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Average downwash at the tailplane at low angles of attack and subsonic speeds

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THE PREPARATION OF THIS DATA ITEM

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AVERAGE DOWNWASH AT THE TAILPLANE AT LOW ANGLES OF ATTACK AND SUBSONIC SPEEDS

CONTENTS

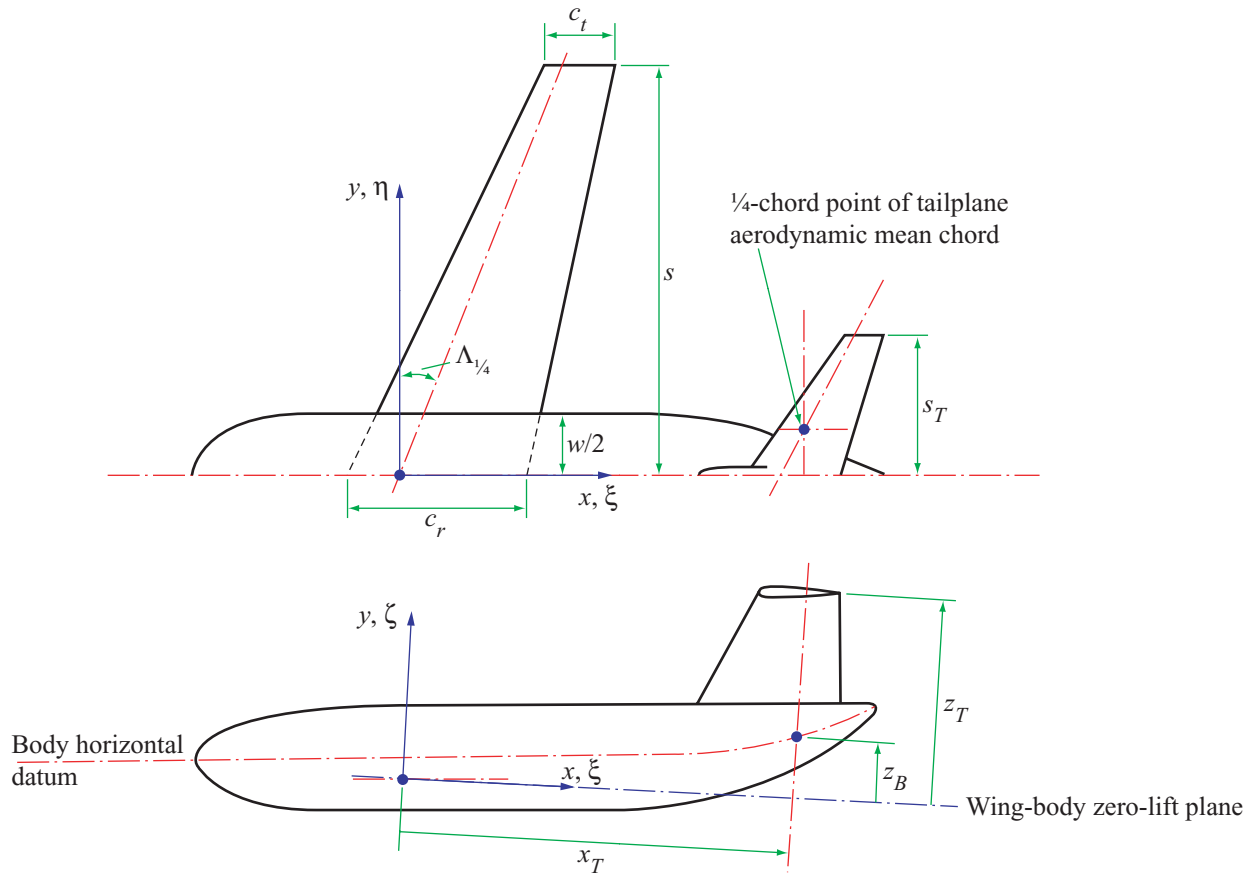
	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	3
3. BASIS OF THE METHOD	4
4. EVALUATION OF EQUATION (3.4) FOR DOWNWASH GRADIENT AT LOW SPEEDS	5
4.1 Downwash Gradient at Zero Tailplane Height (first term in Equation (3.4))	5
4.2 Effect of Tailplane Height on Downwash Gradient (second term in Equation (3.4))	6
5. LOW SPEED DOWNWASH AT ZERO LIFT	6
6. EFFECT OF NACELLES	6
7. EFFECT OF COMPRESSIBILITY	6
8. ACCURACY AND APPLICABILITY	7
8.1 Accuracy	7
8.2 Applicability	7
9. DERIVATION	8
10. EXAMPLE	10
FIGURES 1 to 11	13 to 24

