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GUST RESPONSE MEASUREMENTS ON A MODEL AIRCRAFT

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SUMMARY

A technique has been developed for investigating the symmetrical response of a model aircraft to an up-gust using a sled track. Test results for a rigid slender wing model agree well with calculations.

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* Replaces R.A.E. Technical Report 69273 - A.R.C. 31966

CONTENTS

1 INTRODUCTION

Early design studies of slender wing configurations showed that there was a possibility that the gust response problem was a serious one. However, an unsatisfactory feature of the studies at that time was a lack of experimental data to compare with methods of predicting the response of this type of wing. It was decided therefore that an exercise should be carried out at model scale, in which the disturbance would be provided by an artificially-produced up-gust of known characteristics.

The method adopted was to mount the model on a sled, propelled by rockets along a track past the mouth of an open-jet wind tunnel. The model was mounted in such a way as to have freedoms in heave and pitch; no other freedoms were allowed since it was assumed that the response would be symmetrical if it were a perfect up-gust.

Measurements were made of the acceleration histories of various points on the model; these were compared with calculated responses and showed reasonably good agreement, particularly in respect of peak accelerations.

2 GENERAL CONSIDERATIONS

2.1 Possible experimental methods

Three methods of investigating gust response at model scale were initially considered:-

(i) Mounting a model in a wind tunnel equipped with some means of changing the flow direction so as to generate a sinusoidal gust,

(ii) using a free flight model flown through an artificially-produced gust, and

(iii) mounting a model on a sled and propelling it through a gust.

These methods were reviewed in the light of existing facilities. Methods (i) and (ii) would have entailed a considerable amount of development work since no suitable facilities were available. Method (iii) was the obvious choice since the R.A.E. possessed a sled test track equipped with an open-jet wind tunnel producing a gust across the track. (This facility had been developed for measuring gust-induced pressures on a delta wing[1]). The experiment was accordingly designed around this facility, with the model mounted on the sled in such a way that it was free to pitch and heave as it passed through the gust.

2.2 Gust tunnel

The wind tunnel mounted beside the track to produce the gust is rectangular in section. It consists of a tapered box having a nozzle facing the track giving a gust length of 4.6 m (15 ft) over a working height of 1.4 m (4.5 ft) (Fig.1.) Six fans are mounted in the end of the box away from the track to provide the drive. No attempt has been made to smooth the flow by means of honeycombs, but nevertheless the wind velocity is sensibly uniform across the length of the gust, with a mixing zone at the edges about 0.3 m (1 ft) thick. The air-speed with all the fans running is 13.7 m/s (45 ft/s), and there is at present no means of altering this other than turning some of the fans off which spoils the velocity profile. All the tests have therefore taken place with a gust velocity of 13.7 m/s (45 ft/s) but provision of a speed control for the tunnel may be made.

2.3 The model

The model wing geometry was decided by the availability of a mould and templates which had been used to make a flexible flutter model[2]. This model was based on an early design for a supersonic transport, and consisted of a slender wing and fuselage. The engine nacelles, fin and control surfaces were not represented. The wind planform was a modified slender delta, the sweepback of the leading edge being 67° out to 60% semi-span, increasing to 90° sweepback at the tips, (Fig.2). The wind section was symmetrical, with sharp leading edges.

The model was made of wood, the wing being spruce and the fuselage balsa. Ballast weights of G.E.C. Heavy Alloy (specific gravity 16.5) were added to give the model an appropriate mass and pitching moment of inertia, with a centre of gravity position to give the model a realistic static margin (see Section 4.2).

The model mass was approximately 1.6 kg (3.5 lb); its speed through the gust about 43 m/s (140 ft/s). As the gust velocity was restricted to about 14 m/s, this gave a ratio of model velocity to gust velocity of approximately 3 to 1, representing a change of incidence at gust entry of some 18°.

These particulars imply that the model could, for example, represent a 1/60 scale version of an aircraft flying at 150 m/s (300 kt) eas at a height of 11 km (36000 ft) and an all-up weight of 89000 kg (197 000 lb).

2.4 Model support

The requirement for the model support system was that it should allow the model freedom in heave and pitch, whilst restraining it in yaw, roll, sideslip and along the line of flight. The pitch axis was to be as nearly as possible on the fore-and-aft position of the model centre of gravity so that there should be minimum coupling between the heave and pitch modes. With the gust applied across the track, these requirements meant that the model had to be mounted with the wing plane vertical so that the heave freedom was a horizontal translational freedom.

Many different systems of model support were considered, including parallelogram-type linkages, before the final scheme, illustrated in Figs.2 & 3, was decided on. The model was mounted on a recirculating ball spline to provide the translational freedom. The splined shaft was a 0.9 m (3 ft) long, 0.019 m (0.75 in) diameter circular steel bar with three semicircular grooves cut along its length. The model was mounted on a bush with three corresponding grooves and three channels for ball bearing circulation. The bush had two projecting pegs which located in ball races in the model to provide the pitch freedom. (Fig.3.) Friction forces opposing heave and pitch motions were kept very low by the use of this system.

The splined shaft was fixed at its ends to the support rig carried on the end of a long tubular dart. This was mounted on springs on the sled to isolate the model as far as possible from track vibration. (Figs.4 and 5).

2.5 Instrumentation

The response of the model was obtained by measuring accelerations at various points using sub-miniature piezo-electric accelerometers built into the model. The signals were taken from the transducers through brushes sliding along copper strips bonded to the splined shaft. Transmission of the signals from the sled to the recording equipment was the subject of a good deal of development work which is described in Section 3.2.

A cine camera running at 150 frames per second was carried on the sled to provide a visual record of model behaviour.

The sled track was equipped with coils to produce electrical pulses when a magnet on the sled passed over them. The pulses were recorded alongside the acceleration records to indicate model position along the track; model velocity was also derived from this record.

The moment of entry into the gust was indicated by a signal produced by the model intercepting a light beam to a photo-cell mounted on the side of the gust producing wind tunnel.

3 EXPERIMENTAL TECHNIQUE

3.1 Basis of method

As already explained, the model was mounted on a sled propelled by solid fuel rocket motors past the mouth of an open-jet wind tunnel blowing horizontally across the track. The model was held with the wing plane vertical at the end of the horizontal splined shaft nearest to the tunnel, and was released just before it reached the gust. This ensured a maximum of translational motion for the model since the initial motion was away from the tunnel. The model was held during the run up to the tunnel by a length of fine steel wire which was fused electrically by means of a circuit triggered at a set point along the track.

The rocket motors accelerated the sled for about 1½ seconds, after which the sled coasted, decelerating at about ½ g as it passed through the gust. The velocity of the sled could be changed by using different numbers of motors, but nearly all the tests were carried out using two three inch diameter rockets, giving a velocity through the gust of about 43 m/s (140 ft/s).

At the end of the track the sled was stopped by an arrester wire.

The signals from the accelerometers in the model were taken to recording equipment at the side of the track. This consisted of a magnetic tape recorder and an ultra-violet recorder to give a quick look at the results. The pulses from the coils along the track and the signal from the photo-cell on the tunnel wall were recorded at the same time. The records also included a time-base.

The sled-mounted cine camera was started from the test control point just before the rocket motors were fired.

3.2 History of development

Most of the difficulties associated with the development of the test technique were connected with signal transmission between transducers in the model and the recording system.

