Wall Corrections to Longitudinal Components Measured on Wind-Tunnel Models with Tails

by

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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.

INTRODUCTION

Some doubt has recently been expressed¹ 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 proposed¹ 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.

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 \(\frac{\partial C_m}{\partial i_t a_W}\) is obtained. The change in tunnel constraint between the wing and the tail is obtained theoretically\(^2\) and the correction is then:

\[
\Delta C_m = - (\Delta \alpha_t - \Delta \alpha_W) \left( \frac{\partial C_m}{\partial i_t a_W} \right) \quad (1)
\]

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 \((15)\) of Heyson becomes:

\[
C_m = C_{m\text{ meas}} + \Delta C_m \quad (2A)
\]
The right hand side of this equation comprises two parts. The term
multiplied by \((1 - \frac{q_t}{q_w})\) 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 \(\frac{\partial a_t}{\partial \alpha_t}\) is
the partial derivative \(\left(\frac{\partial C_m}{\partial \alpha_t}\right)\). The overall factor \(\frac{q_t}{q_w}\) 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 deriva-
tion 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:

\[
\Delta C_m = \frac{\partial a_t}{\partial \alpha_t} a_t \left(\Delta a_t - \Delta \alpha_w\right)
\]  

It is worth pointing out that the factor \(\left(\frac{\partial C_m}{\partial \alpha_t}\right)\) in this equation will in
fact be taken into account in the experimental determination of \(\left(\frac{\partial C_m}{\partial \alpha_t}\right)\) used

where

\[
\Delta C_m = \frac{q_t S_t \ell_t}{a_t S_w a_w} \left(1 - \frac{q_t}{q_w}\right) \left(\frac{C_{L_t} \ell_t}{a_t} \frac{d C_{m_t}}{d \alpha_t} + \left(\frac{h'}{\ell_t} C_{D_t} - C_{L_t}\right) \cos \epsilon \right.
\]

\[
+ \left(\frac{h'}{\ell_t} C_{L_t} + C_{D_t}\right) \sin \epsilon \right)
\]

\[
- \left(\frac{q_t}{q_w} \Delta a_t - \Delta \alpha_w\right) \left(\frac{d C_{m_t}}{d \alpha_t} - \frac{2h'}{\ell_t} C_{D_{it}} - \frac{h'}{\ell_t} C_{L_t} - a_t - C_{D_t}\right) \cos \epsilon
\]

\[
+ \left(\frac{h'}{\ell_t} C_{D_t} + \frac{h'}{\ell_t} a_t - C_{L_t} + \frac{2a_t C_{D_{it}}}{C_{L_t}}\right) \sin \epsilon \right) \right\}
\]  

\(\text{(2B)}\)
in equation (1) but this factor is of minor importance compared with the two
factors \(1 - \frac{q_t}{q_w}\) and \(\frac{q_t}{q_w} \cdot \Delta a_t - \Delta a_w\) in equation (2B).

The correction of Heyson, equations (2) above, henceforth called the
second approximation, will in general differ little from the first approxima-
tion 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:

\[
\Delta C_L = - (\Delta a_t - \Delta a_w) \left( \frac{\partial C_L}{\partial a_t} \right) \tag{4}
\]

\[
\Delta C_D = - (\Delta a_t - \Delta a_w) \left( \frac{\partial C_D}{\partial a_t} \right) \tag{5A}
\]

The derivative \(\frac{\partial C_D}{\partial a_t}\) will not be approximately linear and is best
obtained from an assumed drag relation, neglecting the contribution of the tail-
plane lift:

\[
C_D = (C_D)_{WB} + \frac{S_t}{S_w} \left( C_{D ot} + \frac{k_t}{\pi A_t} C_L^2 \right)
\]

therefore

\[
\left( \frac{\partial C_D}{\partial a_t} \right)_{a_w} = \frac{2k_t}{\pi A_t} \frac{C_L^2}{C_{D ot} + \frac{k_t}{\pi A_t} C_L^2}
\]

So that the correction is:

\[
\Delta C_D = - (\Delta a_t - \Delta a_w) \frac{2k_t}{\pi A_t} \frac{C_L^2}{C_{D ot} + \frac{k_t}{\pi A_t} C_L^2} \left( \frac{\partial C_L}{\partial a_t} \right) \tag{5B}
\]

