

ESDU Wings S.02.04.13

PROFILE DRAG COEFFICIENTS FOR A TWO-DIMENSIONAL BICONVEX AEROFOIL WITH ZERO HEAT TRANSFER AT SUPERSONIC SPEEDS

1. NOTATION AND UNITS

		SI	British
C_D	total drag coefficient (total drag per unit span)/($\frac{1}{2}\rho V^2 c$)		
C_{Df}	skin friction drag coefficient (skin friction drag per unit span)/($\frac{1}{2}\rho V^2 c$)		
C_{Dp}	profile drag coefficient (profile drag per unit span)/($\frac{1}{2}\rho V^2 c$)		
C_{Dw}	wave drag coefficient in inviscid flow (wave drag per unit span)/($\frac{1}{2}\rho V^2 c$)		
C_{Dwv}	viscous form drag coefficient (viscous form drag per unit span)/($\frac{1}{2}\rho V^2 c$)		
c	aerofoil chord	m	ft
M	free-stream Mach number		
R	Reynolds number based on aerofoil chord, Vc/ν		
t	maximum thickness of aerofoil	m	ft
V	free-stream velocity	m/s	ft/s
x_t	distance of transition point aft of leading edge	m	ft
ν	free-stream kinematic viscosity	m ² /s	ft ² /s
ρ	free-stream density	kg/m ³	slug/ft ³

2. NOTES

In Figures 1 and 2 the profile drag coefficient, C_{Dp} , is plotted against the distance of the transition point from the leading edge for two-dimensional biconvex aerofoils, of thickness/chord ratio $t/c = 0.05$ and 0.10 respectively, for a series of values of Reynolds number and Mach number. It is assumed that there is no heat transfer occurring to or from the aerofoil. The profile drag coefficient, C_{Dp} , is defined (see Item No. Aero W.S.00.03.03) by $C_{Dp} = C_{Df} + C_{Dwv}$, where C_{Df} is the skin friction drag coefficient which is due to the viscous shear stress at the surface of the wing and C_{Dwv} is the viscous form drag coefficient which is due to the effect of the boundary layer in changing the pressures on the aerofoil surface from those predicted by inviscid flow theory.

To obtain the total drag coefficient, C_D , of the aerofoil, the inviscid flow wave drag coefficient, C_{Dw} , must be added to the profile drag coefficient; thus $C_D = C_{Dw} + C_{Dp}$. Methods of calculating C_{Dw} are described in Item No. Aero W.S.00.03.03, but it should be noted that it is unnecessary to make any further allowance for the effect of the boundary layer in calculating C_{Dw} since such allowance is made by the viscous form drag in the sum for profile drag.

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Figures 1 and 2 are based on the calculations made in Derivation 1 together with further calculations for boundary layer displacement effects on the external velocity distribution.

Similar data for a flat plate are given in Item No. Aero W.S.02.04.12 and information given in that Item may, if necessary, be used to assist interpolation for thickness/chord ratios less than 0.05. It may be noted that for a flat plate $C_{D_{wv}}$ is zero; hence $C_{Dp} = C_{Df}$ in this case.

The data can be used for wings of finite span except that, within the region covered by the tip Mach cones, the pressure distribution on the wing will differ from the two-dimensional pressure distribution and there may be a corresponding difference from the two-dimensional profile drag.

3. DERIVATION

The Derivation lists selected sources of information that have assisted in the preparation of this Item.

1. YOUNG, A.D.
KIRKBY, S. The profile drag of biconvex and double wedge wing sections at supersonic speeds. Proceedings of the NPL Symposium on boundary layer effects in aerodynamics. HMSO, 1955.

4. EXAMPLE

Find the total drag coefficient of a two-dimensional aerofoil of biconvex section of 4 per cent thickness/chord ratio at a Mach number of 2.5 and Reynolds number of 10^7 at zero incidence assuming that transition occurs at mid-chord.

From Figures 1b and 2b, with $R = 10^7$, $M = 2.5$ and $x_t/c = 0.5$,

$$C_{Dp} = 0.00216 \text{ for } t/c = 0.10 \text{ and } C_{Dp} = 0.00247 \text{ for } t/c = 0.05.$$

Also, from Item No. Aero W.S.02.04.12, for a flat plate

$$C_{Df} = C_{Dp} = 0.00273 \text{ for } t/c = 0.$$

Hence, interpolating for $t/c = 0.04$, $C_{Dp} = 0.0025$

Using the second-order theory given in Item No. Aero W.S.00.03.04, the wave drag coefficient in inviscid flow for this aerofoil section at zero incidence and a Mach number of 2.5 is

$$C_{Dw} = 0.0037.$$

Hence the total drag coefficient

$$\begin{aligned} C_D &= C_{Dw} + C_{Dp} \\ &= 0.0037 + 0.0025 \\ &= 0.0062. \end{aligned}$$