Initially a radio telemetry single channel sender was carried on the sled with a receiver at a ground station alongside the track. The signals from the transducers in the model were fed to the transmitter through a multiplexing switch. The sampling rate of the switch was chosen to enable acceptable analysis accuracy to be obtained from the sampled signals within the bandwidth of model response. Unfortunately, the high noise level that occurred on the records obtained with this system made analysis virtually impossible. Most of the noise was associated with the transducer, cathode-follower system than in use, and with sled and model-mount vibration. Little progress could be made in eliminating noise unless continuous rather than sampled records of model response were available.

The radio telemetry transmission system was replaced by a miniature tape recorder carried on the sled. This was on eight channel f.m. recorder with a bandwidth from zero to 200 Hz. Tests with this unit gave results which enabled improvements to be made to the suspension of the model-mounting structure to attenuate the level of sled vibration which was transmitted to the model. Improvements were also made to the transducer system, the cathode-followers being replaced by field-effect transistor source-followers which could be positioned close to the transducers to avoid long intermediate leads. Nevertheless, the recorder itself was found to be very susceptible to vibration, particularly to angular motion about the axis of the flywheel-capstan assembly. Attempts to overcome this difficulty were largely unsuccessful.

At this stage, several schemes based on a direct cable link between the sled and a stationary recording system were considered. Although the direct link has obvious attractions, and is certainly simple in principle, previous sled experiments had shown that it was by no means easy to devise a link that operated successfully and reliably, particularly when the link had to be a multicore screened cable of low strength. Largely because of this experience no effort had been made to develop a direct link system for the present experiments. It was found, however, that if the six-core signal cable was coiled carefully inside a cylindrical drum and pulled out through a flaired nozzle at one end of the drum a clean delivery of cable could be obtained at the speeds and accelerations of the sled[3] (Fig.6). The drum and cable were therefore carried on the sled with the free end of the cable fixed to the ground behind the sled. Since the link was only required between the starting end of the track and a point just past the gust, it was necessary to store no more than 140 metres (460 ft) of cable in the drum and to provide a snap connector block to allow the cable to pull free when it was fully paid out.

This arrangement not only operated completely reliably, but because the cable was paid out smoothly onto the track, with no significant damage, it was possible to use the same cable for several tests.

The transducer system was modified again by substituting charge amplifiers in place of the source-followers in order to take advantage of a smaller installation and the elimination of cable-length effects.

4 PROVING TESTS

4.1 Properties of model

The model weighed 1.57 kg (3.45 lb) and its measured pitching moment of inertia about the cg was 0.046 kgm^2 (157 lb in^2).

Although this model was built to be nominally rigid, it necessarily had some degree of flexibility. A resonance test was therefore made to check that the mode frequencies were sufficiently high for flexibility to be ignored in the calculation of gust response and also to look for possible sources of noise on the acceleration records. The model was mounted on the splined shaft and excited by a small electro-magnetic unit coupled to the bush on which the model was pivoted. Outputs from the accelerometers in the model were fed into a resolved components indicator and vector plots of the acceleration response were made[4]. Analysis of these plots showed that there was 0.06 of critical damping in the fundamental bending mode at a frequency of 91.5 Hz. No other modes of vibration were found below 200 Hz (which was the upper limit of the frequency range of the track measurements).

4.2 Model stability tests

Because the model had freedoms in heave and pitch, static stability tests were made in the R.A.E. 5 ft open-jet wind tunnel. The support frame holding the model was rigged in the tunnel (Fig.2) and the model was tested up to 61 m/s (200 ft/s). It was found that the model needed trimming to fly at zero lift and pitching moment. This was accomplished by means of small spoilers on the trailing edge of the wing. A slight tendency was noted for the model to come to rest at the middle of the splined shaft, presumably due to the pressure field produced by the support frame.

Measurements of lift, drag and pitching moment were made in the R.A.E. No.2 11 ft wind tunnel.

The model support rig used in the track tests was mounted on a stand in the tunnel, (Fig.7) and the model itself was rigged from the tunnel balance. The recirculating ball bush in the model was replaced by a plain bush with a clearance round the splined shaft so as to eliminate any friction forces between the model and the support rig.

In order to assess the interference between the support rig and model, several configurations were tested:-

(1) the model on its own (with the hole in the bush blocked up),

(2) the model plus the stand,

(3) the model plus support rig plus stand, the standing being adjusted so that the model was positioned in the middle of the splined shaft, and

(4) the same configuration as (3) but with the stand lowered so that the model was positioned at one end of the shaft.

All tests were made at a wind speed of 46 m/s (200 ft/s).

The results are shown in Figs.8 and 9. The curves give a mean value for $C_{L\alpha}$ between $\alpha = -15^{\circ}$ and $+15^{\circ}$ of 2.11 and for $C_{M\alpha}$ of 0.067. This gives a static margin of 3.2% of root chord for the model mounted on its support rig.

5 RESULTS

5.1 Test results

Not all of the many tests made produced satisfactory records. Examination of the ciné films showed that the electrical release mechanism for the model sometimes operated too soon so that the model was already part way along the splined shaft when it entered the gust. There was then insufficient travel left for it to avoid striking the support frame as it passed through the gust. This produced very large signals which overloaded the transducer amplifiers.

A set of results is shown in Fig.11. The accelerometer signals have been filtered to attenuate frequencies above 150 Hz. It should be noted that the traces are not all to the same amplitude scale since the accelerometers have slightly different sensitivities. The signals on the record from the photo-electric cell are due to the interruption of the light beam not only by the model but also by various parts of the sled.

The high frequency content of the accelerometer signals appears to be due mainly to vibration of the model in its fundamental mode (91 Hz in still air). Tests in the laboratory indicate that some, if not most, of this vibration is excited by the motion of the model along the splined shaft; the recirculating ball spline, although having very low frictional properties, gives rise to a good deal of mechanical noise. Possible methods of improvement are discussed in Section 6.1.

5.2 Calculations

The calculations of the model response to the gust were made using the methods developed at the R.A.E. by Mitchell[5,6]. The model was assumed rigid, with freedoms in pitch and heave only. The static margin was taken as 3.2% of the root chord. The response to the exit from the gust was obtained by superimposing a second step gust response on the first.

The results of the calculation are shown in Fig.10 in the form of accelerations at the various accelerometer stations on the model for a model velocity of 39.7 m/s (135 ft/s) and a 13.8 m/s (45 ft/s) gust 4.6 m long (15 ft), (39.7 m/s was the measured sled velocity on the particular test run with which comparison is made).

5.3 Comparison

Comparisons between calculated and measured accelerations for a particular test run are shown in Fig.10.

The magnitude of the first maximum in the acceleration is accurately predicted in each case by the calculations. However, the test results show a more rapid fall off in acceleration than the calculations, particularly on exit from the gust.

That the acceleration records are a genuine record of the model response is confirmed by integrating the cg trace to obtain displacement, and comparing it with the ciné film record (Fig.12). There is good agreement between the visual record and the integration of the measured acceleration, within the limits of measurement accuracy from the film.

It is likely that the calculations will be more accurate for the entry to the gust than for the exit, since the method used in the calculations (superimposing a down gust) is not truly representative of the real conditions. The different characteristics of entry and exit were clearly shown in the pressure measurements of Hunt and Roberts[7]; these showed a fairly slow build up of pressure on entry to the gust, but a very rapid decay on exit. This is not likely to be well represented in the calculations by the linear aerodynamics which were used.

