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Measurement of Aircraft Attitude Relative to Flight Path during Dives

By

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR), MINISTRY OF SUPPLY

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Summary.—This report deals with the development of a technique for direct recording of the attitude of an aircraft relative to flight path during dives, *i.e.*, the direction of incidence of free airflow relative to aircraft datum, using a wind vane coupled to a Desynn transmitter. Results obtained in dives under steady conditions of dive angle and A.S.I. show agreement with those deduced from level flight results using the conventional airflow-incidence/lift-coefficient relation. Included are the details of the instrumentation required to obtain simultaneous records of the flight conditions (A.S.I. height, dive angle) and corresponding incidence under non-steady conditions such as exist during rocketry attacks.

1. *Introduction.*—For the purpose of sight harmonisation for rocket firing it is necessary to know the direction of incidence of airflow, otherwise called the attitude of the aircraft, relative to flight path at the instant of release.

This information is normally obtained by extrapolation of results obtained in unaccelerated level flight, using a pendulum inclinometer to give attitude relative to horizontal and thus airflow incidence, since the aircraft is flying level. Details of this method are given in Appendix I. In a rocketry attack, however, the flight conditions are not steady, the aircraft is still accelerating along its flight path and, due to the sight setting being deflected below its line of flight, it is flying along a curve of approach, there being as a result an acceleration normal to the line of flight.

Direct extrapolation from the level flight results does not allow for any effect which either, or both, of these conditions of flight may have on the direction of incident airflow. As a result, sight harmonisation after the first calculated sight setting has been tried, usually consists of a series of empirical changes of sight setting in order that the practically determined mean point of impact is coincident with the aiming point.

It has been the purpose of this series of tests to develop a method of direct recording of airflow direction which can operate in dives and other conditions of accelerated flight such as exist during a dive attack.

In this method the direction of the airflow is measured by a wind vane mounted forward of the aircraft on a pole. This has the inherent disadvantage that airflow in front of aircraft for quite a considerable distance is distorted, and the resultant direction as indicated by the wind vane will be affected by this distortion.

* A. & A.E.E. Report Arm/Res/13—received 16th May, 1947.

In order to eliminate this error due to upwash, the wind vane readings in level flight were compared with incidence values given by the normal inclinometer method, thus giving a flight calibration including the distortion of airflow effect. This report deals with the calibration of the vane, the checking of its operation in level flight and in constant A.S.I. dives, and with the suggested instrumentation for recording during rocketry attacks.

2. *Range of Investigation.*—The aircraft used was a normal Mosquito FB VI, details of which are given in Appendix IV.

The programme covered may be split into three parts.

2.1. Measurement of level flight attitude, thus obtaining incidence as indicated in Appendix I. For this part of the test two new dead beat inclinometers were developed in an attempt to overcome the oscillation troubles normally experience with pendulum inclinometers. Details of these are given in Appendix II. An attempt was also made to attach an air plunger damping system to an M/C inclinometer of the type normally used. Details of this are also given in Appendix II.

2.2. During the above flights direct readings of the direction of the airflow were obtained, using a wind vane mounted forward of the aircraft on a pole (*see* attached photographs, Fig. 1) and recording by means of the Desynn system on an indicator read by the observer.

Comparison graphically of the incidence results obtained under 2.1. and the readings of the wind vane indicator thus gave a calibration of wind vane reading against airflow incidence which compensated for any upwash effect due to the disturbance of airflow in front of the aircraft.

2.3. Wind vane readings were then taken during constant A.S.I. dives : the change of the aircraft heading in the pitching plane was recorded continuously during the dive by means of a Barnes twin axis Accelerometer and Pitch recorder. Prior to the dive the aircraft was flown level at 208 knots when the Gyro in the recorder was uncaged. Synchronisation of the readings of the Barnes Recorder and the wind vane, which were taken in the level flight period prior to the dive and when steady conditions in the dive were reached, was obtained when the observer pushed a press button operating a relay circuit which cut out the recording lamp in the Barnes Recorder.

The dives were comparatively shallow and thus, as the A.S.I. was constant, the conditions of flight could be regarded as unaccelerated apart from the error induced by the change in air density reacting upon the A.S.I. reading ; a small error as the loss in height is not great in a shallow dive.

In order to complete the sequence of tests, records of incidence, A.S.I., altimeter, and dive angle will be taken during rocketry dives when accelerated flight conditions prevail to ascertain what effect these conditions may have on the airflow. Instrumentation for this is described in Appendix III.

