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PROJECT 'Y'
PRELIMINARY LOW SPEED TUNNEL TESTS

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To - Dr. J. J. Green

A. V. Roe Canada Limited
Malton, Ontario

J. Dubbury

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PROJECT 'Y'
PRELIMINARY LOW SPEED TUNNEL TESTS

1. INTRODUCTION

The conception of Project 'Y' is based on a very large flat circular engine in which the gas flows radially outwards and is ejected at the periphery. Thus the aircraft possesses the novel feature that the jets issue from a large fraction of the wing's perimeter and, since the jet pipes must be as short as possible, the wing is of very low aspect ratio (a modified circle) (see Fig. 2.1). Further, the very high thrust weight ratio is utilized to accomplish vertical take-off and landing, the latter manoeuvre involving flight at large angles of incidence up to 90°.

The above factors place the aircraft's external aerodynamics well beyond the range of available experience. Thus, a rough preliminary investigation (under conditions for which the influence of the jets may be expected to be a maximum; i.e. low speed and high thrust and incidence) was essential to enable a future programme of tests to be planned.

The results of such a preliminary investigation are described in the following report.

2. MODEL EMPLOYED

The model employed is shown in Fig. 2.1. It was constructed as the simplest model likely to demonstrate the general magnitude of the effects. It is unrepresentative of the full scale aircraft in the following major respects.

(i) The very large pipe necessary to carry the air to the model will unfortunately have very large interference effects.

(ii) The air intake has been eliminated, and since the mass flow is very large this may be expected to have some influence.

(iii) No vertical fins are present - at this point in the design their exact form and disposition is still not finalized.

(iv) Using a cold jet it is impossible to reproduce simultaneously the correct thrust coefficient and mass flow ratio.

The incidence of the model was variable in steps by the substitution of final support pipe sections of differing radii of curvature. The available range of incidences was -.05°, +10.22°, 21.02°, 30.72°, 41.05°, 45.05°, 49.83°, 55.15° and 61.30°.

The trailing edge control surfaces between which about 40% of the jet flow is exhausted, were variable over the settings of 0, 8°, 16°, 24°, by means of a series of central locking plugs. Both control surfaces were varied in the same sense so that only η (not ξ) variations were available.

A half plane model would have eliminated the support interference effects but was not employed at this stage since it would have necessitated the manufacture of a special balance.

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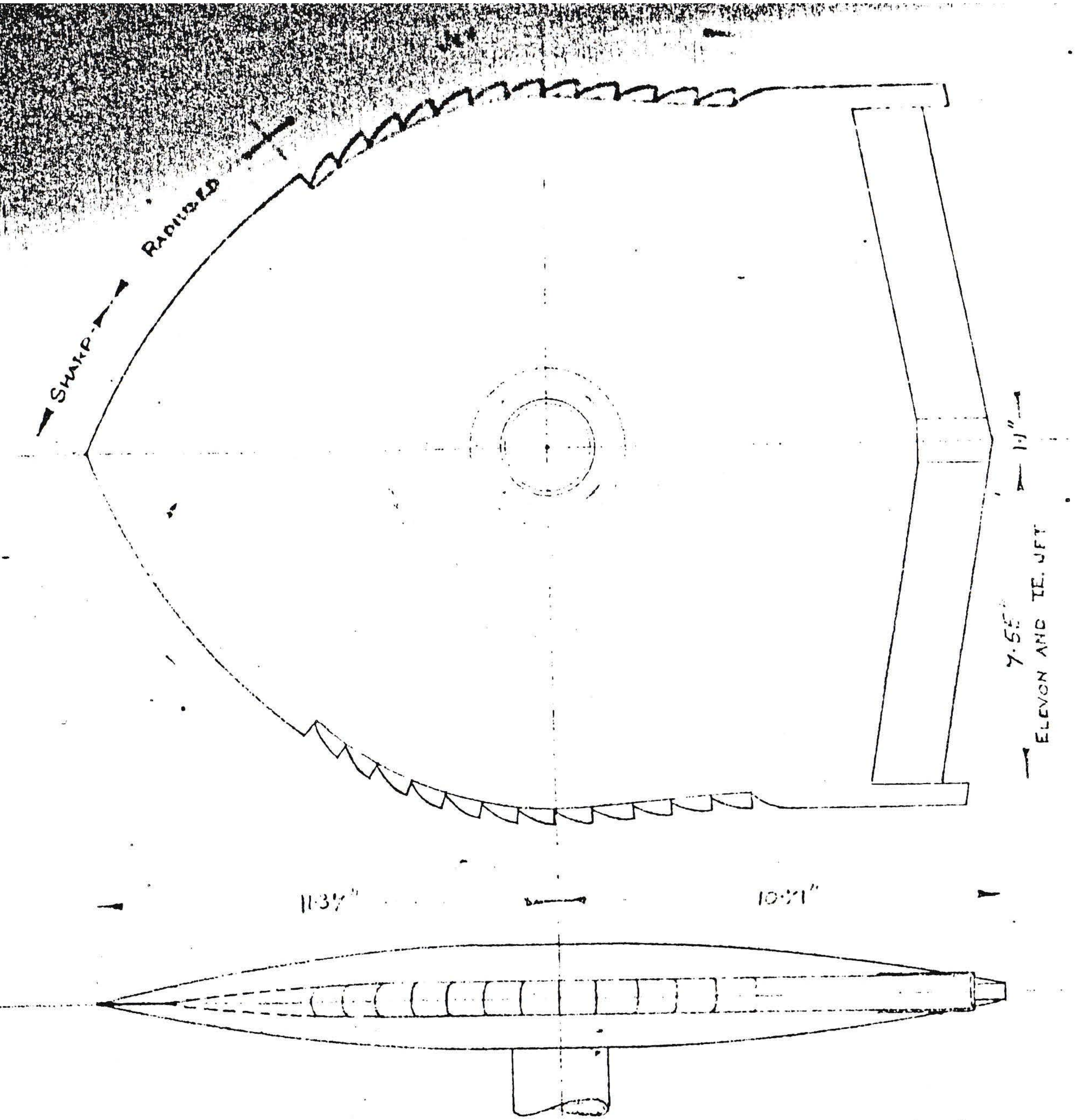
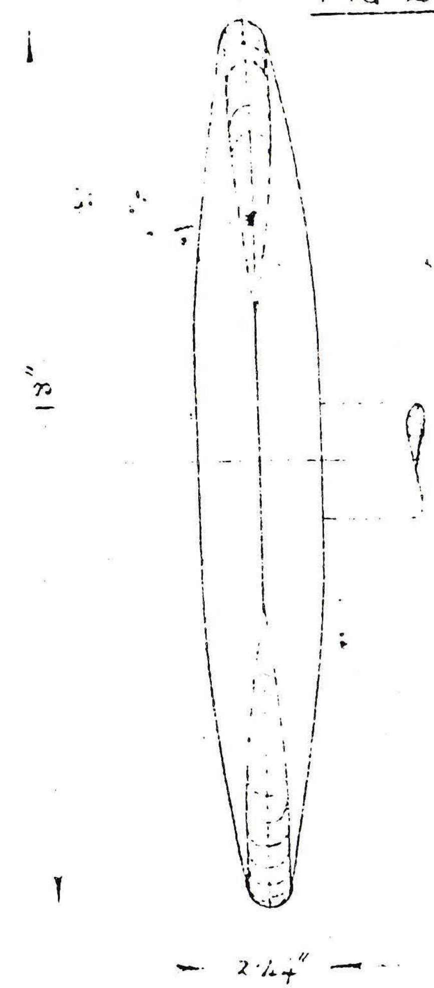
Fig 2.1.





