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# Wind-Tunnel Experiments on a Simple Lifting-Jet Body with and without Wings

*By*

*W. J. G. Trebble, B.Sc.*

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# WIND-TUNNEL EXPERIMENTS ON A SIMPLE LIFTING-JET BODY WITH AND WITHOUT WINGS

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W. J. G. Trebble, B.Sc.

## SUMMARY

Low-speed wind-tunnel tests have been made on a body with a vertical jet efflux to investigate the interference loads arising from the interaction between the mainstream and the efflux. As the ratio of free-stream velocity to jet efflux velocity is increased from zero, the lift increment due to the jet is reduced by the interference and a nose-up pitching moment increment is produced. Forward movement of the jet exit increases the lift loss. If a wing is fitted, an appreciable alleviation of the lift loss arises from the circulation lift carried on the wing, but the nose-up pitching moments are larger.

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## 1 INTRODUCTION

During the past few years, considerable effort has been devoted to the development of V/STOL schemes for aircraft including the possible use of multiple lifting engines mounted in nacelles. Wyatt[1] has made comprehensive wind-tunnel tests of a simple installation containing two ducted fans mounted in a nacelle to which wings can be attached in either a high or a low position. The results of these tests showed that the effect of increasing mainstream speed is to produce large lift losses, together with nose-up pitching moments which are much large than can be explained by simple considerations of the effect of intake momentum drag. This lift reduction is largest when only one ducted fan is operated, and a marked deterioration is observed when the fan is moved to a more forward station. It would appear that the lift loss is caused by a low pressure region on the underside of the body behind the duct exit.

Since these experiments were made with both the intake and the exit represented, it was not possible to isolate their respective effects. Measurements have therefore now been made on a similar (but smaller) blowing model to determine the interference between the mainstream and the jet efflux alone, i.e. without an upper surface intake.

## 2 DETAILS OF MODEL AND TESTS

Tests were made in the No.1 $11\frac{1}{2}$ ft × $8\frac{1}{2}$ ft wind-tunnel at R.A.E. Farnborough on the model illustrated in Fig.2, which is a 0.7 scale version of the one tested by Wyatt[1] in the 13 ft × 9 ft wind-tunnel at R.A.E. Bedford. The body could either be tested in isolation or with an unswept high wing of gross aspect-ratio 1.8. The wing mid-chord point was located halfway along the body. A special dural pressure-box (Fig.3) could b fitted into the body with its centre at either 0.41 or 0.59 of the body length. The model was hung on a pair of struts from the overhead balance. For convenience, the pivot point was slightly above half depth at the fore-and-aft position of the centre of the jet exit, but the results have been corrected to give moments about the geometric centre of the body and, alternatively, the centre of the jet exit.

The external air-feed system, illustrated schematically in Fig.1, is similar to that used in Ref.2, where it is described in greater detail. Compressed air is passed through a 3 inch diameter ring main into eight equally spaced flexible tubes and hence into the base of the strut leading to the pressure-box (Fig.3) inside the model. The original strut was made of brass but, because of its weight and length, small errors in incidence produced quite large changes in the zero readings on the pitching-moment balance. Hence, for the present tests, a new strut was made from glass cloth and araldite, the strut weight being thereby reduced from 45 lb to 9 lb, so that no difficulty was experienced in repeating pitching-moment zeros. A strut guard, extending from the floor of the tunnel to a point about 6 inches from the upper surface of the model, was used to protect most of the strut from external aerodynamic forces. The small part of the strut exposed to the mainstream had an elliptic cross section but, within the strut guard, the section quickly changed to a circle with its diameter equal to the major axis of the ellipse. Inside the body, the top of the pressure-box could be changed (Fig.3) so that the strut could hang vertically at model incidence angles $-10^\circ$, 0 and $+10^\circ$.

To ensure good accuracy in the repeatability of incidence measurements, a beam of light was reflected from a concave mirror on the model to a ground glass screen in the tunnel roof. The calibration of this screen provided about 2 inch movement per degree, so that the incidence angle could be maintained to 0.02 degrees even with an allowance for model vibrations at relatively high mainstream speed. The absolute angle of incidence was measured with an inclinometer at zero mainstream speed.

Measurements were made of the lift, drag and pitching moment of the model, both with and without wings, over a range of mainstream speed from 0 to 80 ft/sec at angles of incidence of 0° and ±10°.

The mass-flow rate of the compressed air was measured with the aid of a 4 inch diameter orifice plate in a 6 inch diameter supply pipe. The jet efflux velocity ($V_J$) was determined from the mass flow, as the mean velocity through the exit which had an area of 0.200 sq ft; fortunately, mainstream flow had no effect on the jet velocity for a given supply pressure. Static pressure measurements were also made at the base of the strut and inside the pressure-box.

## 3 EXPERIMENTAL RESULTS

Non-dimensional increments in lift and pitching moment due to the jet can conveniently be plotted against the ratio of mainstream speed to jet efflux velocity. There is progressive reduction in the lift increment due to the jet as the mainstream speed is increased (Fig.4), accompanied by a tendency for this deficiency to become greater as the incidence becomes more positive. As expected, the reduction in lift is greater when the efflux emerges from the forward duct, because there is then a larger lower surface area aft of the jet to carry the suctions created by the interaction of the mainstream and the jet efflux. When the mainstream speed reaches about one-third of the jet efflux velocity, there is some decrease in the rate of reduction of lift increment with mainstream speed.

On the isolated body, a further increase in the mainstream speed to half of the jet efflux velocity results in a further steepening of the rate of loss of lift with mainstream speed, to such an extent that about half of the installed lift is lost. There is very little effect on lift when wings are added to the model with a forward jet (Fig.7) but the wings have a significant favourable effect with the jet in the aft position. Moreover, with the aft jet on the winged model (Fig.4b), the lift increment even begins to recover again at the high mainstream speed. This implies that the circulation induced about the wing by the jet efflux increases as the latter is moved closer to the wing trailing edge, as might reasonably be expected.

With moments taken about the body centre, the forward jet produces a large nose-up moment at zero mainstream speed, whilst the aft jet gives an equally large nose-down moment (Fig.5), as would be expected from the geometry. Mainstream speeds of up to one-third of the efflux velocity have little effect on the moment contribution from the forward jet, but with the aft jet there is a rapid reduction in the nose-down moment as the mainstream speed is increased, at least above a speed ratio of one-tenth. With further increases in mainstream speed, the moment contributions become more nose-up, even with the forward jet.

