



ESDU 97002

Issued March 1997
With Amendments A to D
August 2007
Supersedes in part
ESDU 75013

Information on the use of Data Items on high-lift devices

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes in part Item No. 75013, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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INFORMATION ON THE USE OF DATA ITEMS ON HIGH-LIFT DEVICES

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	5
2.1 Presentation of Data	5
3. INCREMENTS IN LIFT COEFFICIENT	6
3.1 Increments at Zero Angle of Attack and in Maximum Lift Coefficient	6
3.1.1 Aerofoils (see Table 3.1)	6
3.1.2 Wings (see Table 3.2)	8
3.2 Lift Curve	8
4. PITCHING MOMENT COEFFICIENT INCREMENT (SEE TABLE 4.1)	11
4.1 Increment at Zero Angle of Attack	11
4.2 Pitching Moment Curve	11
5. DRAG COEFFICIENT INCREMENT (SEE TABLE 5.1)	13
5.1 Zero-lift Drag Coefficient Increment	14
5.2 Lift-dependent Drag Coefficient	15
6. ADDITIONAL DATA (SEE TABLE 6.1)	16
6.1 Plain Flaps Acting as Controls	16
6.2 Aerofoil with slotted flap	17
6.3 Fuselage Interference	17
6.4 Ground Effect	17
6.5 Loads on Flaps and Controls	17
6.6 Gap Effect on Drag of Flaps and Controls	17
6.7 Superseded Items	17
7. REFERENCES	19

INFORMATION ON THE USE OF DATA ITEMS ON HIGH-LIFT DEVICES

1. NOTATION AND UNITS

		SI	British
A	aspect ratio, b^2/S		
a_1	basic wing linear lift-curve slope	rad^{-1}	rad^{-1}
b	wing span, 2s	m	ft
C_D	drag coefficient, $(\text{drag})/qS$		
C_{Dp}	profile drag coefficient		
C_{Dv}	trailing-vortex drag coefficient		
C_{D0}	extrapolated (notional) zero-lift drag coefficient for basic wing (high-lift devices undeployed), see Section 5		
ΔC_{D0}	increment in C_{D0} due to full-span trailing-edge flaps		
ΔC_{D0u}	value of ΔC_{D0} for full-span flaps on unswept wing		
C_L	lift coefficient; $(\text{lift})/qc$ for aerofoil, $(\text{lift})/qS$ for wing		
C_{L1}	lift coefficient due to incidence and any camber or twist		
C_{Lm}	maximum lift coefficient of aerofoil with high-lift devices deployed		
ΔC_{Lm}	increment in aerofoil maximum lift coefficient due to high-lift devices		
ΔC_{Lml}	increment in aerofoil maximum lift coefficient due to leading-edge devices		
ΔC_{Lmt}	increment in aerofoil maximum lift coefficient due to trailing-edge flaps		
C_{LmB}	maximum lift coefficient of basic aerofoil (high-lift devices undeployed)		
C_{LmaxB}	maximum lift coefficient of basic wing (high-lift devices undeployed)		
C_{Lmaxw}	maximum lift coefficient of wing with high-lift devices deployed		

Issued March 1997 - 16 pages
 With Amendments A to D, August 2007 - 22 pages
 This page Amendment D

