Shock interaction in a Transverse injection from a Bumped Surface in a Supersonic Crossflow

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ABSTRACT The current study explores a supersonic crossflow injection technique employing two transverse jets: Jet^1 positioned at the bottom wall of the duct, and another transverse jet (Jet^2) situated atop an elevated curved surface downstream of Jet^1. Schliren flow visulization techniques and Numerical methods have been employed in order to investigate the shock structres formed in the flow field. The schliren flow visulization revelead two separate bow shock waves being formed due to the presnece of the two jets. It is seen that the strength of the Bow shock wave formed from the Jet^1 is greater than the strength of the second bow shock from the second jet (Jet^2), and these two Bow shocks interact in the duct region and forming a stronger shock. The strong shock reflects from the top wall forming a Mach reflection near to the top wall and thus creating a subsonic patch of flow in the duct. These observations are further explored using CFD simulations which reveals that the significanltly higher penetration of the Jet^2 is due to the reduction in the momentum of the supersonic crossflow, caused by mulitiple bow shocks formed upstream to the Jet^2.

1 INTRODUCTION

Fuel injection in a scramjet engine is widely sought area of research. Due to the low residence time of the supersonic crossflow, air fuel mixing in scramjet engine poses many challenges. One of the major challenge is the penetration of the injected fuel into the combustion chamber. One of the most efficient yet simple method of fuel injection is injecting the fuel in the transverse direction to the crossflow (Zhang et al.). The fuel ports can be present either on the bottom wall or on the wall of strut (Hsu et al.). Various studied have been carried out in order to increase the jet penetration from a transverse jet (Huang). One such method of injection is to inject the fuel from two separate injectors having the same mass flow rate as that of a single injector. This configuration which is also known as the ‘tandem injection’ method results in a greater penetration as compared to a single jet (de Maag et al., Smink et al.). This is caused by the shielding of the jet in the downstream location from the high momentum of the supersonic crossflow. This shielding effect is caused by the bow shock wave created by the first jet reducing the momentum of the incoming supersonic crossflow and thus resulting in greater penetration of the overall jet. A second bow shocks is also formed by the second jet which interacts with the first bow shock and thus forming a combined bow shock which acts as an incident shock on the opposite wall. The primary objective of the present work is to further increase the penetration of tandem injection by introducing a bump in the bottom wall and placing the second injector (Jet^2) on top of the bump, as shown in the Fig.1. The bow shocks formed from the Jet^1 (see Fig. 1) and Jet^2 are expected to further interact and form a shock interaction in the duct region. The objective of this study is to examine the shock structures formed in such a flow field, the type of shock interaction and its impact on the mixing characteristics.

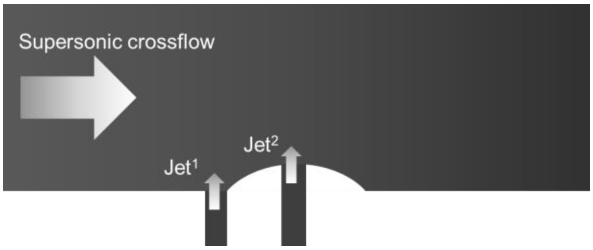

Figure 1: Schematics representation of the flow field.

2 METHODOLOGY

The experimental setup utilized a supersonic blowdown wind tunnel, as illustrated in Fig. 2. A reciprocating compressor, capable of reaching a maximum pressure of 30 bar and delivering 40 CFM, supplied the compressed air required for the experiment. This compressor fed two 3m^3 storage tanks, which is stored till the pressure builds up to 20 bar which then used accordingly. To maintain a consistent pressure air supply, a pressure regulating valve (PRV) in the wind tunnel adjusted the pressure in the supply line. The flow of air was controlled by a ball valve. Downstream of the PRV, a settling chamber, equipped with a pressure gauge and a port for measuring stagnation pressure, was connected. The test section, attached to the settling chamber, features a convergent-divergent nozzle capable of generating a steady supersonic flow with a designed Mach number of 2.2. The bottom plate of the test section consists of a transverse jet injector (Jet^1) and a bumped injector (Jet^2) downstream to the Jet^1. The air is supplied to the injector through separate feedlines as shown in Fig. 2.

