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24-ft Tunnel Tests on a High-Lift Model

Downwash and Velocity Measurements at the Tailplane

By

C. H. NAYLOR, B.Sc., A.C.G.I., D.I.C.

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR)
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Reports and Memoranda No. 2649*
March, 1942

Summary.—Reasons for Enquiry.—Pitching moment measurements in the 24 ft. tunnel have shown that the high-lift model with double Fowler flaps down and slat open, although reasonably stable without slipstream, becomes unstable at the higher thrust coefficients required for level flight and climb. In some cases the tailplane contributed nothing to the longitudinal stability of the model. The present tests have been made to investigate the airflow in the neighbourhood of the tailplane.

Range of Investigation.—Measurements at $R = 0{\cdot}86 \times 10^6$ were obtained over an incidence range of 25 deg. at thrust coefficients up to $Tc_0 = 1{\cdot}8$. The lift coefficient without slipstream varied from $C_L = 2$ to $C_L = 4{\cdot}3$ over this range. Measurements were made in a plane normal to the thrust line, moving with the model, at intervals of 0·067 wing-span units, over an area enclosing all reasonable tailplane positions.

Results.—The effect of the increased velocity is mainly confined to the region of the slipstream, while the increase in downwash angle with thrust coefficient extends over a wider range in both directions.

Conclusions.—The variation in downwash angle and velocity is such as to make the tailplane a destabilising rather than a stabilising member, at constant throttle with the flaps and slat in operation with the tailplane in any practicable position. This is due to the large downwash angles associated with the relatively low aspect ratio wing. The stability could be improved by the use of a higher-aspect ratio wing. The effect of slipstream on the complete aeroplane, however, is not necessarily destabilising with flaps down because of the favourable effects of a high thrust line and of the slipstream velocity over the wing and flaps.

1. *Introduction.*—A series of tests have been made on a complete model fitted with double Fowler flaps, wide-chord ailerons and a full-span slat, to investigate the problems associated with high-lift devices.

The tests with slipstream showed that high thrust coefficients were required for level flight and climb to overcome the high drag with flaps and slat in operation, and that in this condition the aeroplane would be unstable even with the C.G. forward at $0.25c$. Under these conditions the tailplane appeared to contribute nothing to the stability of the aeroplane. This does not necessarily mean that this high-lift aeroplane is unstable at constant throttle since the stabilising effects of a high thrust line and of the slipstream over the wing may outweigh the destabilising effect of the tail, as is the case on a particular high-lift aeroplane now in the design stage. It is open to question whether stability in level flight with flaps down and slat open is essential but a high degree of instability would doubtless be inadvisable.

Instead of estimating mean downwash and effective velocity at the tailplane by measuring pitching moment over a range of tailplane settings, it was decided to investigate the airflow over a wider region near the tail in an attempt, not only to explain the behaviour of the existing tail, but to show if another tailplane position would produce better results.

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* R.A.E. Report Aero. 1738—received 8th June, 1942.

2. *Method of Measurement.*—For the exploration the tail unit was removed and four universally mounted pitot-static vanes were attached to a vertical bar which could be fixed in any position on a horizontal bar through the rear of the body (*see* Fig. 1). Downwash and inwash angles were recorded photographically by means of four ' Robot ' cameras mounted on a similar vertical bar.*

The pitot static tubes were calibrated separately in order to obtain the local velocity. The observed downwash angles have been corrected for tunnel-wall interference to make the results applicable to free air conditions at the same wing lift coefficient.

3. *Accuracy.*—Downwash and inwash angles recorded by the films were read to about half a degree. Oscillation of the vanes caused some difficulty but the exposure time was usually long enough to obtain a mean of several periods.

The random error in the velocity measurement is probably less than 1 per cent.

4. *Presentation of Results.*—Curves of downwash and inwash angles, and velocity squared at constant thrust coefficient have been plotted against incidence in Figs. 2, 3, 4. The curves have been placed in the same relative positions as the points to which they refer. Only a few points will be discussed as the curves are self-explanatory.

