Computational Analysis The Effect Of Micro Vortex Generator In E2R Scramjet Engine

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Abstract

This project deals about the performance of scramjet by introducing Micro Vortex Generator (MVG's) at the internal inlet of E2R scramjet engine. At the inlet, the interaction of shock-waves with the boundary-layers (shock-wave/boundary-layer interactions (SWBLI)) which results in boundary-layer thickening and can trigger separation, which lead to large losses and distortion at the engine face. This problem can be solved by employing MVG at the inlet. The Scramjet flow fields are determined using Computational fluid dynamics (CFD) as a design tool, to provide a detailed account of the micro vortex generator effects in the flow interactions. The comparative studies were made on the two cases scramjet engine with MVG and without MVG. On account of the computational results, the Scramjet engine with MVG has better compression and cyclic temperature ratio which enhanced the combustion efficiency.

Keywords— *CFD, Micro vortex generator, Scramjet Engine, Shockwave Boundary Layer Interaction.*

1. Introduction

The evolutionary of air breathing engines has gone through many steps, from propellers to turbofans, turbojets, ramjets and finally to scramjets. The scramjet engine construction is similar to the ramjet engine. As flight Mach numbers increase beyond Mach 5, the use of supersonic combustion can provides higher performance (i.e. specific impulse) due to inlet efficiency. In a conventional jet engine, the inlet works in combination with the mechanical compressor to provide the necessary high pressure for the entire engine. In hypersonic speeds adequate compression can be achieved by forebody and internal inlet, the initial external compression by forebody which contributes to the drag and moments of the vehicle and internal inlet compression provides the final compression of the propulsion cycle. The air in the captured stream tube undergoes a reduction in Mach number with related to increase in pressure and temperature as it passes through the system of shock waves. A Scramjet air induction phenomenon includes vehicle bow shock and isentropic turning Mach waves, shock-boundary layer interaction, non-uniform flow conditions, and three-dimensional effects. At the internal inlet, the interaction of shock-wave/boundary-layer interactions (SWBLI) results in boundary-layer thickening and trigger separation zone, both of which lead to large losses. To avoid flow distortion and to maximize inlet pressure recovery, wall-suction or bleed is frequently employed to improve boundary-layer performance by removing low momentum fluid from the near-wall region via a number of holes, slots or scoops. Although effective, conventional bleed systems result in reduced mass flow to the engine, thereby reducing engine thrust. Recently, there has been resurgence in interest in the use of Micro vortex generators (MVGs) to reduce separation in engine inlets. In a way to increase the efficiency, it is placed at the internal inlet. In inlet which helps in smoothing the shock wave/boundary layer interaction leads to increase in compression ratio and better cyclic static temperature.

2. E2R Engine

The scramjet engine E2R model, Total length is about 2200 mm, and at the entrance of the inlet, the width and the height of the internal ducts are 200 and 250 mm, respectively. The origin of the x-coordinate for the graphs in this paper is at the leading edge of their top wall. At the inlet-combustor section, the modified engine model E2R has a new ramp block that fully covers the top wall. The block has two ramps with different angles at its forward section, that is, the inlet and isolator sections. The first ramp has an angle of 7.6o to the engine axis. The subsequent second ramp has 14.2o. These angles are adopted to prevent separation at the leading edges. The geometrical contraction ratio is 7.94 for the E2R. These ramp blocks are not actively cooled by water. From the combustor section to the exit of the E2R, the ramp block has a steady slope of 9o. This angle was selected to produce sufficient pressure on the slope and reduce divergence loss of the exhaust flow. Though a smaller angle could not be adopted because of insufficient length of the existing duct from the constant area combustor to the nozzle sections, the angle is smaller than the reattachment angle of a supersonic flow at a backward-facing step, about 18o (Refs. 7 and 8). On the E2R in the combustor section, there are backward-facing steps 4 mm in height for flame-holding.