For the fundamental consideration of the mainstream interference effects, it is more helpful to discuss moments taken about the centres of the respective jet exits, as in Fig.6. There is then a steady increase in nose-up moment due to interference as the mainstream speed is increased, in all cases the rate of increase being greater on the winged model (Fig.6b). On the isolated body there is a tendency for a larger nose-up moment contribution from the forward jet than from the aft jet as would be expected from the greater lift loss. Such moment increases can, of course, arise from either movement of the centre of the interference load behind the jet exit, changes in the magnitude of the downward load, or both. On the winged model, the greater nose-up moments are in contrast associated with the aft jet because substantial jet induced circulation lift is then carried on the wing.

In Fig.8, the position of the centres of action of the interference load is plotted against the ratio of mainstream speed to efflux velocity. The downward interference load on the body alone moves rapidly rearwards as the mainstream speed is increased to about one-fifth of the efflux velocity. Further increase in mainstream speed moves the interference load slightly forward but, with a mainstream speed exceeding a third of the efflux velocity, the load centre again moves aft. With wings fitted and the aft jet, the extra upward interference load due to jet induced circulation round the wing acts near the wing leading edge. The extra load due to wing circulation induced by the forward jet is so small (Fig.7) that it is not possible to make a realistic appraisal of the position at which the load acts.

## 4 CONCLUSIONS

The effect of the interaction between a uniform stream and a jet efflux emerging perpendicularly from a body is to reduce the lift increment due to the jet. The negative interference lift thus produced acts behind the jet exit, giving a nose-up moment contribution. Forward movement of the jet exit increases the size of the interference. On a winged model, the lift losses are not as high as on an isolated body because the efflux induces favourable wing circulation lift, but this extra lift is accompanied by greater nose-up moments.

From forthcoming experimental results on a geometrically similar model with a ducted fan instead of a pure jet, it should be possible to derive the effects due to the addition of an upper surface intake.

## LIST OF SYMBOLS

| | |
|---|---|
| $\ell$ | length of body |
| d | exit diameter of jet |
| X | distance of centre of action of interference load from centre of body, positive rearwards |
| $V_o$ | mainstream velocity |
| $V_J$ | jet efflux velocity |
| T | installed thrust |
| $\Delta L$ | lift increment due to the jet |
| $\Delta D$ | drag increment due to the jet |
| $\Delta M$ | moment increment due to the jet |
| $\alpha$ | angle of incidence |

## LIST OF REFERENCES

| No. | Author | Title, etc. |
|---|---|---|
| 1 | Wyatt, L. | Wind tunnel experiments on a nacelle containing two lifting fans, with and without wings.<br>Unpublished M.O.A. Report. |
| 2 | Trebble, W.J.G. | Some wind-tunnel experiments on a bluff body with a lifting jet.<br>Unpublished M.O.A. Report. |

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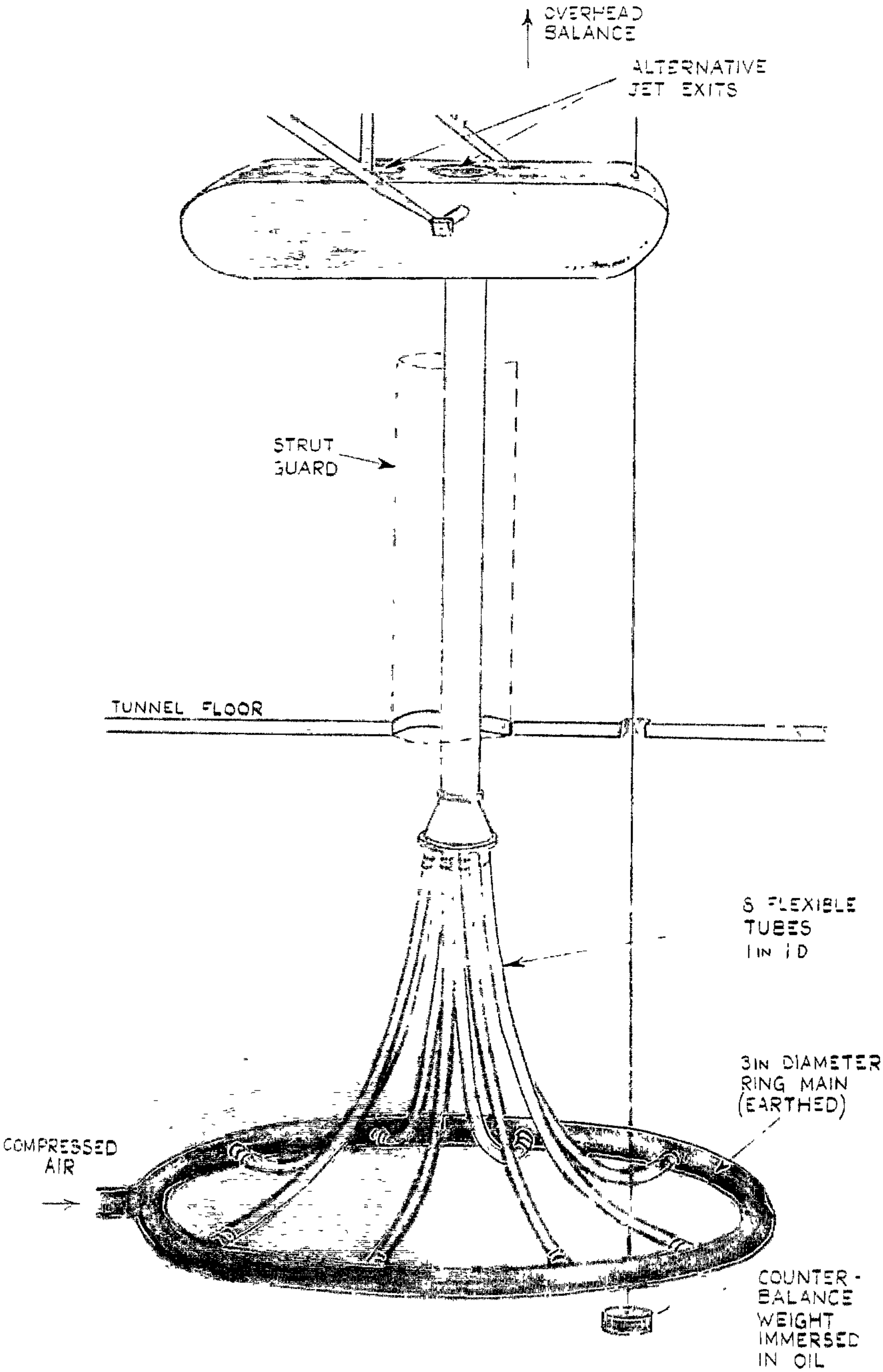


FIG I SCHEMATIC VIEW OF MODEL AND RIG.

