NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-404

Detailed Pressure Distribution on a Blunted 60-deg Half-Angle Cone at Mach Numbers of 6.08 and 9.46

Donald W. Kurtz

JET PROPULSION LABORATORY
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Approved by:

Bain Dayman, Jr.

Bain Dayman, Jr., *Manager*
Aerodynamic Facilities Section

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Abstract

An investigation of the detailed pressure distribution on a spherically blunted 60-deg half-angle cone was conducted in the hypersonic wind tunnel at the Jet Propulsion Laboratory. Wind tunnel tests on a specially designed model indicated that the pressure coefficient distribution over the surface seemed to be almost independent of Mach number at 6.08 and 9.46. At both Mach numbers, the nose pressure remained within a band of 3% through angles of attack from 0 to 6 deg. Beyond 2 deg, the displacement of the stagnation point from the longitudinal body axis was not a linear function of angle of attack. Although base pressures were measured, they are not included here because support interference yielded questionable data.

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I. Introduction

The requirements for a suitable atmospheric reentry body involve a multitude of trade-offs and compromises that include:

(1) High drag characteristics.

(2) Aerodynamic stability.

(3) Heat dissipation.

(4) Suitable packaging.

The vehicle must exhibit high drag characteristics, so as to utilize the planetary atmosphere for initial deceleration, simultaneously demonstrate a fair degree of stability, and provide suitable packaging for the experiments. At hypersonic speeds, the heat dissipation in the boundary layer, which surrounds the skin of the vehicle, creates extremely high temperatures. This dictates another essential consideration. Highly blunted bodies afford a compromise capable of satisfying the demanding requirements of the vehicle. Wind tunnel studies, performed on a variety of configurations at subsonic, supersonic, and hypersonic speeds, indicate satisfactory drag, stability, and heating characteristics. Because of their geometric simplicity, highly obtuse cones are well suited for this purpose.

To obtain a detailed pressure distribution over the face, edge, and base of a blunted cone, a high-speed test program was undertaken in the 21-in. hypersonic wind tunnel at JPL. The test was conducted at two Mach numbers. At Mach number 6.08, the angle of attack was −8 to +16 deg. At Mach number 9.46, the angle of attack was 0 to +12 deg. The principal results of the investigation[a], derived from testing a model and recording pressure measurements, are summarized.

[a]The complete results of this program are contained in JPL document SR 900-183, available on request to J. Jackson, Support Section Technical Information and Documentation Division, Jet Propulsion Laboratory, Pasadena, Calif.

II. Model

The model consisted of a "sharp edge" 60-deg half-angle cone with a nose bluntness ratio δ of 0.23. The edge was constructed (see Fig. 1) such as to approximate the structural considerations necessary for a full-size cone.

A total of 25 pressure ports (Fig. 1) were installed on the model; 21 on the face, one on the edge, and three on the base. Those on the face were aligned in two complementary rays with staggered radii in order to accomplish a maximum of coverage with a minimum of interference. The edge and three base ports were colinearly aligned with one of the forebody rays, but were in the opposite quadrant.

Two chromium-alumel thermocouples were installed on the model to continually monitor and record local temperatures for thermal-creep[b] considerations. One thermocouple was mounted on the base and one was mounted internally behind the model nose.

The 4-in.-diam stainless steel model was mounted on a 1-in. hollow sting, which housed all 25 pressure tubes and the nose thermocouple, and carried the base thermocouple in such a manner as to allow roll angles of ± 90 deg without any interference or damage to the tubes or thermocouples.

