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Investigations on Compressible Mixing Layers in Confined Ducts

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ABSTRACT

The lacuna in addressing the fundamentals of compressible mixing layers subjected to pressure gradients in confined ducts motivated the current investigations. Studies are conducted on a canonical compressible mixing layer established between M_1=2.0 and M_2=1.5 flows within a suction type supersonic wind tunnel. Pressure gradients are imposed on the mixing layer by placing appropriate inserts on the test section walls. High speed schlieren visualizations and static pressure measurements are performed. Interesting shock-shear layer interactions are observed in the test section.

1. Introduction

Compressible turbulent mixing layers are crucial in many modern aerospace devices such as the high speed air-breathing engines and supersonic ejectors. A number of studies have been carried out to understand the behavior of compressible turbulent mixing layers by the use of canonical mixing layer established within the experimental rig using a splitter plate supplied with fluid streams of different flow properties on either side [1,2]. A significant practice in all these experimental efforts was to design the setup such that the overall pressure gradient applied on the mixing layer is insignificant, and the growth rate of such zero pressure gradient mixing layers were reported. The highlighting fact that was consistently observed in all the studies is that compressibility drastically reduced the growth rate of compressible mixing layers. In particular, studies on supersonic ejectors showed that not only is the mixing layer subjected to a variety of pressure gradients due to the flow and variations in the flow passage, there are strong interactions of shock with the mixing layer that can lead to shock fluctuations within the duct [3]. However, such a flow scenario where in the mixing layer is subjected to significant pressure gradients and with shock impinging on it has not been studied. This motivated the current study wherein a compressible mixing layer is established between two streams of differing Mach number in the test section of a suction type wind tunnel. The flow topology is such that the condition that the pressures across the mixing layer be the same is relaxed. Further, pressure gradients are imposed upon this mixing layer by introducing inserts onto the walls of the test section such that the resulting flow produces either shocks that impinge on the mixing layer or produce gradual pressure gradients. The objective of the study is to understand the gasdynamics of these interactions of the compressible mixing layer when pressure gradients are imposed upon it. The experimental study involves the use of high speed schlieren technique to visualize the mixing layer and pressure measurements to quantify the pressure gradients present in the flow. The cases are also studied using numerical tools to infer in detail the observed flow phenomena. The results, comparing the different flow scenarios are discussed in detail in this conference presentation.

2. Experimental Setup

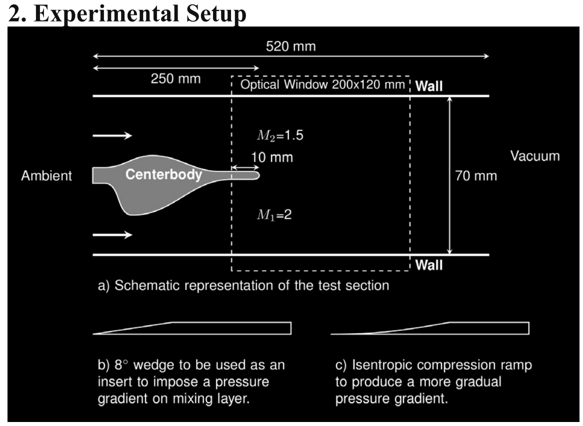

Fig. 1 Schematic of the test section and the inserts used to create area variations in the test section.

Two supersonic flows are generated of M_1=2.0 and M_2=1.5 respectively by placing a contoured centerbody in a suction type wind tunnel and the compressible turbulent mixing layer develops between them. The total height of the test section is 70 mm and the length is 520 mm, while the centerbody has a length of 250 mm, as shown in Figure 1. The straight portion of the centerbody that forms the splitter plate is 3 mm thick (designed based on rigidity considerations for the rather large pressure difference that exists across the splitter plate) and is rounded off at the lip. Optical glass windows of 200 mm length are placed on the sides of the test section to aid flow visualization. The standard Z type schlieren arrangement with a high speed camera (Photron FASTCAM) is used to take high speed schlieren images at a maximum of 8000 fps in order to resolve the unsteady shock oscillations that are characteristic of such flows. One of the side walls is replaceable with an acrylic wall with static pressure ports placed in two rows at a distance of 17.5 mm on either side of the splitter plate. Static pressure measurements are conducted by using KYOWA pressure transducers with signal conditioners that directly acquire data at 5 kHz and transmit it to a

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personal computer for storage and further analysis. The experiments are conducted by creating a vacuum of < 5 kPa in a dump tank at the downstream end of the test section while the upstream is exposed to ambient surroundings. A valve that separates the test section from the vacuum dump tank is operated manually at the start of the experiment and held open for a duration of 3-4 secs. The required supersonic flow is established within the test section.