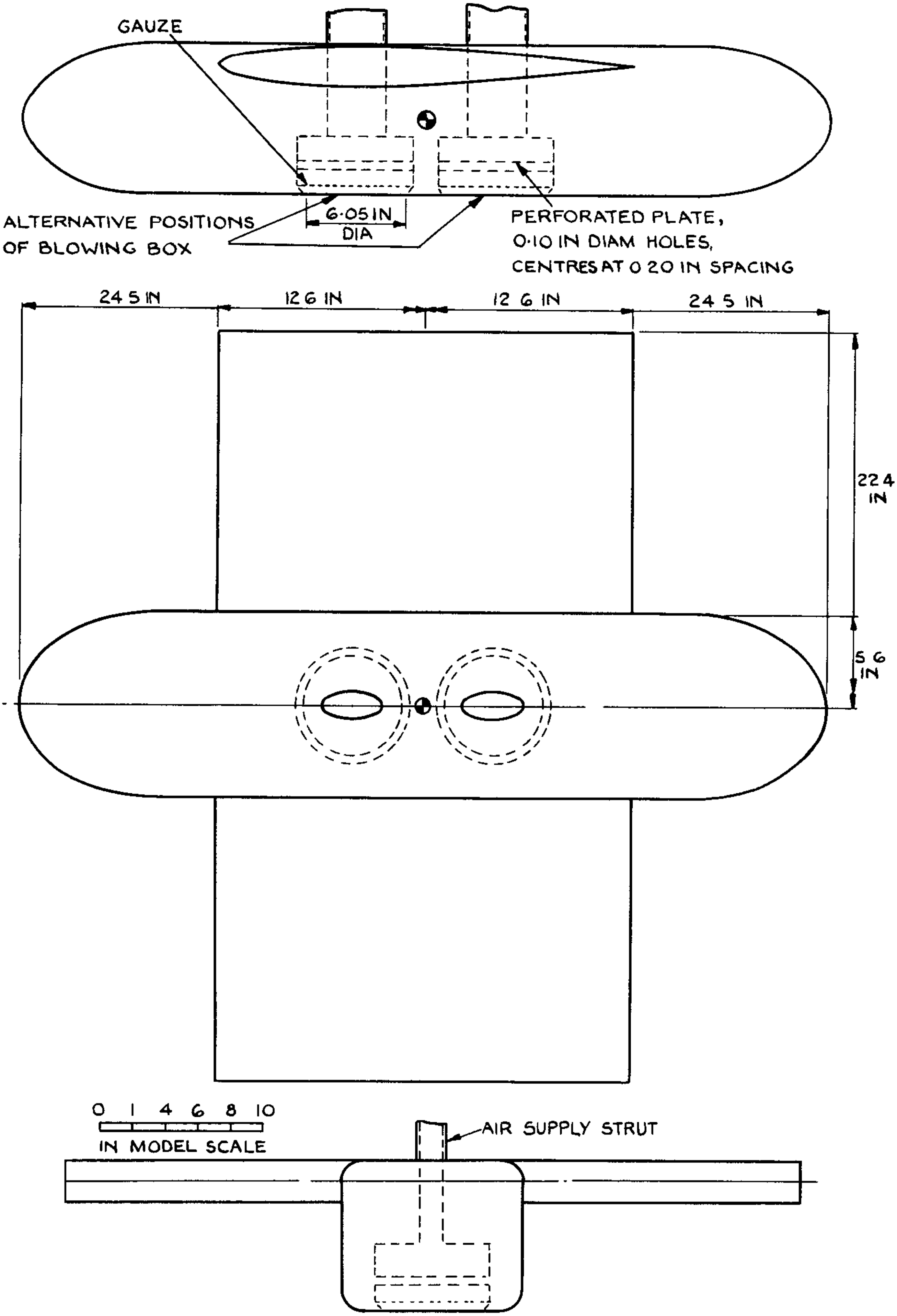
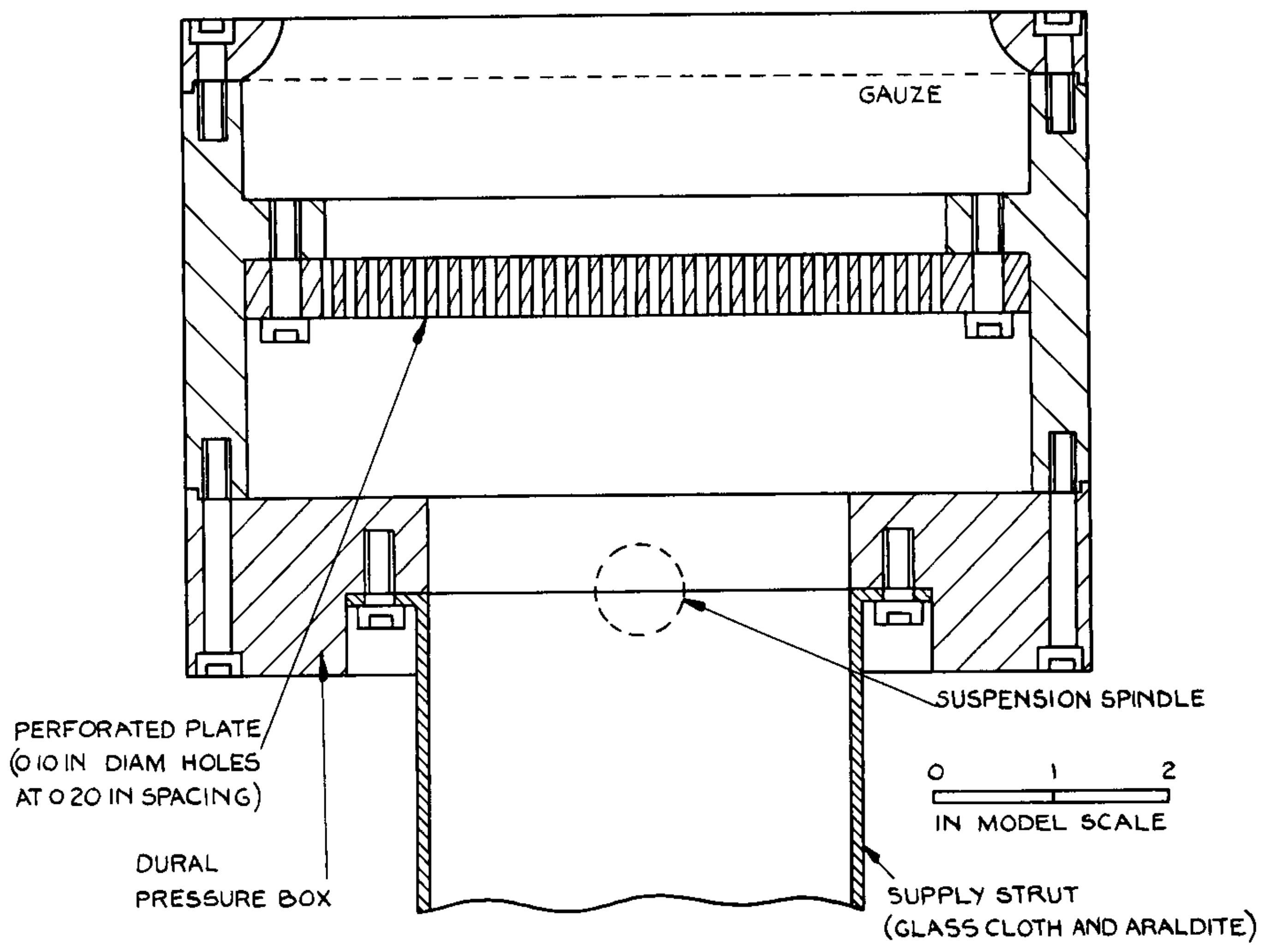
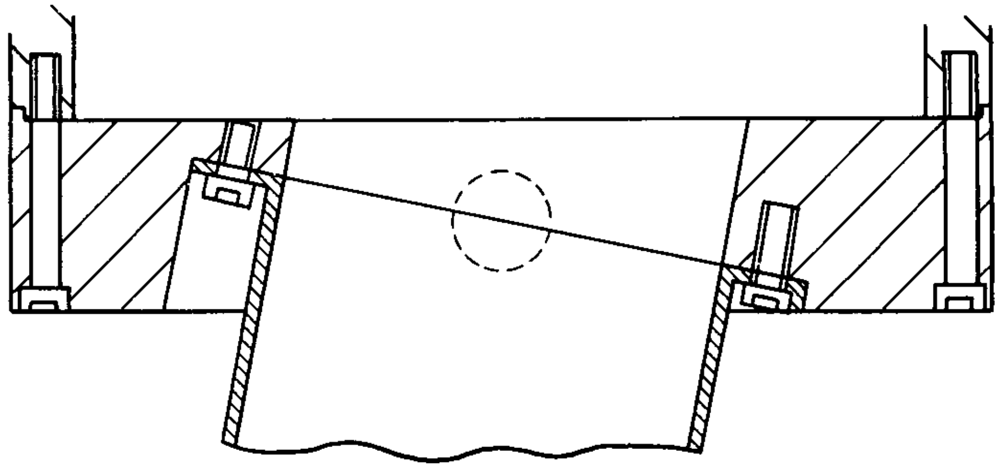