3. *Results of Investigation.*—3.1. *Level Flight.*—In working out the corrections to A.S.I. reading the position error used was that measured on this aircraft. It was assumed that the mean weight of the aircraft during measurements was 18,000 lb.

Fig. 3 shows the results of plotting both the inclinometer reading relative to aircraft datum and wind vane Desynn reading against V_i. From these smoothed curves a curve of Desynn reading against airflow incidence was obtained as shown in Fig. 4.

From the level flight inclinometer results in Fig. 3 a curve of $W \cos \gamma / V_i^2$ against incidence was obtained as in Fig. 5. (For level flight $\gamma = 0$, and the plot is thus W / V_i^2 against incidence.

3.2. *Constant A.S.I. Dives.*—Plotted on Fig. 5 are the incidence values obtained from the wind vane reading using the calibration curve in Fig. 4 extrapolated. As the aircraft is diving the $\cos \gamma$ term must be taken into consideration in the term $W \cos \gamma / V_i^2$. This was obtained to a close approximation by taking $W \cos \phi / V_i^2$ when ϕ is the angle of dive as given by the Barnes recorder.

This is an approximation, as the Barnes does not give the true angle between aircraft flight path and horizontal, but the angle between aircraft datum in level flight at 240 m.p.h. A.S.I. and the aircraft datum in the dive.

4. *Discussion of Results.*—4.1. *Level Flight.*—As a check the incidence against $W \cos \gamma / V_i^2$ curve in Fig. 5 was compared with results obtained on another Mosquito VI aircraft (11th part of Report No. AAEE 767,3). The two curves are displaced through an amount equivalent to a shift in incidence of 0·95 deg, but there is good agreement between their slopes.

The calibration (Fig. 4) of the wind vane obtained from the curves in Fig. 3 is a smooth curve and as such justifies the extrapolation necessary for the obtaining of the results in dives.

4.2. *Dives.*—Here the scatter of the experimental points about the extrapolated part of the $W \cos \gamma / V_i^2$ against incidence curve has a deviation of incidence angle less than 0.1 deg with only one exception. The scatter is probably due to small inaccuracies in flying, it being extremely difficult to judge and hold steady the necessary dive angle.

From the agreement it appears that the method of air calibration of the wind vane does overcome the difficulty normally present with such methods of measuring airflow, *i.e.* that of placing the vane far enough in front of the aircraft to be clear of upwash.

5. *Conclusions.*—5.1. The results obtained by the wind vane method of measuring incidence in constant A.S.I. dives are consistent with values obtained by extrapolation from level flight inclinometer results.

5.2. The method should, therefore, be successful under flight conditions similar to those existing in rocketry attacks, and thus it should be possible to record automatically A.S.I., altimeter and airflow incidence simultaneously on an automatic observer, which in addition can be synchronised with a Barnes recorder giving continual records of dive angle.

The suggested instrumentation for these tests is given in Appendix III, and trials are proceeding with the equipment indicated.

APPENDIX I

The Inclinometer Method of Measuring Airflow Incidence in Level Flight.

This method consists of measuring the angle between the aircraft datum and the horizontal in level flight using some type of gravity inclinometer, either pendulum or spirit level. Since the aircraft is flying level the airflow towards it is horizontal and thus the angle obtained with the inclinometer, the so-called attitude of the aircraft, gives the angle between datum and airflow incidence.

The programme of tests consists of taking readings of the inclinometer over the level speed range at a convenient altitude.

From the readings a curve of attitude against V_i (the equivalent airspeed) is plotted, and a curve of lift coefficient C_L against airflow incidence may be plotted, from

$$C_L = \frac{W \cos \gamma}{\frac{1}{2} \rho_0 V_i^2 S},$$

Where
W weight of aircraft,
V_i equivalent airspeed (ft/sec),
ρ_0 density of air at sea level,
S gross wing area,
γ_0 angle of flight path to horizontal = 0 deg for level flight.

The C_L against incidence curve is a straight line, and from it may be deduced (by extrapolation if necessary) the incidence for any given conditions as specified by W, γ and V_i, if the conditions are such that acceleration normal to the flight path is zero. The attached diagram, Fig. 6, shows the angles under consideration during the completely general case of an aircraft not flying horizontally.

APPENDIX II

Development of Damped Pendulum Inclinometer.

Due to random vibrations in level flight great difficulty was experienced during these trials in obtaining readings from the normal M/C inclinometer type (Brit. Pat. No. 512193). An attempt was therefore made to construct an inclinometer with some system of damping.

