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Trials of an Experimental Low Airspeed Indicator for Helicopters

by

Staff of Airborne and Helicopter Division

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Summary

The need for low airspeed measurement in helicopter flight test work has led to the development, at A. & A.E.E., of a low airspeed indicator designed to function within the rotor downwash. The instrument measures the magnitude and direction of the resultant flow beneath the rotor and resolves the horizontal component, this component being approximately equal to the forward speed of the helicopter. Results of calibration flights are shown for level flight, climb and descent.

During a limited assessment the instrument functioned satisfactorily at forward speeds down to zero, but handling limitations of the helicopter prevented steady descents being made at forward speeds below about 5-7 knots.

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1. Introduction

The need for an accurate indication of low airspeeds has long been apparent in helicopter flight test work where measurements are frequently required in hovering or at low speeds. Such an instrument may also prove to be of operational value in permitting techniques not considered practical at present.

Though satisfactory above 20 knots the conventional fixed pitot-static system is inadequate below this speed since the pressure difference is too small to be detected by normal airspeed indicators, and the rotor downwash affects the indication, producing large position errors. Several sensitive devices have been tried on helicopters to measure these low forward speeds but in all cases at A. & A.E.E. the downwash affected the indication to such an extent as to make it unusable.

The conclusion was reached that a satisfactory device would have to take full account of the rotor downwash and an idea from Dr. Cheeseman led to the development of a horizontal airspeed indicator described herein.

2. Principle of operation

The instrument was designed to measure the magnitude and direction of the airspeed at a point under the rotor and to compute the horizontal component of this velocity, which, in unaccelerated flight, is shown to be approximately the same as the horizontal airspeed of the helicopter.

If V_L' = horizontal component of the resultant flow just beneath the rotor disc

V_L = horizontal component of aircraft speed

v = induced velocity at rotor

α_H = disc incidence relative to the horizontal

Then

$$V_L' = V_L + v \sin\alpha_H$$

For normal helicopter flight conditions, $v \sin\alpha_H$ is small compared to V_L since the induced velocity is small at high speeds and α_H small at low speeds; hence $V_L' \simeq V_L$.

If the velocity of the resultant flow beneath the rotor is measured and also the cosine of the angle of this relative to the horizontal, then the product of these two quantities will give V_L' and hence the horizontal airspeed of the helicopter.

Fig. 1 shows the theoretical values of the resultant flow V' at the rotor disc for a Sycamore helicopter. It will be seen that in level flight V' is always greater than 17 knots, and thus there should always be a reasonable airflow to be detected by a pitot-static head pointing in the direction of the resultant airstream. In powered descent however there will be cases near the vortex ring state when the flow over the detecting head will be very small and the equipment may not perform satisfactorily under these conditions.

Consideration has been given to the effects of horizontal swirl in the rotor downwash. Estimates for a Sycamore in hovering flight, based on propeller theory, showed a horizontal component in the downwash of about 3 knots in the region of the detecting head.

It should be noted that a horizontal datum is presupposed from which to measure the angle of the resultant flow. For the purpose of these tests the aircraft fuselage was taken as the datum. A refinement would, of course, be to provide a space gyro datum.

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3. Description of instrument.

The magnitude and direction of the resultant airflow beneath the rotor were measured by a pitot static head swivelling $\pm 90^{\circ}$ in the pitching plane on a horizontal spindle. (Fig. 2). The head was kept pointing into the airflow by a pair of vanes.

The pitot and static pressures were ducted through the spindle to the supporting body and thence to the airspeed transducer.

The spindle, which rotated with the pitot-static head, drove a scotch yoke mechanism through 1:1 gearing. The crosshead of the yoke carried a wiper arm working over a potentiometer. The movement of the cross head of the scotch yoke, and hence the output of the potentiometer, was proportional to the cosine of the angle of rotation of the driving crank.

This assembly was mounted on a vertical support tube carried on a horizontal pole projecting laterally from the aircraft fuselage on the side of the retreating blade (Fig. 3). The detecting head was approximately 6 feet from the rotor centre, at 90° in azimuth, and $3\frac{1}{2}$ feet below the rotor disc.

The airspeed transducer was similar to a normal airspeed indicator except that the capsule operated the wiper arm of a potentiometer instead of the usual pointer. This potentiometer output was approximately a square law relationship over the range 0-40 knots and linear thereafter as shown in Fig. 4. The transducer was mounted on the support tube of the swivelling head assembly in order to minimise the length of pressure piping necessary, thus reducing lags and losses.

The electrical leads from the cosine potentiometer and the airspeed potentiometer were taken to a control box fitted on the rear seat of the aircraft.

Fig. 5 shows the electrical circuit of the system. The arm containing the fixed resistors R_1 and R_2 and the airspeed potentiometer P_1 was fed with a regulated voltage supply; this arm formed an elementary square rooting system. The output from this potentiometer was proportional to total pitot speed between 10 and 40 knots as shown in Fig. 6. Since the resultant flow for normal flight is never likely to be much under 17 knots (Fig. 1) the departure from linearity at low speeds is of little significance.

The output of the airspeed arm was then fed to the cosine potentiometer. The voltage from this potentiometer wiper was thus proportional to $V' \cos \beta$, where V' was the total flow and β its direction relative to the fuselage datum, and was measured on a 0-1 milliammeter. Trimming resistors were fitted for adjustment of the full scale meter reading corresponding to $V' = 40$ knots, at $\beta = 0$.

In order to obtain permanent records of the system performance, galvanometers in a Hussenot continuous trace recorder were connected to the output of the airspeed arm and in parallel with the indicating meter. Calculations showed that the circuit should be reasonably accurate, though ideally buffer stages should be inserted between the airspeed and cosine potentiometers and between the cosine potentiometer and the indicating meter.

4. Tests made

Initial tests were aimed at calibrating the low airspeed indicator in level flight at two rotor speeds, 245 and 287 r.p.m. Subsequently check tests were made in climbing flight at full power and in powered descents. All tests were made using a Sycamore Mk.3 helicopter.

