Influence of Rear Body Eccentricity on Supersonic Base Pressure

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Base pressure measurements for a blunt cone in the presence of a following body of different eccentricities are presented. The measurements were carried out for sting-supported models on a blowdown-type Mach 2 wind tunnel. The results were obtained for a range of Reynold's number in which its influence was suspected to be appreciable, on the basis of earlier investigations by other authors. The variation of Reynold's number was obtained by changing the stagnation pressure of the tunnel. The influence of following bodies on the base pressure was found to be appreciable, whereas the dependence of the base pressure on the Reynold's number in the range of investigation was not found to be marked. Also, it was found that the asymmetric body affected the symmetry of base pressure, setting a cross force on the blunt cone under test. The study could be of relevance to the prediction of base pressure of multistage rockets in flight when the lower stage after separation is in proximity to the upper stages.

Nomenclature

d = diameter of rear body
D = diameter of base of blunt cone
x = axial distance of the front face of the rear body from the base
e = eccentricity (i.e., distance between axes of the test body and the rear body), mm
p_B = base pressure
p_∞ = freestream static pressure
N_{R_B} = Reynold's number based on base diameter
N_{R_L} = Reynold's number based on body length

Introduction

THE supersonic base pressure problem has been a subject of extensive investigations recently. The influence on base pressure of Reynolds number, Mach number, fore- and aft-body geometries, presence of following bodies, etc., has drawn considerable attention from researchers in this field.[1-4] The available theoretical models of the supersonic base pressure problem even now are far from satisfactory, thus stressing the need of further extensive systematic experimental investigations.

In multistage rockets, the base pressure of upper stages could be affected seriously by the proximity of a lower stage after they separate from one another. Thus, useful information could be obtained by physically simulating the poststaging conditions and studying the nature of base pressure variations. To the authors' knowledge, data available on base pressure in the presence of rear bodies are quite meager. A preliminary short study only was carried out by Mishra for the case of axisymmetric rear bodies.[5]

Reynolds number is one of the most important flow parameters that affect the base pressure. The influence of Reynolds number on base pressure has been studied experimentally for a cone-cylinder model by Kurzweg[1] at $M_\infty = 1.50\text{-}5.0$ and $N_{R_L} = 0.4\text{-}4.4 \times 10^6$; by Bogdonoff[2] at $M_\infty = 2.95$ and $N_{R_L} = 0.4\text{-}1.0 \times 10^6$; and by Kavanan[6,7] at $M_\infty = 2.10$, 2.84, 2.95, and 4.0 for $N_{R_L} = 10^2\text{-}10^7$. At low Reynolds number for laminar flow, the base pressure rapidly increases with increase in N_{R_L} until it reaches a maximum value in the vicinity of $N_{R_L} = 1.0 \times 10^5$. Further increase in Reynolds number results in a sharp fall in the base pressure until it reaches a minimum value near $N_{R_L} = 1.0\text{-}2.0 \times 10^6$ (transition range). With a further rise in N_{R_L}, the base pressure gradually attains almost a constant value. Survey of the literature provides little information on the Reynolds number effects on base pressure for a blunt cone model and that, too, in the presence of following bodies in its wake.

The purpose of this paper is to present the results of base pressure for a blunt cone in the presence of a body in its near wake. The effects on base pressure of following body eccentricities at varying axial locations have been studied. Furthermore, results of preliminary experimental base pressure study for a sphere-cone model with rear body in the Reynolds number range $0.5\text{-}2.0 \times 10^6$ also have been presented. (In view of the earlier mentioned Reynolds number effects investigations, the influence on base pressure of N_R variations is suspected to be drastic in the N_R range under study.)

Experimental Details

Experiments were carried out on an intermittent, blowdown-type supersonic wind tunnel with a test section of 100×50 mm. The experimental setup is shown in Fig. 1. The test model consisted of a sting-supported 30-deg blunt cone of base diameter 17.3 mm and overall length 25.1 mm. The diameter of the sting was 6 mm, i.e., approximately 34.68% of the base diameter. Four rear bodies of the same diameter (14.53 mm) but of varying eccentricities were chosen. The eccentricities chosen were $e = 0$, 0.66, 1.60, and 2.38 mm.

