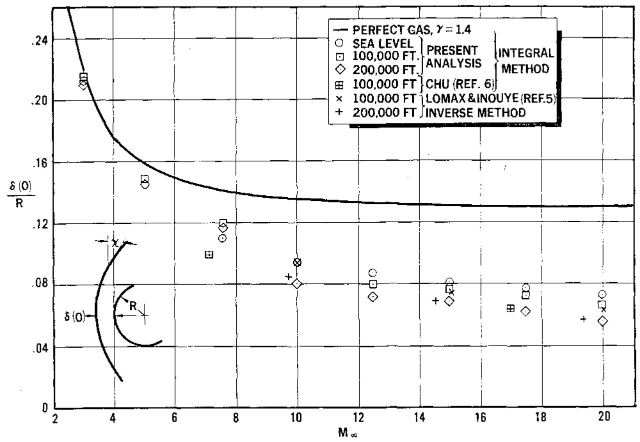

Fig. 2 Shock detachment distance (sphere).

Sphere

As in the perfect gas case, the sphere calculation involves adjustment of the shock detachment distance until the singular behavior of the expression for dv_{s0}/ds is restricted to a sufficiently small neighborhood of the body sonic point. An additional factor, introduced in the equilibrium case, which influences convergence is the smoothness of the thermodynamic data, i.e., slope discontinuities in curve or surface representations of the data are not allowable in the critical sonic region. Since a given Mollier surface is composed of a number of segments "patched" together, discontinuity problems may arise at the boundaries of the segments. Nonconvergent cases were, in fact, encountered for certain free-stream conditions employing both thermodynamic subroutines. The Arnold Engineering Development Center routine was used predominantly for the sphere calculations, owing to its smoother surface transitions.

Figure 2 presents the variation of shock detachment distance with Mach number and altitude for the sphere case. Equilibrium air results are plotted as discrete points, since the nonmonotonic behavior would require a large number of computed cases to establish continuous curves. Inverse method detachment distances[5] are in substantial agreement with present results. Reference 6 also employs the direct integral method; however, the governing equations and thermodynamic procedures differ from those of the present analysis, e.g., the differential equation for the surface velocity [Eq. (6)] is obtained by integration of the unmodified continuity equation.

A comparison of representative sphere pressure distributions is shown in Fig. 3. Perfect gas results for the direct and inverse method were found to coincide closely with respective equilibrium curves and are therefore not indicated.

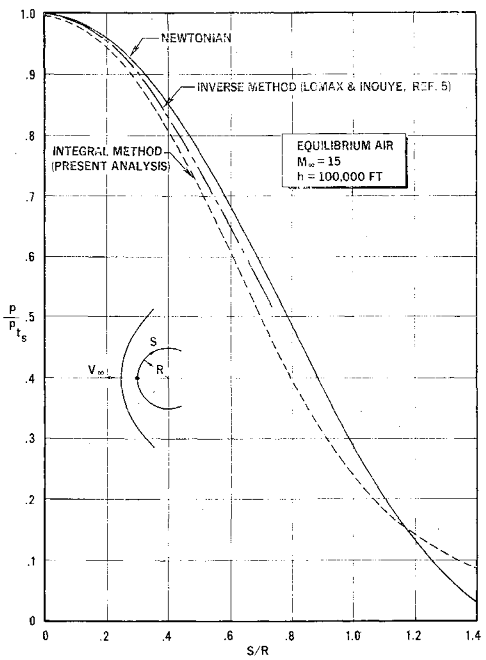

Fig. 3 Surface pressure distribution (sphere).

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Modified Blast-Analogy for the Blunt Flat Plate with Sweep and Attack

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The analogy to an explosion has been applied to simple blunt shapes in hypersonic flow with a moderate degree of success. For an unswept plate at zero angle of attack the

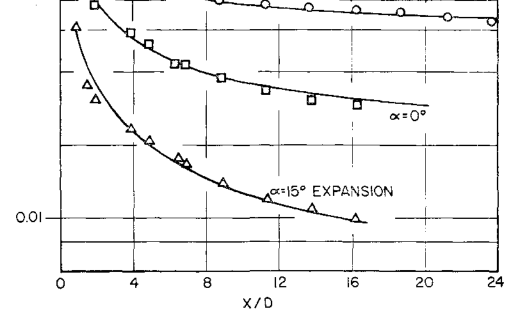

Fig. 1 Pressures on an unswept cylinder-edged flat plate at a Mach number of 7.

