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Effects of isolated body and wing-body interference on rolling moment due to sideslip: L_v (With Addendum A for nacelle effects)

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes Item No. A.06.01.05, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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EFFECTS OF ISOLATED BODY AND WING-BODY INTERFERENCE ON ROLLING MOMENT DUE TO SIDESLIP: L_v (With Addendum A for nacelle effects)

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EFFECTS OF ISOLATED BODY AND WING-BODY INTERFERENCE ON ROLLING MOMENT DUE TO SIDESLIP: L_v (With Addendum A for nacelle effects)

1. NOTATION AND UNITS

The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in Item No. 86021. Coefficients and aerodynamical derivatives are evaluated in aerodynamic body axes with origin at the aircraft centre of gravity, assumed to lie on the locus of centroids of the body cross sections and in the plane normal to that locus that passes through the quarter-chord point of the wing aerodynamic mean chord, and with the wing span as the characteristic length. The derivative L_v is often written as $\partial C_l / \partial \beta$ or $C_{l\beta}$ in other systems of notation, but attention must be paid to the reference dimensions used and it is to be noted that a constant datum value of V is employed in the Hopkin system.

		SI	British
A	aspect ratio, b^2/S		
b	wing span	m	ft
C_L	lift coefficient of wing-body combination		
C_l	rolling moment coefficient, $\mathcal{L}/\frac{1}{2}\rho V^2 S b$		
d	maximum diameter for body of circular cross-section	m	ft
$f(A)$	aspect ratio correction factor		
H	height of ellipse equivalent to body reference cross-section (see Section 2)	m	ft
h_0	vertical distance of quarter-chord point of wing centre-line chord from centroid of body reference cross-section, positive if below centroid and negative if above (see Section 2)	m	ft
h	wing vertical position relative to body, defined by Equation (4.1)	m	ft
$\mathcal{L}$	rolling moment	N m	lbf ft
L_v	aero-normalised rolling moment derivative due to sideslip, $(\partial \mathcal{L} / \partial v) / \frac{1}{2} \rho V S b$		
$(L_v)_b$	isolated body contribution to L_v		
$(L_v)_h$	that part of L_v due to interference arising from vertical position of wing on body, $(L_v)_{w+b} - (L_v)_w - (L_v)_b$		
$(L_v)_w$	isolated gross wing contribution to L_v (see Item Nos Aero A.06.01.03, Aero A.06.01.09 and 80033)		
$(L_v)_{w+b}$	wing-body combination contribution to L_v		

