



Zero-lift drag coefficient increment due to full-span plain flaps

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ZERO-LIFT DRAG COEFFICIENT INCREMENT DUE TO FULL-SPAN PLAIN FLAPS

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ZERO-LIFT DRAG COEFFICIENT INCREMENT DUE TO FULL-SPAN PLAIN FLAPS

1. NOTATION AND UNITS

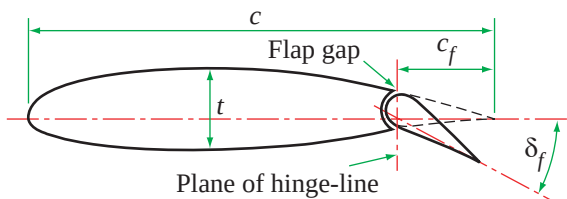
		SI	British
A	wing aspect ratio, $4s^2/S_w$		
C_D	drag coefficient based on S_w		
ΔC_D	increment in C_D at constant C_L , as used in Item No. 87024, Reference 26		
C_{D0}	notional zero-lift drag coefficient for clean wing (i.e. $\delta_f = 0$), see Sketch 3.1		
ΔC_{D0}	increment in C_{D0} due to deflection of full-span flaps, see Section 3		
ΔC_{D0u}	value of ΔC_{D0} for unswept wing with full-span flaps		
C_L	total lift coefficient based on S_w		
ΔC_{Lf}	lift coefficient increment due to flap deflection		
c	wing chord	m	ft
c_f	flap chord, see Sketch 1.1	m	ft
K	trailing vortex drag factor for part-span flaps (see Item No. Aero F.02.01.08, Reference 20)		
R	Reynolds number based on freestream conditions and aerodynamic mean chord		
S_w	wing planform area	m ²	ft ²
s	wing semi-span	m	ft
t	section maximum thickness	m	ft
α	wing angle of attack	deg	deg
α_0	wing angle of attack for zero lift (flaps undeployed)	deg	deg
γ	angle between chord line of aerofoil section and line joining mid-thickness point at hinge location to trailing edge of undeflected flap, measured in streamwise plane, see Sketch 1.2	deg	deg
δ	$1 + \delta$ is trailing vortex drag factor for basic wing planform (see Item No. 74035, Reference 25)		

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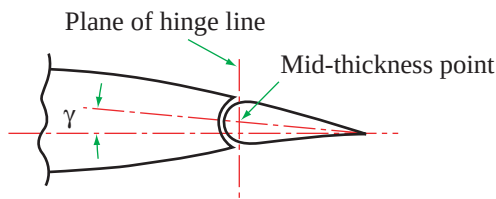
		SI	British
δ_f	flap deflection angle, measured in streamwise plane, see Sketch 1.1	deg	deg
λ	taper ratio, wing tip chord/wing centre-line chord		
$\Lambda_{1/4}$	wing quarter-chord sweep	deg	deg
μ	part-span flap factor on ΔC_{D0} (see Item No. Aero F.02.01.07, Reference 18)		

Subscripts

<i>expt</i>	denotes experimental value
<i>pred</i>	denotes predicted value



Sketch 1.1 Streamwise section



Sketch 1.2 Streamwise section

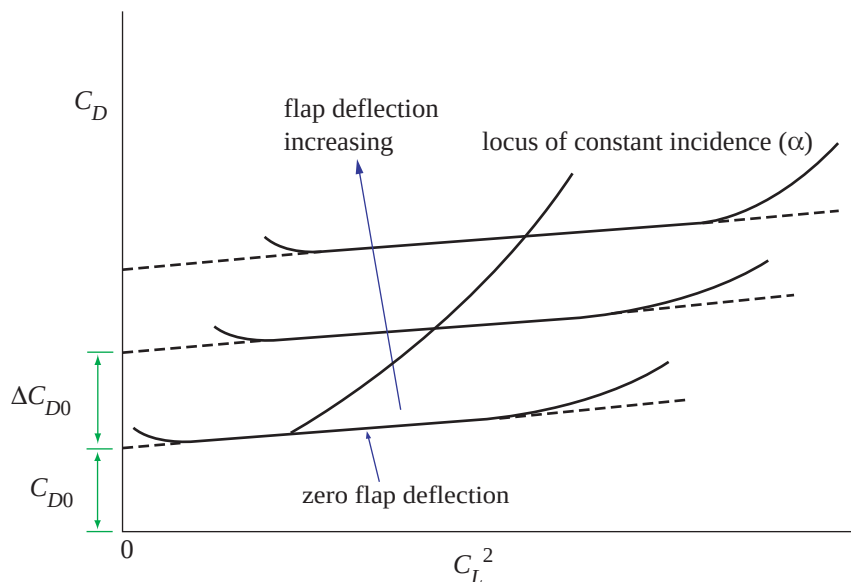
2. INTRODUCTION

This Data Item provides the increment in the zero-lift drag coefficient of a wing, ΔC_{D0} , due to the deployment of full-span plain trailing-edge flaps. The increment is to be used within the prediction method for the wing total drag coefficient, C_D , over the range of total lift coefficient, C_L , where there is a parabolic variation of C_D with C_L . The anticipated form of the parabolic variation is implicit in the empirical correlation of ΔC_{D0} that is presented.