AREA = 2·201 FT^2 (FOR ENVELOPE ENCLOSING NOZZLES)
G.M.C. = 1·46½ FT
L.E. OF G.M.C. ·25½ FT AFT OF APEX.
TOTAL NOZZLE AREA = 8 IN^2
APPROX. 4% OF THRUST VIA ELEVONS

MODEL G.A.

TEST SET UP

.e tunnel employed was the 9' x 7' low speed tunnel at Woodford, England; pable of a maximum EAS of 200 f/s.

.e disposition of the model and air supply pipes relative to the working ction is shown in Fig. 3.1. Photographs of the model as mounted are shown 1 Figures 3.2, 3.3 and 3.4 and of the air supply pipes surrounding the working ection in Figures 3.5 and 3.6.

ne two labyrinth seals were arranged as shown so that there would be no estraint or reaction on the model due to the high pressure air supply system. ne air was stored in a 1750 ft.^{3} boiler temporarily impressed for this purpose; he supply being from a 128 BHP deisel compressor, a power operated guillotine alve controlling the supply of air to the model from the tank.

he capacity of the pump was far from adequate to maintain a steady thrust at realistic level so that subsequent to the initial switch on, the thrust apidly diminished. The resulting variation of force on the model made peration of the balance by normal means (i.e. by balancing out the weigh beams via the jockey weights) impracticable. This difficulty was met by estraining the weigh beams by inductance strain gauges, the readings from which were registered continuously on micro-ammeters which were calibrated against jockey weight movement. The forces and moments on the model then being given in general by the combination of jockey weight movement and galvonometer reading. Further, the tunnel speed fluctuated significantly during the runs as a result of varying thrust and drag so that it was necessary also to continuously record q, a pitot static head being installed in the working section just ahead of and below the model. (See Figures 3.1 and 3.2).

After a small amount of initial investigation the system was adopted whereby the instruments (i.e. galvonometers registering lift and drag or moment, a pressure gauge registering tunnel q and a pressure gauge registering the supply air pressure in the final down pipe) were recorded by a ciné camera (operated on a push button single shot basis).

The tunnel balance was not capable of measuring pitching moments simultaneously with lift and drag so that separate moment and lift and drag runs were necessary.

4. THEORETICAL APPROACH

To obtain conditions of exact flow similarity the following parameters must be maintained unchanged.

(a) Mach Number.
(b) Reynolds Number.
(c) Thrust coefficient ($C_T = \frac{T}{qS}$)
(d) Mass flow ratio.

($r_m = \frac{m}{\rho S V}$ where m is mass flow slugs/sec.)