FIG. 2. G.A. OF MODEL.

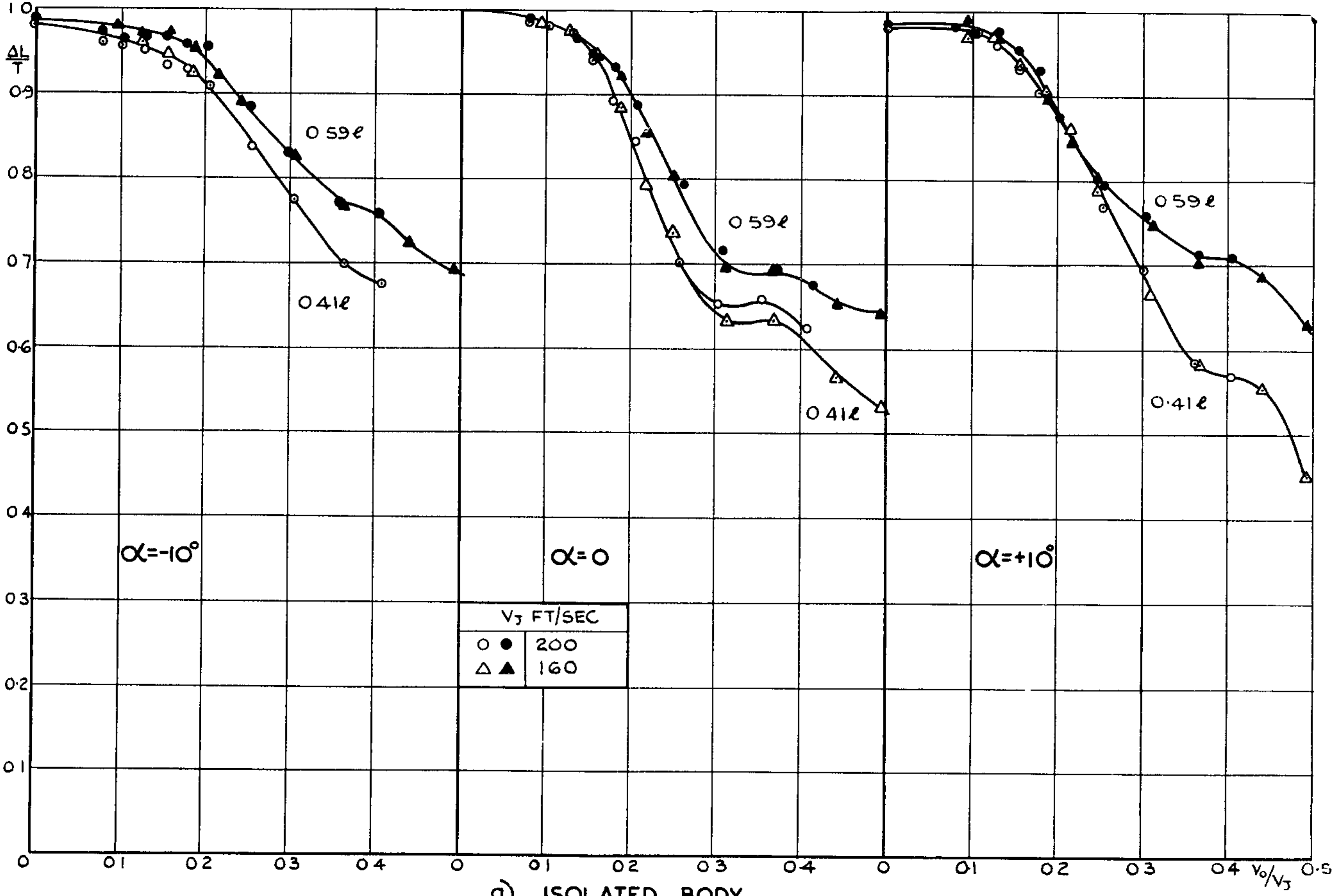


a) PRESSURE-BOX FOR ZERO INCIDENCE TESTS



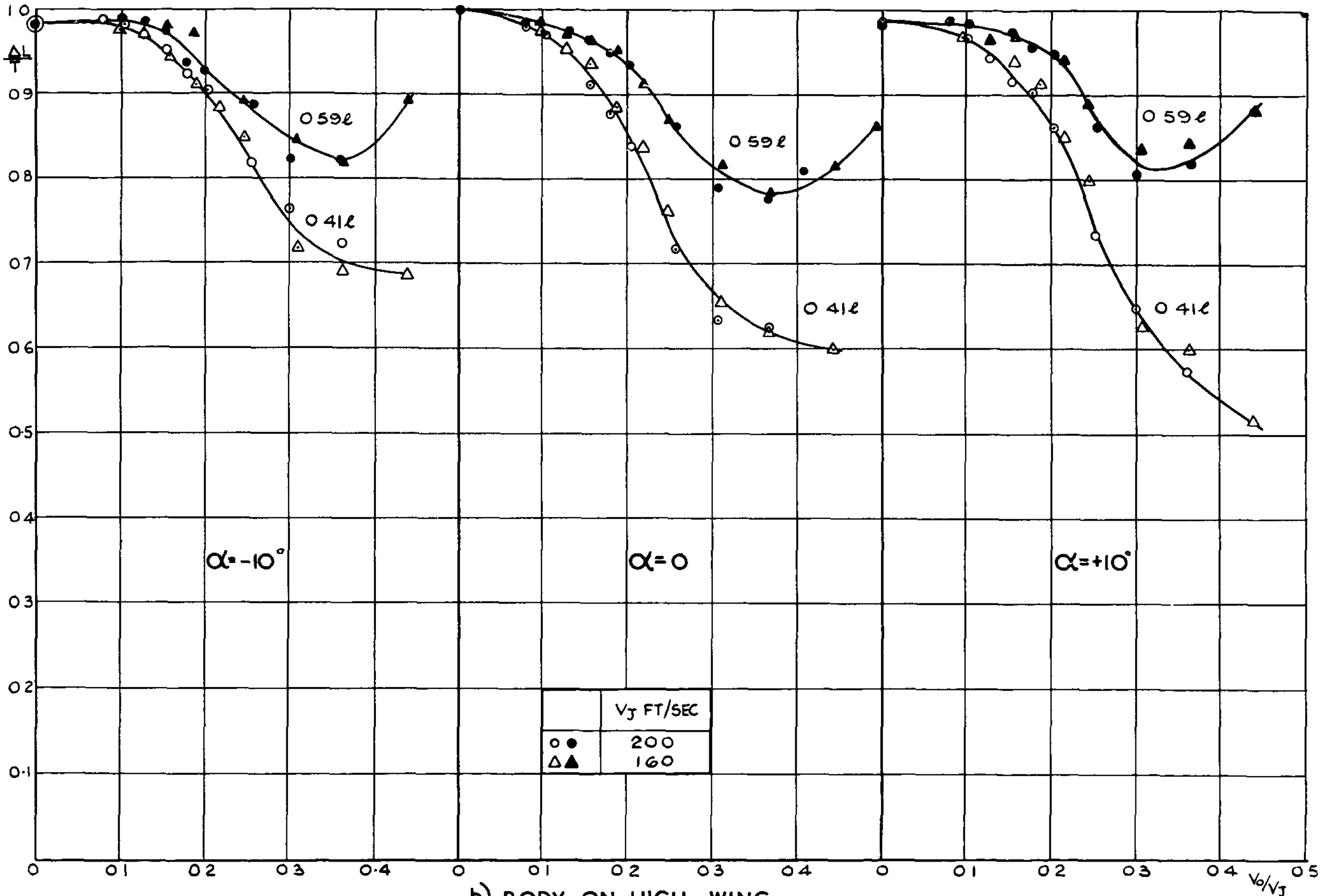
