CoA Note No. Aero. 160

THE COLLEGE OF AERONAUTICS
CRANFIELD

MEASUREMENTS OF THE MOMENTS OF INERTIA OF THE MORANE-SAULNIER M.S. 760 'PARIS' AIRCRAFT

by

W.G. Bradley

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- by -

W.G. Bradley, B.Sc.(Eng.), Grad.R.Ae.S.

SUMMARY

This note describes the measurement of the moments of inertia, of a Morane-Saulnier M.S.760 'PARIS' aircraft. The moments of inertia in pitch, roll, and yaw were measured by the spring-constrained oscillation method. The cross-product of inertia and the inclination of the principal axis, were also determined by a variation of this method.

Inertias were measured in three different fuel conditions. The results are given in Tables I - VI.

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CORRIGENDUM

Fig. 7 title should read: View of the aircraft on the rolling rig.

Contents

Page

Summary

List of symbols 1

1. Introduction 2

2. Test methods 2

2.1 Measurement of the position of the centre of gravity 2

2.2 Measurement of the moment of inertia in pitch 3

2.3 Measurement of the moment of inertia in roll 4

2.4 Measurement of the moment of inertia in yaw 5

2.5 Measurement of the inclination of the principal axis of inertia and the cross product of inertia 6

3. Measuring equipment 6

3.1 Measurement of oscillations 6

3.2 Measurement of spring rate 7

4. Results 7

4.1 Measurement of the moment of inertia in pitch 7

4.2 Measurement of the moment of inertia in roll 8

4.3 Measurement of the moment of inertia in yaw 8

4.4 Measurement of the inclination of the principal axes and the product of inertia 8

Conclusions 9

List of references 9

Tables 11

Figures

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
hx, hy	ft.	Height of centre of gravity of aircraft above the knife edge in the rolling and pitching oscillations.
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 inertias, defined in Tables II to V.
lx, ly	ft.	Perpendicular distance from centre line of restraining springs to axes of oscillation in roll and pitch.
lx′, ly′	ft.	Perpendicular distance from aircraft centre of gravity to axes of oscillation in roll and pitch.
P_x, P_y, P_z	sec.	Periods of oscillations about roll, pitch and yaw oscillation axes.
$\frac{b}{2}$	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
δ	deg.	Angle between X body reference axis and line joining forward and rearwards, yaw spring attachment points.
ϵ	deg.	Angle of inclination of principal axis of inertia to longitudinal body axis of aircraft.

Subscripts

K.E.	Refers to inertias measured about knife edges
C.G.	Refers to inertias measured about the orthogonal body axes passing through the aircraft's centre of gravity
S	Shift of axis term
RIG	Inertia of rig and ancilliary equipment.

1. Introduction

The measurement of an aircraft's aerodynamic derivatives forms an important aspect of flight testing. It allows earlier wind tunnel measurements to be checked against full-scale data, and the measurement of the rotary derivatives, i.e. l_p, n_p, l_r, n_r, m_q and m_w, which is extremely difficult, if not impossible, to obtain from wind tunnel tests.

The measurements of these rotary derivatives almost invariably involves the analysis of suitable dynamic manoeuvres, usually the short period pitching oscillation, and the Dutch roll lateral oscillation. The results obtained from these manoeuvres, are highly dependent on the assumed aircraft moments of inertia. It follows that, in order to obtain accurate derivatives, the aircraft's moments of inertia must be known very precisely.

Experience has shown that manufacturers' figures for inertias, or those calculated from the aircraft weight schedule, are not accurate enough for this sort of work. It was therefore necessary to measure the aircraft's moments of inertia physically.

The method used was that described in references 1, 2 and 3. Briefly, the method consists of pivoting the aircraft about knife-edge fulcrums, or suspending it from a single suspension point, constraining it by means of coil springs. The equipment needed for this method is relatively simple and inexpensive.

The M.S.760 'Paris' is a particularly easy aircraft on which to use this method of inertia determination. Jacking points and slinging points are situated extremely conveniently, and, being of a 'screw-in' type, lend themselves very easily to the attachment of knife-edges, springs, etc. A drawing of the relevant points is shown in figure 1.

2. Test methods

2.1 Measurement of the position of the centre of gravity

The position of the aircraft's centre of gravity was found by the method described in reference 2. The arrangement is shown in figure 3. The aircraft was mounted on knife-edges attached to the wing jacking points, the knife-edges fitting into standard aircraft jacks, shown in figure 3. The jacks rested on a weighbridge. The nose of the aircraft was supported by a sling attached to the forward slinging points, and the sling was fixed to a 30 cwt. beam balance which was supported by a mobile crane. The arrangement is shown in figure 1. Readings of the weighbridge and beam balance reactions were made with the aircraft longitudinal axis inclined at various altitudes to the horizontal, between $17\frac{1}{2}°$ nose up and 8° nose down.

It is particularly important in this exercise that the forward sling should be vertical at all times. This was ensured by suspending a plumb bob from the beam balance between the sling wires. In this way, the sling could be aligned with the plumb bob by horizontal movement of the crane.

The aircraft's undercarriage was retracted and the cabin ballasted to simulate the crew of four. The position of the centre of gravity was found not to vary with aircraft attitude. This is probably due to the shape of the fuel tank. The measured positions of the centre of gravity are shown in Table 1.

The accuracy of the measurement of the longitudinal position, of the centre of gravity is believed to be ±0.25″ and that of the vertical ±0.5″.

The accuracy of the aircraft's all up weight is believed to be ±4 lb.

2.2 Measurement of the moment of inertia in pitch

Figure 5 shows the general arrangement of the aircraft on its pitching rig. A pitching axis parallel to the aircraft's lateral axis was set up, by supporting the aircraft on knife-edges attached to the wing jacking points. The rear of the aircraft was supported by a bank of coil springs fixed to the rear fuselage slinging point, as shown in figure 6. In this way the second order oscillatory system was established.

The motion of the aircraft was measured by a low friction linear potentiometer attached to the aircraft nose probe; the output of the potentiometer was recorded on a galvanometer trace recorder.