A qualitative assessment of the instrument was made at low speeds and in steep approaches.

/Flight...

Flight calibrations were made using three methods, described below, all tests being made in reasonably steady winds of less than 10 knots.

(a) Formation on vehicle

The first attempts at flight calibration were made by formating on a vehicle driven along the runway in the same direction as the wind. A sensitive cup anemometer was mounted on the vehicle with the cups about 3 feet above the roof. This anemometer gave a continuous display of true airspeed on a meter mounted before the driver and thus it was possible to drive the vehicle at known airspeeds.

This system of calibration produced considerable scatter in the results at the lower speeds due mainly to the difficulty of formating accurately on a slowly moving vehicle. The difficulty was enhanced by the need for the aircraft to be some distance away so that the rotor downwash did not affect the anemometer.

After a few preliminary tests this method was discarded.

(b) Speed course

In this method a speed course 150 yards long was laid out into wind. The pilot flew over the course in both directions at approximately 100 feet altitude and at a nominal reading on the visual meter of the low airspeed indicator. The time for each run was taken by observers on the ground and by an observer in the aircraft who also operated the Hussenot recorder. The wind speed was checked between each run by a cup anemometer mounted on a 20 foot pole.

(c) Camera obscura

The third method made use of a camera obscura which projected an image of the aircraft on to a plotting table. This image was plotted across the table at one second intervals with the aid of an audible timing device, thus giving the track and a measure of the horizontal speed of the helicopter. The aircraft was simultaneously tracked by a recording theodolite set up about a mile away to determine accurately the height of the aircraft, this data being required to define the scale of the camera obscura plot. Communications links were established from the camera obscura to the theodolite and aircraft.

The aircraft made runs into wind or downwind over the camera obscura at heights between 1000 feet and 2000 feet, depending on the test. When the image appeared on the plotting table observers in the aircraft and at the theodolite were instructed to start their respective recorders. At some time during each plot all records were synchronised by a count-down from the camera obscura.

Before and after calibration runs, smoke puffs were fired from the aircraft at the operating height to determine wind speed and direction. These puffs were plotted as above.

From the assembled data the airspeed of the helicopter was calculated and compared against the recorded low airspeed indication.

5. Results of tests

5.1 Level flight

The calibrations obtained in level flight for two rotor speeds are shown in Fig. 7; the speed course method was used for most of these tests, though two points obtained from the camera obscura are shown. Whilst the curves for each rotor speed are well established there is an appreciable steepening of the curve in the 0-20 knot region in the case of the higher

/rotor...

With this in mind it will be realised that the scatter of the level flight results of Fig. 7 is not large. The scatter of the climb and descent tests (Figs. 9 & 10), is considerably greater than that of the level flight case, but it is possible that this reflects the increased difficulties in technique rather than shortcomings of the instrument. Support for this view was obtained from the qualitative assessment during which the mean level flight calibration was marked on the pilot's visual meter. This calibration enabled the pilot to maintain steady and consistent indications of low airspeeds during level flight, climbs and descents made in light or zero winds.

In its present form the low airspeed indicator could be a useful instrument for test purposes and its value in this field will be investigated. The difficulty of calibration however will at present limit its application to a single aircraft.

From the operational aspect, there is general agreement among pilots who have used the low airspeed indicator that such an instrument appears to be desirable and that it permits manoeuvres not practical with current instrumentation. It is possible however that handling problems of particular current helicopters at very low speeds may prevent the potential value of such an instrument from being fully exploited in the near future, e.g. in steep approaches.

Consideration has been given to the advisability of combining the present low airspeed indications (which are horizontal speeds) with vertical speed indications to present 'speed along the flight path'. In general the handling characteristics of a helicopter depend on the direction of the flight path as well as the speed along it. This is particularly true at low speeds as can be seen by considering the difference in handling between a helicopter flying level at 5 knots and one attempting to descend vertically at the same speed (500 ft./min.). It is necessary therefore to present vector information to the pilot and the most practical solution appears to be separate indications of the horizontal and vertical components of the vector, since these are the references through which the helicopter is controlled.

The present instrument has mechanical limitations of $\pm$ 90° in the pitching plane and ways of extending this range are being examined so that indications of backwards flight may be obtained.

It is considered however that the low airspeed indicator described in this Report shows sufficient promise to warrant more development than can be undertaken at this Establishment. It is recommended therefore, that a small number of prototype instruments (possibly 3 or 4) should be made by an interested firm for flight evaluation by other Units, e.g. R.A.E., B.E.A.

rotor speed. A mean of these results may be drawn differing by less than 2 knots from the mean curves for individual rotor speeds. This mean calibration is shown in Fig. 8 plotted against airspeed. Check calibration points for this were obtained at 270 r.p.m. in level flight using the camera obscura and are shown in Fig. 9.

5.2 Climbing flight

Results obtained in climbing flight at full power and rates of climb between about 600 and 1000 ft/min. using the camera obscura are shown in Fig. 9. The scatter of results about the mean level flight calibration is considerable though there appears to be a steepening of the calibration curve for climbing flight.

5.3 Powered descent

The camera obscura technique was again used in the powered descent calibration for rates of descent between about 100 and 500 ft/min., depending on speed, and the results are shown in Fig.10. There is considerable scatter in the results, reasons for which are discussed later, but there appears to be a shift of about 3 knots away from the mean level flight calibration.

5.4 Pilot assessment

During calibration runs considerable difficulty was experienced at low speeds in maintaining the desired low airspeed indicator readings. It was not clear at first whether these difficulties arose from the need to position the aircraft precisely in space, requiring constant changes between instrument and external references, or whether the low airspeed indicator itself gave inadequate indication. Subsequent checks however showed that the instrument gave steady indications enabling low and zero forward speeds to be maintained in level flight and climb.

An investigation was made into the value of such an instrument during steep approaches. Initial tests on to a flight path indicator set at 15° (wind 0-3 knots) showed that steady descents at 10 knots could be made with the pilot not looking out, flight path references being passed to him by an observer as 'high/low' indications. At 5 knots however great difficulty was experienced in holding steady conditions.