Base pressure was measured by means of 0.5-mm-i.d. stainless-steel probes positioned at three different locations at the base (viz. top, side, and bottom), about 3.0 mm below the

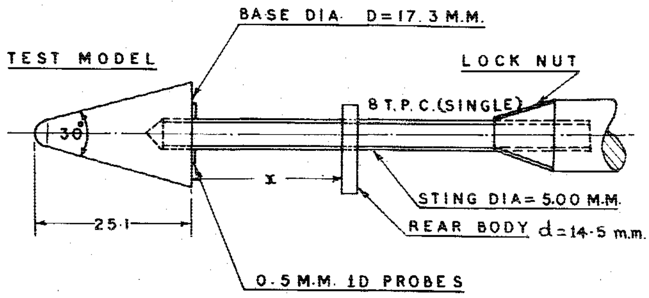

Fig. 1 Experimental setup.

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; LV/M Aerodynamics.

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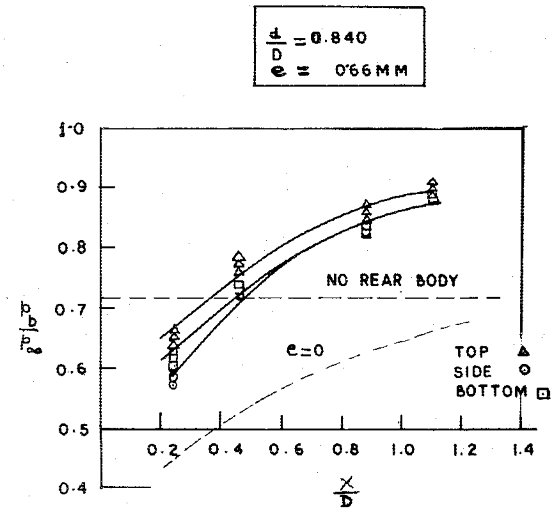

Fig. 2 Experimental results of the base pressure.

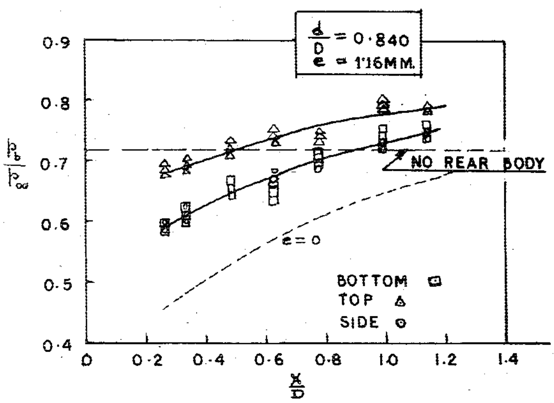

Fig. 3 Experimental results of the base pressure.

shoulder of the base. The freestream static pressure and the base pressure probes all were connected to a multilimb mercury manometer.

The test Mach number in all cases was 2.067. The test Reynolds number variation was obtained by changing the supply stagnation pressure. In all cases where the effect of eccentricity for a range of axial locations was studied, the Reynolds number was maintained at 3.5×10^5/cm.

Results and Discussion

The experimental results of the base pressure in the presence of eccentric rear bodies at changing axial locations are presented in Figs. 2-4. The test Reynolds numbers, as mentioned earlier, were maintained at 3.5×10^5/cm. Figure 5 shows the effects of Reynolds number on base pressure in the presence of eccentric rear bodies at fixed locations. Figures 2-5 have superimposed on them base pressure variations for the case of an axisymmetric rear body and also for the case when no rear body is present. (Curves are least-squares fits.)

Influence of Rear Body Eccentricity

The presence of an axisymmetric rear body in the rear wake results in a fall of p_B for all of the axial locations for the ratio of rear body diameter to the base diameter under consideration. The result qualitatively agrees with that of Ref. 5 for unit diameter ratio. But with increasing x, the base pressure steadily increases. Naturally, the $e=0$ curve asymptotically approaches the "no rear body" line. Closer to the base, the rear body is enveloped completely by the "dead water region." Thus vorticities formed in the near wake are destroyed, resulting in appreciably low p_B values. With the advance in axial position, this effect starts wearing off.

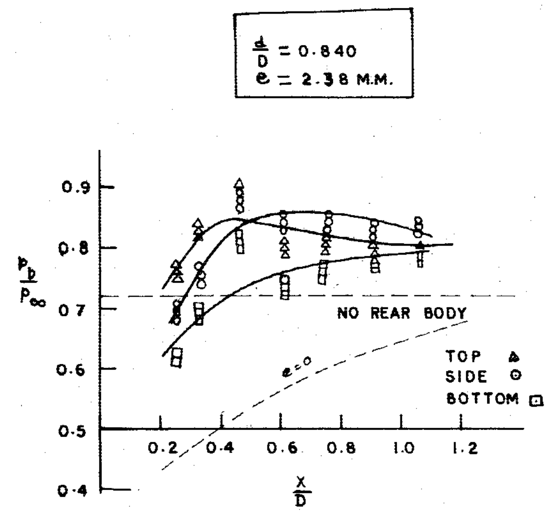

Fig. 4 Experimental results of the base pressure.