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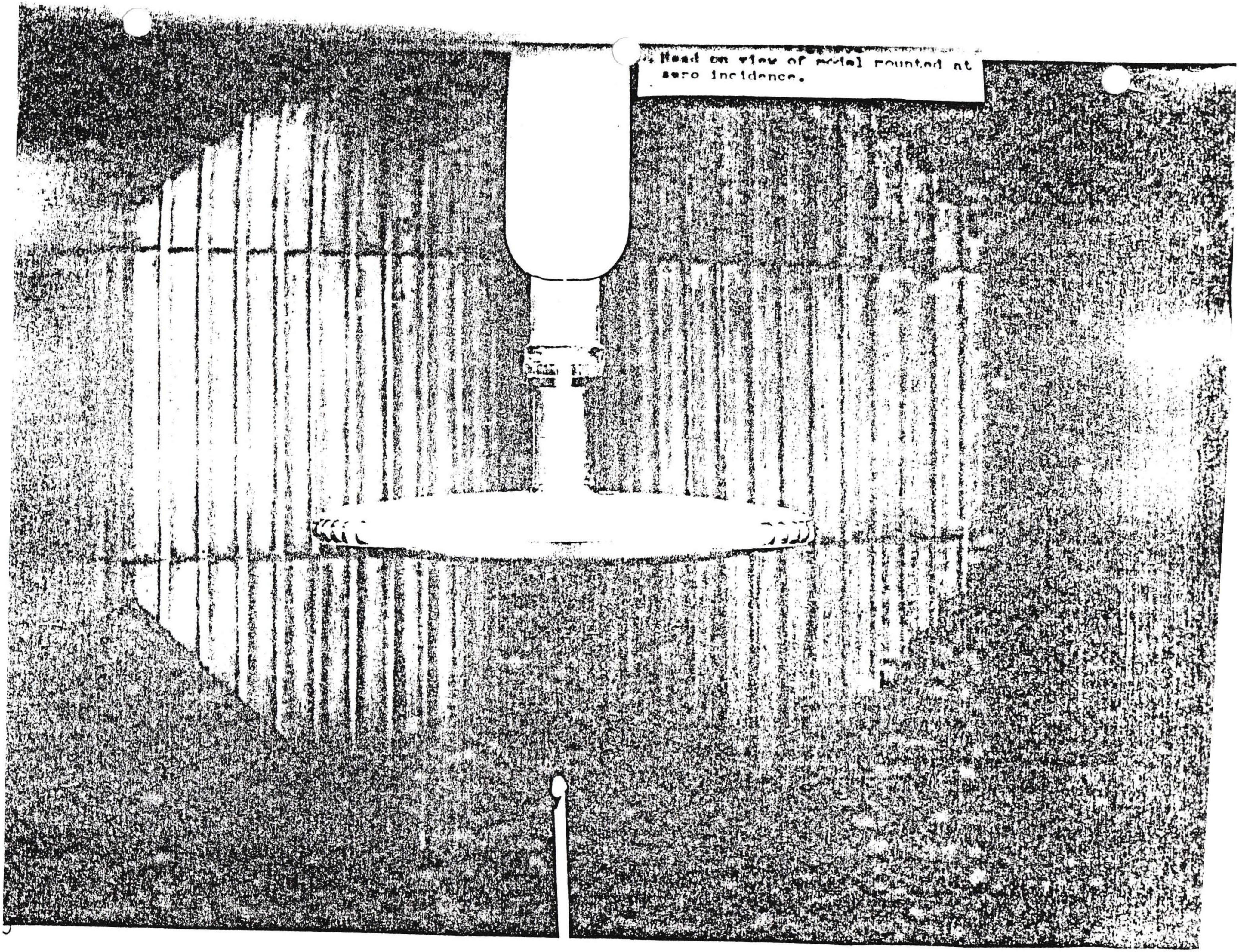
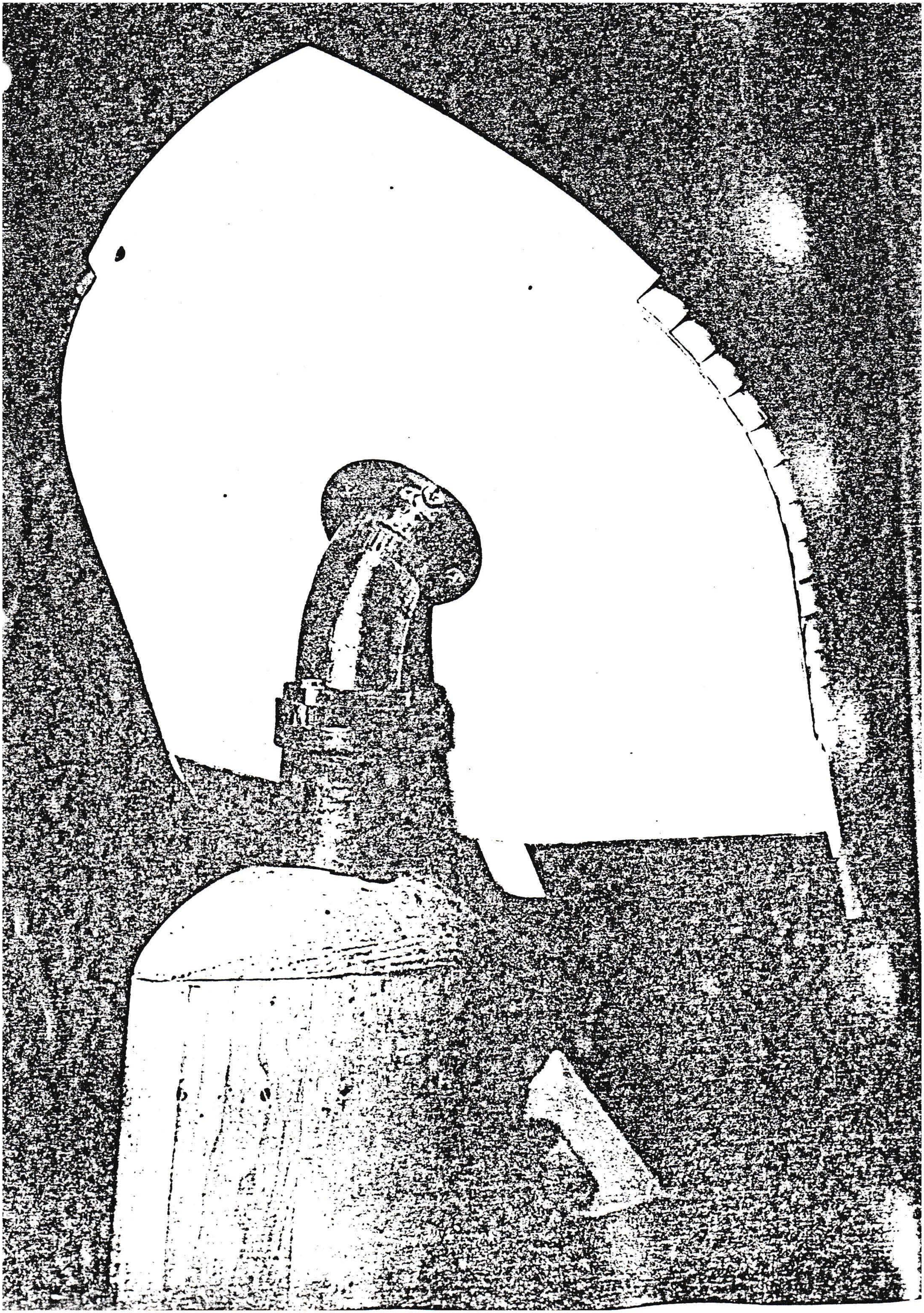