The equation of motion for small amplitude oscillations about knife edge supports, assuming the aircraft to be a rigid body, is given by:

$$I_{y_{KE}}\ddot{\theta} + (c_y l_y^2 - Wh_y)\theta = 0 \qquad (1)$$

The second term in the equation represents the restoring moment of the coil springs, while the third term takes into account the moment arising from the movement of the aircraft's centre of gravity.

Equation (1) can be solved to give a relationship between the aircraft's moment of inertia, the restoring moment, and the period of the aircraft's oscillation.

$$I_{y_{KE}} = (c_y l_y^2 - Wh_y)\left(\frac{P_y}{2\pi}\right)^2 \qquad (2)$$

The moment of inertia about the aircraft's pitch axis, passing through the centre of gravity and parallel to axis of oscillation, is given by the equation

$$I_{y_{C.G.}} = I_{y_{K.E.}} - I_{y_{RIG}} - I_{y_s}$$

where $I_{y_{RIG}}$ is the moment of inertia of the associated rig, comprising the parts of the spring attachment rig which moves with the aircraft and the inertia of one third of the true mass of the restoring springs, about the knife edges.

I_{y_s} is equal to $\left(\frac{W}{g} + V\rho\right) l_y'^2$ and accounts for the shift of axis and the correction term due to the bouyancy of the air displaced by the aircraft.

Another term, referred to as the 'additional mass' effect, has been omitted in the measurements referred to in this report. The term accounts for the additional mass of air entrapped by the aircraft and moved with it during the oscillation. The effect of this term is therefore dependent on altitude, and inertias used in flight measurements should be corrected for the difference in the correction due to altitude. In the case of the M.S.760, most of the flight stability work is carried out at a nominal altitude of 10,000 ft. The difference in the correction between 10,000 ft. and sea level, which should be applied to flight results, is therefore small enough to be neglected.

2.3 Measurement of the moment of inertia in roll

Figure 7 shows the general arrangement of the aircraft and equipment for the measurement of the rolling inertia.

The aircraft was supported by a cradle under the centre fuselage and at the nose jacking point as shown in figure 8. The cradle was positioned by outriggers attached to the wing jacking points, and rested on a single knife-edge, placed on the ground. The nose was supported by a knife-edge fixed to the forward fuselage jacking point. In order to get the axis of oscillation parallel to the fuselage longitudinal datum, a distance piece was inserted between the nose knife edge and the fuselage.

It was not possible to mount the whole aircraft on a single cradle, because the fuselage frames carrying the front and rear wing spars are positioned aft of the aircraft's centre of gravity. Other fuselage frames are not considered strong enough for this purpose.

Single coil springs were attached to the wing picket points, situated at about mid-span position. The aircraft motion was measured by a low friction linear potentiometer mounted near the mid-span position.

An expression, similar to (2), exists for the rolling inertia, relating the measured inertia to the restoring moments and the period of the oscillation.

$$I_{x_{K.E.}} = \left(c_x l_x^2 - W h_x\right)\left(\frac{P_x}{2\pi}\right)^2 \qquad (3)$$

Applying similar corrections to those used in the pitching inertia for rig inertias and transference of axis, equation (3) becomes

$$I_{x_{C.G.}} = I_{x_{K.E.}} - I_{RIG} - I_{x_s} \qquad (4)$$

where again I_{x_s} is given by $\left(\frac{W}{g} + V\rho\right) l_x{}'$.

2.4 Measurement of the moment of inertia in yaw

Figure 9 illustrates the arrangement of the aircraft for determination of the moment of inertia in yaw, and the inclination of the principal axis, by the NACA method.

The aircraft was suspended by a four-wire sling attached to fore and aft slinging points already in the airframe. The sling geometry was modified slightly (for each load condition) to allow the oscillation axis to pass through the aircraft's centre of gravity, and to maintain the fuselage longitudinal datum horizontal. The sling was supported by blocks and chains in the hangar roof. Two blocks were coupled together by means of a large shackle and swivelling hook to give a very low friction bearing. Torsional restraint was applied by four coil springs horizontally attached to two cradles. The cradles were mounted on the aircraft fuselage, equal in distance from either side of the centre of gravity. The springs were attached to tongues underneath the cradles. Provision was made to alter the height of the individual spring positions. The cradles, shown in figure 10, were necessarily fairly robust structures in order to transmit the thrust of the springs without bending or slipping around the fuselage; they were strapped around the fuselage with steel strip and wire and joined together by tensioned wire to prevent longitudinal separation. The aircraft's motion was measured by means of two rate gyro's mounted on the cockpit floor, measuring the rates of yaw and roll.

The aircraft's moment of inertia about the oscillation axis of the supporting system is given by

$$I_{z_{SLING}} = c_z l_z{}^2 \left(\frac{P_z}{2\pi}\right)^2 \qquad (5)$$

Equation (5) is exact, only when the axis of oscillation is the resultant axis of the combined vectors of the restoring moment and the aircraft's angular acceleration. Although the aircraft is of course, free to roll on this rig, the effect of roll is negligible, provided the angle between the resultant angular acceleration vector and the oscillation axis is less than 5°.

Since the oscillation axis necessarily passes through the aircraft's centre of gravity, there is no correction for transference of axis. The only correction to be applied therefore, is to account for the rig inertia. The expression for the yawing inertia then becomes

$$I_{z_{C.G.}} = I_{z_{SLING}} - I_{z_{RIG}} \qquad (6)$$

2.5 Measurement of the inclination of the principal axis of inertia and the cross product of inertia

The method used for these measurements was that proposed in reference 1. The method consists of measuring the inertially induced rolling motion when the yawing axis is not normal to the inertia principal axis. This is achieved by verifying the vertical positions of the fore and aft restoring springs, i.e. the angle δ, until a spring position is found for which there is no induced rolling motion when the aircraft is oscillated in yaw. This null value of the angle δ, denoted δ_o, then bears a simple relationship to the inclination of the principal axis.

$$\epsilon = \tfrac{1}{2} \tan^{-1} \left[\frac{2I_{z_{c.g.}} \cdot \tan \delta_o}{I_{z_{c.g.}} - I_{x_{c.g.}}} \right] \qquad (7)$$

It is not practical to find this null position by trial and error. The method adopted was to vary the angle δ, and to record the ratio of the roll amplitude to yaw amplitude for each angle, by taking several values of δ, both positive and negative, an interpolation can easily be obtained to give δ_o; that is, the spring inclination angle at which there is no inertially induced rolling. The product of inertia $I_{xy_{C.G.}}$ can also be determined from a simple expression involving $I_{z_{C.G.}}$ and δ_o.

$$I_{xy_{C.G.}} = I_{z_{C.G.}} \tan \delta_o \qquad (8)$$

3. Measuring equipment

The two most important measurements involved in these tests were the measurement of the periods of oscillations, and of spring rates.