b) ADAPTOR FOR $\alpha = 10°$

FIG 3. SECTION THROUGH CENTRE OF PRESSURE-BOX



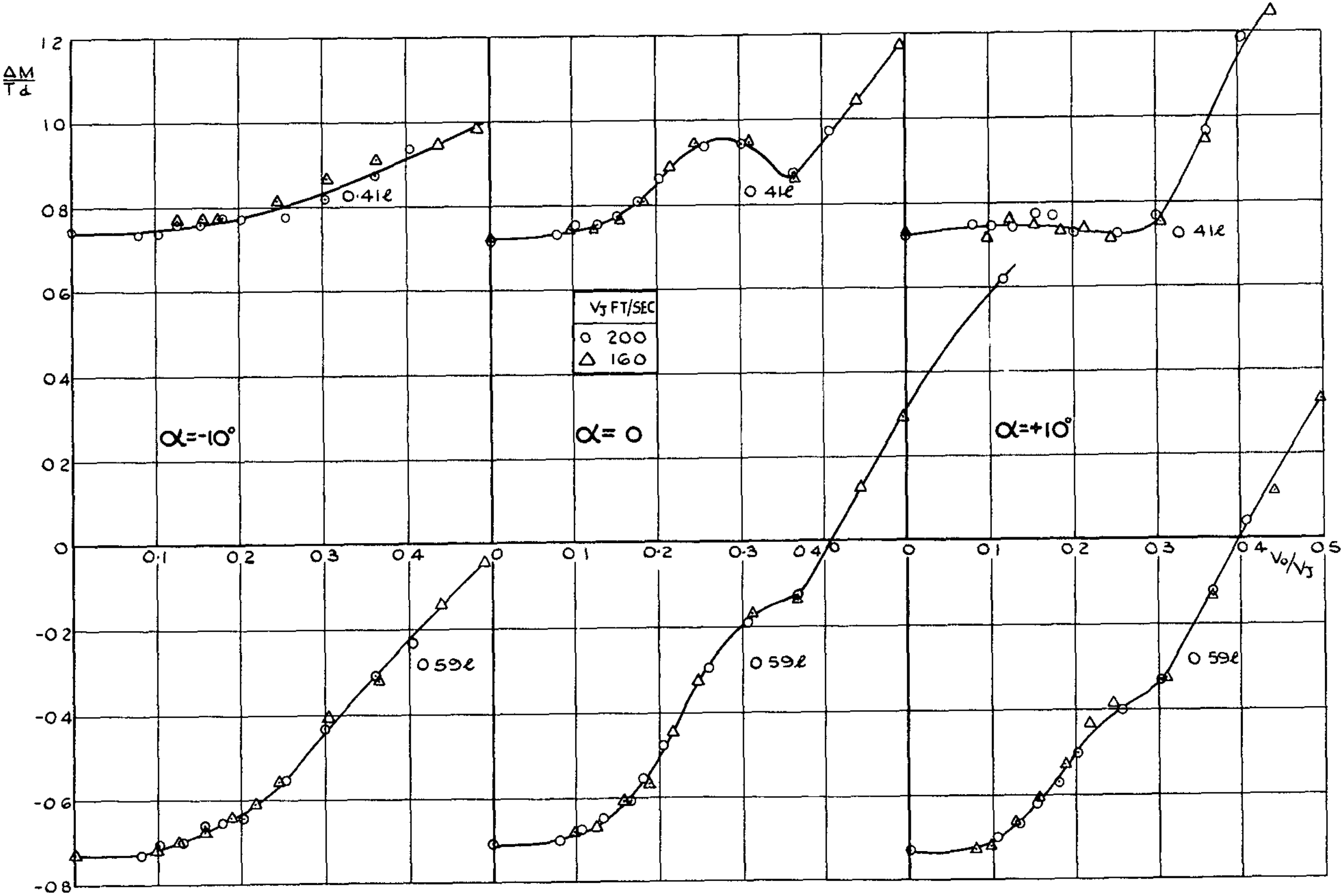
a) ISOLATED BODY

