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by

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A CONTROL-SURFACE OSCILLATORY DERIVATIVE RIG FOR USE WITH HALF-MODELS IN HIGH-SPEED WIND TUNNELS

by

K. C. Wight
N. C. Lambourne

SUMMARY

A rig for the measurement of control surface oscillatory derivatives on half-models with part or full span controls with a hinge-line sweepback range of -7^o to $+50^o$ has been developed for use in medium-size high-speed wind tunnels. Instrumentation allows measurements of the normal force, pitching moment and rolling moment on the model and hinge moment on the control to be made in the presence of high noise levels. Incidence, mean control angle, amplitude and frequency can be varied. The paper describes the rig in detail, the methods of calibration and measurement, and the experience gained using the rig in two high-speed tunnels.

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* Replaces RAE Technical Report 75026 - ARC 36192

CONTENTS

1 INTRODUCTION

A derivative rig for measurement of forces due to oscillating control surfaces is now in use at RAE Bedford. Construction and development of the rig was first started by Hawker Siddeley Dynamics, Coventry under contract with the then Ministry of Aviation, for use in the Coventry 20in × 22in high-speed tunnel and the rig was later acquired by the Aerodynamics Division NPL, Teddington where development was completed. It was then used in the 18in × 14in high-speed tunnel at Teddington. After amalgamation of the Division with the Aerodynamics Department RAE the rig was transferred to RAE Bedford, where it has been used in the 3ft × 3ft high-speed tunnel. Some of the details of the rig have already been reported by Hawker Siddeley Dynamics[1] and briefly by NPL[2], but since then the method of measurement has been changed considerably. The purpose of this paper is to give an account of the rig in its present condition and as used in a typical application.

2 SCOPE OF RIG

The rig was designed for use with a half model with oscillating control surface in a moderate size high-speed wind tunnel. Briefly the model is supported on a strain gauged balance that measures the dynamic forces whilst the control surface is oscillated. Another strain gauged unit measures the oscillating hinge moment. The four complex derivatives relating to normal force, pitching moment, rolling moment and hinge moment (L_β, M_β, B_β, H_β) can be measured. Provision is made for altering the amplitude and frequency of oscillation of the control surface and also the wing incidence. The mean position of the control surface relative to the wing is adjustable to obtain static derivatives. Full or part span controls can be used and a wide range of control surface hinge-line sweepback can be accommodated. The size of the model that can be accepted depends on the load-carrying capacity of the strain gauged members. The original design catered for a particular set of models which fixed the maximum loading. Different strain gauge units would be needed to cope with increased loading if larger models are used. In addition, the weight of the model may impose certain restrictions on the maximum frequency at which the control surface can be oscillated without giving rise to unwanted resonances. Thus conflicting requirements govern the design of the rig support system. On the one hand, a high stiffness in the strain gauge units is necessary to keep the rig natural frequencies as high as possible whilst on the other hand, too stiff a system will lead to an output from the strain gauged members too small to measure. In addition, whilst the model itself must be as light as possible so as not to add more mass than necessary to the rig, it must also be very stiff in order to minimise distortion due to the flap oscillation and to the wing static loading. The highest loading likely to occur is at high incidence and high Mach number and this provides a design criterion so that the resulting strains are within the limits of the support members. This means some sacrifice of signal strength at the lower incidences and Mach numbers, but this can usually be overcome by increased amplification of the signals.

Tables 1, 2 and 3 give the essential features and loading capabilities of the rig together with a typical set of values for Planform E of the F and V series[3] which is the model used in the recent series of tests. Since it is proposed to use the rig with a larger model in future tests, new support members have been made to cater for the increased loadings envisaged. These are listed in the table under the heading 'future condition'.

3 DETAILS OF RIG

3.1 Support system

The basic principle of the load measuring system is illustrated diagrammatically in Fig.1, which is taken from Ref.1. Three strain gauged units support a trapezium shaped block of light alloy to which the model is bolted. A shaft, driven by a vibrator, passes through the block and is attached to the control surface. The latter is attached to the wing by a thin steel flexure bearing. The support units, one of which is shown in detail in Fig.2, are machined from the solid and have relatively thin outside members or strips, which are strain gauged. Forces applied to the model produce moments at the units which cause compression and tension of the strips, the centre member acting as a fulcrum. A high stiffness is achieved by the wide spacing between the outer members. The support units are attached to cylindrical pillars, two in the vertical plane and one in the horizontal plane (Fig.1) which are bolted to a rigid cast iron frame forming the earthed member of the structure. The cylindrical pillars are thinned down at certain places along their length to allow flexibility (Fig.2). Referring to Fig.1, when a vertical force is applied to the system it is sensed mainly by units 1 and 2, whilst a moment applied about an axis through units 1 and 2 is sensed mainly by unit 3, the pillars bending to accommodate the appropriate moments.

In practice the strain gauges mounted on units 1 and 2 form a 4-arm bridge. When these are connected in one sense the bridge output is proportional to the total vertical force. When they are connected in the opposite sense the bridge output is proportional to the moment about a horizontal axis, which, in the static case, would be midway between the two, if their sensitivities are equal. Unit 3 senses the moment about a horizontal axis passing approximately through units 1 and 2. It has two active strain gauges with two unstrained compensating gauges.

The model is bolted to the block supported by the three units and thus units 1 and 2 measure the normal force and pitching moment and unit 3 the rolling moment. Ideally, the output of each of the normal force, pitching moment and rolling moment bridges would be proportional to the appropriate component and independent of the other two. In practice, for static loads, this is approximately true for the rolling moment, but the normal force and pitching moment show small interference effects. In the dynamic case all three components show some interdependence, but this is relatively small. (See typical values given in Appendix A.)