6 FURTHER DEVELOPMENT

6.1 Test techniques

There remain two problems with the test technique described in this report; the unreliability of the mechanism for releasing the model from its locked position at the end of the supporting shaft, and mechanical noise in the recirculating ball spline.

Little difficulty is anticipated in improving the release mechanism, and a redesigned system has already been produced.

The elimination, or significant reduction in ball spline noise is more difficult. Lubrication reduces the noise, but results in a marked increase in friction which cannot be tolerated. On the other hand, avoidance of lubrication promotes wear of the tracks in the shaft, which in turn increases the noise level.

Several modifications which retain the ball spline have been considered, among them the provision of a spring mount for the model on the spline. However, such a modification is ruled out by the conflicting requirements of vibration isolation and rigidity in yaw and roll.

Attention has therefore been turned to schemes which dispense with the ball spline altogether. Among these, the possibility of mounting the model on a gas bearing which can move along a shaft appears the most attractive from the point of view of low noise and friction. The need to provide yaw restraint can be met by mounting the model either on a carriage which can move along two parallel circular shafts or on one which moves along a non-circular shaft. The latter is preferable from both the aerodynamic and design points of view, but poses difficulties in manufacture owing to the fine tolerances necessary.

The main difficulty involved in the use of a gas bearing is the problem of gas supply. To avoid interference with the model, it would appear preferable to supply gas to the bearing via the supporting shaft rather than the sliding bush. However tests showed that using a hollow supporting shaft with rings of radial holes all along its length gives a very high gas consumption (all the holes except the few covered by the bush being vented straight to atmosphere); moreover the load carrying capacity of the bearing is much less than when the gas is supplied via holes in the bush. The drawback of this latter method is that the gas store must either be carried alongside or inside the model, or, if the store is on the sled there must be a supply pipe to the model. The weight of the smallest gas bottle and valves which could be used to operate the bearing is unfortunately too great to allow it to be carried on the model or bush, where it would add to the effective mass of the model. The only alternative method appears to be a flexible supply pipe from the sled to the model. It should prove possible to arrange the pipe so as to cause minimum interference with the translational freedom.

6.2 Future uses for the gust track

It has been suggested that tests similar to the present series might be performed using other types of model. Once the experimental technique is completely developed, this could be done fairly easily.

The use of a flexible model has been proposed to investigate the degree of structural representation necessary in the calculations to predict the response accurately. This would probably be a beam network type model[2] covered in flexible plastic foam to give the same aerodynamic shape as the present rigid model. However the support noise problem would have to be overcome since a model with modal frequencies in the bandwidth of the support noise spectrum would have a much greater response to the noise input than the rigid model. This would tend to invalidate any results where aerodynamically-induced structural vibrations were of interest.

It has also been suggested that the response to lateral gusts would be a useful field for research. The main problem for such tests would be the suspension of the model, since this would have to allow almost all freedoms except fore-and-aft movement. It would probably be worth examining the possibilities of letting the model fly free through the gust using a trailing cable from it to transmit the signal to the sled.

7 CONCLUSIONS

An experimental technique for investigating the symmetric response of a rigid model to up-gusts has been developed to the point where useful results have been obtained.

Some problems remain to be solved however before the techniques could be applied to flexible models.

Comparison of calculated response with the measured results shows that the theory is able to give very accurate values for the maximum accelerations at gust entry, and that it agrees well with the general pattern of response in spite of the certain simplifying assumptions.

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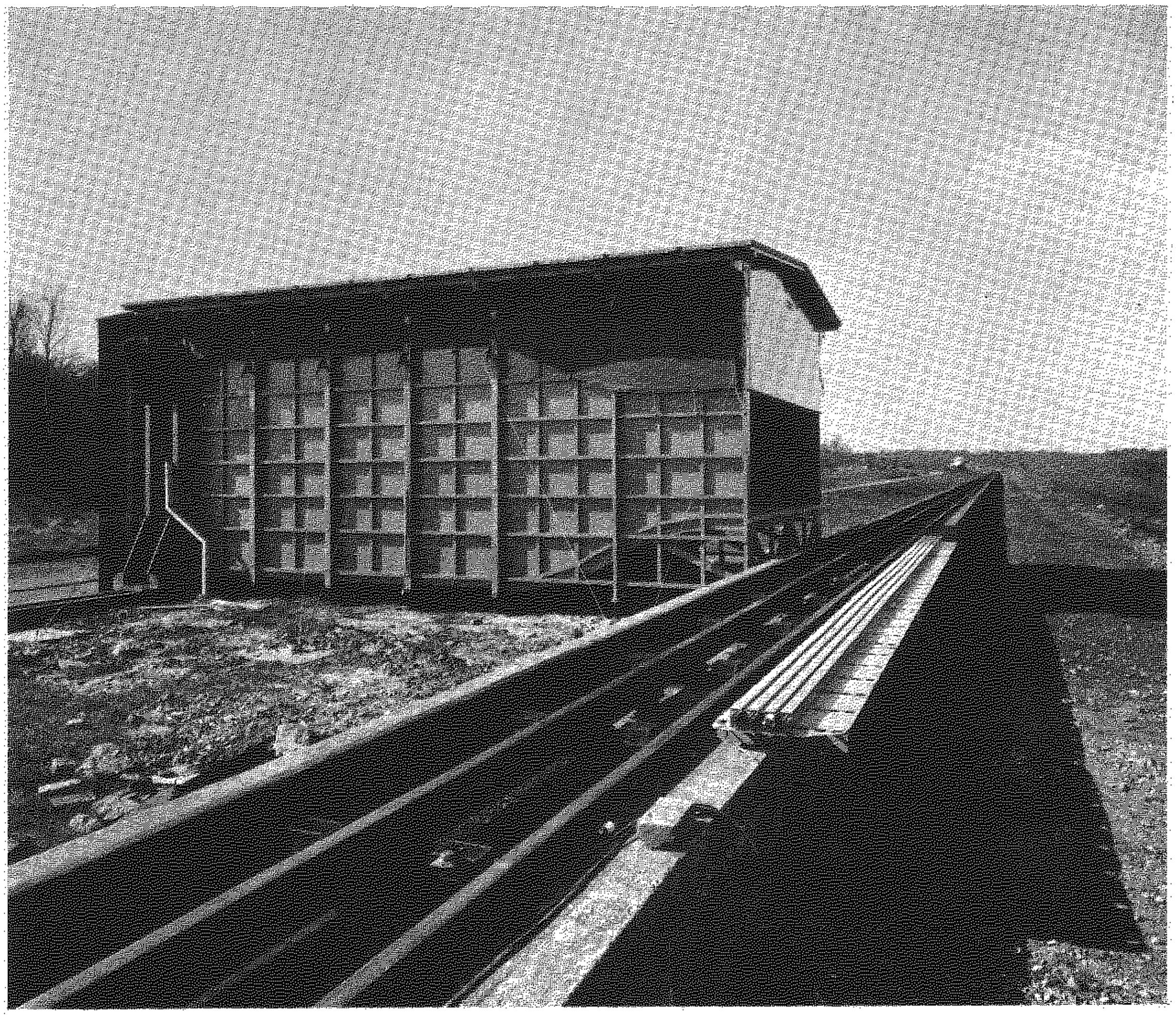