Head on view of model mounted at zero incidence.



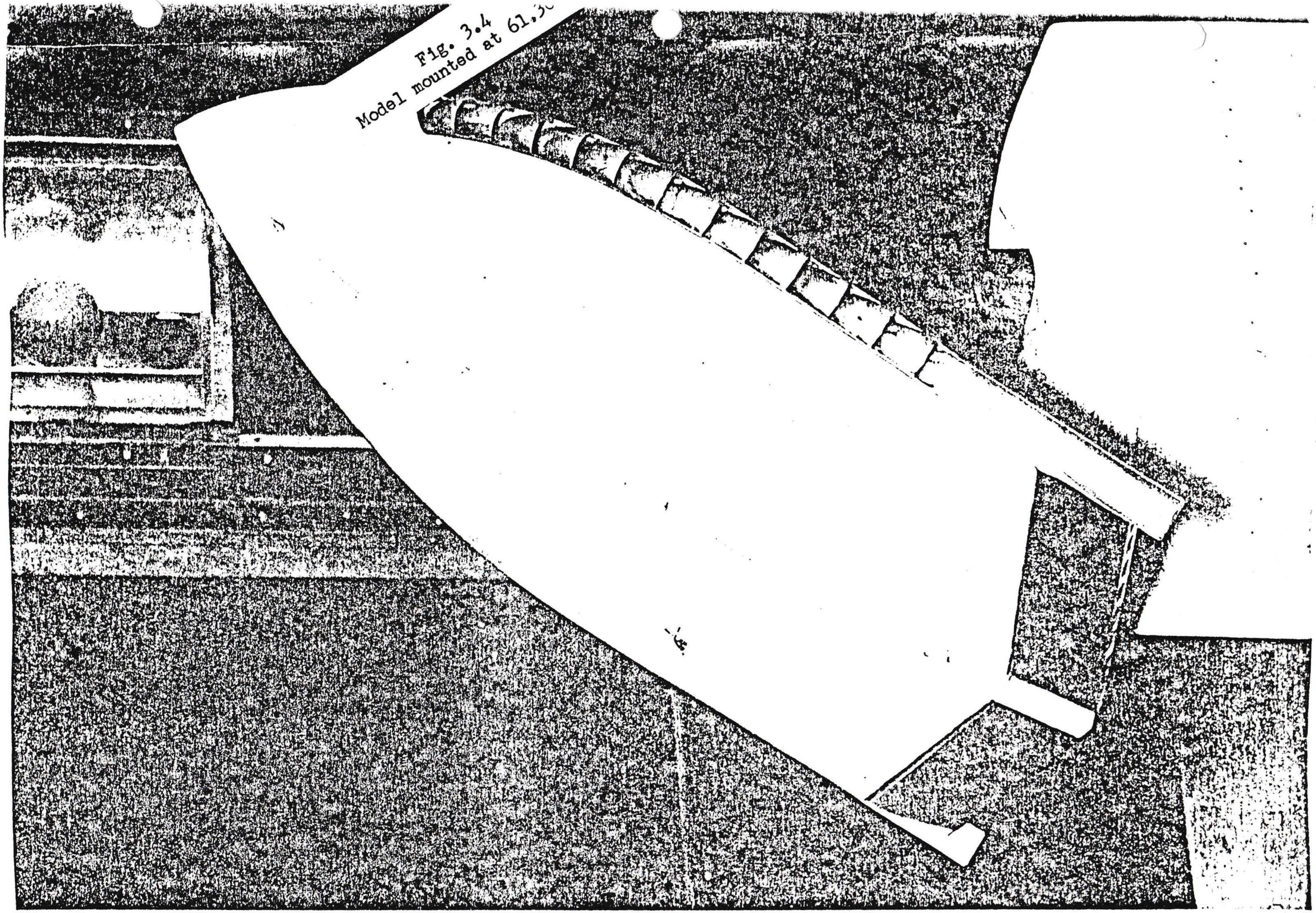


Fig. 3.4
Model mounted at 61.3

. THEORETICAL APPROACH (continued)

