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D. A. Lovell

Aerodynamics Dept., R.A.E., Farnborough

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D. A. Lovell

Aerodynamics Department, R.A.E., Farnborough

SUMMARY

Calculations have been made of the magnitude of the wall corrections to pitching moment for two models with tails using two methods of correction and two stages of approximation for each method. It is found that the first stage of approximation is accurate enough for values of lift coefficient up to four. For higher values of lift coefficient, it is suggested that it is not worth using the second approximations as the theory of wind tunnel wall-interference is not sufficiently accurate in its predictions for flows with the large values of downwash inherent in high-lift systems such as lifting jets or rotors.

The correction to lift calculated for the two models is shown to be non-negligible and it is recommended that it is applied in tests where differences are to be taken between tail-on and tail-off tests.

* Replaces R.A.E. Technical Report 68212 - A.R.C. 30826

CONTENTS

1 INTRODUCTION

Some doubt has recently been expressed[1] about the accuracy of the established methods of applying wind tunnel wall-corrections to the pitching moments measured on aircraft models with tails, in particular for large models having high lift coefficients. A more exact method of correcting such measurements has been proposed[1] but it has not been applied to experimental results.

The problem of correction may be split into two stages. Firstly it is necessary to determine the magnitude of the tunnel wall interference, (i.e. the blockage and lift constraint effects). This is not considered in detail in this Report but the limitations of the existing methods of prediction have been mentioned where they are relevant. The second stage is the application of these values of tunnel interference to predict the magnitude of the corrections to the model force and moment measurements. It is the theory of this process that is considered here.

In this Report the magnitude of the corrections has been calculated for two model tests and the results of the new and established methods compared. The models operated at lift coefficients up to four. The application of the corrections to model tests at even higher values of lift coefficient has been considered.

The results of the calculations showed that the established method of correction is sufficient for the tests considered. If a higher tailplane power than existed in these model tests were needed for trimming purposes it may be necessary to use a more complicated correction method at these values of lift coefficient. At higher values of lift coefficient it is felt that the direct measurement of the interference is likely to prove very difficult and that no meaningful corrections can be applied until a theory has been developed for the wall interference effects on model flows with very large downwashes (e.g. caused by lift jets or rotors). Until then the alternative is to make a smaller model relative to the tunnel size so that the corrections may be neglected.

2 THE TWO METHODS OF APPLYING WIND TUNNEL WALL-CORRECTIONS FOR MODELS WITH TAILS

The tunnel interference can be split into two parts; the blockage constraint effect giving rise to dynamic pressures (free stream) different at the wing (q_W) and the tail (q_t) from the empty tunnel value, and the lift constraint effect giving rise to a change in the free stream incidence at the wing $(\Delta\alpha_W)$ and the tail $(\Delta\alpha_t)$. The notation used is shown in Fig.1. All wind tunnel results are corrected for the tunnel interference at the wing so that we are only concerned with the difference between the tunnel interference at the wing and the tail. There are two methods by which the correction for the difference in interference may be applied. In the first method the additional force or moment caused by the change of free stream incidence and dynamic pressure at the tail, due to the difference in the tunnel interference, is removed and the tail setting is left unchanged. The second method assumes that the tail setting has been changed by an amount equal to the difference between the constraint at the wing and the tail. However it should be noted that curves at constant values of tail setting are normally required from the model tests so that it is necessary to cross plot the results of a number of test runs with different tail settings in order to derive results for constant tail setting if this method of applying the corrections is used.

2.1 Method 1. Removing the difference in constraint between the wing and the tail

The only correction normally made is to pitching moment and this is obtained in the following manner. From measurements of pitching moment obtained for a range of tail setting (i_t), the slope $\left(\frac{\partial C_m}{\partial i_t}\right)_{\alpha_W}$ is obtained. The change in tunnel constraint between the wing and the tail is obtained theoretically[2] and the correction is then:

$$\Delta C_m = -(\Delta\alpha_t - \Delta\alpha_W)\left(\frac{\partial C_m}{\partial i_t}\right)_{\alpha_W} \quad . \tag{1}$$

This method of correction, which we shall call the first approximation, takes no account of the difference in blockage between the wing and the tail. Heyson[1] has derived a more comprehensive correction to pitching moment in terms of the tailplane characteristics and the tunnel interference effects on the dynamic pressure and incidence. If the pitching moment coefficient is referred to the dynamic pressure corrected for blockage at the wing and the standard mean chord, the equation (13) of Heyson becomes:

$$C_m = C_{m_{meas}} + \Delta C_m \tag{2A}$$

where

$$\Delta C_m = \frac{q_i\, S_t\, \ell'}{q_W\, S_W\, \bar{c}_W}\Bigg\{\left(1 - \frac{q_t}{q_W}\right)\left[\frac{\bar{c}_t}{\ell'}\, C_{m_{ot}} + \frac{C_{L_t}\, \bar{c}_t}{a_t\, \ell'} \cdot \frac{dC_{m_t}}{d\alpha_t} + \left(\frac{h'}{\ell'}\, C_{D_t} - C_{L_t}\right)\cos\varepsilon + \left(\frac{h'}{\ell'}\, C_{L_t} + C_{D_t}\right)\sin\varepsilon\right]$$

$$- \left(\frac{q_t}{q_W}\,\Delta\alpha_t - \Delta\alpha_W\right)\left[\frac{\bar{c}_t}{\ell'}\,\frac{dC_{m_t}}{d\alpha_t} + \left(\frac{2h'\, a_t\, C_{D_{it}}}{\ell'\, C_{L_t}} - \frac{h'}{\ell'}\, C_{L_t} - a_t - C_{D_t}\right)\cos\varepsilon + \left(\frac{h'}{\ell'}\, C_{D_t} + \frac{h'}{\ell'}\, a_t - C_{L_t} + \frac{2a_t\, C_{D_{it}}}{C_{L_t}}\right)\sin\varepsilon\right]\Bigg\} \quad . \qquad (2B)$$

The right hand side of this equation comprises two parts. The term multiplied by $\left(1 - \frac{q_t}{q_W}\right)$ is the difference in tailplane contribution to the overall pitching moment that arises when the free stream dynamic pressure at the tailplane is changed from the actual value of q_t to the required value of q_W (see beginning of section 2). The term multiplied by $\left(\frac{q_t}{q_W}\,\Delta\alpha_t - \Delta\alpha_W\right)$ is the partial derivative $\left(\frac{\partial C_m}{\partial i_t}\right)_{\alpha_W}$. The overall factor $\left(\frac{q_i}{q_W}\right)$ is necessary as the mean dynamic pressure incident on the tailplane is different from the free stream value due to the impingement of the wake of the wing and the body on the tailplane. The reader is referred to Ref.1 for further details of the derivation of this equation but it should be noted that Heyson assumes linear lift and pitching moment curves and a parabolic drag curve.

Various stages of simplification of this equation may be made. The crudest approximation, obtained for small downwash, tail height small compared with the tail arm and negligible C_{D_t}, $C_{D_{it}}$ and C_{L_t} compared with the lift curve slope of the tailplane, is:

$$\Delta C_m = \frac{q_i\, S_t\, \ell_t\, a_t}{q_W\, S_W\, \bar{c}_W}\,(\Delta\alpha_t - \Delta\alpha_W) \quad . \qquad (3)$$

It is worth pointing out that the factor $\left(\frac{q_i}{q_W}\right)$ in this equation will in fact be taken into account in the experimental determination of $\left(\frac{\partial C_m}{\partial i_t}\right)_{\alpha_W}$ used in equation (1) but this factor is of minor importance compared with the two factors $\left(1 - \frac{q_t}{q_W}\right)$ and $\left(\frac{q_t}{q_W} \cdot \Delta\alpha_t - \Delta\alpha_W\right)$ in equation (2B).

