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Yawing moment coefficient for plain ailerons at subsonic speeds

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YAWING MOMENT COEFFICIENT FOR PLAIN AILERONS AT SUBSONIC SPEEDS

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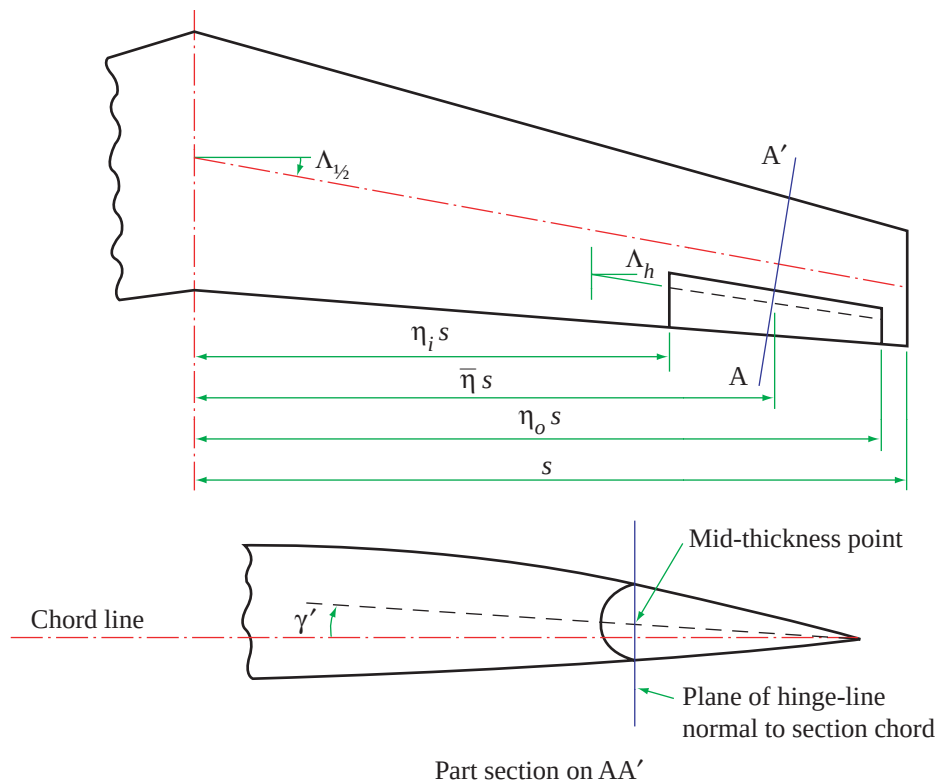
YAWING MOMENT COEFFICIENT FOR PLAIN AILERONS AT SUBSONIC SPEEDS

1. NOTATION AND UNITS (see Sketch 1.1)

		SI	British
A	aspect ratio		
b	wing span	m	ft
C_L	lift coefficient of wing and flap system with ailerons undeflected, $L/1/2\rho V^2 S$		
ΔC_{Lf}	component of lift coefficient due to deployment of trailing-edge flaps		
C_l	rolling moment coefficient due to ailerons, $\mathcal{L}/1/2\rho V^2 Sb$		
C_n	yawing moment coefficient due to ailerons, $\mathcal{N}/1/2\rho V^2 Sb$		
C_{ni}	contribution to C_n due to changes in induced drag		
C_{np}	contribution to C_n due to changes in profile drag		
c_f/c	ratio of aileron chord aft of hinge line to local wing chord at mid-span of aileron		
$F(\eta)$	function defining C_{ni} for ailerons that extend from η to wing tip		
G	function in calculation of C_{ni} see Equation (2.3) and Figure 1		
H	function in calculation of C_{ni} see Equation (2.3) and Figure 2	deg ⁻¹	deg ⁻¹
J_f	empirical factor for converting ΔC_{Lf} into effective twist angle in calculation of C_{ni} see Equation (2.3). Taken as 18.0 degrees	degree	degree
J_δ	empirical factor applied to δ_t in calculation of C_{ni} see Equation (2.3). Taken as 1.4		
L	lift	N	lbf
$\mathcal{L}$	rolling moment, positive starboard wing down	N m	lbf ft
$L_{\xi'}$	rolling moment derivative with respect to ξ' , $\partial C_l / \partial \xi'$ for ailerons that extend from η to wing tip	rad ⁻¹	rad ⁻¹
M	Mach number		
$\mathcal{N}$	yawing moment, positive nose to starboard	N m	lbf ft

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S	wing planform area	m^2	ft^2
s	wing semispan	m	ft
V	free-stream velocity	m/s	ft/s
β	compressibility parameter $(1 - M^2)^{1/2}$		
γ'	angle between chord line of aerofoil section and line joining mid-thickness point at hinge line to trailing edge of undeflected aileron, measured at mid-span of aileron in plane normal to hinge line	degree	degree
δ_t	geometric twist angle of wing tip relative to root chord, positive leading-edge up	degree	degree
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		
η	$(\eta_i + \eta_o)/2$		
λ	wing taper, ratio of tip chord to centre-line chord		
$\Lambda_{1/4}$	sweepback of wing quarter-chord line	degree	degree
$\Lambda_{1/2}$	sweepback of wing half-chord line (needed in calculation of $L_{\xi'}$)	degree	degree
Λ_h	sweepback of control hinge line	degree	degree
μ	part-span factor in calculation of C_{np} , see Figure 3		
μ_i, μ_o	values of μ at η_i and η_o , respectively		
ξ'	aileron deflection angle measured in plane normal to hinge line, arithmetic mean of deflection angles of port and starboard ailerons, positive for starboard aileron down and port aileron up, $\frac{1}{2}(\xi'_p + \xi'_s)/57.3$	radian	radian
ξ'_p	deflection of port aileron measured from chord line in plane normal to hinge line, positive trailing-edge up	degree	degree
ξ'_s	deflection of starboard aileron, measured from chord line in plane normal to hinge line, positive trailing-edge down	degree	degree
ρ	free-stream density of air	kg/m^3	slug/ft^3