or normal model testing there are wide ranges over which changes in Mach umber are of negligible significance (i.e. for $M \ll M_{crit}$). However, this is ot necessarily so for the present tests since even at very low model Mach umbers the jet Mach Number will be high. Thus if C_T is of the required alue, but the model Mach Number is incorrect then (since the jet Mach umber is always high) the jet pattern will not be accurately reproduced. It is thus possible that variations in model Mach Number at the low speed end of the range may have much greater significance than is normally experienced.

Besides the conventional significance of Reynolds Number, there are present effects dependent on the viscous mixing of the main flow with the jets, which may possibly have important repercussions. (The effects of the flow induced by the jets is shown to be very large in the present experiment).

The two quantities C_T and τ_m cannot be simultaneously correct when using a cold jet; thus even if the first three quantities are correct the mass flow ratio will be too great.

It is obviously important to establish, the relative significance of the four parameters, since it is not practical in any tests, however elaborate, to reproduce all four simultaneously.

The forces in the model were (artificially) divided into two parts.

(i) Those due to the jet thrust.
(ii) Those due to the aerodynamic reactions on the aircraft.

The jet reactions on the aircraft are assumed to be those measured under static thrust conditions, and the aerodynamic reactions the difference between the tunnel on and tunnel off observations taken at identical supply pressures. Although this approach is vulnerable to detailed criticism it is in the final analysis valid in that the aircraft's behaviour is only dependent on the gross forces and moment acting on it so that how they are artificially split up is immaterial.

In these tests only the symmetric quantities, lift, drag and pitching moment have been investigated.

5. TEST RESULTS

Due to the short tunnel period allocated to these tests combined with the time initially lost in evolving a satisfactory test technique, it was not possible to compute any of the results before the conclusion of the test period. Thus two difficulties have subsequently become apparent which cast doubt on the control effectiveness and pitching moment observations.

TEST RESULTS (continued)

It was found early in the investigation that the model thrust was sufficient to produce an appreciable q in the working section. Since observations of static thrust were required a board was placed immediately ahead of the model to produce approximately still air conditions. This expedient was employed in all static thrust runs over the incidence range $-.05^\circ$ to 41.05° inclusive. At greater incidences it was noted that little or no q was recorded, and so for the runs 45.05° to 61.30° the board was not used. The corresponding lift and drag observations are given in Fig. 5.1.

If the force applied to the model had been in a purely chordwise direction the observations would lie along the straight lines shown. The runs are clearly divided into two groups.

(i) Those for which a board was placed in front of the model; the smaller incidences.

(ii) Those for which no board was used; the higher incidences.

In the former cases the line of action of the resultant forces is near to the anticipated chordwise direction but the general scatter is high. This latter suggests that the board was responsible for appreciable buffeting.

In the latter cases the initial observations were approximately in the right direction but a large angular error rapidly developed and was maintained throughout each run. The amount of scatter present in these runs is much reduced. A reasonable explanation of this systematic drift is that the action of the jet efflux induced a circulation within the confines of the working section of sufficient magnitude to cause appreciable normal forces on the model.

It is possible that reactions at the labyrinth seals and asymmetries in the model jet system might have contributed to the above phenomenon; however, it seems certain that such effects, if present, are very small as they would represent consistent errors occuring at all incidences.

In the light of Fig. 5.1. a decision had to be made as to what would be acceptable values of static thrust and their corresponding lift and drag components. What has been assumed throughout the rest of this report is that the chordwise component of the observed forces represents the true gross static thrust; this is then split into lift and drag components for subtraction from the total lift and drag measurements to give aerodynamic quantities on which C_L and C_D are based.

Using the above assumption, static thrust is plotted against indicated supply pressure for each incidence in Fig. 5.2.

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TEST RESULTS (continued)

he uneven spacing of the various incidence curves means that at a given supply ressure, the thrust varies irregularly with incidence; which is demonstrated y the cross plot of Fig. 5.2 given in Fig. 5.3. There would seem to be no alid reason for doubting these thrusts, so that it must be concluded that the ariations correspond with blockage differences associated with the incidence daptor pipes.

he joint between the adaptor pipe and the final down pipe was sealed with cork gasket. These were somewhat crudely cut and had to be changed from time o time.

If the variations in thrust were partly due to blockage differences caused by these gaskets, then there may exist considerable thrust disparities between those run on which moments and those on which lifts and drags were measured. The moment corrections due to thrust were appreciable as the balance virtual centre was not on the chord line. Thus the lift and drag coefficients can be expected to be of greater accuracy than the moment coefficients.

In Figures 5.4 and 5.5 the variations of C_L and C_D have been plotted against C_T, all observations having been taken at a tunnel EAS of approximately 160 f/s and no corrections having been made for support interference or tunnel constraint. The dotted portions of the curves are regions over which no observations have been made. The observed points have been plotted for $\alpha = -.05^\circ$, 21.02°, 41.05° and 61.30° to show the general level of scatter present.

