



Wing lift coefficient increment at zero angle of attack due to deployment of leading-edge devices at low speeds

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WING LIFT COEFFICIENT INCREMENT AT ZERO ANGLE OF ATTACK DUE TO DEPLOYMENT OF LEADING-EDGE DEVICES AT LOW SPEEDS

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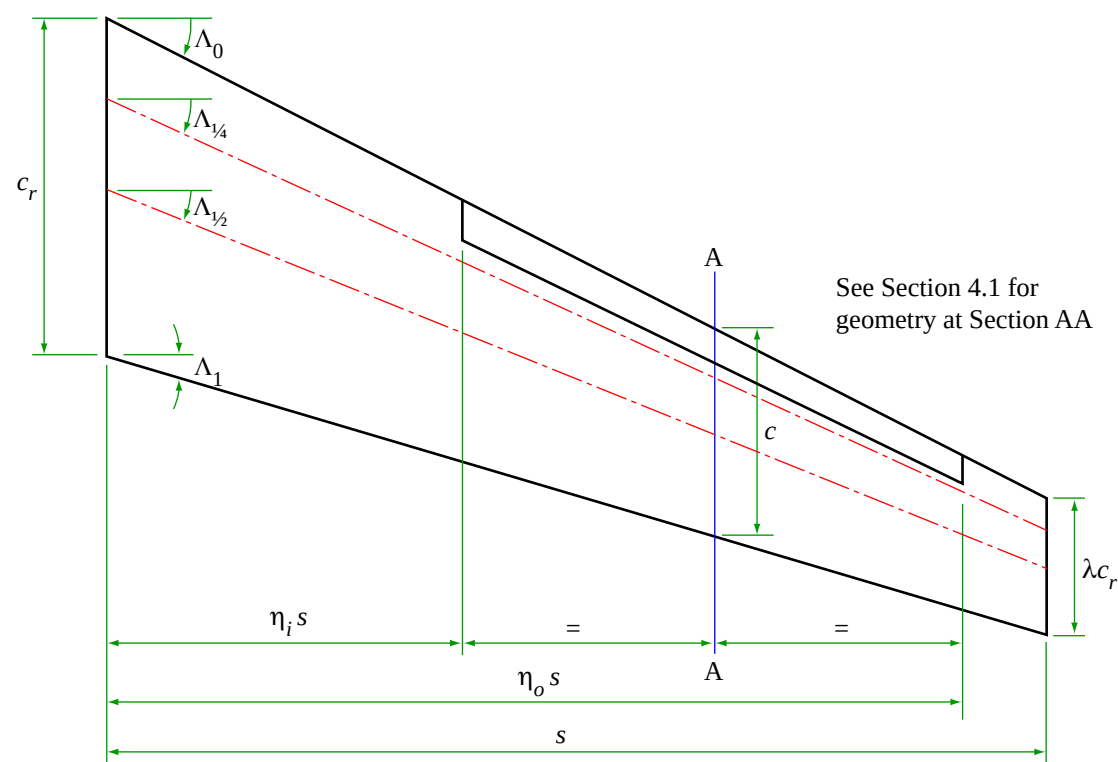
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1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
A	aspect ratio, $2s / \bar{c}$		
a, b	construction lengths in Sketch 4.2	m	ft
a_l	theoretical rate of change of lift coefficient with leading-edge device deflection, Equation (4.3)	rad^{-1}	rad^{-1}
a_1	basic wing lift-curve slope, $dC_L / d\alpha$ (see Item No. 70011)	rad^{-1}	rad^{-1}
C_L	lift coefficient, lift / qS		
ΔC_{L0l}	increment in aerofoil lift coefficient at $\alpha = 0$ due to deployment of leading-edge device, based on c		
$\Delta C'_{L0l}$	increment in aerofoil lift coefficient at $\alpha = 0$ due to deployment of leading-edge device, based on c'		
ΔC_{L0lw}	increment in wing lift coefficient at $\alpha = 0$ due to deployment of leading-edge device, based on S		
ΔC_{L0tw}	increment in wing lift coefficient at $\alpha = 0$ due to deployment of trailing-edge flap, based on S		
c	chord of basic aerofoil chosen to be representative of wing, <i>i.e.</i> chord at mid-span of leading-edge device panel, see Sketch 1.1	m	ft
c'	extended aerofoil chord, <i>i.e.</i> chord with leading-edge device deployed, see Sketches 4.1 to 4.3	m	ft
c_{el}	effective chord of leading-edge device, see Table 4.1	m	ft
c_l	chord of leading-edge device, see Sketches 4.1 to 4.3	m	ft
c_r	wing root (centre-line) chord, see Sketch 1.1	m	ft
$\bar{c}$	wing geometric mean chord	m	ft
$\bar{\bar{c}}$	wing aerodynamic mean chord	m	ft
c'_l	extended chord of leading-edge device, see Sketches 4.1 to 4.3	m	ft
Δc_l	chord extension due to deployment of leading-edge device, see Sketches 4.1 to 4.3	m	ft

