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Low-speed longitudinal aerodynamic characteristics of slender wings

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LOW-SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF SLENDER WINGS

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LOW-SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF SLENDER WINGS

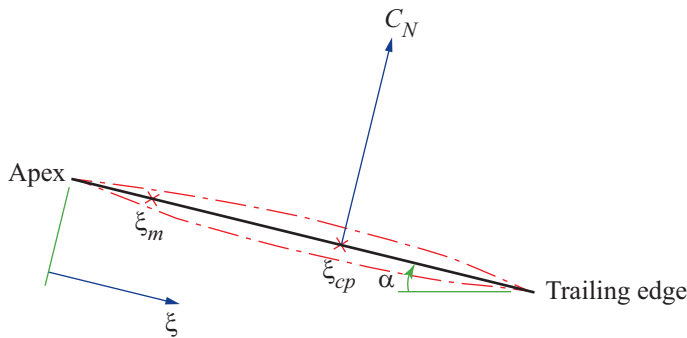
1. NOTATION AND UNITS (see Sketches 1.1 and 1.2)

		<i>SI</i>	<i>British</i>
A	wing aspect ratio, $4s^2/S$		
a	normal-force-curve slope at zero wing incidence, $(dC_N/d\alpha)_{\alpha=0}$	rad^{-1}	rad^{-1}
C_A	axial force coefficient based on S , positive rearwards		
C_D	drag coefficient based on S		
C_{D0}	value of C_D at $C_L = 0$		
C_L	lift coefficient based on S		
C_m	pitching moment coefficient based on S and c_r , positive nose-up, measured about pitching moment axis		
C_N	normal force coefficient based on S , see Sketch 1.1		
c_r	wing centre-line chord, see Sketch 1.2	m	ft
k	correction factor for wing thickness, see Equation (3.2) and Figure 3		
R_{cr}	Reynolds number based on c_r		
S	wing planform area	m^2	ft^2
S_f	wing frontal area at zero incidence	m^2	ft^2
s	wing semi-span, value of $s(\xi)$ at $\xi = 1$, see Sketch 1.2	m	ft
$s(\xi)$	semi-span at station ξ	m	ft
X	value of ξ_{ac} for wing with $s/c_r = 0.3$ and $S_f/S = 0.04$		
x	chordwise distance rearward from wing apex	m	ft
x_a	value of x at centre of planform area	m	ft
x_{ac}	value of x at aerodynamic centre	m	ft

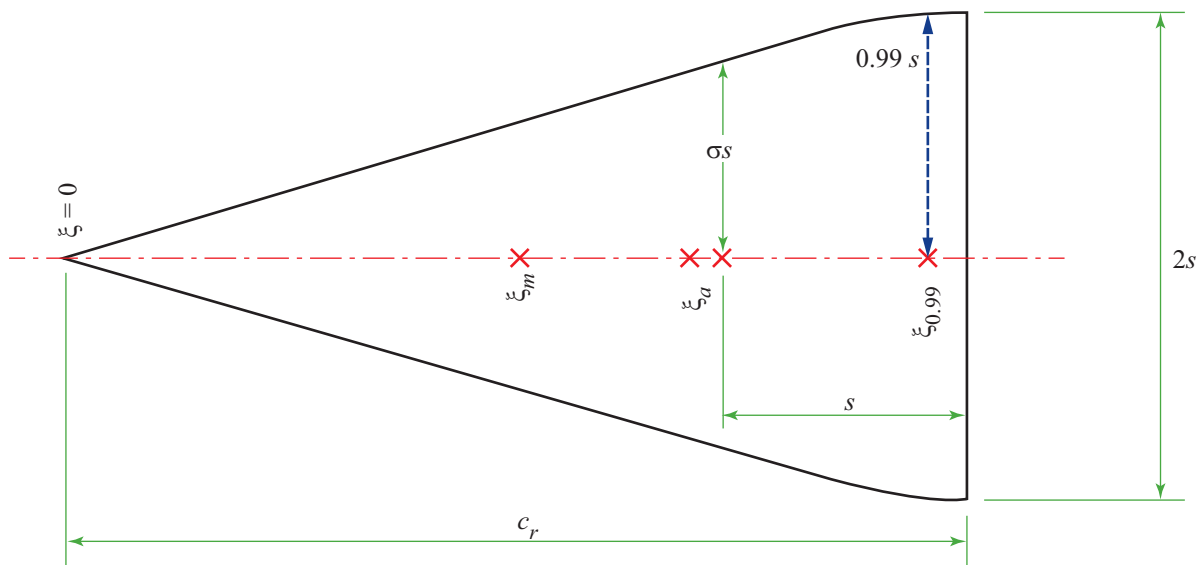
x_{cp}	value of x at centre of pressure	m	ft
α	wing incidence, see Sketch 1.1	rad	rad
ξ	x/c_r , see Sketch 1.1		
ξ_a	value of ξ at centre of planform area, see Sketch 1.2		
ξ_{ac}	value of ξ at aerodynamic centre		
ξ_{cp}	value of ξ at centre of pressure, see Sketch 1.1		
ξ_m	value of ξ at pitching moment axis, see Sketches 1.1 and 1.2		
$\xi_{0.99}$	value of ξ where $s(\xi) = 0.99s$, see Sketch 1.2		
σ	value of $s(\xi)/s$ where $\xi = 1 - s/c_r$, see Sketch 1.2		