In Figures 5.6 and 5.7 these curves have been cross plotted to show the variation of C_L and C_D with α at various values of C_T.

In an effort to show the influence of C_T on lift/drag ratio C_L is plotted against C_D in Fig. 5.8. In this figure support interference has been approximately corrected for by reducing all C_L values at a given C_T by ΔC_L such that $C_L = 0$ at $\alpha = 0$. Similarly all C_D values at a given C_T are reduced to make $C_{Do} = .01$.

In an effort to check the effect of changes of Mach Number and Reynold's Number at a given incidence, runs were made at four tunnel speeds (EAS = 160, 140, 120 and 80 f/s) at $\alpha = 45.05^\circ$. These results are plotted in Figures 5.9 and 5.10.

The moment observations are probably of much smaller accuracy than the lift and drag measurements for the following reasons;

(i) The possible thrust discrepancies already mentioned.
(ii) The large contribution of support drag and interference to the measured moment. If the strut drag was appreciably influenced by the flow induced by the jet efflux, this will introduce large and unknown errors.

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5. TEST RESULTS (continued)

For the above reasons only three of the moment runs have been analysed; those at $\alpha = 30.72^\circ$, 45.05° and 61.30°.

The C_M against C_T curves (corrected by use of the support effects measured at $\alpha = 0$ thrust off) are given in Fig. 5.11. The corresponding C.P. positions (in terms of GMC) and based on model normal forces are given in Fig. 5.12.

The effects of the jet thrust on lift and drag having proved to be great at large incidences, the wing was tufted in an endeavour to obtain a qualitative impression of the corresponding flow pattern. The majority of the tufts were supported on pins about half an inch above the upper surface. An incidence of 41.05° was used and photographs taken thrust off and on. Unfortunately, the model being finished in pale blue, many of the tufts are only barely visible on the negative, and thus for the sake of clarity, tracings have been taken which are reproduced in Figures 5.13 and 5.14.

6. CONCLUSIONS

The most important results are those associated with lift and drag. These are:

(i) That the flow induced by the jet efflux maintained unstalled flow ver the wing up to the highest incidence tested (61.30°).

(ii) That this unstalled condition of the wing occured for a wide range of thrust coefficients <u>below</u> that required for steady level flight, so that it may be concluded that the aircraft will never stall during the landing manoeuvre (take-off incidences are always small). This fundamentally eases landing as there will at no time be any sudden change of aerodynamic force (or presumably moment) (see Figures 5.6 and 5.7).

(iii) That the lift and drag coefficients at large incidences are very large (e.g. $C_L = 2.45$ at $\alpha = 47^\circ$ and $C_T = 1.8$ and $C_D = 2.84$ at $\alpha = 60^\circ$ and $C_T = 1.8$). The large drag coefficients will be of great value since they will materially reduce the time required to reduce speed for landing.

(iv) That these large coefficients represented such large forces on the model as to be of good accuracy (e.g. the increase of drag associated with switching on the jet far exceeded the negative drag component of the thrust at all the higher incidences, so that small errors in the assumed magnitude or line of action of the thrust will represent a small percentage error).

(v) That the presence of the jet materially increased $dC_L/d\alpha$ at incidences less than the thrust off stall (see Fig. 5.6).

(vi) That at smaller incidences the lift drag ratio has been improved by the presence of the jet. In combination with (v) this suggests that the effective aspect ratio has been increased, and holds out the hope that the subsonic cruising conditions may be better than could normally be expected from an aircraft of aspect ratio unity.

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6. CONCLUSIONS (continued)

(vii) That the desirable characteristics mentioned above are essentially due to the peripheral jet system inherent in the Project 'Y' design.

The runs aimed at determining the significance of changes in Mach Number and Reynold's Number suggest at first glance that C_T is the primary parameter but that Mach Number and/or Reynold's Number are not without significance in the range tested. However, it is possible that variations in support interference might be responsible for some of the effects. The Reynold's Number range of the final support pipe (based simply on tunnel velocity) varies from about 106,000 to 213,000. Between the Reynold's Numbers of 100,000 and 560,000 the C_D of a simple cylinder drops abrputly from 1.2 to .32 (based on cylinder area). It is apparent, therefore, that no definite conclusions can be drawn from these runs and that further very careful checks are necessary in any future test programme.

The moment runs analysed (see Figures 5.11 and 5.12) suggest that the C.P. of the aerofoil is well aft at high incidence jet on. This is a highly desirable state of affairs since it simplifies the trimming problem with the far aft C.G. undercarriage down for landing. It is to be expected that the C.P. will tend to move aft due to jet influence since the extra lift is probably largely generated by the maintenance of finite pressure differences between upper and lower surfaces at the wing tips and trailing edge. However, for reasons previously mentioned the accuracy of the C_M and C.P. observations is suspect.

The tuft observations at $\alpha = 41.05^\circ$ show that:

(i) The wing is completely stalled with the thrust off. The tuft all pointing in a generally up stream direction and vibrating violently.

(ii) With thrust on the flow over all but the leading edge is unstalled and perfectly steady.

(iii) The separated flow near the leading edge is apparently suppressed well forward on the wing.

(iv) The flow is deflected outboard (towards the tip jets) on either side of the centre line.

(v) The tufts fastened on the surface (i.e. in the boundary layer) point almost directly at the nearest jets.

