CoA NOTE AERO. NO. 174

THE COLLEGE OF AERONAUTICS

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THE COLLEGE OF AERONAUTICS WHIRLING ARM

INITIAL DEVELOPMENT TESTS

by

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May, 1967

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DEPARTMENT OF AERODYNAMICS

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SUMMARY

The old Whirling Arm of the National Physical Laboratory has been re-erected at the College to provide a facility for the study of ground effect on wings, and other craft operating near the ground. The model is mounted on struts, which differ considerably from those used by N.P.L., and moves over an adjustable floor in a specially constructed channel. This note covers the initial tests conducted on the arm towards making it a fully operational facility.

It is concluded that a full yaw-meter survey is necessary to define the air-flow existing in the channel, during operation of the arm, and that the instrumentation being used needs to be further developed.

This work was carried out under Ministry of Technology Contract No. PD/28/016.

Contents

1.0 Introduction

Recent interest in the behaviour of wings in the presence of the ground has brought under review the various experimental techniques used to simulate ground effect. These techniques are as listed below:

1. Wind tunnel (a) ground board;
   (b) moving belt;
   (c) image wing.
2. Towed model.
3. Free flight or tethered self-propelled model.

A fuller appraisal of these techniques appears elsewhere (e.g. Saunders, 1963; Ashill 1965; Kumar, 1967), and it is obvious that a method utilising a towed model will be most representative of a wing flying close to the ground, as would also a free flight or tethered model. A facility such as a ship tank or whirling arm would thus be an ideal means of studying both the steady and unsteady aerodynamics of wings in ground effect.

This note covers the early development tests on the Whirling Arm at the College with a view towards making it a fully operational facility for the study of ground effect.

2. The College of Aeronautics Whirling Arm

Description

As has previously been mentioned, the whirling arm is a convenient facility for representing a wing flying in ground effect and it was with this in mind that the present whirling arm at the College was reconstructed from the old arm of the National Physical Laboratory. In its original form the NPL Whirling Arm (Ref. 2) was used to measure the lateral derivatives, of wings and aircraft, due to rates of yaw and the claw on which the models were mounted has now been replaced by a platform. Fig. 1 shows the general arrangement of the whirling arm, platform, model support struts and channel and Figs. 2 and 3 show further details. The radius of the model from the centre column of the arm is 27′ 3″ to mid model span. The model itself is midway between the channel walls, and its height above the floor is adjustable by means of the supporting struts and by moving the floor. The moveable floor enables various shapes of the ground (e.g. a wavy ground) to be obtained. The channel is 8′ 6″ wide with its ceiling 7′ above the centre-line horizontal plane of rotation of the arm and was constructed using a Dexion framework (Fig. 4) with hardboard sheets nailed onto a secondary wooden framework. The floor in front of the control room window is made from Mahogany, to prevent warping in that region, and access into the channel is by means of a trapdoor situated there. The arm is driven by a 75 BHP 500V D.C. motor running at 600 r.p.m. with an 18.86:1 gear ratio, giving a design r.p.m. of 30 and a design linear model speed of 86 ft/sec. at model centre span.

Because of the constant rate of rotation of the model the associated aerodynamic effects are present, namely:-

(i) the viscous wake and trailing vortex sheet of the model are both of curved form and it is thought that the effect of the curvature of the latter is small owing to the image effect of the ground.

(ii) the incident velocity on the model varies across its span thereby influencing its lift distribution and boundary layer. For wings whose span is small compared with the radius of the arm the variation in the incident velocity across the span will produce forces not unlike those occurring on the same model travelling at the same centre-span speed in a rectilinear path. The form of the boundary layer is thought to be similar to that occurring over the outer-region of a rotating helicopter rotor blade.

Another unique feature of the arm is that the model flies in its own wake, the extent of which depends on the profile drag of the model and its support within the channel. Consequently the profile drag of the supports has been kept to a minimum compatible with acceptable structural strength. The trailing vortices introduced into the flow field by the model tend to be swept towards the channel walls due to the image effect of the ground and are dissipated more rapidly than would otherwise be expected.