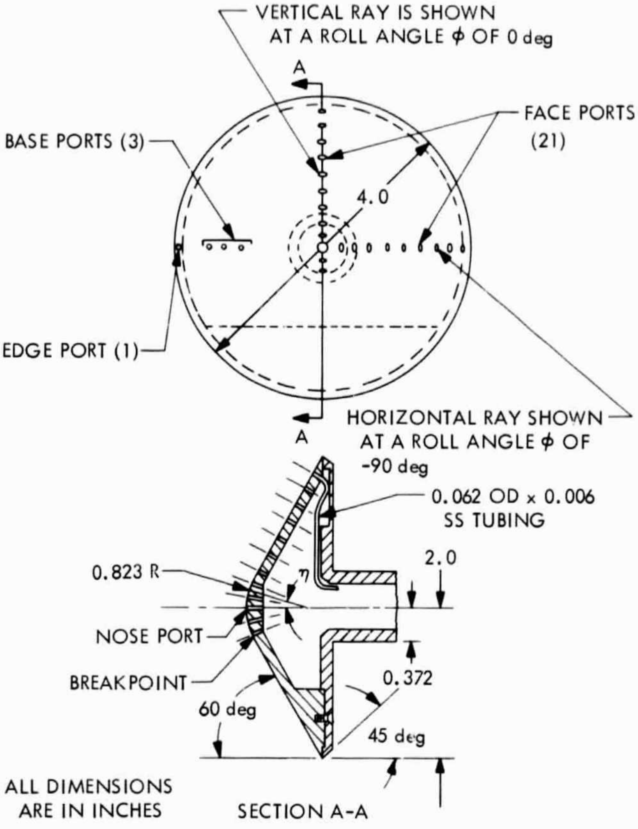

Fig. 1. Test model, front and side views

III. Test Procedure

The investigation was conducted at Mach numbers of 6.08 and 9.46 with Reynolds No./in. of 2.7×10^5 and 1.18×10^5, respectively. The model was sting-supported and had a sting diam-to-model-base-diam ratio of 0.25. The hollow sting, which housed the pressure port tubes and thermocouple leads, was pitched to angles of attack of -8 to $+16$ deg and 0 to $+12$ deg at Mach numbers of 6.08 and 9.46, respectively. To obtain a detailed pressure distribution, the model was rolled through a total of 180 deg at either 30- or 45-deg intervals at each angle of attack. Hence, the two complementary rays were rotated through a common quadrant and these data, when incorporated, resulted in a more detailed radial pressure distribution in this region.

The JPL 100-port multiple pressure measuring system, an updated version of the system described in Ref. 1, was employed to measure and record all surface port pressures. The system was advanced manually to enable the operator to monitor and account for the pressure lag. The pressures at the one edge and three base ports were measured by means of a precision oil micromanometer (Ref. 2) and were subsequently recorded on a digital channel. Settling times for these low pressures were upwards of 5 min. A retractable cooling shield was installed in the tunnel (Fig. 2) to permit model surface cooling by injecting gaseous nitrogen into the flow stream immediately in front of the model. Model cooling was employed near the end of the test to observe possible thermal-creep errors related to the high model-temperature and low base-pressure measurements at the high Mach number (Ref. 3). The entire test was conducted in the 21-inch hypersonic wind tunnel (Ref. 4) at JPL.

IV. Results of Investigation

The results of this cone study are presented in the form of a pressure coefficient as a function of a non-dimensional distance from the nose port. On leeward rays at angles of attack, a characteristic cusp in these curves resulted at the break-point (Fig. 3). The break-

[b]Thermal creep may occur with high temperature, low pressure measurements in small diameter tubes in which the molecule mean free path becomes of the order of the tube diameter. These conditions cause the settled pressure in the tubing to have a higher pressure at the hot end of the model than at the cold end, where the transducer is located.

