

ESDU Wings S.00.03.05

THE CALCULATION OF THE THEORETICAL CHARACTERISTICS OF TWO-DIMENSIONAL AEROFOILS AT SUPERSONIC SPEEDS

1. NOTATION AND UNITS

		SI	British
C_{Dw}	wave drag coefficient		
C_L	lift coefficient		
C_N	force coefficient normal to chord line		
C_x	force coefficient parallel to chord line		
c	aerofoil chord	m	ft
M	Mach number		
p	static pressure	N/m ²	lbf/ft ²
t	maximum thickness of aerofoil	m	ft
V	airspeed	m/s	ft/s
α	incidence of aerofoil	degree	degree
δ	flow deflection, positive for compression	degree	degree
ρ	air density	kg/m ³	slug/ft ³

Subscripts 1 to 5 are used to define regions in which many of the notational quantities apply (see sketches in Figures 1 and 2 and in the Example).

2. NOTES

The flow past a two-dimensional aerofoil at supersonic speeds may be readily calculated, provided that the nose shock wave is attached, by the use of data on shock waves, and on simple-wave flow (Item Nos Aero S.00.03.08 and 09). However, as the aerodynamic coefficients are derived from pressure differences on the surface of the aerofoil, it is difficult, when the flow deflections are small, to obtain these coefficients to the desired degree of accuracy from conventional plots of the data such as are given by the aforementioned Items. The curves in this Item are, therefore, restricted to small flow deflections and the parameters used are appropriate to the particular problem of obtaining the distribution of pressure coefficients around the surface of an aerofoil to the required degree of accuracy.

In Figure 1, the pressure coefficient $p_2/(\frac{1}{2}\rho_1 V_1^2)$ which results from an abrupt flow deflection δ_2 is plotted against the initial Mach number M_1 for constant values of δ_2 . Also shown are lines of constant Mach number M_2 .

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These curves are obtained from shock wave data for compressive deflections (δ_2 positive) and simple-wave flow data for expansive deflections (δ_2 negative). Thus, in the particular case of a sharp-nosed aerofoil at supersonic speeds with an attached shock wave, the curves may be used to obtain the pressure coefficients, referred to the free-stream density and velocity, on the surface of the aerofoil just behind the sharp nose and also the Mach number at this point. The conditions for the nose shock wave to be attached are given in Item No. Aero S.00.03.16.

Following the expansive or compressive deflection at the nose, the flow deflections over the remainder of the aerofoil surface are expansive for all conventional aerofoil sections. In Figure 2, the pressure ratio p_3/p_2 is plotted against the Mach number M_2 for negative (i.e. expansive) values of the flow deflection δ_3 . Also shown are lines of constant Mach number M_3 . These curves, which are obtained from simple-wave flow theory, enable the pressure coefficient on the surface of an aerofoil to be determined at points away from the leading edge as

$$\frac{p_3}{\frac{1}{2}\rho_1 V_1^2} = \frac{p_3}{p_2} \frac{p_2}{\frac{1}{2}\rho_1 V_1^2} \quad (2.1)$$

and δ_3 is the flow deflection measured from a direction tangential to the surface at the leading edge.

In calculating the flow past a two-dimensional body, such as an aerofoil section, using the shock-expansion method, it is assumed that there is no interaction between the shock waves and expansion waves which will affect the flow conditions on the surface of the aerofoil. This is not strictly true as the expansion waves will reflect from the shock waves. In general, however, the effect of this secondary system is negligible within the range of Mach numbers covered by this Item.

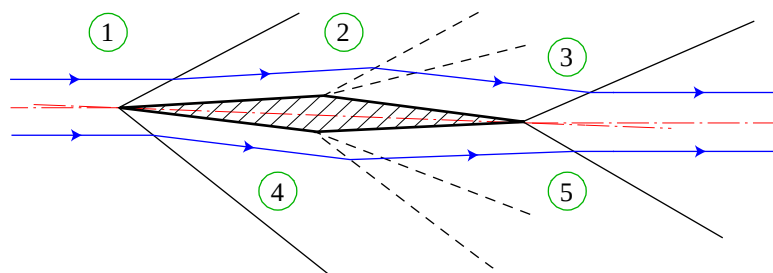
3. DERIVATION

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

1. JOHNS HOPKINS UNIVERSITY Handbook of supersonic aerodynamics. Vol. 2, Navord Rep. 1488, 1950.
2. ROSENHEAD, L. (Ed.) *Compressible airflow: tables*. Clarendon Press, 1952.

4. EXAMPLE

Find the lift and wave drag coefficients for a symmetrical double-wedge section aerofoil in inviscid flow if the nose angle of the section is 10° , the incidence is $+3^\circ$ and the free-stream Mach number is 2.5. A sketch of the aerofoil is shown in Sketch 4.1.



Sketch 4.1