2.1 Structural tests on model platform and support struts

The platform on which the model support struts are mounted, is an 8′ long boxed beam constructed of dural and light alloy in the form of channels sandwiched by plates. It is $20\frac{1}{2}''$ wide and 3″ deep and the entire assembly is further strengthened at its root by additional plates. The model support struts locate perpendicular to the main platform and are prevented from bending by means of two adjustable ties fitted from the struts to the platform root. The model is fitted to the lower struts and balanced by counterweights on the upper struts, thereby ensuring no deformation of the main platform due to centrifugal loads.

The platform and struts were tested in a 50 ton tensile testing machine and suffered no permanent distortion when loaded to twice the normal operating loads. Static deflection of the platform, due to its own weight and that of the model and struts was 0.058″ and was not reduced by a simulated centrifugal load. The model would thus have to be rigged at a bank angle of $0°.6'$ relative to the strut datum points, in order for it to run horizontally over the floor.

2.2 Initial tests on whirling arm

2.2.1 Vibration measurement

Tests to determine the amplitudes of the vertical vibrations of the arm have been completed by using an accelerometer mounted at various stations along the arm and recording its output on a trace recorder via a Dawe

Vibration Meter. The signals to the vibration meter were obtained by utilising the slip rings fitted on the arm central column. The results of the tests are plotted on Fig. 5. It appears that the peak vertical oscillation occurs at about 20 r.p.m. and is due to either a small out of balance of the arm or else due to a slight fault in the main bearings of the arm. The maximum amplitude of ± .001″ is considered within the limits of experimental requirements.

2.2.2 Measurement of floor level

The floor of the channel was levelled by means of a linear potentiometer mounted from the model platform. The potentiometer had a roller bearing that ran on the floor itself and consequently any variation in the floor level from a set datum would be recorded as the arm was slowly rotated. The floor levels at the points of departure from the datum were adjusted until finally a plane to within ± $^{1}/_{8}$″ from the horizontal level was obtained over a circumference of 180 ft.

2.2.3 Flow calibration tests

An assessment of the flow in the channel has been completed by means of a pitot-static and smoke survey. The pitot-static tubes were mounted both on the rotating arm (on the model struts) and at various positions in the channel. The signals in the former cases were recorded via a pressure transducer and the slip rings onto a chart the transducer having been initially calibrated, whilst in the latter cases there was no need to use the slip rings. Table I lists the positions of the p-s tube and the corresponding velocities recorded there. Fig. 6 shows the velocity variation across the channel, including the swirl velocities on either side of a 16 ft. long sealing strip on the lower slot.

Smoke surveys of the channel indicated a small cross flow towards the inner wall of the channel, with the smoke being finally sucked through the slot into the centre of the building. This cross flow, which is of the order of 3 ft/sec., was further confirmed by tufts attached to the floor of the working section.

It is interesting to note that for the case of the pitot-static mounted on the model struts the difference in velocity between the inner and outer struts i.e. 6.6 ft/sec. is not equal to that given by $\Delta r(w)$ = 5.55 ft/sec. the discrepancy being due to different swirl velocities at the two strut positions.

At the present state of development the model platform and struts are unfaired and their contributions to the swirl velocity are presumably significant.

On looking at the velocities measured at 29 ft. radius and 1.4 ft. off the floor, some discrepancies come to light. The pitot-static tube measured a velocity at the strut of 67.6 ft/sec. With no swirl the velocity at the strut = rw = 80 ft/sec., ∴ the swirl velocity should be 12.6 ft/sec. But we are measuring a swirl of 27 ft/sec. and consequently it appears that one, or both, of the two measured values is in error. A comprehensive yaw meter survey is therefore necessary before a final picture of the swirl can be established. This will shortly be done.

2.3 Instrumentation

2.3.1 Introduction

One of the main difficulties encountered in the operation of the whirling arm is that of being able to transmit continuously any set of parameters being measured to recorders in the control room. The central column of the whirling arm has mercury troughs and slip rings through which d.c. signals can be carried to the recorders, but these signals must necessarily be large compared to the noise generated by the commutators. Alternatively, small signals will have to be amplified before transmission through the slip rings.

The model is attached to the supporting struts by means of two strain gauge balances each measuring components of lift, drag and pitching moment. Since the centrifugal loads on the model are high, the various members of the balance are robust for safety reasons and consequently the signals generated by the strain gauges are small. Amplification of these signals would require expensive equipment, particularly if it was needed to amplify at least six channels. Moreover, the amplifiers would have to be mounted on the arm itself and supplied with a suitable d.c. The only other means of avoiding the use of slip rings is to (a) use telemetry or (b) record on the arm itself.