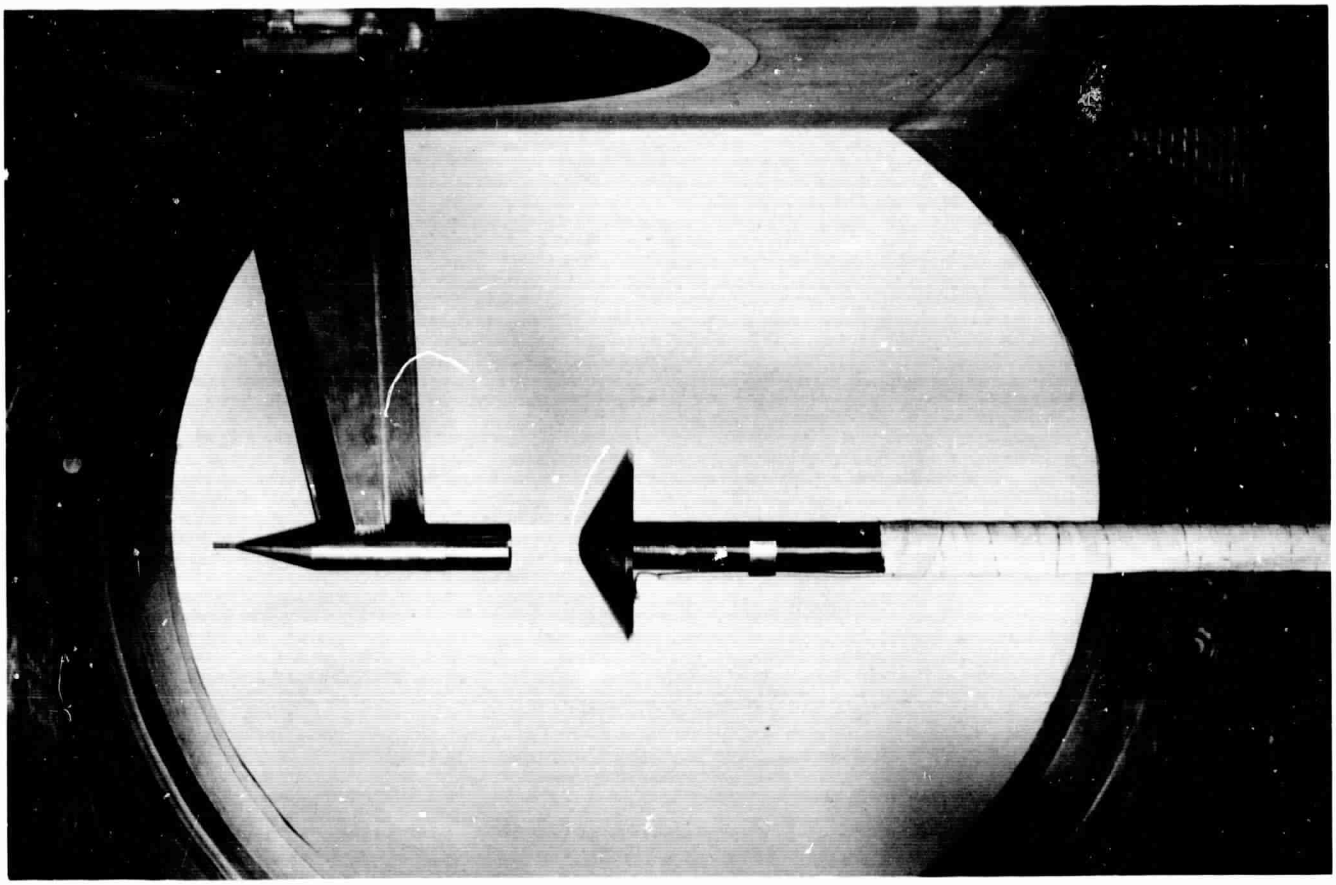

Fig. 2. Test model mounted on 1-in.-diam sting carrying external base thermocouple, with pitot tube-cooling shield down