Fig.1. A view of the sled track and gust tunnel

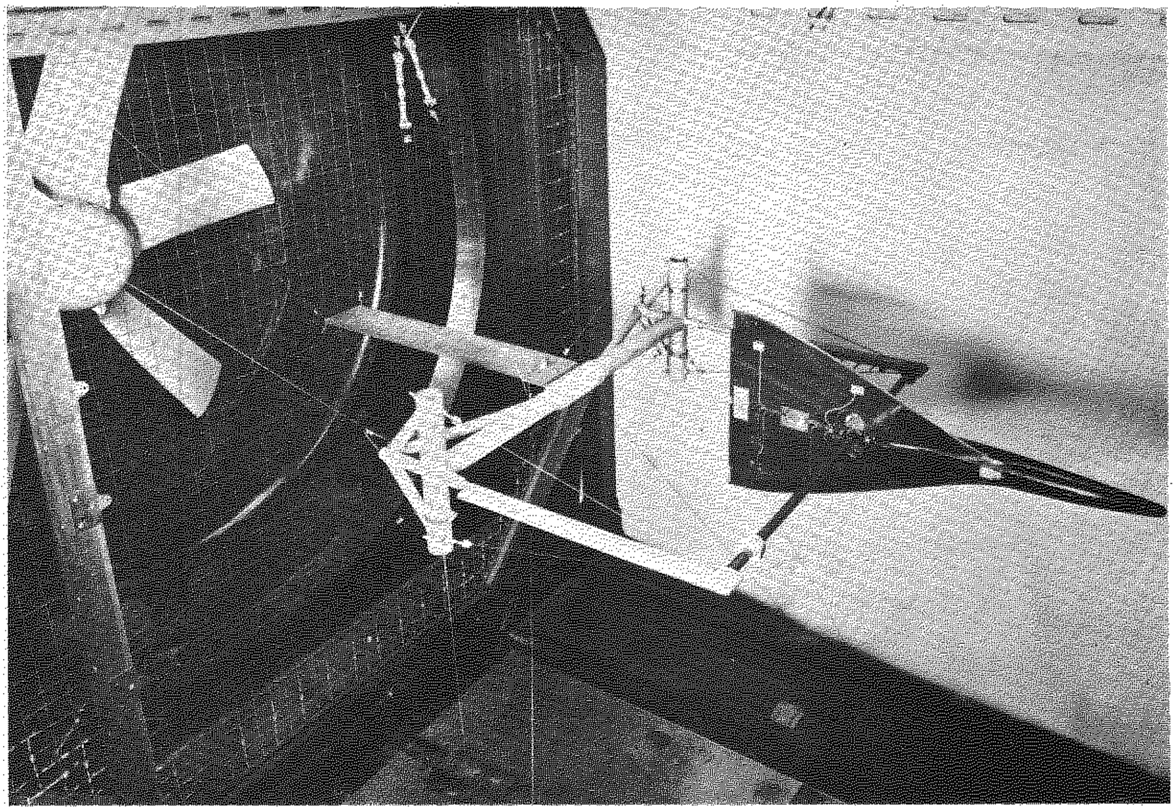

Fig.2. Model in 5ft wind tunnel

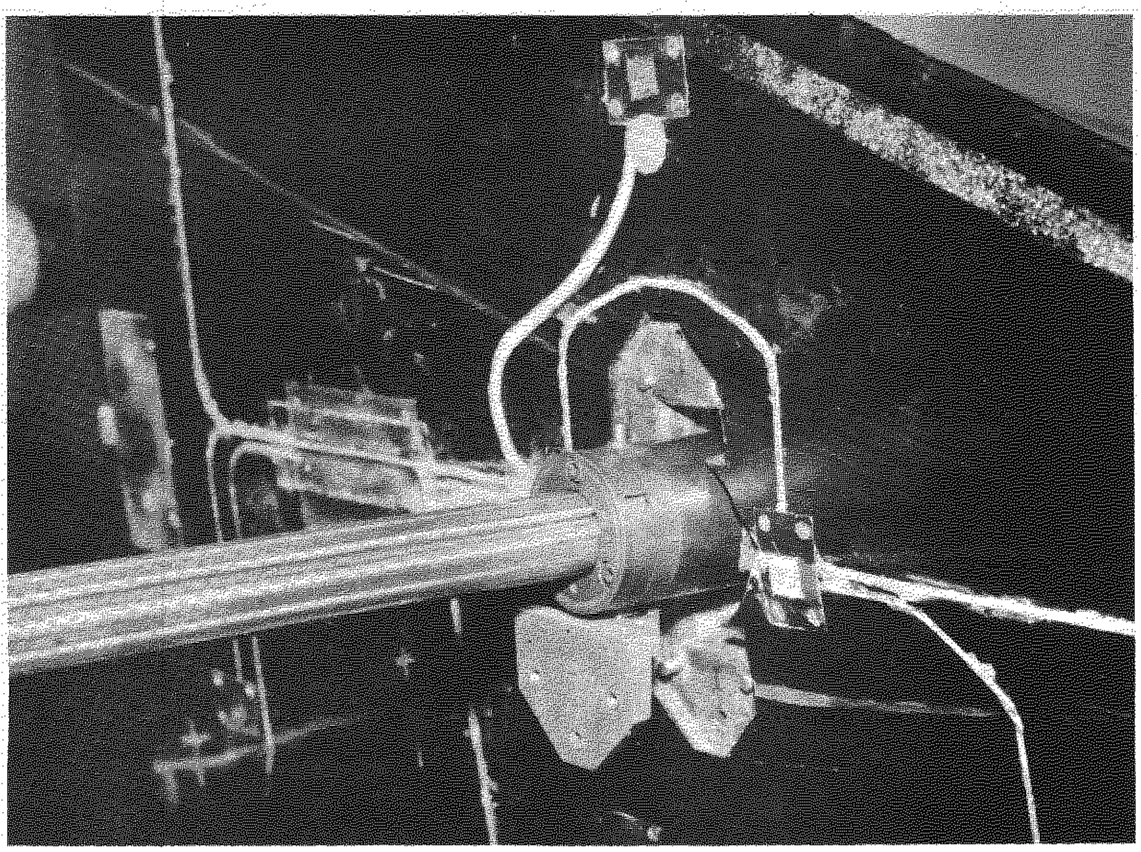

Fig.3. Detail of recirculating ball spline and bush

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