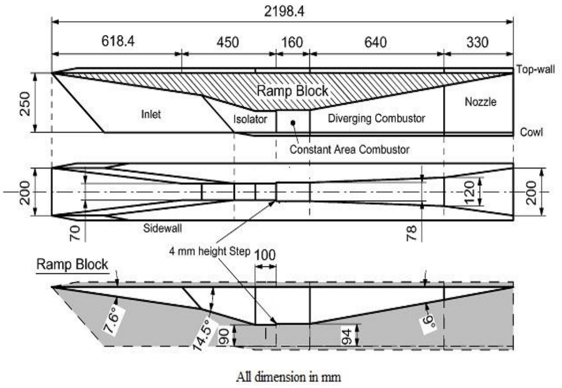

Figure 1: E2R engine configuration

3. Micro Vortex Generator

The MVG is a passive device which induces streamwise vortices would transfer high momentum fluid from the freestream to the boundary-layer and simultaneously removing low momentum fluid from the near-wall region. Based on the literature study carried out, a model of Micro Vortex Generator (MVG), which is sketched in Figure.2, The dimension of MVG height (h) is 2mm, chord (s) is 15mm and angle (A) is 24^{o}.

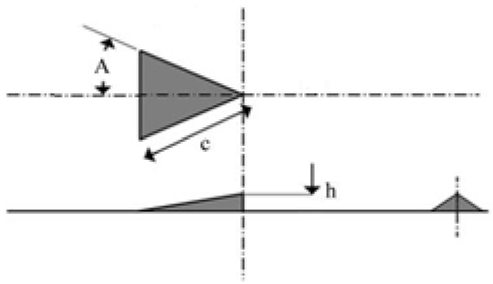

Figure 2: Dimension of MVG

4. Computational setup and Model description

The flow field was simulated using a commercially available ANSYS-FLUENT CFD package [3].High Reynolds number standard k- omega model was used for turbulent flow studies. Based on the literature study carried out, the geometry used for the present analysis is similar to that proposed by Tetsuo Hiraiwa and Takeshi Kanda is shown in Fig. 1. The leading edges of the forebody, cowl and sidewall surfaces were modelled as sharp and MVG is placed at a distance of 6.26 mm from leading edge at the inlet of scramjet engine is sketched in Fig.3. The computational domain is shown in the Fig. 4.

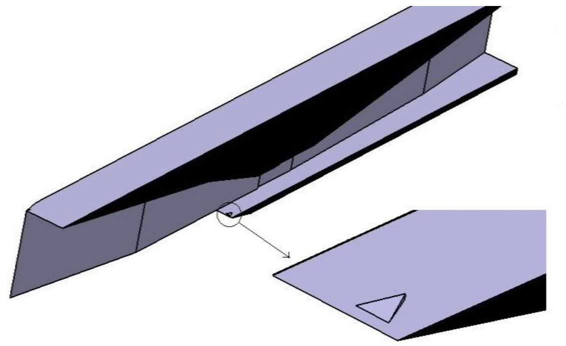

Figure 3: Cross sectional view of E2R engine modelled with MVG

Boundary Condition

Variables	Air stream
Mach	6.7
Temperature (*K*)	330
Pressure (*pa*)	1550
Velocity (m/s)	2549

Table I. Inlet Boundary Condition

The inlet boundary condition applied for the simulation is given in the Table I.

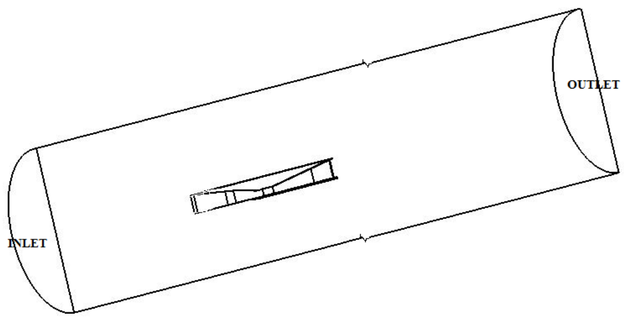

Figure 4: Schematic of Computational domain E2R engine

5. Result and Discussion

The 3D dimensional simulations were carried out and analysis exposed the flow field details of scramjet E2R engine. The inviscid or laminar flow fields are simpler than turbulent flow field within the inlet. Turbulent flow field caused by the thick boundary layer and various viscous interactions and therefore the separation occurs at the inlet. Use of MVG smoothen the thick turbulent boundary layer which is resulting in greater compression.