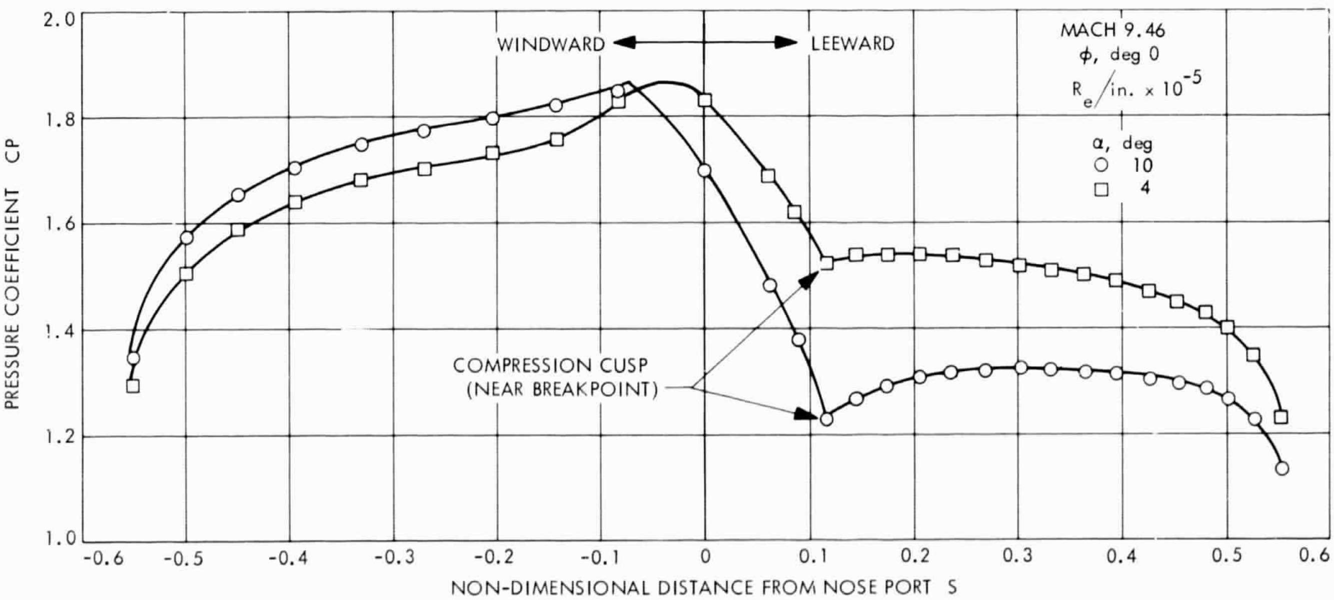

Fig. 3. Pressure distribution along ray, indicating the compression cusp at the leeward breakpoint