3.2 Model

The series of wings for which the rig was originally designed are of solid steel with light alloy control surfaces. Considerable advantage would be gained from the use of hollow wings in materials of high stiffness to density ratios such as titanium alloys or carbon fibre reinforced plastic, since higher flexural and torsional natural frequencies would be obtained. The basic construction of model E, used in the recent tests is typical of other models of the series. It is provided with a tongue about 100 mm × 50 mm × 25 mm bored with a horizontal hole through which the control surface driving shaft passes. The hole is angled according to the sweepback of the control surface hinge line. The tongue is bolted to a substantial light alloy mounting which carries a crossed-spring flexure bearing for the driving shaft (Figs.3 and 4). The control surface mounting consists of three parts. First the control surface itself is attached to the wing by a steel strip hinge. Second, a spigot at the inboard end of the control surface is dowelled to a tungsten carbide shaft, chosen for its high stiffness, to which steel end pieces are brazed. The end remote from the control surface is machined to form a four-bar torque cage (to be seen in Fig.3) which is strain gauged and measures the hinge moment. The third part (Fig.4) consists of a cylindrical end piece terminating in a crossed-spring flexure bearing which is strain gauged and measures angular displacement. A V-shaped groove in this part is the attachment point of a vertical rod, the other end of which is connected to a vibrator.

3.3 Drive

The control surface is oscillated by a Pye-Ling Type V50 vibrator mounted on the earthed frame. A stiff horizontal cantilever flexure has one end attached to the vibrator and the other end bolted to the frame. The purpose of the cantilever is to provide an oscillatory impedance sufficient to swamp the aerodynamic reaction on the control surface and thus ensure that the motion is reasonably independent of changes in the aerodynamics. The force applied by the driving rod from the vibrator is reacted at the bearings of the control surface and its shaft and thus appears as a force on the model. The effect of this on the measurements is neutralized by including a force transducer in the driving rod and subtracting an appropriate amount of its output from the output of the normal force, pitching moment or rolling moment bridges.

The mean angle of the control surface may be adjusted to a small extent by means of distance pieces introduced between the driving rod and the vibrator. A limit is set to this angular position depending on the nature of the control hinge flexure and its amplitude. In the case of Planform E, the total movement was 4°.

3.4 Mounting arrangements

The cast iron frame to which the support units are attached is mounted in a cylindrical box which is closed and sealed with a cover plate on one side and electrical connections are brought out via two 25-way Plessey sockets. The other side of the box is integral with a steel disc which forms part of the tunnel side wall. A circular hole in this plate provides a location for a flange carried on the cast iron frame and allows the model to be fixed in position on the rig. Cover plates above and below the model with a clearance of 0.25 mm are held in position by bolts within the box. The disc carrying the rig and model can be mounted in either of two tunnel side plates. One of these was designed for use with either the 18in × 14in or the 36in × 14in Teddington tunnels. It is rectangular in shape with a circular hole into which the rig disc fits. Pivot arms attached to the box allow the disc to be swung out of the tunnel so that the model can be changed without dismantling the tunnel. When in position, the box and disc can be rotated and a calibrated vernier scale enables accurate settings of incidence to be made.

The second tunnel side plate was designed for the 3ft × 3ft Bedford tunnel. It is circular in shape and has the same facility for incidence setting as the rectangular version. However, there is no provision for swinging the box away from the tunnel since the 3ft tunnel can be readily opened and has sufficient space for obtaining access to the model.

4 METHOD OF MEASUREMENT

4.1 Original system

The original arrangement for determining the forces and moments as designed by Hawker Siddeley Dynamics involved the separate measurement of amplitude and phase of the electrical signals from the strain gauges. This was a natural follow-on from previous work involving measurements on wings performing pitching oscillations[4]. The amplitudes of the strain gauge signals, after amplification, were measured with a valve-voltmeter and the phases with a Muirhead phasemeter. The amplifiers were ac coupled so that for static measurements the gauge excitation had to be changed to ac.

4.2 Present system

Basically the same principle is used, but with resort to more sophisticated equipment for evaluating the phase. The Muirhead phasemeter, although extremely accurate, requires considerable time to adjust. In place of this, a Brookdeal Type 411 phase sensitive detector[5] (PSD) was used initially, but this was later replaced by a Solartron digital transfer function analyser[6] (TFA). Both instruments give readings of the in-phase and in-quadrature components of the input voltage related to a reference voltage, in this case obtained from the motion of the control surface. Since the two amplifiers used for the signal and reference have different phase shifts, a phase-shifting network is introduced to compensate for this. Provision is made for rapid adjustment by switching the reference voltage simultaneously to both amplifiers and adjusting the phase to obtain zero in-quadrature component (Fig.5). A decade potential divider connected to the output of the signal amplifier allows a range of signal levels to be catered for without alteration of the amplifier gain. The reference and signal amplifiers are both dc coupled and this allows static measurements to be made without changing the gauge excitation. A digital ac-dc voltmeter connected to the output of the reference amplifier records the amplitude or displacement of the control surface (Fig.5). The vibrator driving the control surface is operated from a 50 watt amplifier, the input to which is a highly stable Solartron oscillator. Frequency is measured with a Venner countertimer.

5 CALIBRATIONS

Static calibration for normal force, pitching moment and rolling moment is carried out by replacing the model with a rigid bar which extends horizontally from a root block. V-shaped grooves cut in the bar at known intervals enable accurate rolling moments to be applied. A cross piece which can be bolted in any of the grooves is notched at intervals to enable known pitching moments to be applied.

The dynamic calibration is made with the wing in position, since the mechanical properties of the wing determine the overall dynamic characteristics of the system. Known alternating forces at a fixed frequency are applied at each of three positions over the planform of the model. For one of the positions the control surface vibrator is used to provide the force and the control surface driving rod is replaced with a rigid connection to the wing support. For the other two positions a light Tufnol frame, contoured to the model profile, is clamped over the model and provides points for attaching a second vibrator. A strain gauged force measuring unit between vibrator and wing measures the force applied to provide a reference voltage for measuring the phase of the balance signals. When the output responses of the strain gauge bridges are related to the applied force, a set of three complex equations involving the unknown calibration constants is obtained and the solution of these gives the required calibration coefficients (see Appendix A). The tests are repeated for a range of frequencies to determine the variation in the calibration coefficients.