2.3.2 Equipment installed on the Whirling Arm

The speed of rotation of the arm is measured accurately by means of a photoelectric cell which triggers off a microsecond counter at each interruption of a light beam by the model platform. In addition the photocell operates a marker pen on a recorder enabling the position of the arm to be determined at any instant.

An accelerometer mounted at the tip of the platform measures the vertical oscillations of the arm which are interpreted in terms of mean peak displacements, velocity or accelerations by means of a Dawe Vibration Meter, in addition to being recorded on a pen or U-V recorder.

A 24 channel UHF telemetry system is to be used to obtain the information from the strain gauge balances and both are under development. In addition a closed circuit TV camera monitors the model continuously and is used primarily as a safety device.

2.4 Future test programme for the Whirling Arm

The initial flow tests on the whirling arm facility have indicated the immediate need to eliminate the swirl existing in the channel. This will be tackled by fairing in the platform and partially scaling the slot through which the platform projects into the channel. This latter modification may also help to reduce the small cross-flow that exists in the channel. Another means of reducing the swirl would be to roughen the sides of the channel but calculations indicate that there will still be a residual swirl of about 18 ft/sec. The use of vanes and slots in the channel walls is also under consideration. However, a complete yaw-meter survey has to be done to obtain the complete flow pattern in the channel.

Preliminary tests on the strain gauge balance have indicated that the gauges will have to be repositioned on the various component members in order to achieve larger output signals. At present the output signals are well below 10 mV and the amplification of these would need expensive and sophisticated amplifiers in order to be transmitted via the UHF telemetry system. However, once these difficulties have been overcome the next important task would be the calibration of the gauges and to determine the interference on any components of the balance due to a load on one component.

Steady tests on the Clark Y wing (Ashill, 1966) will then be conducted for varying heights above the ground and different endplate configurations. Comparison of these tests with earlier wind-tunnel tests using the image wing method will help to establish the accuracy of the method. Unsteady tests in ground effect will then be conducted.

2.5 Future uses of Whirling Arm facility

It may be pointed out that the whirling arm facility is not necessarily restricted to the study of ground effect on wings. Aerodynamics of any GEM, including wheeled vehicles, may be studied for both the steady and unsteady states and the responses of these machines to novel ground shapes may be determined. Tests on aircraft to determine their response to gusts, and to evaluate their derivatives in continuous pitch or rotation are also feasible. The channel can be converted to a towing tank for hydrodynamic tests and modifications to the floor for the testing of hovercraft skirt materials are also possible.

3. Conclusions

A great deal of development work has still to be done towards making the Whirling Arm facility fully operational. The immediate problem is the elimination, if possible, of the circumferential swirl existing in the channel when the arm is running, and the necessity of conducting a complete yaw-meter survey of the flow. Once the characteristics of the flow have been established more fully, accent may then be placed on the further development of the necessary instrumentation and recording equipment.

References

1. Ashill, P.R. — A review of aerodynamic aspects of ram wing research. CoA Note No. 159, 1965.

2. Halliday, Allwork and Caborn — The new Whirling Arm at the N.P.L. A.R.C. R and M 2286, 1946.

3. Kumar, P.E. — Stability of Ground Effect Wings. CoA Report Aero. No. 196, 1967.

4. Saunders, G.H. — Aerodynamic characteristics of wings in ground proximity. Massachusetts Inst. of Technology. M.Sc. Thesis, June 1963.

Acknowledgements

The author is grateful to Mr. S.H. Lilley of the Aerodynamics Department and to the Flight Department Instrumentation section for invaluable help in developing the Whirling Arm Facility.

Table I

Radial position of pitot-static	Ht. above floor	Velocity ft/sec	R.P.M.	Remarks
26.7 ft.	1.4 ft.	61	26.5 (rw = 74 ft/s)	P-S mounted on strut and rotating with arm
29.0 ft.	1.4 ft.	67.6	26.5 (rw = 80 ft/s)	P-S mounted on strut and rotating with arm
23.5 ft.	10 inches	27	26.5	P-S mounted from floor and fixed
29.0 ft.	1.4 ft.	27	26.0	P-S mounted from floor and fixed
31.25 ft.	10 inches	23.8	26.0	P-S mounted from floor and fixed
27.25 ft.	4.5 inches	30.0	26.5	P-S mounted from floor and fixed
27.25 ft.	4.5 inches	23.9	26	Model and struts removed. P-S on floor.
27.25 ft.	2.6 ft.	22.4	26.5	Model and strut removed. P-S on floor.
27.25 ft.	4.25 ft.	23.4	26.5	Model and struts removed. P-S on floor
23.25 ft.	3.75 ft.	36	26.5	Swirl velocities in slot.
23.33	3.5 ft.	23	26.5	Swirl velocities on either side of a 16 ft long sealing strip on lower slot measured 12 ft. from L.E. of strip.
23.17	3.5 ft.	27	26.5	