The way in which C_D is modelled as a function of C_L is discussed in Section 3, which explains the constraints imposed in the empirical derivation of ΔC_{D0} and hence on its use. (A distinction is made from the analytical method of Item No. 87024 (Reference 26), which is more suited to the use of plain flaps as controls with positive or negative deflections in the range $-20^\circ \leq \delta_f \leq 30^\circ$.) The method for ΔC_{D0} and the use of the increment in the general case that caters for part-span flaps and wing planform effects are discussed in Section 4. The accuracy and applicability of the method are addressed in Section 5. The Derivation and References are given in Section 6 and worked examples are provided in Section 7.

3. MODELLING CONSIDERATIONS

For a wing it is generally found to good accuracy that over much of the practical range of total lift coefficient, the total drag coefficient is parabolic in C_L and so C_D varies linearly when plotted against C_L^2 , provided that the flow is fully attached and the Mach number and Reynolds number are constant. The same is true of a wing with a deflected flap if the flow ahead of the flap remains fully attached. Furthermore, the linear parts of the C_D versus C_L^2 plots at different flap deflection angles, δ_f , are to a first approximation parallel to each other and to the curve for zero flap deflection; Sketch 3.1 shows the idealised case for full-span flaps.



Sketch 3.1 Idealised drag characteristics and linear representations for full-span flaps

The advantage of the representation in Sketch 3.1 is that it permits a simple analysis of the drag characteristics. Extrapolation of the zero flap deflection curve to the $C_L = 0$ axis defines an intercept known as the *zero-lift drag coefficient*, C_{D0} , and extrapolation of each of the other curves defines an increment, ΔC_{D0} , that depends on δ_f . The total drag coefficient of the wing with a deflected flap can then be obtained by adding to the notional total zero-lift drag coefficient a lift-dependent term $(dC_D/dC_L^2)C_L^2$, where (dC_D/dC_L^2) is independent of C_L and, in the ideal case, independent of δ_f . Thus

$$C_D = C_{D0} + \Delta C_{D0} + (dC_D/dC_L^2)C_L^2. \quad (3.1)$$

The coefficients C_{D0} and ΔC_{D0} should be regarded as modelling parameters in Equation (3.1), defined to optimise the prediction of C_D within the linear regions of the curves in Sketch 3.1. They will not, in general, correspond to actual values of C_D at zero lift, as witnessed by the upturn in the solid curves outside the linear regions.

In the simplest analysis, the slope dC_D/dC_L^2 is based on theoretical estimates of the trailing vortex drag and so, for example, would be $1/\pi A$ for an elliptically loaded wing (e.g. Reference 21). With flaps deflected, the omission of other lift-dependent terms is justified on the grounds that available experimental evidence has shown that their effect is unimportant except for small flap deflection angles, with the suggestion that to a first approximation the lift-dependent contributions from the boundary layer are offset by effects due to flap deflection, particularly at large deflection angles. Boundary layer lift-dependent drag for the basic wing without flap deflection is treated in Item No. 66032 (Reference 22, currently under revision).

In practice, although experimental data for C_D will plot linearly against C_L^2 over a range of C_L values, the slopes of the plots will not be parallel at all flap deflection angles, nor correspond to that associated with the supposed vortex drag model. See for example Sketch 3.2, where the dashed lines are drawn to fit the linear regions of illustrative experimental data and compared with a line of slope $1/\pi A$.

To provide a basis for an empirical method in spite of such drawbacks, it is common practice first to identify across the linear curves a locus of constant incidence, α , as shown in Sketch 3.1. Traditionally (Derivation 3) the constant incidence is chosen as six degrees above the zero-lift incidence, i.e. $\alpha_0 + 6^\circ$, see Sketch 3.2. The form of dC_D/dC_L^2 that is to be used in Equation (3.1) for prediction purposes is then postulated, and parallel lines of that slope are drawn through each of the experimental curves at C_L values corresponding to the chosen constant incidence. The parallel lines, shown solid in Sketch 3.3, are continued to form intercepts on the $C_L = 0$ axis, which will then define the increment ΔC_{D0} for a given δ_f that, when employed in Equation (3.1), will locate the predicted drag coefficient parabola so that it is close to the true drag variation over the C_L range of most interest, but possibly only in exact agreement at $\alpha_0 + 6^\circ$.

Sketch 3.4 shows such a reconstructed parabola as a solid line. Reliance on an extrapolation of the dashed lines in Sketch 3.3 to define an increment ΔC_D (described as the *increment at constant lift* in Item No. 87024, Reference 26), would lead to the reconstructed parabola shown dashed in Sketch 3.4, which is too low throughout the C_L range because that estimate of ΔC_D is too small for satisfactory use in Equation (3.1).

The methods in Item No. Aero F.02.01.06 (Reference 19), on slotted flaps of small chord extension, and Item No. 74010 (Reference 24) on split flaps, following on the earlier work of Derivation 3, both used the constant incidence locus procedure to provide correlations of ΔC_{D0} , and that is the method adopted in the present Item.