

ESDU Aircraft S.06.03.03

STABILITY DERIVATIVE L_p . ROLLING MOMENT DUE TO ROLLING FOR RADIAL MULTI-PLANAR WING ARRANGEMENTS AT SUPERSONIC SPEEDS

1. NOTATION AND UNITS (see sketch in Figure 1)

The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in ESDU 86021. Coefficients and aeronormalised 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, $4s^2/S_1$		
C_l	rolling moment coefficient, $\mathcal{L}/\frac{1}{2}\rho V^2 S_1 s$		
c_r	wing chord at centre-line	m	ft
c_t	wing tip chord	m	ft
F	interference correction, $(L_{p(n)} - L_p)/L_p$		
$\mathcal{L}$	rolling moment	N m	lbf ft
L_p	rolling moment derivative due to rolling of coplanar pair of half-wings, $(\partial \mathcal{L}/\partial p)/\frac{1}{2}\rho V S_1 s^2$		
$L_{p(n)}$	rolling moment derivative due to rolling of multi-planar wing arrangement		
M	free-stream Mach number		
n	number of half-wings		
p	angular velocity in roll	radian/s	radian/s
S	sum of gross area of all half-wings, $nS_1/2$	m ²	ft ²
S_1	gross area of one pair of half-wings, $(c_r + c_t)s$	m ²	ft ²
s	spanwise distance from centre line to tip of half-wing	m	ft
V	airspeed	m/s	ft/s
β	Mach number parameter, $(M^2 - 1)^{1/2}$		
λ	ratio of half-wing tip chord to centre-line chord, c_t/c_r		
ρ	air density	kg/m ³	slug/ft ³

Issued January 1957
With Amendment A, October 1982 – 5 pages

2. NOTES

Figure 1 gives values of F as a function of βA for various values of λ for cruciform wings ($n = 4$) of rectangular, delta and cropped delta form. The derivative L_p may be obtained from ESDU Aero A.S.06.03.01; $L_{p(n)}$ is then obtained from the relation

$$L_{p(n)} = L_p(1 + F). \quad (2.1)$$

The curves are based on an extension of linearised supersonic flow theory wherein the cruciform wing with supersonic leading-edges is reduced to a planar boundary-value problem by means of the principles of super-position and reflection. When the leading edges are subsonic the reduction to a planar problem is only partial and the solution is completed by an iterative process.

For three-wing ($n = 3$) configurations theoretical results are available only for slender delta wings, $\beta A \approx 0$, for which the interference correction F is -0.1 , compared with -0.19 for the cruciform delta-wing arrangement. It is suggested that an estimate of the interference correction for other three-wing configurations could be obtained by factoring the corresponding cruciform wing correction by the slender-wing correction ratio, $0.1/0.19$.

As for a coplanar pair of wings (see ESDU Aero A.S.06.03.01) this Item is least reliable in the region where either the leading or trailing edges of the wings become sonic. For rectangular wings limited experimental evidence suggests that, for Mach numbers greater than about 1.1, for round-nosed sections $L_{p(n)}$ will be of the order of 90 ± 10 per cent of theory and, for sharp leading-edge sections, 95 ± 5 per cent. For delta and cropped delta wings, overall values of $L_{p(n)}$ predicted by this Item will be of the same order of accuracy as those for coplanar configurations (see ESDU Aero A.S.06.03.01); these remarks apply equally to three-wing and to cruciform configurations. It should be noted that the experimental results referred to were obtained from tests on wing-body combinations. These results should be corrected for the effect of the presence of the body, but as yet there is no theory available with which to make such corrections. ESDU Aero A.S.06.03.02 suggests that, for values of the ratio (body diameter)/(wing span) of the same order as those of the tests (0.2), the effect of the presence of the body is negligible for coplanar pairs of wings and it has been assumed that this will also be true for multiplanar wing arrangements. Experimental evidence is not available for larger values of (body diameter)/(wing span) and it should not be inferred that the effect on L_p due to body will then be negligible.

There is insufficient evidence to indicate whether the correction F may be applied to other planforms.

Where two sets of wings are mounted upon a body in a tandem arrangement (*e.g.* a missile with cruciform wings and a cruciform tail in line with the wings) caution must be exercised in applying this Item.

Slender-body theory suggests that the value of L_p for the in-line combination will be equal to the value for the larger span wing alone, whether it is ahead of, or behind the smaller span wing. This result would obtain only at zero incidence and sideslip, at small values of βA (say, less than 3), and would depend upon the rear surfaces being close enough to the forward surfaces for the vortex sheet system not to be rolled up. If the planes of the two sets of wings are indexed at 45° relative to each other, then the contribution of the rear set again depends on the downwash and sidewash field on them. At zero incidence and sideslip the value of L_p for the combination will be larger than in the in-line case.

In the limit where n tends to infinity, it is of interest to note that the damping moment for a delta wing is given by $L = -\frac{1}{2}\pi\rho Vps^4$ at all Mach numbers, and is independent of aspect ratio. This means that a configuration consisting of an infinite number of radially disposed delta wings has four times the total damping in roll of a coplanar pair of slender delta wings.