AVERAGE DOWNWASH AT THE TAILPLANE AT LOW ANGLES OF ATTACK AND SUBSONIC SPEEDS

1. NOTATION AND UNITS (see Sketch 1.1)

		<i>SI</i>	<i>British</i>
A	aspect ratio of wing planform, $4s^2/S$		
B	factor for body effect on average downwash gradient, see Equation (3.3)		
a_1	wing lift-curve slope	radian ⁻¹	radian ⁻¹
c_r	wing root (centre-line) chord	m	ft
c_t	wing tip chord	m	ft
$\bar{c}$	aerodynamic mean chord of wing	m	ft
F	downwash averaging factor, see Equation (4.1)		
H_p	downwash parameter on centre line ($\eta = 0$, $\zeta = 0$,) of plane vortex sheet, see Equation (4.2)	radian	radian
H_{pe}	downwash parameter for wing with elliptic loading	radian	radian
$H_{p\infty}$	value of H_p as $\xi \rightarrow \infty$	radian	radian
ΔH_p	correction to H_p	radian	radian
K_M	factor for Mach number effect on average downwash gradient, see Section 7		
M	free-stream Mach number		
$R_{\bar{c}}$	Reynolds number based on $\bar{c}$		
S	wing planform area	m ²	ft ²
s	wing semi-span	m	ft
s_T	tailplane semi-span	m	ft
w	maximum width of body	m	ft
x, y, z	orthogonal co-ordinates with origin at quarter-chord point of wing centre-line chord; x -axis located on intersection of plane of symmetry and wing-body zero-lift plane		

x_T	distance of tailplane behind quarter-chord point of wing centre-line chord	m	ft
z_B	height of body centre line above x -axis	m	ft
z_T	height of tailplane above x -axis	m	ft
α	angle of attack measured from datum, body horizontal datum, for example	degree	degree
α_0	angle of attack for zero wing-body lift	degree	degree
ε	downwash angle	degree	degree
$\bar{\varepsilon}$	average downwash angle across tailplane mounted on wing-body combination, see Section 3	degree	degree
$\bar{\varepsilon}_0$	value of $\bar{\varepsilon}$ at zero wing-body lift	degree	degree
$\Lambda_{1/4}$	sweepback angle of wing quarter-chord line	degree	degree
$\Lambda_{1/2}$	sweepback angle of wing half-chord line	degree	degree
λ	ratio of wing tip chord to centre-line (root) chord, c_t/c_r		
$\xi, \eta, \zeta,$	$x/s, y/s, z/s$		
$\xi_T, \eta_T, \zeta_T,$	$x_T/s, s_T/s, z_T/s$		
ζ_B	z_B/s		
<i>Superscript</i>			
*	denotes wing-tail combination		
<i>Subscripts</i>			
M	denotes Mach number		
0	denotes $\zeta_T = 0$		



Note: To cater for other than straight-tapered planforms the equivalent wing planform concept described in Item No. 76015 (Derivation 26) should be used.

Sketch 1.1

2. INTRODUCTION

This Item gives data for the average downwash at the tailplane for subsonic speeds and low angles of attack where the lift, pitching moment and downwash characteristics are linear, *i.e.* where the flow is wholly attached. Under these conditions it is a good approximation to assume that up to the location of the tailplane the vortex sheet shed from the wing will be substantially flat, and this assumption is inherent to that part of the method used in this Item which is theoretically based. Under these conditions, and up to the location of the tailplane, it will be assumed that the vortex sheet shed from the wing trailing edge lies in the zero-lift plane for the wing-body combination, and this is taken as the datum from which to measure tailplane height.

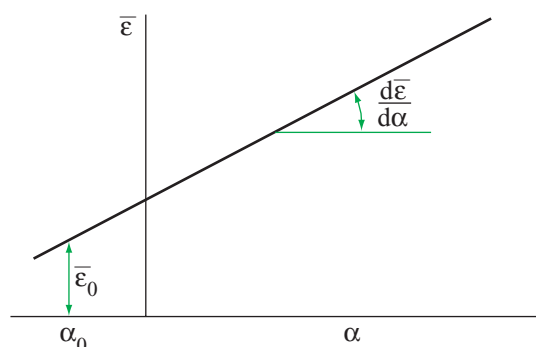
Section 3 gives the basis of the method while Sections 4 and 5 detail the methods whereby the downwash expressions in Section 3 may be evaluation for low-speed flows. A brief discussion of the effects of nacelles is given in Section 6. The effects of compressibility are assessed in Section 7. The accuracy and applicability of the method are outlined in Section 8 and a detailed worked example is given in Section 10. (Item No. 97021 deals with the effect of trailing-edge flap deployment on the average downwash at the tailplane at low speeds.)