To calibrate the control surface displacement system the angular movement of the control surface is measured dynamically by attaching to it a small mirror to reflect a beam of light onto a scale and relating the angular movement to the output of the displacement amplifier. To calibrate the hinge-moment cage a small lever attached to the control surface enables known static hinge moments to be applied; these are related to the output of the cage. Errors arising due to flexibility of the drive system in the dynamic case are shown to be small (Appendix B).

6 DATA ACQUISITION

In future it is intended to operate the rig only with the TFA. This allows the results to be recorded by an on-line teleprinter. A computer program based on the dynamic calibration of the rig will convert the output of the TFA to non-dimensional derivatives.

7 PRACTICAL EXPERIENCE WITH THE RIG

Proving tests with the rig included a set of measurements on a model of the Planform E of the F and V series[3]. This is a tapered sweptback model of aspect ratio 2 with outboard control. Measurements were made firstly in the 18in × 14in tunnel at Teddington and then later in the 3ft × 3ft tunnel at Bedford. In the 18in × 14in tunnel measurements were made in the slotted transonic working section and also with the slots taped over. In the 3ft × 3ft tunnel measurements were made in a transonic working section with top and bottom walls slotted and also in a working section with solid walls. The measurements, which have an intrinsic value apart from providing a test of the rig, are presented and discussed elsewhere[7]; the present paper provides only comments on the experience gained.

At a very early stage in its development, the rig had been tried out in the HSD tunnel at Coventry but with little success because of signal noise caused by tunnel vibration. The fact that the present rig has operated satisfactorily in both the 18in × 14in tunnel and the 3ft × 3ft tunnel is likely to be due to the combination of lower vibration levels and improved signal processing. When the rig was first used in the 18in × 14in tunnel no difficulty was found in measuring the in-phase components, but where the in-quadrature component was relatively small, considerable jitter was present so that the output filter of the PSD had to be set to a relatively long time constant. This increased the time of measurement considerably. Another undesirable feature arose because the noise in the tunnel excited the rig to vibrate at its natural frequencies to such an extent as momentarily to overload the PSD. Hence the potentiometer on the output of the signal amplifier (Fig.5) could not be used at its optimum setting, resulting in decreased accuracy. Towards the end of the tests in the 18in × 14in tunnel a Solartron TFA became available and this was used simultaneously with the PSD for a number of tests. Comparison of the results for the two instruments showed agreement within the limits of experimental error. As with the PSD the same considerations regarding noise arose in the case of the TFA, but now measuring conditions were slightly improved in that the TFA could accommodate a larger input signal without overload. In addition, the fixed integration time of the TFA gave an unambiguous digital display of both in-phase and in-quadrature components simultaneously with continuous re-cycling.

Although no measurements of noise had been made in the 18in × 14in tunnel it was generally conceded that this was a 'quieter' tunnel than the 3ft × 3ft tunnel for which noise measurements are available[8]. Tunnel noise could preclude the satisfactory operation of the rig in the 3ft × 3ft tunnel; thus it seemed desirable, before moving to the 3ft × 3ft tunnel and whilst the 18in × 14in tunnel was operational, to make some measurements of the noise in the latter to find what level was acceptable to the rig. The noise measurements were made with a wall-mounted Bytrex transducer and results compared with those measured in the 3ft × 3ft tunnel. It was found that the 3ft × 3ft tunnel with slotted top and bottom walls had noise levels 2 to $2\frac{1}{2}$ times those in the smaller slotted tunnel. On the other hand the closed 3ft × 3ft tunnel was considerably better than the smaller tunnel with slots sealed, except at low frequencies. These conditions were confirmed when derivative measurements were made in the 3ft × 3ft tunnel. But in spite of the higher noise levels in the slotted working section satisfactory measurements could be made although the scatter of values was increased.

The main effect of the noise was to excite vibration at the natural frequencies of the rig. If the excitation was sufficiently large the TFA became overloaded and hence the input potentiometer could not be used at the optimum setting. Some assessment of the magnitude of the unwanted signals (rig excitation) could be made by noting the potentiometer setting that produced overloading. This was somewhat qualitative, since the overloading was intermittent, but indicated that signals of 10 to 20 times the magnitude of the wanted signal were quite often present. In all cases the average of at least five repeat measurements was taken for each derivative. In a particular case where the signal-to-noise ratio was 1/5, the variation of control hinge moment over the five measurements was ±0.7% for the in-phase component and ±1.2% for the in-quadrature component.

8 CONCLUSIONS

A rig for the measurement of control surface oscillatory derivatives on half-models with part or full span controls with a hinge-line sweepback range of -7° to $+50^{\circ}$ has been developed. It has been tested in two transonic tunnels of widely different size with a sweptback wing of aspect ratio 2. Use of a Solartron transfer function analyser to make the measurements of the small strain gauge signals arising has proved satisfactory in the presence of large amounts of noise. The rig allows variation of incidence, mean control surface angle, amplitude and frequency, over ranges primarily dictated by the strength of the load-bearing units. The lifting surface could represent either a wing, tail or fin and if necessary a half-body could be added at the root without impairing the operation of the rig. Future work with the rig will entail measurements on a wing of aspect ratio 6 with two types of part-span control surfaces.

Acknowledgments

Acknowledgment is made to those at the then Coventry Branch of HSD who played a part in the early design and development and also to staff of the now disbanded Aerodynamics Division, NPL who worked on the commissioning of the rig.

Appendix A

CALIBRATION METHOD

If the force-measuring system provided perfect resolution of components, the oscillatory parts of the normal force (L), pitching moment (M), and rolling moment (B), would each be obtainable from the output of only one strain gauge bridge; i.e.

$$L = k_L E_L$$

$$M = k_M E_M$$

$$B = k_B E_B$$

where E_L, E_M and E_B are the outputs of the bridges.