1. The first system entails electro-magnetic damping, the inclinometer being a modified moving coil low resistance milliameter with the return hair springs removed, the counter balance on the pointer removed (thus making the pointer the pendulum of the instrument), and the ends of the coil shorted together thus giving a dead-beat movement (Type I, Fig. 2). A scale graduated in $\frac{1}{4}$ deg was constructed photographically, and with practice, using a magnifying glass, it was considered possible to estimate the reading to 0·1 deg.

Comparative tests showed that under conditions of vibration which caused a normal M/C inclinometer to be oscillating through 5 deg or more, it was possible to obtain and repeat a steady reading of this instrument within $\frac{1}{4}$ deg. The behaviour of this instrument being so satisfactory, it was decided to construct a similar one with a larger pointer movement and with spring-loaded jewelled pivots. For this purpose an electrical engine speed indicator Mk. IIE Ref. 6A/442 was modified in a similar manner; in this case, however, the pointer counter-balance was increased as the shape and size of the instrument necessitated reading it from above with the scale horizontal, as indicated in the accompanying photograph (Type II, Fig. 2).

This latter instrument appears to function satisfactorily under normal level flight conditions. Full trials for assessing its accuracy have not yet been made.

2. The second system used air damping as used in the Gyro rate-of-turn part of the normal turn and bank indicator.

The damping system of one of these latter instruments has been removed and installed in a normal M/C inclinometer as indicated in Fig. 7. This instrument is also still undergoing tests.

APPENDIX III

General Instrumentation Details.

Details of the wind vane installation are given in the accompanying photographs. For the level flight and constant A.S.I. dive trials the Desynn indicator and a Kollsman accelerometer were mounted on an additional panel in front of the observer.

The Barnes recorder was mounted on the drift sight bracket forward of the observer, and the two automatic observers for the dive and rocketry attack section of the tests were mounted in the cabin in place of radio equipment behind the pilot and observer.

The automatic observers contained the following :—

Auto-Observer 1. A.S.I.
Altimeter.
Desynn to be connected to wind vane when required.
Clock.
Indicator lamp for synchronising the Observer 2 and Barnes recorder.
Veeder frame counter.

Auto-Observer 2. Modified Blind flying artificial horizon giving indication of roll and pitch angles.

Miniature Desynn to be connected to wind vane as required.

Clock.

Indicator lamp as in 1.

Frame counter as in 1.

The auto-observers were operated by two switches, one for the lamps, the other working an impulse circuit which operated the camera triggering solenoids.

Two more switches operated the Barnes recorder; synchronisation was obtained between this latter and auto-observers 1 and 2 by the human observer pressing momentarily a push button which lit the two indicator lamps in the observers and at the same instant operated a relay which cut out the recording lamp in the Barnes recorder. The camera impulse unit was adjustable for triggering from a rate of 1 frame every 2 seconds to 4 frames per second. 35 mm A.4 bombing cameras modified for single-shot operations were used.

The accompanying block diagram (Fig. 8) indicates the layout of the system.

APPENDIX IV

Aircraft Details

The aircraft used was a normal Mosquito FB VI No. TA 501, fitted with Merlin 25 engines and type A5/146 propellers.

Tests were made at the following loadings :—

Take-off weight	18,630 lb.
C.G. aft of datum	14·5 in. undercarriage down.

The following are details of main and tailplane indications :—

Main plane incidence at root :—

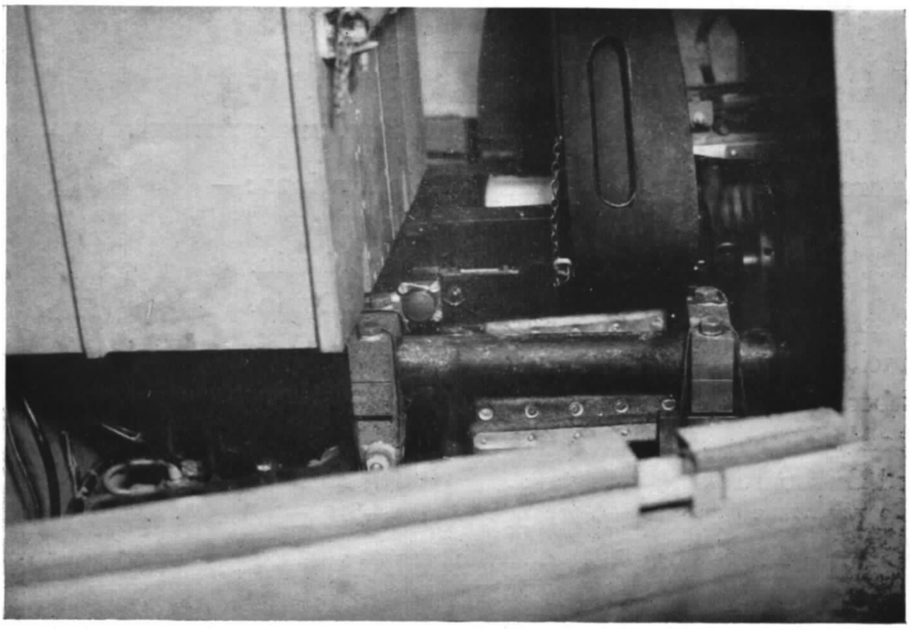
Starboard	2 deg 30 min.
Port	2 deg 22 min.

