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Aerofoil maximum lift coefficient for Mach numbers up to 0.4

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THE PREPARATION OF THIS DATA ITEM

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The technical work involved in the initial assessment of the available information and the construction and subsequent development of the Item was carried out under contract to ESDU by Mr C.D. Hollis and Mr R.G. Williams of British Aerospace plc, Aircraft Group, Bristol.

AEROFOIL MAXIMUM LIFT COEFFICIENT FOR MACH NUMBERS UP TO 0.4

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AEROFOIL MAXIMUM LIFT COEFFICIENT FOR MACH NUMBERS UP TO 0.4

1. NOTATION AND UNITS

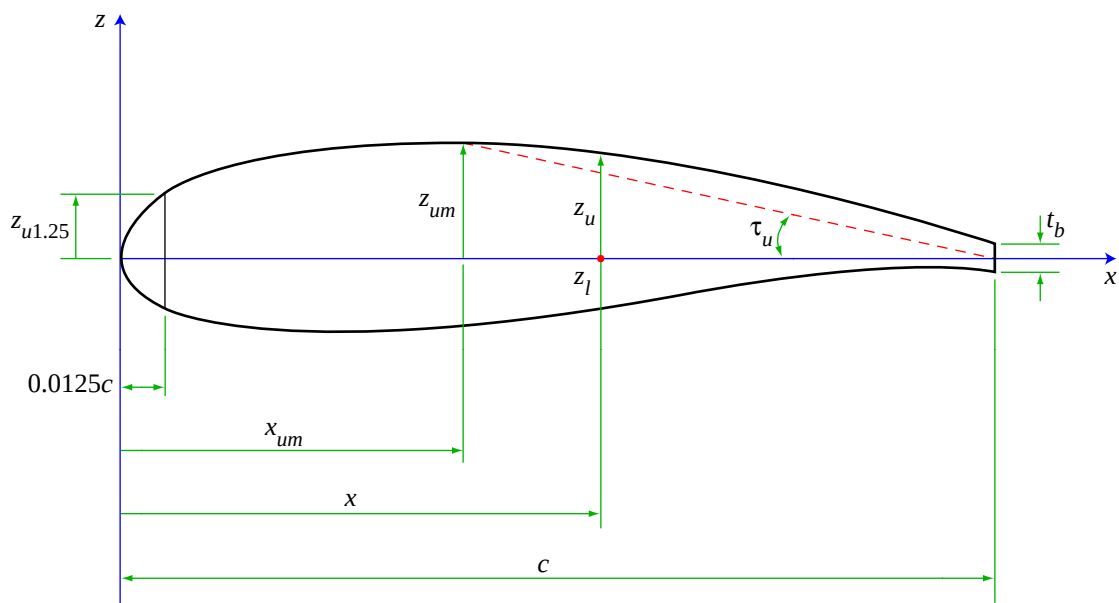
		<i>SI</i>	<i>British</i>
$(a_1)_0$	slope of lift coefficient curve with incidence for aerofoil in incompressible flow	rad^{-1}	rad^{-1}
B_i	coefficients used in estimation of α_0 with $i = 1$ to 14 in Equation (5.1)	rad	rad
C_{Lm}	maximum lift coefficient of aerofoil		
C_{L0}	lift coefficient at zero incidence, Equation (5.3)		
ΔC_L	increment in lift coefficient (see Section 2.2)		
c	aerofoil chord	m	ft
F_1, F_2	parameters in Equation (7.1)		
F_M	factor for effect of Mach number on C_{Lm} (Equation (7.1))		
F_S	factor on C_{Lm} for modern aerofoils in Figure 5		
M	free-stream Mach number		
R_c	Reynolds number based on free-stream conditions and aerofoil chord		
t	maximum thickness of aerofoil	m	ft
t_b	trailing-edge base thickness (see Sketch 1.1)	m	ft
x	chordwise distance measured from aerofoil leading edge, positive rearwards	m	ft
x_{um}	value of x at which z_{um} occurs (see Sketch 1.1)	m	ft
z	aerofoil ordinate measured normal to chord, positive upwards (see Sketch 1.1)	m	ft
z_{ci}	aerofoil camber ordinate with $i = 1$ to 14 in Equation (5.1)	m	ft
z_l	lower-surface ordinate (see Sketch 1.1)	m	ft

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$z_l(x/c)$	lower-surface ordinate at x/c	m	ft
z_u	upper-surface ordinate (see Sketch 1.1)	m	ft
z_{um}	maximum upper-surface ordinate (see Sketch 1.1)	m	ft
$z_u(x/c)$	upper-surface ordinate at x/c	m	ft
$z_{u1.25}$	upper-surface ordinate at $x/c = 0.0125$	m	ft
α	incidence	rad	rad
α_0	zero-lift incidence, Equation (5.1)	rad	rad
τ_u	aerofoil upper-surface angle defined by Equation (3.1), see also Sketch 1.1	rad	rad



Sketch 1.1 Aerofoil geometry

2. INTRODUCTION

At low speeds the two-dimensional flow over an aerofoil normally remains attached at small incidences and the increase of lift with incidence is effectively linear, so that the lift coefficient at any incidence is given by the product of the lift-curve slope, $(a_1)_0$, and the incidence from zero lift, $(\alpha - \alpha_0)$. The variation of lift with incidence remains essentially linear until the onset of flow separation at a particular incidence, which is dependent on the free-stream conditions and aerofoil geometry. Further increase in incidence results in greater extents of flow separation and reduction in the slope of the lift-incidence curve until the total lift coefficient of the aerofoil reaches a maximum value (C_{Lm}) and the aerofoil stalls. At still higher incidences the lift is reduced, perhaps catastrophically.