The correction of Heyson, equations (2) above, henceforth called the second approximation, will in general differ little from the first approximation unless there is a substantial difference in blockage between the wing and the tail. It is therefore worth drawing attention to the corrections to lift and drag forces which arise from the difference in the tunnel interference between the wing and the tail. A first approximation to these corrections can be obtained in a similar way to equation (1). The corrections are:

$$\Delta C_L = -(\Delta\alpha_t - \Delta\alpha_W)\left(\frac{\partial C_L}{\partial i_t}\right)_{\alpha_W} \quad (4)$$

$$\Delta C_D = -(\Delta\alpha_t - \Delta\alpha_W)\left(\frac{\partial C_D}{\partial i_t}\right)_{\alpha_W} \quad (5A)$$

The derivative $\left(\frac{\partial C_D}{\partial i_t}\right)_{\alpha_W}$ will not be approximately linear and is best obtained from an assumed drag relation, neglecting the contribution of the tailplane lift:

$$C_D = (C_D)_{WB} + \frac{S_t}{S_W}\left(C_{D_{ot}} + \frac{k_t\, C_{L_t}^2}{\pi\, A_t}\right)$$

therefore

$$\left(\frac{\partial C_D}{\partial i_t}\right)_{\alpha_W} = \frac{2k_t\, C_{L_t}}{\pi\, A_t}\left(\frac{\partial C_L}{\partial i_t}\right)_{\alpha_W} .$$

So that the correction is:

$$\Delta C_D = -(\Delta\alpha_t - \Delta\alpha_W)\frac{2k_t\, C_{L_t}}{\pi\, A_t}\left(\frac{\partial C_L}{\partial i_t}\right)_{\alpha_W} . \quad (5B)$$

The corrections (4) and (5) are probably accurate enough unless there is a large change in blockage between the wing and tail. The more complete form of the corrections is derived in Appendix A, using the same method as Heyson, equations (A-5) and (A-8).

2.2 Method 2. Changing the tail setting by an amount equal to the difference between the constraint at the wing and tail

The correction to tail setting is:

$$\Delta i_t = \Delta\alpha_t - \Delta\alpha_W \quad . \tag{6}$$

The application of this correction alone is called the first approximation. Heyson[1] derives the additional correction necessary to pitching moment because of the rotation of the resultant force vector at the tailplane and he also includes the correction for the difference in blockage between the wing and the tail. The derived equation is equation (30) of Ref.1, and, in the present notation, is:

$$C_m = (C_m)_{WB} + \frac{q_W}{q_t}\left[(C_m)_t + \frac{S_t\,\ell_t\,\Delta i_t}{S_W\,\bar{c}_W}\left(\frac{h_t}{\ell_t}\,C_{N_{meas}} + C_{A_{meas}}\right)\right] \quad . \tag{7}$$

It is simple to convert the last term of this equation into a function of the tail characteristics as:

$$C_{N_{meas}} = \frac{q_i}{q_W}\left[C_{L_t}\cos(\alpha_B - \varepsilon + \Delta i_t) + C_{D_t}\sin(\alpha_B - \varepsilon + \Delta i_t)\right] \tag{8A}$$

and

$$C_{A_{meas}} = \frac{q_i}{q_W}\left[C_{D_t}\cos(\alpha_B - \varepsilon + \Delta i_t) - C_{L_t}\sin(\alpha_B - \varepsilon + \Delta i_t)\right] \quad . \tag{8B}$$

This additional correction to pitching moment (the last term of equation (7)) is called the second approximation here. Again there are no first order corrections to the lift and drag forces but for completeness the second order corrections have been derived in Appendix A, equations (A-11) and (A-14).

3 CALCULATION OF THE CORRECTIONS

3.1 The method of calculating the corrections

The lift constraint interference due to the tunnel walls at the wing and the tail has been obtained from the theoretical results of Silverstein and White[2] for the two sets of results considered. This theory uses a simple horseshoe vortex system to represent the wing lift. No account is taken of sweep and uniform spanwise loading is assumed. More complete theoretical treatments are reviewed by Garner[3] but, although the lift constraint effect at the wing may be calculated taking into account the effect of chord, sweep-back, planform etc., the calculation of the lift constraint effect at the tail has been improved very little.

The blockage constraint interference at the wing has been calculated using the solid blockage formula recommended by Rogers[3] combined with the streamlined wake blockage for the body throughout the incidence range of the tests and the wing below the stalling incidence and Maskell separated flow wake blockage for the wing above the stalling incidence. The difference in blockage constraint interference at the wing and the tail has been calculated using the method of Evans[4] and has found to be negligible for the two sets of test results considered. However, in order to see the effect of such a difference, calculations have been made with such a difference.

In both sets of results measurements have been made at a number of tail settings so that the derivatives $\left(\frac{\partial C_m}{\partial i_t}\right)_{\alpha_W}$ and $\left(\frac{\partial C_L}{\partial i_t}\right)_{\alpha_W}$ may be calculated directly. Hence the first approximations (1) and (6) for the two methods may be calculated.

To calculate the second approximations knowledge of the tailplane characteristics and local flow conditions are required. This may be obtained by a separate test of the tailplane and a wake traverse in the vertical plane of the tailplane. Such a procedure is time consuming and unlikely to be justified in most model tests. Alternatively the effective tailplane characteristics, (i.e. including any effects of reduced dynamic pressure at the tailplane due to the wing and body wakes) may be derived from the differences between tail on and tail off tests and the mean downwash may be obtained from the intersection of the tail off pitching moment curve with a series of tail on pitching moment curves for different tail settings. Both procedures have been used for one of the sets of results used in the calculations and there is good agreement[9] between the derived effective tailplane characteristic and the product of the mean measured dynamic pressure and the tailplane characteristic measured in a separate test so that the second procedure is recommended.

3.2 Results for a model of an airbus type of aircraft[9]

A general arrangement sketch of the model is shown in Fig.2 and model details are given in Table 1. The model was tested at a speed of 140 ft/sec in an 11.5ft × 8.5ft wind tunnel. The results for two tail settings are shown in Fig.3 for the first method of correction. There is very little difference between the first and second approximations to the corrections. This difference is of the same order as the experimental error; 0.05° on tail setting × 0.06 (the slope of the C_m vs i_t curve) = 0.003.

In Fig.4 the effect of different blockage at the wing and the tail and the effect of an incorrect estimate of the tailplane lift curve slope are shown. Calculations for the model using the method of Evans[4] showed a difference in solid blockage of 0.23% between the wing and the tail. The change in the magnitude of the correction on taking this into account, by using the second approximation, is within the experimental accuracy. The smallest difference in blockage between the wing and tail (0.5%), which produced a noticeable effect on the magnitude of the correction, is plotted in Fig.4. It should be noted that no account has been taken of any difference in wake blockage between the wing and the tail.

A 20% error in the estimation of the tailplane lift curve slope produces approximately the same change in the correction, when using the second approximation, as 0.5% difference in blockage. As it should be possible to estimate the tailplane lift curve slope by the second method outlined in section 3.1 to within 5% it is apparent that the estimation of the tailplane lift curve slope is not a very critical factor in the calculation of the correction.

All the other tailplane characteristics including the mean downwash at the tailplane have little effect on the magnitude of the corrections and ±50% tolerance on the other tailplane characteristics and ±2° on the downwash are reasonable working limits for estimation purposes.

The results of the second method of correcting the pitching moment are not plotted as the difference between the results from the first method and the second method (after cross plotting against tail setting to obtain the curves at constant tailsetting) is within the accuracy of the method of calculation. The second approximation gives a negligible additional correction to pitching moment (0.0006 on C_m).

In Fig.5 the correction to lift is shown for the first method of applying the corrections (equation (4)). Although the correction is not large such a change could be measured experimentally and the difference would be important if tail characteristics are to be derived from tail on and tail off tests. The correction to drag is negligible.

3.3 Results for a model of a jet nacelle aircraft[10]

A general arrangement sketch of the model is shown in Fig.6 and model details are given in Table 1. The model was tested at a speed of 150 ft/sec in an 11.5ft × 8.5ft wind tunnel. A test condition has been chosen with blowing over the nose flap ($C_{\mu N} = 0.042$) and rear flap ($C_{\mu R} = 0.060$) just sufficient for the flow to be fully attached to these surfaces. It is therefore hoped that the jet momentum effect is negligible and that the methods of section 3.1 for calculating the constraint and blockage effects are applicable. The results for the first method of correction are shown in Fig.7. The second approximation again only differs from the first approximation at high incidences. The effect of different blockage at the wing and tail and the effect of a 20% reduction in tailplane lift curve slope on the magnitude of the correction is shown in Fig.8. For this model the actual difference in solid blockage between the wing and the tail is approximately 0.14%. As with the airbus model it can be seen that very accurate knowledge of the blockage and moderately accurate knowledge of the tailplane lift curve slope is required. The effect of errors in the estimation of other terms in the correction is again small compared with the effect of any error in the estimation of the blockage and tailplane lift curve slope.

The results of the second method of correction are shown in Fig.9. The curve for the first approximation agrees with that obtained by the first method within the accuracy of the method of calculation. The second approximation differs from the first approximation by an amount approximately equal to the experimental accuracy.

In Fig.10 the correction to lift is shown for the first method of applying corrections (equation (4)). Again the difference is not negligible. The correction to drag is negligible.

3.4 Some comments on the application of the corrections at higher values of lift coefficient

Two sets of results have been examined in order to assess the possibility of applying corrections at higher values of lift coefficient.