3.1 Measurement of oscillations

The recording equipment used in each test was a T.R.P. 12" galvanometer trace recorder. An accurately calibrated clockwork mechanism giving $^1/_4$ second time markers was used to obtain a coarse measurement of time, and the

$^1/_{100}$ second time marker in the recorder gave the fine measurement.

3.2 Measurement of spring rate

Spring rate was measured by suspending the springs individually from a heavy iron girder, the deflection of which could be neglected. The springs were extended by means of accurately calibrated weights. Deflection of the spring was measured by a vernier height gauge on a solid base.

4. Results

The values of measured inertias are shown in Tables II to V. Values quoted in this note are all referred to aircraft body axes passing through the aircraft's centre of gravity. Use of these inertia values in flight necessitates the conversion of these inertias to a wind axis system.

The inertias were measured with the aircraft in a representative flying condition, i.e. undercarriage retracted; cockpit canopy shut; ballast weighing 160 lbs. on each seat; parachute, harness, and head sets in place; Dutch roll instrumentation and recorders installed. Three fuel states were considered as follows:

1. Main tank 150 gallons only.
2. Main tank 195 gallons only.
3. Main tank 195 gallons and 50 gallons in each tip tank.

Fuel conditions 1 and 2 were carried out to investigate the effect of main tank fuel on the inertias; this was thought to be small since the aircraft centre of gravity is extremely close to the centre of the tank. The results confirmed this conclusion.

Fuel condition 3 was included to find the effect of wing tip fuel. Full tip banks, i.e. 50 gallons in each tank, approximately double the rolling and yawing inertias.

4.1 Measurement of the moment of inertia in pitch

An analysis of the pitching inertia measurements is given in Table II. The first measurement taken, with 150 gallons of fuel in the main tank should not be regarded as an accurate measurement. A rate gyro was used for the measurement of aircraft motion which proved to be unsatisfactory. Fuel conditions 2 and 3, however, are considered accurate inertia determinations. The moment of inertia in pitch with 195 gallons in the main tank and zero tip fuel is 6902 slugs ft^2. The calculated probable error in this measurement is ±54 slug ft^2. (viz. ±0.81%). The decrease in the inertia about the reference axis with the addition of tip fuel is quite marked. The moment of inertia about the knife edges increases with the addition of tip fuel, but owing to the increased axis transfer term, the net effect is a decrease in the moment of inertia about the centre of gravity axis. The increase in the axis transfer term is brought about by the upward movement in the centre of gravity due to the addition of tip fuel. The net decrease in the reference axis inertia, 6902 - 6812 = 90 slugs.ft^2, is well outside the calculated probable error of 61 slugs.ft^2. Similar, but more obvious effects to this are referred to in reference 7.

4.2 Measurement of the moment of inertia in roll

The rolling inertia measurements are analysed in Table III. The addition of full tip tank fuel increases the rolling inertia by a factor of 2.7. The aircraft rolling inertia with full tip tanks is 8692 slugs.ft^2. with a probable error of ±64 slugs.ft^2. (0.74%).

Main tank fuel makes very little difference to the rolling inertia; this is to be expected since the aircraft centre of gravity is very close to the centre of the fuselage fuel tank.

4.3 Measurement of the moment of inertia in yaw

Analysis of the yawing inertia measurements is given in Table IV. Again the inertia is seen to vary little with main tank fuel. The moment of inertia in yaw with full tip tanks is 17,094 slugs.ft^2., with a probable error of ±68 slugs.ft^2. (0.4%). The yawing inertia measurements were taken with the plane of the fore and aft constraining springs parallel to the aircraft's longitudinal axis and therefore perpendicular to the normal axis of oscillation. Full tip tanks increase the yawing inertia by a factor of about 1.7.

4.4 Measurement of the inclination of the principal axes and the product of inertia

Details of these measurements are given in Table V, plots of the ratio of maximum roll amplitude to maximum yaw amplitude against tan δ are shown in figures 11 and 12. The inclination of the principal axis and the product of inertia were not measured with 150 gallons in the main fuel tank. It is not considered that the values of ϵ and $I_{xy_{C.G.}}$ for this fuel case would be greatly different from those measured with 195 gallons in the main tank. The addition of 50 gallons of tip fuel, gives rise to a slight decrease in the inclination of the principal axis but a large difference in the product of inertia $I_{xy_{C.G.}}$. The increase is from 135 slugs.ft^2. with empty tip tanks to 381 slugs.ft^2. with full tip tanks. This increase is no doubt due to the large vertical shift of the aircraft's centre of gravity due to the addition of full tip fuel.

Error estimation for this part of the exercise is somewhat difficult, in the zero tip full case, an error of ±0.005 in the estimation of tan δ_o gives rise to an error of ±50 slugs.ft^2. in $I_{xy_{C.G.}}$ and ±1° in ϵ; with tip tanks full, a possible error of ±.005 in tan δ_0 gives an error of ±68 slugs.ft^2 in $I_{xy_{C.G.}}$ and ±0.5° in ϵ.

Conclusions

The moments of inertia of the Moraine-Saulnier M.S.760 have been determined experimentally, by the spring constrained oscillation method. The results are given in the Tables II to V. An accuracy break down gives probable errors of under 1%, with the exception of the cross product of inertia and inclination of the principal axis, where the probable error is of the order of 10%. The apparent inaccuracy of the latter measurements is not particularly significant in this case since the cross inertia is extremely small.

