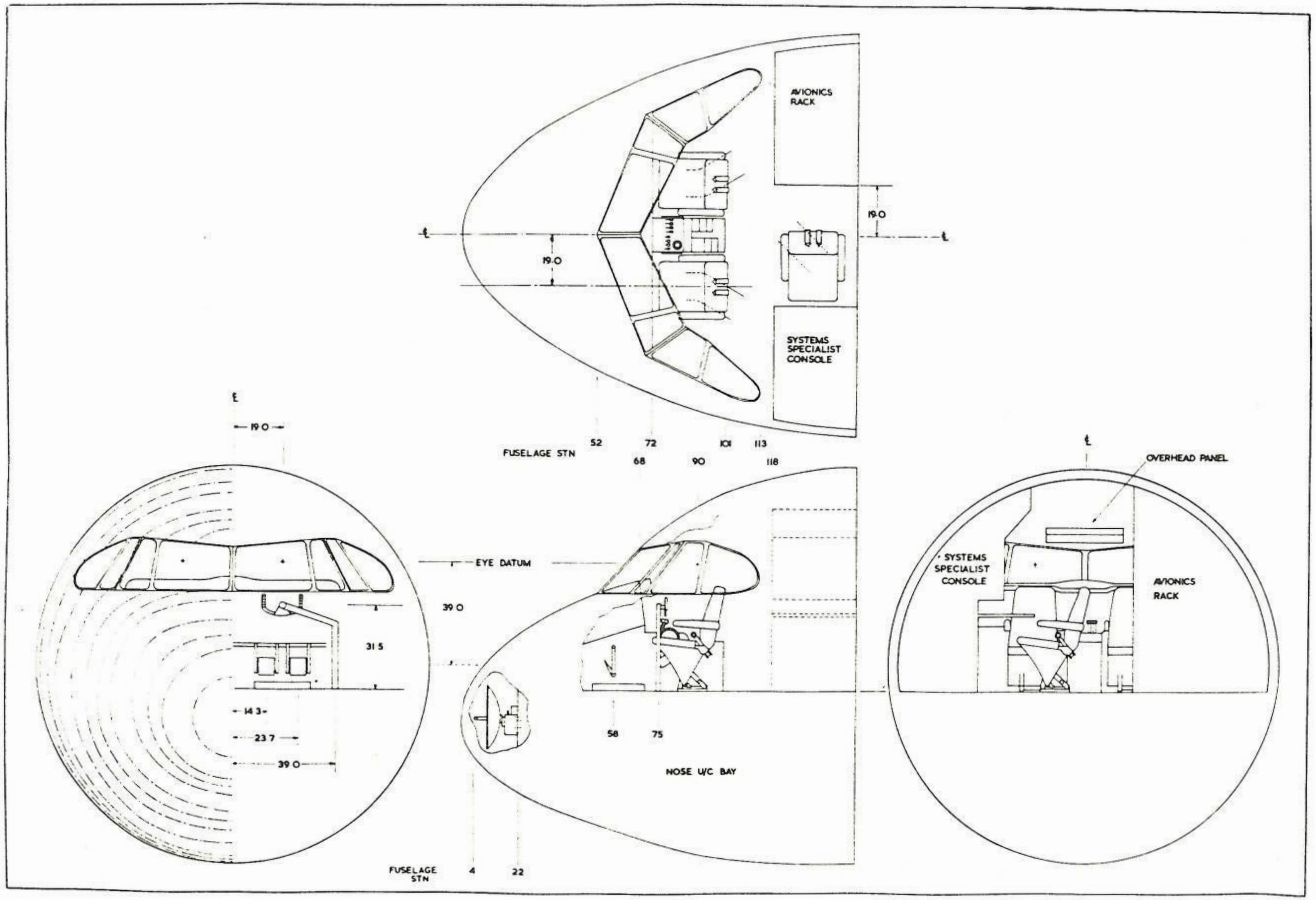
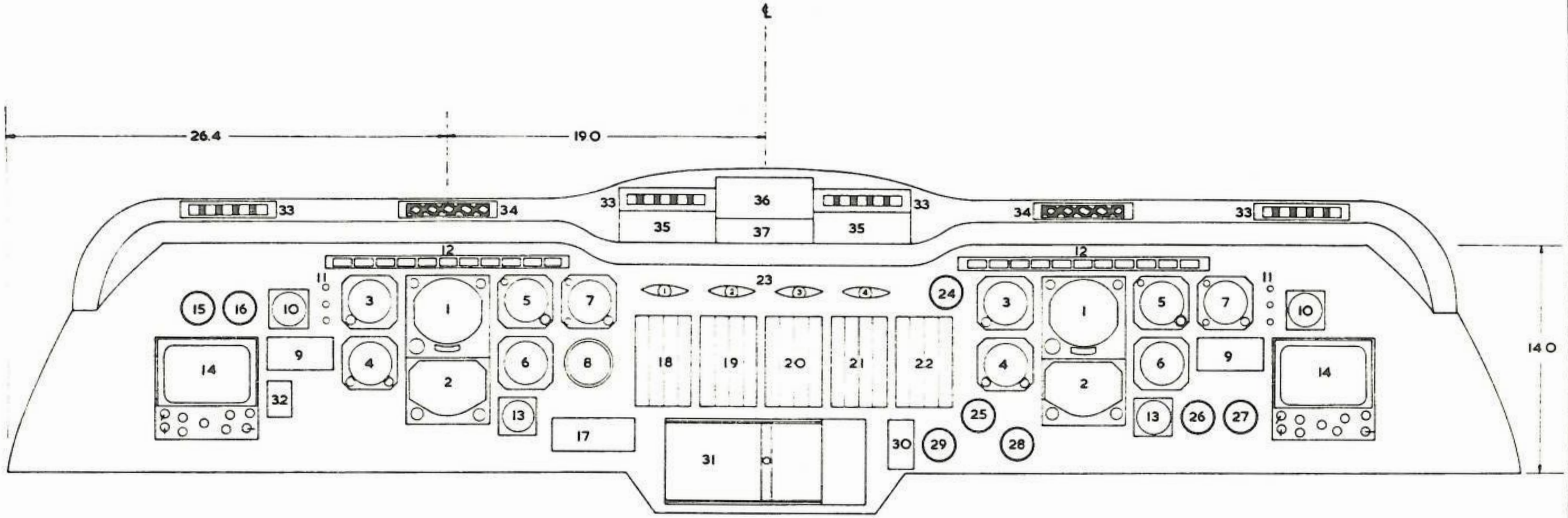