Sketch 1.1 Wing and aileron geometry

2. METHOD*

This Item presents a semi-empirical method for predicting the yawing moment coefficient C_n due to the operation of plain sealed ailerons at subsonic free-stream Mach numbers when the flow over the wing is wholly subsonic. The coefficient is treated as the sum of two components, C_{ni} and C_{np} . The first is due to the asymmetric changes in induced drag caused by aileron deflection, and the second is due to imbalance of the profile drag on the port and starboard wings. Thus the total C_n is

$$C_n = C_{ni} + C_{np}. \quad (2.1)$$

2.1 Induced Drag Contribution

Theoretical considerations of the interaction of the symmetric wing loading due to angle of attack and the antisymmetric loading due to equally deflected ailerons (e.g. see Derivations 5 and 6), show that for a plane wing C_{ni} is proportional to the product of the wing lift coefficient C_L and the aileron rolling moment coefficient $C_l (= L_{\xi}, \xi')$. Derivation 6 goes on to show that if the ailerons are deflected unequally, so that $\xi'_p > \xi'_s$, say, then the appropriate symmetrical loading is for the wing with both ailerons raised by an angle $\frac{1}{2}[\xi'_p - \xi'_s]$. The change in C_{ni} depends on the consequent reduction in lift and is obtained theoretically as a contribution that is proportional to C_l , $\frac{1}{2}[\xi'_p - \xi'_s]$, and $1/A$ to a very good approximation. Other

* A FORTRAN computer program is available for the method of this Item and that of No.88013 as ESDUpac A8840, see Item No. 88040 for details.

terms are necessary to account for any geometric twist of the wing and any deployment of trailing-edge flaps inboard of the ailerons. These considerations enable C_{ni} for ailerons extending from η_i to η_o be expressed in the following form, which has been found to provide an excellent qualitative model,

$$C_{ni} = F(\eta_i) - F(\eta_o), \quad (2.2)$$

where
$$F(\eta) = -GC_L L_{\xi'} \xi' + \frac{H}{A} (\frac{1}{2} [\xi'_p - \xi'_s] \cos \Lambda_h - J_\delta \delta_t + J_f \Delta C_{Lf}) L_{\xi'} \xi'. \quad (2.3)$$

For the particular case of ailerons that extend to the wing tip, $\eta_o = 1$, $F(1) = 0$ and so $C_{ni} = F(\eta_i)$.

The function G has been determined empirically from wind-tunnel data (Derivations 7 to 30) for the rate of change of $C_{ni}/(-L_{\xi'} \xi')$ with C_L , the lift coefficient of the wing and flap system with ailerons undeflected. Figures 1a, 1b and 1c present G plotted against $1/\beta A$ and η for $\lambda = 1.0$, 0.5 and 0.2 , respectively; a cross plot against λ must be made to obtain G at intermediate values of λ . The carpets are comparable in form to the low-speed theoretical results of Derivations 5 and 6, but their empirical nature results in some modest adjustments. In particular there is a somewhat faster decrease in G with decreasing λ for wings of moderate or high aspect ratio. An allowance for compressibility effects has been made by the introduction of the reduced aspect ratio, βA in place of A .

The rolling moment derivative $L_{\xi'}$ for ailerons that extend from η to the wing tip can be calculated by the method of Item No. 88013 (Derivation 4) or experimental values may be substituted if they are available. Note that $L_{\xi'}$, is defined per radian and that ξ' is correspondingly in radians. The other angles in Equation (2.3) are in degrees.

The theoretical function H is given in Figure 2 in terms of λ and η , and has been reproduced from Derivation 6. The angle $\frac{1}{2} [\xi'_p - \xi'_s] \cos \Lambda_h$ allows for unequal (differential) operation of the ailerons measured in a streamwise plane. The influence of geometric twist is taken as the product of an empirical factor J_δ and the relative tip to root twist δ_t . The effect of flap deployment is modelled as an effective twist equal to the product of an empirically determined factor J_f and the component of the lift coefficient due to the flaps ΔC_{Lf} . Comparisons with experimental data (Derivations 22 to 30) showed that no empirical modification of the function H was necessary and that for a sufficient accuracy of prediction J_δ could be taken as 1.4 and J_f as 18.0 degrees. General values of J_δ and J_f have been left in Equation (2.3) as an aid to modelling experimental data. The terms that involve H are influenced by compressibility effects only through any changes in $L_{\xi'}$, and ΔC_{Lf} .

The component of C_{ni} that depends on C_L acts in an adverse manner in that it opposes the direction of the turn expected to accompany the roll produced by the ailerons. For a given aileron rolling moment the remaining terms give constant increments in the opposite sense if the ailerons are trailing-edge up relative to the inboard part of the wing. Thus at constant C_L a greater deflection of the up-going aileron, root-to-tip washout, or flap deployment all provide favourable contributions that will reduce and may overcome the adverse yawing moment. Conversely, if the ailerons are trailing-edge down the adverse yawing moment will increase.

2.2 Profile Drag Contribution

The profile drag contribution C_{np} is estimated by using the method given in Item No. 87024 (Derivation 3) for estimating the drag coefficient increment due to full-span plain flaps at constant lift, together with a part-span factor from Item No. Aero F.02.01.07 (Derivation 1) to allow for the limited extent of the ailerons,