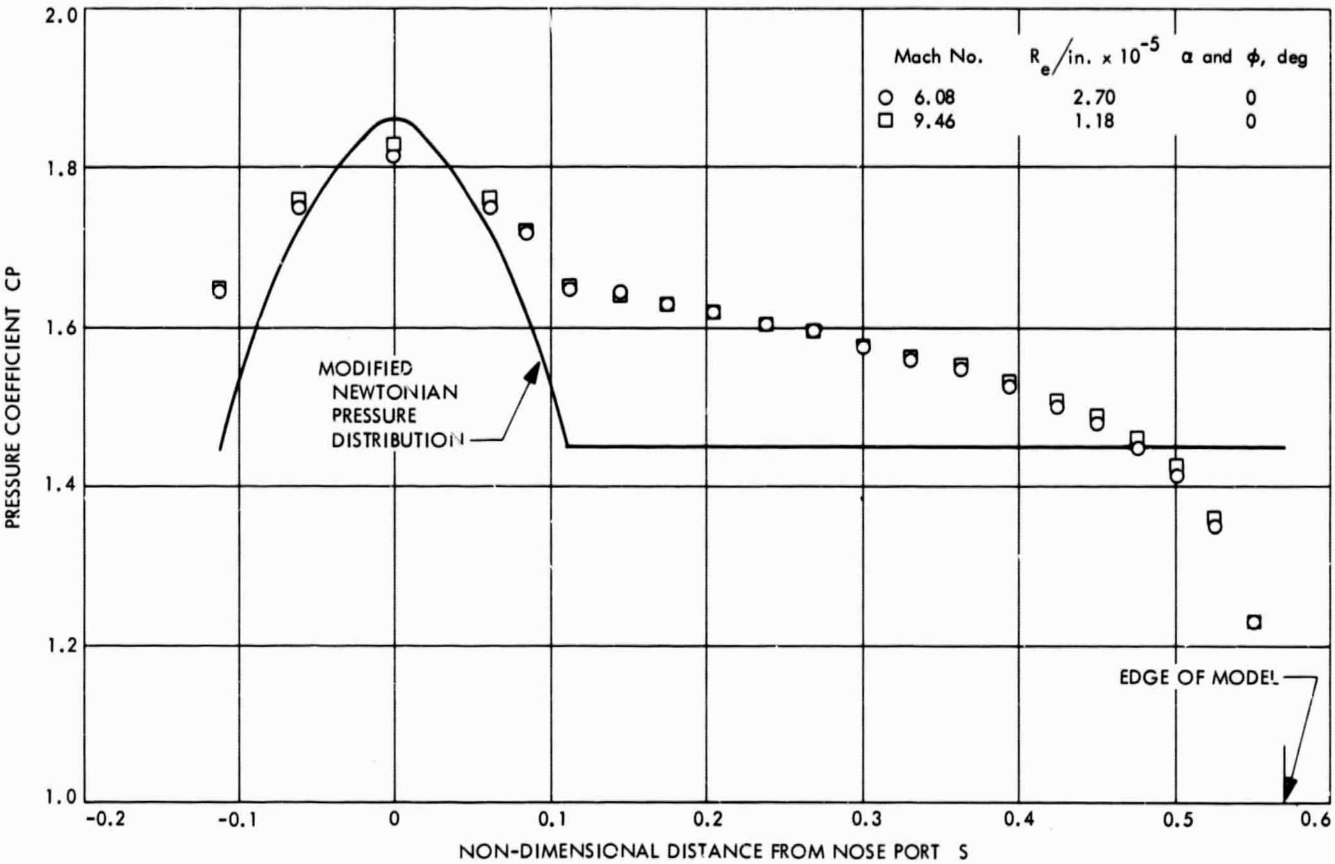

Fig. 4. Comparison of pressure distributions at the two Mach numbers

point is the point (Fig. 1) corresponding to the interface of the spherical nose and conical section. This cusp is the result of an abrupt flow compression at that point; i.e., the flow over the spherical nose acquires angular momentum as it accelerates over the surface. At the interface of the spherical and conical surfaces (Fig. 3), the flow undergoes a compression, which manifests itself in a pressure rise abruptly changing the slope of the pressure coefficient curve at this point. The flow over the face accelerates from a stagnation point near the nose to the sonic point near the sharp edge. In this flow region, the surface pressure is inversely proportional to the square of the local surface velocity. The characteristic negative pressure coefficient gradient over the conical portion of the body is a result of this flow acceleration.

The Mach number variance from 6.08 to 9.46 resulted in a surface pressure coefficient increase of less than 1% at 0-deg angle of attack (Fig. 4). A Newtonian distribution is presented for comparison.

The pressure coefficient on the nose of the cone (Fig. 5) is relatively constant for certain angle-of-attack regions. At angle of attack of −6 deg to +6 deg inclusive, the nose pressure coefficient (S = 0) varies only 2% at Mach number 6.08 and 3% at Mach number 9.46. It is interesting to note that beyond 2 deg (Fig. 6), the displacement of the stagnation point from the longitudinal body axis is