FIG. 4. EFFECT OF MAINSTREAM SPEED ON LIFT INCREMENT.



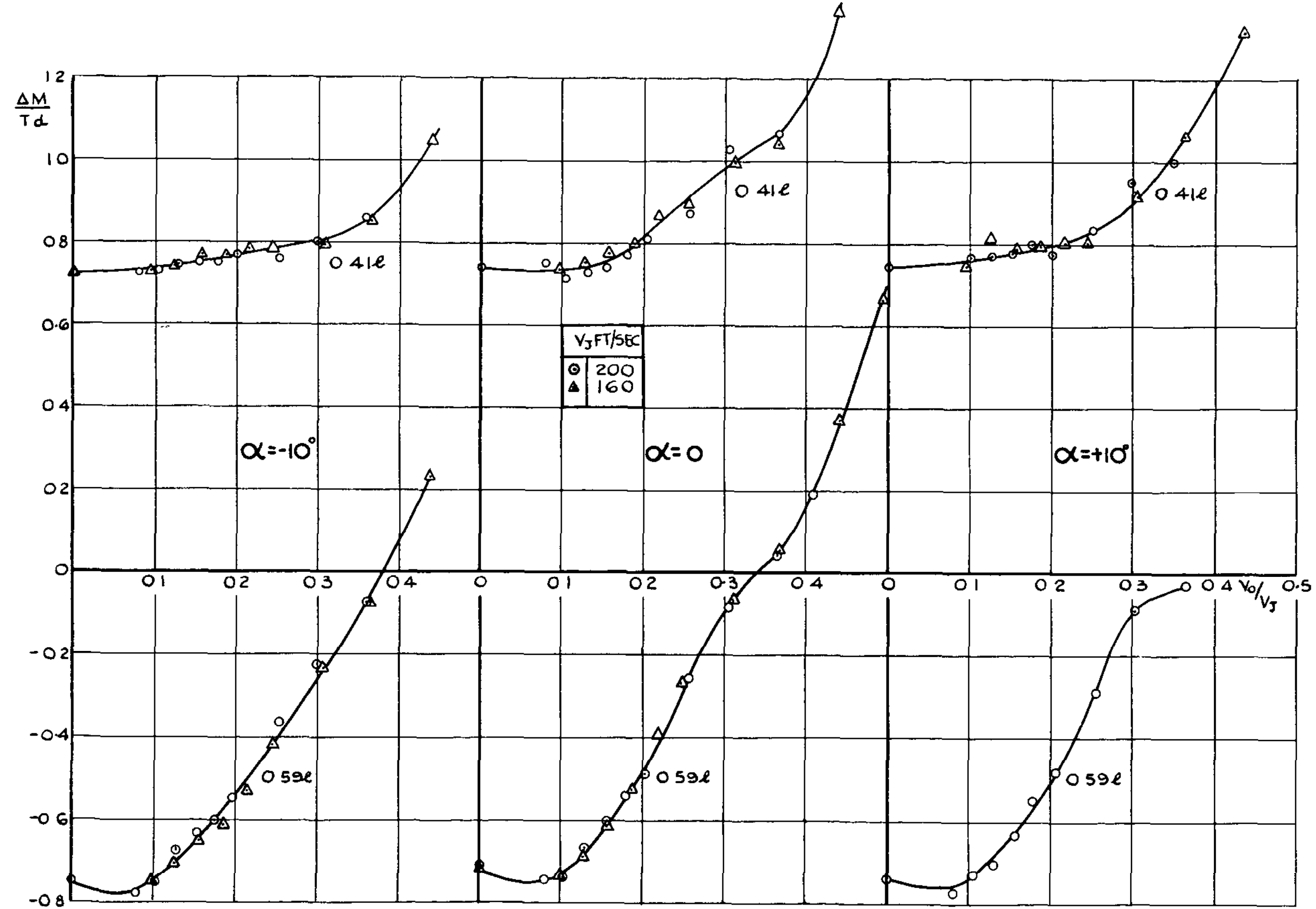
b) BODY ON HIGH WING

FIG. 4. (CONT.)



