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The Instrumentation of an Aircraft (De Havilland "Dove") for Flight-Test Instruction

by

C.F.Bethwaite, B.Sc., A.F.R.Ae.S.

and

A.F.Newell, M.I.Mech.E., A.F.R.Ae.S.

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1. Introduction

The teaching of flight-test methods and techniques plays an important part in the syllabus of the College of Aeronautics, and it has presented several problems, amongst them the provision of a"flying classroom" in which students can undertake flight-test investigations. It is necessary to have the students flying in groups rather than individually, and sufficient instrumentation must be provided so that each student can record all the relevant variables.

For reasons including availability, initial cost, operating cost and general suitability, a de Havilland Dove has been chosen for this purpose, and adapted to carry six students in addition to a pilot and test supervisor. The number of students is limited by the difficulties of providing a sufficient number of some of the test instruments. A drawing of the aircraft is given in fig.1.

The test instrumentation, its problems and the solutions adopted, form the main subjects of these notes. The programme of tests undertaken by the students includes the appropriate parts of the flight-test schedule of a prototype aircraft and that part of the test programme applicable to the Dove is presented in table 1.,showing the measurements required for each of the individual tests. The test equipment required may be summarised as follows

(a) Airspeed indicator
(b) Altimeter
(c) Engine speed indicator and boost pressure gauge (on each engine).
(d) Fuel flowmeter (each engine), indicating rate of flow and integrated flow.
(e) Air thermometer
(f) Control angle indicators (elevator, ailerons and rudder).

/ (g) Control tab

(g) Control tab angle indicators (elevator and rudder).
(h) Control force indicators (elevator, aileron and rudder).
(i) Normal accelerometer (visual).
(j) Sideslip indicator
(k) Rate of roll indicator

It is desirable for students themselves to record the instrument readings, but during dynamic manoeuvres (e.g. measurement of rates of roll) it is necessary to use an automatic observer.

2. Layout

It is not practicable to provide each of the six students with a complete instrument panel embodying all the test instruments listed in the previous paragraph, and, in addition, to provide an automatic observer, so an instrument panel is provided for each pair of students. The layout of the cabin is illustrated in fig.2. Three double seats are situated on the starboard side of the cabin, with an instrument console in front of each seat, leaving space in the rear of the cabin for a parachute stowage (on top of which the automatic observer is mounted) and any additional equipment needed for research investigations (e.g. strain-gauge recorders). With this arrangement it is possible to ballast to the forward and aft C.G. limits.

The instrument panel is illustrated in fig.3 and 4, and includes:-

Air speed indicator
Altimeter (sensitive type)
"Pioneer" accelerometer
Air thermometer (impact bulb type)
Engine speed indicators
Sensitive boost-pressure gauges
"Desynn" indicators (denoting control angles, tab angles, etc.)

Indicators for the Kent fuel flowmeters are mounted separately on the port side of the front bulkhead (fig.5), and a balanced-bridge air thermometer is situated on top of the front instrument console.

In using a side-by-side seating arrangement all the seat loads have had to be taken initially by the floor. This has been strengthened by inserting internal spruce stiffeners in the sandwich construction of the standard floor. A length of heavy extruded top-hat section bolted to the top of the floor supports the central legs of all the seats. The seats are of welded magnesium alloy tube, the back and base being stiffened with plywood and spruce intercostals and upholstered with "Vynide" covered Dunlopillo. Lap-type safety belts are fitted to each seat. The complete double seat weighs 34 lb.

The instrument panels are mounted on tables of plywood and spruce construction, oak-veneered on the external surfaces. The sliding-leaf on the front table

/facilitates ...

facilitates access to the cockpit. Intercommunication station boxes are mounted underneath the tables.

3. Description of Instrumentation

3.1. Airspeed and Height

The introduction of a large number of additional instruments into the normal pitot-static system of the aircraft which serves the pilot's airspeed indicator and altimeter would greatly increase both the lag in the system and the possibility of leaks. Consequently, the airspeed indicators and altimeters on the student's test panels are supplied from a separate pitot-static tube located on the forward fuselage of the aircraft (fig.7). This position has been chosen to give an exaggerated position error, since the position error correction applicable to the normal pitot-static system (pitot tube on fin and static vent on forward fuselage) is small (within ± 1 m.p.h. over most of the speed-range) and therefore not very suitable for demonstration.

3.2. Engine Conditions

Each instrument panel includes master boost gauges (instrument reference number A/251 Negretti and Zambra) connected in parallel with the pilot's boost gauges. The possibility of leaks in the boost system is increased but there is no simple alternative. Lag in the system is perhaps not quite so important as in the case of airspeed and height. Engine speed is normally indicated on the Dove by an electrical tachometer connected to an engine-driven generator. Bench tests show that if more than two indicators are connected in parallel to one generator, the readings do not synchronise until a comparatively high rotational speed is reached and the generator tends to over-heat. Therefore two separate generators are driven from each engine through a gear-box. Each generator is connected to two engine-speed indicators in parallel, so that four simultaneous indications of engine-speed are available, including that on the pilot's instrument panel. The gear-box and generators are mounted in the hinged leading-edge of the wing between the engine nacelle and the fuselage, as shown in fig.8. This system is not entirely satisfactory, since the flexible drive between the engine and the gear-box is overloaded, and there have been several failures. A specially-wound generator operating four indicators in parallel may provide an alternative.

3.3 Fuel Flow

The "Kent" low-reading flowmeter (range 6 gals/hr. to 50 gals/hr.) is satisfactory for the measurement of rate of fuel flow and integrated flow, though the transmitter is bulky. This transmitter is installed between the main fuel filter and the injector unit by dispensing with the methanol bottle which is normally fitted to prevent icing in the pneumatic system at very low temperatures (fig.9). The flowmeters cannot be duplicated and the indicating units are therefore located on a separate panel on the port side of the cabin (fig.5B)

These flowmeters are of the by-pass type, so that the pilot can isolate them from the fuel system during take-off and landing.

/ 3.4. Ambient ...

3.4. Ambient Air Temperature

Ambient air temperature is measured by a balanced-bridge air thermometer, and also by impact-bulb thermometers. The impact-bulb thermometers are sufficiently accurate for most purposes, though the balanced-bridge type is preferable for performance measurements.

The element of the balanced-bridge thermometer located under the port wing (fig.10) is connected to an indicator mounted on top of the front students' instrument panel (fig.4B). The installation has a compressibility calibration factor K=0.9.

The elements of the impact-bulb thermometers are located under the main-planes, one on the port side adjacent to the balanced-bridge pick-up (fig.10), and two on the starboard side. The corresponding indicators are located one on each instrument panel (fig.4A and 4B).

3.5. Control Angles

The angles of all three main flying controls are measured by "Desynns". Four simultaneous indications are required, one on each of the three instrument panels, and one in the automatic observer. Ground experiments show that if two "Desynn" indicators are connected in parallel with one transmitter the calibrations are consistent, though they may differ from that obtained when a single indicator is connected to the transmitter. It is not satisfactory, however, to connect more than two indicators to one transmitter. Therefore two "Desynn" transmitters are connected to each control surface and each transmitter is connected to two indicators in parallel. The disposition of these transmitters in the control circuits is shown in fig.11a and 11b.

(a) Elevators

Two "Desynn" transmitters are mounted side-by-side on a bracket between the tubular members inside the tail-cone (fig.12). The operating arms of the transmitters are interconnected, and are coupled by a simple pin-jointed linkage to the elevator operating lever.

(b) Rudder

Two "Desynn" transmitters are mounted, one on top of the other, on the upper surface of the tailplane (fig.13). The operating arms are connected by a pin-jointed linkage to the rudder operating lever.

The quickly removable tail-cone of the Dove facilitates access to the rudder and elevator "Desynns" for purposes of inspection or maintenance.

(c) Ailerons

Rather than attempt to reproduce fourfold the angle of each aileron one "Desynn" transmitter is connected to each aileron and each transmitter is connected to two indicators in parallel. The transmitters are mounted on simple metal brackets on two strengthened stringers inside the wing, and connected to the aileron operating crank (fig.14), access being gained through the normal inspection door in the lower surface.

/ 3.6.Trimmer...

3.6. Trimmer Angles

(a) Elevator Trimmer

"Desynn" transmitters are mounted inside each of the elevators on brackets supported by the existing ribs (fig.15). The operating arms of the transmitters are connected to the operating rods of the trimmers. The mass-balance of the elevators is adjusted to allow for the weight of the transmitters.

(b) Rudder

A single "Desynn" transmitter is mounted inside the rudder in the same way as in the elevators. Rudder tab angle is indicated on two instrument panels only, but this is adequate for the test programme.

3.7. Control Forces

The measurement of the control forces presents a difficult problem and no satisfactory method of measuring rudder pedal forces is available at present. The R.A.E. type of pedal force indicator cannot be accommodated, due to the relatively small clearance between the rudder pedals and the surrounding structure (e.g. cockpit floor). The controls are cable operated and it is not easily possible to measure the pedal forces through the loads in the control circuit. The use of strain gauges cemented to the rudder torque tube is being investigated, and an attempt is being made to design a much smaller pedal force transmitter.

The elevator and aileron forces are measured by the R.A.E. type stick-force indicator. This is attached to the second pilot's control column (fig.16) since the presence of the thumb-operated brake lever defeats a neat installation on the first pilot's column. For tests involving the measurement of stick-forces, the pilot changes seats before landing, in order to have the use of the brakes. The application of large aileron angles is not easy when gripping the stick-force indicator, and this system is not entirely satisfactory. Furthermore, it is only possible to operate two Desynn indicators in parallel from the stick-force "Desynn" transmitter, so indication of stick-force is not provided on the front instrument panel. A strain gauge system may provide a more satisfactory method of measuring these control forces, and it would be possible to reproduce the reading as many times as required by having several completely independent circuits.

3.8. Normal Acceleration

Direct reading normal accelerometers ("Pioneer" type) are fitted to each instrument panel and one is included in the automatic observer. A similar instrument is also provided in the cockpit for the pilot's use.

3.9. Sideslip

Sideslip is measured by a wind-vane operating a "Desynn", mounted one local wing-chord forward of the leading-edge of the port wing tip (fig.1). After aligning the vane with the fuselage datum as nearly as possible on the ground, the final zero is obtained in flight. The Desynn transmitter is connected to two indicators located

/ on the middle...

on the middle and rear instrument panels.