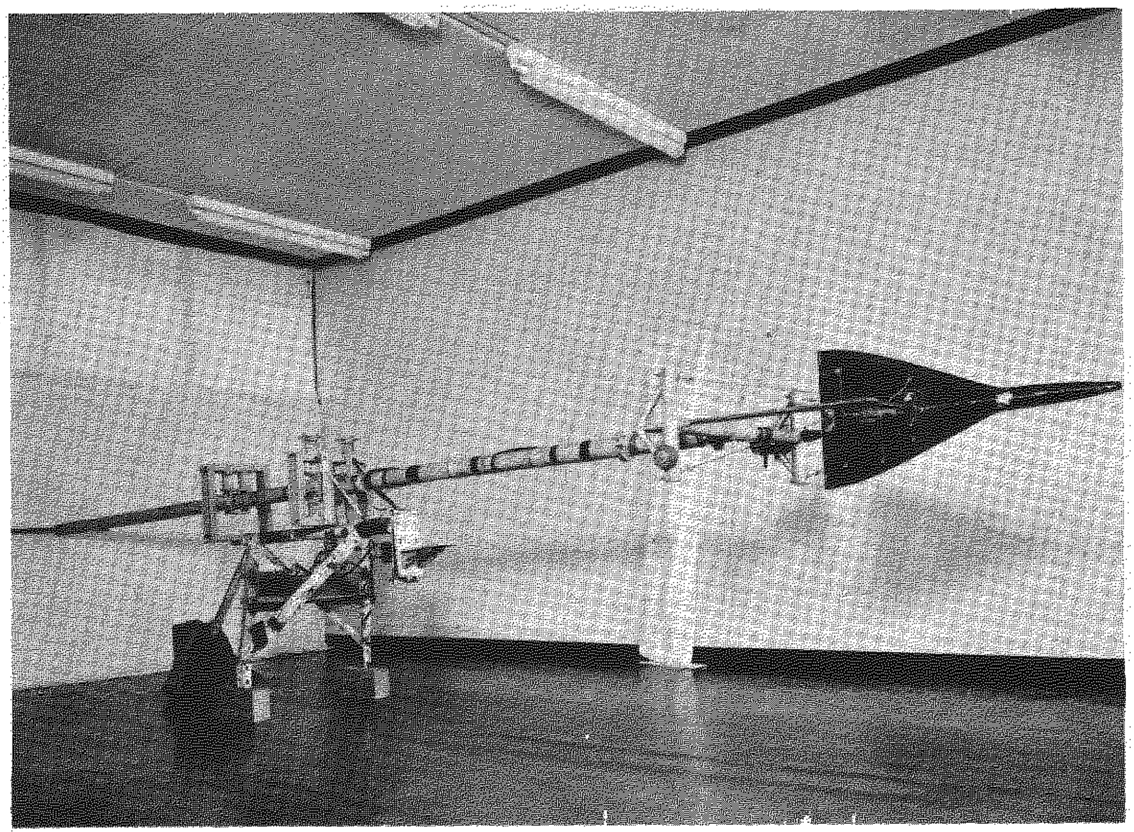

Fig.4. Model support rig as fitted to sled

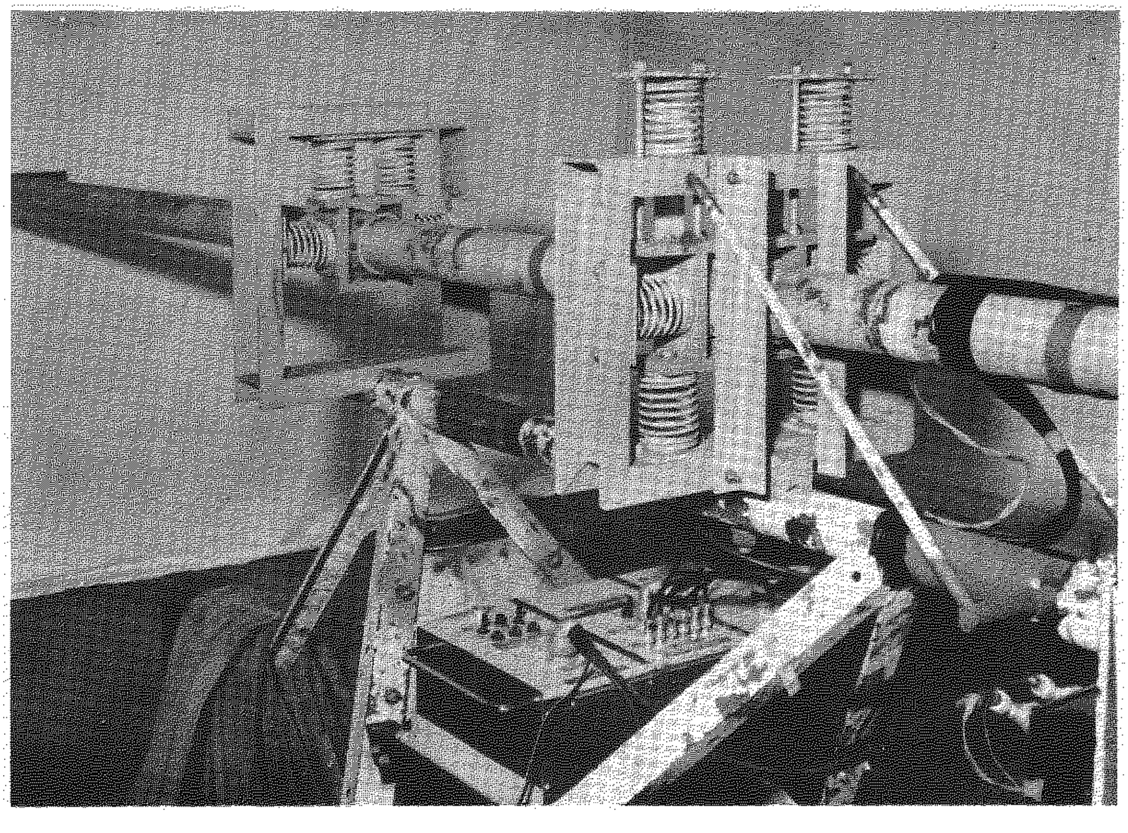

Fig.5. Detail of spring mounts for dart

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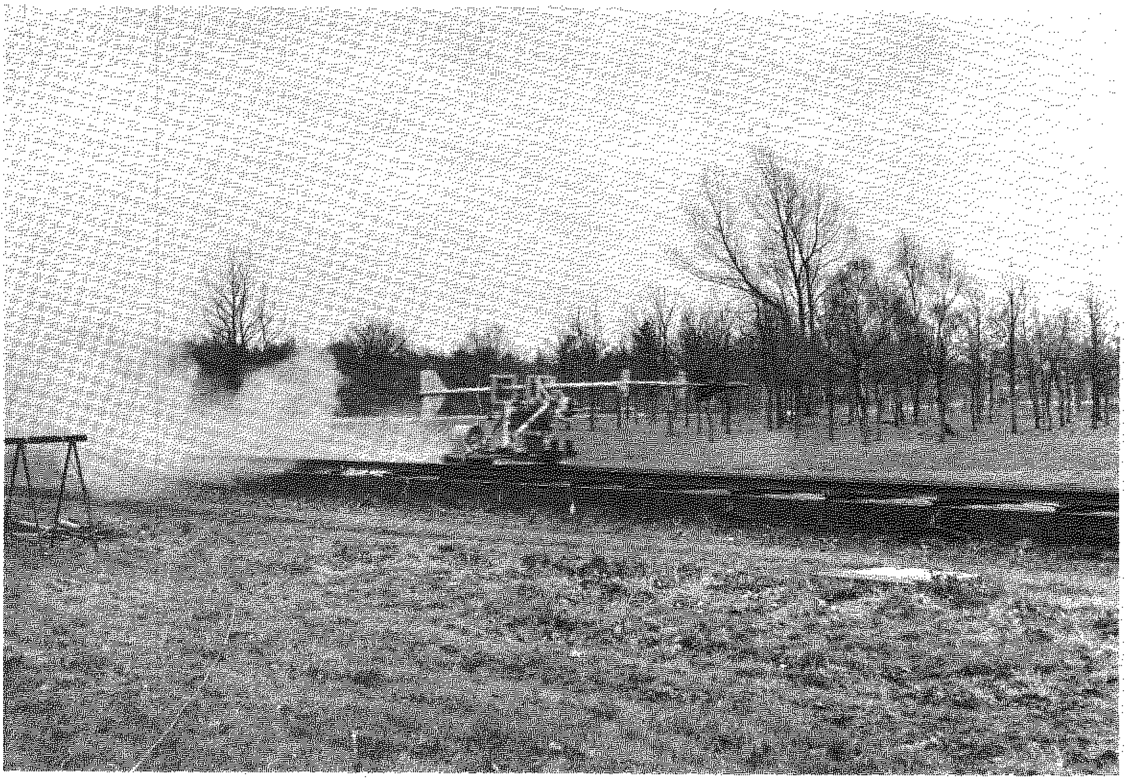

