Effect of Upstream Injection on a Confined Supersonic Cavity Flow

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ABSTRACT The flow field near the cavity of supersonic combustor is highly unsteady and has a significant impact on the mixing and flame stabilization in supersonic flow. In this study the non-reacting flow field of single and twin cavity based rectangular shape supersonic combustor is analyzed. For both the configuration Nitrogen was injected normally from 2 mm diameter injectors located upstream of the cavity in Mach 2.5 isothermal cross flow at different momentum flux ratios. The experiments were conducted with a single upstream injector and multiple equally spaced upstream injectors at three different air flow rates to get combustor entry pressure ranging from 0.3 to 0.5 bar which are relevant in terms of chemically reacting flows. The single and twin cavity flow with upstream injection without combustion were analyzed by simultaneous time resolved pressure measurements and high-speed (20 kHz) schlieren visualization. It was observed that twin cavity configuration flow field shows much involved interaction between shock and shear layer compared to single cavity configuration for both the single and multiple jet injection cases. It is also observed that multiple jet upstream injections case shows more interaction between jet and cavity shear layer compared to single jet case and shear layer tends to lift towards mainstream flow. This mechanism of lifting of shear layer toward the main flow is beneficial in terms of flame stabilization in supersonic flow but at the same time it may reduce the entrainment of fuel jet into the cavity because of shift in the reattachment point of shear layer.

1 Introduction

Combustion in scramjet engine is limited by mixing process and short (< 1μs) residence time inside the combustor. Hence There is requirement of improved mixing and short ignition delay time of fuel being injected in to flow. The use of cavities in flow path has been shown in previous studies (Barnes et al. 2015) helps in combustion. Cavity provides a local subsonic high temperature zone which helps in reducing ignition delay and creates large vortical structure which improves mixing (Liu et al. 2017).

The flow field near the cavity is greatly affected by mass injection and subsequent heat release after the combustion. The common features of cavity flow are shear-layer, recirculation zone and shear layer reattachment point. The upstream injection of fuel jet near the cavity leading edge enhances the free shear layer growth (Ben-Yakar et al. 2001) and helps in stabilizing the cavity oscillations. This jet and cavity interaction significantly changes the flow field around the cavity and hence the entrainment of fuel inside the cavity (Cisneros et al. 2017). In this study the effect of single and spanwise equally spaced three jets on the isothermal flow field of single and twin cavity-based combustor is analyzed with the help of high-speed (20 kHz) schlieren images.

2 Experimtal Setup

The experiments were conducted in high enthalpy blow down test bed (Thakor et al. 2020) of Advance Propulsion Research Laboratory at Indian Institute of science, Bengaluru. The schematic of test section is shown in figure 1. A two-dimensional Mach 2.54 nozzle connected to constant area isolator of 25 mm hight ,100mm width and extended till 250 mm. Bottom wall of cavity combustor has divergence of 2.5 degree. The leading edge of 15 mm deep cavity with L/D ratio of 5 starts at 50 mm from the isolator exit. Trailing edge of cavity slants at 22.5 degree with respect to diverging wall of cavity combustor. Room temperature nitrogen was injected normal to flow direction from 2 mm injectors at sonic condition from H distance upstream of cavity leading edge. For twin cavity experiments top wall of the combustor is replaced by exactly same cavity combustor bottom` wall as shown in Figure 1. For twin cavity experiments nitrogen was injected from both top and bottom wall at H distance from the leading edge of cavity.

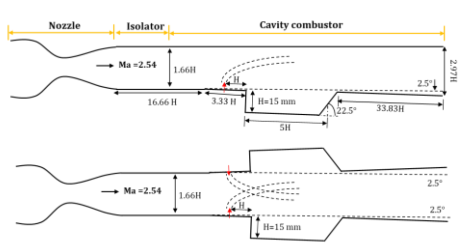
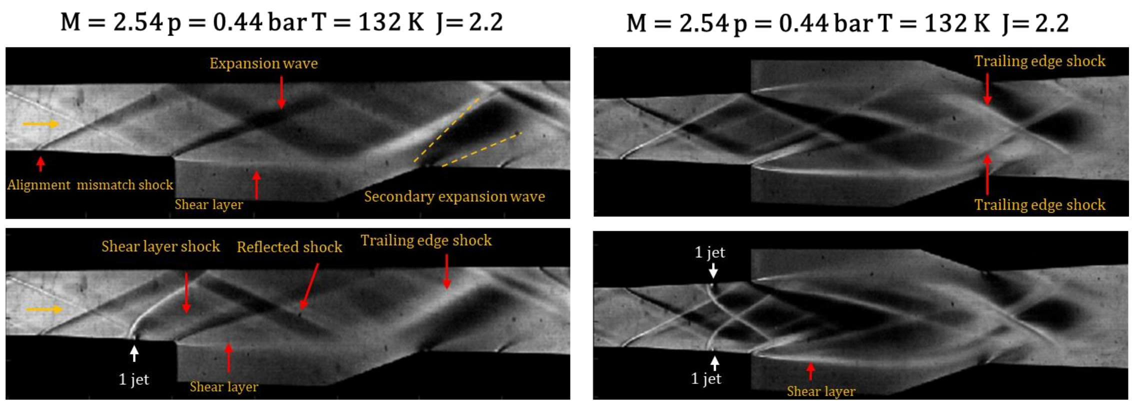


Figure 1. Schematic of single cavity and twin cavity test section

3 Results

Experiments on single and twin cavity configuration were performed for three different air flow rates to get combustor entry pressure 0.30 ,0.45 and 0.55 bar. For each case comparison between average schlieren flow field was done for both single and twin cavity configuration as shown in figure 2. All the major feature of flow like shear layer, secondary expansion fan, trailing edge shock, reflected shocks are explicitly marked on the average image for both the configuration.

3.1 Case A: upstream injection of nitrogen jet at J = 2.2 for 0.44 bar entry pressure:



(a) (b)

Figure 2 Comparison of average density gradient along the flow (a) Top image shows flow without nitrogen and bottom for with jet injection for single cavity configuration (b) for twin cavity configuration at M =2.54, 0.44 bar and J 2.2 value.

It can be observed from the figure (a) with upstream injection the nature of leading-edge expansion wave changes to compression wave. Which is an indication of lifting of shear layer toward the main flow. This also changes the secondary expansion region at the trailing edge of cavity. For the twin cavity case figure (b) flow field shows multiple shock-shock and shock-shear layer interaction when compared with single cavity configuration. In the twin cavity configuration entire core flow can be observed getting affected with injection of nitrogen.

4 REFERENCES

The list of references should be alphabetized by the last names of the first author of each, using the APA formatting. Examples:

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