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Aerofoil and wing pitching moment coefficient at zero angle of attack due to deployment of trailing-edge plain flaps at low speeds

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes, in part, ESDU Aero F.08.01.01 and 02, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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AEROFOIL AND WING PITCHING MOMENT COEFFICIENT AT ZERO ANGLE OF ATTACK DUE TO DEPLOYMENT OF TRAILING-EDGE PLAIN FLAPS AT LOW SPEEDS

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AEROFOIL AND WING PITCHING MOMENT COEFFICIENT AT ZERO ANGLE OF ATTACK DUE TO DEPLOYMENT OF TRAILING-EDGE PLAIN FLAPS AT LOW SPEEDS

1. NOTATION AND UNITS

		SI	British
A	aspect ratio, $2s/\bar{c}$		
a_1	theoretical rate of change of lift coefficient with wing angle of attack	rad^{-1}	rad^{-1}
a_t	theoretical rate of change of lift coefficient for aerofoil with trailing-edge flap deflection, Equation (3.3)	deg^{-1}	deg^{-1}
C_L	lift coefficient; $(\text{lift})/qc$ for aerofoil, $(\text{lift})/qS$ for wing		
ΔC_{L0t}	increment in lift coefficient at zero angle of attack due to deployment of trailing-edge plain flap on aerofoil, based on c		
C_m	pitching moment coefficient; $(\text{pitching moment})/qc^2$ for aerofoil, $(\text{pitching moment})/qS\bar{c}$ for wing, referenced to $c/4$ for aerofoil and $\bar{c}/4$ for wing, see Sketch 1.1		
$\Delta C_{m\alpha 0}$	increment in pitching moment coefficient at zero angle of attack due to deployment of trailing-edge plain flap on aerofoil, based on c^2 and referenced to $c/4$, see Equation (3.1)		
$\Delta C_{mtw\alpha 0}$	increment in pitching moment coefficient at zero angle of attack due to deployment of trailing-edge plain flap on wing, based on $S\bar{c}$ and referenced to $\bar{c}/4$, see Equation (3.6)		
c	basic (plain) aerofoil chord (<i>i.e.</i> chord with high-lift devices undeployed), see Sketch 1.2	m	ft
$\bar{c}$	wing geometric mean chord	m	ft
$\bar{\bar{c}}$	wing aerodynamic mean chord, see Item No. 76003 (Reference 32)	m	ft
c_r	wing root chord, see Sketch 1.2	m	ft
c_t	chord of trailing-edge plain flap, see Sketch 1.2	m	ft

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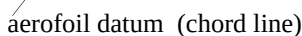
h_2	centre of incremental lift at zero angle of attack due to trailing-edge plain flap deflection on aerofoil section, expressed as fraction of chord, measured positive aft from aerofoil quarter-chord position, see Equation (3.5)		
h_{2T}	theoretical value of h_2 , see Equation (3.4)		
J_p	efficiency factor for plain flap on aerofoil, required in Equation (3.2), see Figure 1		
J_{p0}	efficiency factor for plain flap on wing, required in Equation (3.7), see Figure 3		
K_f	flap-type correlation factor, see Equation (3.8)		
$K_{f\Lambda}$	flap-type correlation factor for wing sweep, see Equation (3.9)		
K	part-span factor; pitching moment coefficient increment due to part-span trailing-edge plain flaps extending symmetrically from wing centre-line divided by pitching moment coefficient increment due to full-span trailing-edge plain flaps at the same deflection angle and wing angle of attack, Figure 4		
K_i	value of K corresponding to $\eta = \eta_i$, required in Equation (3.6)		
K_o	value of K corresponding to $\eta = \eta_o$, required in Equation (3.6)		
K_Λ	part-span factor dependent on wing sweep effect, see Figure 5		
$K_{\Lambda i}$	value of K_Λ corresponding to $\eta = \eta_i$, required in Equation (3.6)		
$K_{\Lambda o}$	value of K_Λ corresponding to $\eta = \eta_o$, required in Equation (3.6)		
M	free-stream Mach number		
q	free-stream kinetic pressure	N/m ²	lbf/ft ²
R_c	aerofoil Reynolds number based on free-stream conditions and c		
$R_{\bar{c}}$	wing Reynolds number based on free-stream conditions and $\bar{c}$		
S	wing planform area, $2s\bar{c}$	m ²	ft ²
s	wing semi-span, see Sketch 1.1	m	ft
t	maximum thickness of aerofoil	m	ft
z_{um}	maximum upper surface ordinate of basic aerofoil, see Sketch 1.2	m	ft
β	compressibility parameter, $(1 - M^2)^{1/2}$		

