

ESDU Aircraft S.06.03.01

STABILITY DERIVATIVE L_p , ROLLING MOMENT DUE TO ROLLING FOR WINGS AT SUPERSONIC SPEEDS

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 aerodynamically normalised derivatives are evaluated in aerodynamic body axes with origin at the aircraft centre of gravity and with the wing span as the characteristic length. The derivative L_p is often written as C_{lp} in other systems of notation, but attention must be paid to the reference dimensions used. In particular, in forming C_{lp} differentiation of C_l may be carried out with respect to $pb/2V$ not pb/V as implied in the Hopkin system. It is also to be noted that a constant datum value of V is employed by Hopkin.

		SI	British
A	aspect ratio, b^2/S		
b	wing span	m	ft
C_l	rolling moment coefficient, $\mathcal{L}/\frac{1}{2}\rho V^2 Sb$		
c_r	wing centre-line chord	m	ft
c_t	wing tip chord	m	ft
$\mathcal{L}$	rolling moment	N m	lbf ft
L_p	rolling moment derivative due to rolling, $(\partial \mathcal{L}/\partial p)/\frac{1}{2}\rho V S b^2$		
M	free-stream Mach number		
p	angular velocity in roll	radian/s	radian/s
S	wing area	m ²	ft ²
V	airspeed	m/s	ft/s
β	Mach number parameter, $(M^2 - 1)^{1/2}$		
$\Lambda_{1/2}$	sweepback of mid-chord line	degree	degree
λ	taper ratio, c_t/c_r		
ρ	air density	kg/m ³	slug/ft ³

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2. NOTES

Figures 1a to 1e give, in parametric form, the variation of the theoretical damping in roll derivative, L_p , at zero lift with Mach number, aspect ratio and sweepback for five values of the ratio c_t/c_r .

The data in the Figures, based on linearised supersonic flow theory, have been obtained from Derivations 3, 4 and 5 with the special case of slender wings ($\beta A \approx 0$) being obtained from Derivation 8.

Linearised supersonic flow theory tends to become unreliable at low values of βA . Experimental evidence has been used as a guide to the lower limit at which the curves may be considered to be reliable. For values of βA below this limit, slender-wing theory gives the value of L_p/A for $\beta A = 0$, and these points are linked to the linearised supersonic flow theory curves by straight lines, shown broken. It may be noted that for $A \tan \Lambda_{1/2} \leq 2$, the slender-wing values are independent of $A \tan \Lambda_{1/2}$.

The results refer strictly to wings of vanishing thickness and to rates of roll in which the wing tip velocity is small compared with the free-stream velocity; the cases considered are uncambered wings with streamwise tips. The calculations are based on the assumption that the wings are rigid, whereas in practice aeroelastic effects can be significant. In particular, in the case of swept-back wings, measured values of L_p will, due to such effects, be in general less than those predicted by this Item.

It should be noted that the kinks shown in the curves correspond to conditions where leading or trailing edges become sonic; such kinks are not likely to occur in practice, and the Item is least accurate in these regions where unpredictable changes in L_p for small changes in M are liable to occur.

Such limited experimental results as are available indicate that, for wings which may reasonably be regarded as rigid, classification into two broad groups characterised by aerofoil section is possible. For wings of sharp leading-edge section, other than those of rectangular planform, measured values of L_p are of the order of 95 ± 5 per cent of those predicted by theory; for round-nosed sections, measured values are about 80 ± 10 per cent of the theoretical. Experimental evidence is not available for wings of rectangular planform, but it may be inferred from indirect evidence on three-wing configurations that at Mach numbers greater than about 1.1, for round-nosed sections L_p will be of the order of 90 ± 10 per cent of theory and, for sharp leading-edge sections, 95 ± 5 per cent.

The effect of mounting the wing on a body may be determined from Item No. Aero A.S.06.03.02, and interference effects from Item No. Aero A.S.06.03.03.

There are no data to indicate the effect of incidence on L_p , although this is expected to be negligible at low values of lift coefficient.

3. DERIVATION

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

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| 1. | BROWN, C.E.
ADAMS, M.C. | Damping in pitch and roll of triangular wings at supersonic speeds. NACA Rep. 892, 1948. |
| 2. | ROBINSON, A. | Rotary derivatives of a delta wing at supersonic speeds. <i>J. Roy. aeronaut. Soc.</i> , November 1948. |
| 3. | HARMON, S.M.
JEFFREYS, I. | Theoretical lift and damping in roll of thin wings with arbitrary sweep and taper at supersonic speeds. NACA tech. Note 2114, 1950. |

4. MALVESTUTO, F.S.
MARGOLIS, K.
RIBNER, H.S. Theoretical lift and damping in roll at supersonic speeds of thin swept-back tapered wings with streamwise tips, subsonic leading edges and supersonic trailing edges. NACA Rep. 970, 1950.
5. RIBNER, H.S. On the effect of subsonic trailing edges on damping in roll and pitch of thin swept-back wings in a supersonic stream. NACA tech. Note 2146, 1950.
6. EDMONDSON, J.L. Damping in roll of rectangular wings of several aspect ratios and NACA 65A-series airfoil sections of several thickness ratios at transonic and supersonic speeds as determined with rocket-powered models. NACA RM L50E26 (TIL 2498), 1950.
7. BLAND, W.M.
SANDAHL, C.A. A technique utilising rocket-propelled test vehicles for the measurement of the damping in roll of sting-mounted models and some initial results for delta and unswept tapered wings. NACA tech. Note 3314, 1950.
8. MANGLER, K.W. Calculations of the pressure distribution over a wing at sonic speeds. ARC R&M 2888, 1955.
9. BROWN, C.E.
HEINKE, H.S. Preliminary wind tunnel tests of triangular and rectangular wings in steady roll at Mach numbers of 1.62 and 1.92. NACA tech. Note 3740, 1956.
10. – Unpublished wind-tunnel and rocket-powered model tests.

4. EXAMPLE

Find the rolling moment derivative due to rolling at a Mach number of 2 for a wing for which $A = 3$, $\Lambda_{1/2} = 30^\circ$ and $\lambda = 0.25$.

$$\beta A = (2^2 - 1)^{1/2} \times 3 = 5.2 \quad \text{and} \quad A \tan \Lambda_{1/2} = 3 \times \tan 30^\circ = 1.732.$$

Hence, from Figure 1d $-L_p/A = 0.041$,

whence $L_p = -0.041 \times 3 = -0.123$.