Acknowledgment

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Supersonic Jet Control via Point Disturbances Inside the Nozzle

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Introduction

IT is well known that the directivity of sound generated by a supersonic jet depends largely on the shape of the jet column and its development. For example, considerable side-line noise reduction was achieved on a Concorde nozzle by squeezing of the axisymmetric jet in the horizontal plane.[1,2] This observation resulted in studies of notched nozzles obtained by cutting wedge shaped notches in the originally conical nozzle.[2,3] The resultant flowfield from the notched nozzle was found to consist of large streamwise vortices shed from the swept edges of the notches[2] and is primarily responsible for the distortion of the jet. Similar distortion of an axisymmetric jet was also observed by placing tabs at the exit of the nozzle.[4–6] In this work, we discuss a novel means by which supersonic jets can be significantly perturbed using single point disturbances that generate streamwise vortices. The present work is the round jet equivalent of the Side-Wall Shock Vortex Generator (SWSVG) recently described by Clemens and Mungal[7] for two-dimensional supersonic mixing layers. In their work it was suggested that shock wave disturbances launched from the wall inside a supersonic nozzle could interact with the splitter tip producing streamwise vortices that lead to significant roll-up of the layer. In this work, we continue this approach of launching disturbances from within a supersonic nozzle in order to generate streamwise vortices that distort the jet column.

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Experimental Details

The experiments described here were performed at the Fluid Mechanics Research Laboratory of Florida A&M University and Florida State University, using a pressure matched converging-diverging nozzle with an exit diameter of 3.11 cm and exit Mach number of 2.1. The stagnation temperature was nominally room temperature. Figure 1 shows a sketch of the nozzle together with the technique used for providing point disturbances within the supersonic nozzle region; small rods (diam=1.6 mm, penetration depth=4.8 mm) were inserted externally to the nozzle using a set screw mechanism at several locations between the throat and exit plane. Machining constraints dictated that the disturbance rods projected upstream at an angle of 28 deg to the jet centerline. Each point disturbance emits a cone shaped disturbance wave; the intersection of the cone and the nozzle lip produces two regions of pressure mismatch that cannot be sustained by the shear layer, and a pair of streamwise vortices are formed.[7]

Four cases were investigated as shown in Fig. 2. If the nozzle exit were viewed from downstream, looking upstream, with 12 o'clock corresponding to the top edge of the nozzle, the cases were 1) undisturbed nozzle; 2) single disturbance at $x=-2.54$ cm, 3 o'clock position; 3) two disturbances at $x=-2.54$ cm, 3 and 9 o'clock positions; and 4) two disturbances, $x=-1.59$ cm at 12 o'clock and $x=-2.54$ cm at 3 o'clock. The local Mach numbers at the disturbance locations $x=-2.54$ and -1.59 cm are 1.9 and 2.0, respectively. Condensation of moisture from the ambient room air that mixes with the cold jet fluid produces a fine condensate fog that marks the mixing region, hence the flow is visualized using the planar laser Mie scattering technique[8] with light pulses (10 ns pulse duration) from a frequency doubled Nd:Yag laser (532 nm, 100 mJ per pulse).

Results and Discussion

Figures 3a–d show views of the jet mixing layer (looking upstream) at a station 3.75 diam downstream of the jet exit. Three images are shown for each case, two instantaneous realizations and a multiple exposure consisting of 20 to 30 independent realizations used to define an ensemble average. The viewing angle of the camera was approximately 30 deg to the jet centerline, and so some distortion is observable.

Figure 3a shows results for the undisturbed nozzle and is used as a basis for comparison. Distortion of the jet mixing layer is comparable to similar views of ideally expanded supersonic jets seen earlier.[9] The ensemble average shows the expected doughnut shape of the jet mixing layer. Figure 3b shows results for a single disturbance, case 2. Here considerable distortion is observed and results from the shock wave disturbance interacting with the lip of the jet (see Fig. 1) inducing roll-up of the jet shear layer. The disturbance is observed throughout the jet, resulting in a polygonal appearance, even though the disturbance generator is applied at the 3 o'clock position. The effect, however, is somewhat more pronounced at the 3 o'clock position. Figure 3c shows that two symmetrically placed disturbances, case 3, convert the jet to a more rectangular and (vertically) symmetric appearance with prominent comer cusps; a similar appearance was also observed further downstream. Figure 3d shows that two asymmetric disturbances produce a more complex, star-like appearance. Because both dis-

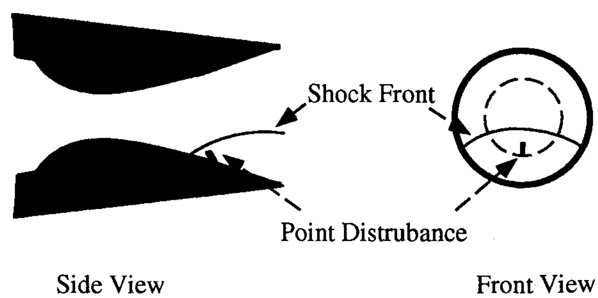

Fig.1 Sketch of supersonic nozzle, disturbance generator, and internal disturbance wave.