H_l	height of slat or vented Krüger flap trailing edge above aerofoil chordline, see Sketch 4.2(a) or 4.2(b)	m	ft
K_0	correlation factor in Equation (4.2) for $\Delta C'_{L0l}$, dependent on type of leading-edge device, see Table 4.1		
L_l	overlap between deployed slat or vented Krüger flap trailing edge and fixed aerofoil nose, see Sketch 4.2(a) or 4.2(b)	m	ft
M	free-stream Mach number		
q	free-stream kinetic pressure	N/m ²	lbf/ft ²
$R_{\bar{c}}$	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
x	chordwise distance aft from aerofoil leading edge	m	ft
x_l	chordwise location of undeployed slat trailing edge, see Sketch 4.2(a)	m	ft
x_n	chordwise location of fixed aerofoil nose, see Sketch 4.2(a)	m	ft
x_τ	chordwise location of trailing edge of c'_l for deployed Krüger flaps and sealed slats, see Sketches 4.3(a) to 4.3(c)	m	ft
z_h	vertical location of hinge for drooped leading edge, see Sketch 4.1	m	ft
α	angle of attack (angle of incidence in Item No. 83040)	rad	rad
β	compressibility parameter, $(1 - M^2)^{1/2}$		
δ_l, δ_l°	deflection of leading-edge device, see Sketches 4.1 to 4.3 (defined positive for leading edge down)	rad, deg	rad, deg
θ_l	angular parameter related to effective chord of leading-edge device, Equation (4.4)	rad	rad
ρ_l	leading-edge radius of basic (plain) aerofoil, see Sketches 4.1 to 4.3	m	ft
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		
$\bar{\eta}$	value of η at spanwise centre of pressure for loading due to angle of attack, see Item No. 83040		

κ	wing taper parameter in Item No. 83040		
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
$\Lambda_{1/2}$	wing mid-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)		
ψ	part-span factor; lift coefficient increment due to part span leading-edge devices extending symmetrically from wing centre-line divided by lift coefficient increment due to full span leading-edge devices at the same deflection angle and wing angle of attack.		
ψ_i	value of ψ corresponding to η_i , Figure 1		
ψ_o	value of ψ corresponding to η_o , Figure 1		



Sketch 1.1 Wing notation (leading-edge devices undeployed)

2. INTRODUCTION

In this Item the increment in lift coefficient at zero angle of attack due to the deployment of leading-edge devices on a wing is derived from the increment due to the deployment of the leading-edge device on an aerofoil section that is representative of the wing. For wings with full-span leading-edge devices a factor, dependent on planform geometry, is applied to allow for three-dimensional effects. For wings with part-span leading-edge devices additional factors are introduced, that are dependent on the leading-edge device and wing geometry. The empirical correlation factors required in Item No. 94027 to provide a good estimation of the increment in lift due to the deployment of a leading-edge device on an aerofoil were found to need modification when applied to a wing, for some types of device, to account for the closer agreement of the theoretical values.

