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Pressure drag of spherically-blunted conical forebodies at zero incidence for Mach numbers of 3 and above

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PRESSURE DRAG OF SPHERICALLY-BLUNTED CONICAL FOREBODIES AT ZERO INCIDENCE FOR MACH NUMBERS OF 3 AND ABOVE

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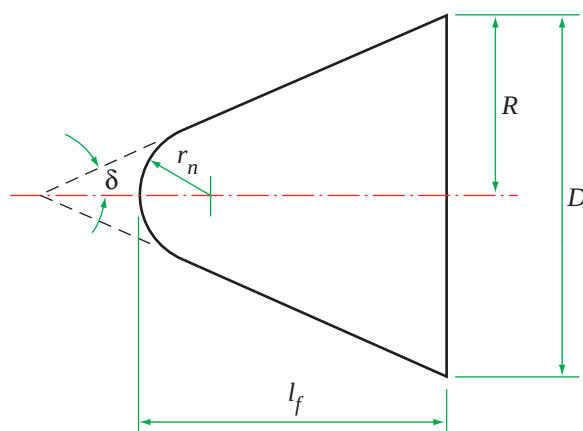
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PRESSURE DRAG OF SPHERICALLY-BLUNTED CONICAL FOREBODIES AT ZERO INCIDENCE FOR MACH NUMBERS OF 3 AND ABOVE

1. NOTATION AND UNITS (see Section 1.1)

		SI	British
C_{Df}	forebody pressure drag coefficient based on base area of cone, (forebody pressure drag) $^{1/2}\gamma p_1 M_1^2 \left(\frac{\pi D^2}{4}\right)$		
C_{Db}	base pressure coefficient, $(p_b - p_1)^{1/2}\gamma p_1 M_1^2$		
C_1	Chapman-Rubesin viscosity coefficient, $\mu_w T_1 / \mu_1 T_w$		
D	base diameter	m	ft
l_f	forebody length	m	ft
M_1	free-stream Mach number		
p_b	base pressure	N/m ²	lbf/ft ²
p_1	free-stream static pressure	N/m ²	lbf/ft ²
R	base radius	m	ft
R_{lf}	Reynolds number based on free-stream flow conditions and forebody length		
r_n	radius of nose blunting	m	ft
T_w	cone wall temperature	K	K
T_1	free-stream static temperature	K	K
γ	ratio of specific heat capacity at constant pressure to specific heat capacity at constant volume, taken as 1.4 for air		
δ	cone semi-apex angle	degree	degree
μ_w	dynamic viscosity at cone wall	kg/m s	slug/ft s
μ_1	free-stream dynamic viscosity	kg/m s	slug/ft s
ρ_n	nose blunting ratio, r_n/R		
$\bar{\chi}_1$	viscous interaction parameter, $M_1^3 (C_1/R_{lf})^{1/2}$		

1.1 Definitions of Geometry



Sketch 1.1

Sketch 1.1 illustrates the geometry of a spherically-blunted cone which can be fully defined in terms of the fineness ratio, l_f/D , the semi-apex angle, δ , and the nose blunting ratio, $\rho_n (= r_n/R)$. The relationship between these parameters is given by

$$\rho_n = \sec\delta(1 + \sin\delta)\left(1 - 2\frac{l_f}{D}\tan\delta\right). \quad (1.1)$$

Figure 1 provides a graphical presentation of Equation (1.1) giving ρ_n as a function of l_f/D and δ . This Figure can be used to determine the amount of blunting required to provide a particular fineness ratio forebody with a cone of given semi-apex angle. With a knowledge of ρ_n and l_f/D the parameter l_f/r_n can be found from

$$\frac{l_f}{r_n} = \frac{2}{\rho_n} \frac{l_f}{D}, \quad (1.2)$$

and curves for given values of l_f/r_n are also shown on Figure 1.

