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MEASUREMENT OF THE MOMENTS OF INERTIA OF A HAWKER SIDDELEY DOVE Mk. 5 AIRCRAFT

by

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DEPARTMENT OF FLIGHT

Measurement of the moments of inertia of a Hawker Siddeley Dove Mk.5 Aircraft

- by -

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SUMMARY

This note describes the measurement of the moments of inertia in roll, pitch and yaw of a Hawker-Siddeley (de Havilland) Dove Mk. 5 aircraft, using a spring-restrained oscillation technique. Using the present equipment it did not prove possible to measure the product of inertia. Inertias were measured in six different fuel conditions. The results are given in Tables I - V.

A device was developed which measures the periods of oscillation of large structures, quicker and more accurately than hitherto possible. This device is described in the Appendix.

Contents

List of symbols

Symbol	Unit	Definition
c_x, c_y, c_z	lb.wt/ft.	Spring stiffness
g	ft/sec^2	Acceleration due to gravity
h_x, h_y	ft.	Height of centre of gravity above the knife edge in the rolling and pitching oscillation.
I_x, I_y, I_z	slugs.ft^2	Moments of inertia in roll, pitch and yaw (for axes definition, see subscripts).
i_A, i_B, i_C	-	Non-dimensional moments of inertia, defined in Tables 2 to 4.
ℓ_x, ℓ_y	ft.	Perpendicular distance from centre line of restraining springs to axes of oscillation in pitch and roll.
$\ell'_x, \ell'_y, \ell'_z$	ft.	Perpendicular distance from aircraft centre of gravity to axes of oscillation in roll, pitch and yaw.
P_x, P_y, P_z	sec.	Period of the oscillation about the roll, pitch and yaw axes.
b/2	ft.	Wing semi-span
ℓ_T	ft.	Tail arm
V	ft^3	Aircraft volume
W	lb.wt.	Aircraft weight
ρ	slugs/ft^3	Air density

Subscripts

A/C + CR	Refers to moments of inertia of aircraft and cradle about axis of oscillation
A/C	Refers to aircraft alone
CR	Refers to cradle alone
S	Shift of axes term

1. Introduction

This note describes measurements made of the moments of inertia of a Hawker Siddeley (de Havilland) Dove aircraft. The tests described are a sequel to those described by the author in Reference 1.

The theory of the method is relatively straightforward and is described in References 1 to 4. The method used in the present tests was the spring-restrained oscillation method wherein the aircraft is pivoted about knife edges or suspension rigs and constrained by means of coil springs. The equipment needed for these measurements is relatively simple and inexpensive, and the corrections necessary to correct for axis transfer are relatively small.

The Dove is a particularly difficult aircraft on which to carry out tests of this nature. The scarcity and singular uselessness (for this purpose) of jacking and strong points on the airframe necessitated the use of a heavy steel cradle on which to mount the aircraft. Knife edges, slings, restraining springs and measuring equipment could then be fitted to the cradle.

2. Design of the cradle

A photograph of the cradle is shown in fig. 1. The cradle was roughly A-shaped and had overall dimensions of 23 feet by 11 feet. At the front, narrow, end the aircraft was located by means of the aircraft's normal nose jacking system. A machined horizontal bar picks up on two locating lugs in the airframe. The ends of the bar passed through vertical supports of the cradle. The aircraft could be clamped to the cradle by means of sleeves on the bar and nuts on the ends of the bar.

At the rear of the cradle the aircraft was fixed by means of specially machined jacking pads fitting into the aircraft's inboard jacking points. The jacking pads were bolted to the upper cross member of the cradle.

The cradle was fitted with castors for ease of ground handling. The cradle configuration had to be altered slightly for each moment of inertia measured, and provision had to be made for the attachment of both lateral and longitudinal knife edges, and yaw and pitch restraining springs. For the yawing tests, the four wire sling was attached to lugs on the four corners of the cradle by means of shackles and turnbuckles. The turnbuckles were used to alter the sling geometry in order to satisfy the requirements that the aircraft plus cradle assembly should oscillate about its combined c.g. and that the aircraft longitudinal datum should remain horizontal.

In order to obtain a close fit onto the aircraft, the cradle was built 'in situ' on the aircraft, the cradle being fixed together with a large number of $\frac{1}{2}''$ BSF nuts and bolts.

3. Test methods

3.1 Measurement of the position of the aircraft's centre of gravity

The location of the aircraft's centre of gravity was determined by the method described in reference 2. The aircraft was positioned with the main wheels resting on a weighbridge and the nose supported by a 2-ton crane via a beam balance, as shown in fig. 2. The beam balance was connected by a sling to the normal nose jacking point. Main wheel and nose reactions were observed with the aircraft in various nose up and nose down attitudes, pivoting about the main wheel axles. The location of the horizontal c.g. was computed from interpolations of the observed readings for the zero inclination condition. The vertical position was computed for each of 10 or so angular positions observed for each loading condition.

The main wheels were mounted on blocks in order to increase the clearance between the tail bumper and the ground, thus enabling a higher angle of incidence to be achieved. The main undercarriage oleos were gagged to prevent compression of the legs from affecting the vertical c.g. results. It was particularly important that the front sling should remain vertical at all angular positions. In order to achieve this a plumb-bob was suspended from the beam balance which was zeroed onto the end of the horizontal (jacking) bar by the fore and aft movement of the crane. Before applying the measured c.g. figures to the inertia tests they were corrected to the undercarriage retracted condition.

The location of the centre of gravity was determined with the aircraft empty of fuel but with a crew of eight on board. The resulting change of c.g. with crew could then be applied to the inertia results, which had to be measured without crew.

The centre of gravity of the cradle was determined in a similar manner to that of the aircraft.

3.2 Measurement of the moment of inertia in pitch

Fig. 3 illustrates the arrangement used for the measurement of the pitching inertia.

