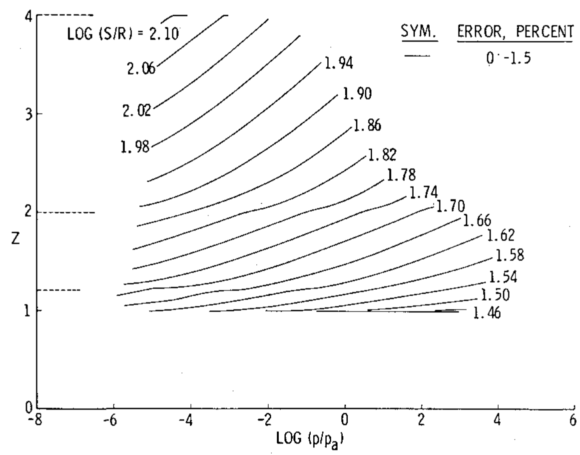

Fig. 3 Compressibility factor Z as a function of pressure and entropy for $T \leq 15{,}000°K$ in air.

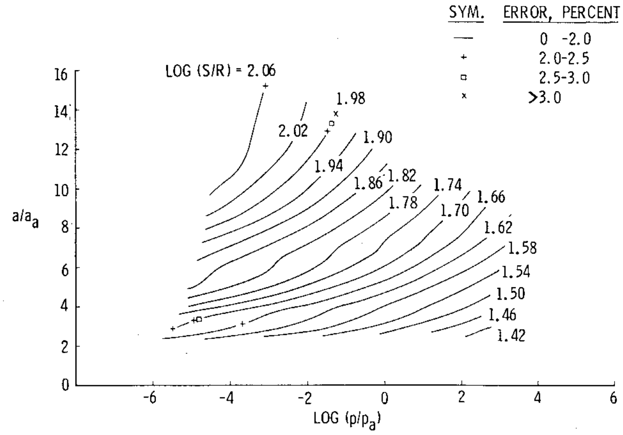

Fig. 4 Dimensionless speed of sound a/a_a as a function of pressure and entropy for $2000 \leq T \leq 15{,}000°K$, where a_a = 1086.98 fps at 1 atm and 273.15°K in air.

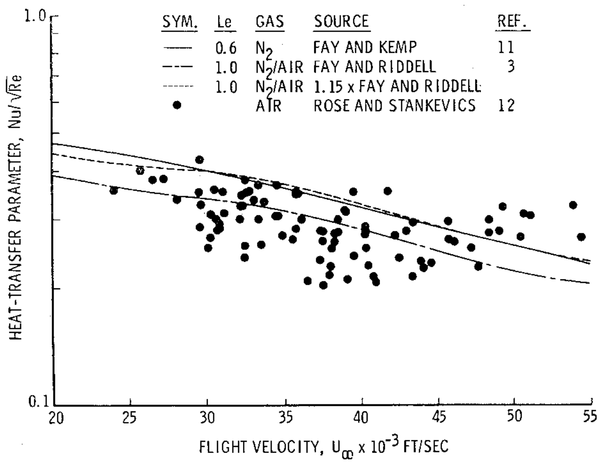

Fig. 5 Comparison between theory and experiment for equilibrium stagnation point heat-transfer at hypervelocity conditions (T_w = 300°K).

tion heat-transfer rate in air and nitrogen at high-temperatures," Arnold Eng. Dev. Center TDR-63-139 (1963).

[3] Fay, J. and Riddell, F. R., "Theory of stagnation point heat transfer in dissociated air," J. Aeronaut. Sci. **25,** 73–85, 121 (1958).

[4] Hilsenrath, J., Klein, M., and Woolley, H. W., "Tables of thermodynamic properties of air including dissociation and ionization from 1500°K to 15,000°K," Arnold Eng. Dev. Center TR-59-20 (1959).

[5] Landis, F. and Nilson, E. N., "Thermodynamic properties of ionized and dissociated air from 1500°K to 15,000°K," Pratt and Whitney Aircraft Rept. 1921 (1961).

[6] Humphrey, R. L. and Neel, C. A., "Tables of thermodynamic properties of air from 90 to 1500°K," Arnold Eng. Dev. Center TN-61-103 (1961).

[7] Hilsenrath, J., private communication, Natl. Bur. Standards (1959).

[8] Hilsenrath, J., Beckett, C. W., Benedict, W. S., Fano, L., Hoge, H. J., Masi, J. F., Nutall, R. L., Touloukian, Y. S., and Woolley, H. W., "Tables of thermal properties of gases," Natl. Bur. Standards Circular 564 (1955).

[9] Hansen, C. F., "Approximations for the thermodynamic and transport properties of high-temperature air," NACA TN 4150 (1958).