Vertical approaches relative to the ground were attempted, again with the pilot relying on information passed to him as 'over/under' indications by the observer. Vertical descents from 1000 feet (wind 20 knots) to 100 feet (wind 5-7 knots) proved to be both practical and comfortable. Similar approaches attempted in zero wind, however, were unsuccessful since with a rate of descent of 150 ft./min. the aircraft could not be controlled accurately when the speed was in the 0-5 knot band. As this region was entered a marked tail down tendency was noted and the control correction resulted in excessive nose down attitudes and increased speed.

In the conditions described above, i.e. below 20 knots, the standard airspeed indicator did not give a usable indication.

6. Discussion and Conclusions

A major difficulty in the development of the low airspeed indicator has been in establishing experimental techniques to calibrate the instrument in flight. These techniques were critically dependent on wind conditions and whilst the windspeed could be monitored continuously during level flight calibrations by the speed course method, the same could not be done during climb and descent using the camera obscura. In these cases the most that could be achieved was a small number of spot checks of the wind at a particular altitude made with smoke puffs during the tests. In addition the pilot's task of flying accurate instrument indications whilst maintaining track within tight limits was considerable.

/With...

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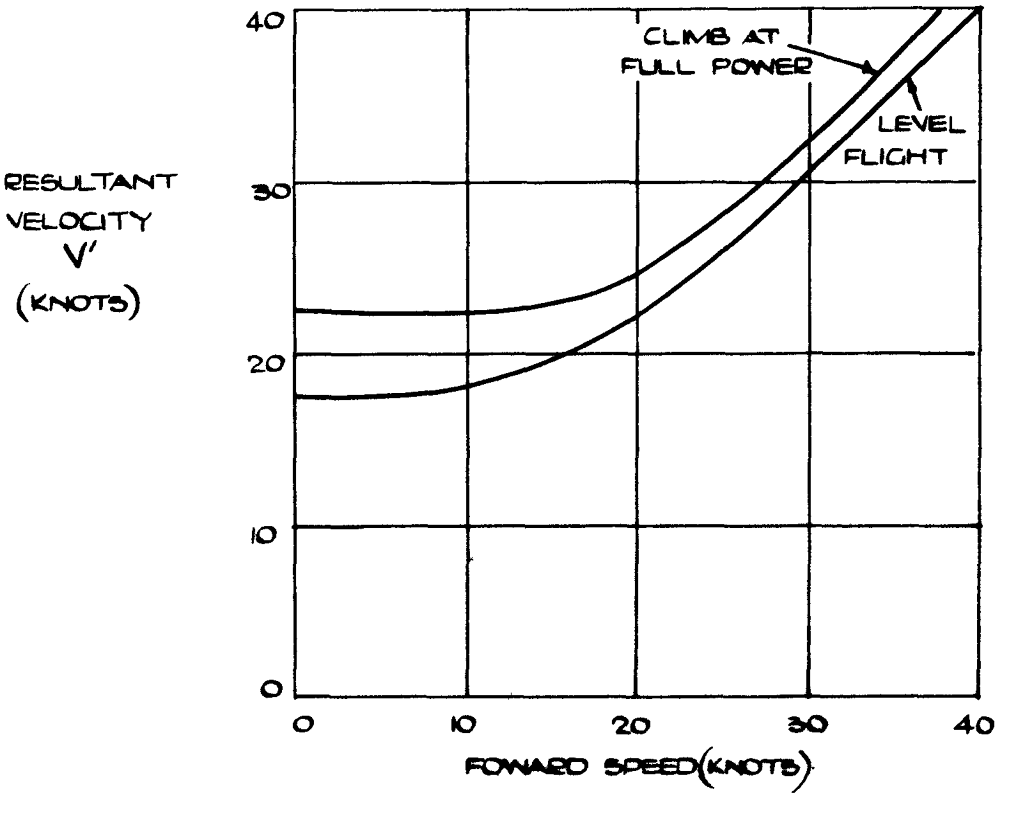
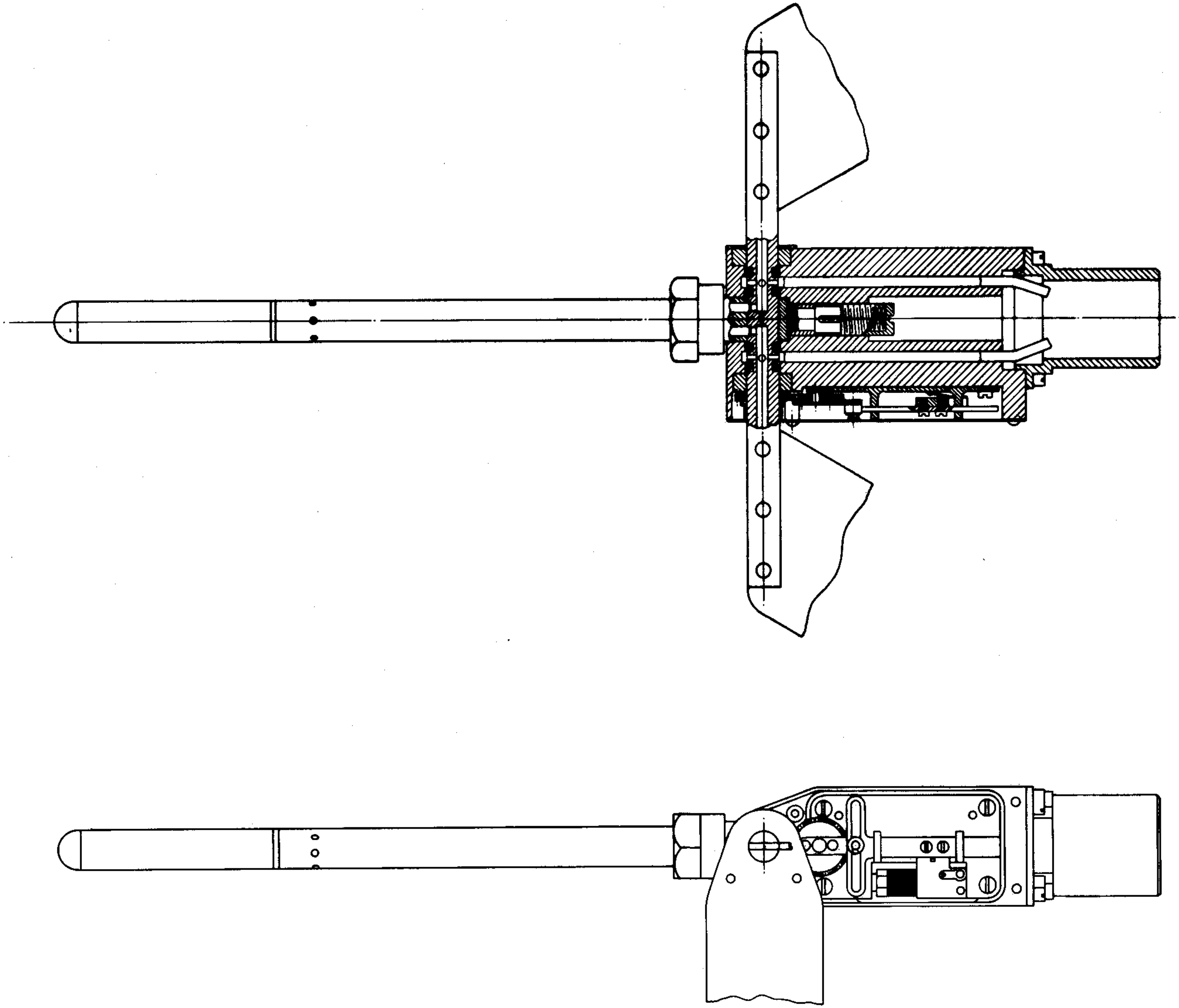
FIG. 1.