The aircraft and cradle were supported on laterally displaced knife edges, fitted to the cradle below the inboard jacking pads. The aircraft nose was supported by a bank of coil springs fixed to the front of the cradle and hanging from a bridge-like structure. The spring stiffness of the system had to be determined 'in situ', in order to take into account the stiffness of the bridge structure.

The aircraft's moment of inertia in pitch, about an axis through the aircraft centre of gravity parallel to the lateral axis, is given by:

$$I_y = I_{y_{A/C+CR}} - I_{y_{CR}} - I_{y_S} \qquad (1)$$

where

$$I_{y_{A/C+CR}} = (c_y \ell_y^2 - W_{A/C+CR}\, h_{y_{A/C+CR}}) \left(\frac{P_{y_{A/C+CR}}}{2\pi}\right)^2 \qquad (2)$$

$$I_{y_{CR}} = (c_y \ell_y^2 - W_{CR}\, h_{y_{CR}}) \left(\frac{P_{y_{CR}}}{2\pi}\right)^2 \qquad (3)$$

$$I_{y_S} = \left(\frac{W_{A/C}}{g} + V\rho\right) \ell_y'^2 \qquad (4)$$

The second term in equation (1) represents the inertia of the aircraft plus cradle about the knife edges. The third term represents the inertia of the cradle alone about the knife edges. The cradle was oscillated separately from the aircraft but using the same springing system. The last term in equation (1) is the shift of axes term which accounts for the shift of axes of the aircraft's inertia from the knife edges to the centre of gravity axis.

The term usually referred to as the 'additional mass correction' has been omitted from the measurements described in this report. This term accounts for the mass of air which is put into motion by the oscillation of the aircraft. This means that the effect of this term is dependent on altitude, and that inertias used in airborne tests should also be corrected for this effect at the relevant altitude. The airborne work on the Dove is normally carried out below 8,000 feet, in which case the difference between the corrections at sea level and 8,000 feet is an order of magnitude smaller than the sea level correction.

No correction has been applied for fuel sloshing effects. These effects are usually corrected for by mathematically 'freezing' the fuel tank contents. It was considered that these effects are best accounted for by measurement of the moments of inertia in as many fuel states as possible, the aircraft being oscillated at approximately the relevant airborne frequencies (short period oscillation for pitching and Dutch roll oscillation for roll and yaw).

3.3 Measurement of the moment of inertia in roll

Figures 4 and 5 show the arrangement used for the measurement of the moment of inertia in roll.

The aircraft and cradle were supported by knife edges displaced fore and aft along the fuselage centre line. Spring restraint was applied by single coil springs fixed to the wing jacking points and firmly anchored to the ground. The knife edges were arranged so that the fuselage longitudinal axis was horizontal.

The cradle's inertia in roll was measured by a similar arrangement as the aircraft and cradle combined. The spring restraint was provided by coil spings hanging from an overhead gantry.

The moment of inertia in roll about an axis passing through the aircraft centre of gravity and parallel to the longitudinal axis is given by an expression similar to equation (1)

$$I_x = I_{x_{A/C+CR}} - I_{x_{CR}} - I_{x_S} \qquad (5)$$

where

$$I_{x_{A/C+CR}} = (c_x \ell^2_{x_{A/C+CR}} - W_{A/C+CR}\, h_{x_{A/C+CR}}) \left(\frac{P_{x_{A/C+CR}}}{2\pi}\right)^2 \qquad (6)$$

$$I_{x_{CR}} = (c_x \ell^2_{x_{CR}} - W_{CR}\, h_{x_{CR}}) \left(\frac{P_{x_{CR}}}{2\pi}\right)^2 \qquad (7)$$

$$I_{x_S} = \left(\frac{W_{A/C}}{g} + V\rho\right) \ell'^2_x \qquad (8)$$

3.4 Measurement of the moment of inertia in yaw

Figures 6 and 7 show the aircraft and cradle on the yawing rig used in these tests. A vertical axis of oscillation was established by supporting the cradle, on which the aircraft rested, by a four wire sling from a mobile crane.

Torsional restraint was provided by four tensioned coil springs attached in pairs to two vertical posts suspended along the centre line of the cradle and either side of the combined centre of gravity.

The ends of the slings were attached to the cradle by means of heavy turnbuckles. The turnbuckles were used to change the sling geometry to cater for shift of the centre of gravity with fuel state. This enabled the axis of oscillation to pass through the combined centre of gravity, and the aircraft fuselage to be kept horizontal.

An attempt was made to measure the product of inertia and the inclination of the principal axis by the method described in references 1 and 2. This method requires measurement of inertially induced roll whilst on the yawing rig. The attempt was thwarted by the presence of the cradle which prevented the aircraft and cradle combination from having a rolling motion at all during a yawing oscillation.

The aircraft's moment of inertia in yaw about a vertical axis passing through the aircraft centre of gravity is given by

$$I_z = I_{z_{A/C+CR}} - I_{z_{CR}} - I_{z_S} \tag{9}$$

where

$$I_{z_{A/C+CR}} = c_z \ell_z^2 \left(\frac{P_{z_{A/C+CR}}}{2\pi}\right)^2 \tag{10}$$

$$I_{z_{CR}} = c_z \ell_z^2 \left(\frac{P_{z_{CR}}}{2\pi}\right)^2 \tag{11}$$

$$I_{z_S} = \left(\frac{W_{A/C}}{g} + V\rho\right) \ell'^2_z \tag{12}$$

The inertia of the cradle $I_{z_{CR}}$ was determined using exactly the same system as the aircraft and cradle combined. The term $I_{z_{CR}}$ is necessary in this instance to account for the shift of axis from the combined c.g. of the aircraft and cradle to the c.g. of the aircraft alone.