(vi) From (iv) and (v) it is deduced that the scavenging action of the jets (under the low speed conditions of the tests) alter the pressure distribution on the upper surface to one in which the pressure diminishes from the centre line outboard. This apparently attenuates the boundary layer to such an extent as to make flow adhesion possible at very large incidences.

These effects are of major importance and are worthy of more detailed investigation.

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6. CONCLUSIONS (continued)

In the test results given no corrections have been made for tunnel constraint. The model was small in relation to the tunnel, however, (model span 18" and tunnel width 9 ft.) which would make the corrections very small.

The span and area of the model have, however, been effectively increased by the presence of the jets, so that in future tests involving the possible use of a smaller tunnel or larger model, the question of the magnitude of correction is likely to present difficulties.

The preliminary results given in Ref. 1 have been broadly confirmed in the foregoing analysis.

It may be finally concluded that the tests have accomplished the main purpose of establishing the order of magnitude of the jet influence.

7. FUTURE TEST PROGRAMMES

It is of immediate importance to establish the relative importance of the various similarity parameters. To this end some test runs with a hot jet efflux are essential.

The trimming and control characteristics of the final aircraft will depend critically on the centre of pressure conditions and control characteristics under various flight conditions. It is impossible to determine these from the present model due to large and unknown support interference. It is essential, therefore, to build a half plane model as the next test stage.

As previously mentioned the mass flow is so high that intake characteristics may well be of appreciable significance. It will thus be necessary to consider the manufacture of a model in which, and the development of a technique by which correct intake and exhaust conditions can be represented simultaneously.

In the absence of a satisfactory theory by which to predict the affects of configuration changes on the aircraft characteristics, it will be necessary to proceed with model testing on an ad hoc basis. Thus the number of models and tests necessary will probably be considerably greater than for a conventional aircraft.

It should be borne in mind that the development of satisfactory test techniques will be difficult and time absorbing as they lie largely beyond the range of present experience.

8. ACKNOWLEDGMENT

The tests were carried out at very short notice and were only made possible by the enthusiastic cooperation, initiative and drive of Mr. E. V. Hall and his tunnel team.

REFERENCE— Preliminary Note on Project 'Y' Low Speed Tunnel Tests
T. D. Earl - July 14, 1953.

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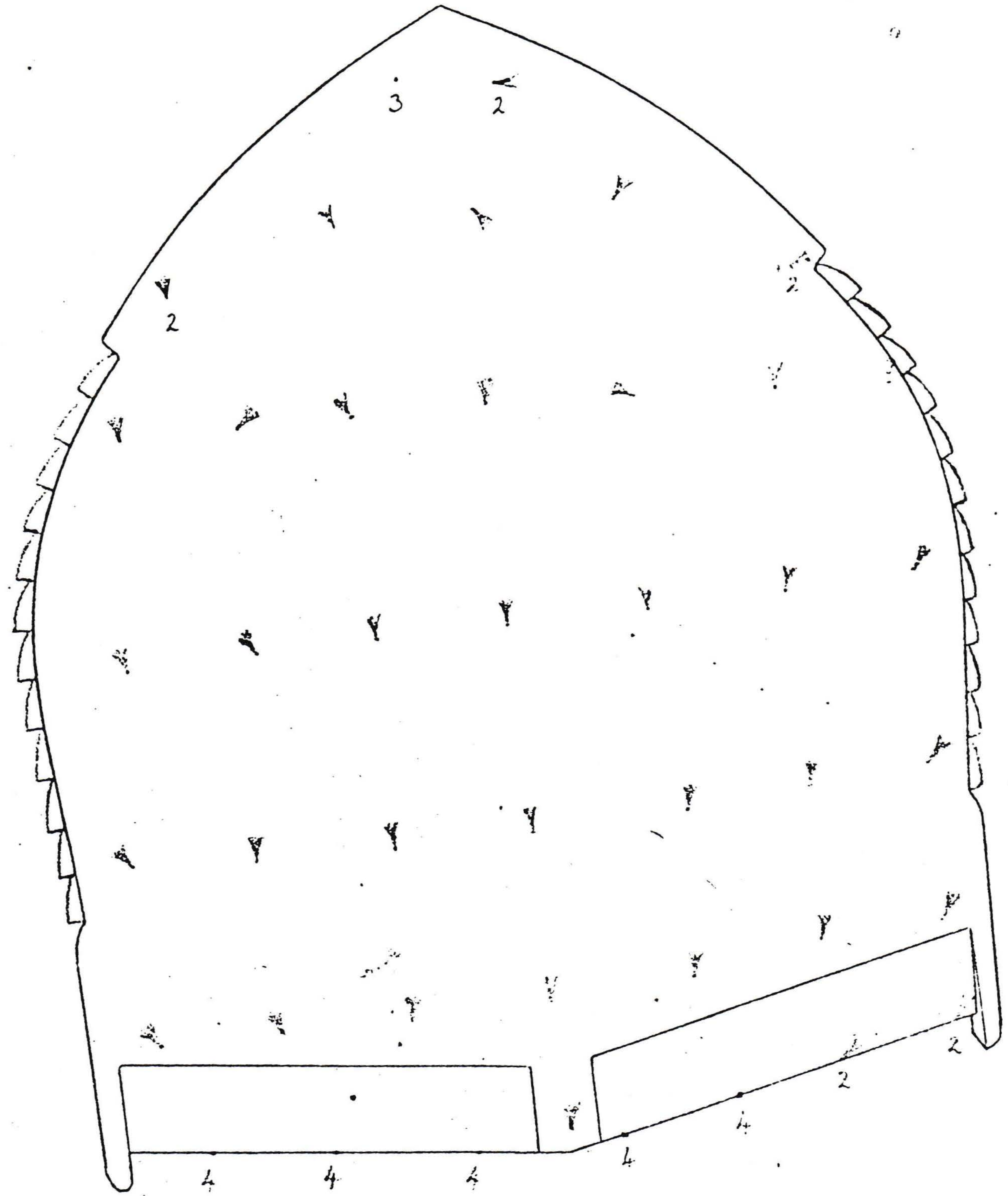
FIG 5.13