Fig.6. Test run using trailing cable

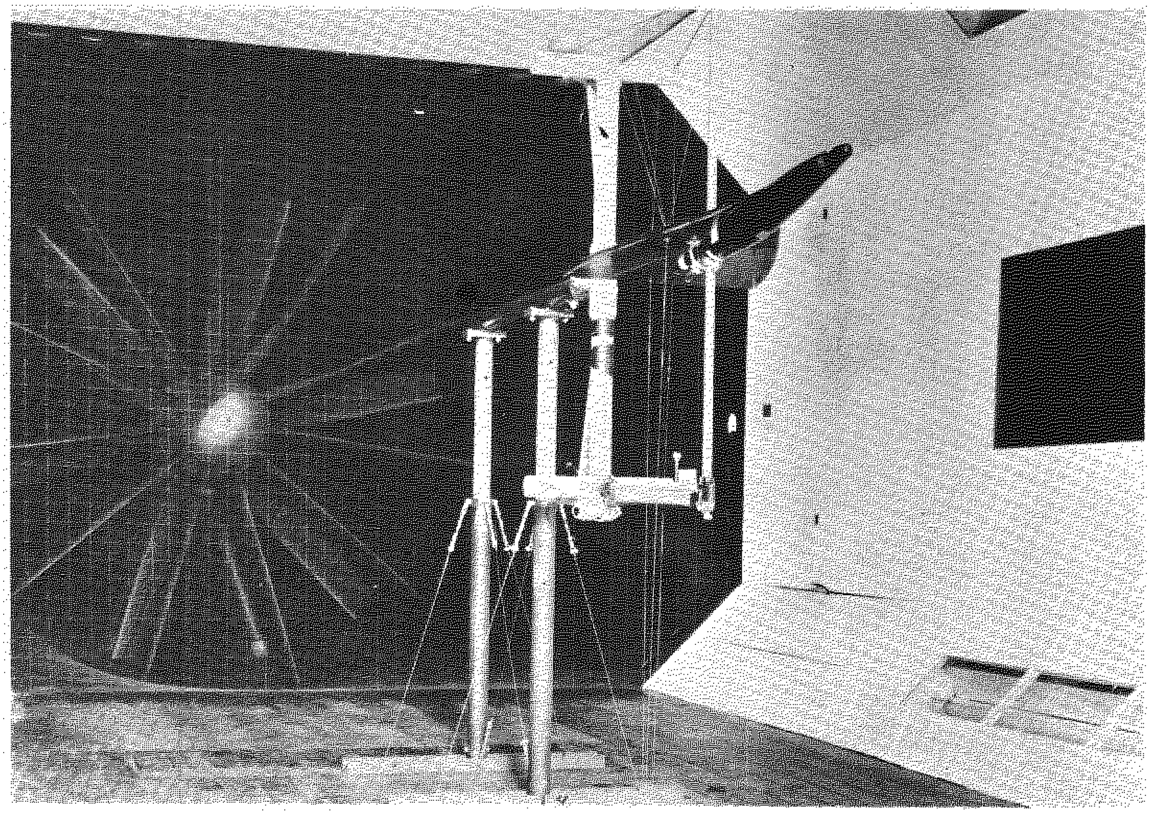

Fig.7. Model in No.2 11ft wind tunnel

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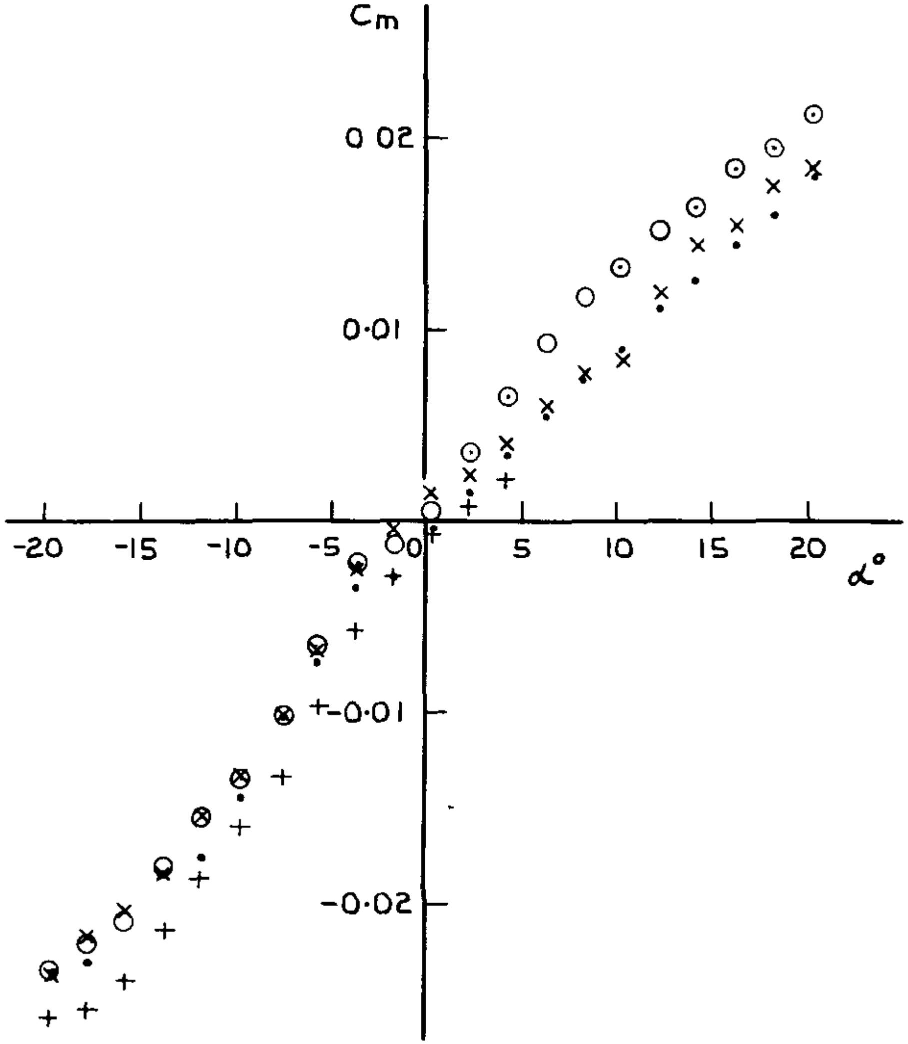