A second vane could be mounted on the starboard wing to give two further indications of sideslip, but so far this has not proved necessary.

3.10 Rate of Roll

An R.A.E. type of rate of roll indicator(spring-restrained gyro operating a micro-desynn) is mounted in the aircraft as close as possible to the C.G. and the corresponding indicator is fitted in the automatic observer.

4. Automatic Observer

In order to give students experience of flight-test observing and also to reduce the time required for analysing the results, it is preferable to take direct observations. In some of the stability and control tests, however,(e.g. measurement of lateral control characteristics) an automatic observer is essential. An ordinary photographic type of observer is anti-vibration mounted on top of the parachute stowage in the rear of the cabin where it is easily accessible and quickly removable for servicing.

5. Special Instrumentation for Research

The instrumentation already described is a permanent feature of the aircraft. Special instrumentation is sometimes fitted to enable individual students to undertake research investigations during their second year at the College. The nature of the research carried out is restricted by the type of aircraft available, but included as examples of the variety of work covered are two investigations which have been successfully carried out.

5.1. Measurement of the loads in the nose undercarriage during landing.

The vertical and horizontal loads in the nose undercarriage at touch-down were measured by Tinsley strain-gauges (nominal resistance 100 ohms) attached to the drag strut and to the nose-wheel fork. The indicated stresses were calibrated against applied loads on the ground. Simple strain-gauge accelerometers were used to measure the shock accelerations at various parts of the structure.

The strain-gauge signals were recorded by an Elliott 10-channel strain gauge recorder giving the out-of-balance resistance as a linear spot deflection on a cathode-ray tube which was photographed by a continuous-film recording camera. The recording unit and camera were anti-vibration mounted on a specially constructed table which replaced the parachute stowage in the rear of the cabin (fig.17).

Since the Elliott recorder unit consumed 250 watts at 230 volts A.C., it was necessary to carry two 116 ampere-hour/12 volt accumulators, together with an inverter capable of supplying the required power. A 6 volt 60 ampere-hour heavy duty accumulator was also included to boost the voltage in case the heavy currents used produced a considerable voltage drop along the power lines.
The entire power supply weighed almost 500 lb., and was installed in a special mounting in the rear luggage compartment (fig.18) This was not an ideal location since the correspondingly rearward centre of gravity position tended to reduce the nose-wheel loads, but it was necessary since the concurrent uses of the aircraft entailed retaining

/ the seating...

the seating arrangement already described.

5.2. Measurement of elevator-tab hinge-moments

In view of the lack of reliable information on the hinge moments of tabs an attempt was made to measure the hinge-moment coefficients of the elevator trimming tab on the Dove; the investigation was undertaken by two second-year students specialising in Aerodynamics.

The tab-force recorder of R.A.E. design was installed in the final operating rod of the tab circuit, as shown in fig.15. This consisted of a sprung strut, the deformation of which was measured by a specially designed miniature Desynn. The elevator mass-balance was adjusted for the additional weight of the tab-force recorder inside the elevator. Trimmer tab angle was measured by a Desynn as already described. Further details of these tests will be included with the final results in a separate report.

6. Conclusions

Since the completion of the permanent instrumentation the aircraft has flown some 400 hours and it has proved very satisfactory as a "flying classroom". Little maintenance of the instrumentation has been required, apart from periodic calibrations, and only one flight has had to be cancelled because of unserviceability of the test equipment; this is noteworthy, in view of the considerable amount of instrumentation fitted. The two problems which are not yet satisfactorily solved are:-

(a) The measurement of the rudder pedal forces

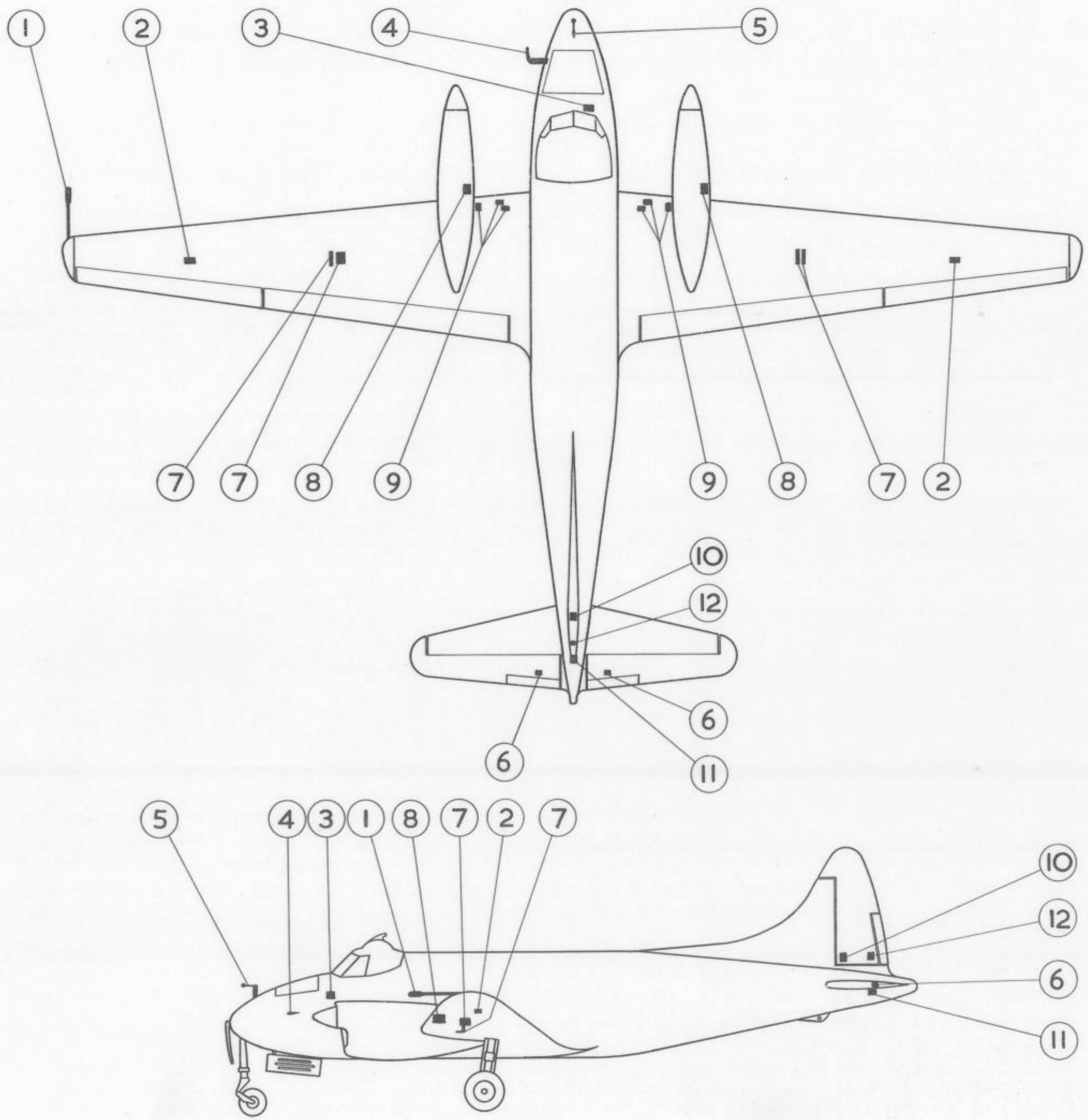
(b) The fourfold indication of engine-speed.

The existing method of driving two generators in parallel is satisfactory except for the apparently excessive strain on the flexible drive. The most attractive solution is undoubtedly a specially wound generator which will serve four indicators without being overloaded. Whether this is a practical and reasonably cheap proposition is still doubtful.

TABLE 1

SUMMARY OF FLIGHT TESTS DEMONSTRATED ON "DOVE" SHOWING INSTRUMENTATION REQUIRED

TEST \ INSTRUMENT	Airspeed indicator	Altimeter	Air thermometer	Engine-speed indicators	Boost gauges	Rate-of-roll indicator	Fuel flowmeter	Accelerometer	Elevator angle indicator	Elevator tab angle indicator	Rudder angle indicator	Rudder tab angle indicator	Aileron angle indicator	Stick-force indicator	Sideslip angle indicator
Position error determination (aneroid)	x	x													
Stalling investigation	x	x							x					x	
Air thermometer calibration	x	x	x												
Speed-power tests	x	x	x	x	x		x								
Partial climbs	x	x	x	x	x		x								
Ceiling climb	x	x	x	x	x		x								
Max. level speed measurement	x	x	x	x	x										
Fuel consumption tests	x	x	x	x	x		x								
Take-off & landing	x		x	x	x				x	x	x			x	
Static stability tests	x	x		x	x		x	x	x	x				x	
Stick-force per 'g'	x	x		x	x		x	x	x	x				x	
Aileron tests; rate of roll	x	x		x	x	x		x			x	x	x	x	x
Behaviour in sideslips	x	x		x	x				x	x	x	x	x	x	x
Engine-cutting tests	x	x		x	x				x	x	x	x	x	x	x