Because of the presence of interactions between the components it is necessary to assume that the oscillatory parts of L, M and B are given by linear combinations of the outputs of all three bridges, i.e.

$$\begin{bmatrix} L \\ M \\ B \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} E_L \\ E_M \\ E_B \end{bmatrix} .$$

In measurements with an oscillating flap, the quantities L, M, B, E_L, E_M and E_B will be complex, their real and imaginary parts corresponding to contributions in-phase and in-quadrature with the flap displacement. Also, because of the dynamic characteristics of the load-measuring system, the sensitivity factors c_{11}, c_{12}, etc. will, in general be complex and dependent on oscillation frequency. The purpose of the calibration process is to determine the complex values of the sensitivity factors for each working frequency. The procedure is to apply known sinusoidal forces to the model at each of three points in turn, the positions being suitably chosen over the model planform. When a vertical force F_1 is applied at $x_1 y_1$ as shown in Fig.6, the normal force, pitching moment and rolling moment are respectively

$$L = F_1 \quad , \quad M = F_1 x_1 \quad \text{and} \quad B = -F_1 y_1 \quad .$$

If the complex outputs of the three bridges are E_{L1}, E_{M1}, E_{B1} when, in effect, *unit load* is applied at x_1y_1 , the following equations should hold:-

$$\begin{bmatrix} 1 \\ x_1 \\ -y_1 \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} E_{L1} \\ E_{M1} \\ E_{B1} \end{bmatrix} .$$

Similarly by applying forces at x_2y_2 and x_3y_3 and measuring the bridge outputs corresponding to unit force we have two further sets of equations

$$\begin{bmatrix} 1 \\ x_2 \\ -y_2 \end{bmatrix} = \begin{bmatrix} C \end{bmatrix} \begin{bmatrix} E_{L2} \\ E_{M2} \\ E_{B2} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} 1 \\ x_3 \\ -y_3 \end{bmatrix} = \begin{bmatrix} C \end{bmatrix} \begin{bmatrix} E_{L3} \\ E_{M3} \\ E_{B3} \end{bmatrix}$$

where $[C]$ is the matrix of unknown sensitivity factors.

More generally, the three sets of equations can be written,

$$\begin{bmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ -y_1 & -y_2 & -y_3 \end{bmatrix} = \begin{bmatrix} C \end{bmatrix} \begin{bmatrix} E_{L1} & E_{L2} & E_{L3} \\ E_{M1} & E_{M2} & E_{M3} \\ E_{B1} & E_{B2} & E_{B3} \end{bmatrix} .$$

Alternatively, to provide an expression for the determination of the elements of the C matrix, the nine equations can be rewritten,

$$\begin{bmatrix} C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ -y_1 & -y_2 & -y_3 \end{bmatrix} \begin{bmatrix} E \end{bmatrix}^{-1} .$$

In practice, the procedure entails measuring the elements of the E matrix, which after inversion and multiplication by the matrix of applied loads, which is real, yields the required elements of the C matrix. The positions over the model at which the calibration forces are applied need to be chosen so that each application emphasises a different component.

In the static case when $f = 0$, the imaginary terms are zero and the following matrix was obtained

$$C = \begin{bmatrix} 2.277 & 0.2839 & 0.0531 \\ 0.0091 & 1.075 & 0.2364 \\ -0.0005 & 0.0005 & -4.349 \end{bmatrix} .$$

This shows the near-independence of the rolling moment on the normal force and pitching moment outputs and the small interference between the other components.

At a frequency of 70 Hz the following was obtained:-

$$C = \begin{bmatrix} 1.959 - 0.0104i & 0.3501 + 0.0556i & 0.4055 + 0.0572i \\ 0.0186 + 0.0030i & 0.959 - 0.0179i & 0.1634 - 0.0224i \\ -0.0275 - 0.0017i & 0.0530 + 0.0211i & -3.813 + 0.0065i \end{bmatrix} .$$

The strong diagonal is still maintained, but increased interference is evident.

Appendix B

CORRECTION TO MEASURED CONTROL SURFACE AMPLITUDE AND HINGE MOMENTS

Referring to Fig.7a:-

Angular displacement of control surface = β_2

Angular displacement at point P , inboard end of shaft = β_1

Torque in shaft = H .

The measured quantities are β_1 and the components of H in-phase and in-quadrature with β_1 .

If H_{β_1} and H'_{β_1} are these components:-

$$H = (\beta_2 - \beta_1)\sigma = H_{\beta_1} + iH'_{\beta_1}$$

where the shaft and cage are assumed to have stiffness σ and negligible inertia. Hence

$$\beta_2 = \left(\beta_1 + \frac{H_{\beta_1}}{\sigma}\right) + \frac{iH'_{\beta_1}}{\sigma}$$

Angles β_1 and β_2 are related by the vector diagram, Fig.7b, where

$$\tan \varepsilon = \frac{H'_{\beta_1}}{\sigma\beta_1 + H_{\beta_1}} .$$

The hinge-moment components are related by the vector diagram, Fig.7c. The required components are:-

$$H_{\beta_2} = H_{\beta_1} \cos \varepsilon + H'_{\beta_1} \sin \varepsilon$$

$$H'_{\beta_2} = H'_{\beta_1} \cos \varepsilon - H_{\beta_1} \sin \varepsilon .$$

Correction to the hinge-moment measurements with wing E amounts to a maximum of -1.3% for the stiffness and 1.5% for the damping. Similarly small corrections also occur for the wing derivatives.

Table 1

TYPICAL PARAMETERS

Typical wing area	0.04 m^2
Typical control surface area	0.004 m^2
Typical root chord	0.3 m
Control surface hinge-line sweepback	-7° to $+50^\circ$
Control surface amplitude (normal to hinge line)	4°
Frequency	0 to 150 Hz
Typical model mass	2 kg

Table 2

MAXIMUM RIG LOADING*

	Present condition	Future condition
Normal force	±620 N	±1.6 kN
Pitching moment (axis at centre of rig)	±95 N m	±240 N m
Rolling moment (axis at root of wing)	±190 N m	±400 N m
Hinge moment (normal to hinge line)	±0.34 N m	±1.8 N m

Table 3

TYPICAL VALUES RELATING TO PLANFORM E (REF.3) WITH $\alpha = 0$, $\bar{\beta} = 0.8^\circ$, $f = 70$ Hz, $M = 0.8$

In-phase components

Normal force	6.4 N
Pitching moment	2.0 N m
Rolling moment	0.73 N m
Hinge moment	0.014 N m

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* Dead load has not been taken into account here as it varies according to the model used.