Fig. 8 C_m vs α curves for model

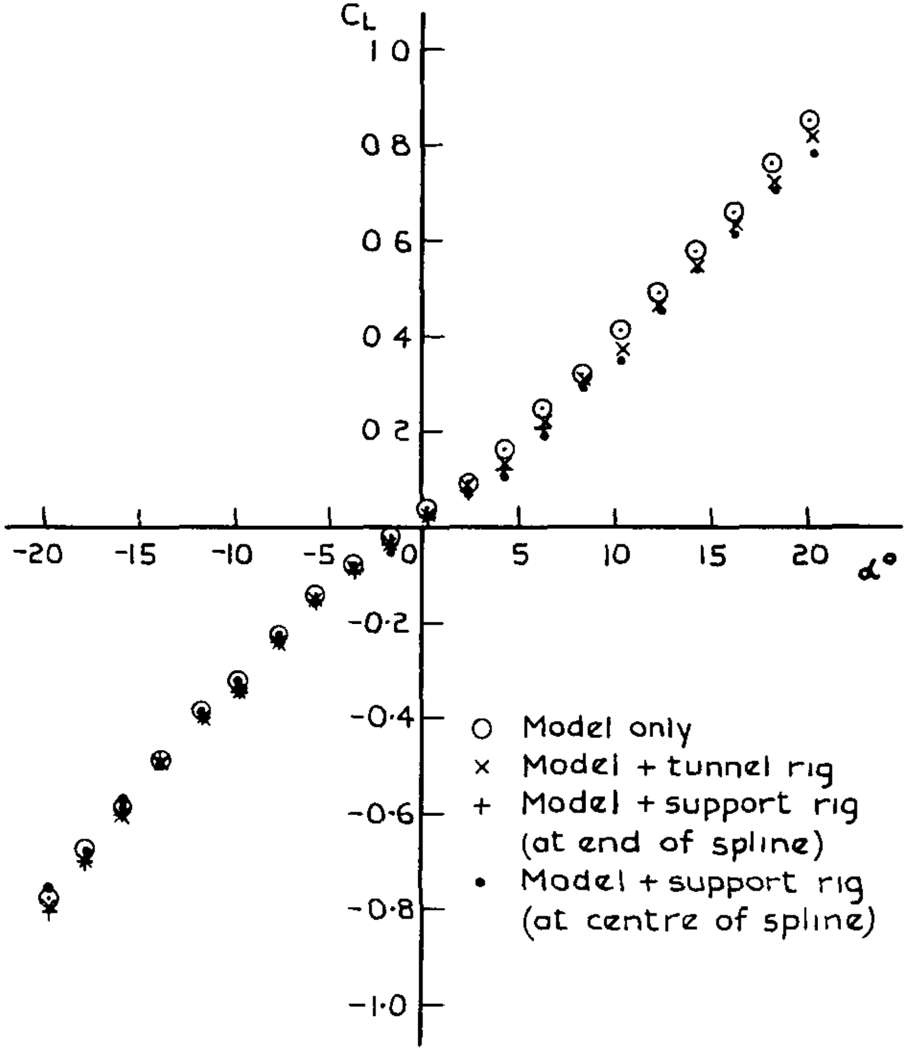

Fig. 9 C_L vs α curves for model

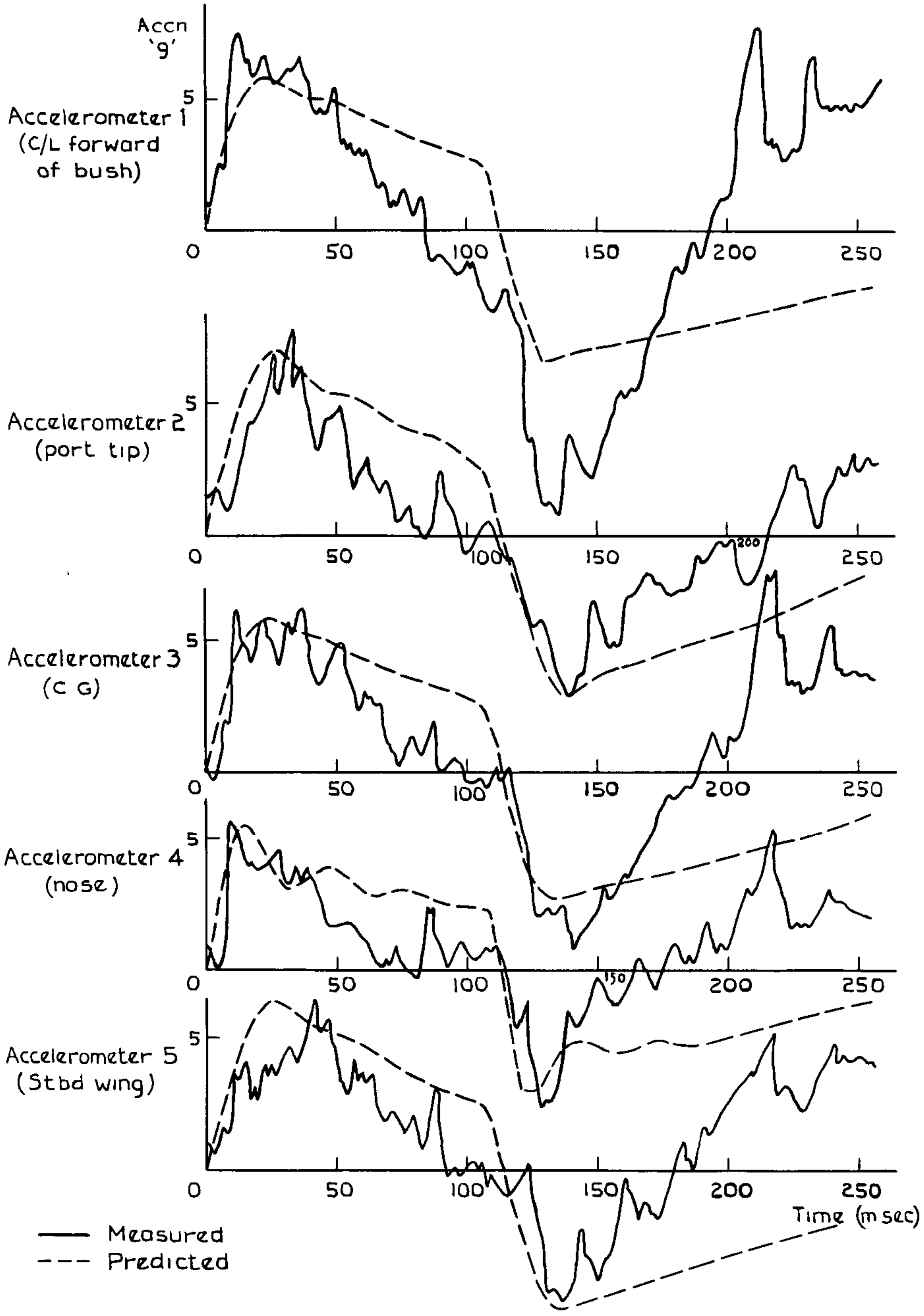

Fig. 10 Comparison of measured and predicted accelerations

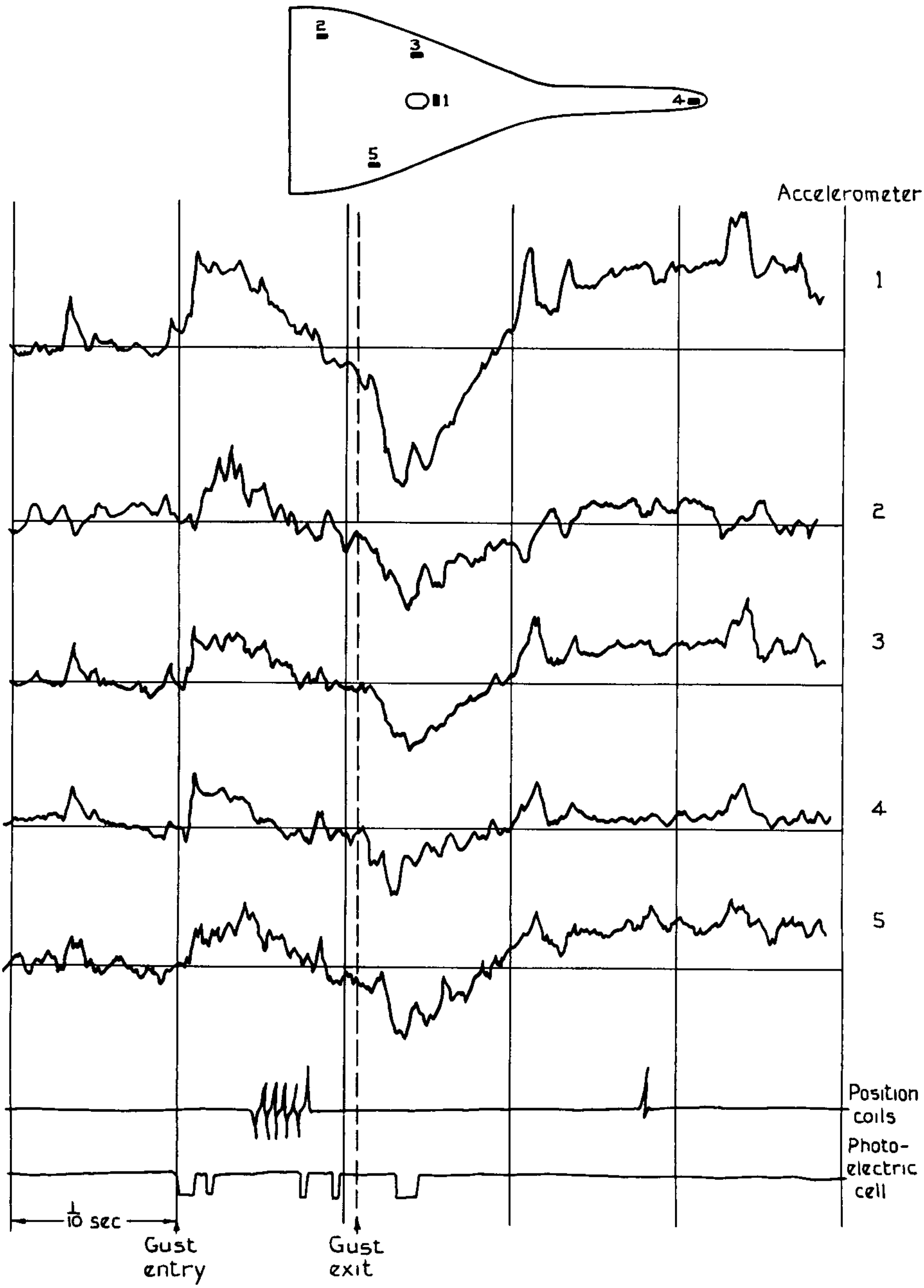