The correction which can be applied to the measured inertias to allow for the effect of full sloshing has been ignored. This was done because the 'frozen solid analogy' is known to be incorrect for a motion which is principally rotational. (Reference 5). The nature of the fuel tanks on the aircraft used in these inertia measurements, coupled with the oscillation frequencies used, gave no apparent 'beating' effects as observed on the inertia tests carried out on the AVRO 707 B aircraft (reference 7). The only way to eliminate this problem is to oscillate the aircraft at, or very near the natural frequencies of the airborne oscillations of interest. (i.e. Dutch Rolls and Short Period Pitching Oscillation). A true representation of airborne inertias will then be obtained. The frequencies of these oscillations vary with aircraft weight, airspeed, and altitude, which means that a large number of tests have to be carried out.

The 'additional mass' correction was also ignored for the reasons explained earlier in the text.

The spring constrained oscillation method for determination of aircraft inertias, appears to yield very good results, provided the equipment used is of a high standard, and particular attention is paid to the measurement of oscillation period and spring constants.

List of references

1.	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.
2.	C.B. Notess C.R. Woodward	An investigation of the experimental determination of aircraft inertia characteristics. W.A.D.C. Tech. Rpt. 53-207, July 1953.

3.	V.J. Pauly R.J. Meyer N.L. Infanti	The determination of the moments of inertia about the lateral axis of a B.25.J airplane. C.A.L. Report No. TB-405-F-9. February 1949.
4.	F.S. Malvestuto L.J. Gale	Formulas for additional mass corrections to the moments of inertia of airplanes. NACA TN 1187 1947.
5.	E.Widmayer J.R. Reese	Moment of inertia and damping of fluid in tanks undergoing pitching oscillations. NACA RML53 E Ola. June 1953.
6.	J.R. Reese J.L. Sewall	Effective moment of inertia of fluid in off set, inclined and swept wing tanks undergoing pitching oscillations. NACA TN 3353. January 1953.
7.	D.H. Perry	Measurements of the moment of inertia of the AVRO 707B aircraft. A.R.C. C.P. 647. August 1961.

Table 1

Analysis of centre of gravity measurements

Fuel Condition		Aircraft Weight (lbs)	Longitudinal C. of G. position aft of aircraft datum (ins)	Vertical C. of G. position about knife edges (ins)
Main Tank	Tip Tanks			
150	0	6470	114.9	15.670
195	0	6793	115.0	16.155
195	50 ea.	7619	115.0	17.955

Table II

Analysis of the measurement of pitching inertia

Fuel condition (gallons)		Aircraft weight (lbs)	Spring Constant ($c_y l_y^2$) (lb.ft.)	Oscillation period (sec.)	Measured moment of (I_{y_M}) inertia of aircraft + rig about knife edges (slugs.ft^2)	Moment of inertia of rig (I_{y_R}) (slugs.ft^2)	Axis Transfer (I_{y_s}) (slugs.ft^2)	Moment of inertia of aircraft about reference axis ($I_{y_{C.G.}}$) (slugs.ft^2)	Non-dimensional inertia $i_B = \frac{I_{y_{C.G.}}}{M l_T^2}$	Probable Error %
Main Tank	Tip Tanks									
150	-	6470	289,429	1.089	8,437	84	1593	* 6760	0.130	-
195	-	6793	289,429	1.105	8,669	84	1683	6902	0.126	0.81
195	50 ea.	7619	402,714	0.947	8,891	91	1988	6812	0.111	0.91

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* Not an accurate measurement.

Table III

Analysis of the measurement of rolling inertia

Fuel Condition (gallons)		Aircraft Weight (lbs)	Spring Constant (lb.ft.)	Oscill-ation Period (sec.)	Moment of Inertia of Aircraft and Rig about the knife edges I_{x_M} (slugs.ft^2.)	Moment of Inertia of Rig I_{x_R} (slugs.ft^2.)	Axis Transfer I_{x_s} (slugs.ft^2.)	Moment of Inertia of Aircraft about centre of gravity reference axis $I_{x_{C.G.}}$ (slugs.ft^2.)	Non-dimensional Inertia $1_A = \frac{I_{x_{C.G.}}}{M(\frac{b}{2})^2}$	Probable Error %
Main Tank	Tip Tanks									
150	-	6470	103,967	1.500	4,886	84	1605	3,197	0.0630	0.84
195	-	6793	103,967	1.532	5,026	84	1742	3,200	0.060	0.84
195	50 ea.	7619	103.967	2.312	10,956	84	2180	8,692	0.145	0.76

Table IV

Analysis of the measurement of the yawing inertia

Fuel condition		Aircraft Weight (lbs)	Spring Constant lb.ft/rad.	Oscillation Period (sec.)	Moment of Inertia of Aircraft and Rig about Suspension (slugs.ft².)	Rig Moment of Inertia (slugs.ft².)	Moment of Inertia about reference axis (slugs.ft².)	Non-dimensional Inertia $i_c = \frac{I_{z_{C.G.}}}{M(b/2)^2}$	Probable Error %
Main Tank	Tip Tanks								
150	-	6470	98,571	2.025	10,239	232	10,007	0.197	0.43
195	-	6793	98,571	2.026	10,249	232	10,017	0.188	0.43
195	50 ea.	7619	98,571	2.635	17,336	232	17,094	0.286	0.40

Table V

Analysis of the inclination of the principal axis and the product of inertia

Fuel Condition		Aircraft Weight lb.	$\tan \delta_o$	I_{xz} slugs.ft^2	$i_E = \dfrac{I_{xz}}{M(\frac{b}{2})^2}$	Inclination of principal axis to aircraft longitudinal datum ϵ
Main Tank	Tip Tanks					
195	-	6793	.0135	135	.0025	2° 28′
195	50 ea.	7619	.0223	381	.0064	2° 6′