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:

$$\Delta i_t = \Delta \alpha_t - \Delta \alpha_W.$$  

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:

$$C_m = (C_m)_{WB} + \frac{q_W}{\rho} \left[ (C_m)_t + \frac{S_t \Delta i_t}{S_W} \left( \frac{h_t}{a_t} \left( C_{N \text{meas}} + C_{A \text{meas}} \right) \right) \right].$$  

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

$$C_{N \text{meas}} = \frac{q_t}{q_W} \left[ C_L t \cos (\alpha_B - \epsilon + \Delta i_t) + C_D_{N t} \sin (\alpha_B - \epsilon + \Delta i_t) \right]$$  

and

$$C_{A \text{meas}} = \frac{q_t}{q_W} \left[ C_L t \cos (\alpha_B - \epsilon + \Delta i_t) - C_D_{N t} \sin (\alpha_B - \epsilon + \Delta i_t) \right].$$

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\textsuperscript{3} but, although the lift constraint effect at the wing may be calculated taking into account the effect of chord, sweepback, 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\textsuperscript{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\textsuperscript{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 \( \frac{\partial C_M}{\partial \alpha_W} \) and \( \frac{\partial C_L}{\partial \alpha_W} \) 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\textsuperscript{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\textsuperscript{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 x 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 x 0.06 (the slope of the $C_m$ vs $\theta_t$ 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 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 (0.3%), 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 0.3% 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

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 x 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:

\[ \delta L = L_t (\Delta \alpha_t, q_t) \cos (\Delta \alpha_t - \varepsilon) + D_t (\Delta \alpha_t, q_t) \sin (\Delta \alpha_t - \varepsilon) \]  \hspace{1cm} (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:

\[ \delta L = L_t (\Delta \alpha_w, q_w) \cos (\Delta \alpha_w - \varepsilon) + D_t (\Delta \alpha_w, q_w) \sin (\Delta \alpha_w - \varepsilon) \]  \hspace{1cm} (A-2)

If the tailplane lift and drag are defined as:

\[ L_t = a_t \frac{q_t}{q_w} q_{t,w} S_t \]  \hspace{1cm} (A-3)

\[ D_t = \left[ c_{D_{ot}} + \frac{k}{\pi A_t} \frac{a_t^2}{q_w} \right] a_{t,w} S_t \]  \hspace{1cm} (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_t}{q_w} \frac{S_t}{S_w} \left[ \left( 1 - \frac{q_t}{q_w} \right) \left[ C_{L_t} \cos \varepsilon - C_{D_t} \sin \varepsilon \right] \right. \right.

\[ - \left( \frac{a_t}{q_w} \Delta \alpha_t \Delta \alpha_w \right) \left[ \left( a_{t,w} \cos \varepsilon + \left( C_{L_t} - \frac{2a_t}{C_{L_t}} C_{D,wt} \right) \sin \varepsilon \right) \right] \]  \hspace{1cm} (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:

\[ \delta D = D_t (\Delta \alpha_t, q_t) \cos (\Delta \alpha_t - \varepsilon) - L_t (\Delta \alpha_t, q_t) \sin (\Delta \alpha_t - \varepsilon) \]  \hspace{1cm} (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:

\[ \delta D = D_t (\Delta \alpha_w, q_t) \cos (\Delta \alpha_w - \varepsilon) - L_t (\Delta \alpha_w, q_w) \sin (\Delta \alpha_w - \varepsilon) \]  \hspace{1cm} (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:

\[ \Delta C_D = \frac{q_t}{q_w} S_t \left[ \left( 1 - \frac{q_t}{q_w} \right) \left[ C_{D_t} \cos \varepsilon + C_{L_t} \sin \varepsilon \right] \right. \\
+ \left. \left( \frac{q_t}{q_w} \Delta \alpha_t - \Delta \alpha_w \right) \left[ \left( C_{L_t} - \frac{2 a_t C_{D_t}}{C_{L_t}} \right) \cos \varepsilon - C_{D_t} \sin \varepsilon \right] \right] \]  \hspace{1cm} (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:

\[ \delta L = \frac{q_t}{q_w} q_t S_t \left[ C_{L_t} \cos (\varepsilon - \Delta \alpha_t) - C_{D_t} \sin (\varepsilon - \Delta \alpha_t) \right] \]  \hspace{1cm} (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:

\[ \delta L = \frac{q_t}{q_w} q_t S_t \left[ C_{L_t} \cos \varepsilon - C_{D_t} \sin \varepsilon \right] \]  \hspace{1cm} (A-10)