ΔC_{Lmax}	increment in wing maximum lift coefficient due to high-lift devices
ΔC_{Lmaxl}	increment in wing maximum lift coefficient due to leading-edge devices
ΔC_{Lmaxt}	increment in wing maximum lift coefficient due to trailing-edge flaps
C_{L0}	aerofoil lift coefficient at zero angle of attack with high-lift devices deployed, $C_{L0B} + \Delta C_{L0}$
ΔC_{L0}	increment in aerofoil lift coefficient at zero angle of attack due to deployment of high-lift devices
ΔC_{L0l}	increment in aerofoil lift coefficient at zero angle of attack due to deployment of leading-edge devices
ΔC_{L0t}	increment in aerofoil lift coefficient at zero angle of attack due to deployment of trailing-edge flaps
C_{L0B}	lift coefficient at zero angle of attack for basic aerofoil (high-lift devices not deployed)
C_{L0Bw}	lift coefficient at zero angle of attack for basic wing (high-lift devices not deployed)
C_{L0w}	wing lift coefficient at zero angle of attack with high-lift devices deployed, $C_{L0Bw} + \Delta C_{L0w}$
ΔC_{L0w}	increment in wing lift coefficient at zero angle of attack due to high-lift devices
ΔC_{L0lw}	increment in wing lift coefficient at zero angle of attack due to leading-edge devices
ΔC_{L0tw}	increment in wing lift coefficient at zero angle of attack due to trailing-edge flaps
C_m	aerofoil pitching moment coefficient at angle of attack, (<i>pitching moment</i>)/ qc^2 , referenced to $c/4$
ΔC_m	increment in aerofoil pitching moment coefficient due to angle of attack from value at $\alpha = 0$
C_{m0}	aerofoil zero-lift pitching moment coefficient
C_{mw0}	wing zero-lift pitching moment coefficient
C_{mw}	wing pitching moment coefficient at angle of attack, (<i>pitching moment</i>)/ $qS\bar{c}$, referenced to $\bar{c}/4$
ΔC_{mw}	increment in wing pitching moment coefficient due to angle of attack from value at $\alpha = 0$
$C_{mw\alpha 0}$	wing pitching moment coefficient at zero angle of attack, $C_{mw\alpha 0B} + \Delta C_{mw\alpha 0}$

This page Amendment A

$C_{m\omega\alpha 0B}$	pitching moment coefficient at zero angle of attack for basic wing (high-lift devices undeployed)		
$\Delta C_{m\omega\alpha 0}$	increment in wing pitching moment coefficient at zero angle of attack due to deployment of leading-edge device or trailing-edge flap either separately or in combination		
$\Delta C_{ml\omega\alpha 0}$	increment in wing pitching moment coefficient at zero angle of attack due to deployment of leading-edge device		
$\Delta C_{mt\omega\alpha 0}$	increment in wing pitching moment coefficient at zero angle of attack due to deployment of trailing-edge flap		
$C_{m\alpha 0}$	aerofoil pitching moment coefficient at zero angle of attack, $C_{m\alpha 0B} + \Delta C_{m\alpha 0}$		
$C_{m\alpha 0B}$	pitching moment coefficient at zero angle of attack for basic aerofoil (high-lift devices undeployed)		
$\Delta C_{m\alpha 0}$	increment in aerofoil pitching moment coefficient at zero angle of attack due to deployment of leading-edge device or trailing-edge flap either separately or in combination		
$\Delta C_{ml\alpha 0}$	increment in aerofoil pitching moment coefficient at zero angle of attack due to deployment of leading-edge device		
$\Delta C_{mt\alpha 0}$	increment in aerofoil pitching moment coefficient at zero angle of attack due to deployment of trailing-edge device		
c	aerofoil chord	m	ft
$\bar{c}$	wing aerodynamic mean chord	m	ft
h_0	aerodynamic centre of aerofoil, taken through zero angle of attack, expressed as fraction of c , measured positive aft from $c/4$		
Δh_0	change in h_0 for aerofoil due to deployment of high-lift devices, measured positive aft		
h_{0w}	aerodynamic centre of wing, taken through zero angle of attack, expressed as fraction of $\bar{c}$, measured positive aft from $\bar{c}/4$		
Δh_{0w}	change in h_{0w} for wing due to deployment of high-lift devices, measured positive aft		
h_1	effective centre of lift due to angle of attack for aerofoil, expressed as fraction of c , measured positive aft from $c/4$		
Δh_1	change in h_1 for aerofoil due to angle of attack with high-lift devices deployed, measured positive aft		
h_{1w}	effective centre of lift due to angle of attack for wing, expressed as fraction of $\bar{c}$, measured positive aft from $\bar{c}/4$		