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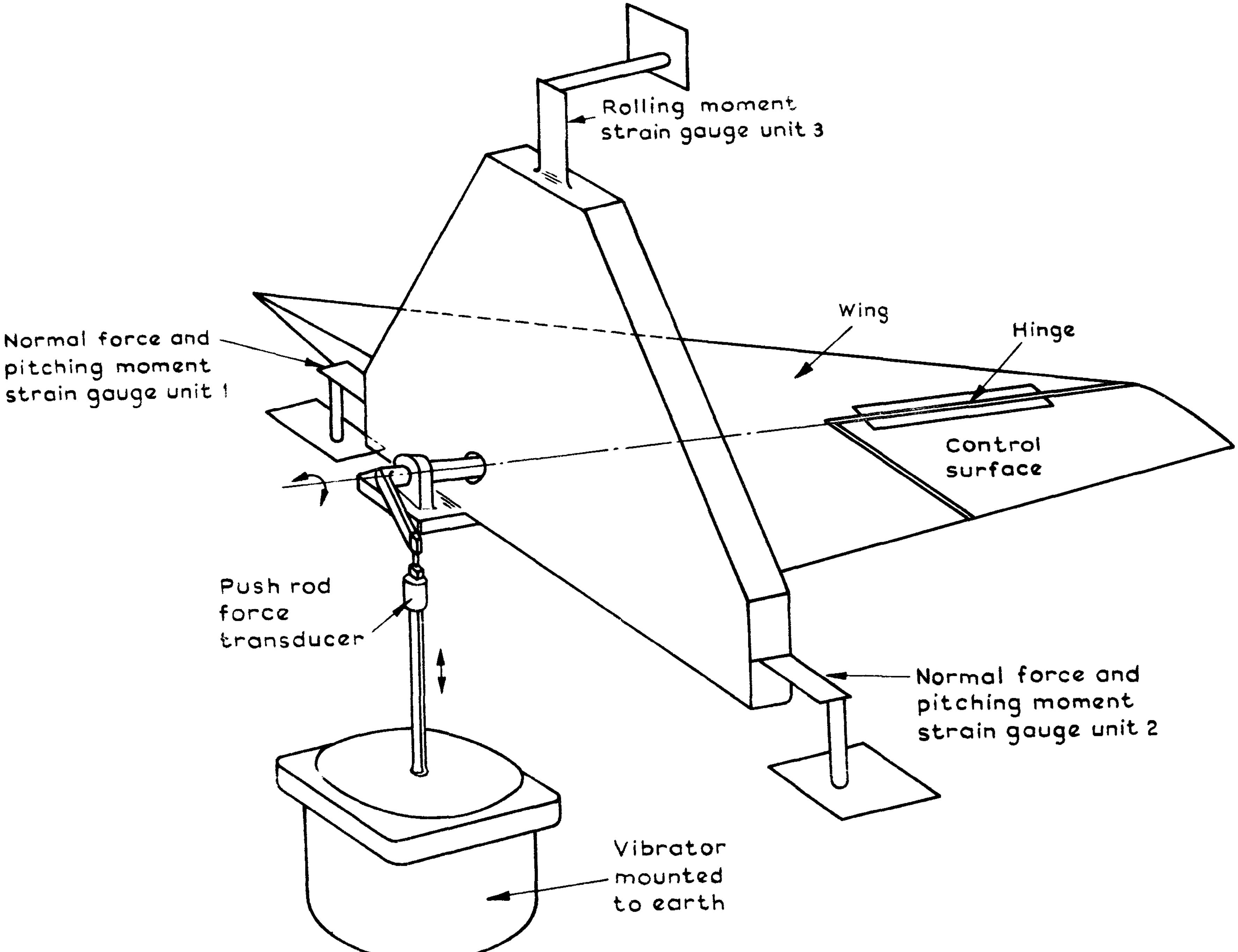

Fig.1 Force measuring system (schematic)