Table VI

Error Analysis

Source of Possible Error	Pitch measurements			Roll measurements			Yaw measurements		
	Possible Error	Probable error in slugs.ft.^{2}		Possible Error	Probable error in slugs.ft.^{2}		Possible Error	Probable error in slugs.ft.^{2}	
		Tip tanks empty	Tip tanks full		Tip tanks empty	Tip tanks full		Tip tanks empty	Tip tanks full
Period	±.002sec.	±37	±37	±.002	±13	±18	±.002sec.	±20	±26
Spring Const.	±13lb/ft. ±17lb/ft.	±43	±45	±5 lb/ft.	±30	±71	±10 lb/ft.	±51	+87
Spring Arm	±.015	±24	±26	±.015 ft.	±17	±17	±.015 ft.	±23	±38
Aircraft Weight	±4 lb.	±2	±2	±4 lb.	±1	±2	-	-	-
Vertical Position of C.G.	±.04 ft.	±31	±39	±.04 ft.	±15	±42	-	-	-
Longitudinal position of C.G.	±.02 ft.	±±43	±49	-	-	-	-	-	-
Weight of rig	±2 lb.	±7	±7	±5 lb.	±4	±4	±5 lb.	±15	+15
Radius of gyration of rig	±.05 ft.	±1	±1	±.05 ft.	±2	±2	±0.1 ft.	±10	+10
Probable Error $= 0.675 \times \sqrt{(\text{possible error})^2}$		±54 or 0.81%	±61 or 0.91%		±27 or 0.84%	±64 or 0.76%		±43 or 0.43%	±64 or 0.40%

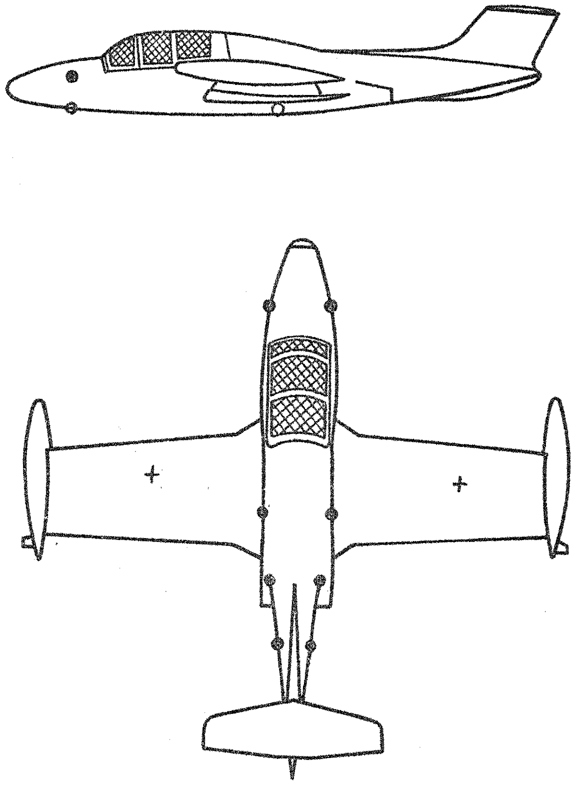

FIG. 1. GENERAL ARRANGEMENT OF PARIS AIRCRAFT SHOWING RELATIVE POSITIONS OF ATTACHMENT POINTS.