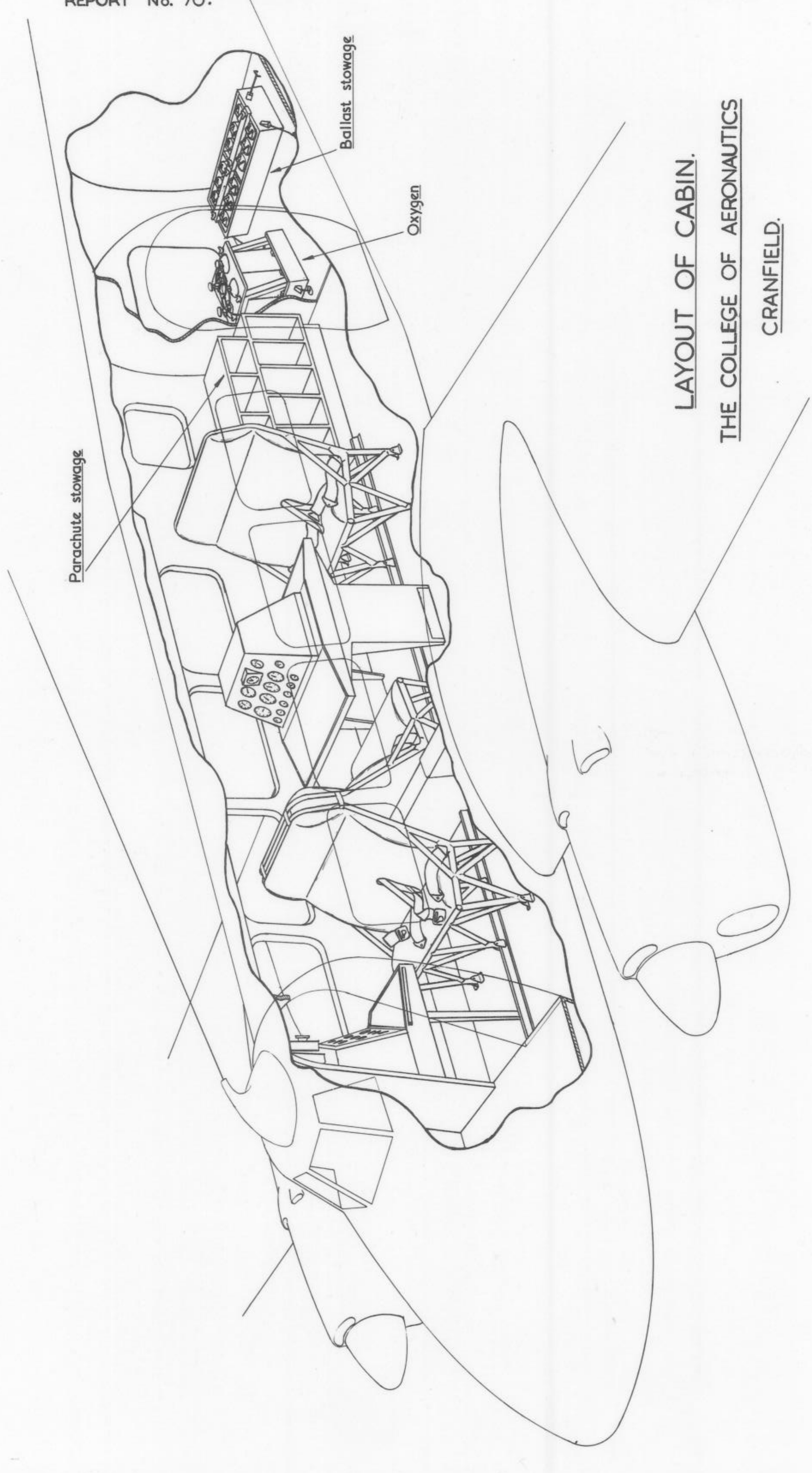


1. Sideslip vane
2. Aileron desynn.
3. Stick force indicator.
4. Extra pitot head.
5. Differential yaw meter.
6. Elevator tab desynn.
7. Air thermometers. (2 impact. 1 impact. 1 balanced bridge.)
8. Fuel flow meters.
9. Engine speed drive.
10. Rudder desynn.
11. Elevator desynn.
12. Rudder tab desynn.

FIG. 1.

G. A. OF INSTRUMENTATION

FIG. 2.



LAYOUT OF CABIN.

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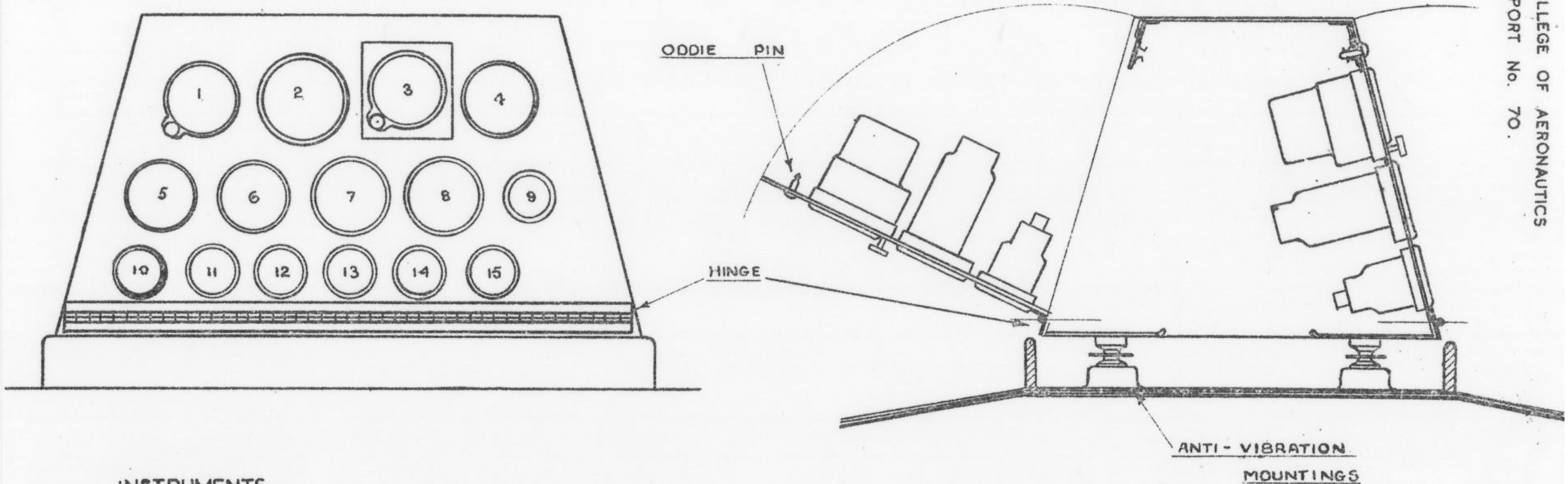


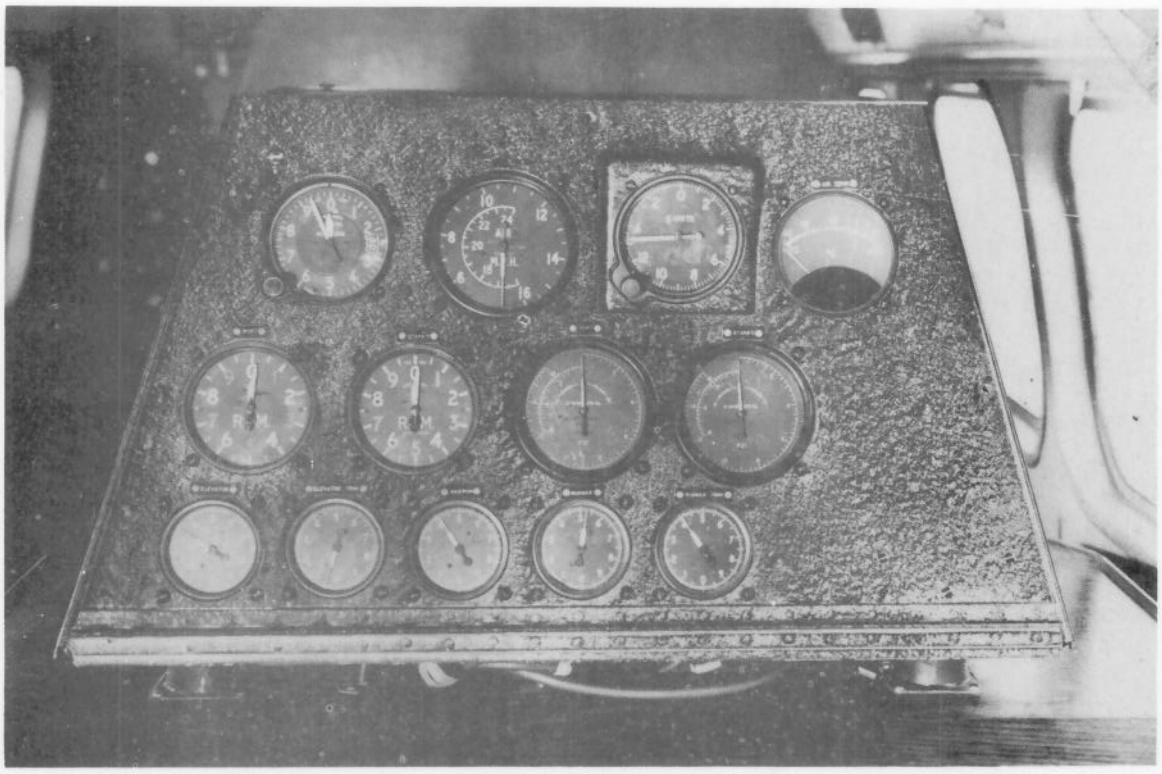
INSTRUMENTS

1.	ALTIMETER	9	DESYNN INDICATOR - SIDE SLIP
2	AIR SPEED INDICATOR	10	" " - ELEVATOR
3	ACCELEROMETER	11	" " - ELEVATOR TRIM
4	AIR TEMPERATURE THERMOMETER	12	" " - AILERON
5	R.P.M. INDICATOR (PORT ENGINE)	13	" " - RUDDER
6	R.P.M INDICATOR (STBD ENGINE)	14	" " - RUDDER TRIM
7	BOOST GAUGE (PORT ENGINE)	15	" " - ELEVATOR FORCE
8	BOOST GAUGE (STBD ENGINE)		

