An Experimental Observation of the Mach- and Reynolds-Number Independence of Cylinders in Hypersonic Flow†

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The relative independence to Mach and Reynolds number of the flow about a blunt body moving at hypersonic speeds has been implied for quite some time by the use of Newtonian concepts to predict pressure distributions. However, unlike the good agreement of axisymmetric blunt bodies with the modified Newtonian theory,[1, 2] pressure distributions on two-dimensional blunted bodies differ from Newtonian. It is the purpose of this note to present a simple expression for the pressure distribution about a circular cylinder, perpendicular to the flow, which has been derived empirically from a recent series of tests at the Aerodynamic Laboratory of The Ohio State University.

The facilities used for the test were the 4-in. and 12-in. continuous, free-jet, hypersonic wind tunnels of the laboratory[3] fitted with axisymmetric nozzles delivering nominal Mach numbers of 10, 12, and 15, and with an electric-resistance-type air heater delivering stagnation temperatures up to 2500°R. Distributions were obtained from a single orifice in the stainless steel cylinder models by rotating them about their centerline and noting the pressure at appropriate intervals. Model-surface temperatures were measured and showed the cylinders to be essentially isothermal at an average level of 65 percent stagnation temperature.

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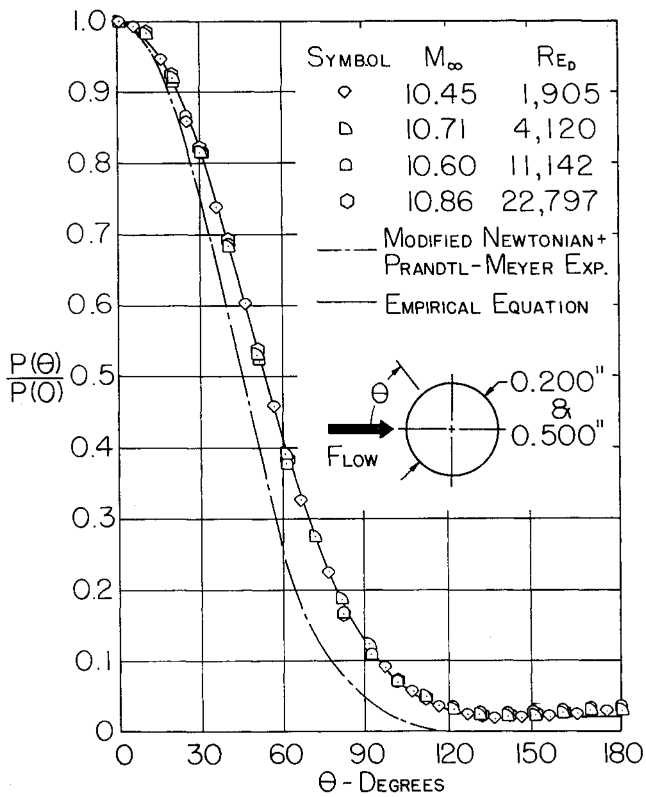

Fig. 1. Reynolds number effect on cylinder pressure distribution.