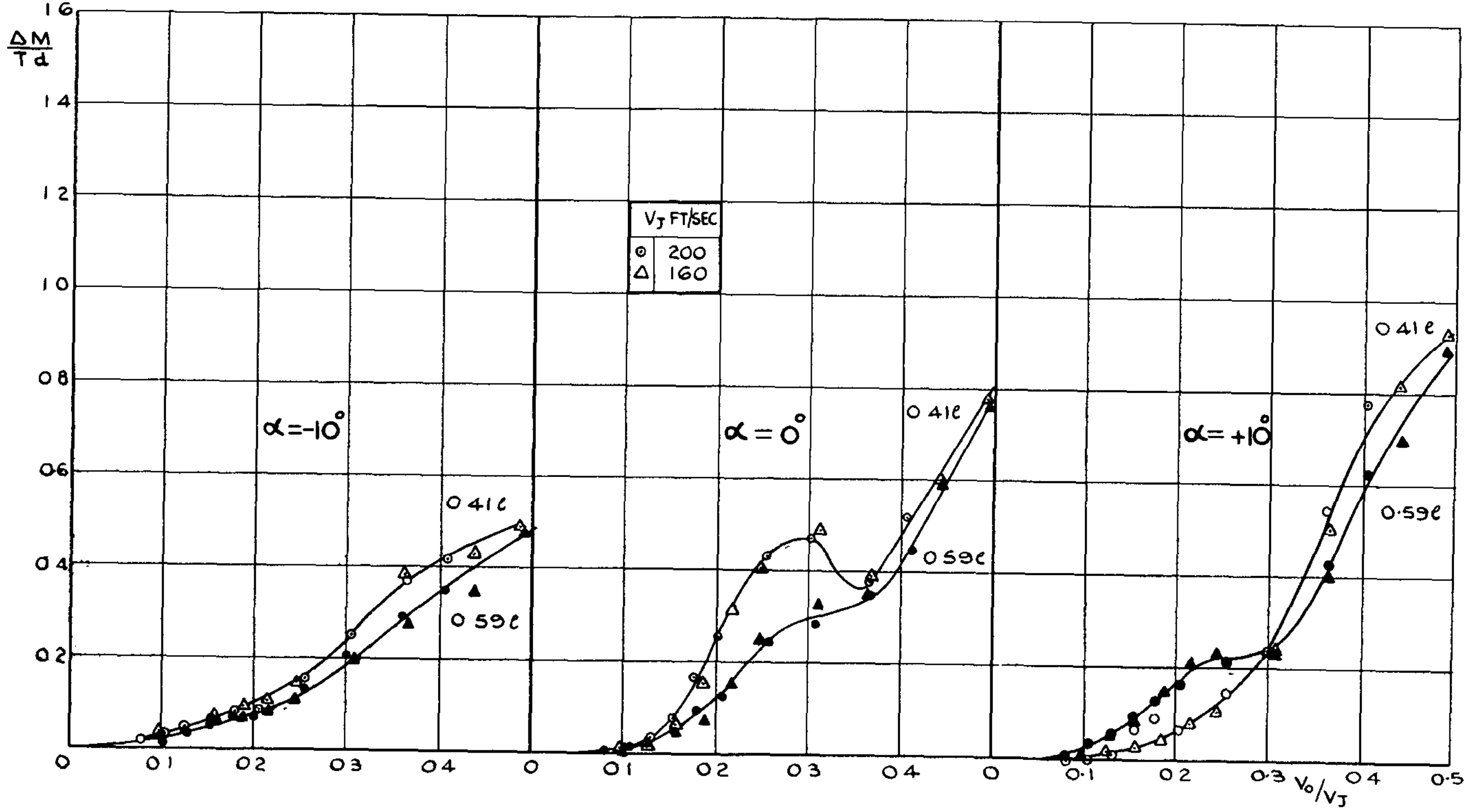
a) ISOLATED BODY

FIG. 5. EFFECT OF MAINSTREAM ON MOMENT INCREMENT ABOUT GEOMETRIC CENTRE OF BODY.



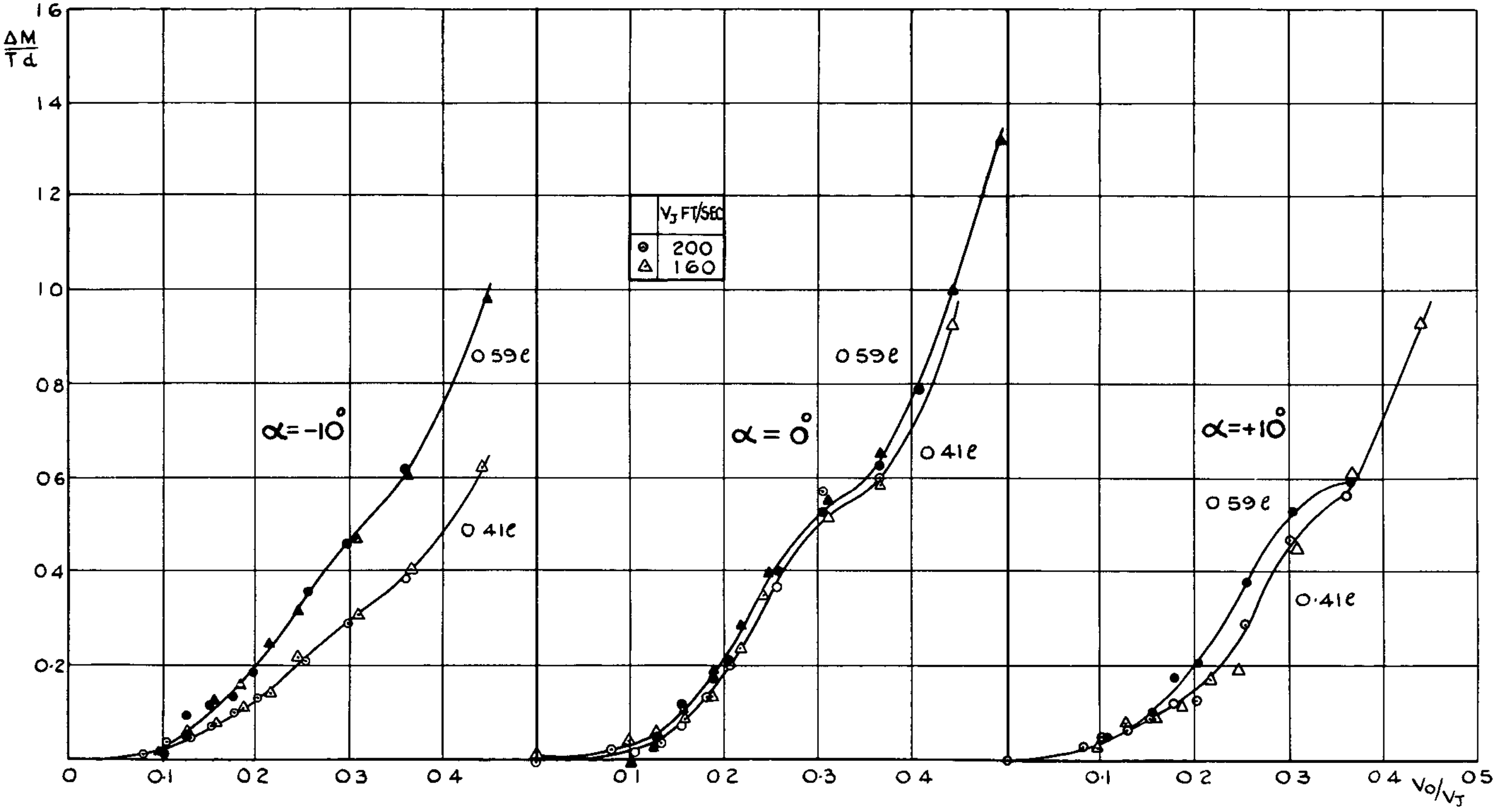
b) BODY ON HIGH WING

FIG. 5. (CONT.)



a) ISOLATED BODY.