[10] Ahtye, W. F. and Peng, T. C., "Approximations for the thermodynamic and transport properties of high-temperature nitrogen with shock-tube applications," NASA TN D-1303 (1962).

[11] Fay, J. and Kemp, N., "Theory of stagnation point heat transfer in a partially ionized diatomic gas," Inst. Aerospace Sci. Paper 63-60 (1963).

[12] Rose, P. H. and Stankevics, J. O., "Stagnation point heat transfer measurements in partially ionized air," Inst. Aerospace Sci. Paper 63-61 (1963).

Nose Bluntness Effects on Cone Pressure and Shock Shape at M = 8.5 to 12.9

Nigel B. Wood
The War Office, Royal Armament Research and Development Establishment, Fort Halstead, England

Measurements of pressure distribution and shock shape were made on 15°-semiangle, spherically blunted cones in the Royal Armament Research and Development Establishment 10-in. hypersonic gun tunnel. The overexpansion in the pressure distribution increased with increasing Mach number, and good agreement with other experimental and theoretical results was obtained for similar values of $M\theta$. If $M\theta$ is greater than about 5, complete correlation of pressure distributions may be expected. The shock shape showed good agreement with Cheng's theory.

SINCE it was realized that a blunted cone, in certain circumstances, may have a lower drag than a corresponding sharp one, a number of investigators have focused their attention on the subject. In particular, the theoretical analyses of Chernyi[1] and Cheng,[2] together with the experimental results of Bertram,[3] have been the subject of considerable interest.

The present note compares the results on a 15°-semiangle spherically blunted cone at three Mach numbers in the Royal Armament Research and Development Establishment 10-in. hypersonic gun tunnel with already available experimental and theoretical results. The tests were made at nominally zero incidence and Mach numbers of 8.5, 10.4, and 12.9, with tip Reynolds numbers based on freestream conditions of 3.1 to 6.2 × 10^5, 1.3 to 2.6 × 10^5, and 0.6 to 1.2 × 10^5, respectively. Figures 1a and 1b* show typical schlieren photographs of the cone at small incidence at M = 8.5 and 10.4. It seems possible that the light and dark regions on the upper surface behind the shock represent approximately the entropy and shock layers considered by Cheng, and Fig. 1a appears to show the shock layer impinging and then skipping along the surface. Bertram suggested that the light region on the blunt cone represented a thick boundary

Received May 22, 1963.

layer. However, comparison with shadow photographs indicates that the boundary layer is not as thick as the white region in the schlieren photograph although it is certainly thicker than on the sharp cone. In the shadow photographs of the blunt cone, the edge of the boundary layer is not defined well, probably due to the presence of the entropy layer. (The outline in Figs. 1a and 1b is that of the window in the conical nozzle.)

Figure 2 shows the pressure distributions measured in the gun tunnel by Statham PA 222 TC strain gage pressure transducers mounted in the model. Corrections were made for incidence errors and for source flow effects in the nozzle.[4] The nondimensional pressure and axial distance parameters on the figures are those of Cheng, and the theoretical curves of Cheng and Chernyi are included for comparison. θ is the cone semiangle, ϵ is the normal shock density ratio, k is the nose drag coefficient, d_N is the nose diameter, and z is the axial distance measured from the tip. It will be seen that the overexpansion is greater as Mach number increases. Even if these results are plotted in terms of the corresponding sharp cone pressure, as suggested by Burke and Curtis,[5] the spread of the results is too great for a satisfactory correlation. However, if the minimum pressure in the overexpansion is plotted against $M\theta$, the present results and other experimental[5–8] and theoretical[9, 10] results fall on a single curve as shown in Fig. 3. This curve tends to a constant value when $M\theta$ is large enough, and it seems likely that the pressure distributions will correlate if $M\theta$ is greater than about 5.

Figure 4 shows the shock shape for the three Mach numbers plotted in terms of Cheng's parameters and compared with Cheng's theoretical shock shape. (R_S is the shock ordinate.) The difference between theory and experiment is due in part to boundary layer, but it can be seen how well Cheng's theory predicts the inflexion point in the shock where the highly curved nose region changes to conical form. It is seen also that the measured shocks were coincident at all Mach numbers. Transition of the boundary layer on the cone was observed at $M = 8.5$, but it did not appear to affect the results within the experimental accuracy.