● FUSELAGE SLINGING POINTS
o JACKING POINTS
+ WING PICKET POINTS

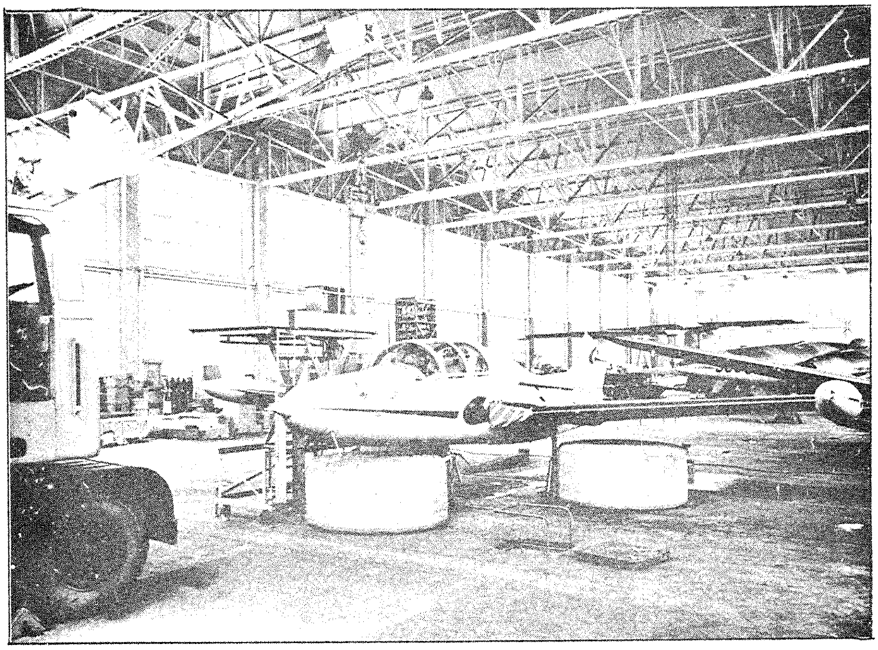

FIG. 3. DETERMINATION OF THE AIRCRAFT CENTRE OF GRAVITY

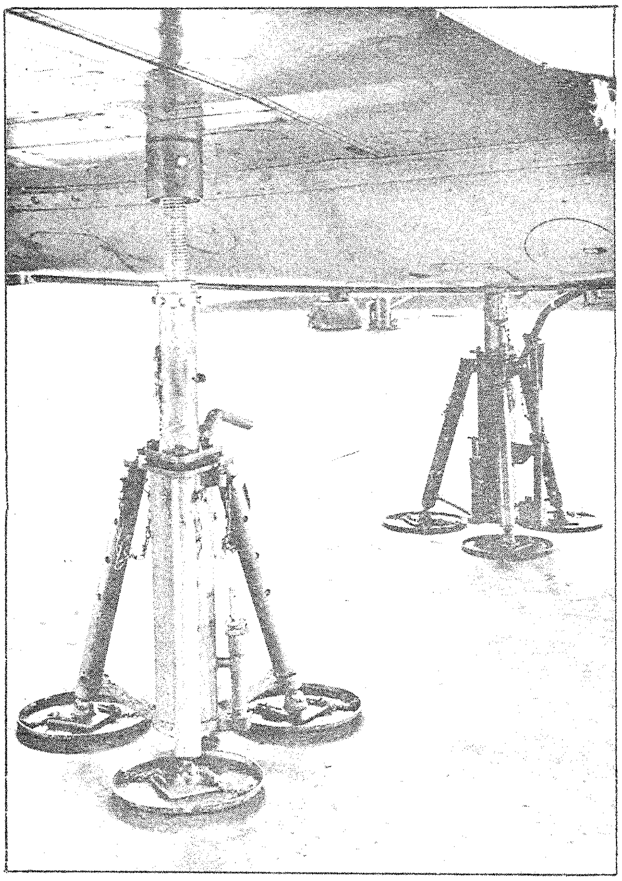

FIG. 4. VIEW OF KNIFE EDGE AND JACK SUPPORT

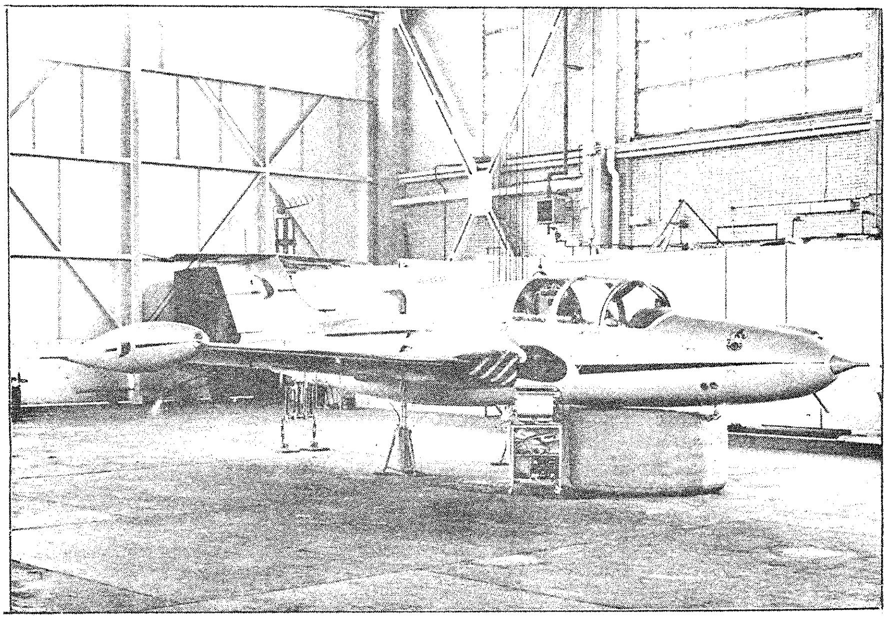

FIG. 5. VIEW OF THE AIRCRAFT ON THE PITCHING RIG

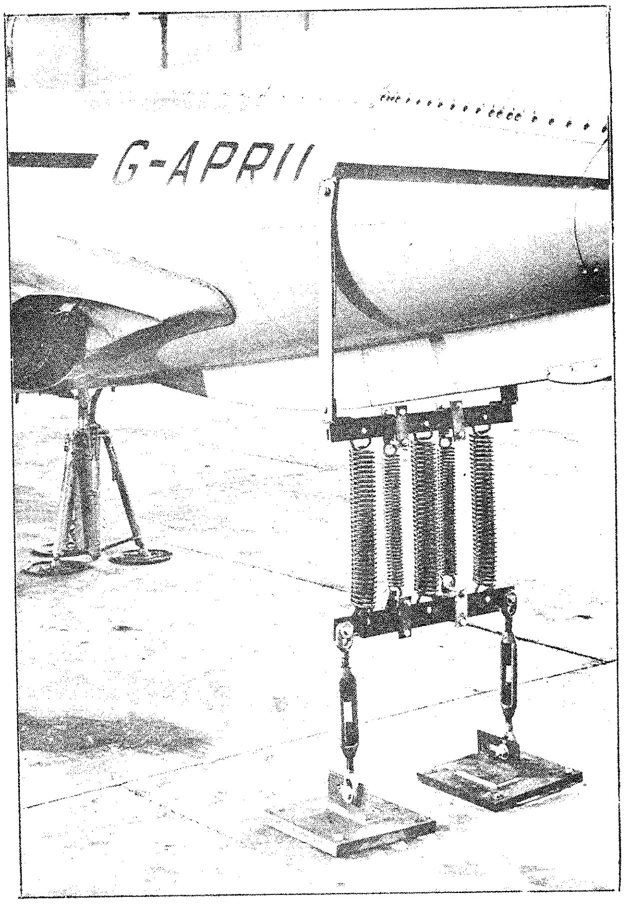