For CFD Simulations Ansys Fluent 2022 R2 was used to simulate the flow field. A 3D domain with hexahedral unstructured mesh is used to simulate the flow field. Details of computational model chosen for present study is shown in Table 1.

Table 1: Computational details

Flux Discretization	Roe-FDS
Spatial Discretization	Second order
Turbulence model	k-ω SST
Working medium	Air [1]
Density change	Ideal gas equation

[1] The injected jets and the crossflow are treated as different species of air for determine the jet penetration and mixing characteristics.

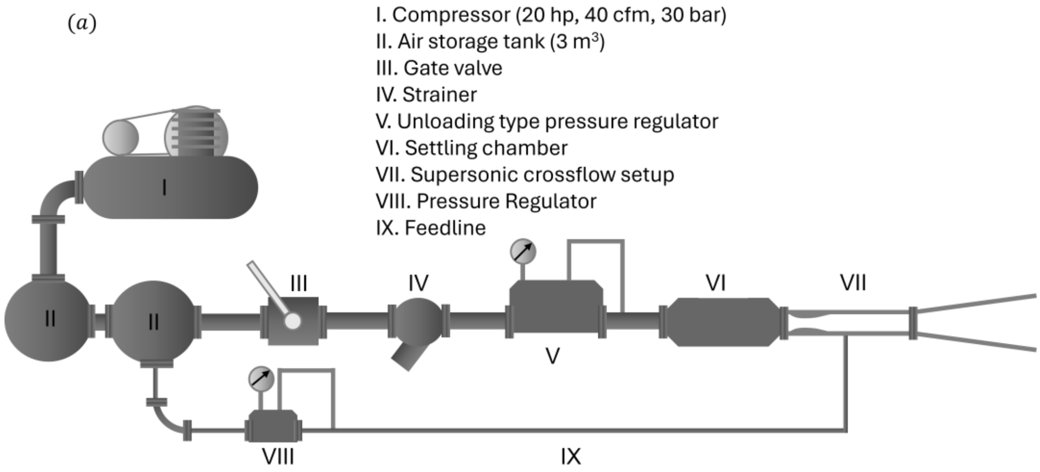

Figure 2: Schematic of the wind tunnel setup used for the experiments done in the present work.

3 RESULTS

Fig.3 (a) shows the instantaneous schlieren images taken for the present study. A Bow shock waves (BS^1) from the first injector placed at the bottom wall can be clearly seen originating near the bottom wall, upstream to the Jet^1. Another Bow shock (BS^2) can also be seen formed upstream to the second injector which located on top of the bumped wall. It is further seen that the two bow shocks interact with each other and form a stronger shock which then gets reflected from top wall and forms a Mach reflection, as shown in Fig.3 (a). Fig.3 (b) shows the contour of x component of the density gradient showing the shock structures obtained from the numerical simulations. Similar shock structures as seen from the experimental schlieren can also be observed from the numerically computed density gradients.

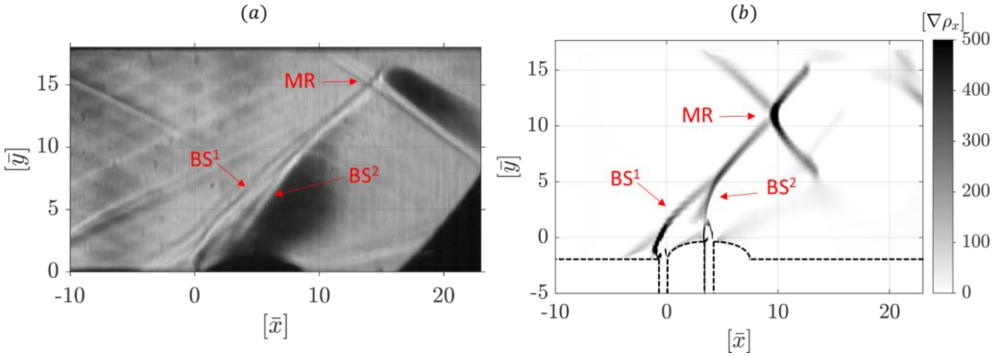

Figure 3: (a) Instantaneous Schlieren Images taken of the flow field for the two transverse jets where one of them is placed at the bottom wall and the other placed downstream to the first and on top of a bumped surface. (b) Contours of x component of density gradient depicting the shock structres produced by the present flow field.

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