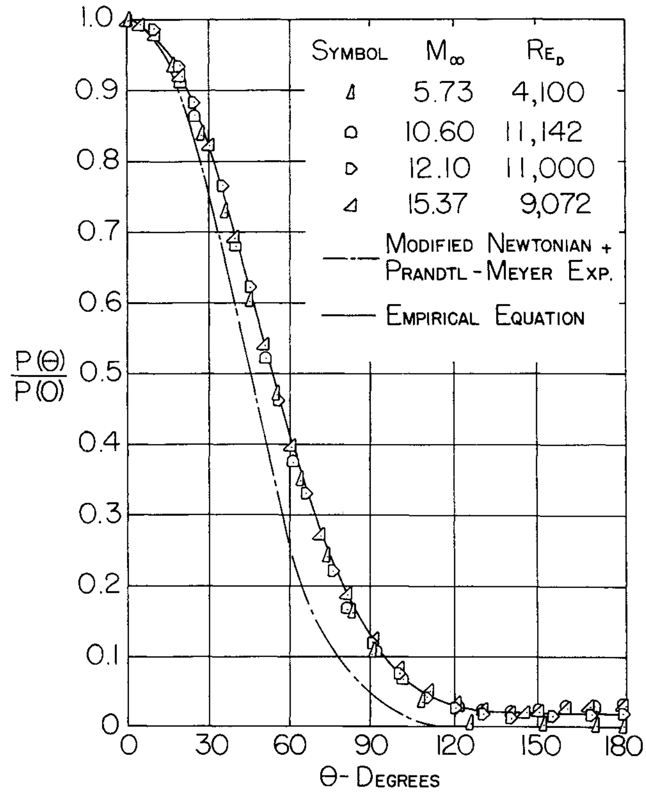

Fig. 2. Mach number effect on cylinder pressure distribution.

Fig. 1 presents pressure distributions obtained at a nominal Mach number of 10 for a range of Reynolds numbers. Fig. 2 illustrates the data obtained from the cylinder at nominal Mach numbers of 10, 12, and 15 at Reynolds numbers on the order of 10,000 based on probe diameter and free-stream conditions. The two figures indicate the relative independence of the pressure distributions to both Mach and Reynolds number. Included in Fig. 2 is the result of a test by Tewfik and Giedt.[4] These authors suggest the use of a cosine series to represent the distributions they obtained on a cylinder in supersonic flow. A slight modification of their expression yields a relation which fits all the data in the range of Mach numbers from 5 to 15 and Reynolds numbers between 1,900 and 23,000 with an average deviation of 0.8 percent and a maximum deviation of 2 percent. The relationship is

$$P(\theta)/P(0) = 0.320 + 0.455 \cos \theta + 0.195 \cos 2\theta + 0.035 \cos 3\theta - 0.005 \cos 4\theta$$

Integration of this expression produces a drag coefficient of 1.314 for the circular cylinder and of 1.365 for a hemi-cylinder. These coefficients are a slight deviation from the Newtonian drag coefficient of 1.333.

When the cylinder expression is compared with the pressure distribution obtained on the hemi-cylindrical nose of a flat plate,[5] good correlation is noted. In Fig. 3, a typical distribution is shown as the plate is pitched from +15° to −10° angle of attack. As can be seen, the agreement is excellent and indicates that the empirical expression can be used to describe the pressure distribution about the nose region of a blunt flat plate at angles of attack.

Summarizing the results of the recent tests, the pressure distributions about circular cylinders are relatively independent of Mach number and Reynolds number in the range tested, but differ substantially from Newtonian. Because of this independence, it is possible to obtain an empirical relationship which describes the pressure distribution about a transverse circular cylinder. This expression has been shown to apply to the nose region of a blunt flat plate at moderate angles of attack, indicating