5.1 Mach Contour Comparison

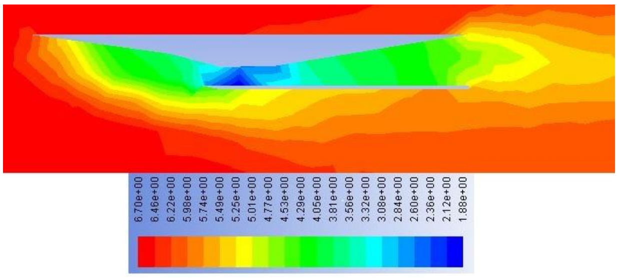

Figure 5: Mach Contour of E2R with MVG

When comparing E2R with and without MVG Mach contour, Fig.6 shows Mach contour of actual case engine has high Mach and micro vortex generator at inlet has an effect which reduced Mach at combustor entry is shown in Fig.5 which results in better combustion efficiency than actual case of engine.

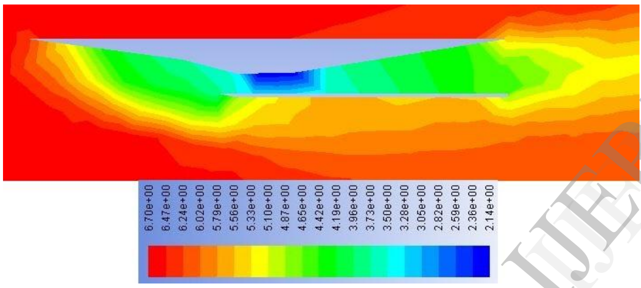

Figure 6: Mach Contour of E2R without MVG

For the effective combustion, Mach at the combustor entrance has to reduce. The inlet without micro vortex generator has Mach of 2.70 and inlet with MVG has 2.35 which is lower than actual case and the graph plot of Mach vs. position is shown in Fig.7.

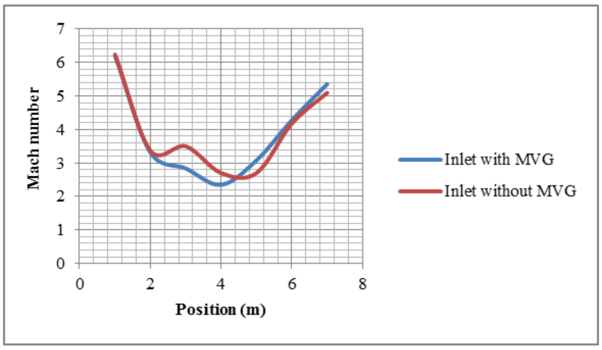

Figure 7: Mach Comparison Graph of E2R with and without MVG

5.2 Temperature Contours Comparison

Contour of Static Temperature with MVG and without MVG is shown in Fig.8 and Fig.9. The formation of shock is illuminated. The inlet without MVG has temperature of 1275.52K at combustor entrance and inlet with MVG has 1301.7K. Fig.8 shows, the temperature at the combustor entrance is raised due to Micro vortex generator.