FIG. 6. EFFECT OF MAINSTREAM SPEED ON MOMENT ABOUT CENTRE OF JET EXIT.



b) BODY ON HIGH WING

FIG. 6. (CONT.)

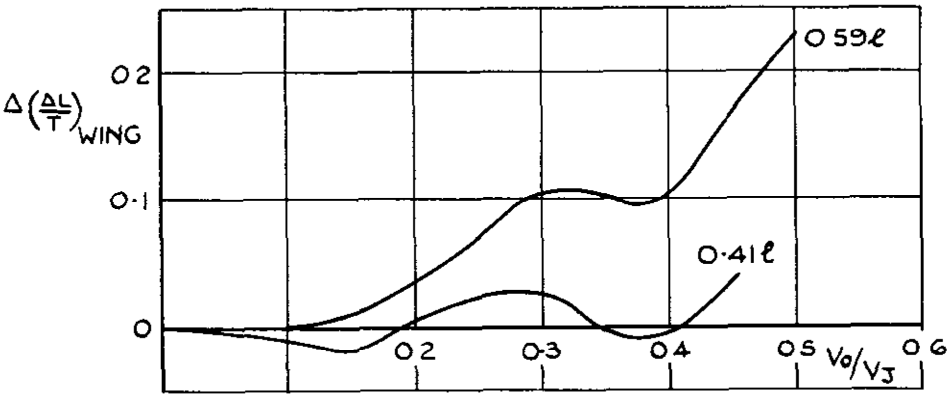


FIG 7 INTERFERENCE LOAD ON WING DUE TO JET.
$\alpha = 0°$

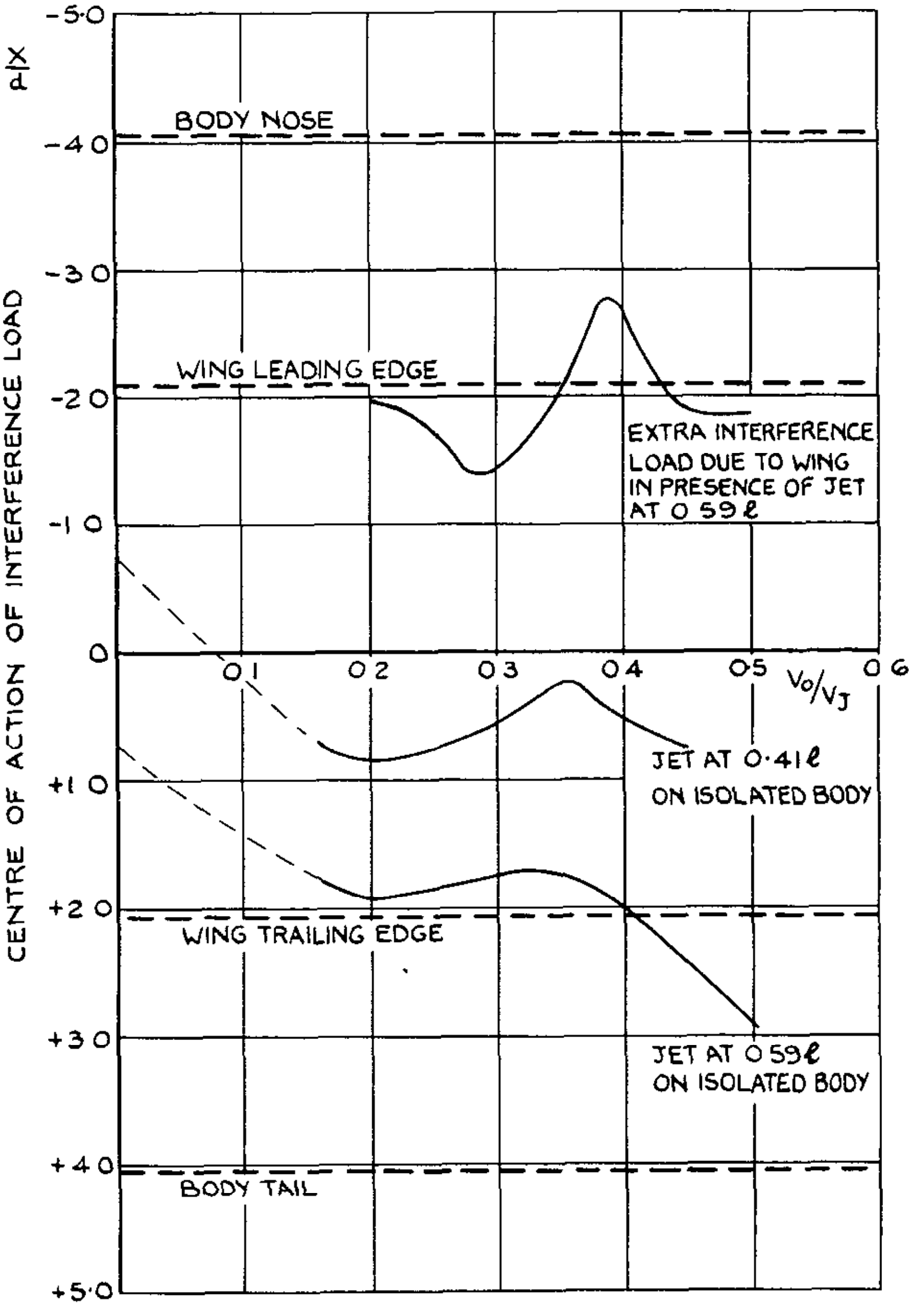


FIG 8 POSITION OF CENTRE OF INTERFERENCE LOAD
$\alpha = 0°$

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