Δh_{1w}	change in h_{1w} for wing due to angle of attack with high-lift devices deployed, measured positive aft		
h_2	centre of incremental lift at zero angle of attack due to trailing-edge flap deflection on aerofoil section expressed as fraction of chord, measured positive aft from aerofoil quarter-chord position		
h_{2l}	centre of incremental lift at zero angle of attack due to leading-edge device deployment on aerofoil section expressed as fraction of basic aerofoil chord, measured positive aft from aerofoil quarter-chord position		
K	constant used in estimation of vortex drag for part-span flaps, see Equation (5.3)		
k_f	vortex drag factor due to flap deflection alone, see Equation (5.4)		
k_1	vortex drag factor due to wing incidence and any camber or twist (with flaps undeflected), see Equation (5.4)		
k_{1f}	vortex drag factor due to interaction between loading due to wing incidence, camber and twist and loading due to flap deflection, see Equation (5.4)		
q	free-stream kinetic pressure	N/m ²	lbf/ft ²
S	wing planform area	m ²	ft ²
s	wing semi-span	m	ft
α	angle of attack	rad, deg	rad, deg
α_{0B}	angle of attack for zero lift of basic wing (high-lift devices not deployed)	rad, deg	rad, deg
α_{0w}	angle of attack for zero lift of wing with high-lift devices deployed	rad, deg	rad, deg
α_{CLmaxw}	angle of attack for C_{Lmaxw}	rad, deg	rad, deg
δ	(1 + δ) is lift-dependent drag factor due to trailing vortex wake		
μ	conversion factor for estimation of ΔC_{D0} for part-span flaps		
τ	section trailing-edge angle	deg	deg

2. INTRODUCTION

This Data Item provides an introductory review of those Data Items in the Aerodynamics Series that deal with the changes in lift, pitching moment and drag of a two-dimensional aerofoil or a wing due to the deployment of high-lift devices.

Section 3 discusses the increments in lift coefficient at zero angle of attack and in maximum lift coefficient due to the deployment of various high-lift devices. The variation of the lift-curve up to the maximum lift coefficient is also addressed.

Section 4 is devoted to the information provided on pitching moment characteristics.

Section 5 discusses the prediction of drag characteristics.

Section 6 refers to some miscellaneous effects treated by other Data Items. In particular, Section 6.1 covers the use of plain trailing-edge flaps as controls.

Section 7 lists the References.

2.1 Presentation of Data

In general, the effects of high-lift devices on the basic aerofoil or wing lift and pitching moment coefficients and on the drag coefficient at zero lift are represented by increments in those quantities caused by a given device deflection. The methods given in the Data Items are largely empirical, being based on extensive wind-tunnel data.

For devices that do not appreciably increase the effective wing area, early tests suggested that the increments were practically independent of the test conditions such as wind-tunnel turbulence and Reynolds number. Provided that the stall region was avoided, a slight variation of the lift and pitching moment coefficient increments with angle of attack could be neglected. For devices that substantially increase the effective wing area, it was found that if the lift and pitching moment coefficient increments were analysed on the basis of the extended area then they too were practically independent of test conditions and varied only slightly with angle of attack. Furthermore, if they were considered as functions of the device deflection angle and the ratio of the device chord to the extended aerofoil or wing chord, they formed a consistent family with the increments of corresponding devices that do not extend the chord. The effect of wing area extension on the profile drag coefficient increments may be neglected provided that the area extension is small. For systems involving large area extensions it is again necessary to base initial calculations on the extended area.

It may be noted that although the increment in wing lift coefficient at zero angle of attack shows a strong dependence on lift-curve slope, the increment in pitching moment coefficient at zero angle of attack is independent of the lift-curve slope. The effect of this is that the centre of lift moves further aft as aspect ratio decreases.

The recent analysis now included in the Data Items shows that the lift coefficient increment at maximum lift coefficient has a Reynolds number dependence. Furthermore, the predictions of the lift and pitching moment coefficients with angle of attack need to include an effect of Reynolds number and a non-linear effect of angle of attack, to provide substantial improvement over the assumption of a linear variation. If the ratio of device chord to wing chord and the dimensionless wing section geometry are not constant along the device span, an estimate must be made using a strip theory.

Most Data Items contain an Accuracy and Applicability Section that discusses the reliability of their prediction methods. This should be consulted when each individual Data Item is used. All Data Items contain one or more worked examples.