THEORETICAL VALUE OF RESULTANT VELOCITY FOR A SYCAMORE ASSUMING UNIFORM FLOW OVER THE DISC.

FIG. 2



SWIVELLING PITOT — STATIC HEAD.

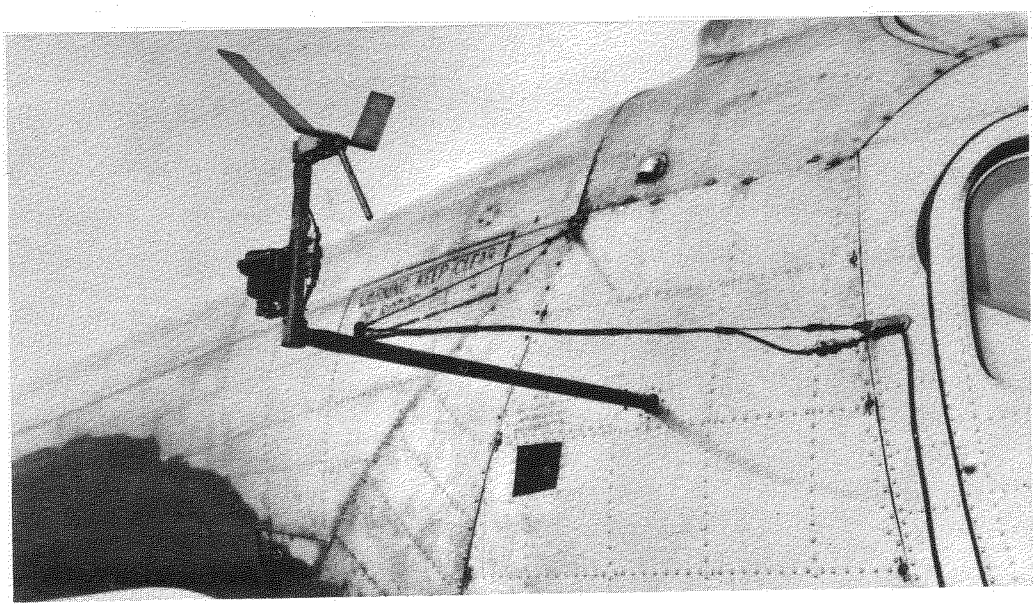


Fig. 3.
MOUNTING OF SWIVELLING HEAD ON AIRCRAFT.