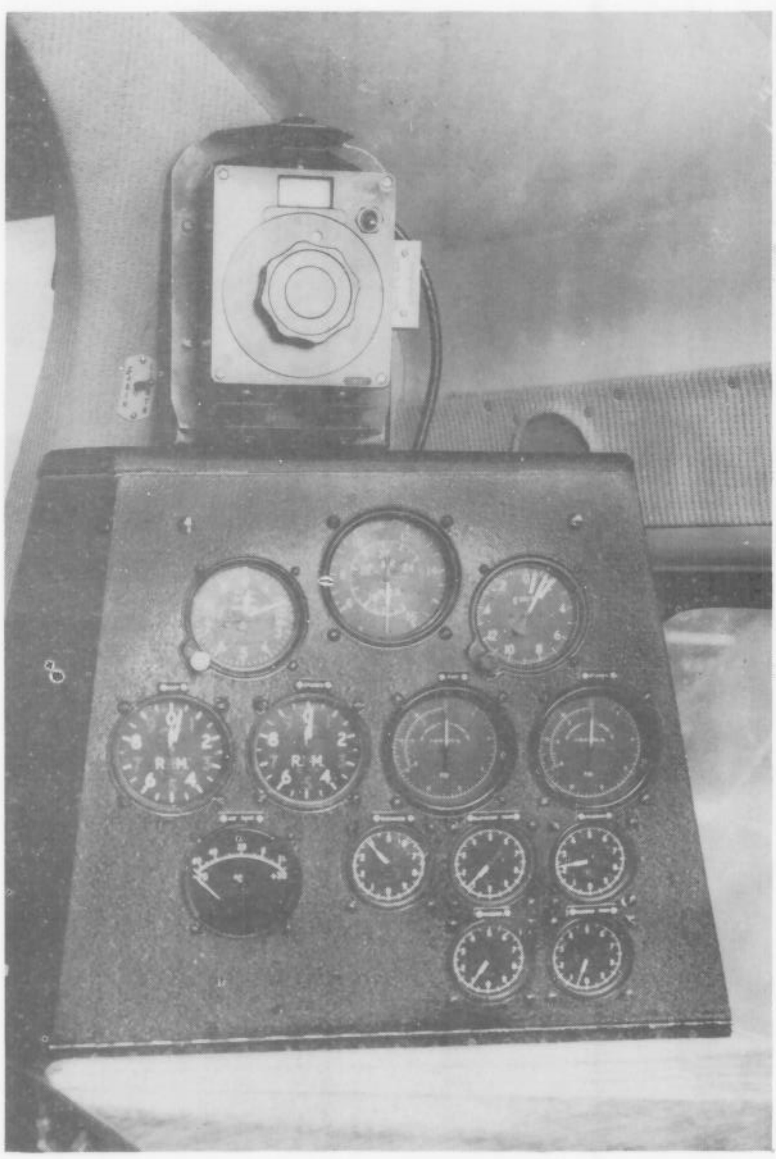
FIG. 3

CENTRE CONSOLE

FIG. 4.