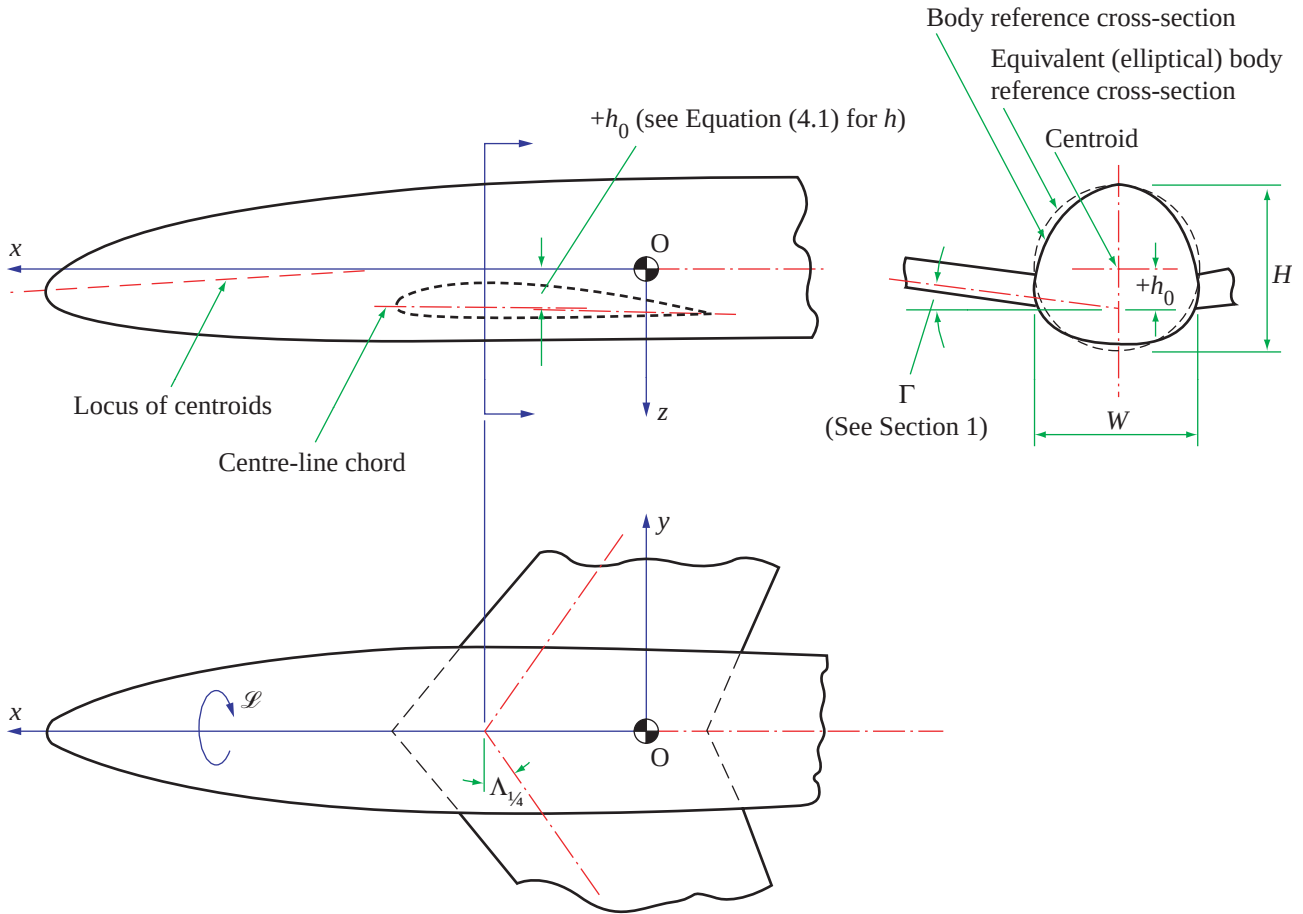
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l_b	body length	m	ft
S	gross wing area	m^2	ft^2
S_b	maximum cross-sectional area of body	m^2	ft^2
V	velocity of aircraft relative to air	m/s	ft/s
v	sideslip velocity	m/s	ft/s
W	width of body reference cross-section (see Section 2)	m	ft
α_b	body incidence measured from body zero-lift value	degree	degree
β	sideslip angle, $\sin^{-1}(v/V) \approx v/V$	rad	rad
Γ	dihedral angle, defined as angle between wing reference plane and projection of quarter-chord line on plane perpendicular to wing centre-line chord; the wing reference plane is that plane normal to plane of symmetry and containing wing centre-line chord	degree	degree
κ	factor in Equation (4.1)	degree ⁻¹	degree ⁻¹
$\Lambda_{1/4}$	angle of sweepback of quarter-chord line	degree	degree
λ	taper ratio (ratio of wing tip chord to wing centre-line chord)		
ρ	density of air	kg/m^3	$slug/ft^3$

2. WING-BODY GEOMETRY (See Sketch 2.1)



Sketch 2.1

2.1 Body Reference Cross-section

The body reference cross-section is that section in the Oyz plane containing the quarter-chord point of the wing centre-line chord.

2.2 Equivalent (Elliptical) Body Reference Cross-section

The equivalent (elliptical) body reference cross-section is that ellipse having the same area, width and centre of area as the body reference cross-section. The height of the ellipse is

$$H = \frac{4}{\pi W} \times \text{area of body reference cross-section}.$$

3. INTRODUCTION

The data given in this Item provide a means of estimating the effect on the rolling moment derivative due to sideslip, L_v , of adding a body to a gross wing. The data apply to low speeds and to lift coefficients for which the flow over the wing-body combination remains fully attached (see Item No. 66033 for wings with symmetrical sections). The gross wing contribution, $(L_v)_w$, may be obtained from Item Nos Aero A.06.01.03, Aero A.06.01.09 and 80033. The fin and rudder contribution to L_v may be obtained from Item No. 70006. Information on the effect on L_v of mounting jet-engine nacelles on the aft portion of the body or below the wing is given in Addendum A of this Item.

Wind-tunnel tests show that when a wing and body are in combination the total value of L_v , i.e. $(L_v)_{w+b}$, is not equal to the sum of the contributions arising from the gross wing and body when tested in isolation, thus demonstrating the presence of interference effects between the wing and body. In the linear lift range these interference effects are primarily due to the vertical position of the wing with respect to the body although there is some evidence to suggest that there can be secondary effects which are lift-dependent, arising from the longitudinal position of the wing relative to the body (see Section 4.2).

The interference arising from the vertical position of the wing with respect to the body, $(L_v)_h$, is caused by changes in the local wing incidence induced by the cross-flow around the body. Theoretical treatments of this effect are given in Derivations 5 and 9, and methods from these two Derivations are used herein (see Section 4.1).

The isolated body contribution, $(L_v)_b$, is usually small compared with the isolated wing and fin and rudder contributions. A simple method of estimating $(L_v)_b$ is given in Section 5.