3.5 Moments of inertia of crew

The moments of inertia calculated from equations 1, 5 and 9 were further corrected for the addition of eight crew members, composed of six students, one pilot and one demonstrator seated on the main spar. The corrections are composed of two parts, the first part due to the inertia of the crew about the aircraft c.g. and secondly the shift of axis term for the shift of the aircraft inertia from the c.g. of the aircraft without crew to the c.g. with crew. The first correction added to and the second subtracted from the empty aircraft's inertias.

The following table gives details of the crew corrections:

	Inertia of crew (slugs.ft^2)	Shift of axis term (slugs.ft^2)
Roll	70	-
Pitch	592	18
Yaw	592	16

4. Measuring equipment

The two most important measurements involved in inertia tests of this nature are the measurements of oscillation period and spring rate.

4.1 Spring rate

The spring rates of the yawing and rolling springs were measured by suspending the springs from a heavy iron girder and loading them with accurate weights. The deflections of both the spring and support were measured by dial gauges. The pitching spring system was calibrated 'in situ' as explained in section 3.2. The spring rates were determined from large scale load/extension graphs. The accuracy of this method is believed to be $\pm\frac{1}{2}\%$.

4.2 Oscillation period

The method used to measure and record the rolling and yawing motions consisted of a linear potentiometer, of low friction, fixed at one end to the aircraft. The potentiometer output was recorded on a T.R.P. 12" galvanometer. The oscillation period was computed by measuring the elapsed time for 10 or more oscillations, using the recorder's own 1/100 second time markers.

For the pitching inertia tests a new device was developed which measured the oscillation period both quickly and accurately.

The apparatus, which is described in the Appendix, consisted of an optical lever system using a projector or a mirror fixed to the cradle which amplified the oscillation movement by means of a light beam. The light beam passed across a photo-electric cell, which via a counter chain passed start-stop signals to a digital time counter. By this means it was possible to measure the elapsed time of 20 cycles to an accuracy of considerably better than ±.02 seconds. The oscillation period was started manually and the time taken for successive sets of 20 cycles was measured.

5. Results

The position of the centre of gravity and the moments of inertia were measured with the aircraft in various fuel states but without crew. The final results were corrected for the addition of crew. The aircraft was otherwise in a representative flying condition, with recorders and all test equipment installed.

5.1 Measurement of the position of the aircraft's centre of gravity

The results of the centre of gravity measurements are shown in Table I. The addition of fuel is seen to move the centre of gravity aft and downwards. The zero fuel with crew case was included to determine the c.g. shift due to crew so that the measured inertias could be corrected. The measured c.g. positions were also corrected for undercarriage retraction ($1\frac{1}{2}''$ up) before they were applied to the inertia results. The movement of the fuel to the rear of the tanks at high angles of 'incidence' was not observed to alter the vertical position of the c.g.

The accuracy of the horizontal centre of gravity location is believed to be better than ±0.25″ and that of the vertical c.g. better than ±0.50″.

5.2 Measurement of the moment of inertia in pitch

An analysis of the measurements of the pitching inertia is given in Table 2.

The pitching inertia is seen to vary quite considerably with fuel load. The greatest difference is between the 50 gallons of fuel case and the full fuel case and at 1076 slugs.ft^2 represents approximately 8% of the full fuel inertia. The probable error for these measurements is ±130 slugs.ft^2, and coupled with the fact that the measurement of the oscillation period in pitch was the most accurate period measurement taken, means that the difference in measured inertia with fuel is undoubtedly due to fuel sloshing. Although the inertia varies appreciably with fuel state, the maximum inertia measured in this series of tests pertains to the full fuel state, which is to be expected.

5.3 Measurement of the moment of inertia in roll

The rolling inertia measurements are analysed in Table 3.

The inertia about the c.g. axis is seen to increase from 10,672 slugs.ft^2 with zero fuel to 11,341 slugs.ft^2 with full fuel. The variation with fuel load is quite smooth and progressive and indicates no fuel sloshing effects. The probable error for these measurements is ±110 slugs.ft^2 or 1.03%.

5.4 Measurement of the moment of inertia in yaw

An analysis of the yawing inertia measurements is given in Table 4. The inertia in yaw is seen to have some dependency on fuel condition; the inertia increases with fuel load except for one condition where it decreases very slightly. The empty aircraft inertia in yaw is 21,519 slugs.ft^2 and the increase due to full fuel 771 slugs.ft^2. The probable error of these measurements is ±165 slugs.ft^2 or 0.75%.

5.5 Effect of fuel sloshing

The moments of inertia in pitch, roll and yaw are shown plotted against aircraft weight or weight of fuel added in fig. 8. The rolling inertia is ostensibly unaffected by fuel sloshing, as evidenced by the smooth and progressive manner with which it varies with fuel contents. The yawing inertia variation with fuel is seen to be progressive but not smooth, which indicates that some degree of fuel sloshing was present during these tests. The variation of the moment of inertia in pitch with fuel contents is neither smooth nor progressive but merely random, indicating that the measurements are subject to quite large fuel sloshing discrepancies.

The Dove's fuel tanks are set in the wings between the fuselage and engines, there being a front and rear tank each side connected by balance pipes. The tanks are baffled fore and aft only, the baffles being fore and aft partitions with large diameter lightening holes. This means that the fuel can slosh fore and aft during the pitching oscillations, and cannot slosh sideways during the rolling oscillation. The yawing oscillation would result in some fore and aft slosh combined with a lateral movement restriction.

The preceeding remarks provide the explanation for the plots shown in fig. 8.

6. Conclusions

The moments of inertia of the Hawker Siddeley Dove Mk. 5 aircraft have been determined experimentally using a spring restrained oscillation technique.

The inertias of the aircraft without fuel but with a crew of 8 people were:-

moment of inertia in roll;	10,672 (±110) slugs.ft^2
moment of inertia in pitch;	12,833 (±130) slugs.ft^2
moment of inertia in yaw;	21,519 (±165) slugs.ft^2

The effect of fuel sloshing on the measured inertias has been explained as being due to the baffling of the fuel tanks.