5. *Discussion of Results.*—5.1. *Downwash Measurements,* Fig. 2.—5.1.1. *Asymmetry of downwash angles.*—The diagrams show a lack of symmetry in the flow on the two sides without airscrew. On the port side in positions 1 and 2 at low thrust coefficients the downwash *vs* incidence curves all become irregular at about $\alpha = 12$ deg. At higher thrust coefficients the continuity of slope is generally maintained up to the maximum incidence at which measurements were made. This suggests a breakdown of flow at the wing root on the port side which is cleaned up by an increase of slipstream velocity.† Elsewhere the regularity of the flow increases as the horizontal distance from the body increases.

5.1.2. *Effect of slipstream on the downwash angle.*—In general, an increase in thrust coefficient causes an increase of downwash angle at all points in the field covered by the measurements. The mean increase in downwash angle per unit thrust coefficient is about 3·5 deg. This increase is not confined to the region occupied by the slipstream, but covers the whole field traversed, the effects on downwash angle being similar to an increase of wing incidence. This effect is present and has been measured on a normal unflapped aeroplane in U.S.A.

5.1.3. *Stability.*—The contribution of the tailplane to stability is proportional to—

$$\frac{d}{d\alpha}\left(\left(\frac{V}{V_0}\right)^2\alpha'\right) = \frac{d}{d\alpha}\left(\frac{V}{V_0}\right)^2(\alpha + \eta_T - \varepsilon) = (\alpha - \varepsilon + \eta_T)\frac{d}{d\alpha}\left(\frac{V}{V_0}\right)^2 + \left(\frac{V}{V_0}\right)^2\left(1 - \frac{d\varepsilon}{d\alpha}\right) \quad \ldots \quad (1)$$

where α wing incidence,

α' tailplane incidence to relative wind at tail,

η_T tailplane setting relative to wing datum,

ε mean downwash angle at the tailplane,

V effective mean velocity at the tailplane,

V_0 stream velocity at infinity.

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* The correct geometrical downwash angle was recorded on the film as the pivot of each vane was on the optical axis of a camera, and this axis was across wind and horizontal. The distance of the vanes from the cameras varied from 1 ft. 3 in. to 4 ft. 3 in.

† A right-handed airscrew was used in these tests.

$(\alpha - \varepsilon + \eta_T)$ must be negative to give the required download on the tail and the second term must be positive unless $d\varepsilon/d\alpha > 1$. Outside the slipstream $d/d\alpha(V/V_0)^2$ is negligible and $d\varepsilon/d\alpha$ is the important term.

$d\varepsilon/d\alpha$ is large at constant thrust coefficient, being about 1·0 at points 4a and 8a between incidence of $\alpha = 5$ deg. to $\alpha = 10$ deg. At constant throttle T_c increases with α and $d\varepsilon/d\alpha$ would be even greater, this means that the effect of the tailplane would be destabilising, except possibly in position (a)). This is not a practicable position as it is below the body and in a region of disturbed flow. Curves giving T_c at constant throttle have been superposed on the C_l/vs α curves in Figs. 2, 3, 4.

5.2. *Velocity Measurements,* Fig. 3.—5.2.1. *Effects of slipstream on stability.*—The velocity increase due to slipstream was much more localised than the increase in downwash angle and it only affected the central portion of the tailplane since the tailplane span was unusually large compared with the airscrew diameter.

In the highest position (a) the tailplane was almost completely clear of the slipstream. In position (b) the tailplane moved into the slipstream on increasing the wing incidence, and the first term of equation (1) is therefore destabilising; this is usual with flaps down. In position (c) this destabilising effect was present at low incidences on the port side of the tailplane and in position (d) it tended to move out of the slipstream at the higher incidences. In this position, however, the whole tailplane passes through the wing wake making the use of this position undesirable.

5.2.2. *Velocity measurement outside the slipstream.*—Outside the slipstream a general increase in $(V/V_0)^2$ of between 5 per cent. and 10 per cent. was found over the field covered by the measurements; this was due to a decrease in static pressure associated with an increase of thrust coefficient. The total head outside the slipstream remained sensibly constant.