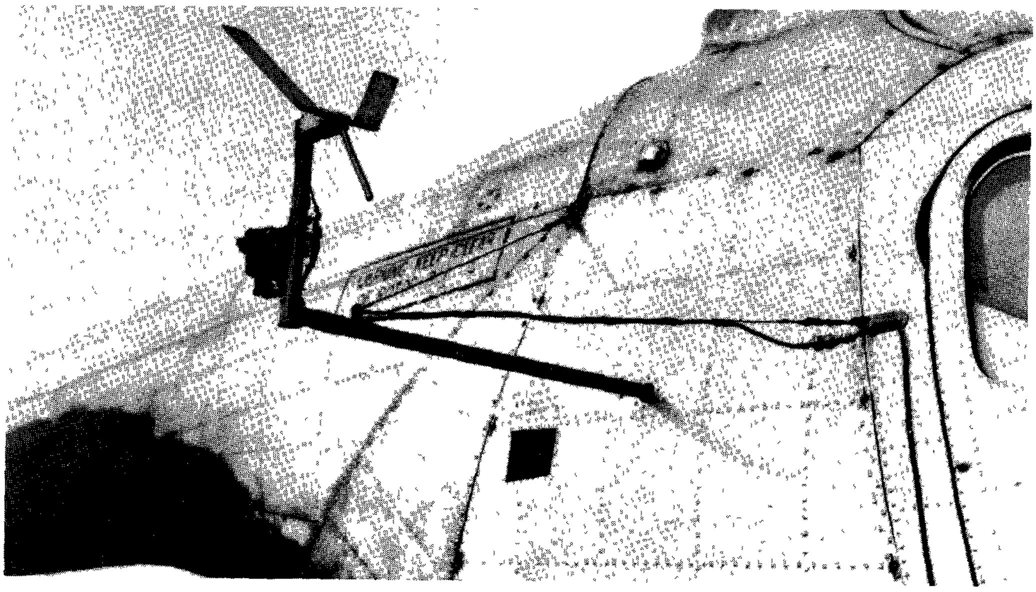
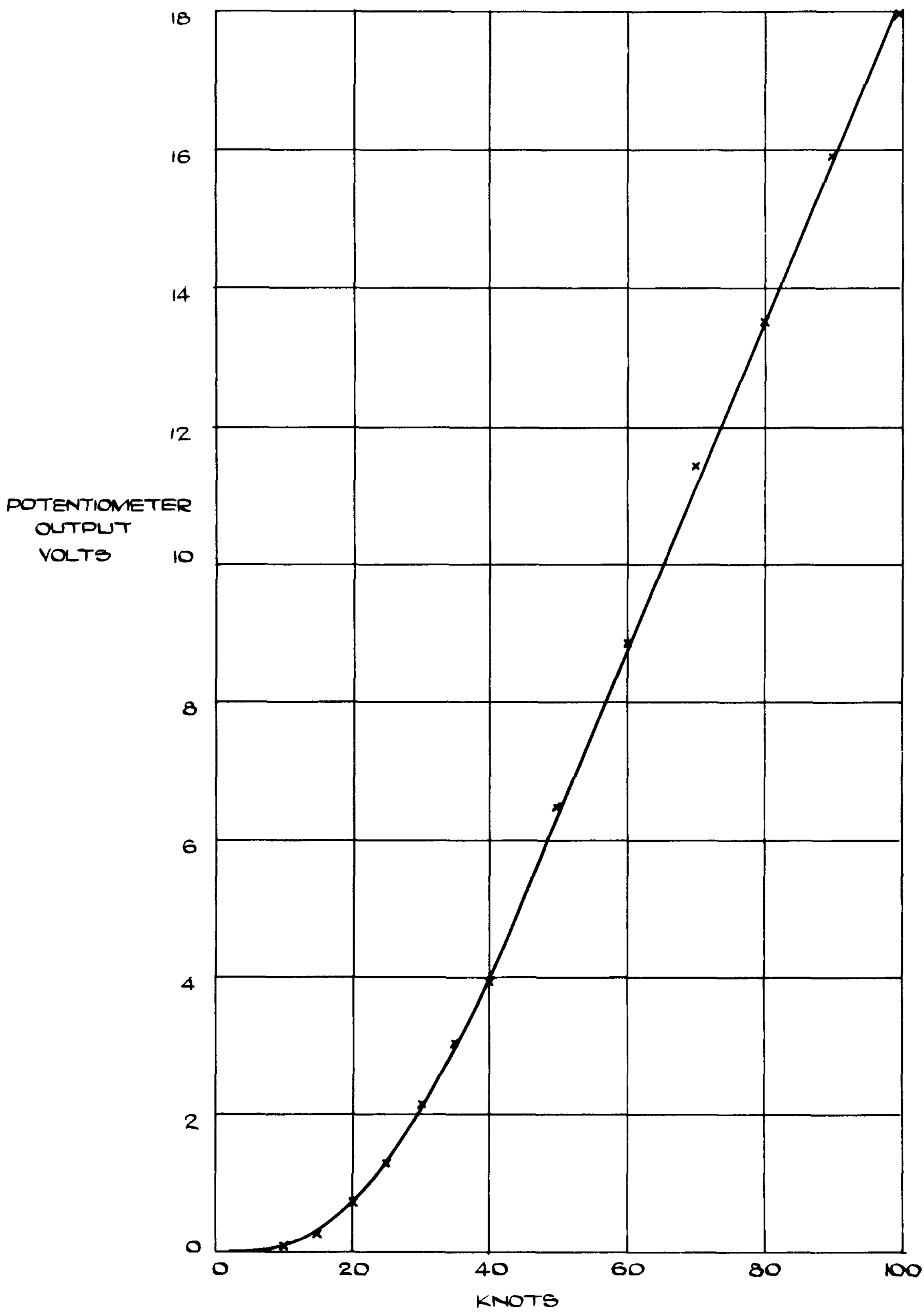


FIG. 3.
MOUNTING OF SWIVELLING HEAD ON AIRCRAFT.

FIG. 4.



CALIBRATION OF AIRSPEED TRANSDUCER.

FIGS. 5 & 6.

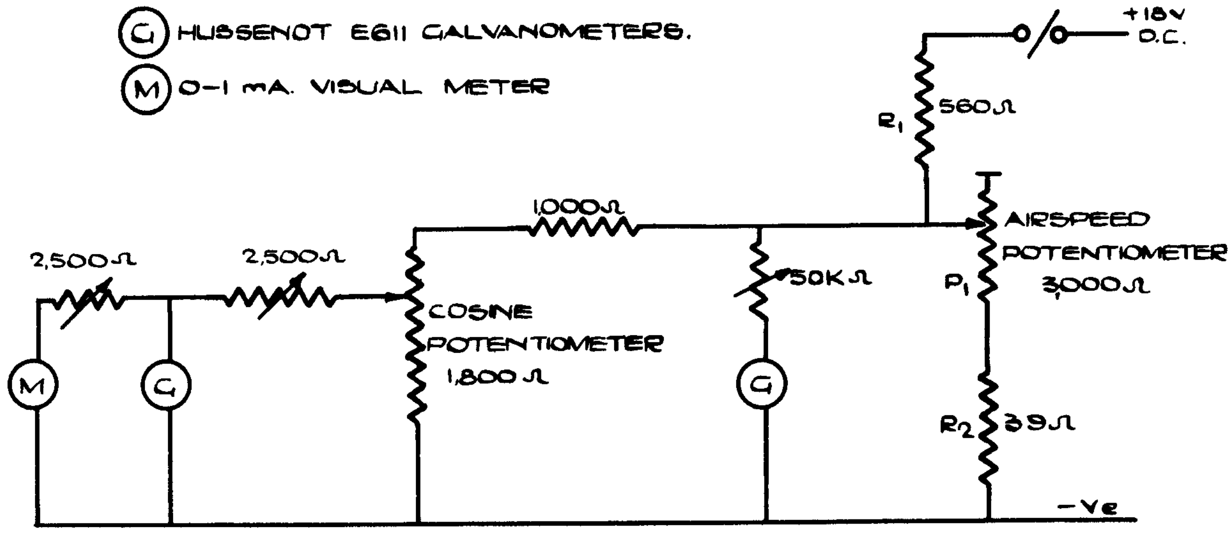


FIG. 5. CIRCUIT DIAGRAM.