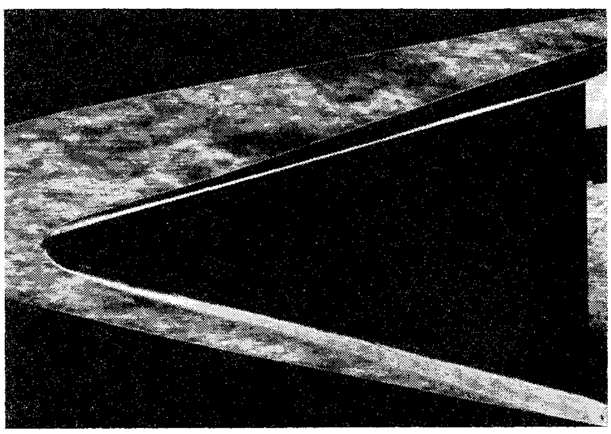

Fig. 1a Flow over cone at $M = 8.5$, $Re_d = 3.1 \times 10^5$.

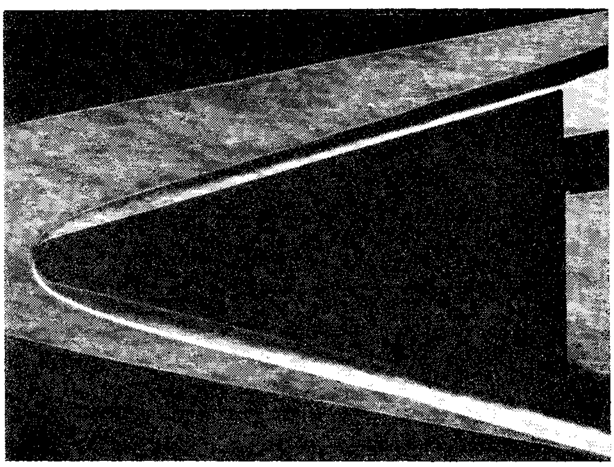

Fig. 1b Flow over cone at $M = 10.4$, $Re_d = 2.6 \times 10^5$.

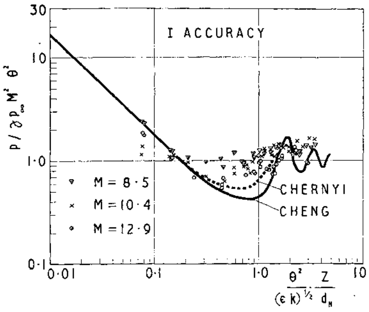

Fig. 2 Pressure distribution.

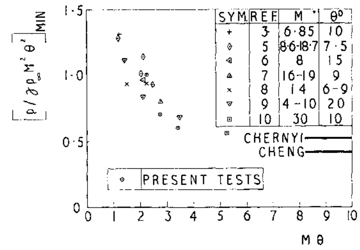

Fig. 3 Correlation of minimum pressure.

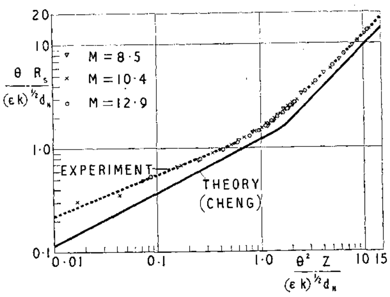

Fig. 4 Shock shape.

References

[1] Chernyi, G. G., "Flow around a thin blunt cone at high supersonic speeds," Soviet Phys.—Doklady **115,** 263–265 (1957).

[2] Cheng, H. K., "Hypersonic flow with combined leading-edge bluntness and boundary-layer displacement effect," Cornell Aeronaut. Lab. Rept. AF-1285-A-4 (August 1960).

[3] Bertram, M. H., "Tip-bluntness effects on cone pressures at $M = 6.85$," J. Aeronaut. Sci. **23,** 898–900 (1956).

[4] Whitfield, J. D. and Norfleet, G. D., "Source flow effects in conical hypervelocity nozzles," Arnold Eng. Dev. Center TDR-62-116 (June 1962).

[5] Burke, A. F. and Curtis, J. H., "Blunt-cone pressure distributions at hypersonic Mach numbers," J. Aerospace Sci. **29,** 237–238 (1962).

[6] "Pressure distribution on a blunted 15° circular cone," Gen. Appl. Sci. Labs. Inc. TR 136 (February 1960).

[7] Lewis, C. H., "Pressure distribution and shock shape over blunted slender cones at Mach numbers from 16 to 19," Arnold Eng. Dev. Center TN-61-81 (August 1961).

[8] Burke, A. F. and Dowling, E. D., "Aerodynamic aspects of the use of a blunt, slender cone as an air-data probe at hypersonic speeds," Cornell Aeronaut. Lab. Rept. AA-1577-Y-4 (November 1962).

[9] Chushkin, P. I., "Supersonic flows around blunted bodies of simple shape," J. Appl. Math. Mech. **24,** 1397–1403 (1960).

[10] Lunev, V. V., "Motion of a slender blunted body in the atmosphere with high supersonic speed," ARS J. **30,** 414–415 (1960).