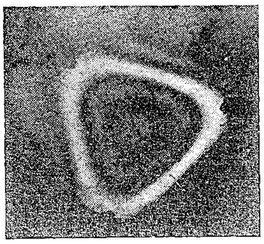

Fig. 3 Fringe pattern at 490 Hz resonance of 31-in.-diam triangular cored mirror.

Fig. 4 Fringe pattern at 450 Hz resonance of 31-in.-diam hexagonal cored mirror.

triangular and hexagonal core mirrors. Dynamic holograms were made of the mirrors with the holes. The data indicated that the same mode shapes occurred and the resonant frequencies were reduced by 5 to 10%.

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Shock-Wave, Turbulent Boundary-Layer Interaction on a Blunted Compression Surface

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Introduction

THE problem of analyzing the internal flow in inlets for aircraft that will fly at hypersonic speeds in the atmosphere is of current interest. The requirement for surfaces on such aircraft to have blunted leading edges has been noted.[1] The presence of a blunt leading edge produces a curved bow shock wave and a resulting downstream flowfield with nonzero vorticity. Thus, the viscous boundary layer (the primary concern here is with a turbulent layer) that develops on the surface may be significantly different from one that develops with the vorticity external to the boundary layer equal to zero. It is of paramount interest in the analysis and design of inlet systems to know what effect this nonzero vorticity flowfield and the resulting differences in the turbulent boundary layer will have on shock-wave boundary-layer interactions that occur inside the inlet.

Analyses proposed to treat interactions between shock waves and turbulent boundary layers have used the assumption of zero vorticity external to the boundary layer and have been limited to flows on flat plates[2] or to flows in a zero pressure gradient, axisymmetric environment.[3] The method of Ref. 4 was applied to a turbulent flow on a flat plate with no external vorticity; however no assumption in that method restricts its use to that class of flows. This Note describes the application of the method of Ref. 4 to analyze a shock wave interacting with a turbulent boundary layer on a blunted compression surface. Only the details of the method of Ref. 4 that specifically apply to the case under consideration are discussed.

Discussion

The experimental investigation described in Ref. 1 studied the effect of leading-edge bluntness on the flowfield downstream of the bow shock wave, including the interaction of a shock wave with the boundary layer. The investigation was carried out on a two-dimensional configuration and included studies of both laminar and turbulent boundary layers. One set of data for a turbulent boundary layer from that study has been singled out for detailed examination in the present paper. The data set was selected to test the ability of the method of Ref. 4 to describe features of shock-wave boundary-layer interactions that were not included in the cases studied in Ref. 4. For example, the selected data exhibit a boundary-layer separation as well as large vorticity contiguous to the viscous boundary layer.

A schematic of the model used in the experiments is shown in Fig. 1. The leading edge radius is 4.77 mm and the shock wave generator setting, α_G, is 6°. Details of the compression surface curvature and alignment with the freestream flow are

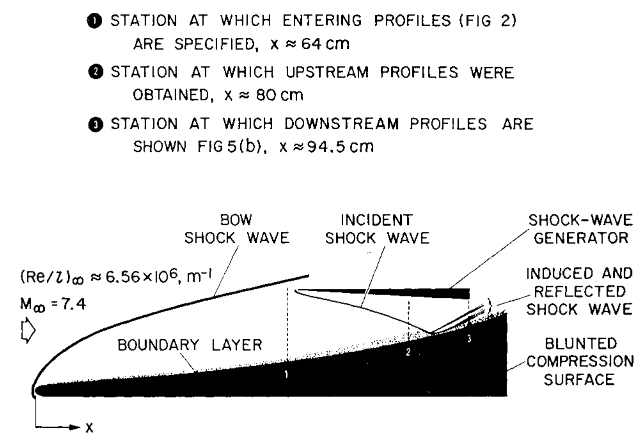

Fig. 1 Schematic of experimental model showing locations of survey stations.