FIG. 6. SHOWING METHOD OF SPRING ATTACHMENT USED IN PITCHING RIG

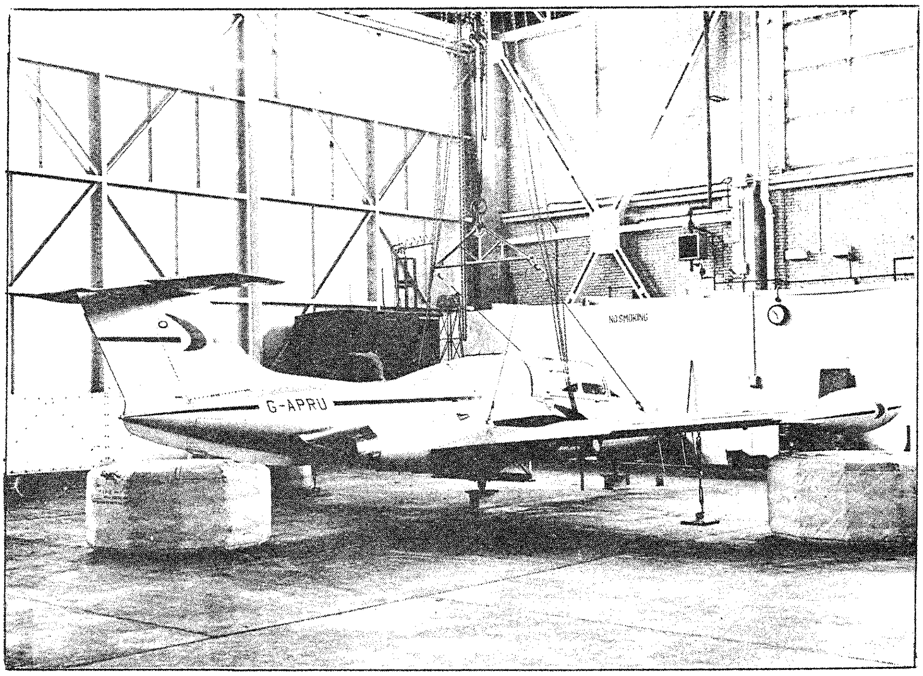

FIG. 7. VIEW OF THE AIRCRAFT ON THE YAWING RIG

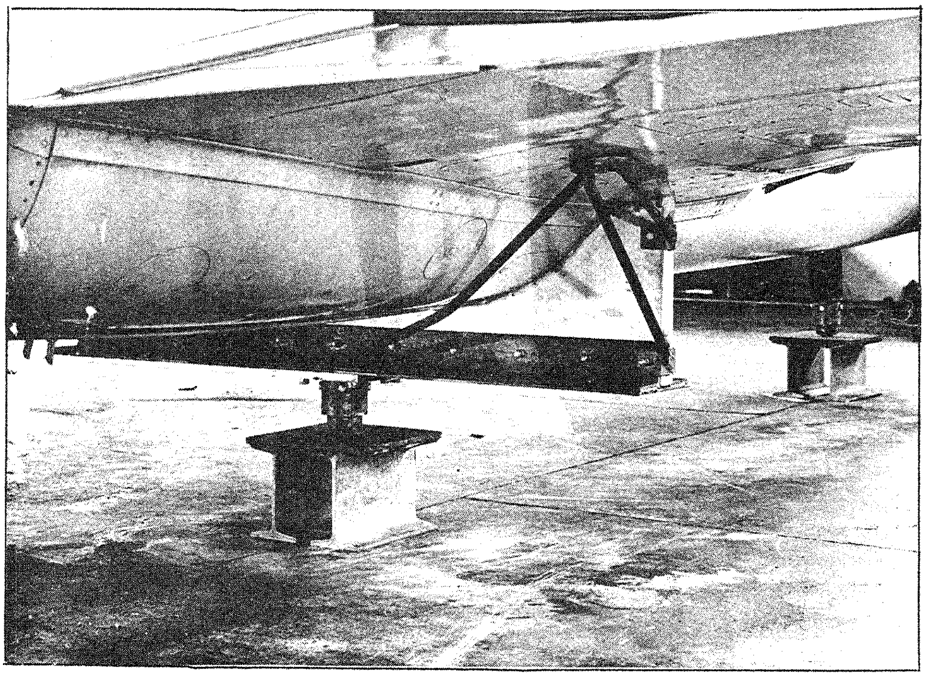

FIG. 8. DETAIL OF CRADLE SYSTEM USED IN THE ROLLING RIG

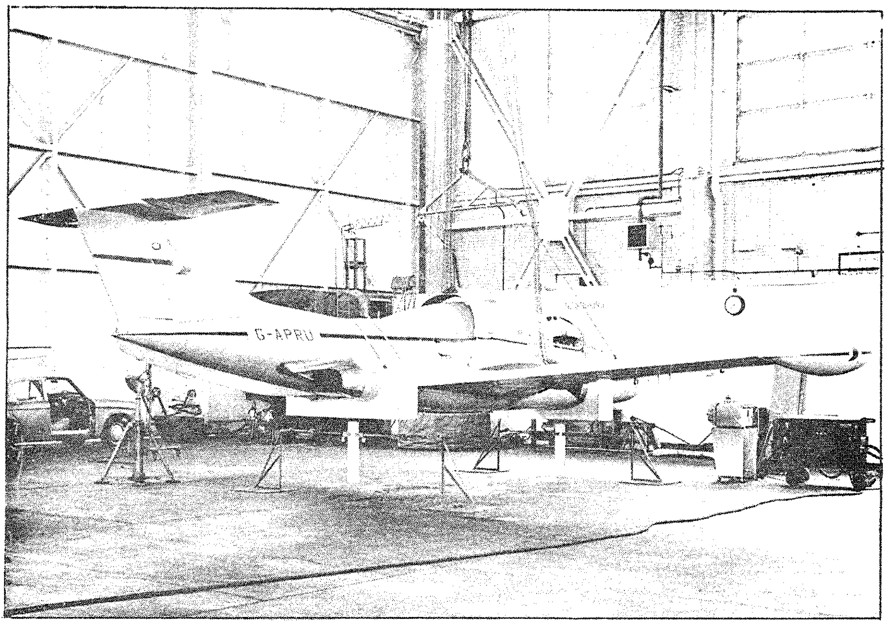

FIG. 9. VIEW OF THE AIRCRAFT ON THE YAWING RIG

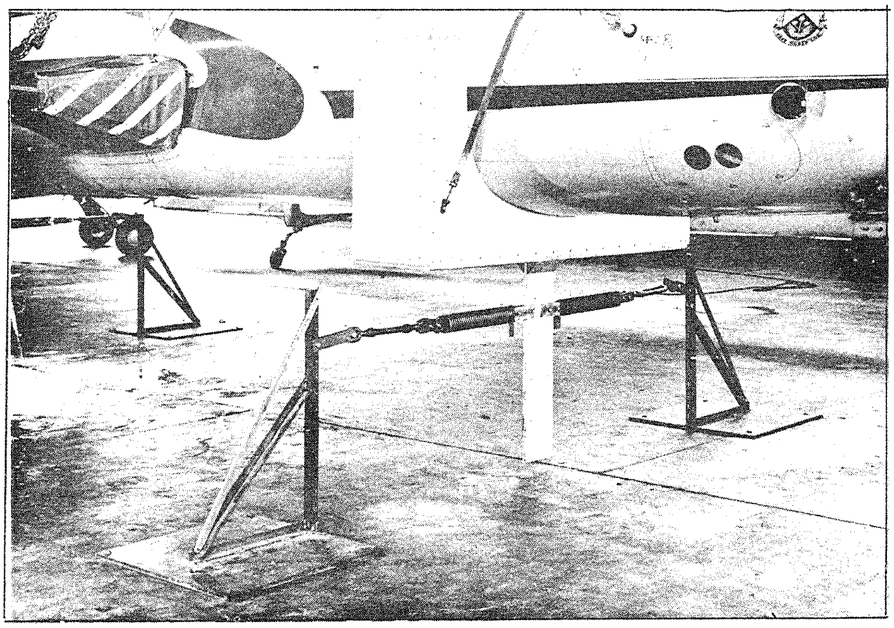