At low speeds, the increment in lift coefficient at zero angle of attack, ΔC_{L0lw} , due to the deployment of a full-span leading-edge device on a high-aspect-ratio rectangular wing is strongly dependent on the corresponding value, for an aerofoil/leading-edge device combination appropriate to the mid-semi-span location. The main parameters that can influence ΔC_{L0l} are the device angle, the change of aerofoil chord length due to leading-edge device deployment, the effective chord of the device, the device type, the flow Reynolds number and Mach number. For leading-edge devices on wings the additional parameters that can influence ΔC_{L0lw} are the wing planform geometry (aspect ratio, taper ratio and sweep), and the spanwise extent of the device. The effects of wing planform geometry are largely accounted for in terms of their effect on the wing lift slope.

3. REQUIRED DATA ITEMS

The ESDU Data Items that may be required in the use of this Item are:

Data Item No.	Derivation No.	To Determine
70011	1	Wing lift-curve slope
76003	2	Wing planform geometry
83040	3	Wing spanwise centre of pressure location
94027	4	ΔC_{L0l}

4. PREDICTION METHOD

The method of this Item requires the use of the characteristics of the representative aerofoil/leading-edge device combination, based on Item No. 94027, but with adjustments to the device-type dependent empirical correlation factors, coupled with empirical corrections for the effects of wing planform geometry, and spanwise extent. Because of these adjustments, all of those parts of Item No. 94027, required in the estimation of ΔC_{L0l} , are included in this Item. It is therefore unnecessary to refer to Item No. 94027 unless further background information is required.

The aerofoil/leading-edge-device combination that is taken as representative of the wing/leading-edge device system is that at the mid-span of the device panel, see Sketch 1.1. By this means the effects of any spanwise variation of either the aerofoil section or the leading-edge-device chord ratio are averaged out.

This Item contains a dedicated part-span factor that is dependent, in addition to leading-edge device spanwise extent, on the spanwise position of the centre of pressure of the loading due to angle of attack for the plain wing.

The method requires the use of streamwise section and leading-edge device geometries and angles, see Sketches 4.1 to 4.3. The primary effects of wing planform geometry in terms of aspect ratio, taper ratio and sweep are realised through their influence on the wing lift-curve slope.

4.1 Determination of ΔC_{L0l}

The general expression for the increment in lift coefficient at zero angle of attack due to the deployment of a leading-edge device on an aerofoil is

$$\Delta C_{L0l} = (c'/c) \Delta C'_{L0l} \quad (4.1)$$

where $\Delta C'_{L0l}$ is the increment in aerofoil lift coefficient at zero angle of attack based on the extended chord length c' , and is given by

$$\Delta C'_{L0l} = K_0 a_l \delta_l \quad (4.2)$$

where K_0 is an empirical correlation factor, which is dependent upon the type of leading-edge device. The lift slope, a_l , is the theoretical rate of change of lift coefficient with respect to the deflection δ_l , positive nose down, given by thin-plate theory (Reference 12) as

$$a_l = -2(\theta_l - \sin \theta_l) \quad (4.3)$$

$$\text{where } \theta_l = \cos^{-1}(1 - 2c_{el}/c') \quad (4.4)$$

$$\text{and } \sin \theta_l = [1 - (1 - 2c_{el}/c')^2]^{1/2} \quad (4.5)$$

in which c_{el} is the effective chord of the leading-edge device.

Combination of Equations (4.2) to (4.5) gives

$$\Delta C'_{L0l} = -2K_0 \delta_l \left\{ \cos^{-1}(1 - 2c_{el}/c') - [1 - (1 - 2c_{el}/c')^2]^{1/2} \right\}. \quad (4.6)$$