5.3. *Sidewash Measurements,* Fig. 4.—5.3.1. *Sidewash angles.*—In general the sidewash angle increases, and the rate of change of sidewash angle with incidence increases negatively as the point under consideration moves towards the tip of the tailplane. This effect is more marked in the higher positions.

5.3.2. *Effect of slipstream on sidewash angles.*—Sidewash angles have been plotted as positive when the direction of flow is towards the body. In general the sidewash angle everywhere increases with thrust coefficient, indicating a convergence of flow at high thrust coefficients; the increase in V^2 discussed in section 5.2.2 is probably associated with this convergence of flow. The changes in downwash and sidewash angles with thrust coefficient are similar.

6. *Conclusions.*—The variation in downwash angle and velocity is such as to make the tailplane a destabilising rather than a stabilising member, at constant throttle with flaps and slat in operation, with the tailplane in any practicable position. This is due to the large downwash angles associated with a relatively low aspect-ratio wing ($A = 5.61$). The stability would be improved by the use of a higher aspect-ratio wing. On the complete aeroplane, the effect of slipstream is not necessarily destabilising because of the favourable effects of a high thrust line and of the slipstream velocity over the wing and flaps.

A wing root stall on the port wing at low thrust coefficients was cleaned up by an increase of slipstream velocity.

Note :—In the caption of Fig. 4 for ' inwash ', read ' sidewash '. The latter term has become more customary since the Report was written.

