



# ESDU 87005

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## Increment in aerofoil profile drag coefficient due to the deployment of a single-slotted flap

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INCREMENT IN AEROFOIL PROFILE DRAG COEFFICIENT DUE TO THE DEPLOYMENT OF A SINGLE-SLOTTED FLAP

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## INCREMENT IN AEROFOIL PROFILE DRAG COEFFICIENT DUE TO THE DEPLOYMENT OF A SINGLE-SLOTTED FLAP

### 1. NOTATION AND UNITS

|                          |                                                                                                                                      | SI     | British |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------|---------|
| $\Delta C_{Dp\alpha 0}$  | increment in profile drag coefficient due to flap deployment on aerofoil at zero incidence, based on aerofoil chord, $c$             |        |         |
| $\Delta C'_{Dp\alpha 0}$ | increment in profile drag coefficient due to flap deployment on aerofoil at zero incidence, based on extended chord, $c'$            |        |         |
| $\Delta C'_{L0}$         | increment in lift coefficient due to flap deployment on aerofoil at zero incidence, based on extended chord, $c'$                    |        |         |
| $c$                      | chord of basic aerofoil, see Sketch 1.1(i)                                                                                           | m      | ft      |
| $c'$                     | extended chord of aerofoil plus flap, see Sketch 1.1(ii) and Equation (4.3)                                                          | m      | ft      |
| $c_t$                    | chord of single-slotted flap, see Sketch 1.1(ii)                                                                                     | m      | ft      |
| $\Delta c_t$             | distance from shroud trailing edge to flap nose measured along flap datum, shown positive in Sketch 1.1(ii), see Section 4           | m      | ft      |
| $c'_t$                   | extended chord of flap, see Sketch 1.1(ii) and Equation (4.2)                                                                        | m      | ft      |
| $x_{cmax}$               | chordwise position of maximum camber of basic aerofoil, measured positive aft from leading edge, see Sketch 1.1(i)                   | m      | ft      |
| $\Delta x_t$             | chordwise gap between shroud trailing edge and flap nose, positive as shown in Sketch 1.1(ii), see Section 4                         | m      | ft      |
| $x_{ts}$                 | chordwise position of shroud trailing edge, measured positive aft from aerofoil leading edge, see Sketch 1.1(ii)                     | m      | ft      |
| $\Delta z_t$             | gap between shroud trailing edge and flap nose measured normal to aerofoil datum, positive as shown in Sketch 1.1(ii), see Section 4 | m      | ft      |
| $\delta_t$               | deflection angle of single-slotted flap, positive as shown in Sketch 1.1(ii)                                                         | degree | degree  |