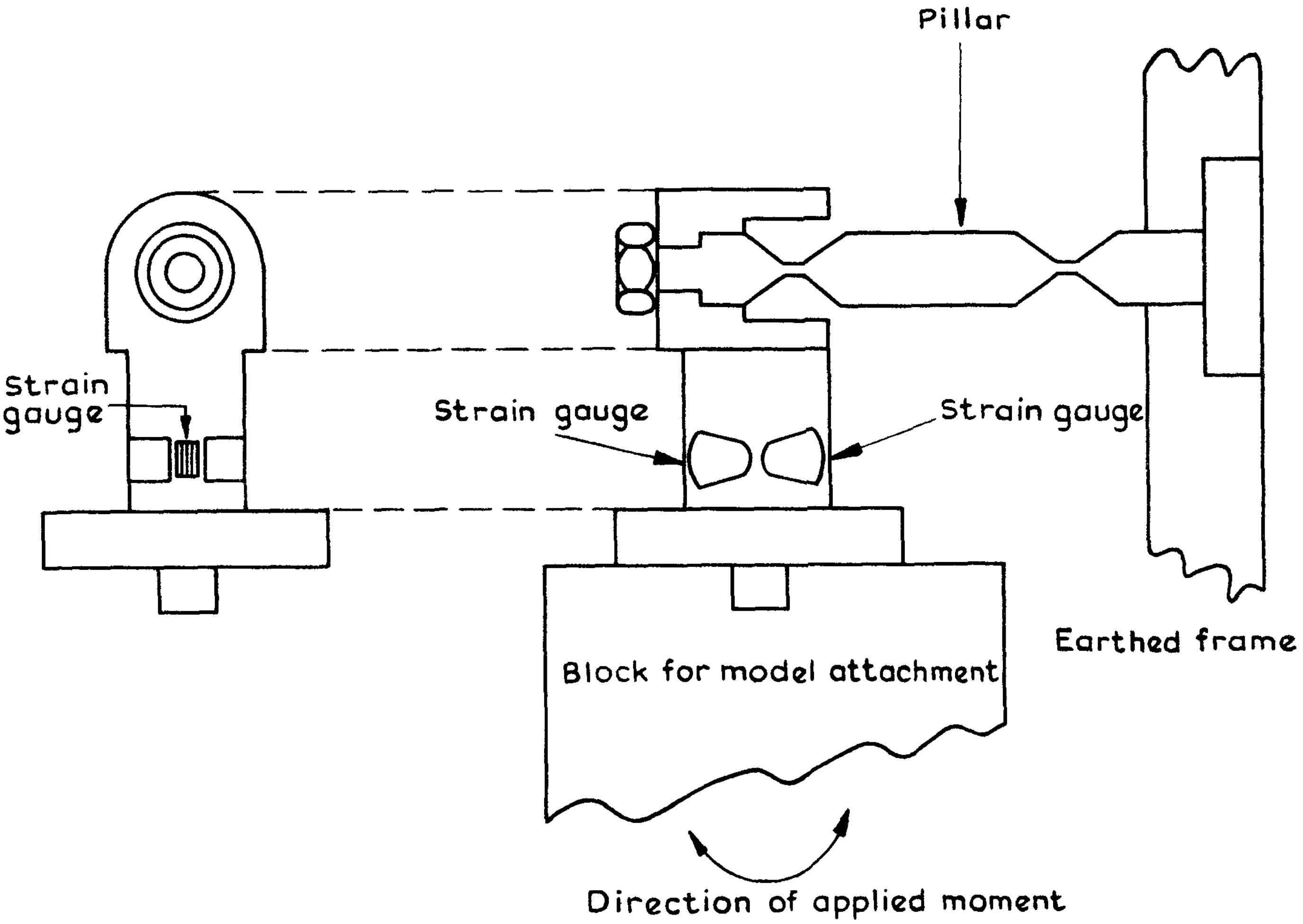

Fig.2 Rolling moment strain gauge support unit

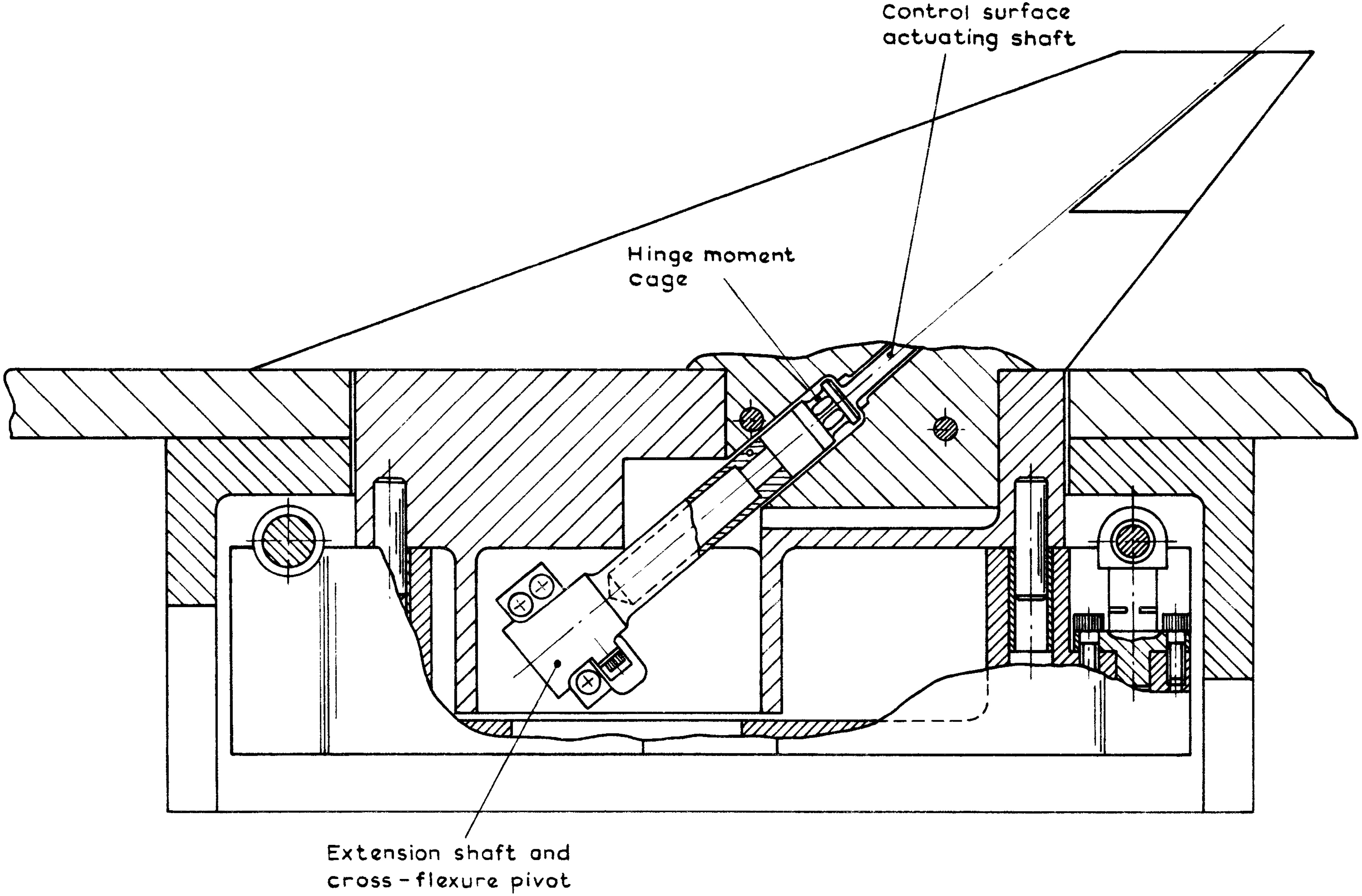

Fig.3 Details of wing mounting and control surface drive