Tailplane incidence :—

Port Outboard	0 deg 25 min.
Port Inboard	0 deg 20 min.
Starboard Outboard	0 deg 28 min.
Starboard Inboard	0 deg 20 min.

Normal Mk. III Rocket Projectors were fitted.

External view.



View of attachment of pole to gun mounting.

FIG. 1.

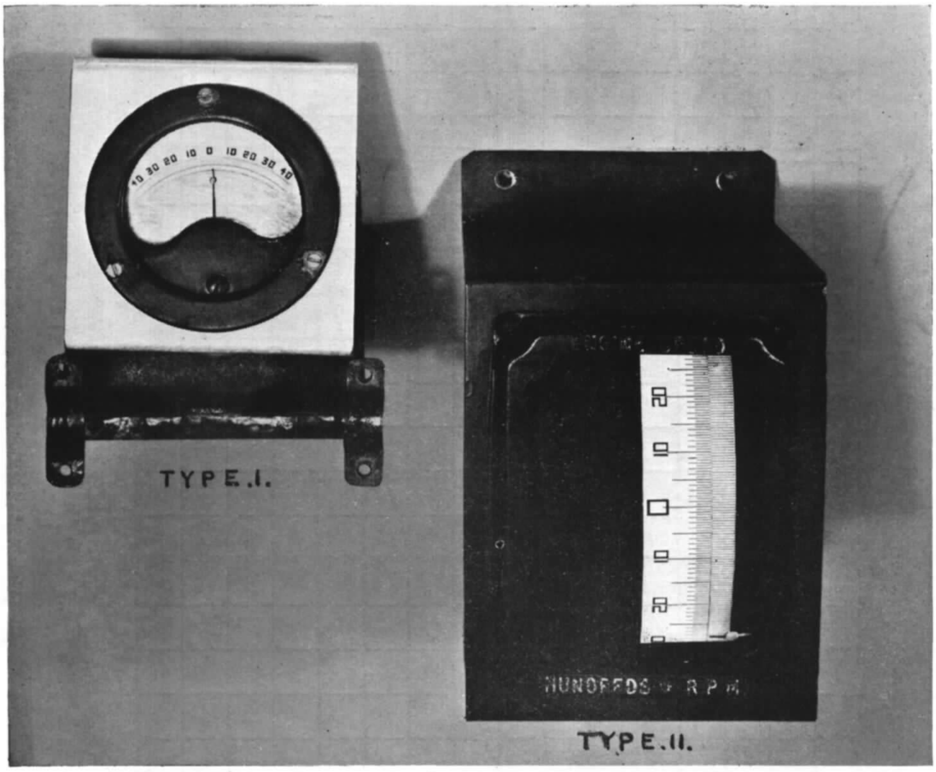


Fig. 2. Pendulum inclinometers with electro-magnetic damping.