Subscripts

- 1 refers to linear part of normal force
- 2 refers to non-linear part of normal force
- * An asterisk (*) denotes wing with $S_f/S = 0.04$.



Sketch 1.1 Coefficient of normal force acting on wing in free air



Sketch 1.2 Wing planform

2. INTRODUCTION

This Item presents the normal and axial force coefficients, the pitching moment coefficient and the position of the aerodynamic centre of uncambered untwisted pointed slender wings with unswept trailing edges and of aspect ratio less than about 2. Also presented are the normal-force-curve slope and the centre of pressure position. The curves are based on an extensive series of tests in Derivation 7 on slender wings of thickness given by $S_f/S = 0.04$. In the case of the normal force, axial force and normal-force-curve slope it is possible to make approximate allowance for arbitrary thickness; for the other aerodynamic quantities indications of the trends are given. Supporting experimental data are contained in Derivations 1 to 6, 8 to 10, 12 to 14. Finally, a rough guide to the effects of small amounts of trailing-edge sweep is included from Derivation 11.

A program of the method is provided as ESDUpac A7106 and is described in Appendix A.

3. NORMAL AND AXIAL FORCES

At all but very small angles of incidence, the flow separates from the sharp leading edges of the wings considered in this Item and the force normal to the wing may be divided into linear and non-linear components associated with the attached and separated flow fields respectively.

Hence,

$$\begin{aligned} C_N &= C_{N1} + C_{N2} \\ &= a\alpha + C_{N2}. \end{aligned} \quad (3.1)$$

The effect of wing thickness on C_{N2} is small, and therefore its effect on C_N may be taken into account by a correction to C_{N1} only, introducing a thickness correction factor on a as follows:

$$a = ka^* \quad (3.2)$$

where a^* from Figure 1 applies to wings of thickness such that $S_f/S = 0.04$ and k from Figure 3 is the correction factor. Figure 2 may then be used for C_{N2} without further allowance for thickness.

Use of the area ratio S_f/S was found to be a convenient measure of wing thickness/chord ratio when correlating the experimental data. For wings with a constant streamwise aerofoil section across the span, such as those in Derivation 7, S_f/S equals the maximum thickness/chord ratio.

Differentiation of Equation (3.1) gives the normal-force-curve slope

$$\frac{dC_N}{d\alpha} = a + \frac{dC_{N2}}{d\alpha}. \quad (3.3)$$

Again, the non-linear term, given in Figure 4, is not significantly affected by thickness.

The axial force is obtained from Figure 5. At the larger incidences this force acts forwards (*i.e.* C_A is negative) due to suction on the under surface of the wing created by the leading-edge vortices. To obtain a value for C_A from Figure 5a an estimate of C_{D0} , the drag coefficient at zero lift, is required. This quantity varies with Reynolds number and boundary-layer transition position. The experimental data for Figure 5a come from wind-tunnel tests with Reynolds numbers (R_{cr}) in the region of 10^6 or 10^7 with boundary-layer transition, at $C_L = 0$, well aft of the leading edge, but at full-scale Reynolds numbers transition usually occurs near the leading edge. Hence, Figure 5b, in which allowance is made for the movement of transition forward with increasing Reynolds number, is provided as an approximate guide to the magnitude of C_{D0} for use when no other estimate is available and only in conjunction with Figure 5a.