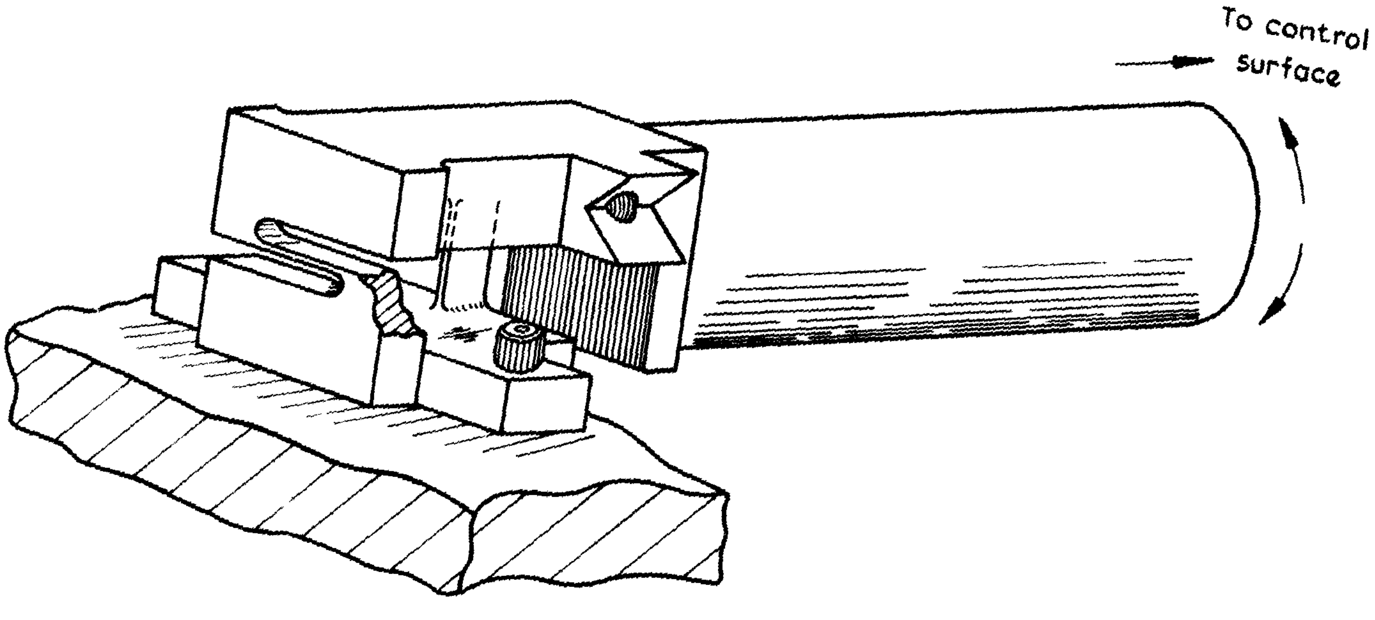

Fig. 4 Details of control surface drive end

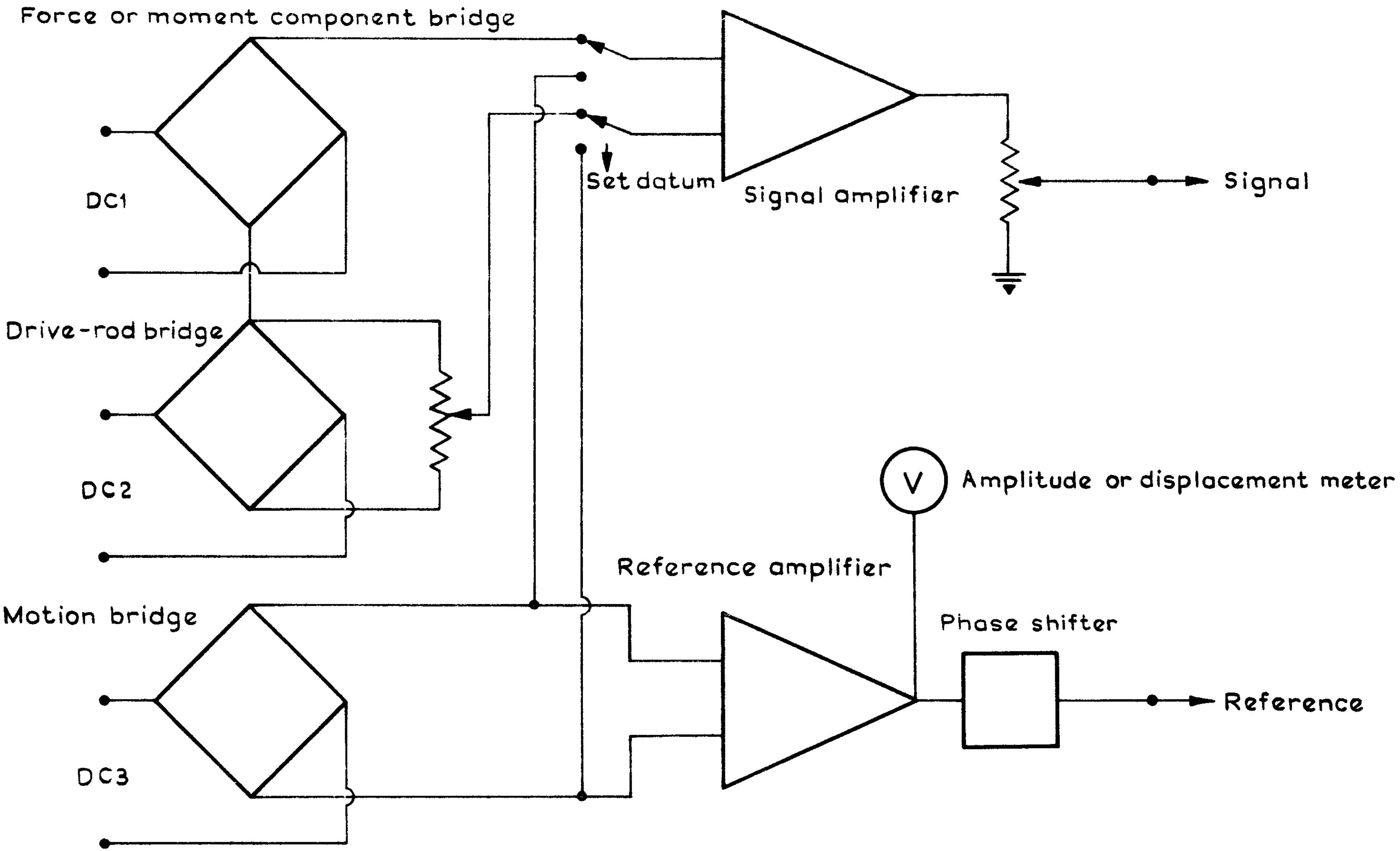

Fig.5 Schematic diagram of circuitry, showing bridge for only one force component