given in Ref. 1. The freestream Mach number and the unit Reynolds number are in Fig. 1. In the study of Ref. 1 profiles of pitot and total pressure, and total temperature were obtained normal to the surface. Three profiles from the experimental study were used in this study. The locations of these profiles with respect to the shock wave generator surface and the interaction region also are shown in Fig. 1. Figure 2 shows the profiles of Mach number, total pressure, total temperature, and flow angle that are required as the initial conditions in the analysis of Ref. 4. The Mach number and total-pressure profiles represent those obtained from a fairing of the data while the flow angles were taken from an inviscid solution of the flowfield that agreed sufficiently well with Mach number and total-pressure profiles to warrant use in this study. The total-temperature profile represents a fairing of the data and indicates that the edge of the viscous boundary layer is near $y = 1.5$ cm. The Mach number at the boundary-layer edge is then about 3.0 while in the outer flow it attains a value near 6.0.

The method of Ref. 4 requires that a division be made between an outer, essentially inviscid layer and an inner, essentially viscous layer. The outer layer is than analysed by the inviscid, method-of-characteristics program described in Ref. 5 and the inner layer by the viscous finite difference program described in Ref. 6. The method is discussed in detail in Ref. 4. For this study, the divison was made at $y = 0.75$ cm in order to have the outer layer entirely supersonic throughout the incident reflected shock system.

The results of this study are shown in Figs. 3–5. Figure 3 shows the predicted static pressures in the interaction region.

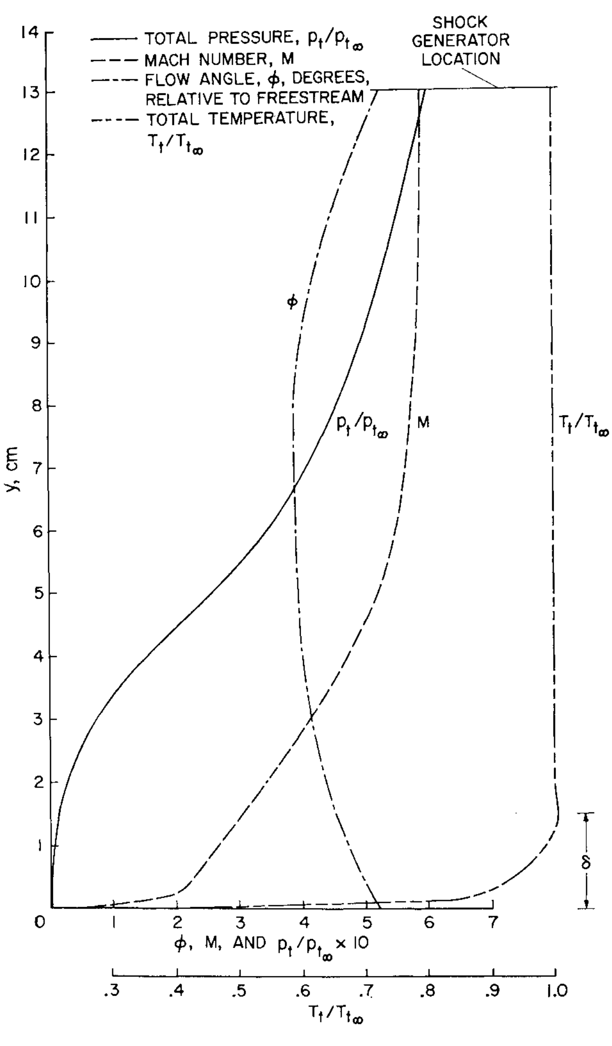

Fig. 2 Entering profiles used in method of Ref. 1.