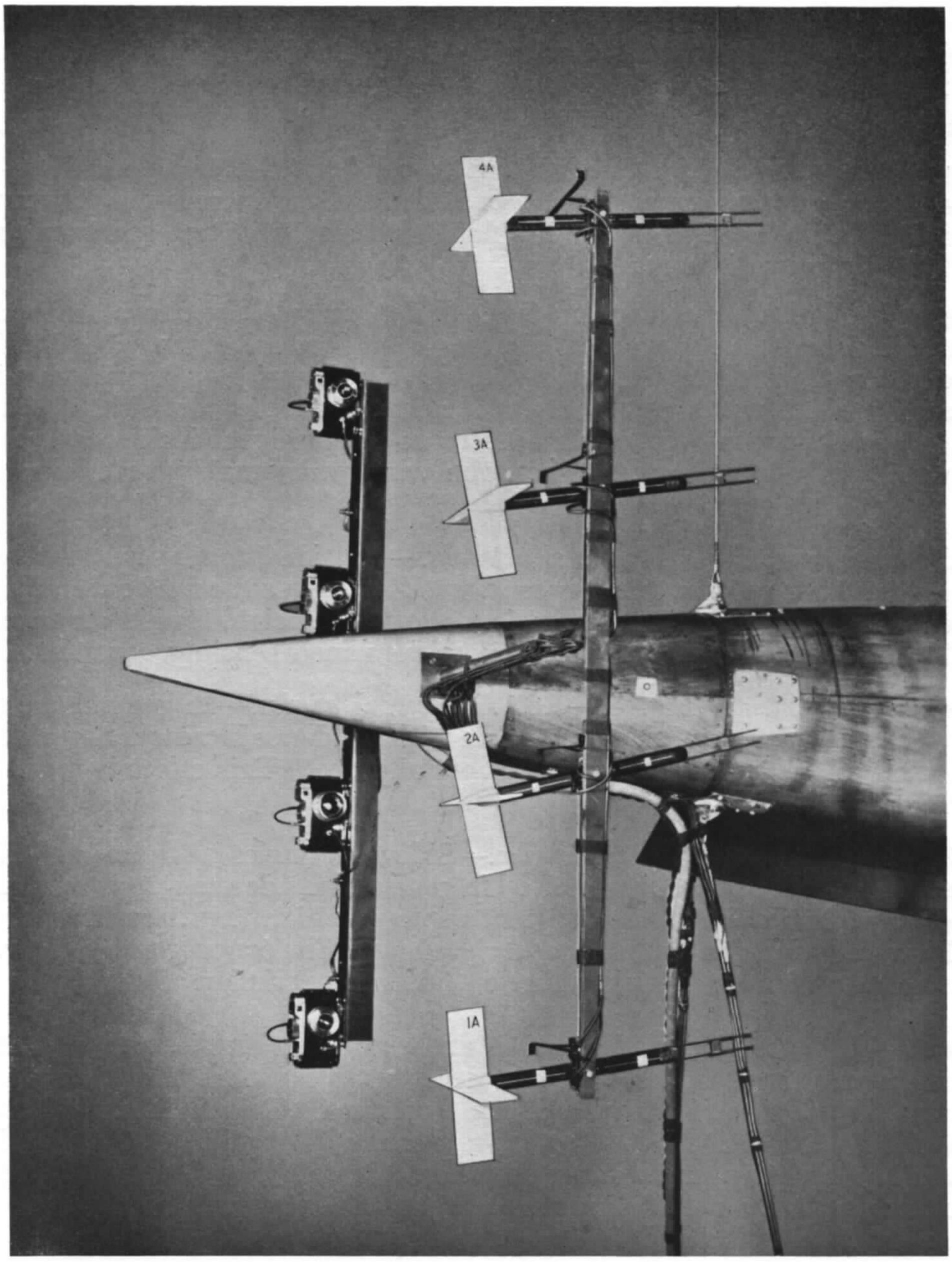

FIG. 1. Apparatus Used for Measurement of Downwash and Velocity at the Tailplane