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ORIGINAL ARTICLE

Effect of ramp-cavity on hydrogen fueled scramjet combustor

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Abstract Sustained combustion and optimization of combustor are the two challenges being faced by combustion scientists working in the area of supersonic combustion. Thorough mixing, lower stagnation pressure losses, positive thrust and sustained combustion are the key issues in the field of supersonic combustion. Special fluid mechanism is required to achieve good mixing. To induce such mechanisms in supersonic inflows, the fuel injectors should be critically shaped incurring less flow losses. Present investigations are focused on the effect of fuel injection scheme on a model scramjet combustor performance. Ramps at supersonic flow generate axial vortices that help in macro-mixing of fuel with air. Interaction of shocks generated by ramps with the fuel stream generates boro-clinic torque at the air & liquid fuel interface, enhancing micro-mixing. Recirculation zones present in cavities increase the residence time of the combustible mixture. Making use of the advantageous features of both, a ramp-cavity combustor is designed. The combustor has two sections. First, constant height section consists of a backward facing step followed by ramps and cavities on both the top and bottom walls. The ramps are located alternately on top and bottom walls. The complete combustor width is utilized for the cavities. The second section of the combustor is diverging area section. This is provided to avoid thermal choking. In the present work gaseous hydrogen is considered as fuel. This study was mainly focused on the mixing characteristics of four

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different fuel injection locations. It was found that injecting fuel upstream of the ramp was beneficial from fuel spread point of view.

1. Introduction

Supersonic combustion is the research area pursued by combustion scientists for optimization of the combustion process. Due to very high speed of air in the combustor and low residence time, it is difficult to achieve sustained and useful combustion in the combustor. Mixing, lower stagnation pressure losses, positive thrust and sustained combustion are the key issues in the field of supersonic combustion. Experimental and numerical research is being carried out by different researchers around the world.

Major focus towards improving the scramjet combustor performance is given to the effective mixing of fuel and air. Due to very high kinetic energy of the air stream, cross stream mixing between fuel and air is very difficult. Hence special fluid mechanism is required to achieve good mixing. In the design of supersonic combustion ramjet engine, fuel injections as well as flame holding are known to play a critical role. Fuel and air must be mixed at molecular level in the near field of fuel injection. To induce such mechanisms in supersonic inflows, the fuel injectors should be critically shaped incurring less flow losses. Then, fuel injection also should be done judiciously to utilize the flow field generated by fuel injectors to the fullest extent. Current investigations are focused on the effect of fuel injection scheme on a model scramjet combustor performance.

The strategy requires the placement of physical obstructions in the combustor to provide stream wise vortices that enhance the mixing of fuel and air. Such approaches are use of backward facing step and ramps [1]. Backward facing step generates recirculation zone that contains hot gases in it and serves as a continuous ignition source. However, the disadvantage of backward facing step is of relatively high stagnation pressure loss. Ramps at supersonic flow generate axial vortices which help in macro-mixing of fuel with air. Interaction of shocks generated by ramps with the fuel stream generates boro-clinic torque at the air & liquid fuel interface, enhancing micro-mixing. Cavities use an integrated approach as fuel injector and flame holder. This was first designed and used by CIAM (Central Institute of Aviation Motors) in Moscow in a joint Russian/French dual-mode scramjet flight-test [2]. Recirculation zones present in cavities increase the residence time of the combustible mixture and hence are better candidates for flame holding.

More over the large scale shear layer oscillations associated with cavities enhance the fuel-air mixing. Experimentally, the use of cavities after the ramp injector was found to significantly improve the hydrocarbon combustion efficiency in supersonic flow. Ben-Yaker et al. [3] used the cavities for flame stabilization in a solid fuel supersonic combustor and demonstrated self ignition as well as sustained combustion of polymethyl-methacrylate (PMMA) for supersonic flow conditions.

There are two types of cavities, open and close [4,5]. Numerical studies on supersonic combustion with cavity [6] and using innovative cavity [7] have dealt with supersonic studies using CFD (computational fluid dynamics) simulation with Fluent code. Due to the low pressure loss experienced by open cavities (Cavity $L/d < 10$), open cavities are useful in supersonic flow. Making use of the advantageous features of ramps and cavities, a ramp-cavity combustor is designed.

2. Combustor geometry

Rectangular scramjet engines are widely preferred from operational point of view. Hence, in our study a scaled two dimensional combustor of size 28 mm × 85 mm is considered for experimental/numerical investigations. The schematic of the combustor is shown in Figure 1.

The combustor has two sections. First, constant height section consists of a backward facing step followed by ramps and cavities on both the top and bottom walls. The ramps are located alternately on top and bottom walls as shown in Figure 2.

A constant area combustor of 28 mm × 40 mm size is designed to locate the rearward facing step. Three ramps are positioned in the base plate and two ramps are positioned alternately in the top plate of the combustor. Cavities of size 50 mm in length and 8 mm deep are located next to the ramps. A diverging combustor of semi-divergence angle of 1.8° joins the constant area combustor for sustained combustion. The complete combustor width is utilized for the cavities. The second section of the combustor is diverging area section. This is provided to avoid thermal choking.

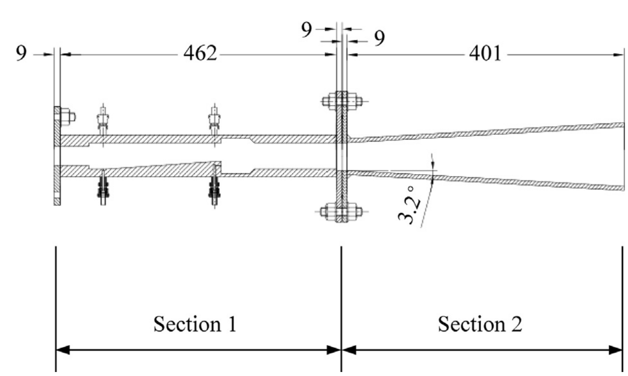

Figure 1 Schematic of the scramjet combustor.