The benefit of hindsight reveals that the cradle used to support the aircraft for the inertia measurements was perhaps too large. The inertias of the cradle, expressed as percentages of the inertia of the aircraft plus cradle about the axes of oscillation were:-

Roll	5%
Pitch	21%
Yaw	17%

No corrections have been applied to the measured inertias to account for fuel sloshing or additional mass effects.

It is suggested that care should be taken in accepting the pitching inertia measurements with the fuel tanks partially full; alternatively lateral baffles should be added to the tanks.

A system has been developed by which the period of oscillations of large or small structures can be measured easier, quicker and more accurately than hitherto possible.

Acknowledgements

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References

1.	W.G. Bradley	Measurements of the moments of inertia of the Morane-Saulnier M.S.760 Paris aircraft. College of Aeronautics Note Aero. No. 160. November 1963.
2.	R.W. Boucher D.A. Rich H.L. Crane C.E. Mathey	A method for measuring the product of inertia and the inclination of the principal longitudinal axis of an airplane. N.A.C.A. T.N. 3084 April, 1954.
3.	C.B. Notess C.R. Woodward	An investigation of the experimental determination of aircraft inertia characteristics. W.A.D.C. Tech. Report 53-207 July, 1953.
4.	V.J. Pauly R.J. Meyer N.L. Infanti	The determination of the moments of inertia about the lateral axes of a B.25J airplane. C.A.L. Report No. TB-405-F-9 February, 1949.
5.	F.S. Malvestuto L.J. Gale	Formulas for additional mass corrections to the moments of inertia of airplanes. N.A.C.A. T.N. 1187 1947.
6.	E. Widmayer J.R. Reese	Moments of inertia and damping of fluid in tanks undergoing pitching oscillations. N.A.C.A. RML 53 E Ola June 1953.

7. J.R. Reese, J.L. Sewall — Effective moment of inertia of fluid in off-set, inclined and swept wing tanks undergoing pitching oscillations.
N.A.C.A. TN 3353
January, 1953.

8. D.H. Perry — Measurements of the moments of inertia of the AVRO 707B aircraft.
A.R.C. C.P.647
August 1961.

Appendix

Time and Period Measuring Apparatus

This apparatus was designed to permit the accurate measurement of the periodic time of oscillation of structures, but could also be used for measurements of elapsed time where movement is present.

A block diagram of the system is shown in fig. 9. A narrow beam of light from a stationary source is arranged to fall on a plane mirror fixed to the oscillating member. Reflected light then forms an optical lever which amplifies the movement of the oscillating structure. The light from the mirror is collected by a simple lens system and focused on the active area of a photo-sensitive transistor. The arrangement is such that for half the period of oscillation the cell is in comparative darkness and illuminated for the other half period. For setting-up purposes the photoelectric cell is de-sensitised and the current flow due to illumination indicated on a moving coil meter. This allows the user to obtain optimum light pick-up.

For period measurement purposes, the photo cell current is fed to a regenerative trigger circuit whose operating point can be varied by a 'ZERO SHIFT' control. The circuit is adjusted so that the trigger operates at the point of maximum velocity of the passage of the light beam across the cell. In this way a fast rectangular voltage waveform is generated having the same period as that of the oscillating structure. This waveform is the input signal to a counter chain which generates start and stop signals. The counter can be switched to divide the input signals by 1 to 10n where n varies from 1 to 10. The start and stop signals gate a digital timer which measures the elapsed time for a pre-determined number of cycles from which the average period can be determined.

TABLE 1

Analysis of centre of gravity measurements

Fuel Condition (gallons)	Aircraft Weight (lbs)	Longitudinal c. of g. position aft of datum (ins)	Vertical c. of g. position above M/W axles (ins)
0	6595	- 3.66	42.05
50	6961	- 2.44	41.08
70	7108	- 2.02	40.70
90	7252	- 1.65	40.22
110	7396	- 1.37	39.94
166 (Full)	7782	- 0.70	37.13
Zero Fuel 8 crew	7912	- 0.69	39.66

TABLE 2

Analysis of the measurement of pitching inertia

Fuel State (gallons)	Weight of Aircraft + Cradle $W_{A/C+CR}$ (lb)	Spring Restraint $(c_y \ell_y^2)$ (lb.ft)	Oscillation Period $P_{y_{A/C+CR}}$ (sec.)	Moment of Inertia of Aircraft + Cradle about Knife Edges $(I_{y_{A/C+CR}})$ (slugs.ft^2)	Moment of Inertia of Cradle about Knife Edges $(I_{y_{CR}})$ (slugs.ft^2)	Axis Transfer (I_{y_S}) (slugs.ft^2)	Inertia Correction for Crew slugs.ft^2	Moment of Inertia of Aircraft + Crew about c.g. axis (I_y) slugs.ft^2	Weight of Aircraft + Crew lb.	Non-dimensional Inertia $i_B = \frac{I_y}{M\ell_T^2}$	Probable Error
0	8,769	736,945	1.018	18,631	3,855	2,517	574	12,833	7,912	.1050	130 slugs.ft^2 or 1.04%
50	9,135	736,945	1.010	18,275	3,855	2,907	574	12,105	8,278	.0947	″
70	9,282	736,945	1.028	18,916	3,855	2,905	574	12,730	8,428	.0978	″
90	9,426	736,945	1.020	18,618	3,855	2,838	574	12,449	8,569	.0941	″
110	9,570	736,945	1.018	18,537	3,855	2,941	574	12,315	8,713	.0915	″
168 (Full)	9,956	736,945	1.0335	19,110	3,855	2,648	574	13,181	9,099	.0938	″