of the High Lift Model.

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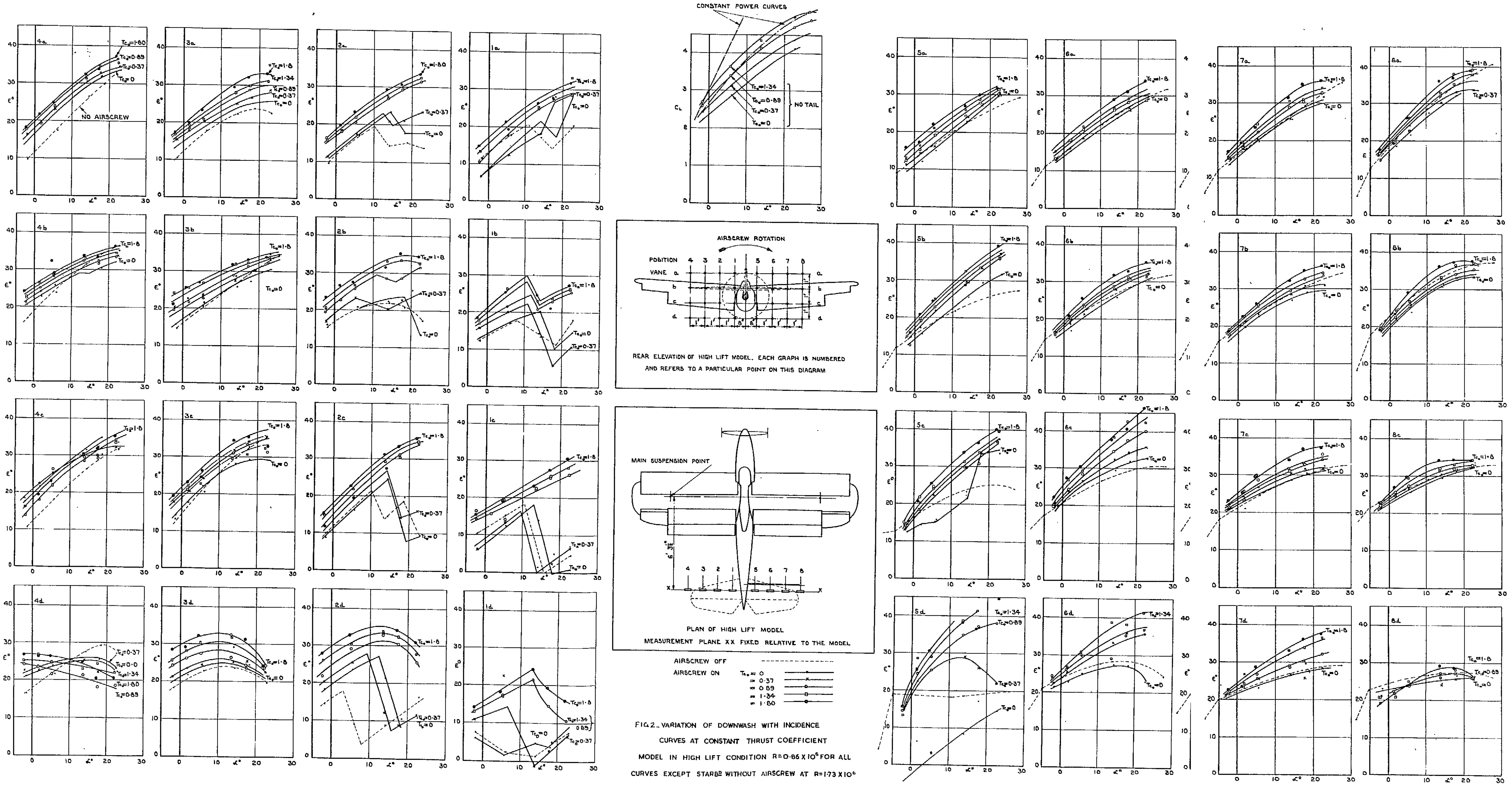