The results of Ref.5 for a jet-flap model give a maximum lift coefficient of approximately ten. The principal difficulty in applying the corrections is the uncertainty of the magnitude of the lift constraint interference at the wing and the tail and the difference in blockage at the wing and the tail. The authors use a method proposed by Maskell[3] for predicting the lift constraint effect at the tail but they do not allow for any difference in blockage between the wing and the tail. It is possible that this may be important as a large addition of momentum at the wing will be equivalent to the placing of sources at the wing and the consequent image system due to the tunnel wall reflections may well give rise to a considerable difference in blockage between the wing and the tail.

The results of Ref.6 for a tilt wing model give a maximum lift coefficient of approximately sixteen. An attempt at applying corrections, using the theory of Heyson[7] for the blockage and lift constraint effects, resulted in an increase in the discrepancies in pitching moment between measurements on the same model in different tunnels.

The inadequacy of the existing theory for predicting the tunnel interference and the consequent uncertainty in correcting wind tunnel results of these types of test has been pointed out by Butler and Williams[8], Maskell[3] and Grunwald[6]. Thus there seems little to be gained from using a more complete method of correction when the basic theory for predicting the lift and blockage constraint for flows with very large downwash is so inadequate. Until an improved theory is available, the corrections should be minimised by using smaller models relative to the tunnel size. Some criteria for determining the appropriate model size are given in Ref.8 and these detailed recommendations are in no way invalidated by the present findings.

4 CONCLUSIONS

For wind tunnels models having lift coefficients up to four, calculations have shown that existing methods of correcting results are sufficiently accurate. Although the second method of correction (changing the tail setting) leads to a smaller correction the accuracy is lost in the cross-plotting procedure necessary to obtain the pitching moment curves at constant tail setting which are usually required.

The second approximations for the corrections derived by Heyson will become important at higher values of lift coefficient but as it is not yet possible to predict the tunnel interference effects with sufficient accuracy there is little to be gained from using the more complete expressions for the corrections.

The calculation of the corrections to lift have been found to be non-negligible and for tests where differences between tail on and tail off values of lift are required it is recommended that the correction be applied. The correction to drag is probably negligible although it might become important if high-lift tailplanes are required as trimming devices for V/STOL aircraft models.

Appendix A

THE CORRECTIONS TO LIFT AND DRAG CORRESPONDING TO HEYSON'S CORRECTION TO PITCHING MOMENT

A.1 Method 1

Using the notation of Fig.1 the measured contribution of the tailplane to the overall lift, bearing in mind the different interference at the wing and the tail, will be:

$$\delta L = L_t (\Delta\alpha_t , q_t) \cos (\Delta\alpha_t - \varepsilon) + D_t (\Delta\alpha_t , q_t) \sin (\Delta\alpha_t - \varepsilon) \qquad \text{(A-1)}$$

resolving perpendicular to the uncorrected free stream direction. Although the tailplane lift and drag depend on the tailplane area, incident dynamic pressure, lift curve slope, incidence etc. the only variables are $\Delta\alpha_t$, $\Delta\alpha_W$, q_t and q_W. Similarly the required contribution to lift when the interference is the same at the wing and the tail will be:

$$\delta L = L_t (\Delta\alpha_W , q_W) \cos (\Delta\alpha_W - \varepsilon) + D_t (\Delta\alpha_W , q_W) \sin (\Delta\alpha_W - \varepsilon) \quad . \qquad \text{(A-2)}$$

If the tailplane lift and drag are defined as:

$$L_t = a_t \alpha_t \left(\frac{q_i}{q_W}\right) q_{t,W} S_t \qquad \text{(A-3)}$$

$$D_t = \left[C_{D_{ot}} + \frac{k_t a_t^2 \alpha_t^2}{\pi A_t}\right]\left(\frac{q_i}{q_W}\right) q_{t,W} S_t \quad . \qquad \text{(A-4)}$$

The correction is then obtained as the difference between (A-2) and (A-1). On substituting (A-3) and (A-4), expanding the sine and cosine terms and ignoring terms containing $(\Delta\alpha_t)^2$ and $(\Delta\alpha_W)^2$ we have:

$$\Delta C_L = \frac{q_i S_t}{q_W S_W}\left\{\left(1 - \frac{q_t}{q_W}\right)[C_{L_t} \cos\varepsilon - C_{D_t} \sin\varepsilon]\right.$$

$$\left. - \left(\frac{q_t}{q_W}\Delta\alpha_t - \Delta\alpha_W\right)\left[(a_t + C_{D_t}) \cos\varepsilon + \left(C_{L_t} - \frac{2a_t C_{D_{it}}}{C_{L_t}}\right)\sin\varepsilon\right]\right\} \quad . \qquad \text{(A-5)}$$

Similarly for drag, the measured contribution of the tail, bearing in mind the difference in interference at the wing and the tail, will be:

$$\delta D = D_t (\Delta\alpha_t , q_t) \cos (\Delta\alpha_t - \varepsilon) - L_t (\Delta\alpha_t , q_t) \sin (\Delta\alpha_t - \varepsilon) \qquad \text{(A-6)}$$

resolving parallel to the uncorrected free stream direction. Similarly the required drag contribution of the tailplane, when the interference is the same at the wing and the tail, will be:

$$\delta D = D_t (\Delta\alpha_W , q_W) \cos (\Delta\alpha_W - \varepsilon) - L_t (\Delta\alpha_W , q_W) \sin (\Delta\alpha_W - \varepsilon) \quad . \qquad \text{(A-7)}$$

Substituting (A-3) and (A-4) into the difference between (A-7) and (A-6) we have on expanding the sine and cosine terms as before:

$$\Delta C_D = \frac{q_i}{q_W} \frac{S_t}{S_W} \left\{ \left(1 - \frac{q_t}{q_W}\right) [C_{D_t} \cos \varepsilon + C_{L_t} \sin \varepsilon] + \left(\frac{q_t}{q_W} \Delta\alpha_t - \Delta\alpha_W\right) \left[\left(C_{L_t} - \frac{2a_t C_{D_{it}}}{C_{L_t}} \right) \cos \varepsilon - C_{D_t} \sin \varepsilon \right] \right\} \quad . \qquad \text{(A-8)}$$

A.2 Method 2

Using the notation of Fig.1 the measured contribution to the overall lift, taking account of the different interference at the wing and the tail, before the tail setting is changed, will be:

$$\delta L = \frac{q_i}{q_W} q_t S_t [C_{L_t} \cos (\varepsilon - \Delta i_t) - C_{D_t} \sin (\varepsilon - \Delta i_t)] \qquad \text{(A-9)}$$

resolving perpendicular to the corrected free stream direction. The downwash is here referred to the rotated tail. After rotating the tail the required contribution will be:

$$\delta L = \frac{q_i}{q_W} q_W S_t [C_L \cos \varepsilon - C_{D_t} \sin \varepsilon] \qquad \text{(A-10)}$$

Hence expanding the sine and cosine terms in the difference between (A-10) and (A-9) and ignoring $(\Delta i_t)^2$ terms we have:

$$\Delta C_L = \frac{q_i}{q_W}\frac{S_t}{S_W}\left[\left(1 - \frac{q_t}{q_W}\right)(C_{L_t} \cos\varepsilon - C_{D_t} \sin\varepsilon) - \frac{q_t}{q_W}\Delta i_t (C_{L_t} \sin\varepsilon + C_{D_t} \cos\varepsilon)\right] . \quad \text{(A-11)}$$

Similarly for the measured contribution of the tail to the overall drag before the tail setting is changed and taking account of the different interference at the wing and the tail we have:

$$\delta D = \frac{q_i}{q_W} q_t S_t [C_{D_t} \cos(\varepsilon - \Delta i_t) + C_{L_t} \sin(\varepsilon - \Delta i_t)] \quad \text{(A-12)}$$

resolving parallel to the corrected free stream direction. After rotating the tail the required contribution will be:

$$\delta D = \frac{q_i}{q_W} q_W S_t [C_{D_t} \cos\varepsilon + C_{L_t} \sin\varepsilon] . \quad \text{(A-13)}$$

Again expanding the sine and cosine terms in the difference of (A-13) and (A-12) and considering $(\Delta i_t)^2$ terms to be negligible, we have:

$$\Delta C_D = \frac{q_i}{q_W}\frac{S_t}{S_W}\left[\left(1 - \frac{q_t}{q_W}\right)(C_{D_t} \cos\varepsilon + C_{L_t} \sin\varepsilon) - \frac{q_t}{q_W}\Delta i_t (C_{L_t} \sin\varepsilon + C_{D_t} \cos\varepsilon)\right] . \quad \text{(A-14)}$$