2. INTRODUCTION

This Item provides a means of estimating the forebody pressure drag at supersonic Mach numbers for spherically-blunted cones at zero incidence (see Section 3). The forebody pressure drag arises from the streamwise integration of the pressure distribution over the forebody. In inviscid supersonic flow this is identical to the wave drag arising from the bow shock wave. In real, viscous, flows however, the boundary layer will not only give rise to a drag component of the skin friction but will also modify the forebody pressure drag due to the presence of the viscous displacement surface. However, for a considerable range of flow conditions boundary layer effects have been found to be small (see Section 4.2) and a good approximation to the total forebody drag is obtained by using the data presented in this Item.

3. FOREBODY PRESSURE DRAG

Figures 2a to 2e present the pressure drag coefficient at zero incidence, C_{Df} , for spherically-blunted conical forebodies in terms of the parameters l_f/r_n and δ for free-stream Mach numbers, M_1 , of 3, 4, 6, 10 and ∞ , respectively. The data were obtained from Derivation 2 and had been calculated using the method of characteristics in potential flow. It is seen that for given values of M_1 and l_f/r_n there is a particular value of δ at which C_{Df} is a minimum. A minimum in pressure drag, however, will occur at a lower value of δ than this (corresponding to a minimum in $C_{Df}D^2$). Alternatively, if C_{Df} is plotted against ρ_n for given values of M_1 and l_f/D , there is a particular value of ρ_n that gives a minimum in C_{Df} (and pressure drag).

The data in Figures 2a to 2e are applicable to cones with $\delta \leq 40^\circ$. For large angle cones ($\delta \geq 40^\circ$) Figure 3 presents C_{Df} as a function of M_1 and δ . The data for $\delta \leq 50^\circ$ were obtained from theoretical inviscid flow calculations for sharp cones (Derivation 1). The data for $\delta \geq 60^\circ$ were obtained from integrations of experimental pressure distributions (Derivations 3, 5, 6 and 10) together with theoretical calculations (Derivations 4, 7, 8, 9 and 11) for a free-stream Mach number of 5.9 on cones with nose blunting ratios of 0, 0.25 and 0.5. The latter calculations, reported in Reference 22, show that nose blunting ratios in the range $0 \leq \rho_n \leq 0.5$ have an insignificant effect on the forebody pressure drag for $\delta \geq 60^\circ$. Similar calculations for $\delta = 45^\circ$ in Reference 22, together with the data for $\delta = 40^\circ$ in Figures 2a to 2e, indicate that the data of Figure 3 for $\delta \leq 50^\circ$ are also applicable for $0 \leq \rho_n \leq 0.5$ (see Section 4.).

This Item can be considered as a companion to Item No. 68021 (Reference 20). That Item, which is empirical, gives foredrag (*i.e.* forebody pressure drag *plus* skin friction drag representative of the range of the test conditions, covering a range of Reynolds numbers, R_{lf} , from 1.4×10^5 to 4.1×10^6) for the Mach number range $1 \leq M_1 \leq 5$.

The data in Figures 2a to 2e of the present Item are wholly consistent with the data given in Item No. 68021 in the overlap region $3 \leq M_1 \leq 5$ (largely because Derivation 2 was also used in that Item and had a major influence on the correlations in this Mach number region. The data in Figure 3 are, however, not so consistent, but the larger differences can be accounted for by the scatter of the experimental data, which is particularly large in the region of $\delta = 50^\circ$ (see Section 4).

4. APPLICABILITY AND ACCURACY

4.1 Applicability

The data in Figures 2a to 2e were obtained from calculations (Derivation 2) using the method of characteristics for the inviscid flow of air, with γ taken as 1.4.

The data in Figure 3 for $\delta \leq 50^\circ$ were obtained from similar calculations for sharp cones (Derivation 1) while those for $\delta \geq 60^\circ$ were obtained from a combination of theoretical calculations (Derivations 4, 7, 8, 9 and 11) and integrations of experimental pressure distributions (Derivations 3, 5, 6 and 10). No data were found for the region bounded by the curve for $\delta = 60^\circ$ and the boundary for sonic surface Mach number on sharp cones. Consequently, this region is subject to considerable uncertainty and is shown with broken lines in Figure 3 (see also Section 4.2). The data in Figure 3 are applicable to sharp cones. They are also applicable to spherically-blunted cones provided that $0 \leq \rho_n \leq 0.5$ and provided that values of l_f/r_n or l_f/D are greater than the values in Table 4.1.