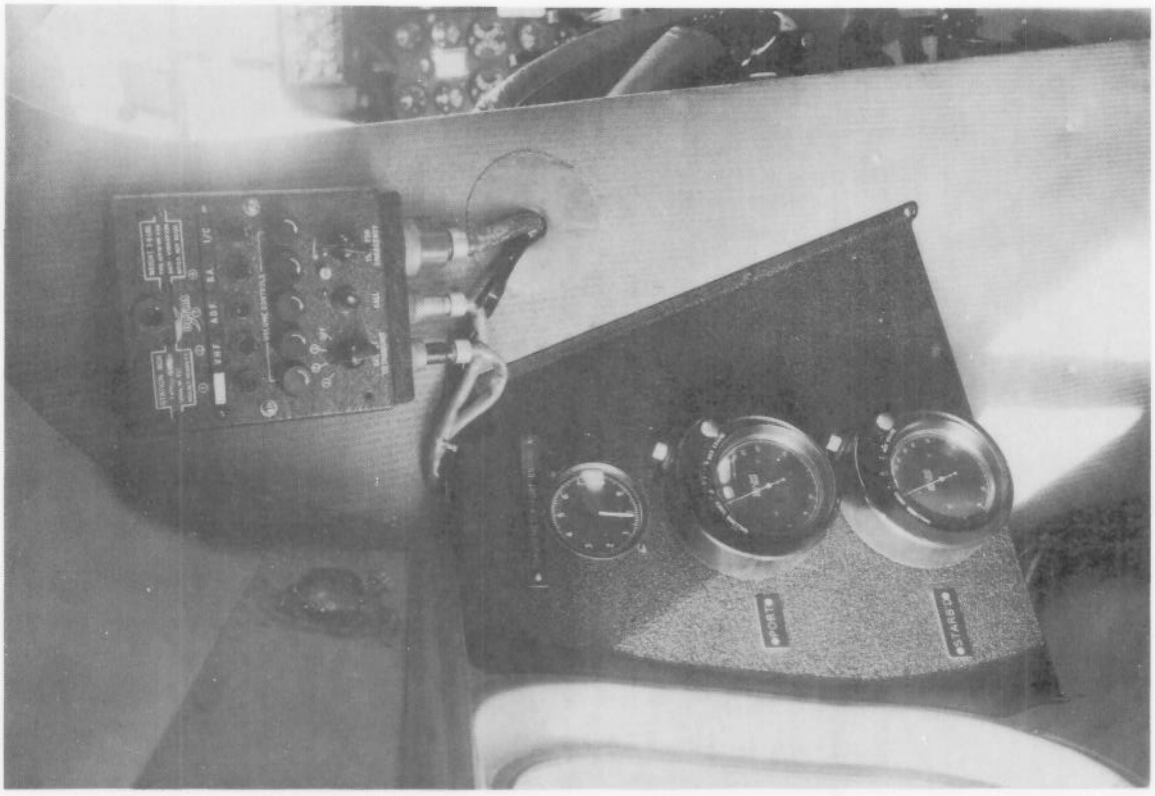


(a) REAR INSTRUMENT PANEL

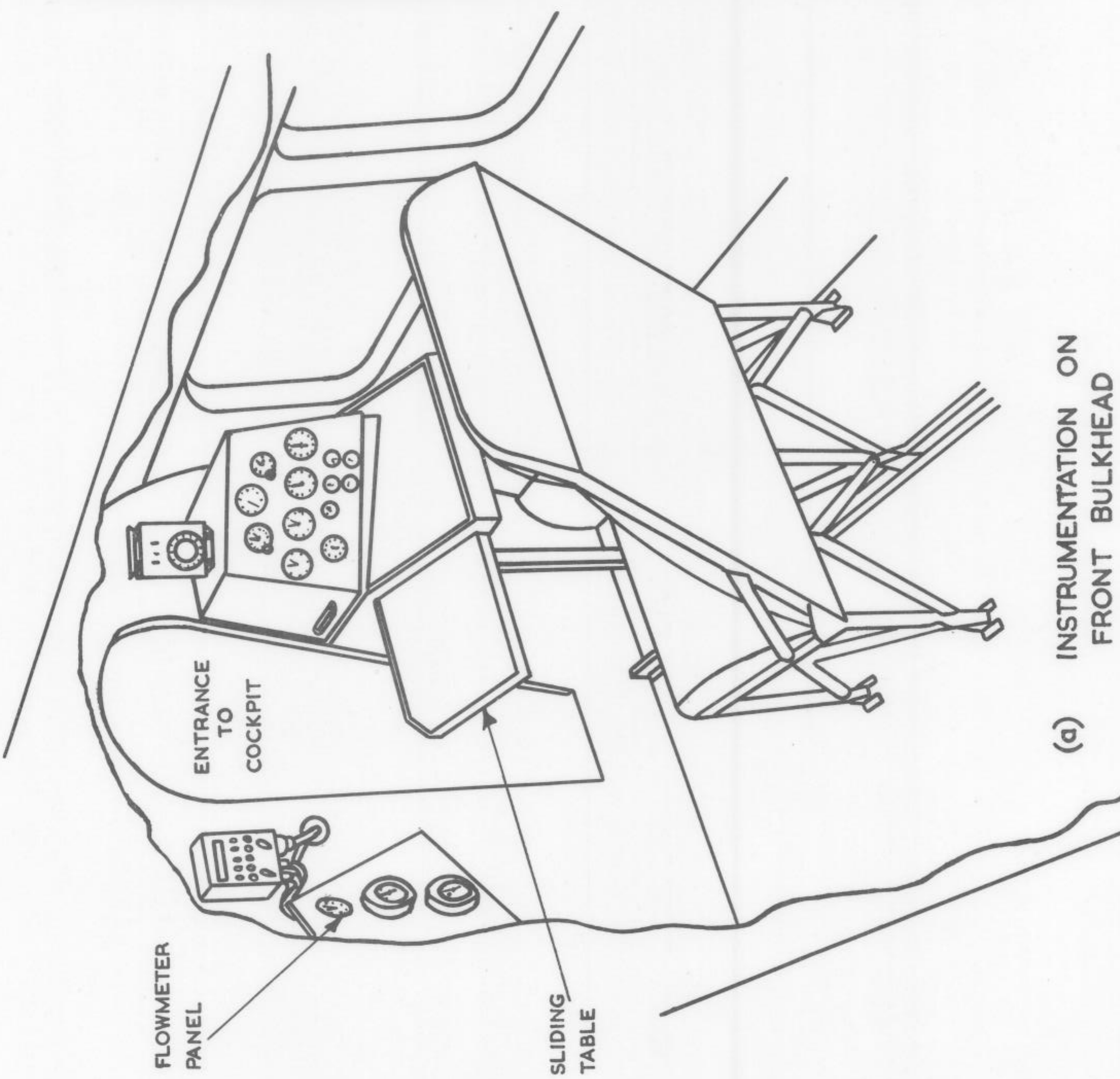


(b) FRONT INSTRUMENT PANEL & BALANCED BRIDGE THERMOMETER

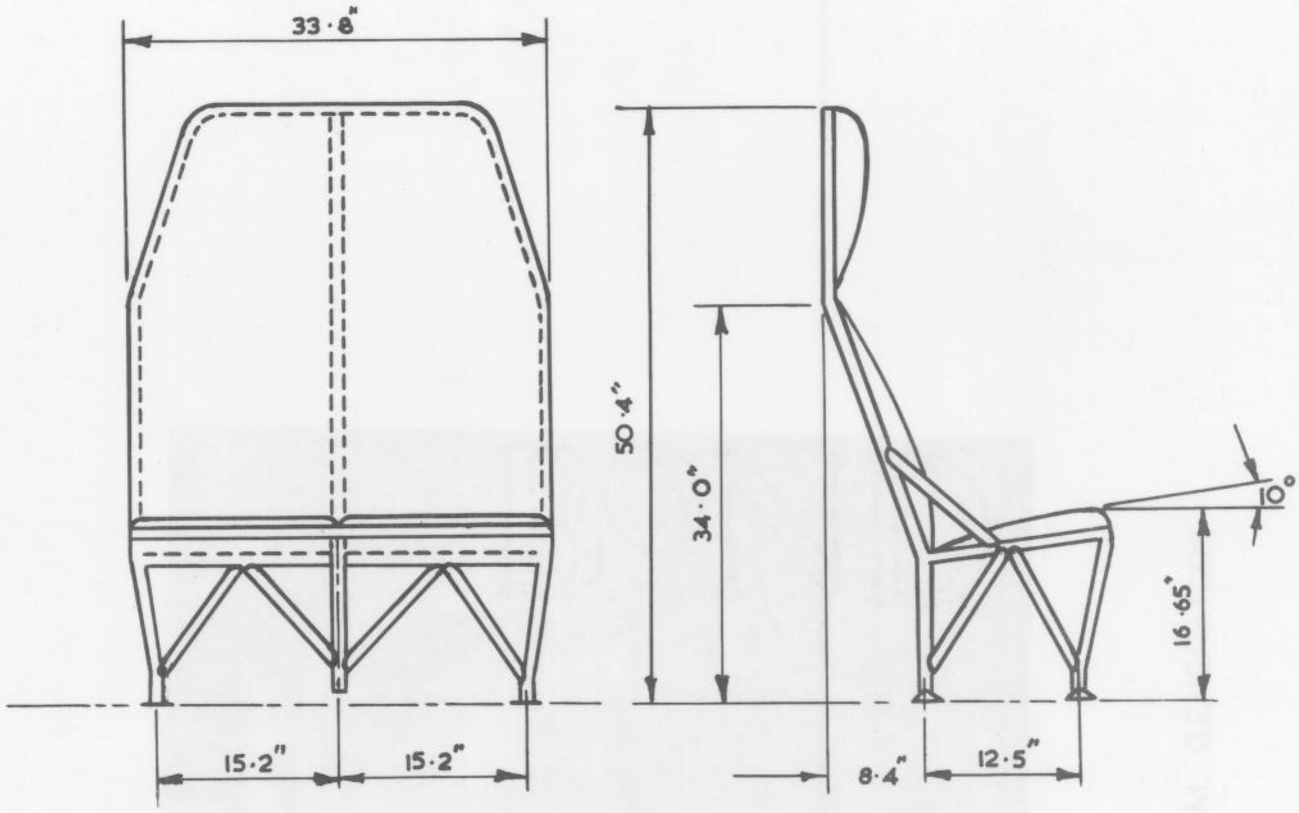
FIG. 5.



(b) FUEL FLOWMETER PANEL AND INTERCOMMUNICATION STATION BOX



(a) INSTRUMENTATION ON FRONT BULKHEAD



PARTICULARS OF SEAT. FIG 6

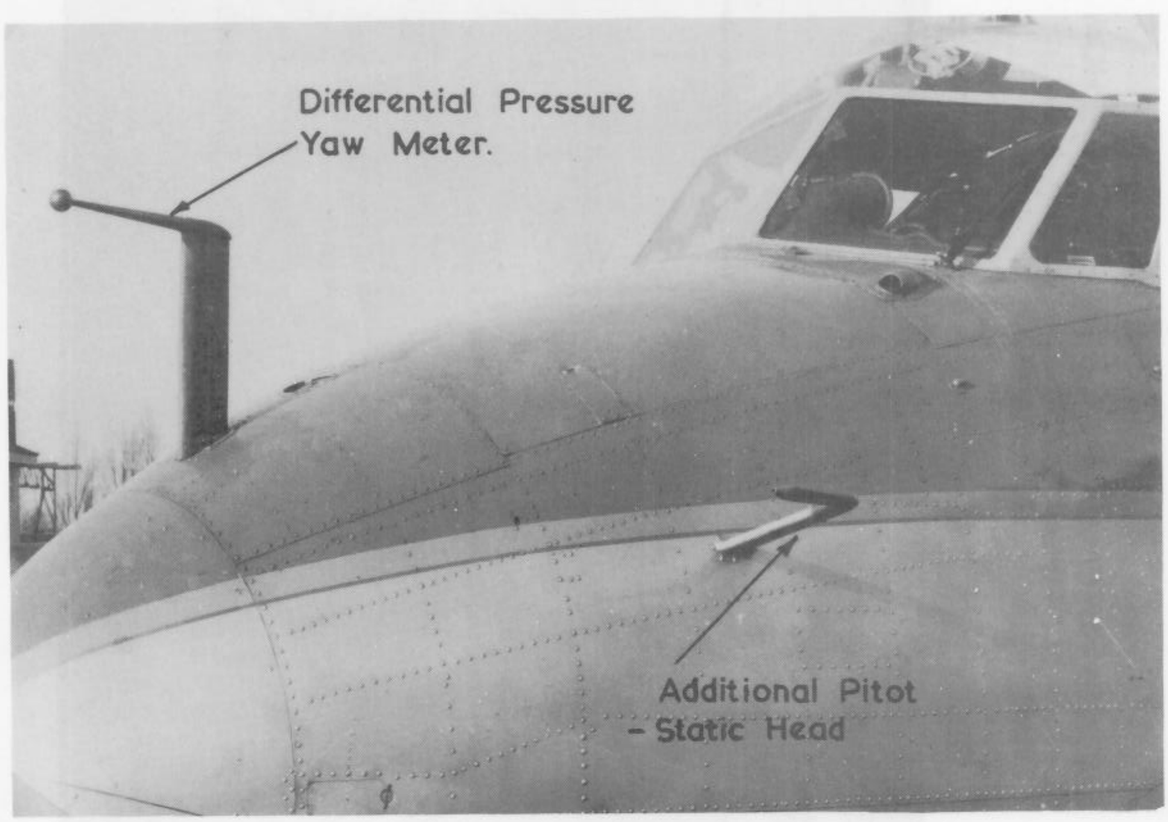
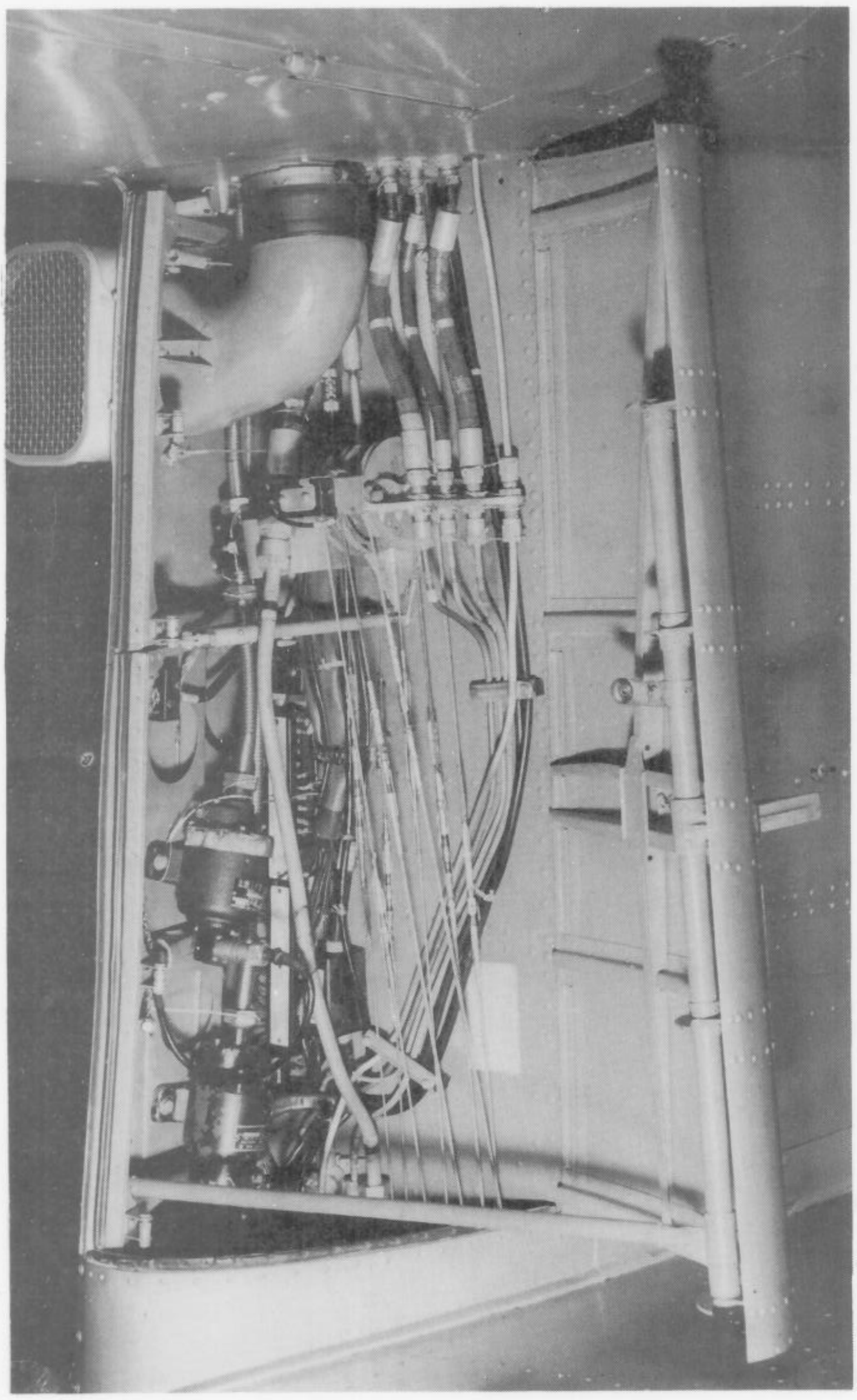
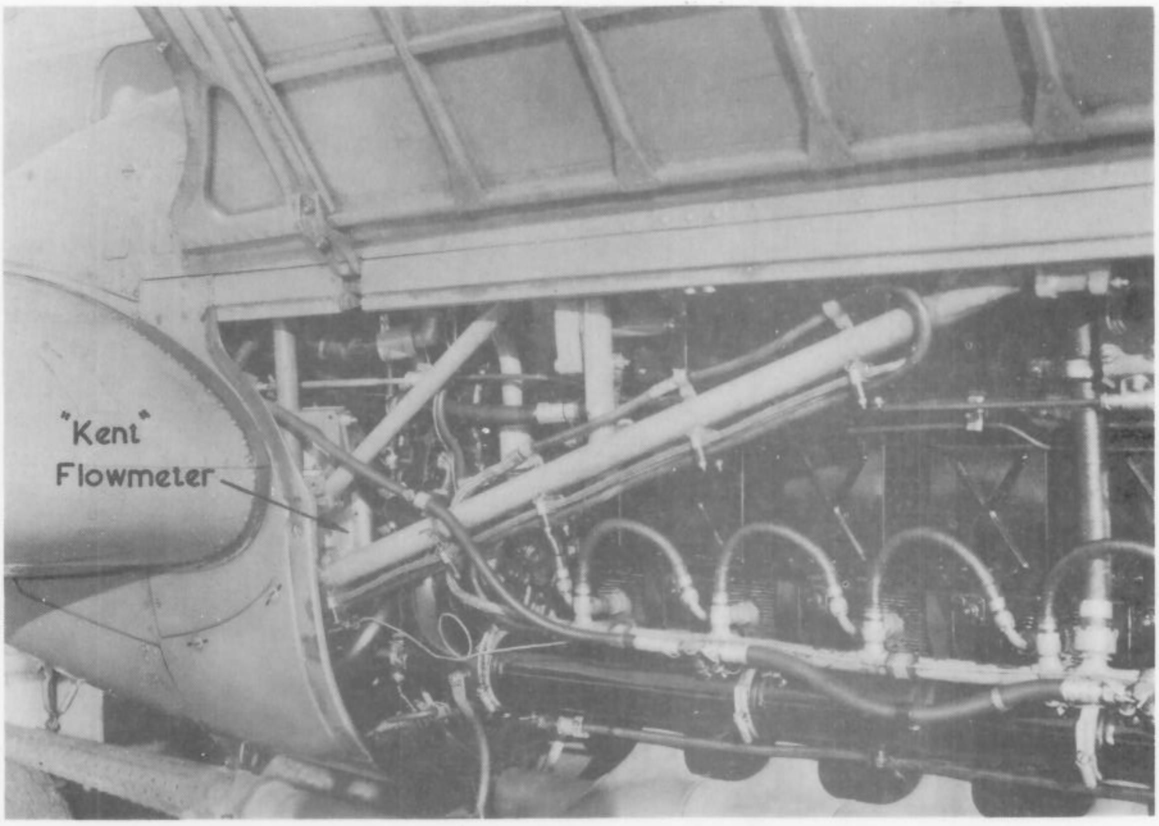