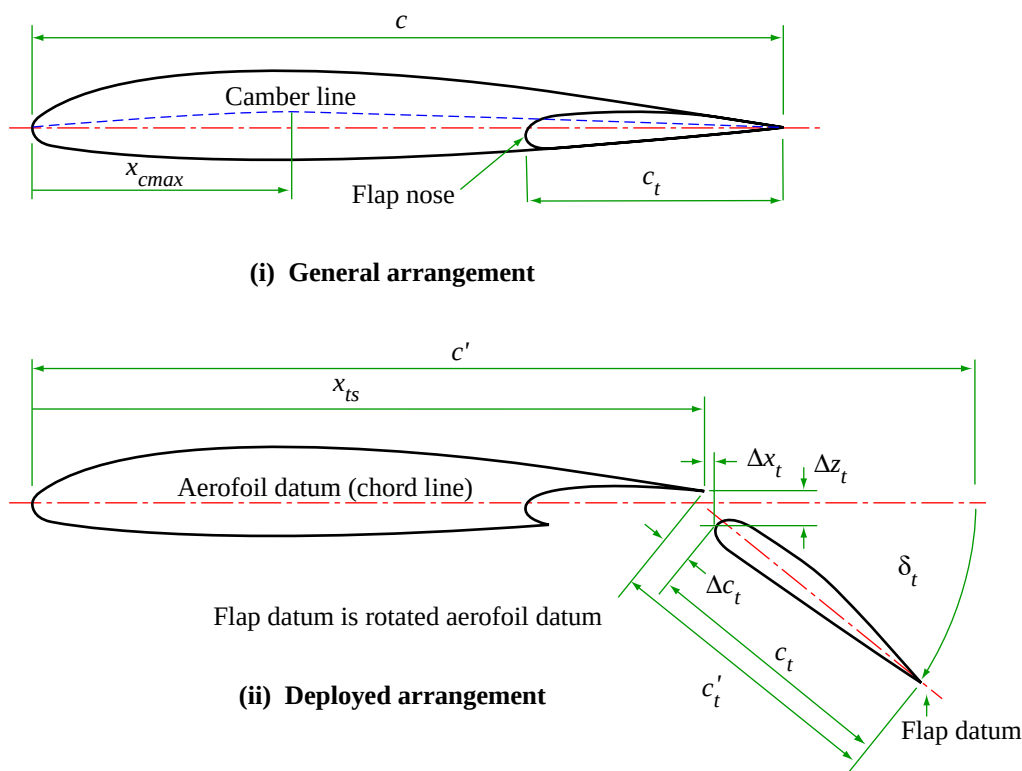
#### Subscripts

$expt$  as in ( ) $_{expt}$  denotes experimental value

$pred$  as in ( ) $_{pred}$  denotes predicted value

Note 'basic' is used to denote the aerofoil with flap undeployed.

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Sketch 1.1

## 2. INTRODUCTION

This Data Item presents an empirical method of determining  $\Delta C_{Dp\alpha 0}$ , the increment in profile drag coefficient due to the deployment of a single-slotted flap on an aerofoil at zero incidence. The method is based on data where the flap slot was optimised for the purpose of maximising lift coefficient at the stall. The method applies at low speeds.

The data are presented as three carpets (Figures 1 to 3) of  $\Delta C'_{Dp\alpha 0}$  in terms of flap deflection angle and extended flap chord ratio. Figure 1 covers a wide intermediate range of  $x_{cmax}/c$ , the dimensionless maximum camber position of the basic aerofoil, whilst Figures 2 and 3 are presented to illustrate the variation of  $\Delta C'_{Dp\alpha 0}$  at forward and aft positions of maximum camber. The basis of the method is outlined in Section 3.

To assist the correlation, it was necessary to base the aerodynamic coefficients on the extended chord,  $c'$ , rather than the basic aerofoil chord. The calculation of  $c'$  and the extended flap chord,  $c'_t$ , is explained in Section 4.

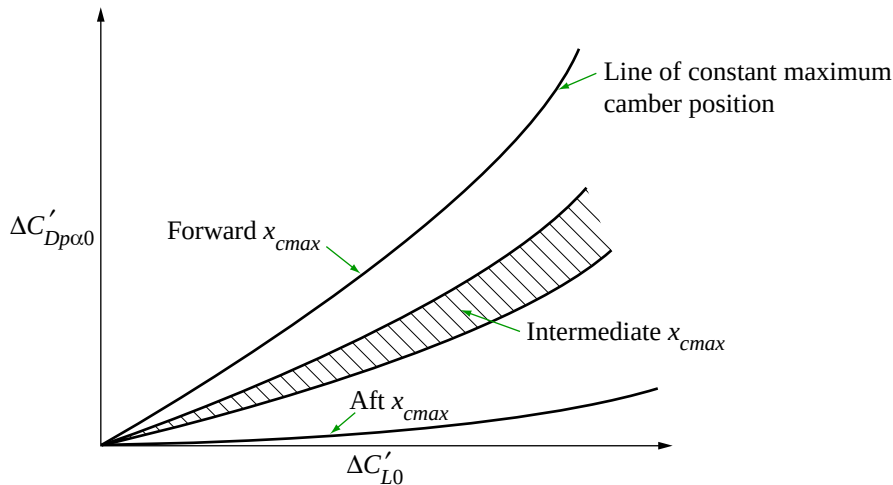
A guide to the accuracy and limitations of the Data Item is given in Section 5. The Derivation and References are given in Section 6. The use of the method is illustrated by means of a worked example in Section 7.