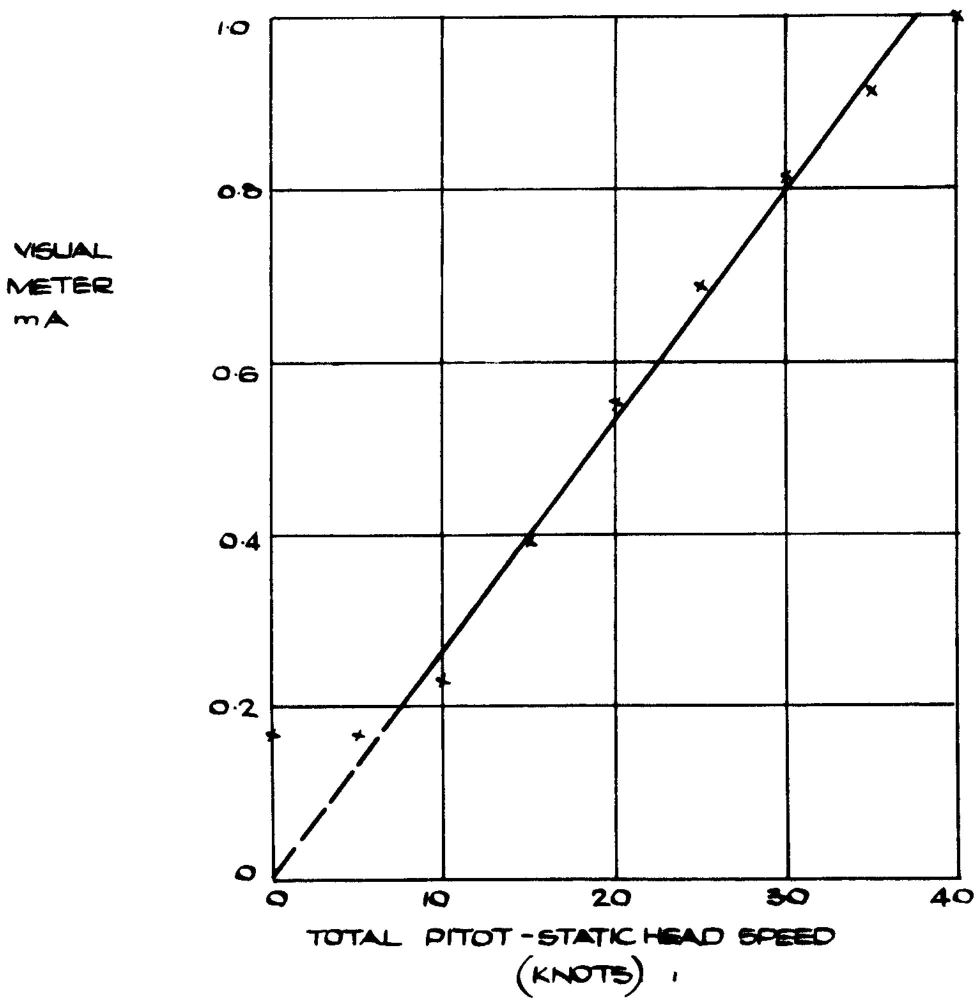
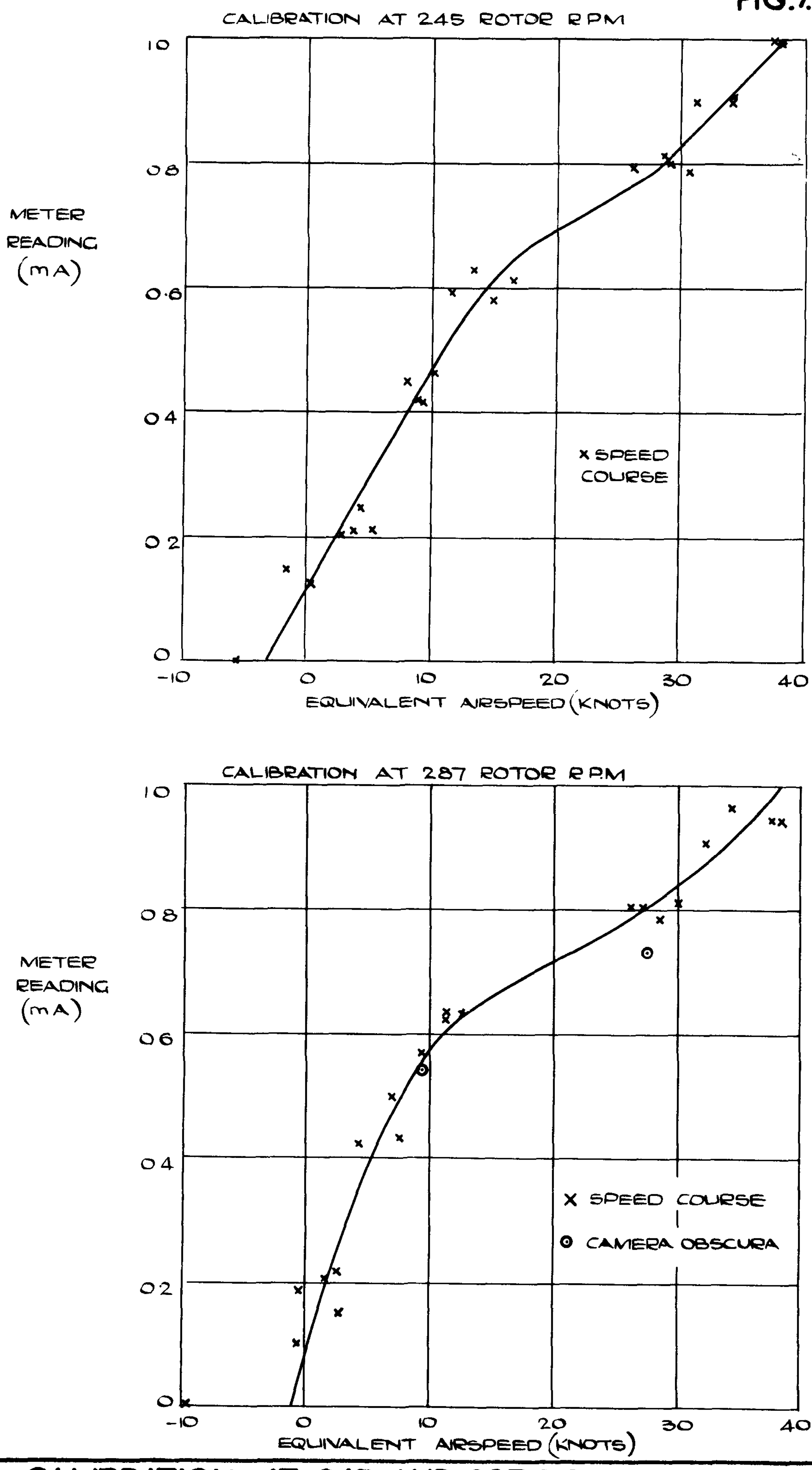