FIG 7

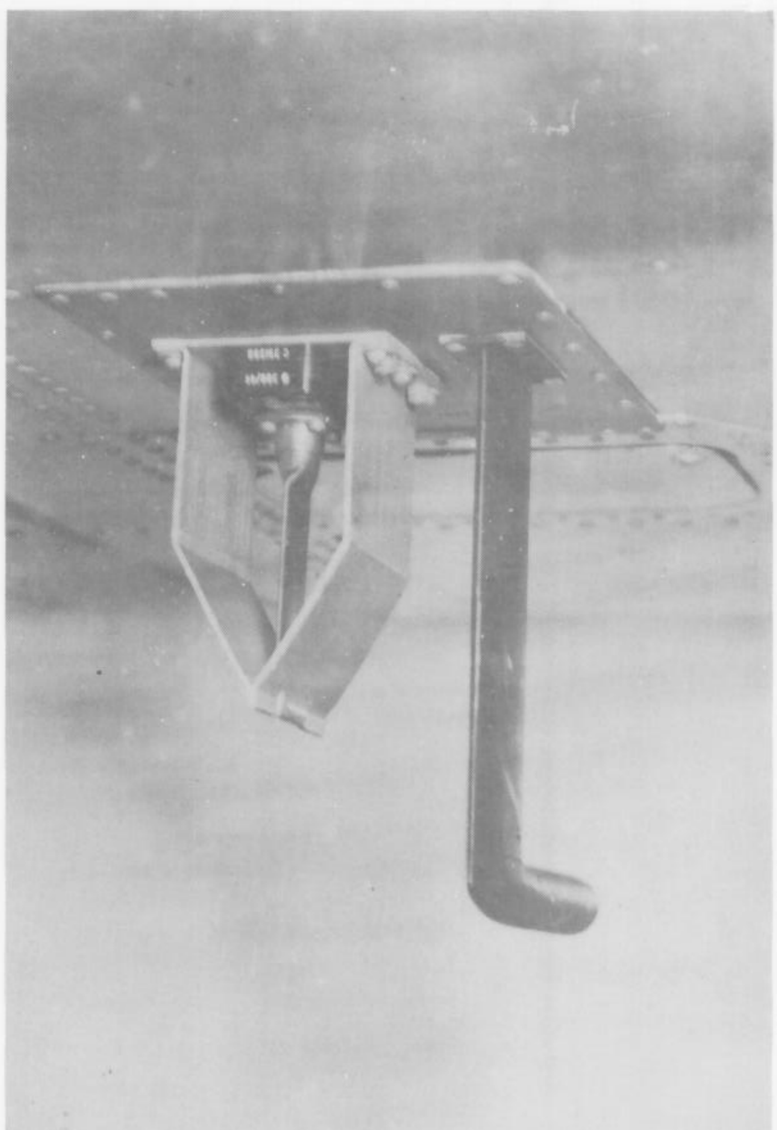
LOCATION OF ADDITIONAL PITOT STATIC HEAD.



LEADING EDGE HINGED OPEN TO SHOW TWIN R.P.M. GENERATORS



"KENT" FLOWMETER TRANSMITTER FIG. 9.



BALANCED BRIDGE & IMPACT BULB THERMOMETER ELEMENTS (PORT WING) FIG. 10.

FIG. 11a.