Table 1

MODEL DATA

	Airbus	Jet nacelle
Wing		
Area S_W	5.556 ft^2	5.556 ft^2
Span	6.667 ft	6.667 ft
Standard mean chord $\bar{c}_W$	0.833 ft	0.833 ft
Aerodynamic mean chord $\bar{\bar{c}}_W$	0.903 ft	0.864 ft
Aspect ratio	8.0	8.0
Taper ratio	0.333	0.5
Sweepback of quarter-chord line	25°	26.1°
Tailplane		
Area S_t	1.621 ft^2	1.25 ft^2
Span	2.547 ft	2.50 ft
Standard mean chord $\bar{c}_t$	0.637 ft	0.5 ft
Aerodynamic mean chord $\bar{\bar{c}}_t$	0.667 ft	0.518 ft
Aspect ratio A_t	4.0	5.0
Taper ratio	0.45	0.5
Sweepback of quarter-chord line	33°	24.9°
Height of hinge point above moments centre h_t	0.362 ft	0.238 ft
Distance of mean quarter-chord aft of pitch centre ℓ_t	3.431 ft	3.175 ft
Body		
Overall length	7.347 ft	5.25 ft
Diameter	1.0 ft	0.833 ft

SYMBOLS

a_t	tailplane lift curve slope
A_t	tailplane aspect ratio
$\bar{c}_t$	tailplane geometric mean chord
$\bar{\bar{c}}_t$	tailplane aerodynamic mean chord
$\bar{c}_W$	wing geometric mean chord
$\bar{\bar{c}}_W$	wing aerodynamic mean chord
$C_{A_{meas}}$	axial force coefficient measured on the tailplane in the direction parallel to the fuselage axis
C_D	corrected drag coefficient of complete model with tail
$C_{D_{it}}$	tailplane induced drag coefficient
$C_{D_{ot}}$	tailplane drag coefficient at zero lift
C_{D_t}	tailplane drag coefficient $(= C_{D_{ot}} + C_{D_{it}})$
$(C_D)_{WB}$	drag coefficient of complete model without tailplane
ΔC_D	correction to the drag coefficient of the complete model
C_L	corrected lift coefficient of complete model with tail
C_{L_t}	tailplane lift coefficient
$(C_L)_{WB}$	lift coefficient of complete model without tailplane
ΔC_L	correction to the lift coefficient of the complete model
C_m	corrected pitching moment coefficient of the complete model with tail
$C_{m_{meas}}$	measured pitching moment coefficient of the complete model with tail
$C_{m_{ot}}$	tailplane pitching moment coefficient at zero lift
C_{m_t}	tailplane pitching moment coefficient
$(C_m)_t$	tailplane contribution to the overall pitching moment coefficient
$(C_m)_{WB}$	pitching moment coefficient of complete model without tail
ΔC_m	correction to the pitching moment coefficient of the complete model

SYMBOLS (Contd.)

$C_{N_{meas}}$	normal force coefficient measured on the tailplane in the direction normal to the fuselage axis
$C_{\mu N}$	momentum coefficient for blowing through the nose slot of the jet nacelle model
$C_{\mu R}$	momentum coefficient for blowing through the gear slot of the jet nacelle model
D_t	drag of the tailplane
δD	contribution of the tailplane lift and drag to the overall drag
h_t	tail height above moment centre measured in body axes
h'	tail height above moment centre measured in wind axes at the tail $h' = h_t \cos(\alpha_B - \varepsilon) - \ell_t \sin(\alpha_B - \varepsilon)$
i_t	tail setting relative to the body axis
Δi_t	correction to tail setting
i_W	wing setting relative to the body axis
k_t	induced drag factor of the tailplane
ℓ_t	tail arm measured in body axes
ℓ'	tail arm measured in wind axes at the tail $\ell' = \ell_t \cos(\alpha_B - \varepsilon) + h_t \sin(\alpha_B - \varepsilon)$
L_t	lift of the tailplane
δL	contribution of the tailplane lift and drag to the overall lift
q_i	mean dynamic pressure incident on the tailplane due to the wake of the wing and body
q_t	free stream dynamic pressure corrected for blockage constraint interference at the tail
q_W	free stream dynamic pressure corrected for blockage constraint interference at the wing
S_t	tailplane area
S_W	wing area
α_B	body incidence
α_t	tailplane incidence $(= \alpha_B + i_t - \varepsilon)$
$\Delta\alpha_t$	lift constraint interference at the tailplane

SYMBOLS (Contd.)

α_W	wing incidence $(= \alpha_B + i_W)$
$\Delta\alpha_W$	lift constraint interference at the wing
ε	mean downwash angle at the tailplane

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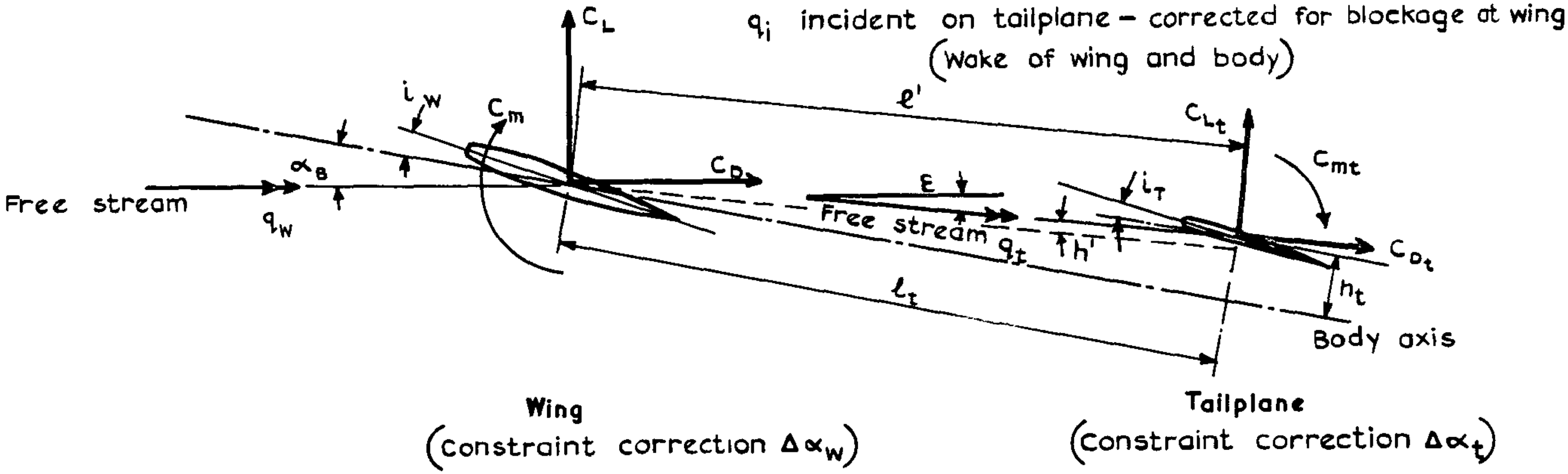