TABLE 3

Analysis of the measurement of rolling inertia

Fuel State (gallons)	Weight of Aircraft + Cradle $(W_{A/C+CR})$ (lb)	Spring Restraint $(c_x \ell_x^2)$ (lb.ft)	Oscillation Period $P_{x_{A/C+CR}}$ (sec.)	Moment of Inertia of Aircraft + Cradle about Knife Edges $I_{x_{A/C+CR}}$ (slugs.ft^2)	Moment of Inertia of Cradle about Knife Edges $I_{x_{CR}}$ (slugs.ft^2)	Axis Transfer (I_{x_S}) (slugs.ft^2)	Inertia Correction for Crew (slugs.ft^2)	Moment of Inertia of Aircraft + Crew about c.g. Axis (I_x) (slugs.ft^2)	Weight of Aircraft + Crew (lb.)	Non-dimensional Inertia $i_A = \frac{I_x}{M(\frac{b}{2})^2}$	Probable Error %
0	8,769	108,631	2.573	13,700	698	2,330	70	10,672	7,912	.0534	110 slugs.ft^2 or 1.03%
50	9,135	108,631	2.655	14,090	698	2,749	70	10,713	8,278	.0513	″
70	9,282	108,631	2.665	14,133	698	2,757	70	10,748	8,425	.0505	″
90	9,426	108,631	2.674	14,176	698	2,749	70	10,799	8,569	.0500	″
110	9,570	108,631	2.688	14,252	698	2,765	70	10,859	8,713	.0494	″
168 (Full)	9,956	108,631	2.706	14,496	698	2,527	70	11,341	9,099	.0458	″

TABLE 4

Analysis of the measurement of yawing inertia

Fuel State (gallons)	Weight of Aircraft + Cradle ($W_{A/C+CR}$) (lb)	Oscillation Period ($P_{z_{A/C+CR}}$) (sec.)	Moment of Inertia of Aircraft + Cradle about Suspension ($I_{z_{A/C+CR}}$) (slugs.ft^2)	Moment of Inertia of Cradle about Suspension ($I_{z_{CR}}$) (slugs.ft^2)	Axis Transfer (I_{z_S}) (slugs.ft^2)	Inertia Correction for Crew (slugs.ft^2)	Moment of Inertia of Aircraft + Crew about Suspension I_z (slugs.ft^2)	Weight of Aircraft + Crew (lb)	Non-dimensional Inertia $i_C = \frac{I_z}{M(\frac{b}{2})^2}$	Probable Error
0	8,769	3.852	25,527	4,464	121	577	21,519	7,912	.1078	165 slugs.ft^2 or 0.75%
50	9,135	3.891	26,047	4,464	152	576	22,007	8,278	.1053	"
70	9,282	3.893	26,074	4,464	165	576	22,021	8,425	.1036	"
90	9,426	3.892	26,061	4,464	177	576	21,996	8,569	.1017	"
110	9,570	3.900	26,168	4,464	188	575	22,091	8,713	.1005	"
168 (full)	9,956	3.917	26,396	4,464	217	575	22,290	9,099	.0960	"

TABLE 5

Error Analysis

Source of Possible Error	Pitching Inertia		Roll Inertia		Yaw Inertia	
	Possible Error	Possible Error in Inertia (slugs.ft^2)	Possible Error	Possible Error in Inertia (slugs.ft^2)	Possible Error	Possible Error in Inertia (slugs.ft^2)
Period	±.002 sec.	±80	±.002 sec.	±25	±.002 sec.	±29
Spring Constant	±20 lb/ft (0.5%)	±105	±5 lb/ft (0.5%)	±86	±10 lb/ft (0.5%)	±127
Spring Arm	±.020 ft.	±50	±.020 ft.	±70	±.020 ft.	±43
Aircraft Weight	±3 lb.	±5	±3 lb.	±5	-	-
Vertical position of c.g.	±.04 ft.	±65	±.04 ft.	±114	-	-
Longitudinal position of c.g.	±.02 ft.	±8	-	-	-	-
Moment of inertia of cradle	±80 slugs.ft^2 (2%)	±80	±14 slugs.ft^2 (2%)	±14	±89 slugs.ft^2 (2%)	±89
Moment of inertia of crew	±20 slugs.ft^2 (4%)	±20	±20 slugs.ft^2 (8%)	±20	±20 slugs.ft^2 (4%)	±20
Probable Error $= 0.675 \text{ x} \sqrt{\Sigma \begin{Bmatrix}\text{possible}\\ \text{errors}\end{Bmatrix}^2}$		±130 or 1.04%		±110 or 1.03%		±165 or 0.75%