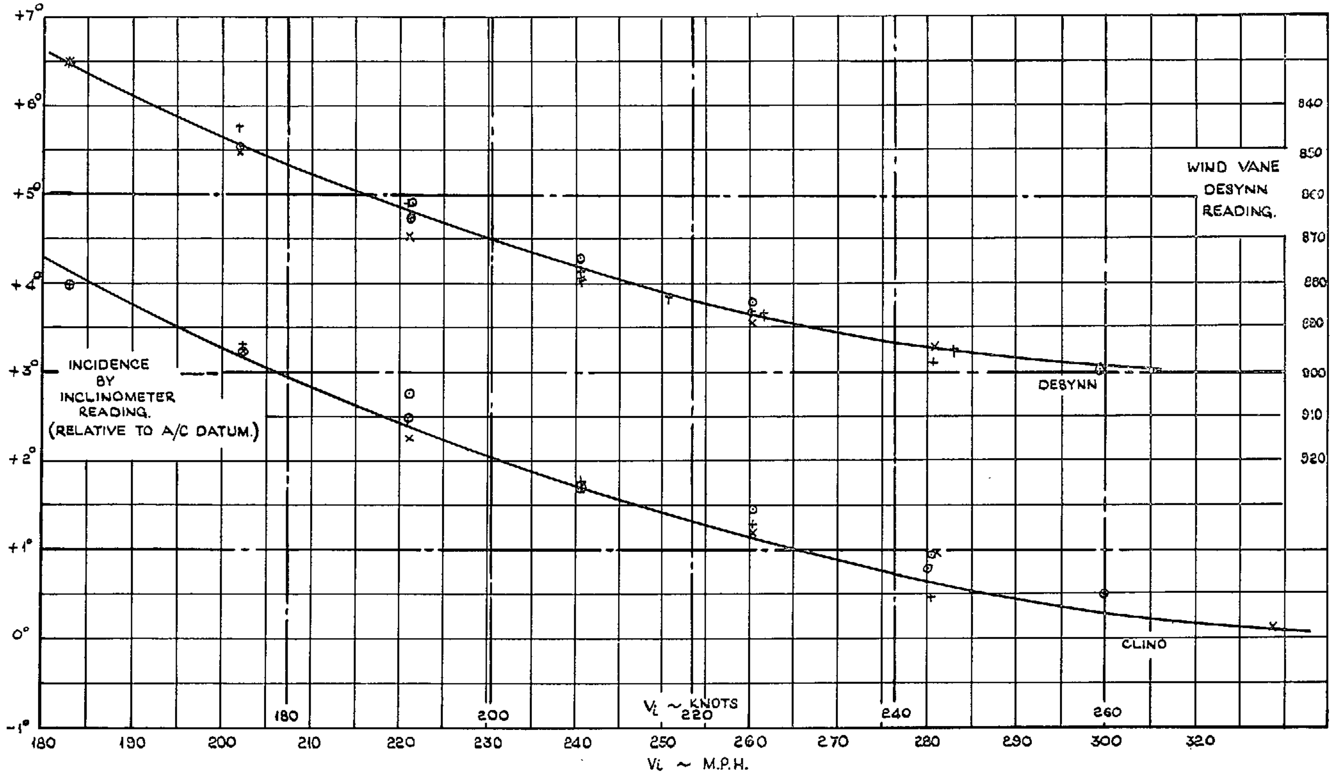


FIG. 3. Variation of incidence (by inclinometer) and wind vane Desynn reading with V_i.