Details of the associated computer program ESDUpac A8705 are provided in Appendix A.

A method for the calculation of the profile drag coefficient increment of wings due to the deployment of single-slotted flaps on wings is given in ESDU 08013 (Reference 19).

### 3. DERIVATION OF THE METHOD

The number of reliable test data for the profile drag of aerofoils with single-slotted flaps was too small to enable a direct parametric study to be made of the effect of geometry and flow conditions. However, it was found that by plotting the data for  $\Delta C'_{Dp\alpha 0}$  against the corresponding lift coefficient increment,  $\Delta C'_{L0}$ , the data for a given position of aerofoil maximum camber,  $x_{cmax}/c$ , tended to correlate as shown in Sketch 3.1.



Sketch 3.1 Variation of  $\Delta C'_{Dp\alpha 0}$  with  $\Delta C'_{L0}$

ESDU 94030 (Reference 17\*) provides a method of estimating  $\Delta C'_{L0}$  in terms of the ratio of the flap extended chord to the aerofoil extended chord,  $c'_t/c'$ , and flap deflection angle,  $\delta_t$ , and it was possible to utilise such estimates in conjunction with the presentation of profile drag coefficient increment in Sketch 3.1 to establish the variation of  $\Delta C'_{Dp\alpha 0}$  with  $c'_t/c'$  and  $\delta_t$ . To do this, for a given  $c'_t/c'$  and  $\delta_t$ , the correlation shown schematically in Sketch 3.1 was entered with the associated estimate of  $\Delta C'_{L0}$  and a value of  $\Delta C'_{Dp\alpha 0}$  read from the ordinate scale for each  $x_{cmax}$  category (forward, intermediate or aft). In this way an initial variation of  $\Delta C'_{Dp\alpha 0}$  with  $c'_t/c'$  and  $\delta_t$  was established for each of the three  $x_{cmax}$  categories across the whole of the range of  $c'_t/c'$  and  $\delta_t$  covered by ESDU 94030.

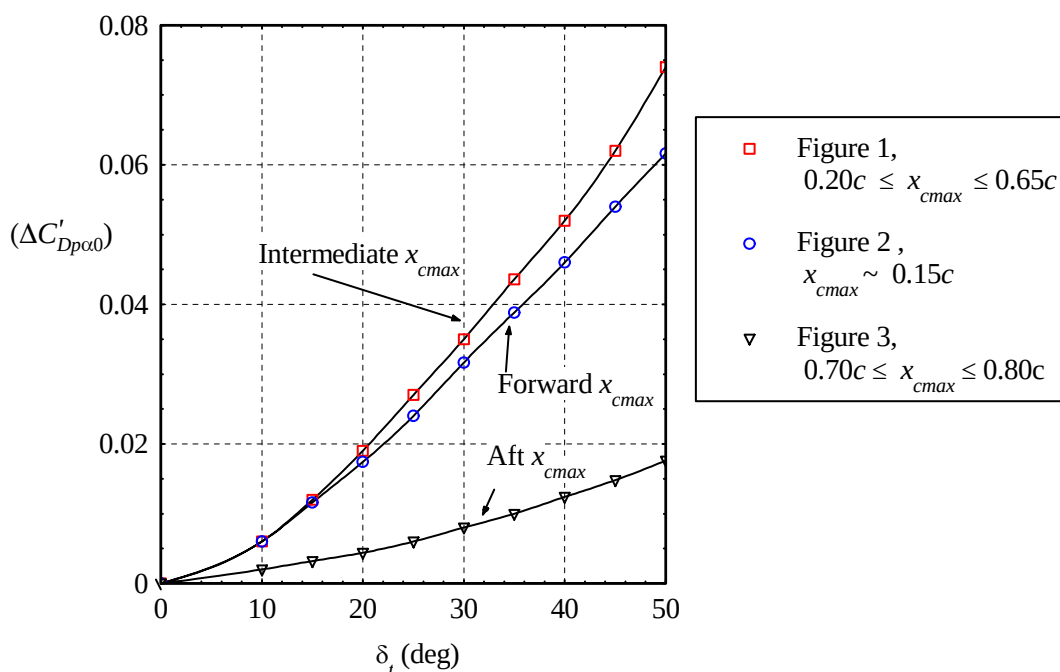
The predictions from those initial variations were then compared with individual experimental data points for  $\Delta C'_{Dp\alpha 0}$  to determine a further necessary correlation factor, which was a function of  $\delta_t$  only, for each  $x_{cmax}$  category. Application of those factors to the initial  $\Delta C'_{Dp\alpha 0}$  variations gave Figures 1 to 3. Note that for given values of  $c'_t/c'$  and  $\delta_t$ , Figure 2 provides rather lower values of  $\Delta C'_{Dp\alpha 0}$  than Figure 1, whilst Figure 3 provides much lower values, see for example Sketch 3.2 which shows the variation with  $\delta_t$  for  $c'_t/c' = 0.2$ . It should be noted that for given  $c'_t/c'$  and  $\delta_t$  the lift coefficient increments associated with the test data used for Figure 2 were rather lower than those used for Figure 1, while those for Figure 3 were significantly higher. This explains the reverse positioning of the data for intermediate and forward  $x_{cmax}$  in Sketch 3.2 in contrast to Sketch 3.1.