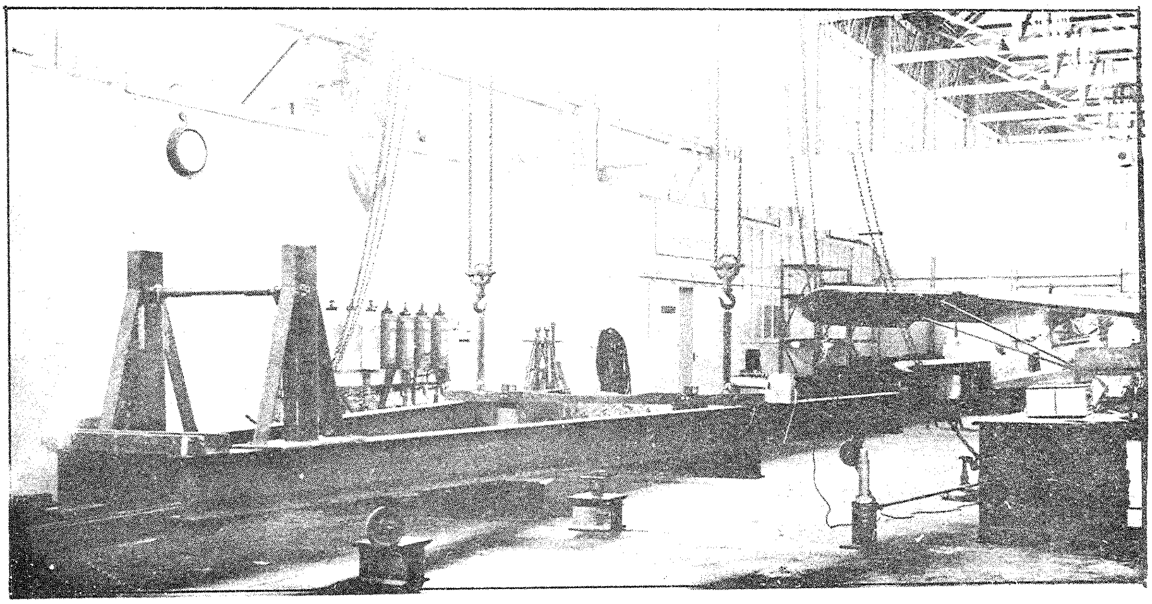

FIG. 1. VIEW OF THE SUPPORTING CRADLE.

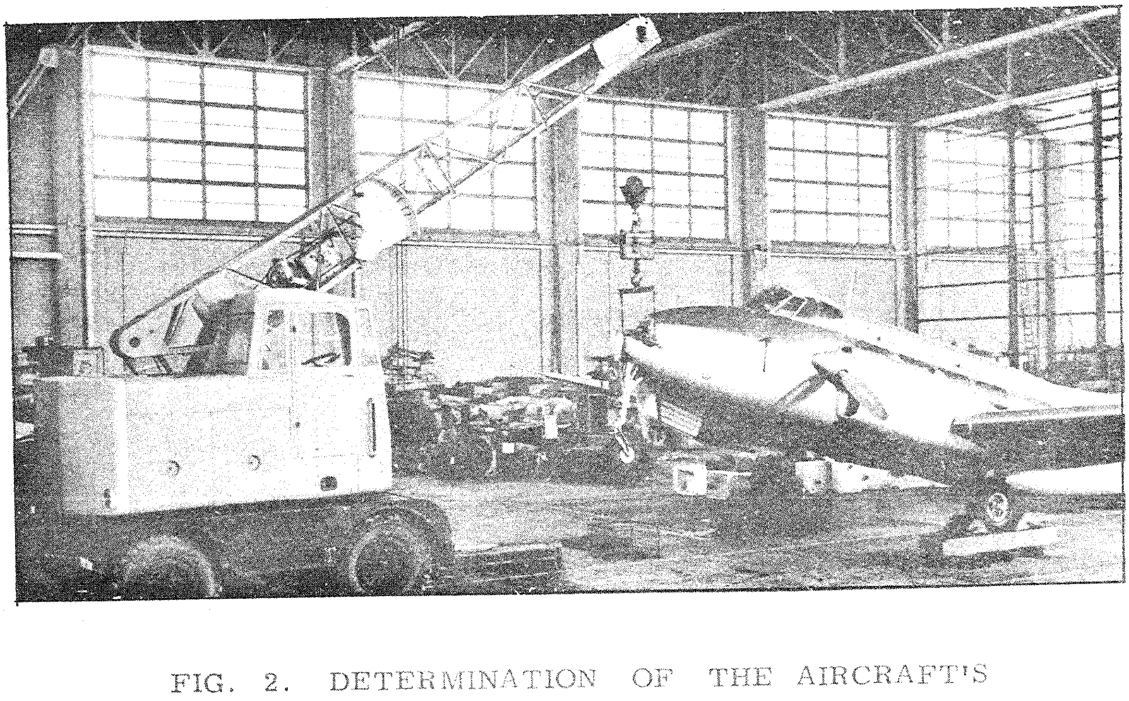

FIG. 2. DETERMINATION OF THE AIRCRAFT'S CENTRE OF GRAVITY.