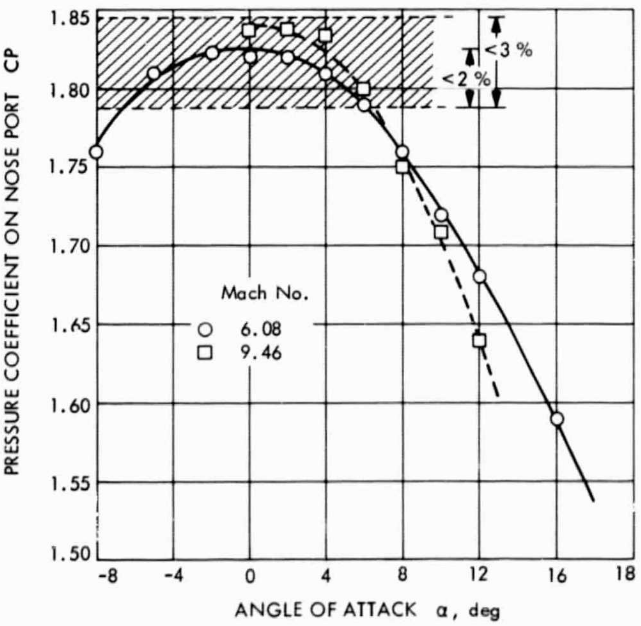

Fig. 5. Variation in pressure coefficient on the nose port as a function of angle of attack for the two Mach numbers

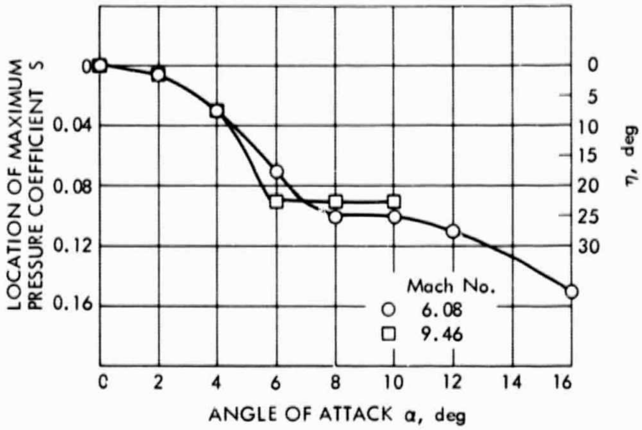

Fig. 6. Maximum CP location as a function of angle of attack for the two Mach numbers

not a linear function of angle of attack. This trend results in a favorable static stability contribution.

The results of the base pressure investigation are not presented. Due to the low pressures at these Mach numbers, the settling times were extremely large and not clearly defined. Also, at these hypersonic Mach numbers, it is expected that the sting support has a significant effect on the measured base pressure. The base pressure is, to a large degree, a function of the wake neck diameter and position, both of which are greatly affected by the presence of a sting. These combined effects resulted in base pressure measurements that were as great as 2½ times the free stream static pressure at Mach 9.46. Due to these high measured pressures, thermal-creep corrections were found not to be applicable.

V. Conclusions

A wind-tunnel test has been performed to determine the detailed pressure distribution over a blunted 60-deg half-angle cone at Mach numbers 6.08 and 9.46. The major conclusions were:

(1) A distinct pressure rise occurred on leeward rays at the breakpoint due to an abrupt flow compression at that point (Fig. 3).

(2) Mach number variance from 6.08 to 9.46 resulted in a pressure coefficient band of less than 1% (Fig. 4).

(3) The displacement of the stagnation point from the longitudinal body axis is not a linear function of angle of attack beyond 2 deg (Fig. 6).

(4) To a large extent, the base pressure of a cone is a function of the wake neck diameter and position, both of which are greatly affected by the presence of a sting.

Nomenclature

D base diameter, in.

d dimensional distance along model surface on a ray from nose port, in.

CP pressure coefficient, $p - p_\infty / q_\infty$

M Mach number

p surface pressure, psi

p_∞ free stream static pressure, psi

q_∞ free stream dynamic pressure, psi

R_e/in. Reynolds No./in.

r_n nose radius, in.

S non-dimensional distance from nose port, d/D

α angle of attack, deg

δ nose bluntness ratio, r_n/D

η angle between longitudinal body axis and position vector emanating from nose radius origin, deg

ϕ angle of roll, deg

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