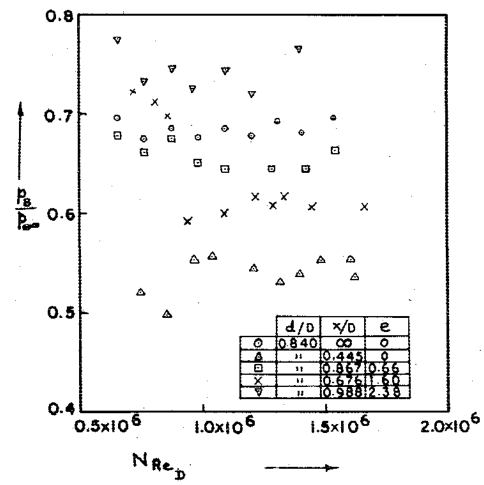

Fig. 5 Effects of Reynolds number on base pressure.

The presence of eccentric rear bodies in the near-wake region results in a necessarily asymmetric flowfield. For a given position of the eccentric rear body, the base pressures for the three different locations (top, side, and bottom) are, in general, different, being largest at the top. The influence of eccentricity on base pressure is found to be quite appreciable as compared to the $e=0$ value. In general, the base pressure value is observed to increase steadily with increasing x. Thus, beyond a certain axial location of the eccentric rear body, the base pressure rises above its "no rear body" value. Closer to the base, the asymmetric rear body, being practically enveloped by the "dead water region," breaks up the vortices, and also it limits the expansion at the base shoulder, thus resulting in a base pressure value larger than $e=0$ values and smaller than "no rear body" values. But farther from the base, the lower tip of the asymmetric rear body extends more and more out of the dead-air region, thus giving birth to stronger and stronger tip shock. The effect of this tip shock is transmitted to the base via the subsonic corridor. Thus the combined effect of the enveloped upper portion and the tip shock at the lower part of the rear body is to raise the base pressure value more and more as the rear body moves farther away from the base in the near-wake region.

Figures 2-4 clearly show the nonequality of the base pressure at the three locations of the model base. This is a natural consequence of an asymmetric flowfield set up by the eccentricity of the rear body even for such small values of the eccentricity. The setting up of nonuniform base pressure on the model naturally would disturb its stability, at least to some extent.

Effects of Reynolds Number

The influence of Reynolds number on base pressure in the range of test N_{RD} is found to be negligible for the case when no rear body is present. As per earlier investigation of Van Hise[8] and others for a cone-cylinder geometry, it would be suspected that the variation in p_B should have been quite drastic. The present study clearly shows that the trend of N_{RL} effect on base pressure of a blunt cone is quite different from that for the case of cone-cylinder geometry.

In the presence of eccentric rear bodies, Reynolds number effect on base pressure in the range under study is not very pronounced except for the case $d/D=0.840$, $e=1.6$ mm, and $x/D=0.676$. The earlier cone-cylinder studies[1,2,7,8] indicate the Reynolds number independency of base pressure in a much higher range ($N_{RD} \approx 4.0\text{-}10.0 \times 10^6$).

Sting Rod Interference

The sting support primarily affects the model flow at or near the base by altering the manner in which the separated flow at the base converges in the model wake. Earlier investigations of Reid and Hastings[9] and of many other authors suggest that the sting interference could be ignored safely for $d/D \leq 0.35$, but later investigations of Kavanan and others predict sting interference for diameter ratios even less than 0.1. Fortunately for the present rear-body investigations, the sting is more or less enveloped by the "dead-air region" between the model base and the rear body; this is so at least for the rear body locations closer to the model base. For rear body positions farther from the model base, say for $x/D > 1.0$, the sting interference would be uncertain and in itself would require a detailed, careful investigation.

Conclusions

1) Axisymmetric rear body in the near wake lowers the base pressure, the effect being more pronounced as the rear body moves closer to the base.

2) The eccentricity of the rear body sets up an uneven distribution of the base pressure, which could affect the stability of the test model.

3) The eccentricity results in appreciably altered base pressure of the blunt cone. For any axial position, the base pressure always is more than the corresponding zero-eccentricity rear body.

4) With increasing axial distance of the eccentric rear body, the base pressure steadily rises, it being less than the corresponding "no rear body" value nearer to the base and being more when farther away from the base.

5) The base pressure of a blunt cone, with and without rear body, is not very sensitive to the variation of Reynolds number in the range under study.

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