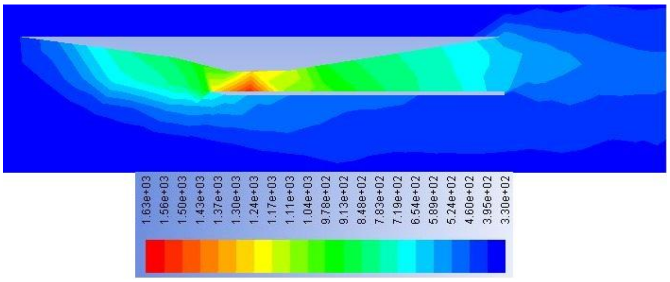

Figure 8: Temperature Contour of E2R with MVG

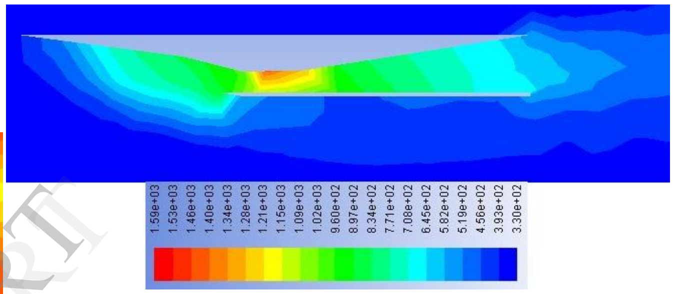

Figure 9: Temperature Contour of E2R without MVG

The comparison between two modelled graph plots is shown in Fig.10. It clear to see rise in temperature is higher in the inlet with MVG than the actual case of inlet and this shows the effect of micro vortex generator, which is effective for the combustion efficiency.

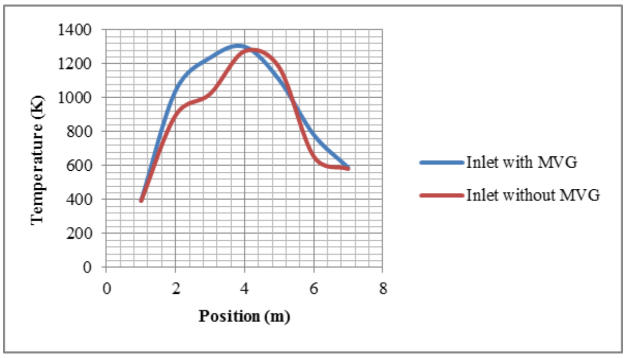

Figure 10: Temperature Comparison Graph of E2R with and without MVG

5.3 Wall y^+ Contours Comparison

Wall y+ in CFD gives out boundary layer formation. The inlet with MVG have smoothen the boundary layer is shown in Fig.15 and Fig.16 shows the actual case of i.e. inlet without MVG has thickened boundary layer.

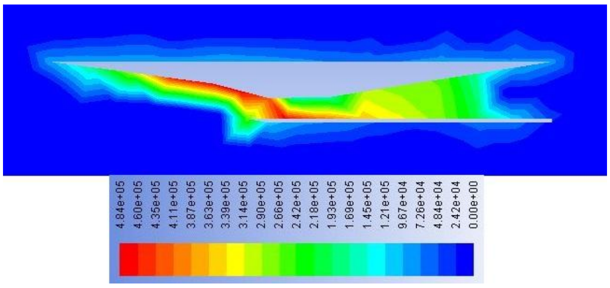

Figure 14: Wall y+ Contour of E2R without MVG

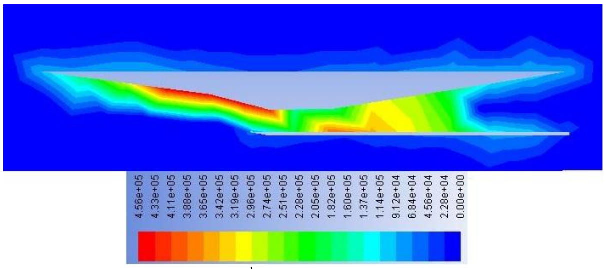

Figure 15: Wall y^+ Contour of E2R with MVG

The boundary layer formation/ Wall y+ graph plot for the actual case and inlet with MVG is shown in Fig.16, the graph cleared that inlet with MVG have depressed the boundary layer.