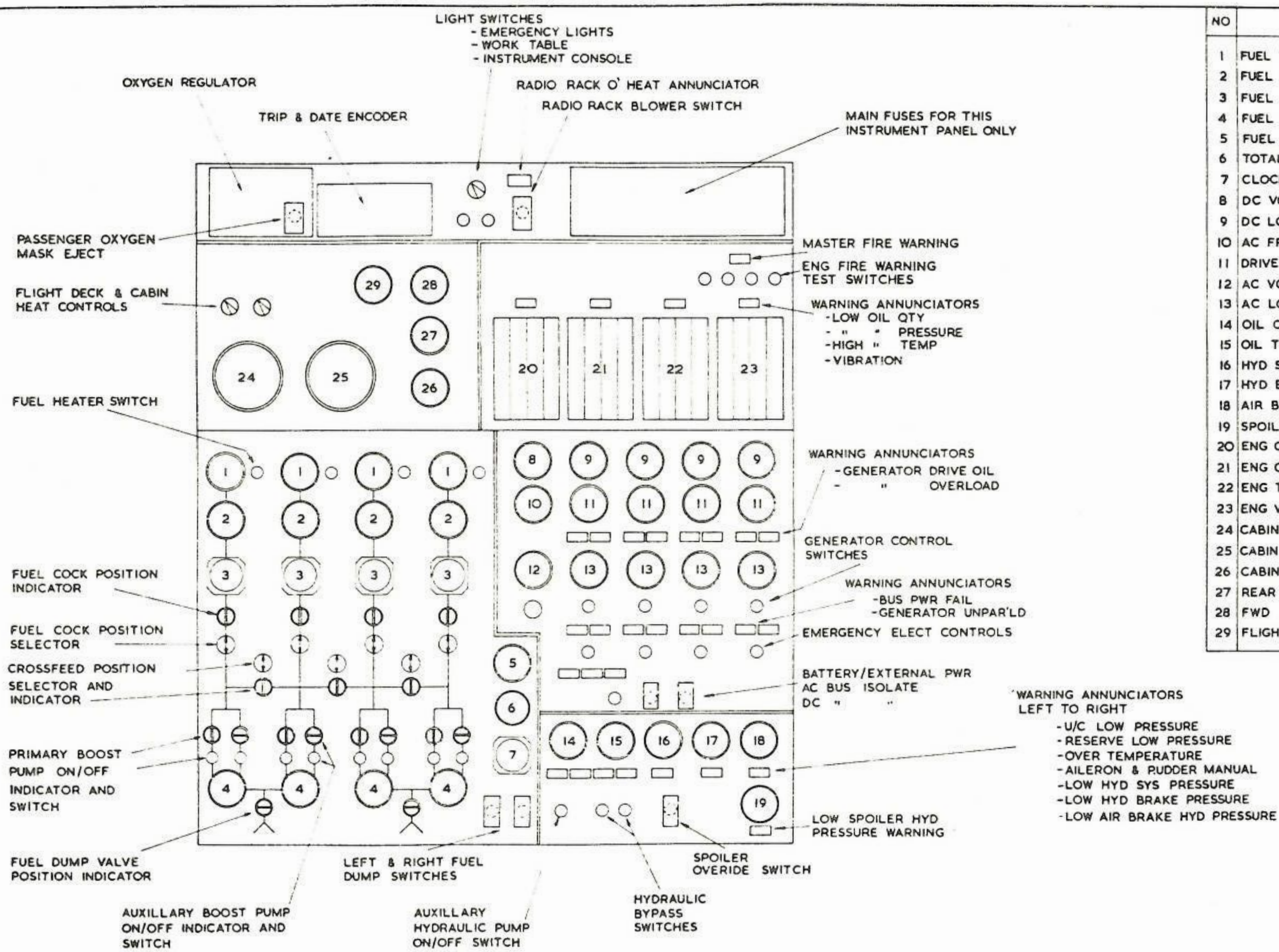


