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Rolling moment derivative, L_{ξ} for plain ailerons at subsonic speeds

Associated software: ESDUpac A8840
See ESDU 88040

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes ESDU Aero C.06.01.01, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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ROLLING MOMENT DERIVATIVE, L_{ξ} , FOR PLAIN AILERONS AT SUBSONIC SPEEDS

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ROLLING MOMENT DERIVATIVE, L_{ξ} , FOR PLAIN AILERONS AT SUBSONIC SPEEDS

1. NOTATION AND UNITS

		SI	British
A	aspect ratio		
$(a_1)_0$	section lift-curve slope with incidence in incompressible flow	rad^{-1}	rad^{-1}
$(a_2)_0$	section lift-curve slope with control deflection in incompressible flow	rad^{-1}	rad^{-1}
b	wing span	m	ft
C_L	lift coefficient, $L / \frac{1}{2}\rho V^2 S$		
C_l	rolling moment coefficient $\mathcal{L} / \frac{1}{2}\rho V^2 S b$		
c_f / c	ratio of aileron chord aft of hinge line to local wing chord, at mid-span of aileron		
K_1	value of Φ_{ξ} for rectangular wing		
K_2	secondary planform component of Φ_{ξ}		
k_1	correction factor for wing thickness		
k_2	correction factor for Reynolds number		
L	lift	N	lbf
$\mathcal{L}$	rolling moment	N m	lbf ft
L_{ξ}	rolling moment derivative with respect to ξ , $\partial C_l / \partial \xi$	rad^{-1}	rad^{-1}
$L_{\xi'}$	rolling moment derivative with respect to ξ' , $\partial C_l / \partial \xi'$	rad^{-1}	rad^{-1}
M	free-stream Mach number		
R	Reynolds number based on aerodynamic mean chord of wing		
S	wing planform area	m^2	ft^2
s	wing semispan	m	ft
t/c	section thickness to chord ratio of wing at mid-span of aileron		

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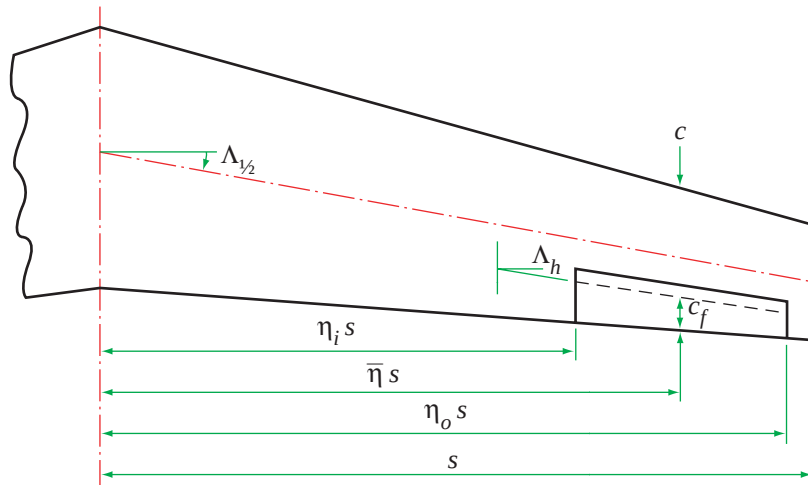


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V	free-stream velocity	m/s	ft/s
α	incidence	rad	rad
β	compressibility parameter, $(1 - M^2)^{1/2}$		
δ	deflection angle of full-span plain control measured in plane parallel to plane of symmetry, positive for trailing-edge down	rad	rad
η	spanwise distance from wing centre-line as fraction of semispan		
η_i	value of η at inboard limit of aileron at hinge line		
η_o	value of η at outboard limit of aileron at hinge line		
$\bar{\eta}$	$(\eta_i + \eta_o)/2$		
λ	wing taper, ratio of tip chord to centre-line chord		
$\Lambda_{1/2}$	sweepback of wing mid-chord line	deg	deg
Λ_h	sweepback of aileron hinge line	deg	deg
ξ	aileron deflection angle measured in plane parallel to plane of symmetry, arithmetic mean of deflection angles of port and starboard ailerons, positive for starboard aileron down and port aileron up	rad	rad
ξ'	aileron deflection angle measured in plane normal to hinge line, $\tan^{-1}(\tan \xi \sec \Lambda_h)$	rad	rad
ρ	density of air	kg/m ³	slug/ft ³
τ	section trailing-edge angle at mid-span of aileron	deg	deg
Φ	part-span lift correction function in Item No. 74012 (Derivation 5), ratio of lift coefficient increment due to flaps of span $b\eta$ extending symmetrically about wing centre-line to lift coefficient increment due to full-span flaps at same deflection		
Φ_ξ	aileron rolling moment correction function, see Section 2.3 and Equation (2.5)		
$\Phi_{\xi i}$	value of Φ_ξ for $\eta = \eta_i$		
$\Phi_{\xi o}$	value of Φ_ξ for $\eta = \eta_o$		

Subscripts

T	denotes theoretical value
$t = 0$	denotes value for section of zero thickness



Sketch 1.1 Wing and aileron geometry

2. METHOD*

This Item presents a semi-empirical method for predicting the rolling moment derivative due to the operation of plain sealed aileron controls for attached flow at subsonic speeds. The method combines a geometrically defined moment arm $\bar{\eta}$ with a full-span control deflection characteristic $\partial C_L / \partial \delta$ that is modified by a correction function $(\Phi_{\xi_i} - \Phi_{\xi_o})$ that allows for the part-span of the ailerons and their effectiveness in producing rolling moment. The derivative for antisymmetric deflection of the ailerons is given by the equation

$$L_{\xi} = -\frac{1}{2} \bar{\eta} (\partial C_L / \partial \delta) (\Phi_{\xi_i} - \Phi_{\xi_o}), \quad (2.1)$$

where the aileron deflection angle is ξ , measured in a plane parallel to the plane of symmetry.