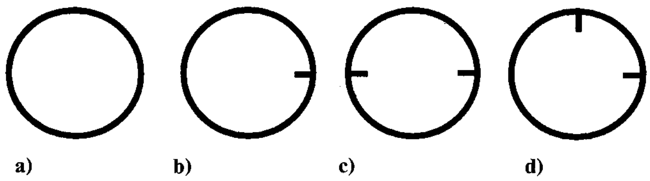

Fig. 2 View of jet nozzle looking upstream showing locations of disturbance generators, cases 1, 2, 3, and 4.

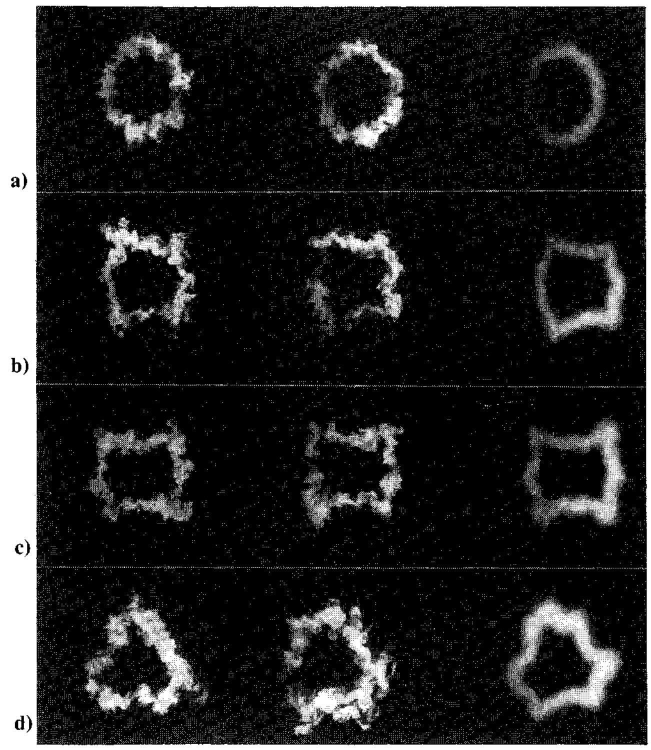

Fig. 3 Upstream views: a) case 1, no disturbances; b) case 2, one disturbance; c) case 3, two symmetric disturbances; and d) case 4, two nonsymmetric disturbances. The first two pictures on the left-hand-side correspond to instantaneous views of the shear layer, and the third picture corresponds to an average.

turbances were also at different upstream locations, there is an additional lack of symmetry of the jet as can be seen by careful examination of the ensemble average. We conclude from these results that azimuthal location as well as axial location are variables that control the final jet appearance.

These results suggest that single point disturbances launched from within the supersonic nozzle are indeed able to produce significant changes to the jet shear layer; the present results appear consistent with the earlier findings[7] for the two-dimensional supersonic mixing layer. These results also appear similar to the larger body of work on jet tabs and the more recent work on delta-tabs.[6] However, a notable difference between the delta-tab work and the present is that the delta-tab is applied externally to the jet lip and also appears to maintain its effectiveness in subsonic jet flows. The present approach relies upon the wave nature of supersonic flows both to create and to propagate the disturbance, and so is not expected to be active in subsonic flows. Finally, we note that although mechanical disturbance generators (rods) were used in the present study, we believe that the same effect can be obtained by the use of fluid-mechanical disturbances such as a jet in a crossflow. Such an approach would also lead to possibilities of active control.

Conclusions

We report here some preliminary results on the use of point disturbances on supersonic jet development. The disturbance generators are located on the supersonic nozzle wall between the throat and the jet exit plane; the resulting fluid mechanical disturbances are felt at the intersection of the disturbance cone and the jet lip. It is shown that a single disturbance generator leads to a polygonal jet appearance; two symmetric disturbances lead to a symmetric, rectangular jet shape; and two nonsymmetric disturbances lead to a star-like appearance; in all cases significant cusps are formed. It would appear from these results that it is possible to contour the jet shape via the number and location (axial and azimuthal) of disturbances. Further investigations of these and related phenomena such as jet noise, mixing efficiency, and thrust loss appear warranted.

Acknowledgment

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Low-Frequency Flow Oscillation over Airfoils near Stall

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Introduction

IT is well known that airfoils, at angles of attack well beyond stall, and bluff bodies experience flow oscillation at the nondimensional shedding frequency or Strouhal number St of approximately 0.20. However, many airfoils also exhibit a low-frequency flow oscillation at or near stall where St=0.02. This Note briefly reviews what is known about this flow phenomenon and presents new measurements at higher Reynolds numbers. In a study of

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