Fig.1 Definition of quantities used in obtaining corrections

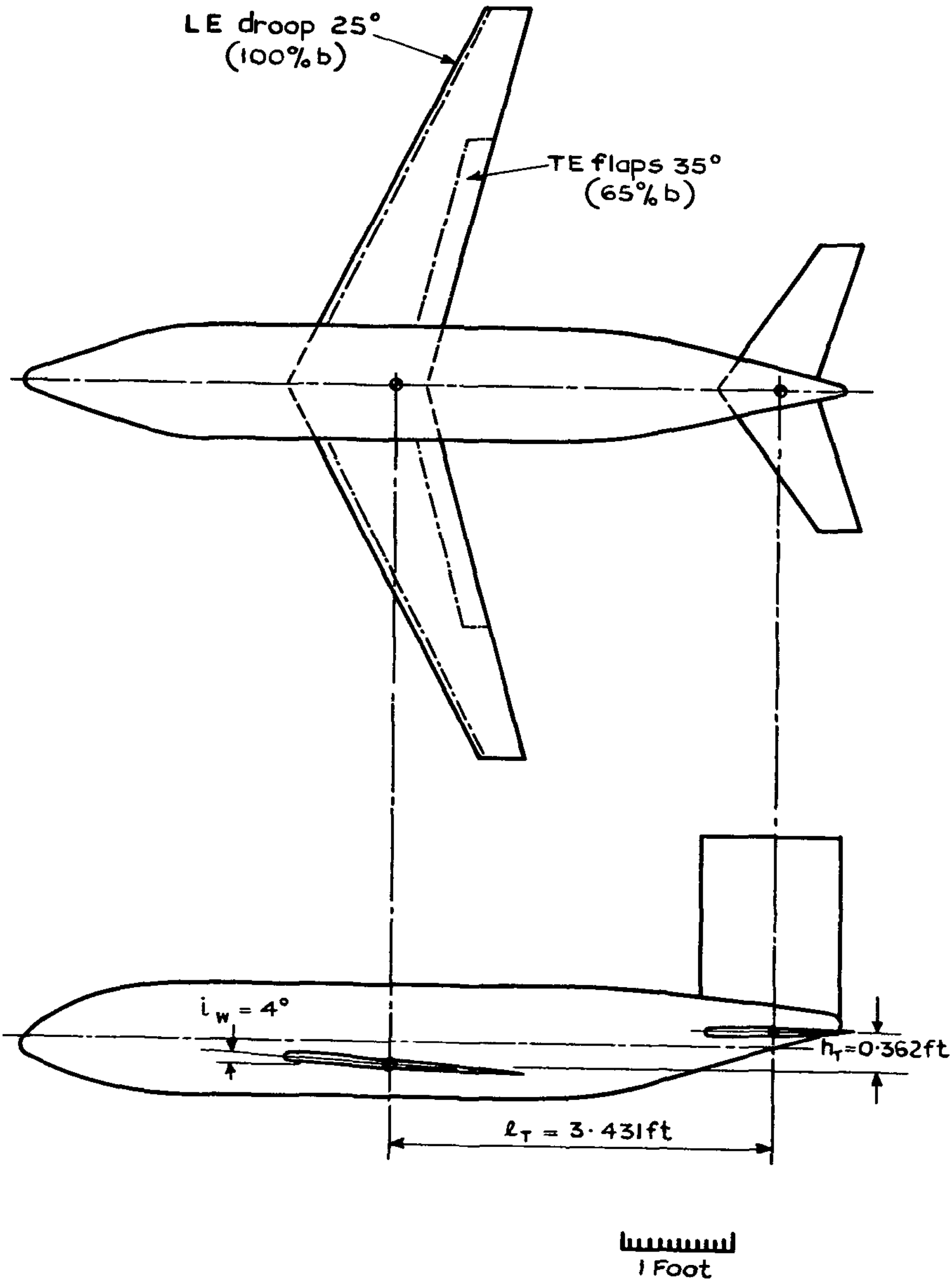

Fig.2 GA of airbus model

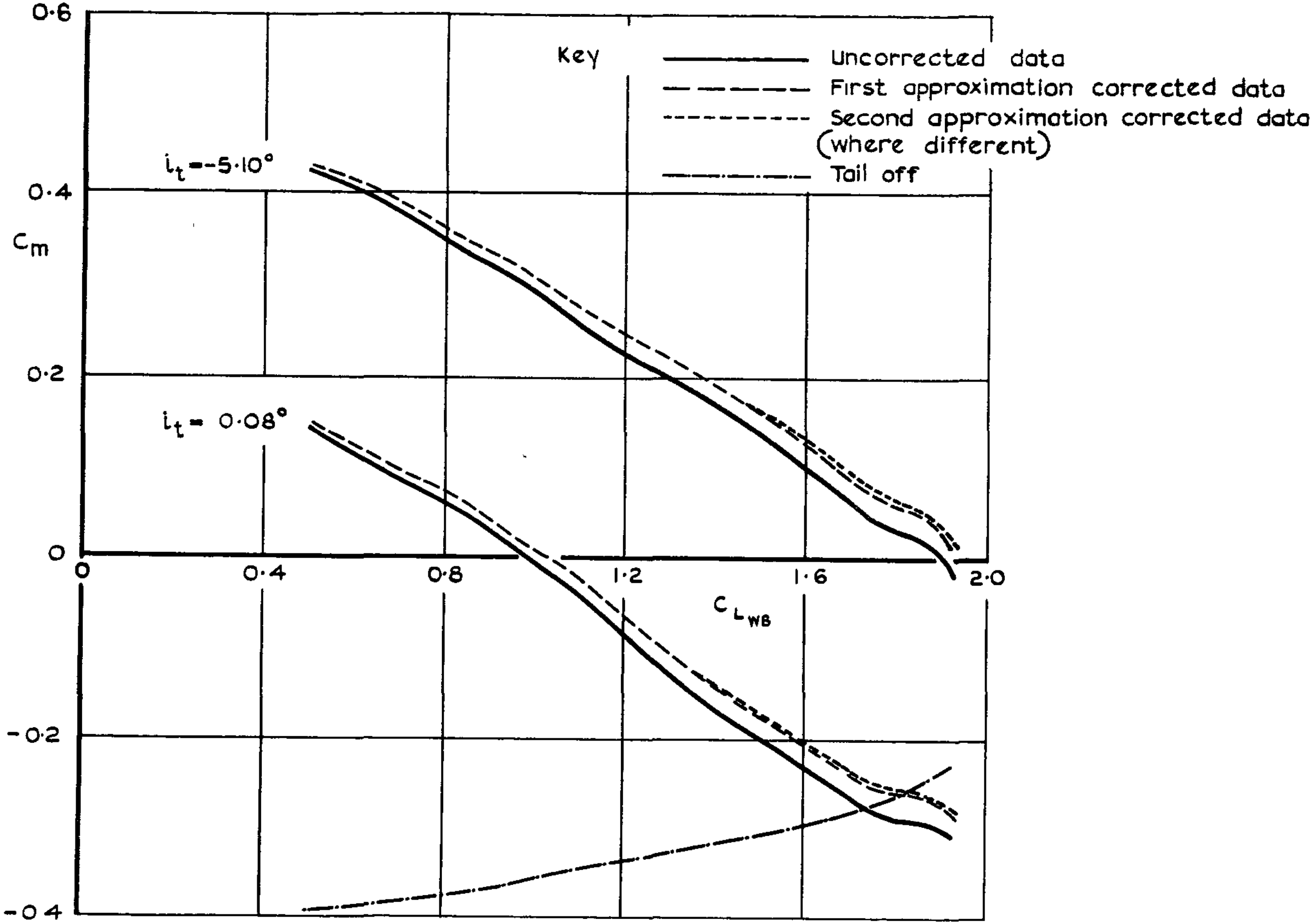

Fig.3 Airbus model – first method of applying corrections. C_m vs $C_{L_{WB}}$

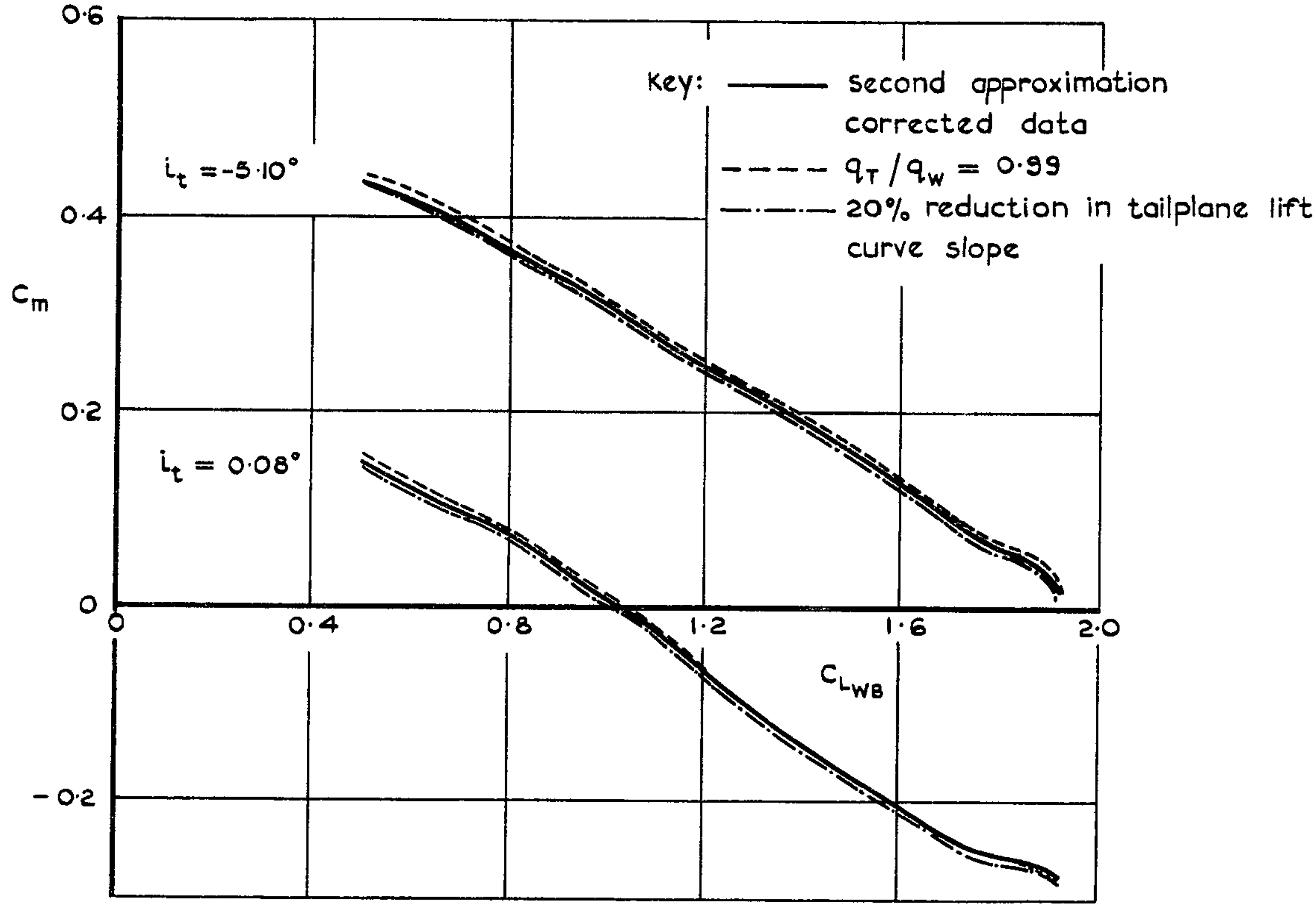

Fig.4 Airbus model — first method, second approximation; effect of changing q_T/q_W and tailplane lift curve slope. C_m vs $C_{L_{WB}}$