3. INCREMENTS IN LIFT COEFFICIENT

3.1 Increments at Zero Angle of Attack and in Maximum Lift Coefficient

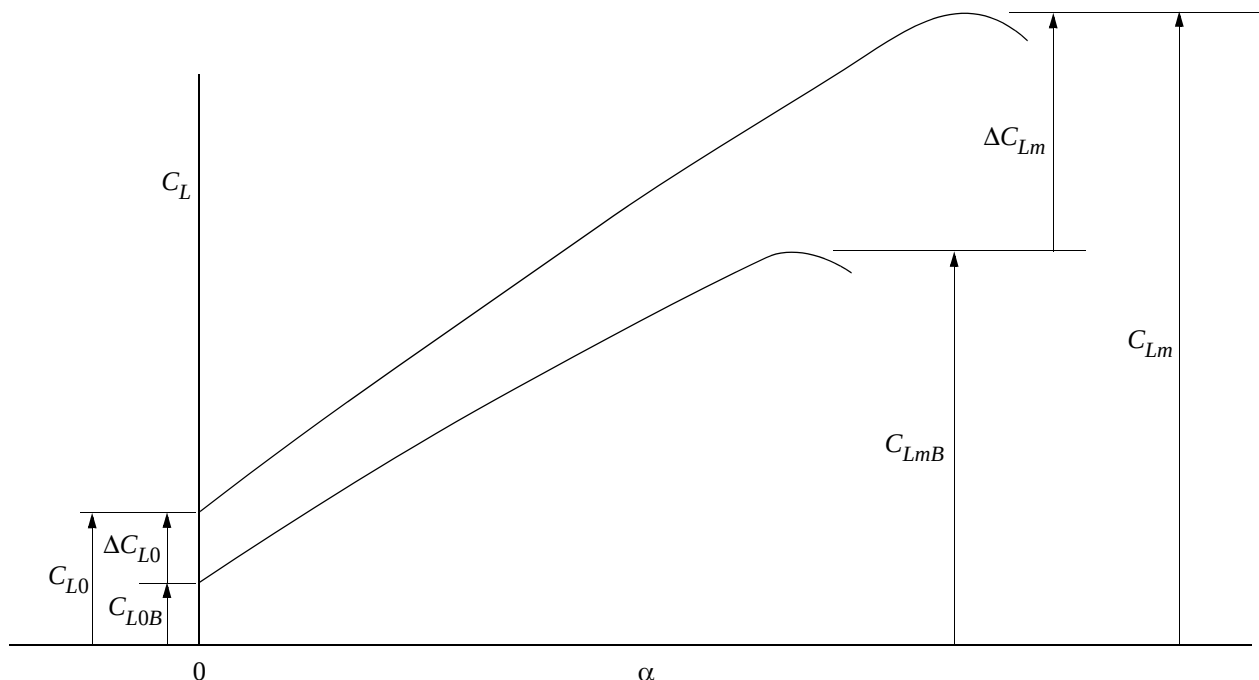
3.1.1 Aerofoils (see Table 3.1)

An introduction to the estimation of the increments in lift coefficient at zero angle of attack and in maximum lift coefficient for aerofoils due to high-lift device deployment at low speeds is provided in Item No. 94026. That Item also discusses stall type and the different characteristics of various types of leading-edge devices and trailing-edge flaps. Data are available in Item No. 94027 for aerofoils with leading-edge devices that include plain leading-edge flaps, drooped leading edges, slats (including sealed slats) and Krüger flaps (including vented Krügers). Data for plain trailing-edge flaps, split trailing-edge flaps and for single-slotted and multiple-slotted trailing-edge flaps, acting alone or in conjunction with leading-edge high-lift devices, are available in Item Nos 94028, 94029, 94030 and 94031, respectively. The increments may be combined with the values predicted for the basic aerofoil in Item No. 84026 to provide total values of the lift coefficient at zero angle of attack and at maximum lift.

$$\text{Thus} \quad C_{L0} = C_{L0B} + \Delta C_{L0} = C_{L0B} + \Delta C_{L0l} + \Delta C_{L0t} \quad (3.1)$$

$$\text{and} \quad C_{Lm} = C_{LmB} + \Delta C_{Lm} = C_{LmB} + \Delta C_{Lml} + \Delta C_{Lmt}, \quad (3.2)$$

as illustrated in Sketch 3.1. (Item No. 94026 provides further qualitative discussion on the different effects of leading-edge devices and trailing-edge flaps of various types.) Table 3.1 shows where methods for predicting the constituent terms of Equations (3.1) and (3.2) may be located.



Sketch 3.1 Build up of C_{L0} and C_{Lm} for aerofoils