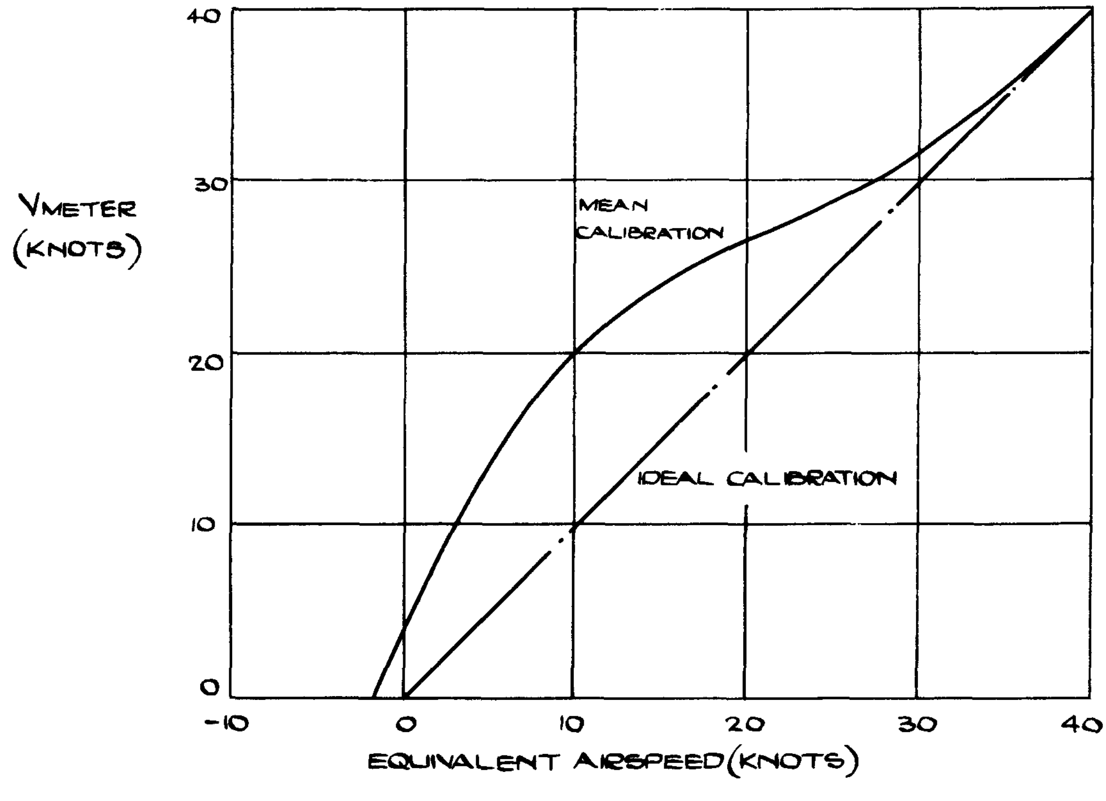
FIG. 6. VISUAL METER READING v TOTAL PITOT – STATIC HEAD AT $\beta = 0°$.

FIG.7.



CALIBRATION AT 245 AND 287 ROTOR R.P.M.

FIG.8.



LEVEL FLIGHT MEAN CALIBRATION FOR ALL ROTOR SPEEDS.

FIGS.9&10.