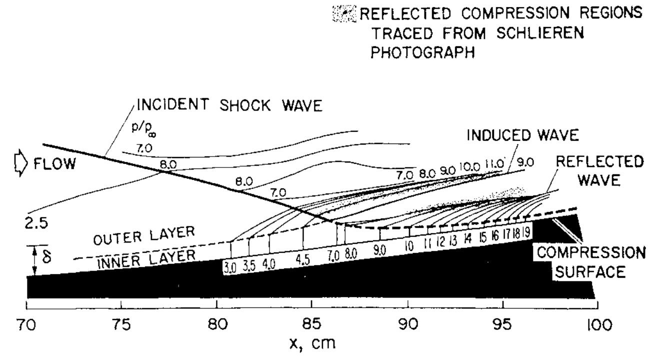

Fig. 3 Predicted static pressure in interaction region.

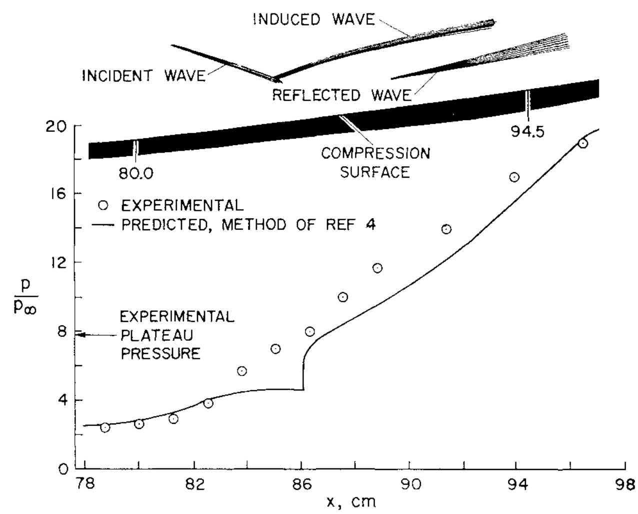

Fig. 4 Comparison of experimental and predicted surface pressures.

The dividing line between the inner and outer flows is shown throughout the interaction region. The static pressure is assumed constant in the inner layer as shown. The predicted incident shock is essentially coincident with the experimental shock. The predictions are compared with the reflected compression regions that were traced from a schlieren photograph of the interaction. The predicted upstream compression region appears to originate slightly too far upstream when compared with the experimental results; however, its location may be adequately determined for purposes of continuing an inviscid solution of the outer flow. The predicted downstream compression region seems to be in general agreement with that observed. These comparisons, which relate pressure contours with the shock-wave pattern, are primarily qualitative in nature; additional and more quantitative results appear in Figs. 4 and 5.

Figure 4 shows the predicted surface pressure distribution compared with the experimental values. These pressures are properly alined with a tracing of a schlieren photograph that provides the shock-wave pattern shown. The over-all prediction of the pressure distribution is reasonably good, with the predicted pressure generally less than the experimental value. This underprediction of pressure may occur because the predicted plateau pressure is only about half that observed experimentally (Ref. 1 shows additional data obtained for a range of incident shock strength that verify the indicated value of plateau pressure). This discrepancy in plateau pressure and the result noted previously, that the upstream compression region originates too far upstream, indicate that the laminar mixing employed in the inner layer is probably inadequate to describe the details that occur in the sublayer of