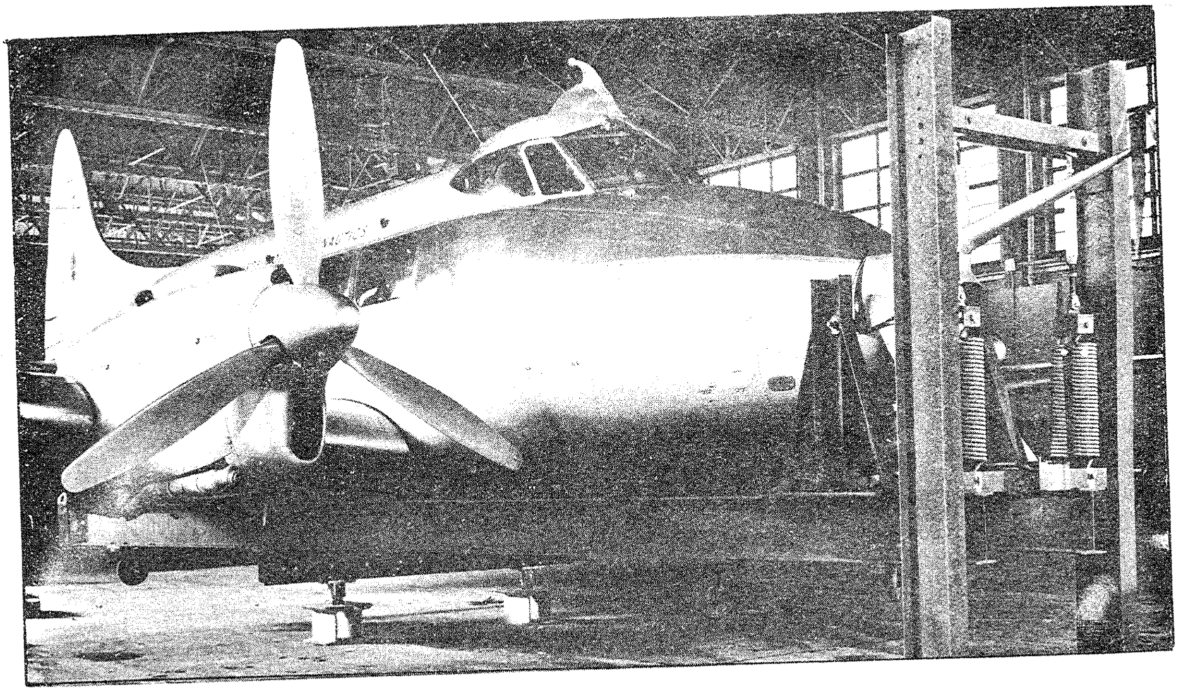

FIG. 3. VIEW OF THE AIRCRAFT IN POSITION FOR THE PITCHING INERTIA TESTS.

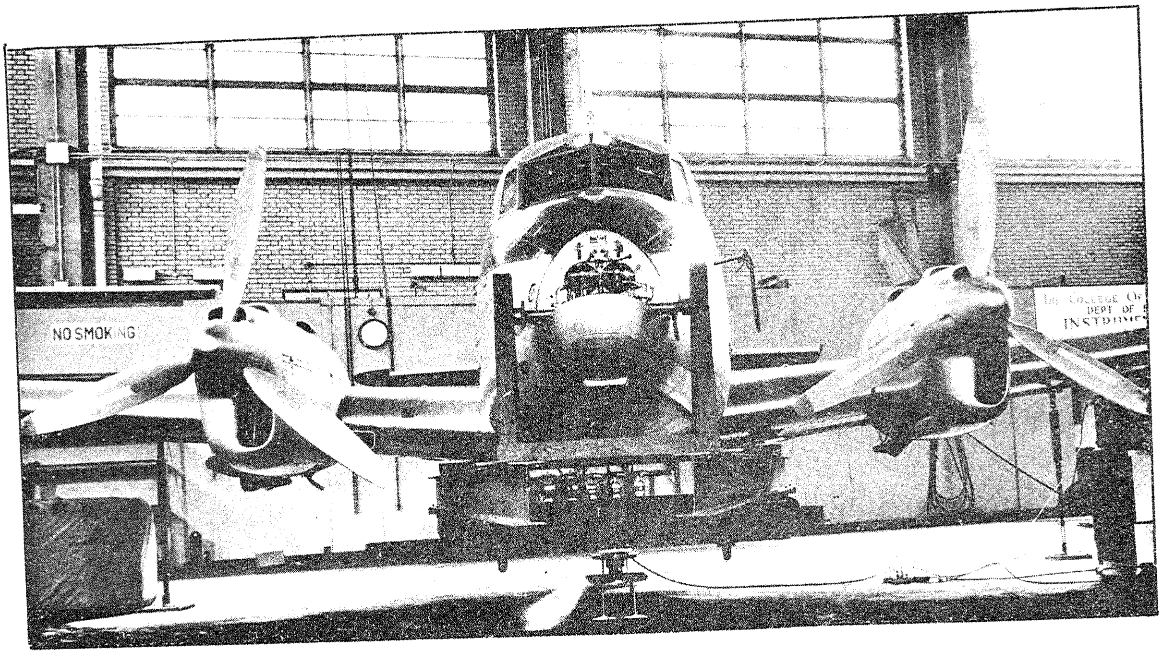

FIG. 4. VIEW OF THE AIRCRAFT IN POSITION FOR THE ROLLING INERTIA TESTS.

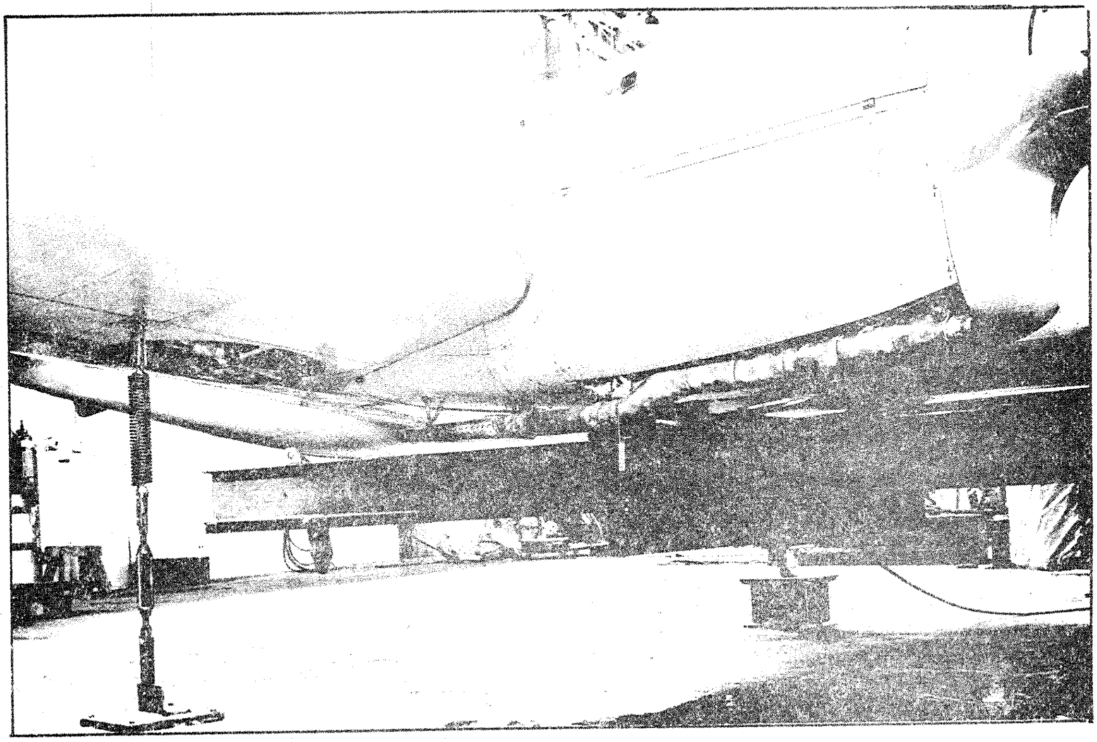

FIG. 5. VIEW OF THE METHOD OF SPRING ATTACHMENT USED IN THE ROLLING INERTIA TESTS.