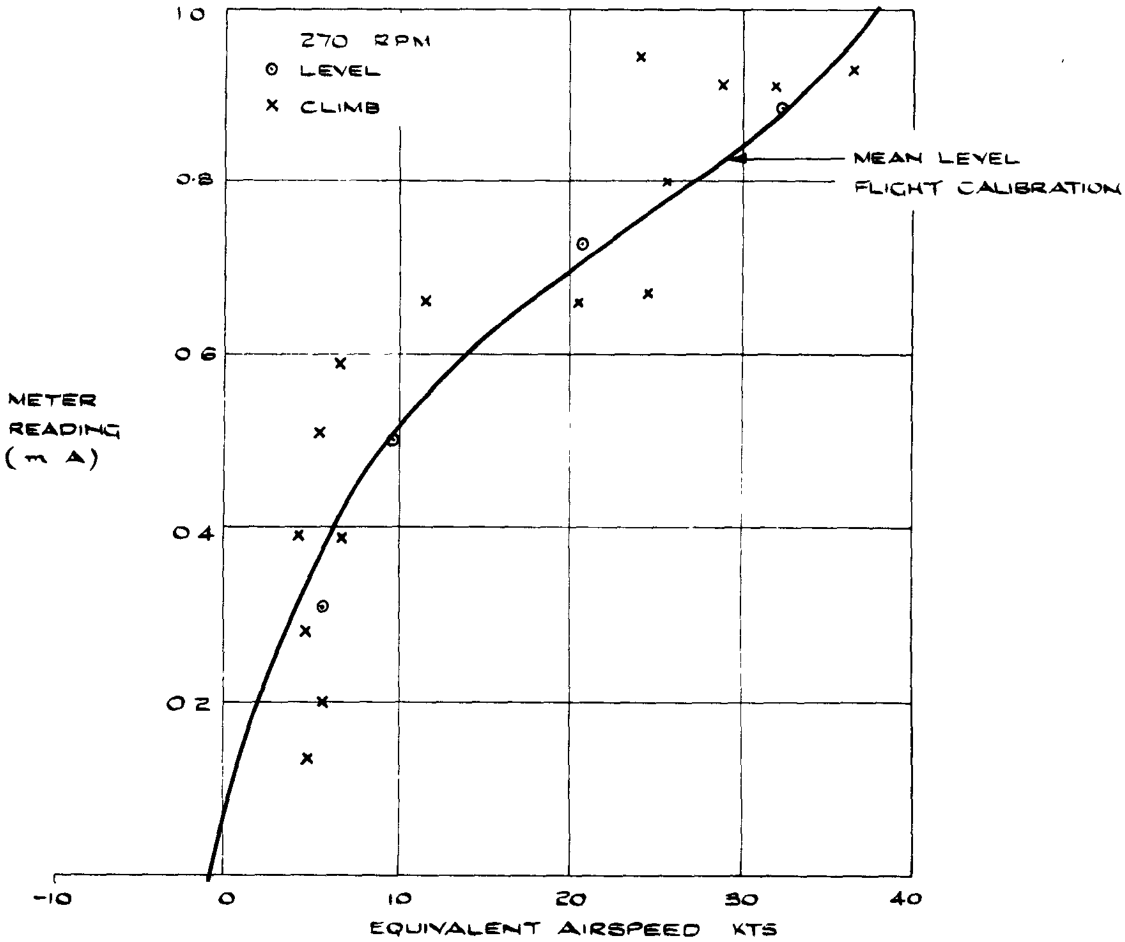


FIG. 9. CLIMB CALIBRATION.

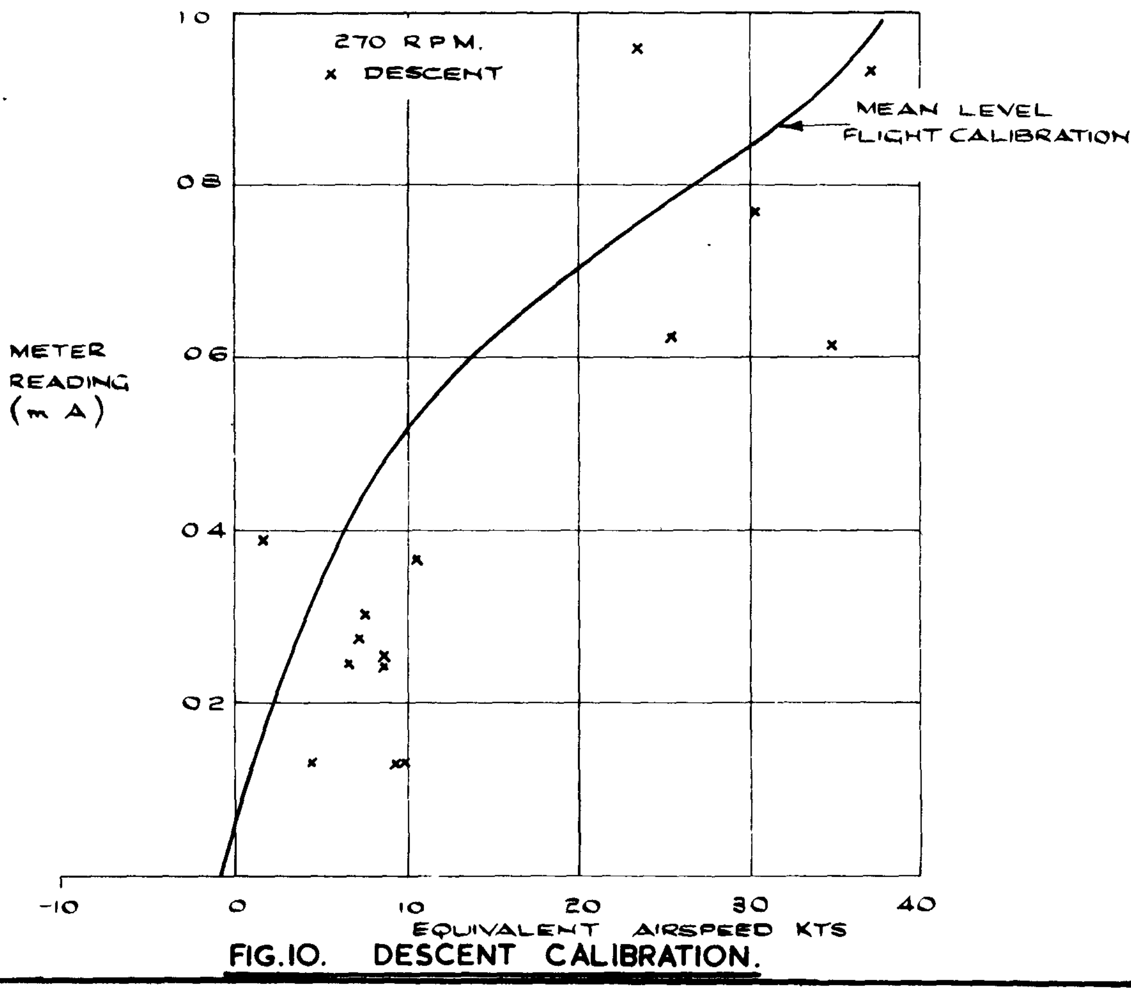


FIG.10. DESCENT CALIBRATION.

CALIBRATION IN CLIMB AND DESCENT.

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