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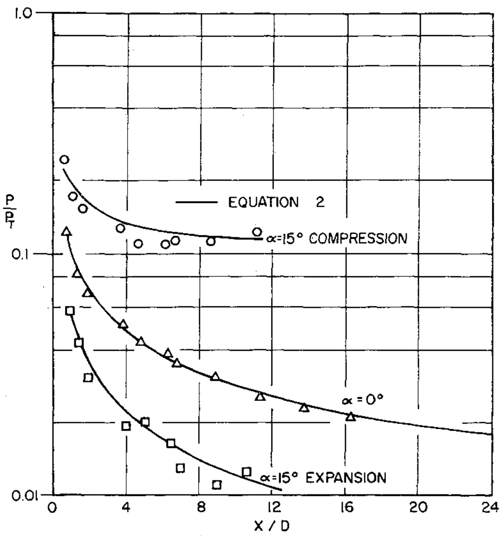

Fig. 2 Pressures on an unswept cylinder-edged flat plate at a Mach number of 12.

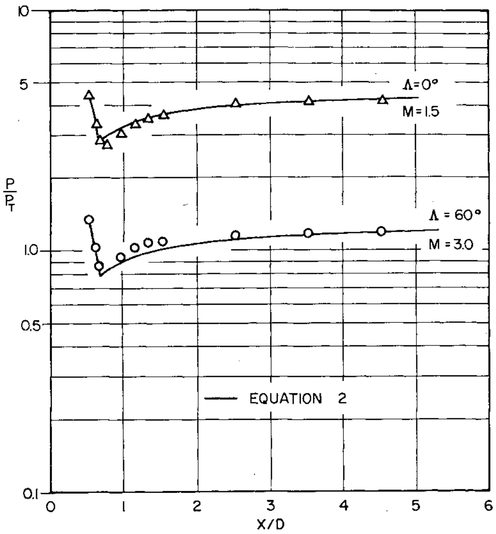

Fig. 4 Pressures on a cylinder-edged 10° wedge at supersonic speeds.

analogy yields for the surface pressure at X from the nose

$$p/p_\infty = F/(X/D)^{2/3} \tag{1}$$

where D is the nose diameter, and F is a function of the specific-heat ratio and the nose-drag coefficient. Through comparisons with experimental measurements and with characteristic theory, the following modifications have been proposed to improve the accuracy of the formula: addition of a constant, movement of the origin for X, and iteration to a higher order; some of these are discussed and evaluated in Ref. 1.

By interpreting X as surface distance from the stagnation point, adding unity on the premise that the pressure eventually decays to the free-flow static pressure, and determining F by matching pressures at the junction between the flat plate and the leading edge (rather than using the blast function), the formula has been found[2] to be in excellent agreement with experiment. The extension to angle of attack and to swept plates is straightforward and the general form can be written

$$p/p_L = K/(X/D)^{2/3} + p_w/p_L \tag{2}$$

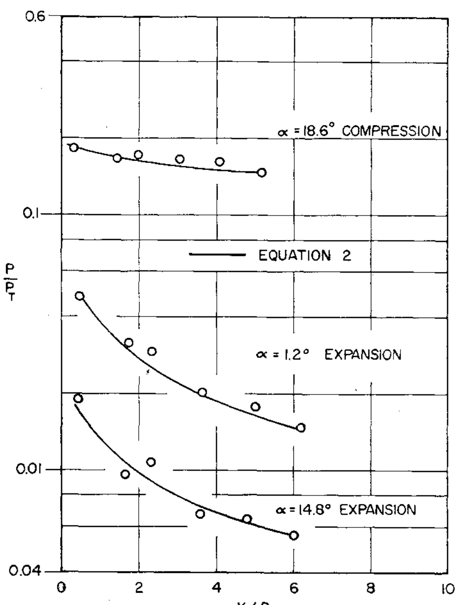

Fig. 3 Pressures on a cylinder-edged flat plate at a Mach number of 14 and sweep angle of 50°; data from Ref. 6.

Here p_L is the leading line pressure, becoming normal-shock stagnation pressure for zero sweep, and p_w is the sharp-wedge pressure. K is determined by the pressure match at the plate-leading edge junction.

For the case of a cylindrical leading edge, the pressure distributions on cylinders are well-established,[3,4] and this information may be used to find K.

Equation (2) is compared with experimental data[5,6] in Figs. 1–3 to show the typical behavior; other comparisons made in Ref. 2 and 6 on blunt plates and delta wings show similar excellent agreement, providing the local surface Mach number is high enough to prevent strong end effects. Figure 4 shows the behavior when the component of Mach number normal to the leading edge is less than about 3; in such cases the wedge pressure becomes higher than the pressure at the junction point.

The procedure does not work for axisymmetric blunt bodies. However, it appears to provide a simple accurate engineering formula for flat-plate flows. As such, it can form a base for examining other effects such as viscous interactions, real-gas effects, end influences, and interference.

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