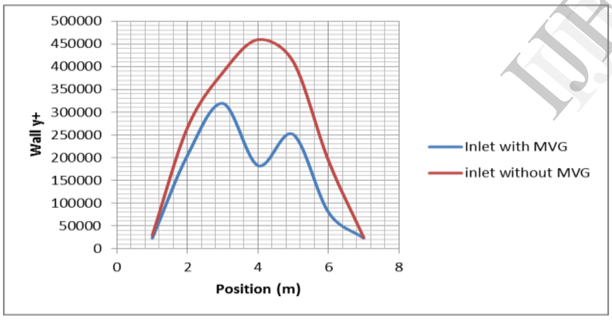

Figure 16: Wall y+ Comparison Graph of E2R with and without MVG

5.4 Pressure Contours Comparison

On comparing the result of pressure, the inlet with MVG, by controlling SWBL and adverse pressure gradient has higher pressure ratio than the inlet without MVG. The comparison graph plot for pressure vs. position of engine is shown in Fig.7. This shows the scramjet engine with MVG have good pressure recovery

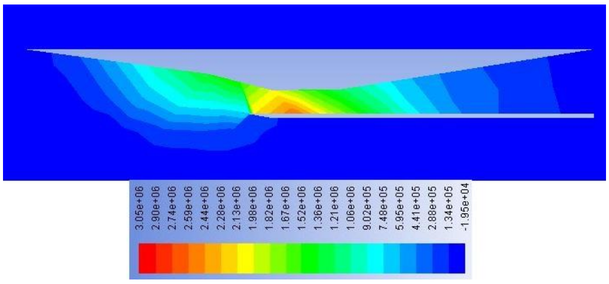

Figure 17: Pressure Contour of E2R with MVG

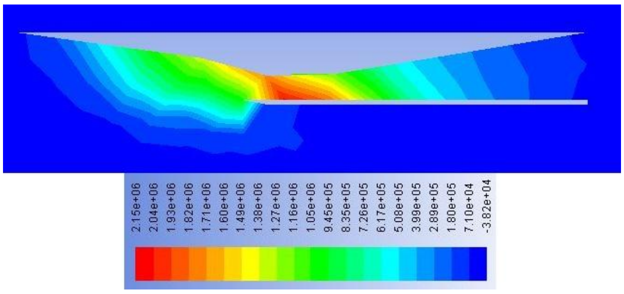

Figure 18: Pressure Contour of E2R without MVG

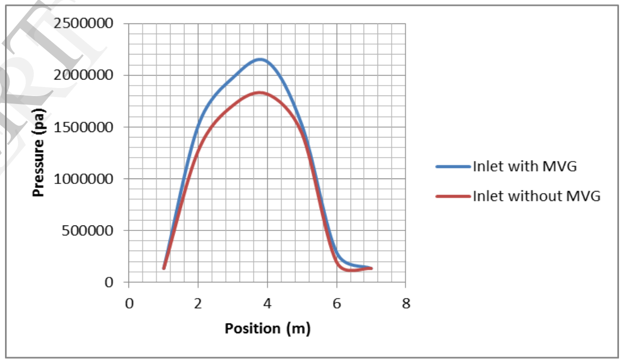

Figure 19: Pressure Comparison Graph of E2R with and without MVG

From the discussion it's cleared that for the effective combustion process, the required raise in pressure and temperature with reduced Mach is obtained by use of MVG at the inlet and compared result is given in the Table 2.

	Scramjet Engine	
	With MVG	**Without MVG**
Compression ratio	11.3	9.49
Mach (M_3)	2.35	2.70
Temperature, T_3 (K)	1301.7	1275.52
Cyclic static temperature	3.94	3.86

Table 2: Result obtained

6. Conclusions

The flow features of the scramjet engine have been analysed using computational fluid dynamics for the two cases, the inlet with micro vortex generator and without. The inlet with MVG controls the shock-wave/boundary-layer interactions.

1. By the use of MVG, the shock wave boundary layer interaction has found to be smooth and there is also considerable increase in temperature, pressure, compression and cyclic static temperature ratio, which leads to effective combustion.
2. By controlling the fluid flow, flame holding is stabilized in the combustion chamber were the performance of combustion is enhanced than actual case.

7. References

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