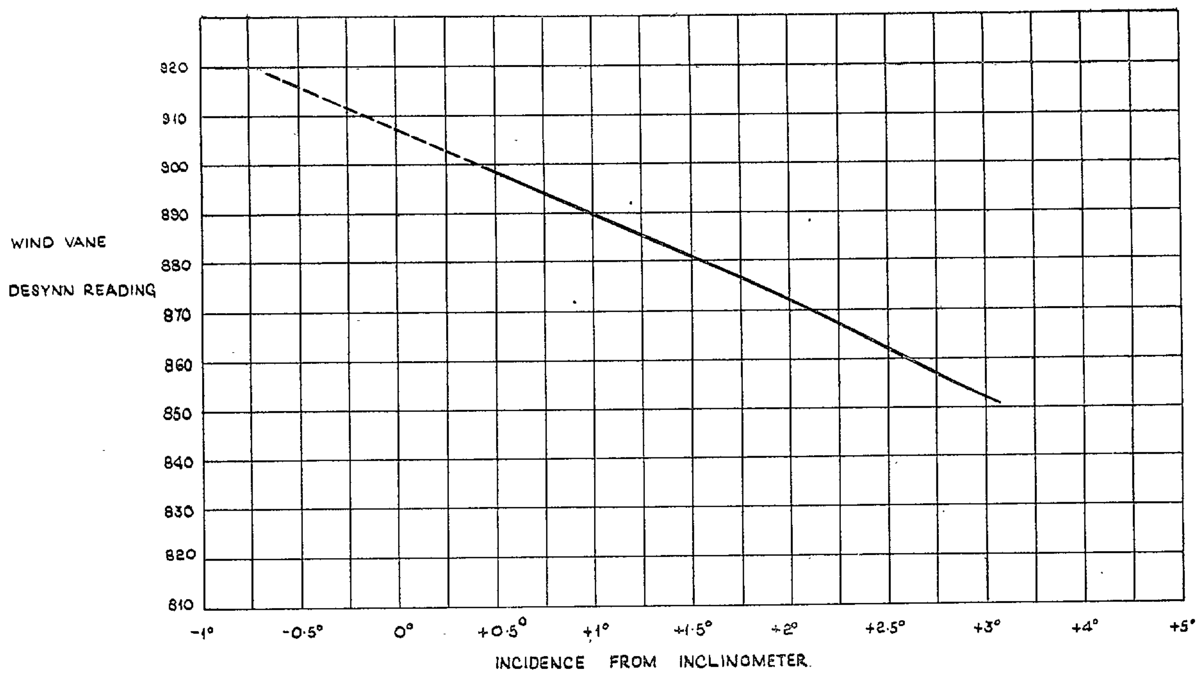


FIG. 4. Wind vane flight calibration.—Smoothed result.

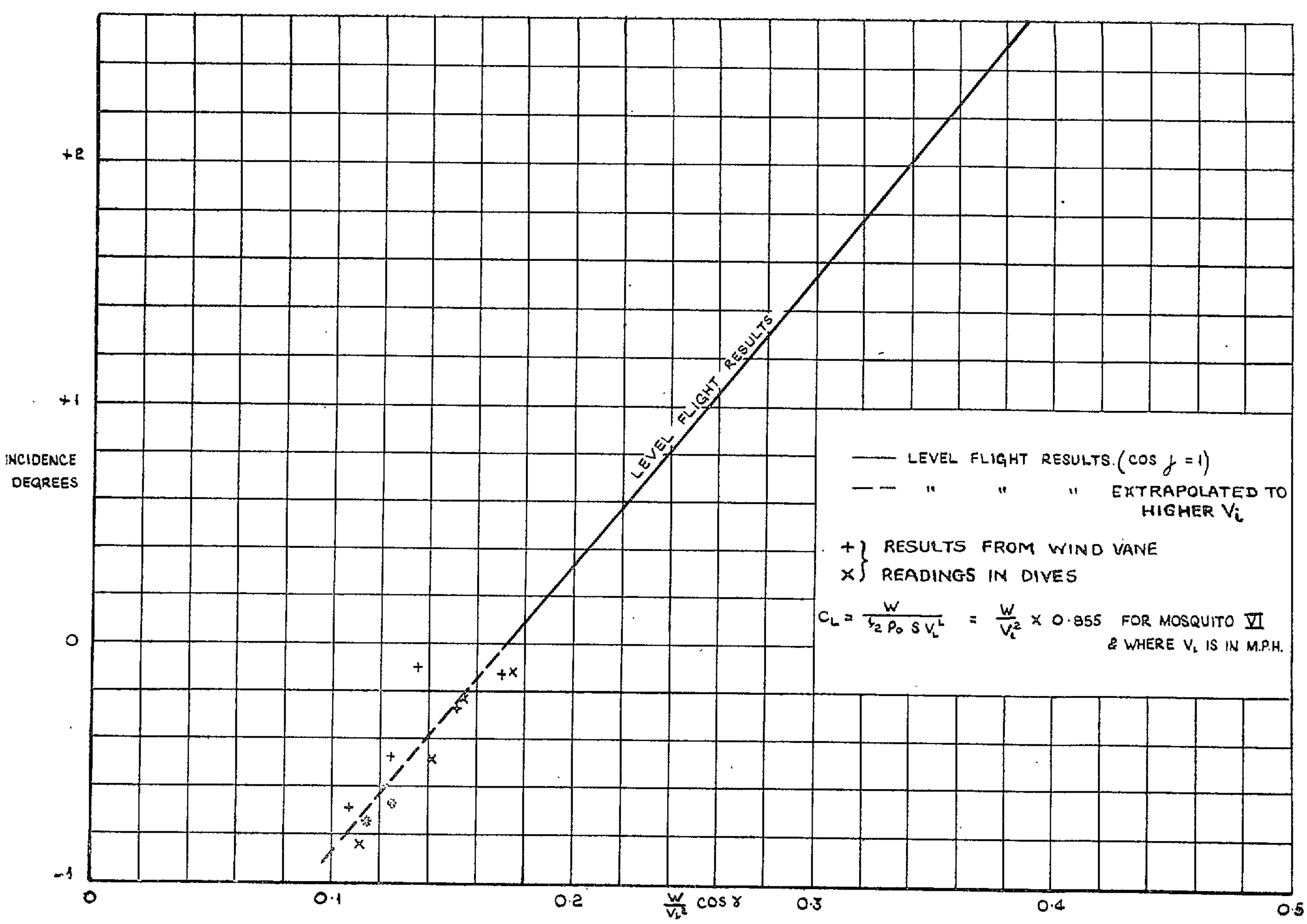


FIG. 5. Air flow incidence relative to aircraft datum.