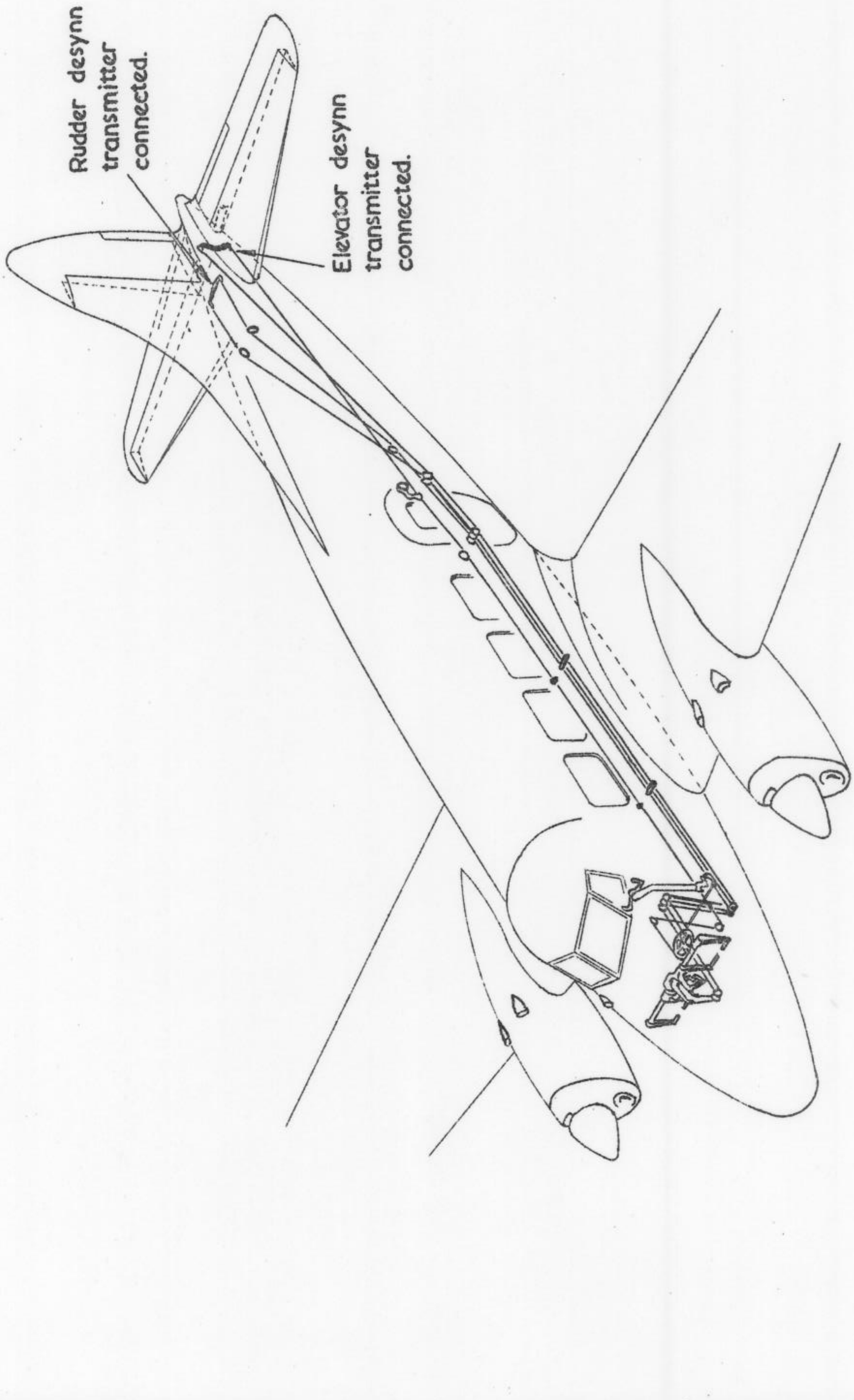
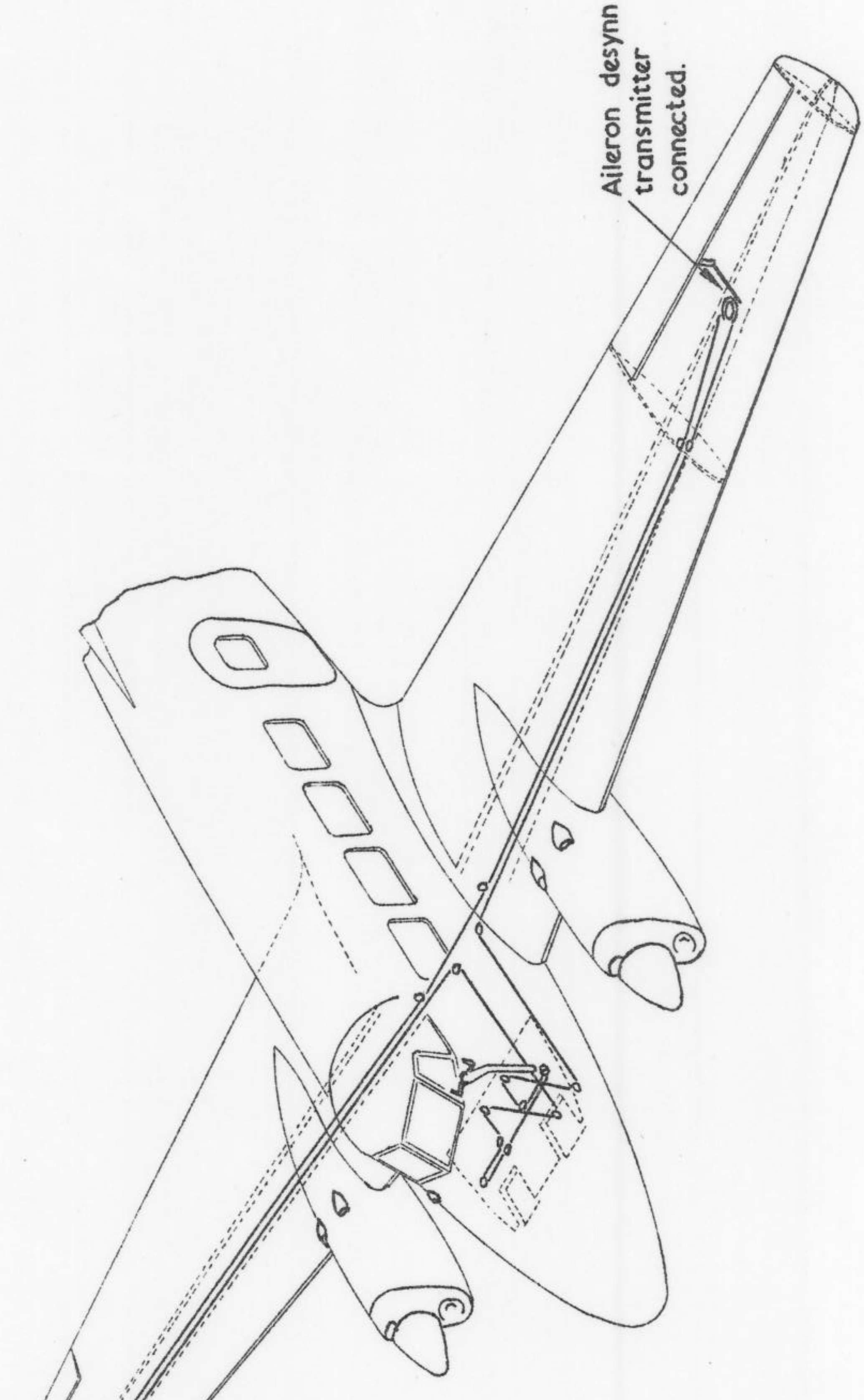
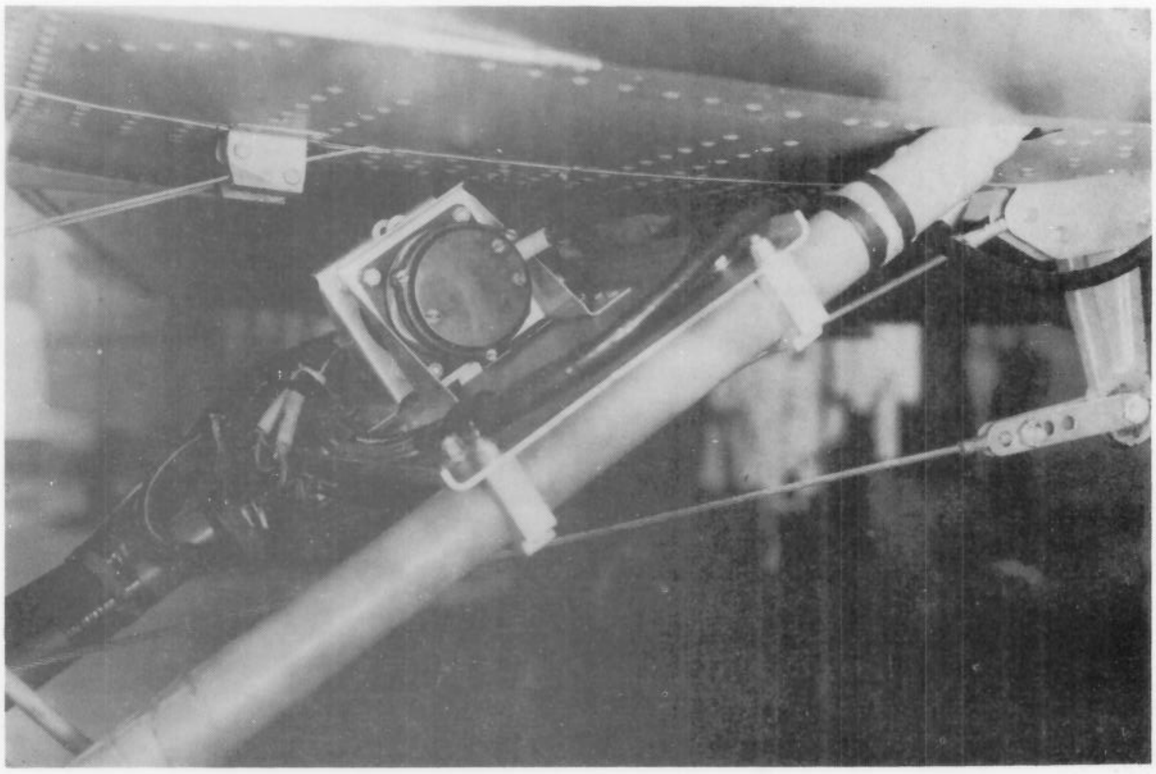
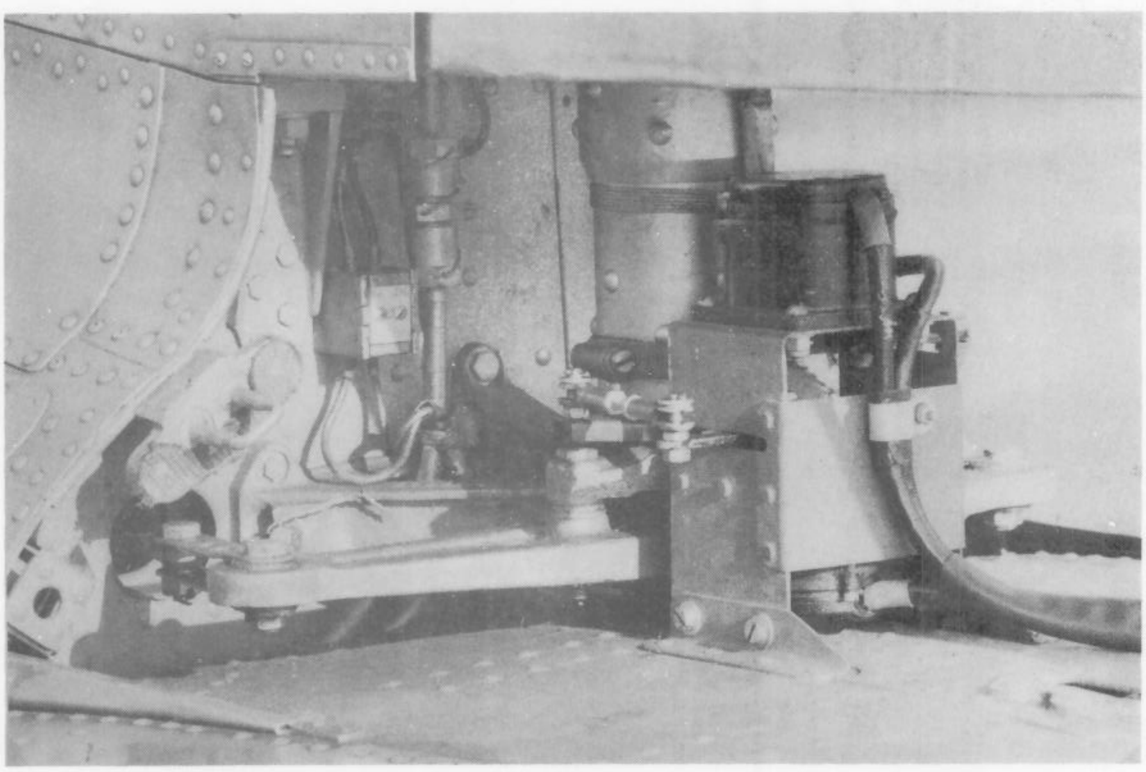

Rudder desynn transmitter connected.
Elevator desynn transmitter connected.

FIG. 11b.