3. BASIS OF THE METHOD

At low angles of attack, where the lift and pitching moment characteristics are linear, the average downwash at the tailplane (see Sketch 3.1) is given by

$$\bar{\varepsilon} = \bar{\varepsilon}_0 + \left(\frac{d\bar{\varepsilon}}{d\alpha} \right) (\alpha - \alpha_0) \quad (3.1)$$

where $\bar{\varepsilon}_0$ is the value of $\bar{\varepsilon}$ at zero wing-body lift (*i.e.* at $\alpha = \alpha_0$) and $d\bar{\varepsilon}/d\alpha$ is the average downwash gradient appropriate to the tailplane mounted on a wing-body combination.

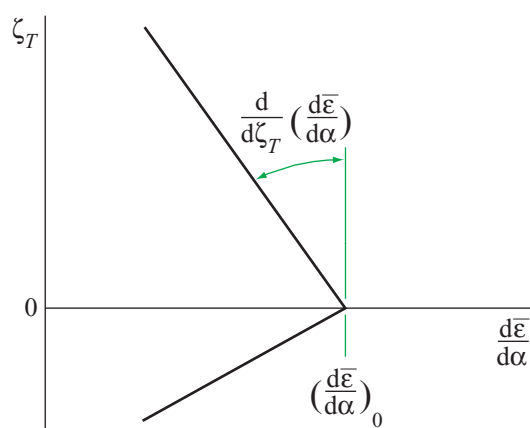


Sketch 3.1

For the purposes of a downwash calculation the tailplane is assumed to be located on the lateral axis passing through the quarter-chord point of the aerodynamic mean chord of the tailplane at a distance ζ_T downstream of the quarter-chord point of the wing centre-line chord.

If a linear variation in average downwash gradient with tail height, ζ_T , is assumed (see Sketch 3.2)

$$\frac{d\bar{\varepsilon}}{d\alpha} = \left(\frac{d\bar{\varepsilon}}{d\alpha} \right)_0 - \left| \zeta_T \right| \left| \frac{d}{d\zeta_T} \left(\frac{d\bar{\varepsilon}}{d\alpha} \right) \right|. \quad (3.2)$$



Sketch 3.2

Now the term $(d\bar{\varepsilon}/d\alpha)_0$ in Equation (3.2) can be expressed in the form

$$\left(\frac{d\bar{\varepsilon}}{d\alpha}\right)_0 = B \times \left(\frac{d\bar{\varepsilon}}{d\alpha}\right)_0^* \quad (3.3)$$

in which $B = \frac{(d\bar{\varepsilon}/d\alpha)_0}{(d\bar{\varepsilon}/d\alpha)_0^*}$ and the superscript * denotes the value for a wing-tail combination.

Combination of Equations (3.2) and (3.3) gives

$$\frac{d\bar{\varepsilon}}{d\alpha} = B \times \left(\frac{d\bar{\varepsilon}}{d\alpha}\right)_0^* - \left| \zeta_T \right| \left\| \frac{d}{d\zeta_T} \left(\frac{d\bar{\varepsilon}}{d\alpha}\right) \right\|. \quad (3.4)$$

4. EVALUATION OF EQUATION (3.4) FOR DOWNWASH GRADIENT AT LOW SPEEDS

4.1 Downwash Gradient at Zero Tailplane Height (first term in Equation (3.4))

The average downwash gradient at the tailplane of a wing-tail combination when the tailplane is immersed in the wing vortex sheet ($\zeta_T = 0$) may be estimated using the following equation developed in Derivation 29. The equation, which assumes a flat vortex sheet, was derived using the method of Derivation 19, in which the spanwise loadings were given by lifting-surface theory for the series of wing planforms in Derivation 22, together with an empirical correction.

$$\left(\frac{d\bar{\varepsilon}}{d\alpha}\right)_0^* = \frac{2a_1}{\pi A} (H_p + \Delta H_p) F \quad (4.1)$$

where $F = \left(\frac{d\bar{\varepsilon}/d\alpha}{d\bar{\varepsilon}/d\alpha}\right)_0^*$

and $H_p = H_{pe} - (1 - H_{p\infty})$. (4.2)

Values of a_1/A are obtained from Item No. 70011 (Derivation 23) for *incompressible flow*, $M = 0$; compressibility effects are dealt with in Section 7. Figures 1a to 1d present data for $H_{p\infty}$, the downwash parameter at an infinite distance downstream ($\xi_T \rightarrow \infty$) on the centre line ($\eta_T = 0$, $\zeta_T = 0$) of the vortex sheet shed from the wing. Figure 2 presents the variation of the downwash parameter H_{pe} with downstream distance from the quarter-chord point of the wing centre-line chord (ξ_T) and the quarter-chord sweep ($\Lambda_{1/4}$) for a flat vortex sheet behind an elliptically-loaded wing. Figure 3 provides an empirically-derived correction, ΔH_p , to give good agreement with experimental downwash gradient data for wing-tail combinations[†], (Derivations 1, 2, 3 and 7).