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

$$\delta D = \frac{q_t}{q_W} q_t S_t \left[ C_D t \cos (\varepsilon - \Delta i_t) + C_L t \sin (\varepsilon - \Delta i_t) \right] \quad (A-12)$$

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

$$\delta D = \frac{q_t}{q_W} q_t S_t \left[ C_D t \cos \varepsilon + C_L t \sin \varepsilon \right] \quad (A-13)$$

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:

$$\Delta C_D = \frac{q_t}{q_W} S_t \left[ (1 - \frac{q_t}{q_W}) \left( C_D t \cos \varepsilon + C_L t \sin \varepsilon \right) - \frac{q_t}{q_W} \Delta i_t \left( C_L t \sin \varepsilon + C_D t \cos \varepsilon \right) \right] \quad (A-14)$$
### Table 1
**MODEL DATA**

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<th>Airbus</th>
<th>Jet nacelle</th>
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<tr>
<td><strong>Body</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall length</td>
<td>7.347 ft</td>
<td>5.25 ft</td>
</tr>
<tr>
<td>Diameter</td>
<td>1.0 ft</td>
<td>0.833 ft</td>
</tr>
</tbody>
</table>
SYMBOLS

\( a_t \)  
\( A_t \)  
\( c_t \)  
\( \bar{c}_t \)  
\( c_w \)  
\( \bar{c}_w \)  
\( C_{A_{\text{meas}}} \)  
\( C_D \)  
\( C_{D_{\text{it}}} \)  
\( C_{D_{\text{tot}}} \)  
\( (C_D)^{\text{WB}} \)  
\( \Delta C_D \)  
\( C_L \)  
\( \bar{C}_L \)  
\( (C_L)^{\text{WB}} \)  
\( \Delta C_L \)  
\( C_m \)  
\( C_{m_{\text{meas}}} \)  
\( C_{m_{\text{tot}}} \)  
\( C_m \)  
\( (C_m)^t \)  
\( (C_m)^{\text{WB}} \)  
\( \Delta C_m \)  

- tailplane lift curve slope
- tailplane aspect ratio
- tailplane geometric mean chord
- tailplane aerodynamic mean chord
- wing geometric mean chord
- wing aerodynamic mean chord
- axial force coefficient measured on the tailplane in the direction parallel to the fuselage axis
- corrected drag coefficient of complete model with tail
- tailplane induced drag coefficient
- tailplane drag coefficient at zero lift
- tailplane drag coefficient \( = C_{D_{\text{tot}}} + C_{D_{\text{it}}} \)
- drag coefficient of complete model without tailplane
- correction to the drag coefficient of the complete model
- corrected lift coefficient of complete model with tail
- tailplane lift coefficient
- lift coefficient of complete model without tailplane
- correction to the lift coefficient of the complete model
- corrected pitching moment coefficient of the complete model with tail
- measured pitching moment coefficient of the complete model with tail
- tailplane pitching moment coefficient at zero lift
- tailplane pitching moment coefficient
- tailplane contribution to the overall pitching moment coefficient
- pitching moment coefficient of complete model without tail
- correction to the pitching moment coefficient of the complete model
SYMBOLS (Cont'd.)

\( C_{N_{\text{meas}}} \)  
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

\( S_D \)  
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  
\[ h' = h_t \cos (\alpha_B - \epsilon) - \ell_t \sin (\alpha_B - \epsilon) \]

\( \ell_t \)  
tail setting relative to the body axis

\( \Delta \ell_t \)  
correction to tail setting

\( i_W \)  
wing setting relative to the body axis

\( k_t \)  
induced drag factor of the tailplane

\( \ell \)  
tail arm measured in body axes

\( \ell' \)  
tail arm measured in wind axes at the tail  
\[ \ell' = \ell_t \cos (\alpha_B - \epsilon) + h_t \sin (\alpha_B - \epsilon) \]

\( L_t \)  
lift of the tailplane

\( \Delta L \)  
contribution of the tailplane lift and drag to the overall lift

\( q_{\text{w,e}} \)  
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

\( \alpha_B \)  
body incidence

\( \alpha_t \)  
tailplane incidence  
\[ (= \alpha_B + i_t - \epsilon) \]

\( \Delta \alpha_t \)  
lift constraint interference at the tailplane
SYMBOLS (Contd.)