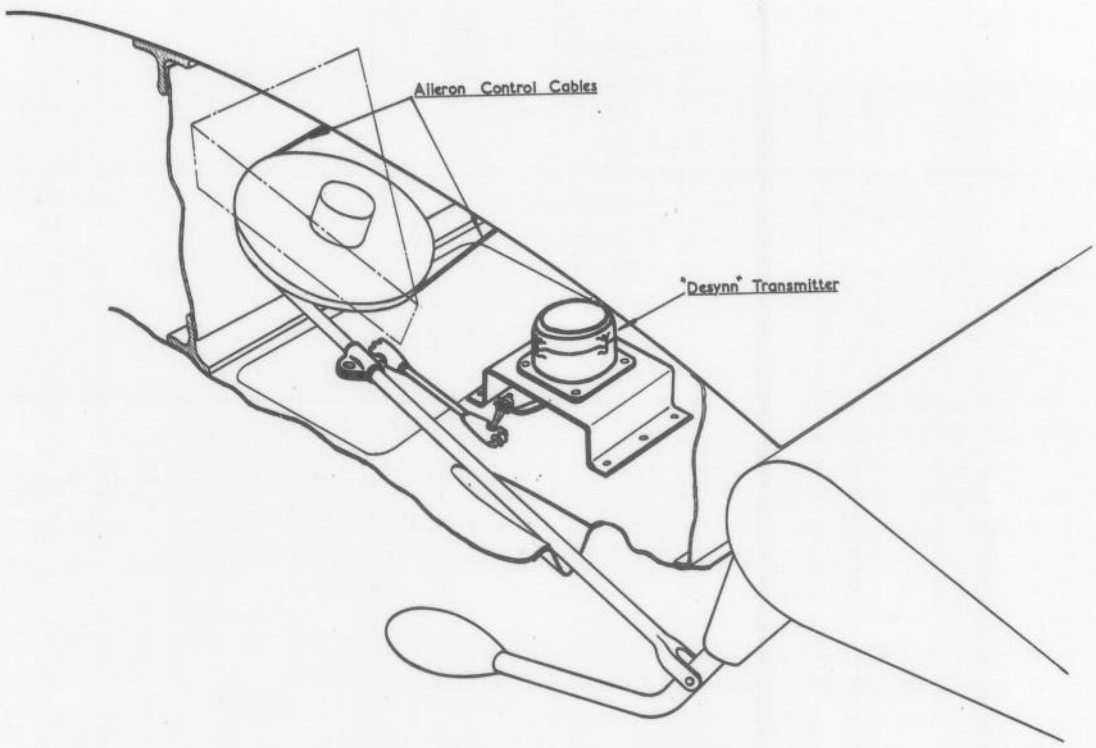




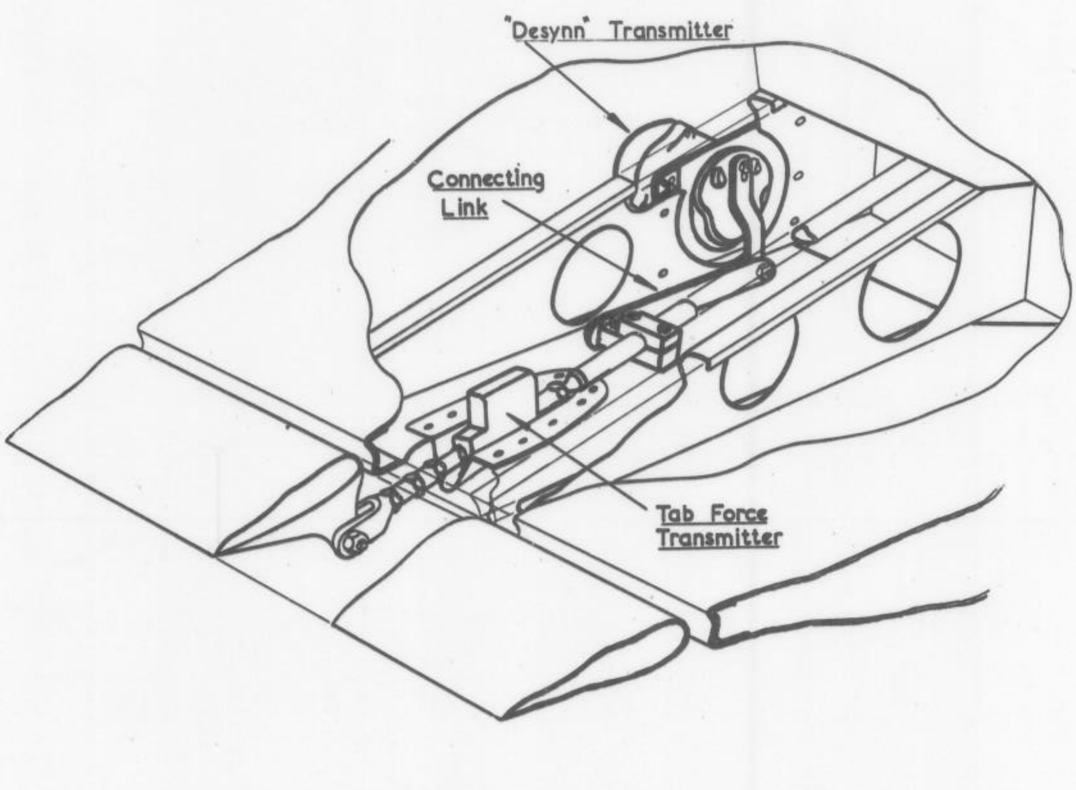
ELEVATOR "DESYNN" TRANSMITTERS FIG 12



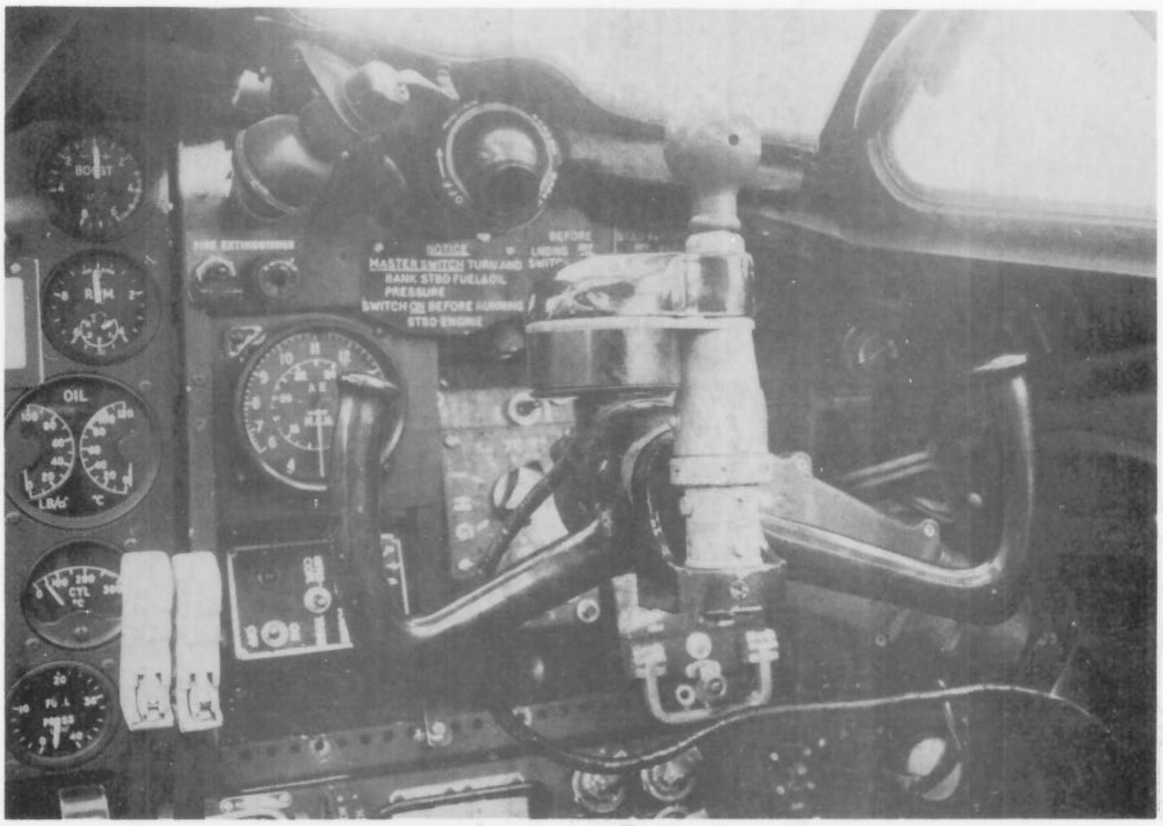
RUDDER "DESYNN" TRANSMITTERS FIG. 13.



AILERON ANGLE "DESYNN" TRANSMITTER FIG. 14.

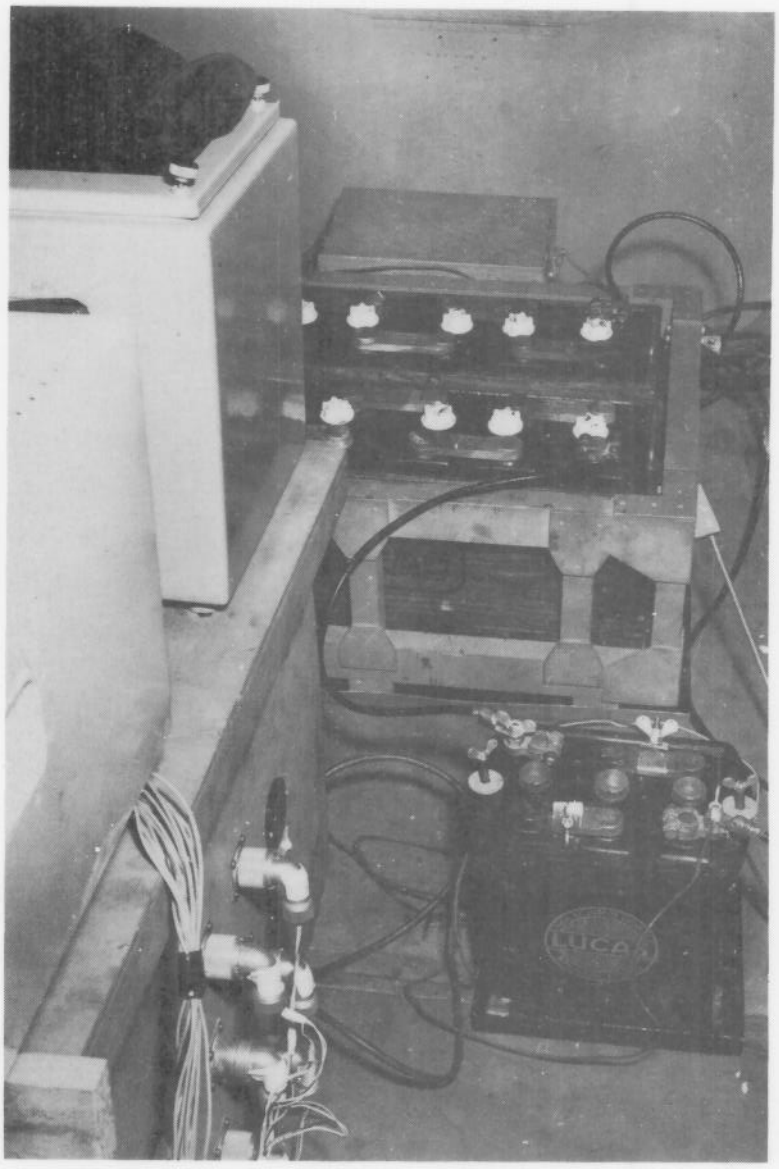


ELEVATOR TAB ANGLE "DESYNN" TRANSMITTER FIG. 15.



STICK FORCE INDICATOR FIG. 16.

ELLIOT 10-CHANNEL STRAIN GAUGE RECORDER FOR NOSE U/C LOAD MEASUREMENT FIG. 17.



POWER SUPPLY FOR ELLIOT STRAIN GAUGE RECORDER.

(MOUNTED IN REAR LUGGAGE COMPARTMENT.)