After graphical evaluation of  $\Delta C'_{Dp\alpha 0}$  in terms of  $c'_t/c'$  and  $\delta_t$  from Figure 1, 2 or 3, the increment in aerofoil profile drag coefficient at zero incidence is simply

$$\Delta C_{Dp\alpha 0} = \Delta C'_{Dp\alpha 0} \frac{c'}{c'_t} \quad (3.1)$$

The equations of Section 4 may be used to find the extended chords  $c'_t$  and  $c'$ .

\* The method was originally given in ESDU 85033 (Reference 12), now superseded.



**Sketch 3.2 Variation of  $\Delta C'_{Dp\alpha 0}$  with  $\delta_t$  for  $c'_t / c' = 0.2$**

## 4. CALCULATION OF EXTENDED CHORDS

Sketch 1.1(ii) illustrates a single-slotted flap at a location suitable for producing high maximum lift.

The dimensions  $\Delta x_t$  and  $\Delta z_t$  define the position of the flap nose relative to the shroud trailing edge after the flap is deployed. The distance measured parallel to the aerofoil chord line is  $\Delta x_t$  and is positive, as in Sketch 1.1(ii), if there is large rearward translation of the flap so that the flap nose is aft of the shroud trailing-edge. For small translations, where there is an overlap and the flap nose remains forward of the shroud trailing edge,  $\Delta x_t$  is negative, as in the worked example in Section 7. The position of the flap nose below the shroud trailing edge is defined by the distance  $\Delta z_t$  measured normal to the aerofoil chord line, which is positive, as in Sketch 1.1(ii), for all practical configurations.

For a flap deflection angle  $\delta_t$ , the displacement of the flap nose along the flap datum shown in Sketch 1.1(ii) is

$$\Delta c_t = \Delta z_t \sin \delta_t + \Delta x_t \cos \delta_t, \quad (4.1)$$

and this will be positive or negative depending on the values of  $\Delta z_t$ ,  $\Delta x_t$  and  $\delta_t$ .

Alternatively and equivalently,  $\Delta c_t$  may be obtained by measurement from a diagram of the aerofoil with flap deployed. It is the perpendicular distance between two lines drawn normal to the flap datum, one to pass through the flap nose and the other to pass through the shroud trailing edge, see Sketch 1.1(ii). When the line through the flap nose is aft of that through the shroud trailing edge,  $\Delta c_t$  is positive. If the line through the flap nose is ahead of that through the shroud trailing edge,  $\Delta c_t$  is negative.