The total effect, on the rolling moment due to sideslip, of adding a body to a wing is therefore estimated from this Item as

$$(L_v)_h + (L_v)_b. \quad (3.1)$$

The wing-body combination contribution to L_v may be obtained by adding the gross wing contribution to the above expression, i.e.

$$(L_v)_{w+b} = (L_v)_w + (L_v)_h + (L_v)_b. \quad (3.2)$$

4. INTERFERENCE COMPONENTS

4.1 Due to Vertical Position of Wing on Body, $(L_v)_h$

Figure 1a presents, for $A = 6$, the parameter $|(L_v)_h|/(1 + W/H)f(A)$ plotted against $|h/H|$ for various values of H/b . It should be noted that $(L_v)_h$ values obtained from this Figure adopt the same sign as h/H . Figure 1b gives the aspect ratio correction factor, $f(A)$, as a function of aspect ratio.

Figure 1a was obtained by the method of Derivation 5, which, by making certain approximations, allows a simpler solution than that of Derivation 9. Also the method of Derivation 5 happens to provide better agreement with available experimental data than that of Derivation 9, especially for the larger values of H/b . Figure 1b was obtained from Derivation 9.

The curves in Figures 1a and 1b were derived, for incompressible fully-attached flow, on the assumption that a body of infinite length and constant elliptical cross-section is in combination with an unswept wing of elliptic planform with no dihedral or twist. The data can be applied, however, to wing-body combinations with finite body lengths*, other body cross-sections and other wing planforms, both with and without dihedral as shown later.

If the shape of the body reference cross-section (see Section 2.1) departs from the elliptical section assumed in the Derivation of Figures 1a and 1b, empirical evidence (Derivation 9) suggests that the actual cross-section in the reference plane should be replaced by an equivalent, elliptical, section (see Section 2.2).

In order to determine the wing vertical position, h , relative to the equivalent body reference cross-section, in terms of the height of that section, H , for the general case of a wing with dihedral, the following expression should be used;

$$\frac{h}{H} = \frac{h_0}{H} - \kappa \Gamma, \quad (4.1)$$

where Γ is the dihedral angle (assumed constant across the wing semi-span) in degrees. The parameter κ (from Derivation 9) is given in Figure 2 for ranges of values of $|h_0/H|$ and H/b . It will be seen that when the dihedral angle is zero the wing vertical position reduces to h_0 , the vertical distance of the quarter-chord point of the wing centre-line chord from the centroid of the body reference cross-section.

4.1.1 Comparison with experimental data

Agreement with experimental data for $(L_v)_h$ for wing-body combinations in which the wing has zero dihedral (Derivations 1 to 4, 10, 11, 14 and 17) is generally within about ± 0.015 . The test data cover the ranges $2.3 \leq A \leq 6.4$, $0 \leq \lambda \leq 1$, $0 \leq \Lambda_{1/4} \leq 52^\circ$, $-0.42 \leq h_0/H \leq 0.44^\dagger$, $0.11 \leq H/b \leq 0.24$, $0.54 \leq W/H \leq 1$ and $-0.4 \leq C_L \leq 0.8$. This agreement with the experimental data is a little worse than the experimental scatter in only a few cases. The experimental data indicate no consistent trends due to wing taper or sweep, and such effects are small and submerged in the general scatter.

Agreement with experimental data for $(L_v)_h$ for wing-body combinations in which the wing has dihedral (Derivations 1, 2, 4, 6 and 8) is again generally within ± 0.015 . The test data cover the ranges $5.2 \leq A \leq 6.9$, $0.25 \leq \lambda \leq 1.0$, $1.5^\circ \leq \Gamma \leq 6^\circ$, $0 \leq \Lambda_{1/4} \leq 5^\circ$, $-0.59 \leq h/H \leq 0.39$, $0.11 \leq H/b \leq 0.19$, $0.54 \leq W/H \leq 1.0$ and $-0.4 \leq C_L \leq 0.8$.

The experimental data from the above-mentioned Derivations related (with one exception) to bodies of either elliptical or circular cross-section. The data from Derivation 1 relate to two bodies with cross-sections grossly different from elliptical, but good agreement is obtained with values from this Item when equivalent, elliptical, sections (see Section 2.2) are used.

4.1.2 The effect of flap deflection

The limited experimental data (Derivations 3, 6, 8, 10 and 11) for the effect of flap deflection are generally small in magnitude, but their trends are inconsistent.

* Provided that at least a quarter of the body length lies ahead of the quarter-chord point of the wing centre-line chord (see Derivation 9).

† Although the curves in Figure 1a have only been taken up to $|h/H| = 0.6$ the calculations have been extended up to 1.0 in Derivation 9. Experimental data from Derivation 7 for parasol-wing configurations ($|h_0/H|$ up to 0.8) are shown in Derivation 9 to substantiate the theoretical calculations for these configurations.