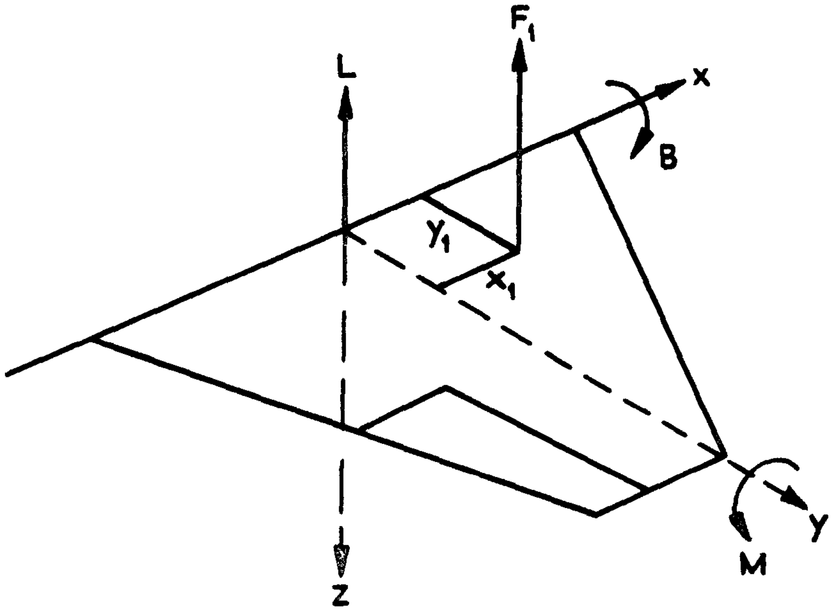

Fig.6 Dynamic calibration diagram

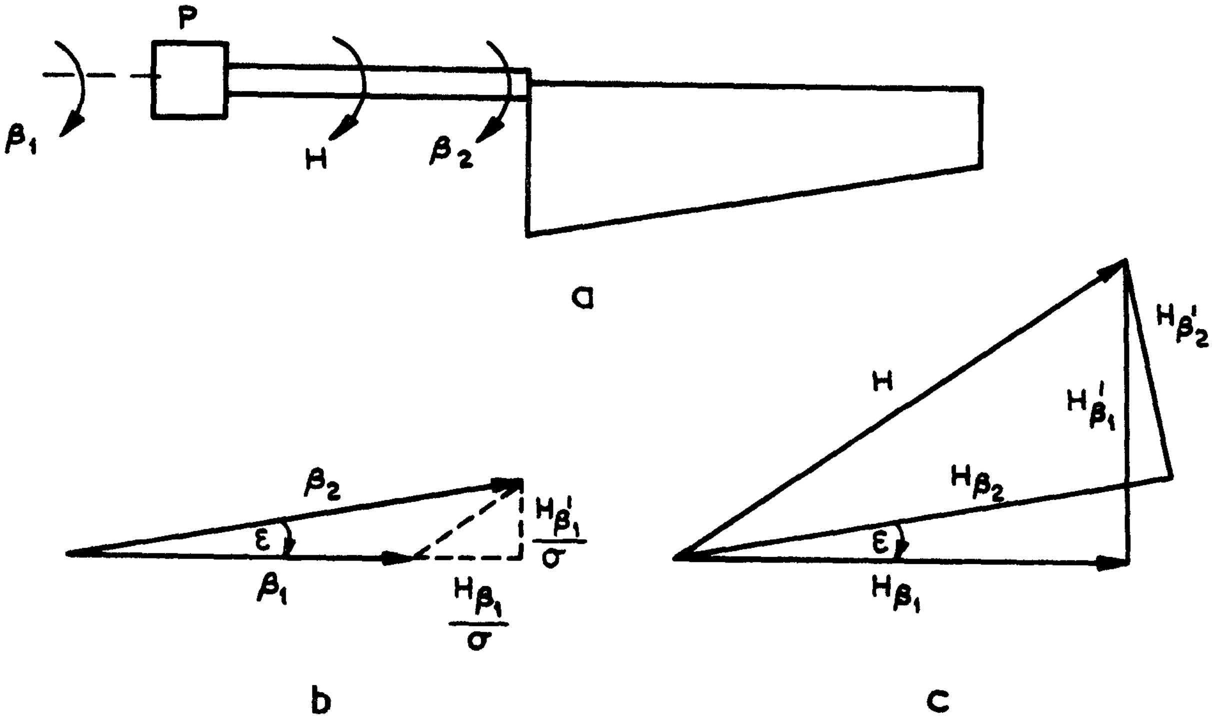

Fig.7a-c Representation of control surface and vector diagrams

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A CONTROL-SURFACE OSCILLATORY DERIVATIVE RIG FOR USE WITH HALF-MODELS IN HIGH-SPEED WIND TUNNELS

A rig for the measurement of control surface oscillatory derivatives on half-models with part or full span controls with a hinge-line sweepback range of −7° to +50° has been developed for use in medium-size high-speed wind tunnels. Instrumentation allows measurements of the normal force, pitching moment and rolling moment on the model and hinge moment on the control to be made in the presence of high noise levels. Incidence, mean control angle, amplitude and frequency can be varied. The paper describes the rig in detail, the methods of calibration and measurement, and the experience gained using the rig in two high-speed tunnels.

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