REAR ELEVATION OF HIGH LIFT MODEL. EACH GRAPH IS NUMBERED AND REFERS TO A PARTICULAR POINT ON THIS DIAGRAM

PLAN OF HIGH LIFT MODEL
MEASUREMENT PLANE XX FIXED RELATIVE TO THE MODEL

FIG.2_ VARIATION OF DOWNWASH WITH INCIDENCE CURVES AT CONSTANT THRUST COEFFICIENT MODEL IN HIGH LIFT CONDITION $R = 0{\cdot}86 \times 10^6$ FOR ALL CURVES EXCEPT STARBD WITHOUT AIRSCREW AT $R = 1{\cdot}73 \times 10^6$

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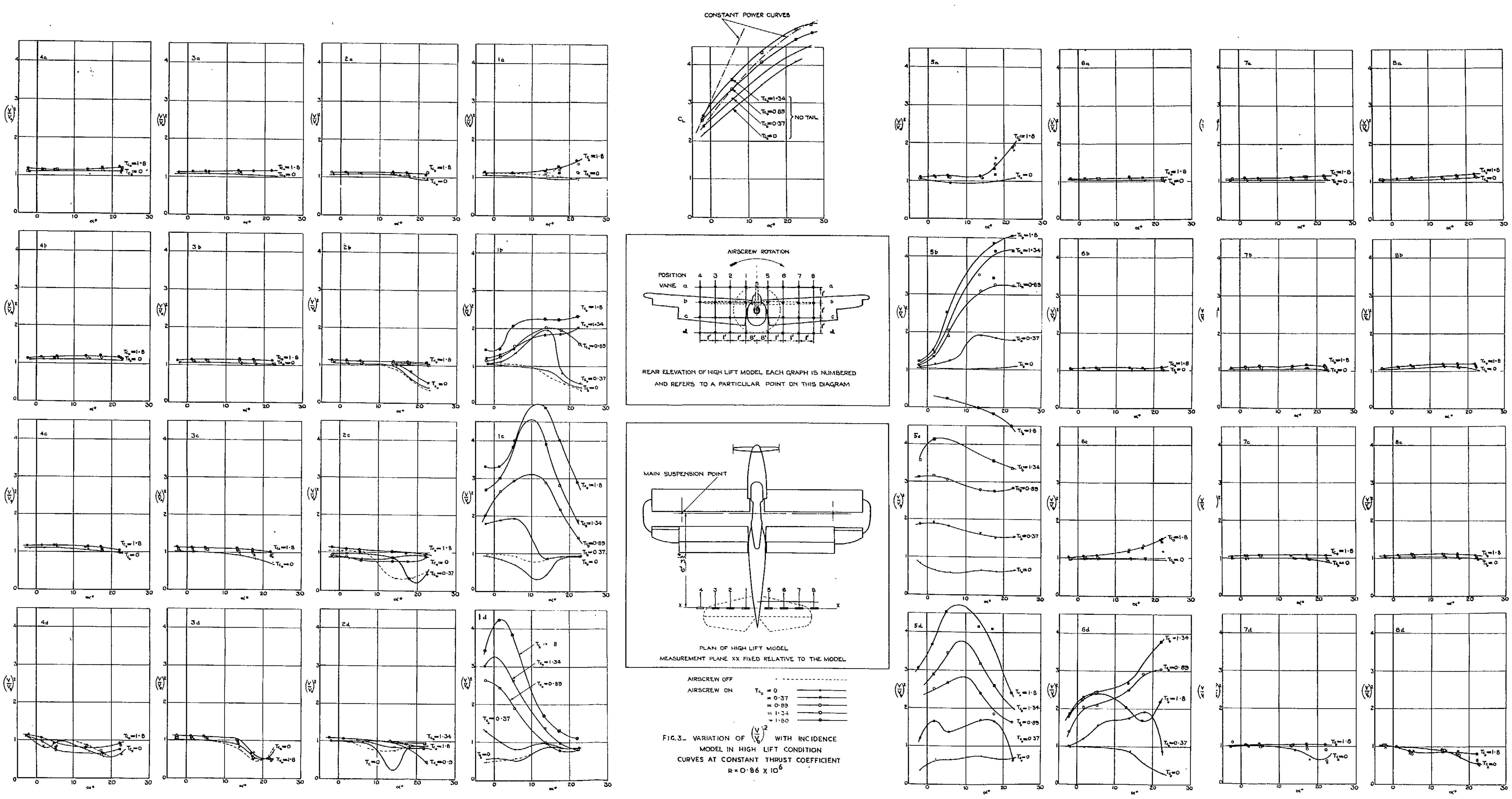
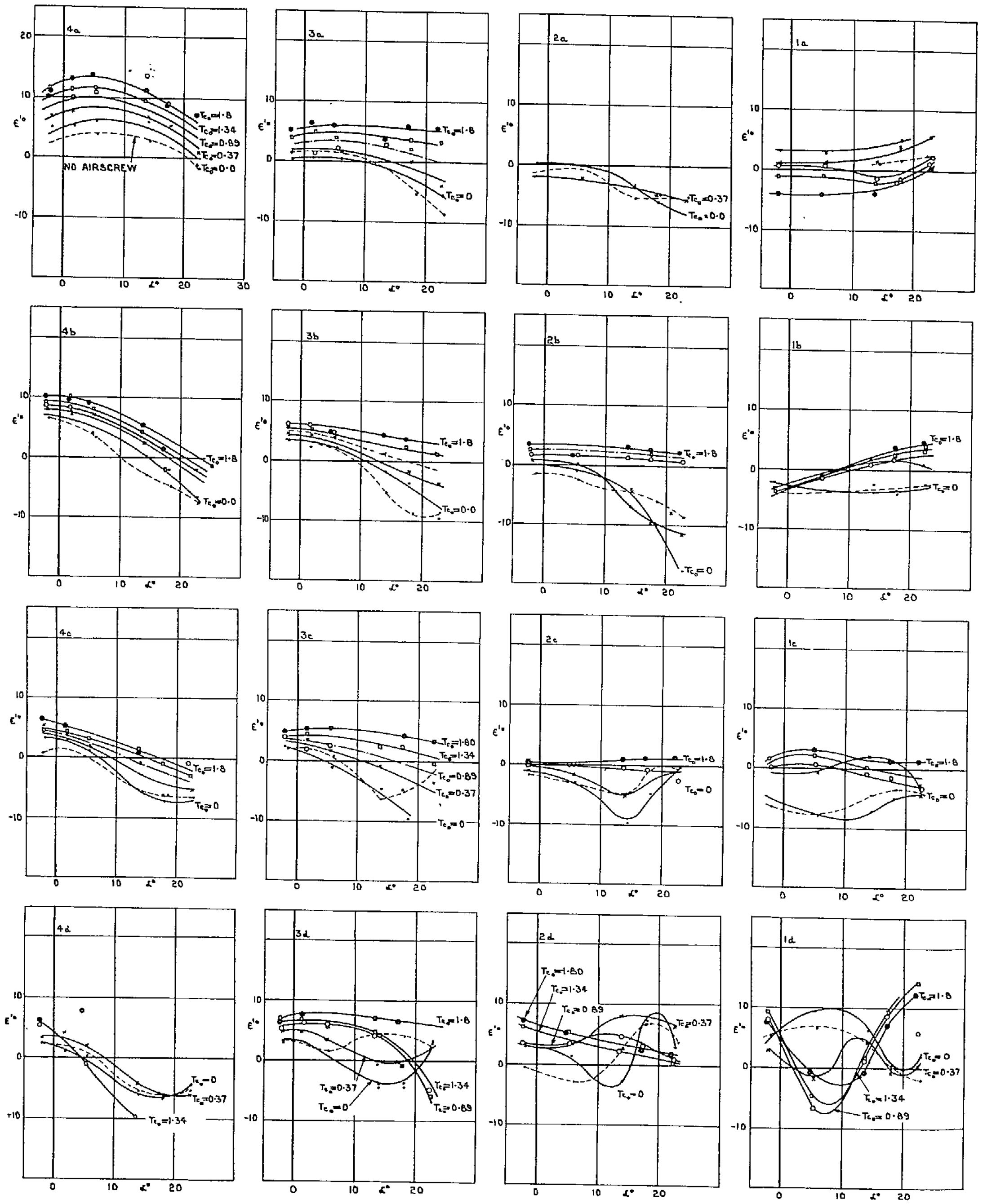
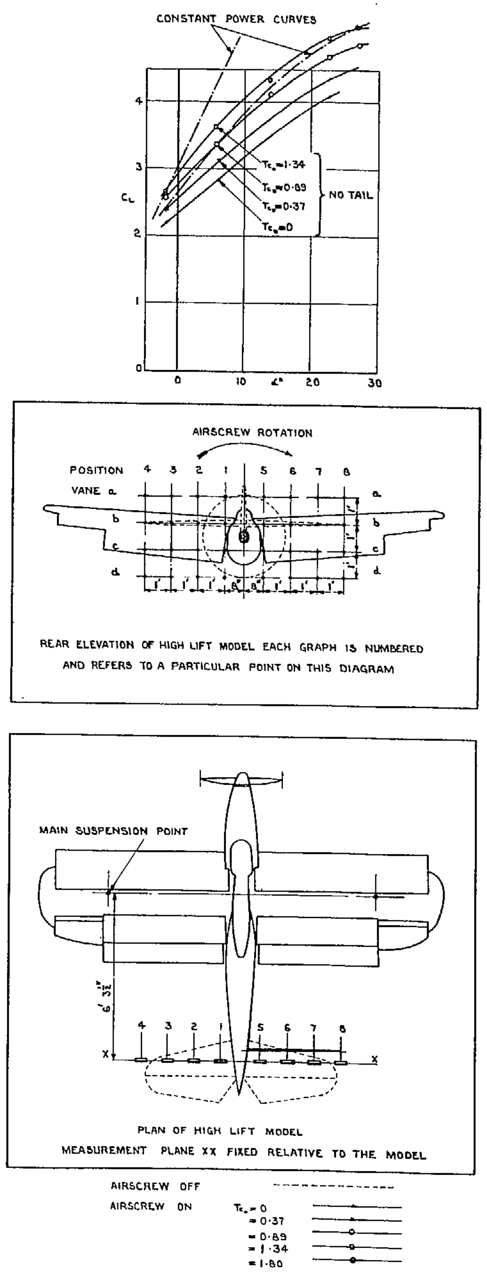