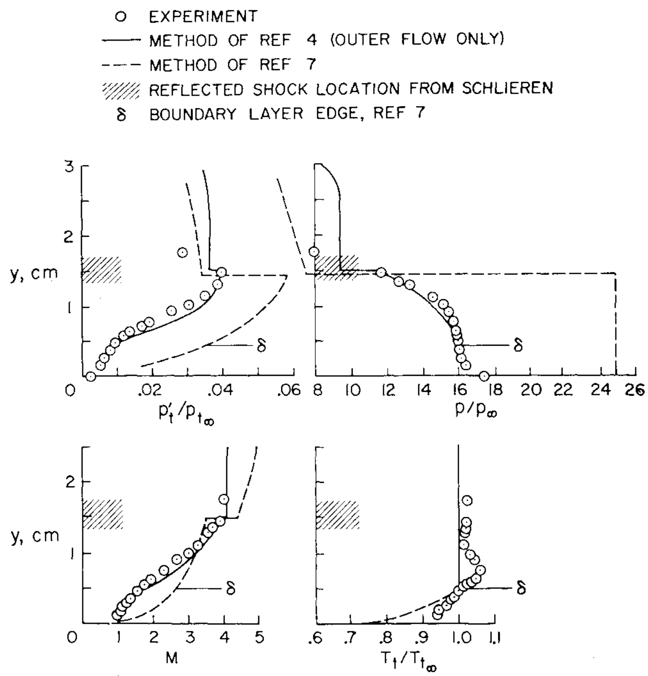

Fig. 5 Comparison of experimental and predicted profiles of Pitot pressure, static pressure, Mach number, and temperature downstream of interaction (Station 94.5 cm).

a turbulent boundary layer which contains an extensive region of separation.

Figure 5 shows profiles of experimental and predicted Pitot and static pressure, Mach number, and total temperature at station 3 (Fig. 1) just downstream of the interaction; at station 2 upstream the measured and predicted profiles agreed well. The predictions obtained by the methods of Ref. 4, which uses a control-volume type of analysis for interactions, and Ref. 7 are shown for comparison with each other as well as with the data. The outer layer results, shown for the method of Ref. 4, are in good quantitative agreement with the experimental data. It is worth noting that although the method of Ref. 7 greatly overpredicted the Pitot and static pressures below the reflected shock, the predicted Mach number near the shock was about the same as that obtained experimentally and by the method of Ref. 4. This result points out that Mach number profiles must be examined with caution because a seemingly correct Mach number may result from incorrect Pitot and static pressures.

In conclusion, it appears that the method of Ref. 4 affords a considerable improvement over previously used control-volume type models, and is applicable for interactions that occur between a shock wave and turbulent boundary layer developed over a compression surface having a blunt leading edge. This improvement applies primarily in the outer layer. Further improvement in the method will be required before better prediction can be made of the flow in the inner viscous layer. In particular, the method used for determining the inner layer must be capable of predicting the correct plateau pressure in the separated region. Some improvement might be expected with the use of more advanced boundary-layer techniques that permit the conditions on the dividing line (e.g., entropy, velocity gradient ($\partial u/\partial y$), and pressure gradient ($\partial p/\partial y$)) to match those imposed by the flow in the outer layer.

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A Venus Planetology Mission Based on the Planetary Explorer Spacecraft

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THE National Academy of Sciences has recommended,[1] that a series of low cost missions—including orbiters, atmospheric probes, and landers—be used for early exploration of the planet Venus. We have undertaken a preliminary study to identify a mission concept, investigate a range of Venus lander missions, and define the mission that appears most promising within the constraints imposed. In the execution of this study, the basic tasks were to determine if a worthwhile lander mission, in the 800 lb class, can be configured and what technology or state of the art advances may be required.

Objectives

The science objectives presented in the NAS report are interpreted as follows: 1) Chemical composition of surface materials; identify the most abundant materials at widely separated sites. 2) Surface topography; identify surface features, elevation variations, microscopic imaging of surface materials, petrography. 3) Active seismology; determine the surface structure to 0.5 km depth. 4) Passive seismology; observe natural seismic activity at 3 sites. 5) Determine if an iron core is present. 6) Measure heat flux from the planet interior. 7) Measure atmospheric pressure and temperature at the surface.

In view of the current national goals and anticipated fiscal policies, it is necessary to provide the highest possible scientific return for the least cost. Measurements such as pressure-temperature profiles, atmospheric composition and wind velocity, which are capable of being made by probable earlier atmospheric probe or orbiter missions,[2,3] have been omitted. The science experiments and instruments considered are listed as follows: 1) Active seismology—3-axis seismometer,

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Index category: Entry Vehicles and Landers.

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