Figures 4 to 7 present the factor, F , to apply to the centre-line downwash gradient to estimate the average downwash gradient across the tailplane span. The factors were calculated for tailplanes located one wing semi-span downstream (*i.e.* $\xi_T = 1$) but they are not very sensitive to variation in ξ_T over the usual range for tailplane location ($0.5 \leq \xi_T \leq 2$). For wings with elliptic loading the factor is close to unity.

The factor B , accounting for the effect of the body on the average downwash gradient at the tailplane, is given by Figure 8 which was obtained from a correlation of experimental data for wing-body-tail combinations (Derivations 2, 5, 8 to 18, 21, 25, 27 and 30) having values of $w/2s$ ranging from 0.1 to 0.2.

[†] The tailplane in these cases was usually attached to the wing with a very slender boom assumed to provide negligible interference with the wing downwash field.

4.2 Effect of Tailplane Height on Downwash Gradient (second term in Equation (3.4))

The rate of change of average downwash gradient at the tailplane with tailplane height, $|d(\bar{d}\bar{\epsilon}/d\alpha)/d\zeta_T|$, assumed independent of tailplane height, is obtained from the empirically-derived curve in Figure 9 for wing-body-tail combinations (Derivations 2, 6, 8 to 15, 18, 21, 25, 27 and 30) having values of $w/2s$ in the range 0.1 to 0.2. The experimental data were found to correlate rather better when the effects of planform were taken out via a_1/A (obtained from Derivation 23) and when the effects of tailplane span were taken out via the downwash averaging factor, $F^\dagger$. The curve given is appropriate to high tailplanes ($\zeta_T > 0$). For low tailplanes ($\zeta_T < 0$) the indications are that a factor of about 1.3 should be applied to the values of $|d(\bar{d}\bar{\epsilon}/d\alpha)/d\zeta_T|$ obtained from Figure 9.

5. LOW SPEED DOWNWASH AT ZERO LIFT

The zero-lift value of the average downwash at the tailplane, $\bar{\epsilon}_0$, may be influenced by a number of parameters. They include tailplane location, afterbody geometry, wing twist, wing-body setting angle and junction design, in addition to Reynolds number. Investigation of a number of experimental data indicated that the most significant single parameter is the height of the tailplane above the body centre-line, $\zeta_T - \zeta_B$, see Sketch 1.1. The curve given in Figure 10 is the mean line drawn through the data (Derivations 2, 4, 5, 8 to 18, 21, 25, 27, 28 and 30) and represents the trend with variation in tailplane height quite well although the scatter of the experimental data about the mean is large (about ± 1 degree). Further attempts to reduce the scatter by identifying other parameters felt to be significant proved unsuccessful, largely owing to the ad hoc nature of the test data. It is not, therefore, currently possible to predict $\bar{\epsilon}_0$ to any great accuracy.

6. EFFECT OF NACELLES

The addition of engine nacelles can have a very significant effect on the downwash at the tailplane. Very few data (Derivation 30) are available on which to base an assessment of nacelle effect.

For rear-fuselage mounted nacelles, from the results for four models, there is a consistent increase in average downwash gradient at the tailplane ranging from 0.02 to 0.08, with a mean value of 0.06. The effect on average downwash at zero wing-body lift for these nacelles ranges from 0.1 to -0.8 degrees with a mean value of about -0.2 degrees. These values should be used only as a guide to the magnitude of the likely effects of adding rear-fuselage mounted nacelles.

For under-wing mounted nacelles the data, from only two models, are inconclusive in that there are opposing signs between the models for the effects on both downwash gradient and downwash at zero wing-body lift.

7. EFFECT OF COMPRESSIBILITY

Figure 11 provides an estimate of the effect of Mach number on $\bar{d}\bar{\epsilon}/d\alpha$ up to that at which the aerodynamic characteristics start to diverge rapidly. The factor $K_M (= (\bar{d}\bar{\epsilon}/d\alpha)_M / (\bar{d}\bar{\epsilon}/d\alpha)_{M=0})$ in Figure 11 has been derived empirically from relatively few test data in Derivations 4, 17 and 27.

The effect of compressibility on $\bar{\epsilon}_0$ can be assumed to be insignificant up to the divergence Mach number defined in the previous paragraph.

[†] Note that the use of this factor, corresponding to $\zeta_T = 0$ implicitly assumes that it is applicable to tail heights other than zero, which is not a bad approximation for the range of tail heights in practice ($-0.1 < \zeta_T < 0.5$).