REAR ELEVATION OF HIGH LIFT MODEL EACH GRAPH IS NUMBERED AND REFERS TO A PARTICULAR POINT ON THIS DIAGRAM

PLAN OF HIGH LIFT MODEL
MEASUREMENT PLANE XX FIXED RELATIVE TO THE MODEL

FIG. 3. VARIATION OF $\left(\frac{V}{V_0}\right)^2$ WITH INCIDENCE
MODEL IN HIGH LIFT CONDITION
CURVES AT CONSTANT THRUST COEFFICIENT
$R = 0·86 \times 10^6$





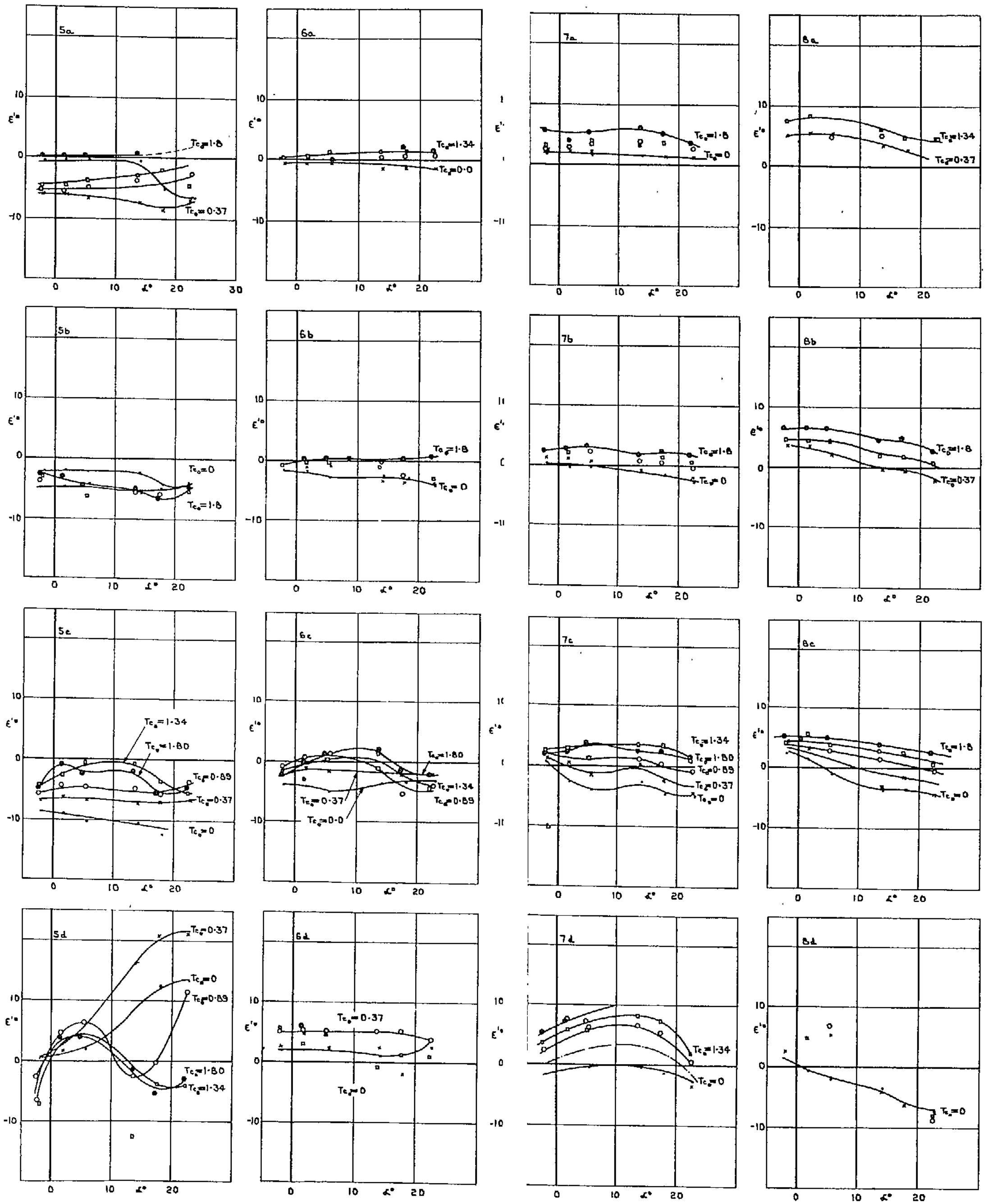


FIG. 4. VARIATION OF INWASH WITH INCIDENCE MODEL IN HIGH LIFT CONDITION CURVES AT CONSTANT THRUST COEFFICIENT $R = 0.86 \times 10^6$

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