\( \alpha_w \) \quad \text{wing incidence \( (= \alpha_B + i_w) \)}

\( \Delta \alpha_W \) \quad \text{lift constraint interference at the wing}

\( \varepsilon \) \quad \text{mean downwash angle at the tailplane}
<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Title, etc.</th>
</tr>
</thead>
</table>
| 1   | H.H. Heyson             | Equations for the application of wind-tunnel wall corrections to pitching moments caused by the tail of an aircraft model.  
NASA TN D-3738 (1966)                                                                                      |
| 2   | A. Silverstein, J.A. White | Wind-tunnel interference with particular reference to off-centre positions of the wing and to the downwash at the tail.  
AGARDograph 109 (1966)                                                                                      |
| 4   | J.Y.G. Evans            | Corrections to velocity for wall constraint in any 10 x 7 rectangular subsonic wind tunnel.  
A.R.C. R & M 2662 (1949)                                                                                     |
| 5   | S.F.J. Butler, M.B. Guyett, B.A. May | Six-component low-speed tunnel tests of jet-flap complete models with variation of aspect ratio, dihedral, and sweepback, including the influence of ground proximity.  
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| 6   | K.J. Grunwald           | Wall effects and scale effects in V/STOL model testing.  
AIAA Navy Aerodynamic Testing Conference (1964)                                                                  |
| 7   | H.H. Heyson             | Linearized theory of wind-tunnel jet-boundary corrections and ground effect for VTOL/STOL aircraft.  
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| 8   | S.F.J. Butler, J. Williams | Further comments on high-lift testing in wind-tunnels with particular reference to jet-blowing models.  
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<th>No.</th>
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</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>D.A. Lovell</td>
<td>The low-speed tailplane performance of a high-capacity transport aircraft.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R.A.E. Technical Report (to be published)</td>
</tr>
<tr>
<td>10</td>
<td>R.C.W. Eyre</td>
<td>Low speed wind-tunnel tests on an AR 8 swept wing subsonic transport research model with B.L.C. blowing over nose and rear flaps for high-lift.</td>
</tr>
</tbody>
</table>
Fig.1 Definition of quantities used in obtaining corrections
Fig. 2 GA of Airbus model

- LE droop 25° (100% b)
- TE flaps 35° (65% b)

- $i_w = 4°$
- $h_T = 0.362$ ft
- $L_T = 3.431$ ft

1 Foot
Fig. 3 Airbus model—first method of applying corrections. $C_m$ vs $C_{LWB}$
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 $\alpha_w$
Fig. 6 GA of jet nacelle model

- LE blowing slot (100%b) drop 30°
- TE blowing slot (100%b) flaps 60°
- $l_w = 0°$
- $h_T = 0.75\text{ft}$
- $l_T = 3.175\text{ft}$
Fig. 7 Jet nacelle model — first method of applying corrections. $C_m$ vs $C_{LWB}$
Fig. 8 Jet nacelle model - first method, second approximation; effect of changing $q_T/q_W$ and tailplane lift curve slope. $C_m$ vs $C_{L_{WB}}$. 

Key:
- Second approximation corrected data
- $q_T/q_W = 0.99$
- 20% reduction in tailplane lift curve slope
- $i_T = C^\circ$
Fig. 9 Jet nacelle model - second method of applying corrections. $C_m$ vs $C_{LWB}$

Key:
- First approximation corrected data
- Second approximation corrected data (where different)

$t_t = 0^\circ$ (in both cases corrected data has been cross plotted to obtain $C_m$ vs $C_{LWB}$ at $t_t = 0^\circ$)
Fig. 10. Jet nacelle model—first method of applying corrections, Cl vs W.

--- Uncorrected data
--- Tail off
--- First approximation corrected data

Key:
- $\alpha = 0^\circ$

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough, Hants, 1965. K.A.
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.
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.