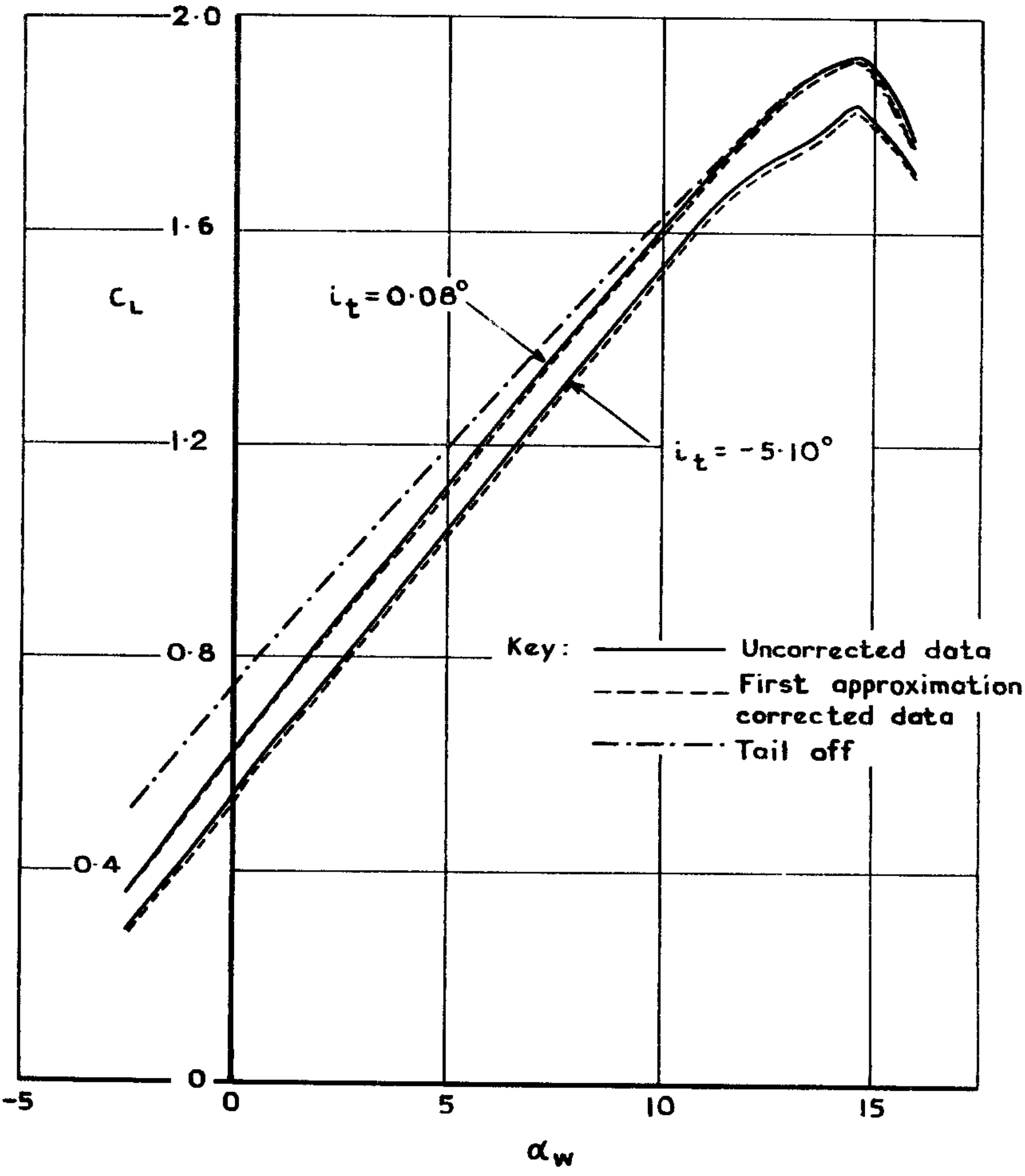

Fig.5 Airbus model – first method of applying corrections. C_L vs α_W

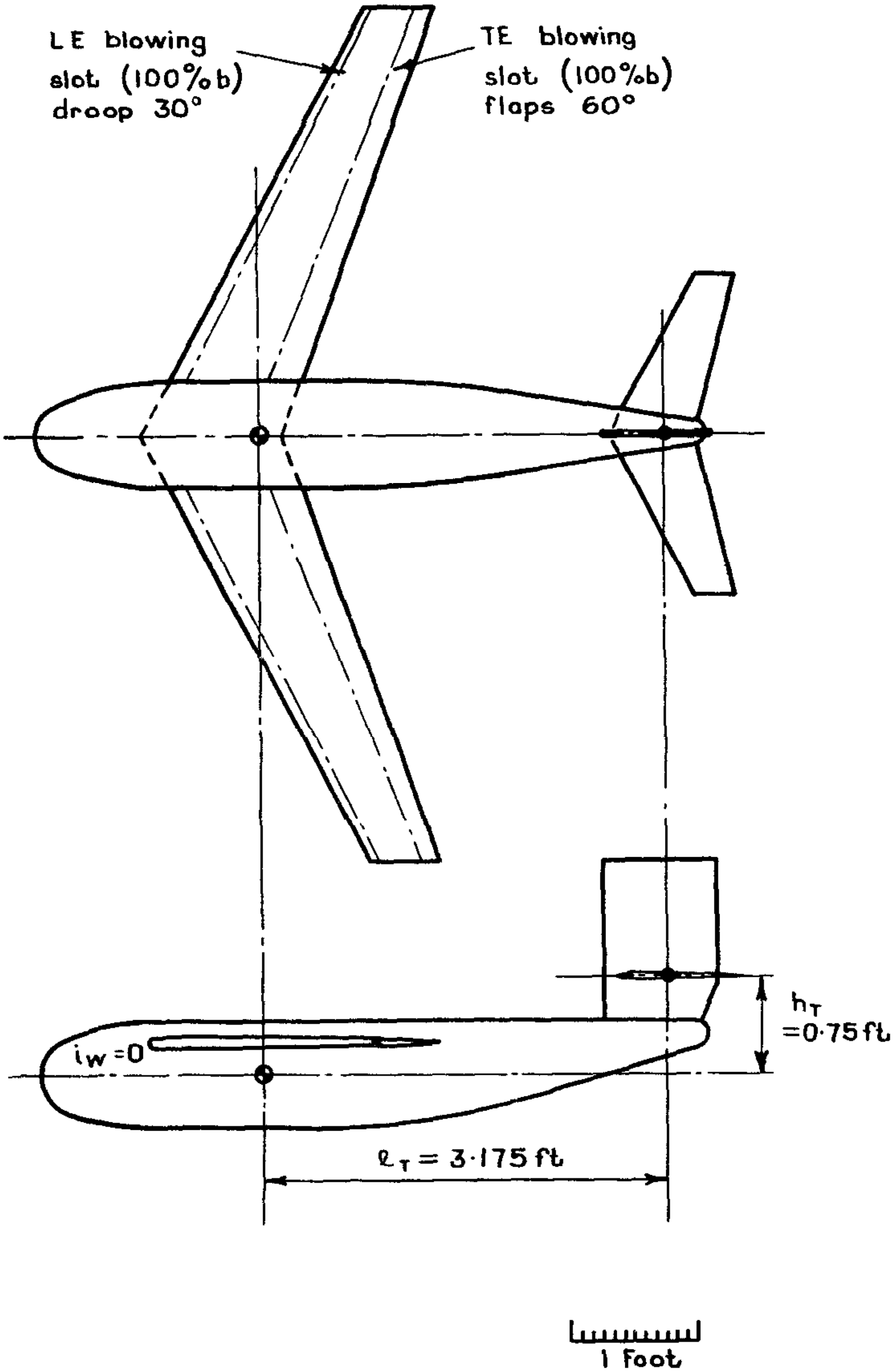

Fig.6 G A of jet nacelle model

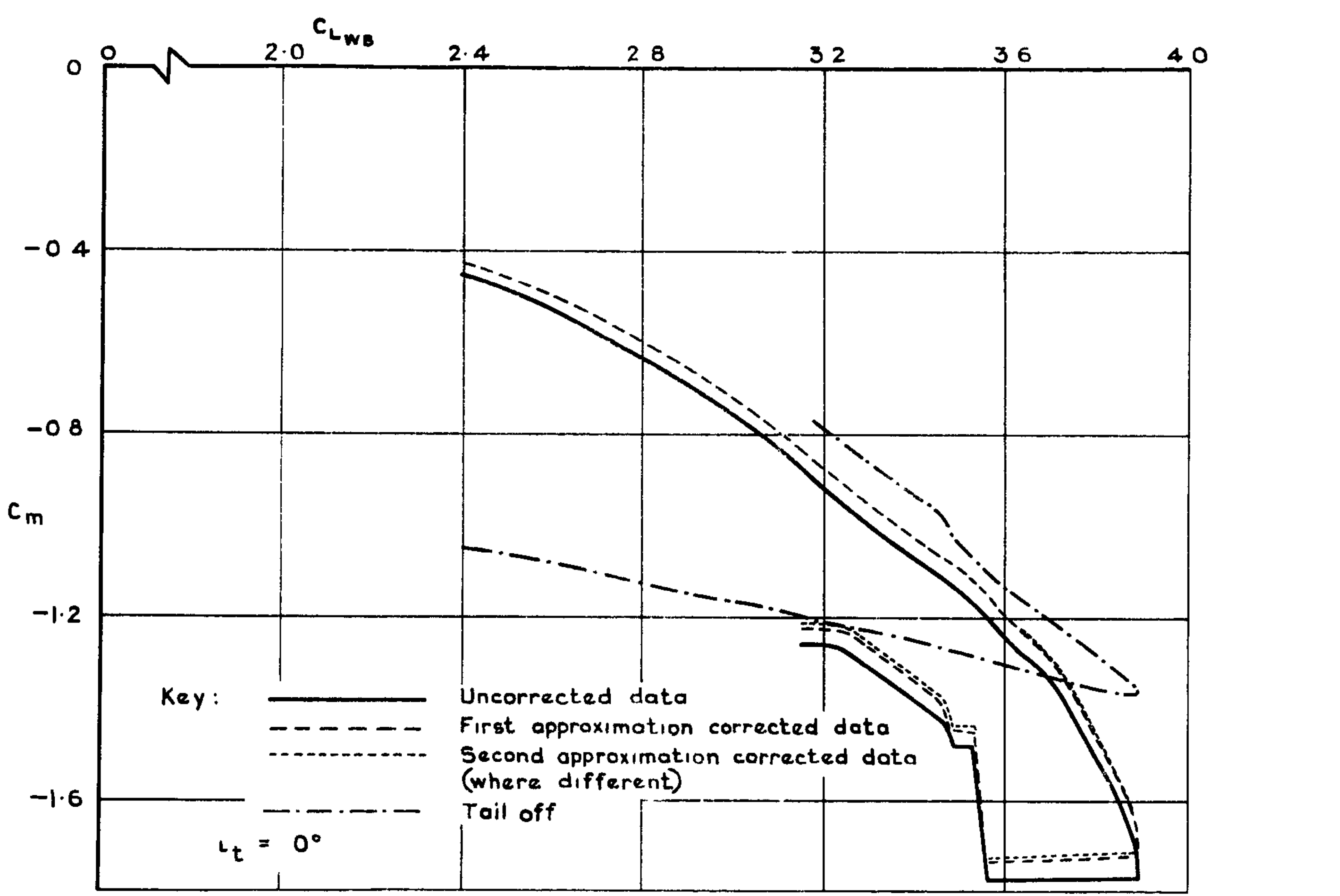