3. Results and Discussions

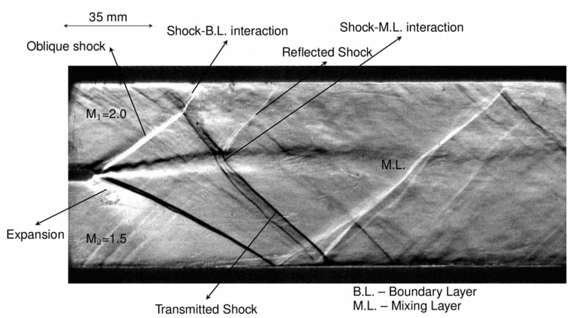

Fig. 2 An instantaneous schlieren image of the compressible mixing layer formed between M_1=2.0 and M_2=1.5 flows in the test section of the wind tunnel.

Figure 2 clearly shows the compressible mixing layer formed between M_1=2.0 and M_2=1.5 flows and the associated shock structures. The convective Mach number of the mixing layer estimated from the conditions of the flow is 0.32 and the Reynolds number at an X location of 70 mm is Re_1=0.863x10^6 and Re_2=1.025x10^6. The compressible mixing layer bends towards the M_1=2.0 flow since at the edge of the splitter plate the static pressure is higher at M_2=1.5 and lower at M_1=2.0. The expansion fan that causes this flow turning is distinctly visible. On the other hand a shock is formed at M_1=2.0 side. The flow from M_2=1.5 continues to turn and expand until it is restricted by the presence of the mixing layer which causes an oblique shock to develop. The shock from M_1=2.0 interacts with the boundary layer causing a local separation bubble and resultant shock structure. This shock interacts with the mixing layer. Thereafter from the series of shock structures it is clear that the pressure is higher at the top than at the bottom and consequently the mixing layer starts bending downwards. Simultaneously the thickness of the mixing layer also increases. This flow scenario is named the Plain Mixing Layer since no inserts are placed to impose any external pressure gradients on the mixing layer.

Figure 3 and Figure 4 show the schlieren images when inserts are placed on the bottom wall of the test section on Mach 1.5 side. The inserts produce a small variation in the area of the test section, causing flow turning and imposing pressure gradients on the mixing layer.

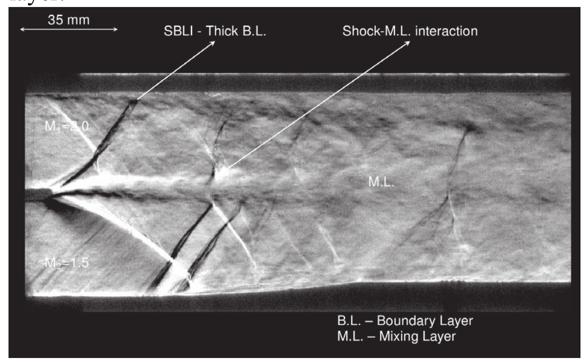

Fig. 3 Instantaneous schlieren image, when the isentropic ramp is palced on the Mach 1.5 side, 35 mm away from the splitter plate.

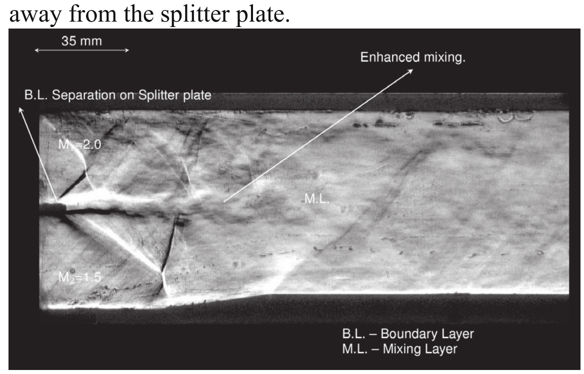

Fig. 4 Instantaneous schlieren image, when a wedge is placed on the Mach 1.5 side, 35 mm away from the splitter plate.

Clearly significant differences can be observed in the two cases from Figure 2. A wedge represents a sharp change and causes a stronger shock system that completely changes the characteristic of the mixing layer. The isentropic ramp is more gradual and the interesting point to observe here is that the boundary layer at the opposite wall thickens significantly because of the adverse pressure gradient. Thus there is a mutual interaction between shocks-mixing layers and bounday layers.

4. Conclusions and Future Work

The experiments have shown interesting shock-shear layer interactions within a confined duct when the mixing layer is subjected to pressure gradients. They are being investigated through analysis of images, pressure measurement and CFD. More details shall be described in the conference.

5.References

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