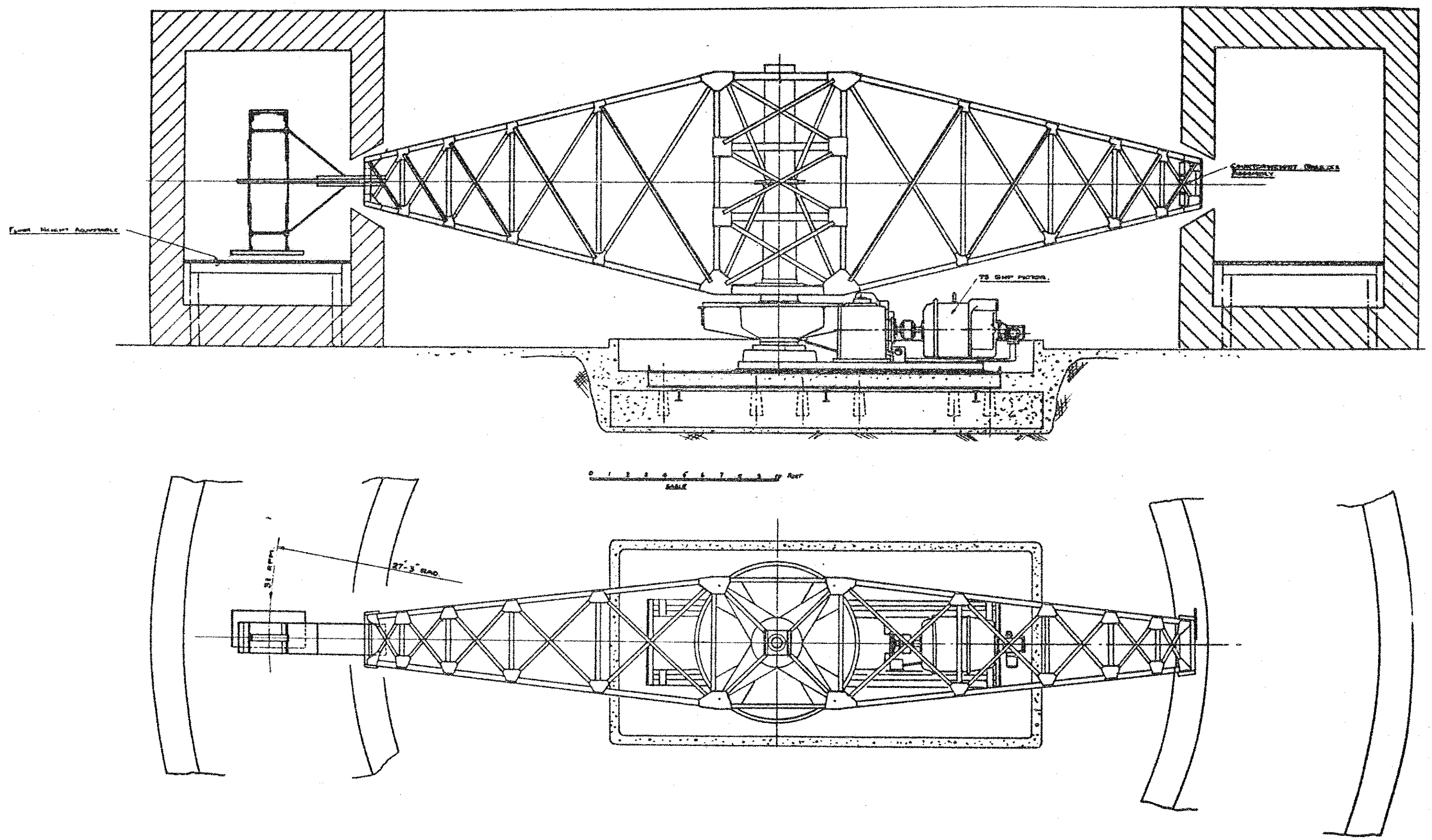
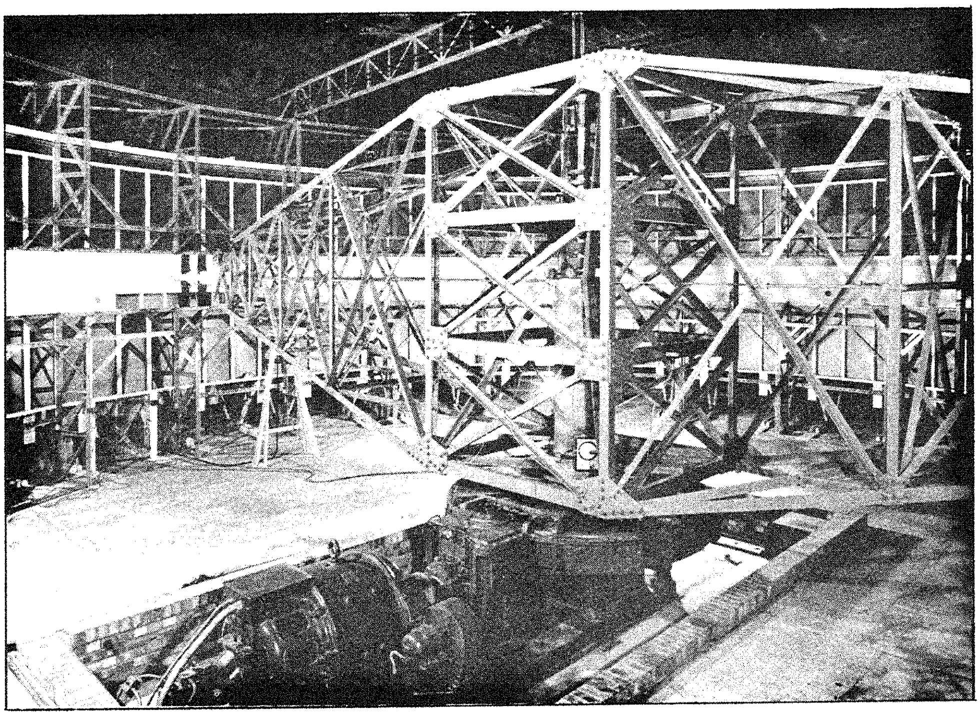