Fig. 7 Jet nacelle model — first method of applying corrections. C_m vs $C_{L_{WB}}$

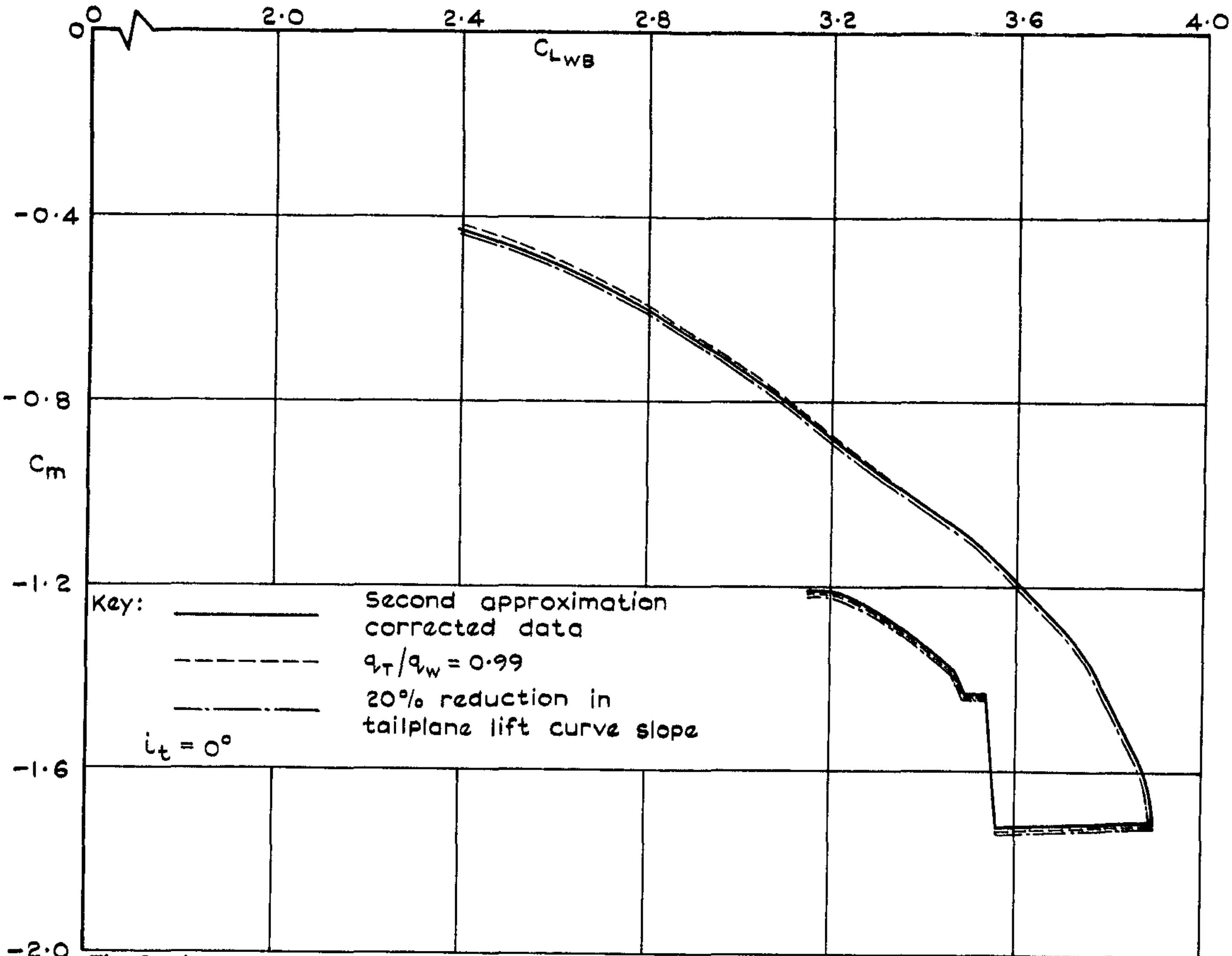

Fig.8 Jet nacelle model – first method, second approximation; effect of changing q_T/q_W and tailplane lift curve slope. C_m vs $C_{L_{WB}}$