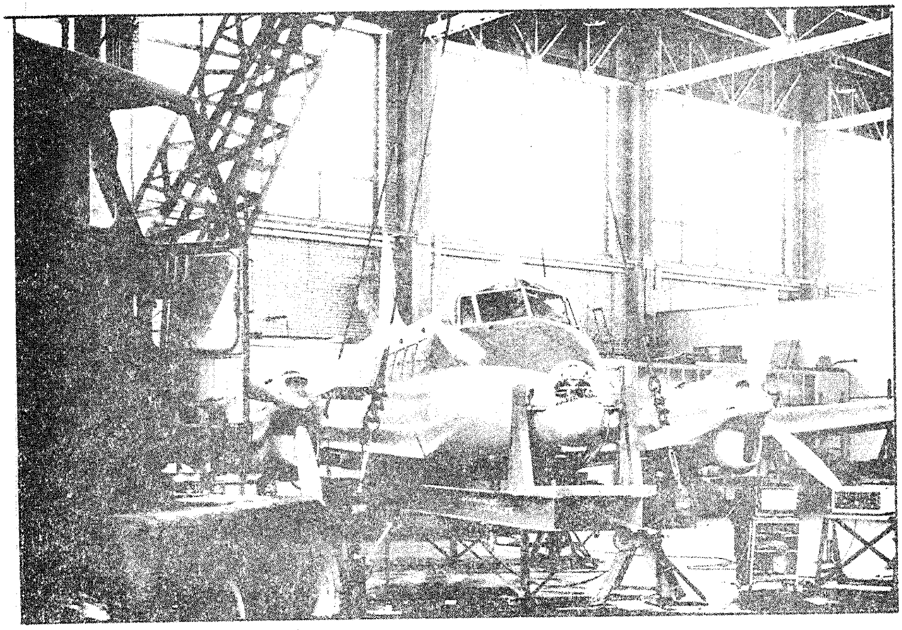

FIG. 6. THE AIRCRAFT IN POSITION FOR THE YAWING INERTIA TESTS.

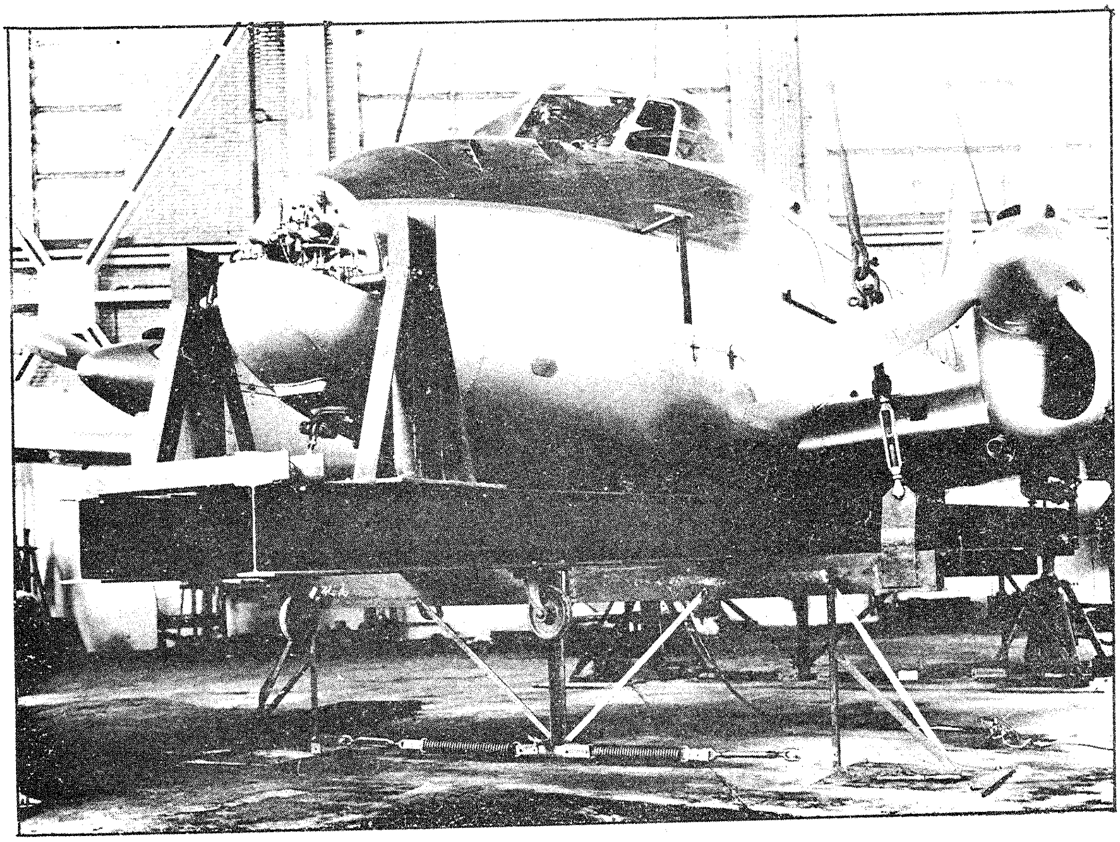

FIG. 7. VIEW OF THE METHOD OF SPRING ATTACHMENT USED IN THE YAWING INERTIA TESTS.