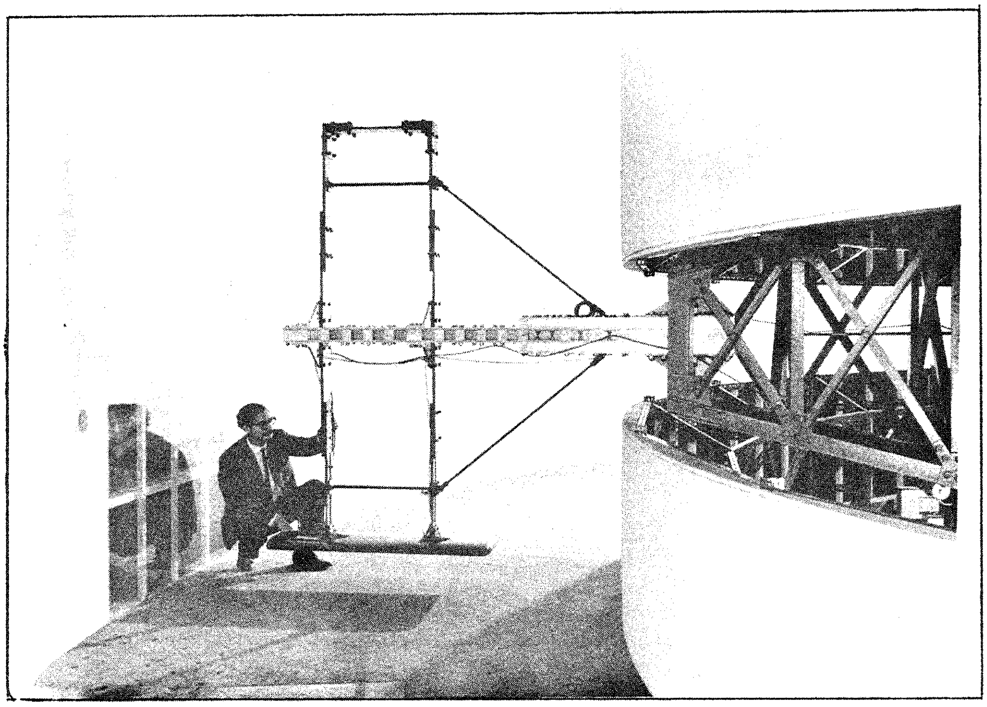