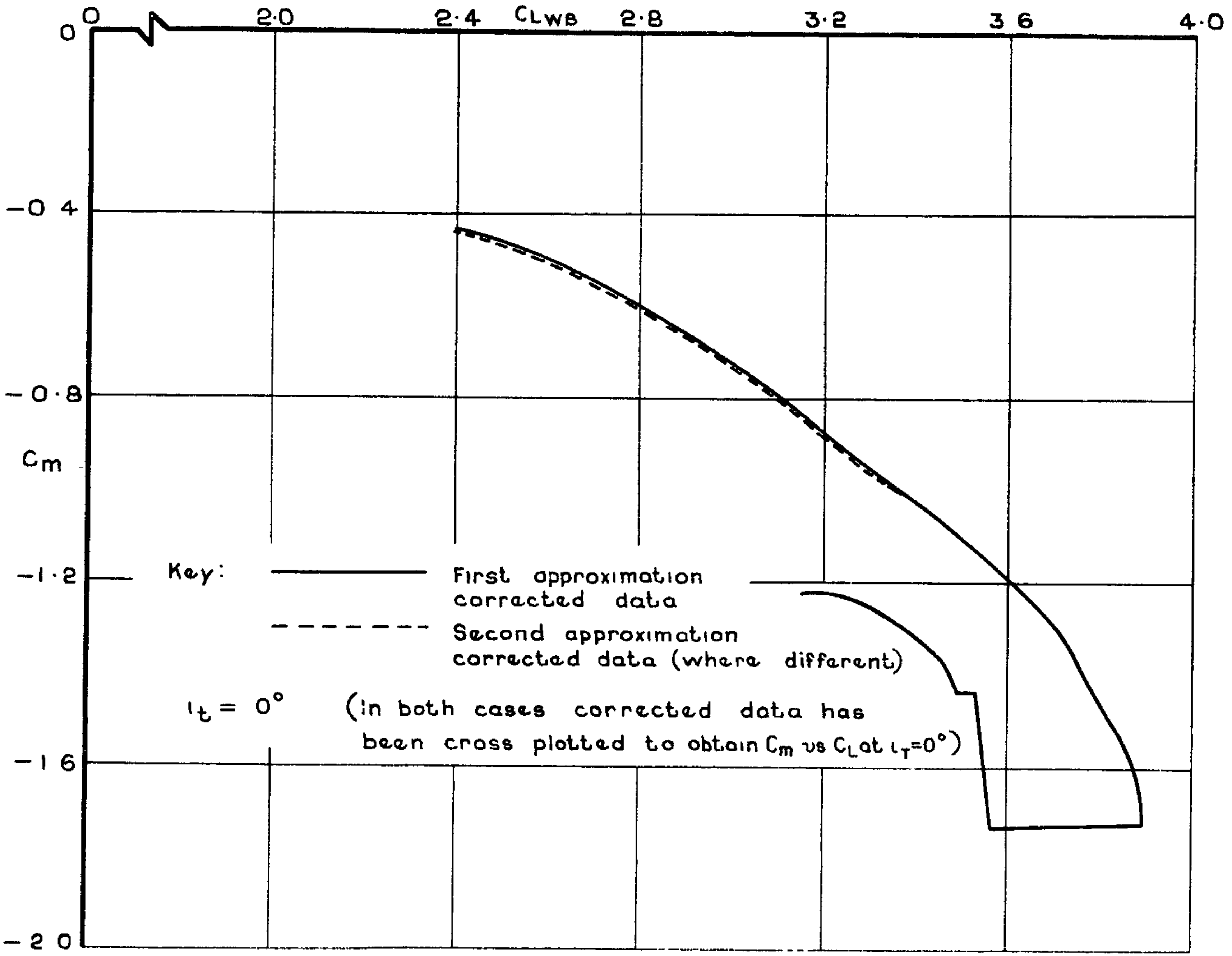

Fig.9 Jet nacelle model—second method of applying corrections. C_m vs C_{LWB}

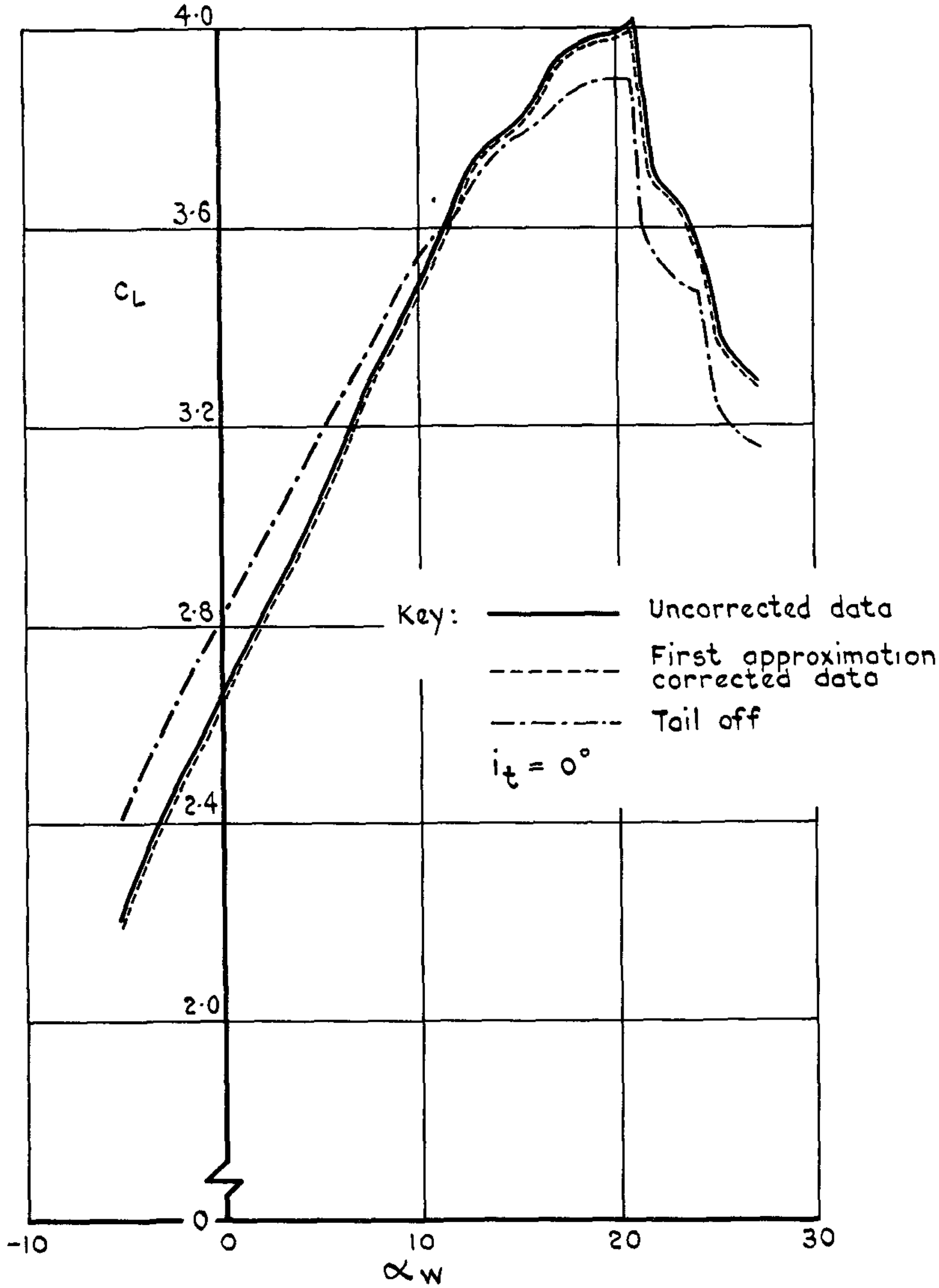

Fig. 10 Jet nacelle model—first method of applying corrections, C_L vs α_W

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WALL CORRECTIONS TO LONGITUDINAL COMPONENTS MEASURED ON WIND-TUNNEL MODELS WITH TAILS

Calculations have been made of the magnitude of the wall corrections to pitching moment for two models with tails using two methods of correction and two stages of approximation for each method. It is found that the first stage of approximation is accurate enough for values of lift coefficient up to four. For higher values of lift coefficient, it is suggested that it is not worth using the second approximations as the theory of wind tunnel wall-interference is not sufficiently accurate in its predictions for flows with the large values of downwash inherent in high-lift systems such as lifting jets or rotors.

(over)

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DETACHABLE ABSTRACT CARDS

The correction to lift calculated for the two models is shown to be non-negligible and it is recommended that it is applied in tests where differences are to be taken between tail-on and tail-off tests.

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