FIG. 10. DETAIL OF CRADLE AND SPRING ATTACHMENT SYSTEM USED IN THE YAWING RIG

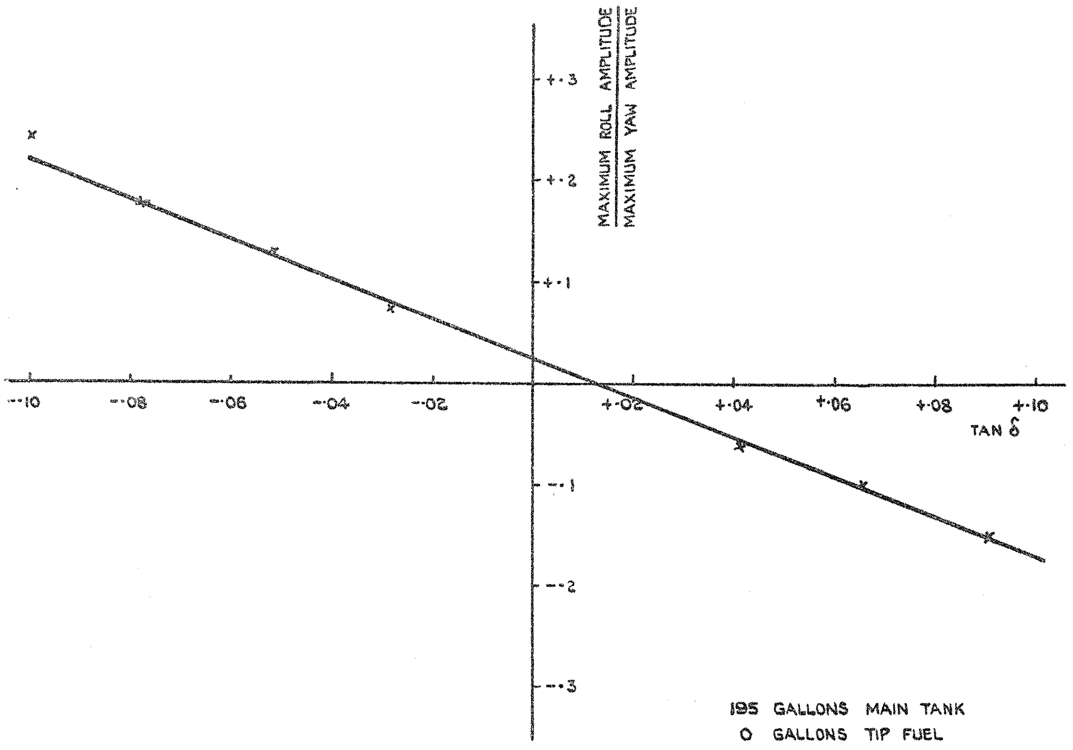

FIG. 11. GRAPH OF RATIO OF MAXIMUM ROLL AMPLITUDE TO MAXIMUM YAW AMPLITUDE PLOTTED AGAINST TAN δ FOR FUEL CONDITION 2.

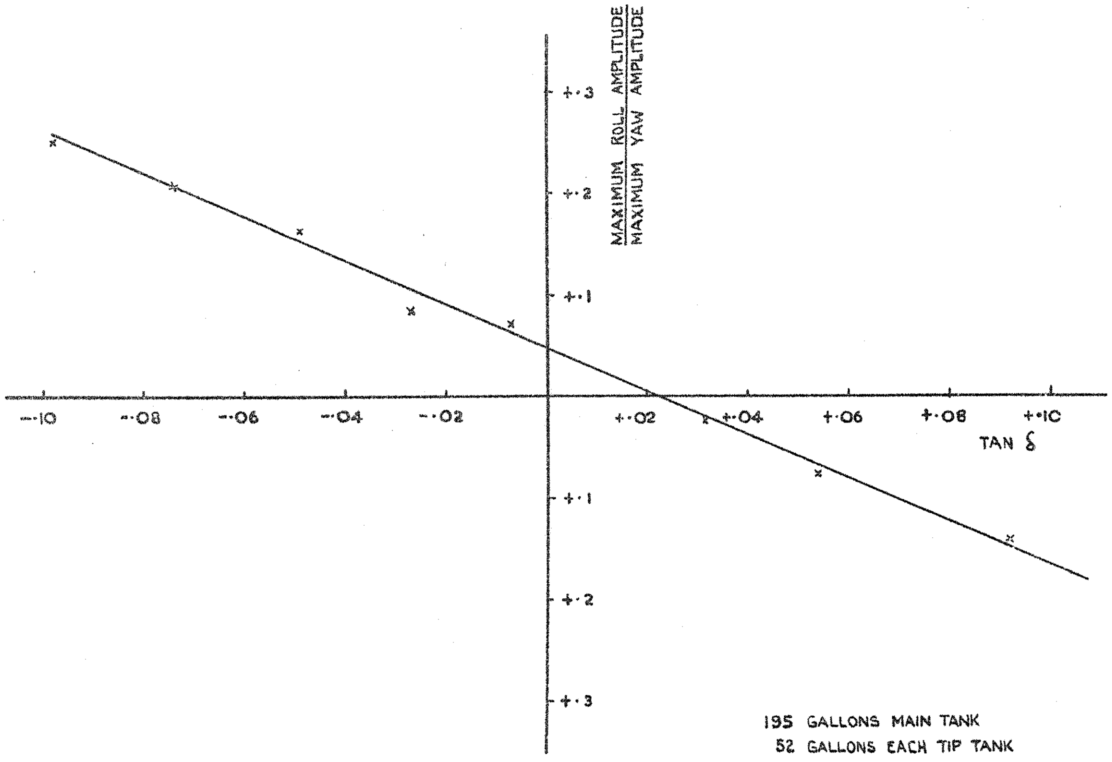

FIG. 12. GRAPH OF RATIO OF MAXIMUM ROLL AMPLITUDE TO MAXIMUM YAW AMPLITUDE PLOTTED AGAINST TAN δ FOR FUEL CONDITION 3.