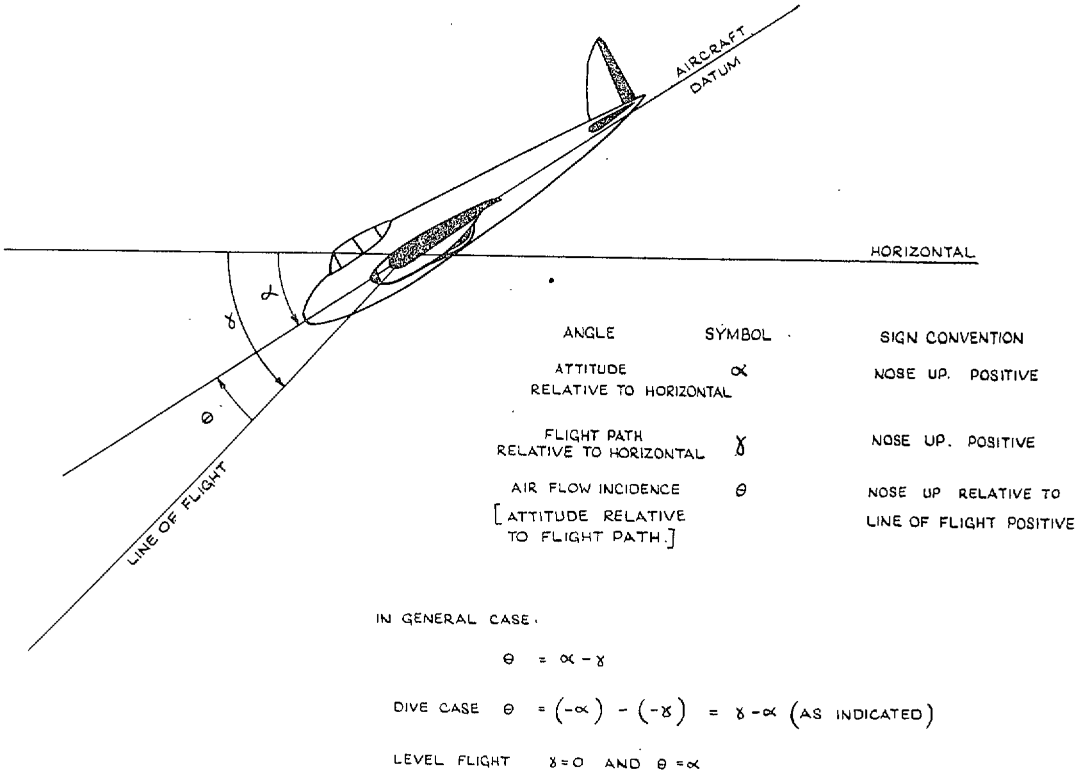


FIG. 6. Angles associated with attitude and incidence measurements.