δ_t°	deflection of trailing-edge flap, positive trailing edge down, see Sketch 1.2	deg	deg
η	spanwise distance from wing centre-line as fraction of semi-span		
η_i	value of η at inboard limit of flap, see Sketch 1.1		
η_o	value of η at outboard limit of flap, see Sketch 1.1		
Λ_0	wing leading-edge sweep angle, see Sketch 1.1	deg	deg
$\Lambda_{1/4}$	wing quarter-chord sweep angle, see Sketch 1.1	deg	deg
Λ_1	wing trailing-edge sweep angle, see Sketch 1.1	deg	deg
λ	wing taper ratio (tip chord/root chord)		
ϕ_t°	angle between aerofoil datum and tangent to upper surface at trailing edge, see Sketch 1.2	deg	deg

Subscripts

α_0	denotes value at zero angle of attack
$()_{expt}$	denotes experimental value
$()_{pred}$	denotes predicted value

Sketch 1.2 Deployed plain flap notation (at Section AA)



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2. INTRODUCTION

This Item provides a method to obtain the increment in pitching moment coefficient at zero angle of attack, due to deployment of trailing-edge plain flaps, either on an aerofoil or on a wing.

For aerofoils the method predicts the centre of lift position, h_2 , due to plain flap deployment, based on the thin-aerofoil theory of Derivation 29 and modified to obtain correlation with the experimental data of Derivations 4 to 11, 22 and 23. This is combined with the increment in aerofoil lift coefficient calculated from Item No. 94028 (Derivation 2) to estimate the pitching moment coefficient increment.

For wings with full-span trailing-edge plain flaps, factors, dependent on planform geometry, are applied to the pitching moment coefficient increment on a section that is representative of the wing, to allow for three-dimensional effects. Derivations 30 and 31 were used as the basis for these factors, with some adjustment to the simple theoretical assumptions. The method of Item No. 97011 (Derivation 3) is used (instead of Item No. 94028) to predict the increment in section lift to obtain the section pitching moment increment. For wings with part-span trailing-edge flaps, additional factors are introduced that are dependent on taper ratio, aspect ratio, sweep and spanwise extent of the flap.

Section 3 describes the prediction method and Section 4 discusses Mach number and Reynolds number effects. The accuracy and applicability of the method are addressed in Section 5. The Derivation and References are given in Section 6. Section 7 illustrates worked examples for an aerofoil and a wing.

3. PREDICTION METHOD

The method for aerofoils requires the use of Item No. 94028, to determine the lift increment characteristics of the aerofoil/flap combination from which to derive the pitching moment coefficient increment.

However, for wings the method requires the use of Item No. 97011 to determine the lift increment characteristics of the representative section/flap combination from which to derive the section pitching moment coefficient increment. The *streamwise* section and flap geometries and angles at the mid-span of the flap panel are taken to be representative of the wing/flap system, see Sketches 1.1 and 1.2. By this means, the effects of spanwise variation are averaged out. Empirical corrections allow for the effects of wing planform geometry and the spanwise extent of the flaps.

3.1 Aerofoil Pitching Moment Coefficient Increment $\Delta C_{m\alpha 0}$

The increment in the pitching moment coefficient at zero angle of attack for deployment of a plain flap on an aerofoil is obtained as the product

$$\Delta C_{m\alpha 0} = -\Delta C_{L0t} h_2 . \quad (3.1)$$

Here, ΔC_{L0t} is the increment in lift coefficient at zero angle of attack due to deployment of a plain flap on an aerofoil and is evaluated as

$$\Delta C_{L0t} = J_p a_t \delta_t^\circ , \quad (3.2)$$

where J_p is an empirical efficiency factor taken from Item No. 94028, and is given in Figure 1 as a function of the angle $(\delta_t^\circ + \phi_t^\circ)$, see Sketch 1.2, and a_t is the theoretical rate of change of lift coefficient with

respect to the deflection angle δ_t° , positive trailing edge down, at constant angle of attack, given by thin-plate theory as

$$a_t = (\pi/90) \left\{ \pi - \cos^{-1}(2c_t/c - 1) + [1 - (2c_t/c - 1)^2]^{1/2} \right\}. \quad (3.3)$$

Values of a_t have been evaluated and the results are presented in Figure 2a.