THRUST OFF $\alpha = 41.05°$

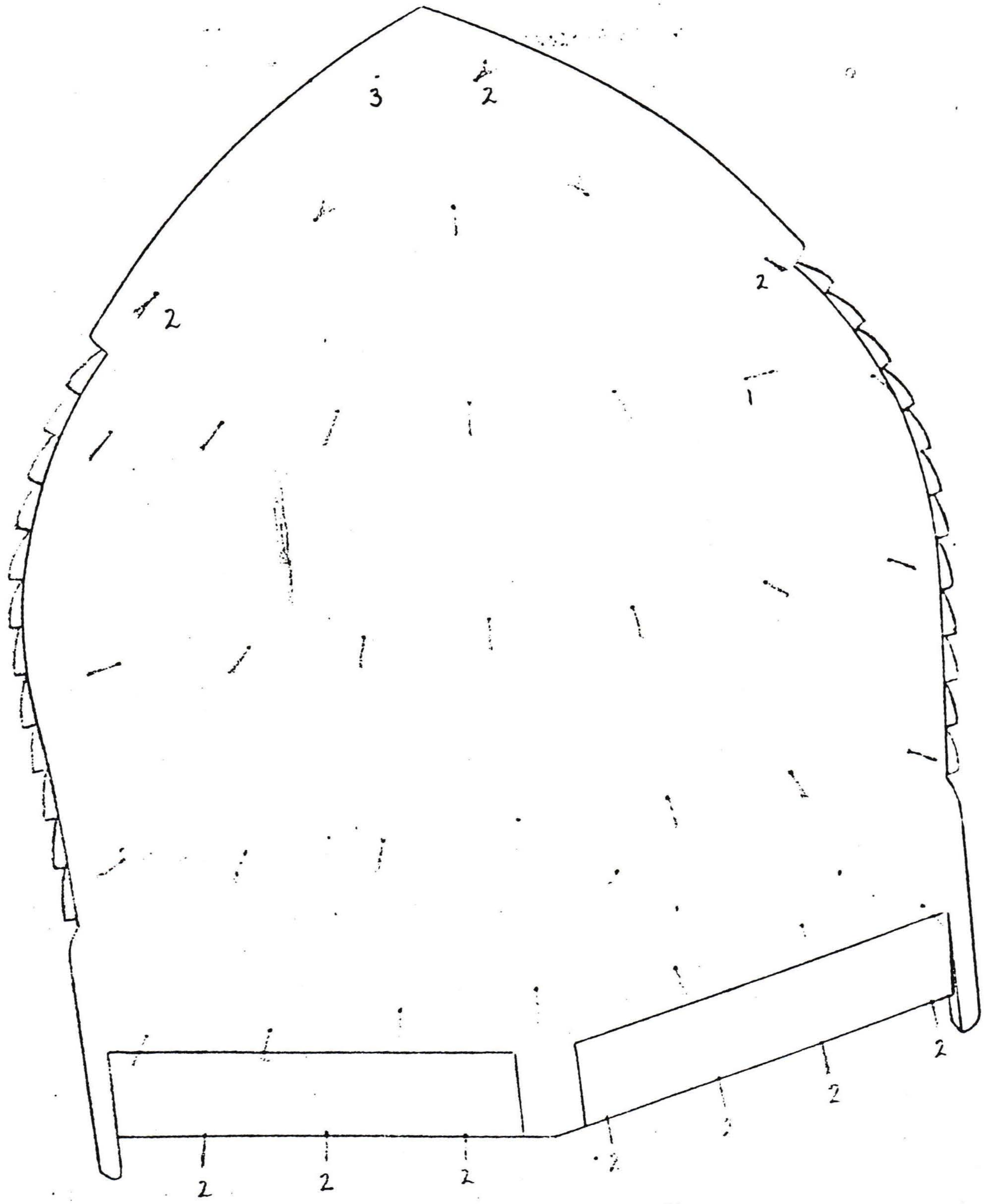


2/ TUFT ON SURFACE.
3/ TUFT NOT VISIBLE IN PHOTOGRAPH
4/ TUFT SUCKED IN BETWEEN CONTROL SURFACES.

N.B ASYMMETRY OF TRACING DUE TO CAMERA BEING TO [illegible] OF PLANE OF SYMMETRY OF MODEL.

FIG 5.14

THRUST ON $\alpha = 41.05°$



1) TUFT AT BOTTOM OF PIN ON WING SURFACE.
2) TUFT FASTENED TO WING SURFACE.
3) TUFT NOT VISIBLE IN PHOTOGRAPH.

N.B. ASYMMETRY OF TRACING DUE TO CAMERA BEING TO PORT OF PLANE OF SYMMETRY OF MODEL

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