The lift and drag coefficients may now be evaluated from the formulae

$$C_L = C_N \cos \alpha - C_A \sin \alpha, \quad (3.4)$$

$$C_D = C_N \sin \alpha + C_A \cos \alpha. \quad (3.5)$$

4. CENTRE OF PRESSURE, PITCHING MOMENT AND AERODYNAMIC CENTRE

The points of action of the linear and non-linear components of normal force are given for wings of $S_f/S = 0.04$ in Figures 6 and 7 as distances ahead of ξ_a , the non-dimensional centre of planform area. Data from these Figures in conjunction with Figures 1 and 2 allow the centre of pressure position to be found from

$$\xi_{cp} = \frac{C_{N1} \xi_{cp1} + C_{N2} \xi_{cp2}}{C_N}, \quad (4.1)$$

and the pitching moment about an axis through $\xi = \xi_m$ to be found from

$$C_m = C_{N1}(\xi_m - \xi_{cp1}) + C_{N2}(\xi_m - \xi_{cp2}), \quad (4.2)$$

where $\xi_{cp1} = \xi_{cp1}^*$ and $\xi_{cp2} = \xi_{cp2}^*$ from Figures 6 and 7. With increasing wing thickness the point of action of the linear component of normal force moves forward towards the wing apex and that of the non-linear component moves rearward. Tests in Derivation 10 on a delta wing with $A = 1.46$ ($s/c_r = 0.365$) have shown that, at $\alpha = 16^\circ$, the effects of increasing S_f/S from 0.04 to 0.12 are to decrease ξ_{cp1} by approximately 4% of its former value and increase ξ_{cp2} by approximately 25%.

Figure 8 gives the position of the aerodynamic centre for wings with $S_f/S = 0.04$. In Derivation 7, it was found convenient to correlate the test data in terms of wings of slenderness ratio $s/c_r = 0.3$. Hence, Figure 8a presents the position of the aerodynamic centre for the wing if its slenderness ratio were 0.3 and Figure 8b gives the correction for slenderness; the distance of the aerodynamic centre ahead of the centre of area is the sum of the ordinates of the two graphs.

5. TRAILING-EDGE SWEEP

The results of a brief series of tests, described in Derivation 11, indicate the effects of small amounts of trailing-edge sweep on the aerodynamic quantities. In these tests trailing-edge sweep was applied to a series of models with the same leading-edge planform simply by increasing or decreasing the centre-line chord to cover the range of sweepback between $+5^\circ$ and -15° .

From Derivation 11 the effects on C_{N1} , x_{cp1} and C_A of changes in trailing-edge sweep appear to be negligible. Derivation 11 indicates on the other hand that the value of C_{N2} is increased with increase in trailing-edge sweepback in a manner such that C_{N2} is approximately inversely proportional to the planform area, and its point of action is moved such that its distance $(x_a - x_{cp2})$ ahead of the centre of area remains roughly constant. The limited data suggest that the distance $(x_a - x_{ac})$ of the aerodynamic centre ahead of the centre of area varies proportionally to the centre-line chord.

6. ACCURACY

Figure 1 gives values of the linear normal-force-curve slope a^* to within $\pm 0.02 \text{ rad}^{-1}$. The correction for thickness is not known so accurately; the scatter of the data for Figure 3 increases with increase in S_f/S so that for a wing with $S_f/S = 0.12$ the error in the value of the normal-force-curve slope a may be $\pm 0.05 \text{ rad}^{-1}$. In Figure 2, the non-linear normal force term $C_{N2}/(A\sigma\alpha)$ is predicted to within $\pm 0.05 \text{ rad}^{-1}$ and, in Figure 4, the non-linear normal-force-curve slope term $(dC_{N2}/d\alpha)/\sigma A$ should be predicted to within $\pm 0.1 \text{ rad}^{-1}$. The axial force term $(C_A - C_{D0})$ found from Figure 5a is generally accurate to within $\pm 20\%$.

For wings with $S_f/S = 0.04$, Figures 6, 7 and 8 should give the non-dimensional distances ahead of the centre of area for the point of action of the linear normal force $(\xi_a - \xi_{cp1}^*)$, for the point of action of the non-linear normal force $(\xi_a - \xi_{cp2}^*)$ and for the aerodynamic centre $(\xi_a - \xi_{ac}^*)$, respectively, to within ± 0.01 .

7. DERIVATION

The Derivation lists selected sources that have assisted in the preparation of this Item.

1. POCOCK, P.J.
LAUNDRY, W.E. Some aerodynamic characteristics of delta wings at low speeds. Proc. Second Can. Symp. on Aerodyn., Inst. of Aerophysics, Univ. of Toronto, pp. 39-68, February 1954.
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3. PECKHAM, D.H. Low-speed wind-tunnel tests on a series of uncambered slender pointed wings with sharp edges. ARC R&M 3186, 1958.