Fig. 11 Typical trials record

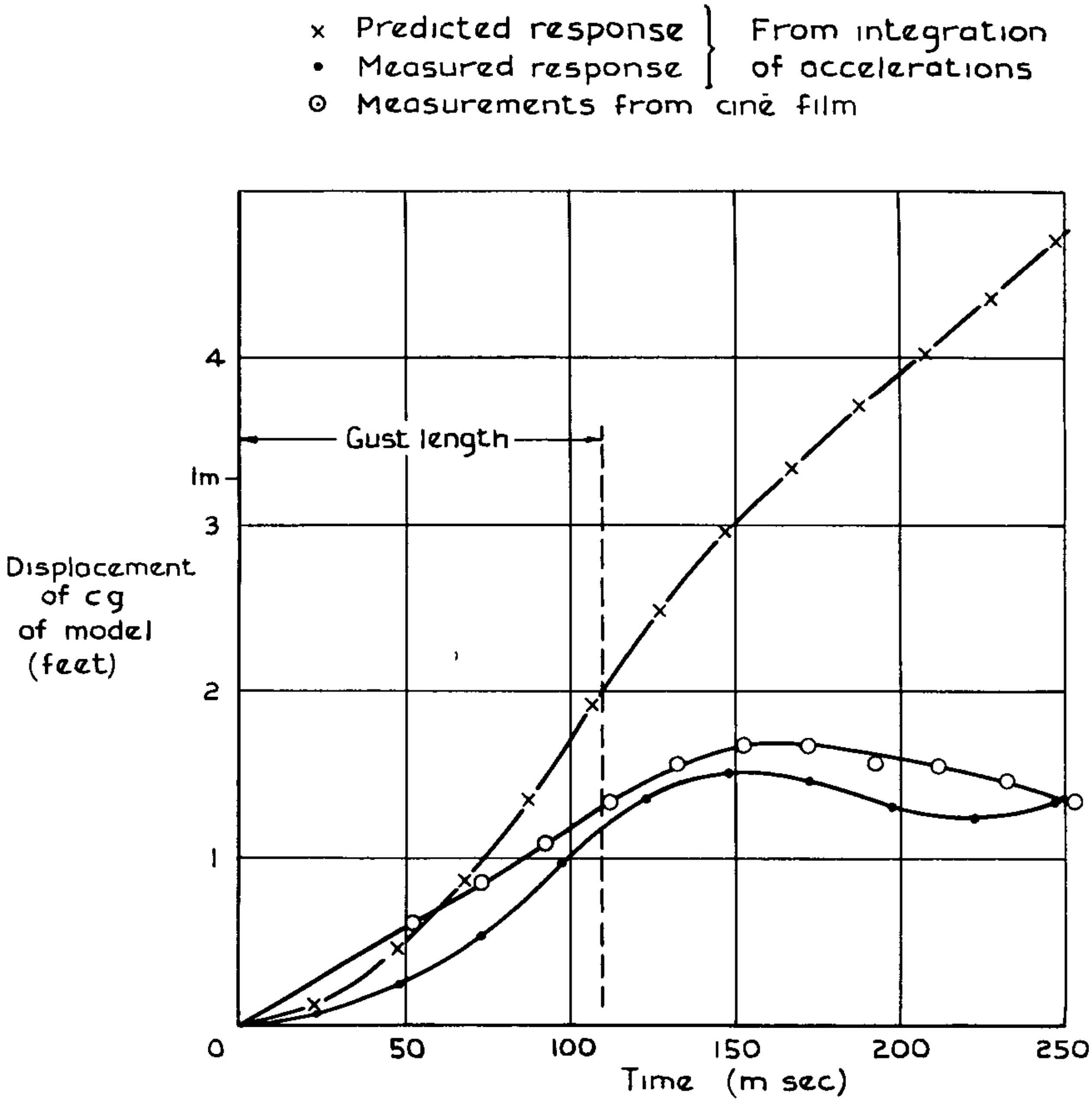

Fig. 12 Comparison of integrations of predicted and measured accelerations with measured displacement

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