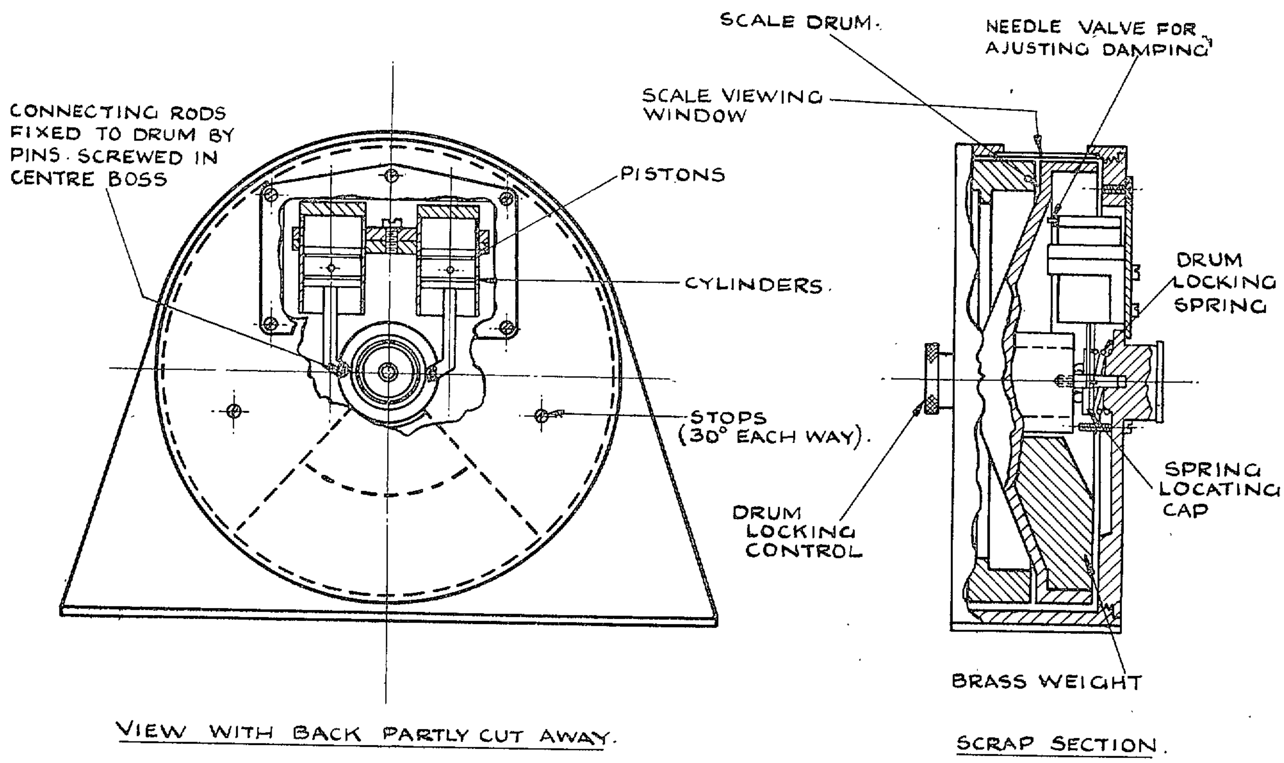


FIG. 7. M/C inclinometer with air dashpot damping.

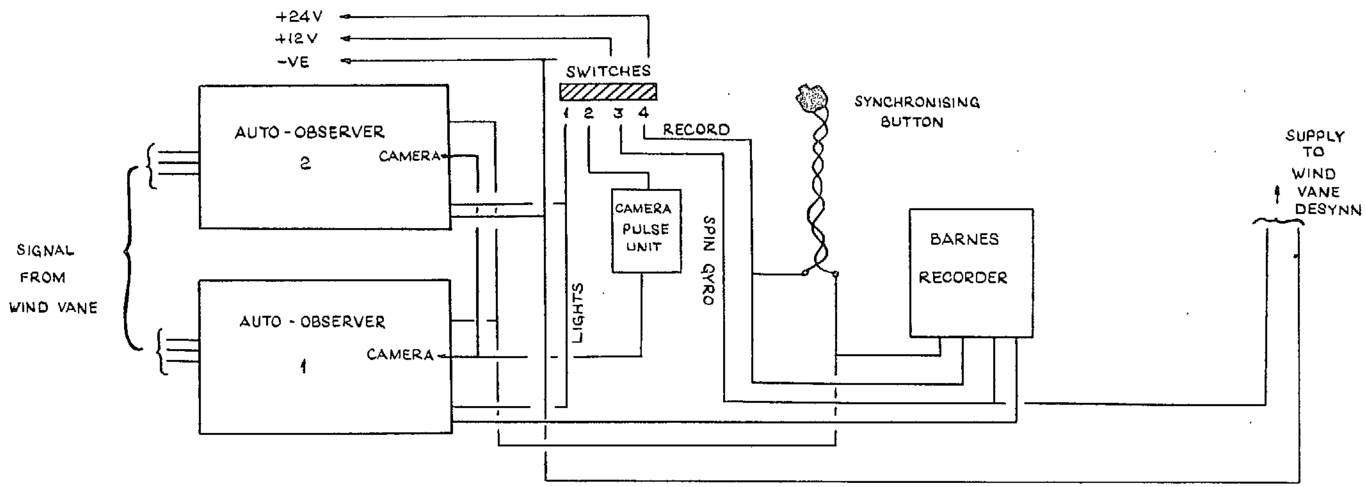


FIG. 8. Block diagram of auto-observer, Barnes recorder and Desynn supply system.

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