If the aileron deflection angle is ξ' , measured in a plane normal to the hinge line, the corresponding derivative is

$$L_{\xi'} = L_{\xi} \cos \Lambda_h, \quad (2.2)$$

where Λ_h is the sweepback of the aileron hinge line.

2.1 Moment Arm

In Equation (2.1), $\bar{\eta}$ approximates to the spanwise moment arm of each aileron expressed as a fraction of the semispan s . It is taken as

$$\bar{\eta} = \frac{1}{2} (\eta_i + \eta_o), \quad (2.3)$$

* A FORTRAN computer program is available for the method of this Item and that of Item No. 88029 as ESDUpac A8840, see Item No. 88040 for details.

the mean of the aileron inboard and outboard limits measured at the hinge line. This simple geometric definition neglects the effect of wing taper, but this is small for practical aileron spans ($\eta_o - \eta_i \leq 0.4s$).

An extra factor of $\frac{1}{2}$ appears in Equation (2.1) because the rolling moment coefficient is based on a reference length equal to the full span b

2.2 Plain Control Derivative

The derivative $\partial C_L / \partial \delta$ in Equation (2.1) is the rate of change of lift coefficient due to control deflection for full-span plain controls, as predicted by the method in Item No. 74011 (Derivation 4), where it is presented in terms of the theoretical wing lift-curve slope $[\partial C_L / \partial \alpha]_T$, wing and control geometry, Reynolds number and Mach number in the form

$$\frac{\partial C_L}{\partial \delta} = \left[\frac{\partial C_L}{\partial \delta} / \frac{\partial C_L}{\partial \alpha} \right]_T \left[\frac{\partial C_L}{\partial \alpha} \right]_T [1 - k_1 k_2]. \quad (2.4)$$

The first expression in brackets on the right hand side of the equation is given in Figure 1 as a carpet in terms of $1/\beta A$ and c_f/c . The second expression in brackets is evaluated using Item No. 70011 (Derivation s3) which gives $[\partial C_L / \partial \alpha]_T / A$ in terms of λ , βA and $A \tan \Lambda_{1/2}$. The factors k_1 and k_2 appearing in the third expression in brackets are given in Figures 2 and 3; k_1 corrects for section thickness and is given in terms of $(t/c) \sec \Lambda_{1/2}$ and c_f/c , and k_2 corrects for Reynolds number and is given in terms of $\log_{10} R$ and c_f/c . Although the methods in Item Nos 74011 and 70011 are presented for wing planform parameters under the assumption of straight taper, they may be used for other planforms by employing the geometric technique in Appendix A of Item No. 76003 (Derivation 6) to construct an "equivalent" straight-tapered wing to provide suitably representative values of λ , A and $A \tan \Lambda_{1/2}$.

The data in Figures 1 to 3 have been reproduced directly from Item No. 74011 to avoid cross referencing. Values of c_f/c and t/c appropriate to the mid-span of the aileron should be taken. In the original construction of the correction factors k_1 and k_2 it was assumed that the section geometry was such that $\tau = 100 t/c$ (degrees). If τ lies outside the range $50t/c \leq \tau \leq 150t/c$ it is necessary to use Item Nos Aero W.01.01.05 (Derivation 1) and Aero C.01.01.03 (Derivation 2) to calculate the necessary section properties and replace the term $[1 - k_1 k_2]$ by its full form $[(a_2)_0 / (a_2)_0]_{T=t=0} / [(a_1)_0 / 2\pi]$, with t/c and τ measured in a plane normal to the wing mid-chord sweep line.

2.3 Rolling Moment Correction Factors

The term $(\Phi_{\xi i} - \Phi_{\xi o})$ in Equation (2.1) allows for the finite span of the ailerons and for their effectiveness in producing rolling moment. Calculation of $\Phi_{\xi i}$ and $\Phi_{\xi o}$ is carried out by evaluating the correction function Φ_{ξ} at $\eta = \eta_i$ and $\eta = \eta_o$ respectively. The function Φ_{ξ} is expressed in terms of a value K_1 appropriate to a rectangular wing, from which is subtracted a secondary planform component, K_2 , so that

$$\Phi_{\xi} = K_1 - K_2. \quad (2.5)$$

Figure 4a gives K_1 as a carpet in η and $1/\beta A$ for $0 \leq \eta \leq 1$ and $0 \leq 1/\beta A \leq 0.5$. Figures 4b and 4c show, for $0.08 \leq 1/\beta A \leq 0.30$, the central part of the carpet on an expanded scale. Figure 5 gives K_2 as a function of η for a series of values of the planform parameter $A \tan \Lambda_{1/2} - 8\lambda$.

The functions K_1 and K_2 have been established by analysing the wind-tunnel data on rolling moment in Derivations 7 to 39, and by making use of some of the results in Item No. 74012 (Derivation 5) which gives a function Φ for converting the lift coefficient increment due to full-span flaps to that for symmetrically