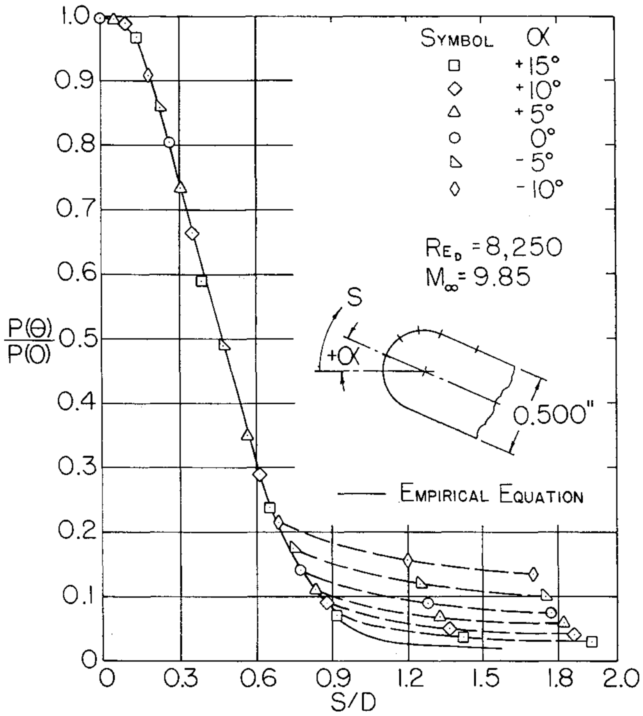

FIG. 3. Pressure distribution about the nose region of a blunt flat plate.

little dependence of the nose pressure distribution upon the afterbody shape for the conditions tested.

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Euler Load of a Stepped Column—An Exact Formula

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SYMBOLS

E_iI_i = rigidity of ith section
l_i = length of ith section
$k_i^2 = P/E_iI_i$
$S_i = k_i \tan k_il_i$
$T_i = \tan k_il_i/k_i$

THE EULER buckling load of the uniform column with the end conditions shown in Fig. 1 is the (lowest) root of the transcendental equation[1]

$$T = l \qquad (1)$$

The method[1] can be extended to the case of the stepped column shown in Fig. 2. For $\eta > 2$ the method is laborious. However it is possible to obtain the corresponding transcendental equation for general n; viz.,

$$\sigma_1 - \sigma_3 + \sigma_5 - \ldots = (1 - \sigma_2 + \sigma_4 - \ldots) \sum_1^n l_i \qquad (2)$$

where

$$\sigma_{2r+1} = \Sigma T_iS_jT_k \ldots S_lT_m \qquad 2r + 1 \text{ factors} \qquad i<j<k<\ldots<l<m$$

and

$$\sigma_{2r} = \Sigma S_iT_j \ldots S_kT_l \qquad 2r \text{ factors} \qquad i<j<\ldots<k<l$$

Eq. (2) may be solved numerically with the aid of tables of the tangent function.

By this method we obtain the Euler buckling load without, in effect, solving for the buckled shape of the column. Again, we obtain the "exact" Euler load and, lastly, the form adduced in Eq. (2) is general. All these are advantages over any energy method.

When n is any specified integer, direct (and laborious) extension of the method[1] can be shown to lead to Eq. (2). However eq. (2) is true for general n.

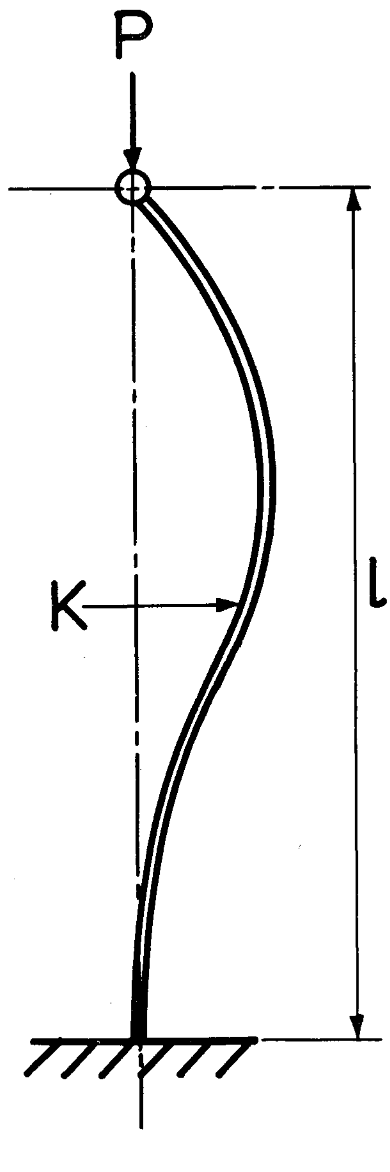

FIG. 1.