2.1 Types of Stall

There are various types of stall related to where the flow separations occur on the aerofoil. The types of stall can be classified as follows.

- (i) Trailing-edge stall, resulting from a trailing-edge flow separation which moves forward with increasing incidence.
- (ii) Leading-edge stall, resulting from a sudden separation of the laminar boundary layer near the leading edge, due to the bursting of a small bubble, which generally occurs without subsequent flow reattachment.
- (iii) Thin-aerofoil stall, which is due to a leading-edge separation reattaching to form a separation bubble. The reattachment point moves progressively aft with increasing incidence.
- (iv) A combined trailing-edge and leading-edge stall.

Further details of these types of stall and the effect on the aerofoil force characteristics can be found in Derivations 4 and 7, and Reference 22.

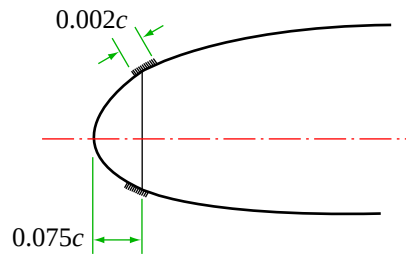
For low speeds, and for aerodynamically smooth aerofoils, the type of stall has been found (Derivation 4) to depend on the Reynolds number and the value of the upper-surface ordinate of the aerofoil at the 0.0125 chord location, $z_{u1.25}$ (see Sketch 1.1).

For the correlation of aerofoil maximum lift coefficient it has been found necessary to consider the aerofoils in only two groups, those with $z_{u1.25}/c < 0.017$ and those with $z_{u1.25}/c \geq 0.017$. These groups can be considered to contain aerofoils with predominantly leading-edge and trailing-edge stalls, respectively. Accordingly, the experimental values of C_{Lm} for the two groups have been correlated using leading-edge and trailing-edge geometrical parameters, respectively.

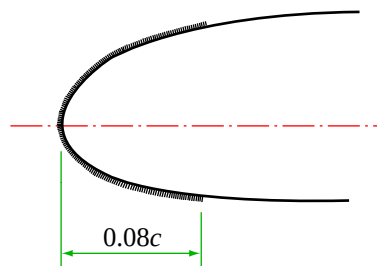
2.2 Scope of the Item

The main parameters that influence C_{Lm} are aerofoil geometry, surface condition (*i.e.* smooth or rough), Reynolds number and Mach number. Maximum lift coefficients are presented in terms of incremental lift coefficients, ΔC_L , added to the lift coefficient at zero incidence, C_{L0} , which is useful in its own right as a measure of the effect of camber on lift. This approach was adopted to account for the main influence of aerofoil camber on maximum lift so that data for cambered and symmetrical aerofoils could be considered together. Procedures for obtaining ΔC_L are given in Sections 3 and 4 for aerofoils with smooth and rough leading edges, while the procedure for obtaining C_{L0} is given in Section 5 and requires a detailed knowledge of the aerofoil geometry.

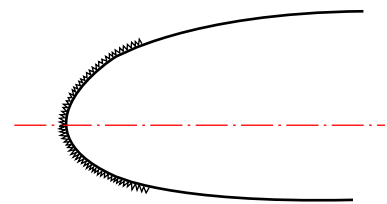
For the purposes of this Item a smooth aerofoil is defined as one with either no leading-edge roughness (*i.e.* natural boundary-layer transition) or with a small band of minimum roughness just sufficient to fix transition. This is the common practice for present day wind-tunnel tests; NASA, for example, use roughness boundary layer trips as illustrated in Sketch 2.1. A rough leading edge can be considered as similar to that obtained with ice formation or similar to that corresponding to the extent and size of roughness grains commonly used to fix boundary-layer transition in wind-tunnel tests of aerofoils at NACA some years ago, see Sketch 2.2a. Thus the data of Section 4, compared to those of Section 3, can be used as an indication of the loss in C_{Lm} due to ice formation.



Sketch 2.1 Small-grain roughness for fixing boundary-layer transition in NASA tests (typically 0.0042 inch carborundum grains for a 24 inch chord model)



Sketch 2.2a



Sketch 2.2b

(a) Large-grain roughness for fixing boundary-layer transition in NACA tests (typically 0.011 inch carborundum grains for a 24 inch chord model, covering 5 to 10 per cent of treated surface area)

(b) Ice formation

A factor is given in Section 6 that has to be applied for modern, rear-loaded, aerofoils which terminate with a small trailing-edge base thickness and incorporate large rear camber as illustrated in Sketch 1.1. Finally, the effect of Mach number on C_{Lm} , for $M \leq 0.4$, is obtained from Section 7.

To apply the method presented in this Item various aerofoil geometrical parameters are required that are defined with respect to the aerofoil chord line. For the purposes of this Item the chord line is defined as the straight line connecting the leading and trailing edges. For an aerofoil with a finite base thickness the trailing-edge point is taken as the mid-thickness point. The leading edge is defined as that unique point at which a circle centred at the trailing-edge point is tangential to the aerofoil.

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