The centre of the lift increment at zero angle of attack, h_2 , expressed as a fraction of the chord and measured positive aft from the quarter-chord point, is derived empirically from its theoretical value in Derivation 29 for a hinged plate on a thin aerofoil

$$h_{2T} = 0.25[1 - (2c_t/c - 1)^2]^{1/2} [1 - (2c_t/c - 1)] / \left\{ \pi - \cos^{-1}(2c_t/c - 1) + [1 - (2c_t/c - 1)^2]^{1/2} \right\}. \quad (3.4)$$

Values of h_{2T} have been evaluated and are given in Figure 2b.

An incremental adjustment to obtain correlation with experimental data gives

$$h_2 = h_{2T} + 0.012(44 - \delta_t^\circ) z_{um}/c + 0.011(c_t/c)^3 \delta_t^\circ, \quad (3.5)$$

where

c_t/c is the ratio of the flap chord to the aerofoil chord,

δ_t° is the flap deflection angle, in degrees,

and

z_{um}/c is the ratio of the maximum upper-surface ordinate to the aerofoil chord as shown in Sketch 1.2.

3.2 Wing Pitching Moment Coefficient Increment $\Delta C_{mtw\alpha 0}$

For a wing at zero angle of attack the increment in pitching moment coefficient due to plain flap deployment is correlated to be

$$\Delta C_{mtw\alpha 0} = -K_f (K_o - K_i) \Delta C_{L0t} h_2 + K_{f\Lambda} (K_{\Lambda o} - K_{\Lambda i}) (A/2) \Delta C_{L0t} \tan \Lambda_{1/4}, \quad (3.6)$$

where A is the aspect ratio and ΔC_{L0t} is now calculated for the representative section of the wing, taken at flap mid-span and, instead of Equation (3.2),

$$\Delta C_{L0t} = J_{p0} a_t \delta_t^\circ, \quad (3.7)$$

where J_{p0} is an empirical efficiency factor for a plain flap on the representative section, taken from Item No. 97011 and given in Figure 3.

The part-span factors K_i and K_o are obtained from Figure 4 as functions of taper ratio and the inboard and outboard limits of the trailing-edge plain flap, η_i and η_o respectively.

The flap type correlation factors for plain flaps have been derived from the data of Derivations 12 to 17 and 20 to be

$$K_f = (a_1/2\pi)^{0.46} \quad (3.8)$$

$$\text{and} \quad K_{f\Lambda} = \cos \Lambda_{1/4}, \quad (3.9)$$

where a_1 is the wing lift slope obtained from Item No. 70011 (Derivation 1).

The part-span wing sweep factors $K_{\Lambda i}$ and $K_{\Lambda o}$ are obtained for plain flaps from Figure 5 as functions of taper ratio and the inboard and outboard limits of the trailing-edge plain flap, η_i and η_o respectively.

Note that for all cases with a full-span plain flap or an unswept quarter-chord line the second term in Equation (3.6) has a value of zero.

The data for K_Λ were obtained from Derivation 30 in the simplified form

$$K_\Lambda = \frac{\eta(1-\eta)[(1+2\lambda) - \eta(1-\lambda^2)]}{4(1+\lambda+\lambda^2)}, \quad (3.10)$$

which is equivalent to Figure 5.

4. EFFECTS OF MACH NUMBER AND REYNOLDS NUMBER

4.1 Mach Number Effects

High local Mach numbers will occur at low free-stream Mach number as a result of high angle deployment of trailing-edge plain flaps. Significant Mach number effects will occur at free-stream Mach numbers greater than about 0.2, at large values of $(\delta_t^\circ + \phi_t^\circ)$, and at progressively smaller values as Mach number is increased. None of the data considered for this Item was for a Mach number greater than 0.27.

4.2 Reynolds Number Effects

For the data used in the derivation of this Item no effect of Reynolds number on $\Delta C_{mt\alpha 0}$ or $\Delta C_{mtw\alpha 0}$ was found over the ranges of Reynolds number shown in Tables 5.1 and 5.2.