FIG.1. WHIRLING ARM FOR AERODYNAMIC RESEARCH.





FIGS. 2,3. VIEW OF WHIRLING ARM, CHANNEL AND MODEL.

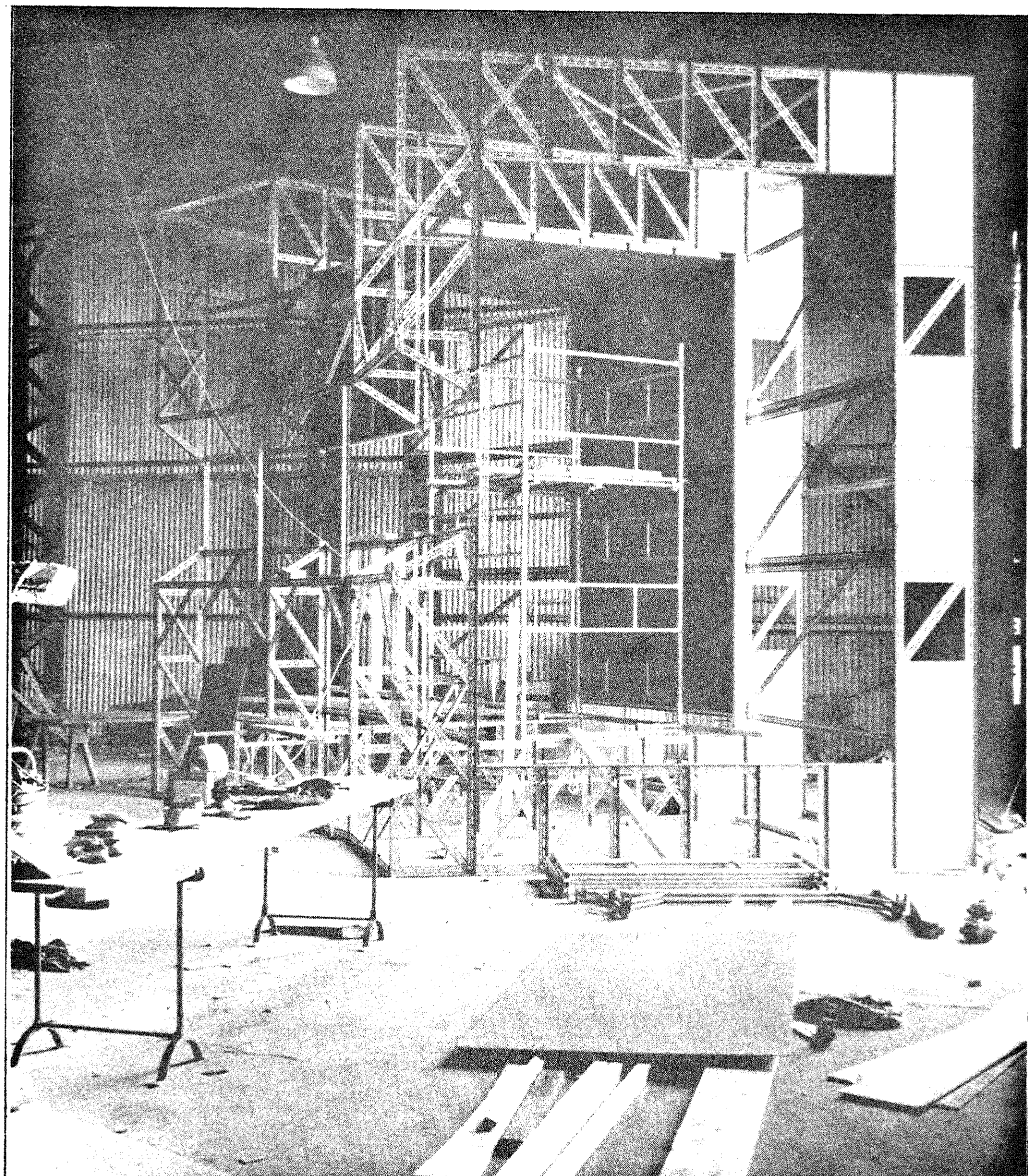
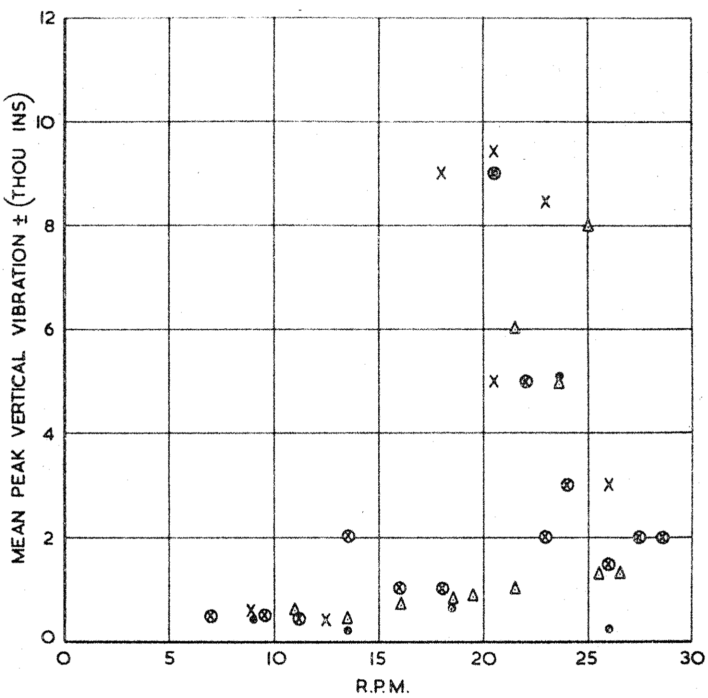
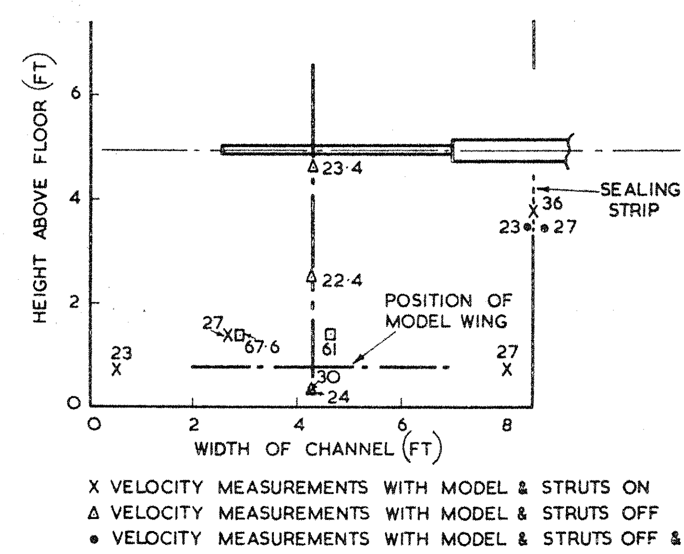


FIG.4. CONSTRUCTION OF CHANNEL FOR WHIRLING ARM FACILITY.



X ACCELEROMETER 7 FT OUTBD FROM CENTRAL COLUMN
∘ ACCELEROMETER 19′9½″ OUTBD FROM CENTRAL COLUMN
Δ ACCELEROMETER 23′5½″ OUTBD FROM CENTRAL COLUMN
⊗ ACCELEROMETER 29′3½″ (TIP) OUTBD FROM CENTRAL COLUMN

FIG. 5. VERTICAL OSCILLATIONS OF WHIRLING ARM.



X VELOCITY MEASUREMENTS WITH MODEL & STRUTS ON
Δ VELOCITY MEASUREMENTS WITH MODEL & STRUTS OFF
• VELOCITY MEASUREMENTS WITH MODEL & STRUTS OFF & WITH A 16 FT SEAL ON LOWER SLOT.
⊡ VELOCITY MEASURED AT THE STRUTS DURING ROTATION

FIG. 6. VELOCITY DISTRIBUTION IN CHANNEL.