



ESDU 72021

Issued September 1972
With Amendments A to C
November 2009
Supersedes ESDU Aero
A.06.01.02 and A.06.01.08

Effect of wing on rolling moment due to yawing

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Item, which supersedes Item Numbers Aero A.06.01.02 and A.06.01.08, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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EFFECT OF WING ON ROLLING MOMENT DUE TO YAWING

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EFFECT OF WING ON ROLLING MOMENT DUE TO YAWING

1. NOTATION AND UNITS

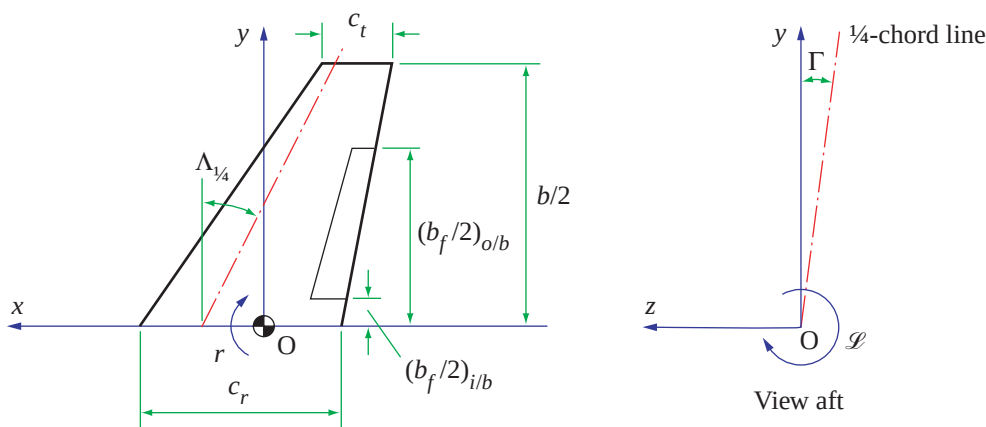
The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in Item No. 86021. Coefficients and aeronormalised derivatives are evaluated in aerodynamic body axes with origin at the aircraft centre of gravity and with the wing span as the characteristic length. The derivative L_r is often written as C_{lr} in other systems of notation, but attention must be paid to the reference dimensions used. In particular, in forming C_{lr} differentiation of C_l may be carried out with respect to $rb/2V$ not rb/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		
a_1	lift-curve slope at zero lift	rad^{-1}	rad^{-1}
$a_{2\infty}$	slope of lift increment curve with flap deflection in two-dimensional flow	rad^{-1}	rad^{-1}
b	wing span	m	ft
$(b_f)_{i/b}$	spanwise distance between inner ends of flaps	m	ft
$(b_f)_{o/b}$	spanwise distance between outer ends of flaps	m	ft
C_L	wing lift coefficient		
C_l	wing rolling moment coefficient, $\mathcal{L}/\frac{1}{2}\rho V^2 S b$		
c_r	root chord	m	ft
c_t	tip chord	m	ft
$f_1(A)$	function of aspect ratio (see Equation (3.1))		
$f_2(A)$	function of aspect ratio (see Section 3.4)		
$g(\Lambda_{1/4})$	function of sweepback of quarter-chord line		
$\mathcal{L}$	wing rolling moment	N m	lbf ft
L_r	aeronormalised rolling moment derivative for the wing, $(\partial \mathcal{L} / \partial r) / \frac{1}{2} \rho V S b^2$		
M	Mach number		
r	angular velocity in yaw	rad/s	rad/s

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S	wing area	m^2	ft^2
V	velocity of aircraft relative to air	m/s	ft/s
Γ	dihedral angle (see Sketch 1.1)	degree	degree
δ_f	flap deflection	degree	degree
ε	wing twist, <i>i.e.</i> angle between no-lift lines of root and tip sections (positive for wash-out) see diagram in Figure 4)		
$\Lambda_{1/4}$	sweepback of quarter-chord line	degree	degree
λ	taper ratio, c_t/c_r		
ρ	density of air	kg/m^3	slug/ft^3
Suffixes			
f	denotes quantity arising from deflection of trailing-edge flaps		
p	denotes planform contribution to L_r		
0	denotes quantity in incompressible flow ($M = 0$)		
Γ	denotes quantity arising from dihedral		
ε	denotes quantity arising from twist		



Sketch 1.1

2. INTRODUCTION

The data given in this Item provide a means of estimating the contribution of a straight-tapered swept wing to the rolling moment derivative due to yawing at lift coefficients for which the flow remains fully attached (see Item No. 66033 for wings with symmetrical sections) and at Mach numbers for which the flow is subsonic over the whole of the wing. Some data are included for slender wings of delta and gothic planform.

The basic planform contribution (p) and the contributions due to dihedral (Γ), twist (ε) and deflected trailing edge flaps (f) can be taken into account, *i.e.*

$$L_r = (L_r)_p + (L_r)_\Gamma + (L_r)_\varepsilon + (L_r)_f. \quad (2.1)$$

3. INCOMPRESSIBLE FLOW ($M = 0$)

3.1 Planform Contribution, $(L_{r0})_p$

Figure 1a presents data for the planform contribution to L_{r0} , which is proportional to the overall lift coefficient. Ranges of aspect ratio from 1 to 12 and taper ratio from 0 to 1 are covered. The sweepback function $g(\Lambda_{1/4})$, involved in the ordinate parameter of Figure 1a, is given in Figure 1b for angles of sweepback of the quarter-chord line up to 60 degrees.