FIG. 9 COCKPIT LAYOUT



1	FLIGHT DIRECTOR	23	FIRE CONTROL
2	COURSE INDICATOR	24	OAT
3	MACH/AIRSPEED	25	FLAP POSITION
4	RMI	26	CABIN ALTITUDE
5	SERVO ALTIMETER	27	CABIN VERTICAL SPEED
6	VERTICAL SPEED	28	KRUGER POSITION
7	RADIO ALTIMETER	29	U/C POSITION
8	STANDBY HORIZON	30	U/C ACTUATOR
9	NAV/GUIDANCE FAILURE	31	MOVING MAP
10	CLOCK	32	SPEED PLACARD
11	MARKER BEACON LIGHTS	33	G/R PVD
12	WARNING ANNUNCIATORS	34	FLIGHT PVD
13	TURN & SLIP	35	NAV FREQUENCY
14	WEATHER RADAR	36	A/P MODE SELECT
15	LEFT BRAKE PRESSURE	37	REMOTE CONTROL
16	RIGHT BRAKE PRESSURE		
17	TRIM INDICATOR		
18	EPR		
19	N 1		
20	EGT		
21	N2		
22	FUEL FLOWS		

FIG. 10. MAIN INSTRUMENT PANEL LAYOUT



NO	UNIT
1	FUEL TEMPERATURE
2	FUEL PRESSURE
3	FUEL FLOWS
4	FUEL QUANTITY
5	FUEL TANK TEMP
6	TOTAL FUEL QUANTITY
7	CLOCK
8	DC VOLT
9	DC LOAD
10	AC FREQUENCY
11	DRIVE OIL TEMP
12	AC VOLT
13	AC LOAD
14	OIL QUANTITY
15	OIL TEMPERATURE
16	HYD SYS PRESSURE
17	HYD BRAKE PRESSURE
18	AIR BRAKE PRESSURE
19	SPOILER HYD PRESS
20	ENG OIL QUANTITY
21	ENG OIL PRESSURE
22	ENG TEMPERATURE
23	ENG VIBRATION
24	CABIN PRESS CONTROL
25	CABIN ALT & DIF PRESS
26	CABIN V/S
27	REAR CABIN TEMP
28	FWD
29	FLIGHT DECK TEMP

FIG. 11. SYSTEMS SPECIALIST INSTRUMENT PANEL