The curves given in Figure 1a were obtained by the application of lifting-surface theory (Derivation 11) to unswept wings. The sweepback function in Figure 1b is empirical and was obtained using Figure 1a and the wind-tunnel data of Derivations 4, 6, 7 and 12. The data were calculated on the assumption that the centre of gravity of the aircraft (assumed to be the centre of rotation) coincides with the longitudinal position of the wing aerodynamic centre. The effect of the finite distance between the centre of gravity and the aerodynamic centre in practical cases is not however likely to be large.

Agreement between values of $(L_{r0})_p$ estimated from this Item and the available wind-tunnel data for plain wings (Derivations 1, 4, 6, 7 and 12) is generally within ± 10 per cent.

Derivation 14 establishes expressions for the planform contribution to L_{r0} in fully-attached flow relating to slender delta and gothic wings with aspect ratios less than unity. These expressions may be reduced to

$$\frac{(L_{r0})_p}{C_L} = \frac{1}{a_1} f_1(A). \quad (3.1)$$

The function $f_1(A)$ for delta and gothic wings is plotted in Figure 2. Values for a_1 , the slope of the lift curve at zero lift, for use in Equation (3.1), may be obtained from Item No. 71006.

Comparison of Equation (3.1) with experimental data (Derivation 13) at low incidences for two low aspect ratio ($A = 0.53$ and 1.07) delta wings obtained under oscillatory conditions are not conclusive (see Derivation 14). Although agreement is within about 20 per cent for the lower aspect ratio model, the experimental data for the higher aspect ratio model are very erratic, being heavily dependent on the oscillation frequency, and the agreement with Equation (3.1) is poor.

3.2 Dihedral Contribution $(L_{r0})_{\Gamma}$

Figure 3 gives data for the dihedral contribution to L_{r0} in terms of sweepback angle. These data were derived for untapered wings of large aspect ratio (Derivation 5) using lifting-line theory. The method of Derivation 5 indicates that the effect of decreasing the aspect ratio is to decrease the dihedral contribution to L_{r0} , but the effect is negligible for aspect ratios down to about 4 or 5. There is very little experimental evidence with which to compare the theoretical data. Tests on an untapered wing of aspect ratio 2.61 and 45 degrees of quarter-chord sweepback (Derivation 5) indicate that Figure 3 provides values, for this case at least, that are about 20 per cent low. It will be appreciated that this error would have been larger if the effect of finite aspect ratio had been included in Figure 3.

For slender wings, with aspect ratio less than unity, Derivation 14 gives expressions from which the following values may be deduced:-

$$\frac{(L_r)_{\Gamma}}{\Gamma} = 0.00194 \text{ per degree, for delta wings,} \quad (3.2)$$

$$\text{and} \quad \frac{(L_r)_{\Gamma}}{\Gamma} = 0.00218 \text{ per degree, for delta wings,} \quad (3.3)$$

3.3 Twist Contribution, $(L_{r0})_{\epsilon}$

Figure 4 presents data for the contribution of wing twist to L_{r0} for unswept wings. These data apply to those cases where twist is present on an unswept wing such that the local incidence is reduced linearly with spanwise distance from the root (wash-out) – see diagram in Figure 4.

The data are based on lifting-line calculations in Derivation 3 for aspect ratios up to 8. Above this aspect ratio the data are extrapolated using as guides asymptotic values for two-dimensional flow and values estimated using the method of Derivation 2 for wings with rounded tips.

In the absence of other information concerning the effects of sweep, and since on physical grounds the effect of increasing sweep is to increase the magnitude of the twist effect on L_{r0} , it is suggested that tentative use of the sweep factor given in Figure 1b may be made.

No experimental data for the effect of wing twist have been found.

3.4 Flap Contribution, $(L_{r0})_f$

Figure 5a provides data for the contribution to L_{r0} arising from the deflection of trailing-edge flaps on unswept wings of aspect ratio 12. The data are given in terms of an aspect ratio function, $f_2(A)$, which can be obtained from Figure 5b, and in terms of the parameter $[(a_{2\infty}/2\pi)\delta_f]$, which can be considered as the change in incidence at constant lift coefficient equivalent to the deflection of the flaps in two-dimensional flow. This parameter may be satisfactorily estimated for plain flaps by using the inviscid flow value of $a_{2\infty}$ given by Item No. Aero C.01.01.03 and by using the lift increment ($\equiv a_{2\infty}\delta_f/57.3$) given by Item No. 74009 for split flaps and Item Nos. Aero F.01.01.08 and 09* for slotted flaps. It is useful to note that flaps not extending into the centre line of the wing may be taken into account by subtracting the value of $(L_{r0})_f$ corresponding to $(b_f/b)_{i/b}$ from that corresponding to $(b_f/b)_{o/b}$.

* To convert lift increments from these Items (for $A = 6$) to two-dimensional flow conditions a factor of 1.4 (suggested by lifting-line theory) should be applied.