Computational analysis of Scramjet Isolator with effects of Bleed air

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Abstract

Scramjet Isolator's main function is to decelerate the high-speed flow within the scramjet engine and stabilize the flow before it enters the combustor to a suitable condition. The difference in pressure due to combustion will spread forward and may impact the isolator flow area. This resulted in the inlet region creating "Un-start" status. To prevent this state of un-starting, the insulator will be built to keep the shock train inside the isolator. Indeed, insulator leads to extra weight and viscous drag which greatly affects scramjet engine performance. For the impact of divergent angle or Bleed air, and so on, shorter insulator should be used to reduce the extra weight. This thesis deals with the theoretical analysis of scramjet isolator efficiency by injecting bleed air into the inside of the isolator flow. Testing was conducted at the inlet Mach number M=1.3 and by injecting the bleed air for different Mach numbers (0.3, 0.35, 0.4). Comparisons were made with various cases and with the base model as well. The models were developed using CATIA V5, and the research was carried out using the software program ANSYS Workbench. The bleed air insulator is best able to obstruct the inlet Un-start condition due to the shock train

Key words: Isolator, Shock train, Bleed Air, un-start

Introduction

A scramjet engine allows a car to reach hypersonic speeds as its combustion takes place at supersonic speeds. The turbojet engine has rotating components which restrict its maximum velocity. The airflow inside the engine should not slow down to maximum velocity. An development from the turbojet engine toward this idea is the ramjet engine, in which the spinning components are omitted. When the aircraft travels at hypersonic level, there is no drastic slowing down of the airflow inside the car. The insulator is a critical component in a scramjet engine. It allows the supersonic flow to reach the necessary combustion energy. The isolator helps the combustor to produce the necessary heat and to regulate the combustor pressure without causing a state called "Inlet Un-start" in which the shock train prevents airflow into the isolator. The isolator's function is to insulate the inlet from the combustor. Without this critical part, the engine can enter un-start condition resulting in airflow disgorgement from the combustor and out of the inlet. That would result in enormous thrust loss.

Inside the isolator the shock train forms moves along the length of the isolator through the presence of strong shock wave, the separation of boundary layers and an over-expansion phase. To avoid disgorgement the shock train's departure pressure will be greater than the combustor's back pressure. This is a schematic view of the shock train insulator.

Waltrup and Billig conducted studies on the creation of shock trains in cylindrical ducts. They explain how the shock train grows within a cylindrical duct for supersonic movement, by removing the boundary layer within the duct. If the pressure change with a weak oblique shock is adequate to break the boundary layer, and the total rise in the pressure of the duct becomes higher, a repetitive sequence of reflecting shocks develops to achieve this increase in pressure. Stockbridge has been studying the creation of shock trains within an annular duct. It was determined that an isolator duct of adequate length was required to prevent a combustion-generated shock system from propagating upstream in a supersonic stream and disturbing the air inlet's external flux. Dutton and Carroll performed studies on rectangular ducts undergoing chaotic encounters with several shocks at the

boundary layer. The techniques used were imaging of spark Schlieren, simulation of the surface oil flow, and laser Doppler Velocimetry as well. The flow was checked at the entrance with mach numbers M=1.6 and 2.45.

Modeling and Simulations

This research is an attempt to explore the effects of bleed air on the scramjet insulator in a numerical way. The key aim of this bleed air is to reduce shock train control in order to prevent an inlet un-start state. The geometry setup was performed using CATIA V5 program, and the grid generation component was performed using ANSYS Workbench.

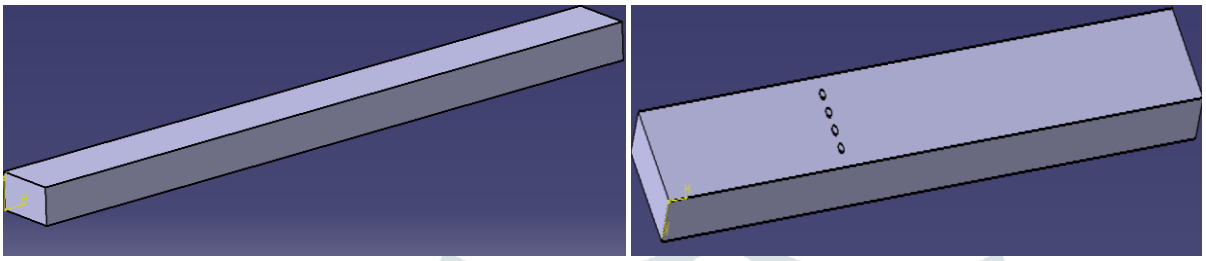


Figure 1. Scramjet Isolator with and without bleeds

The unstructured 3-dimensional mesh was used for measuring the flow within the device. Given the complexity of the research, unstructured mesh is sufficient. The mesh was analyzed after the meshing process to test their consistency.

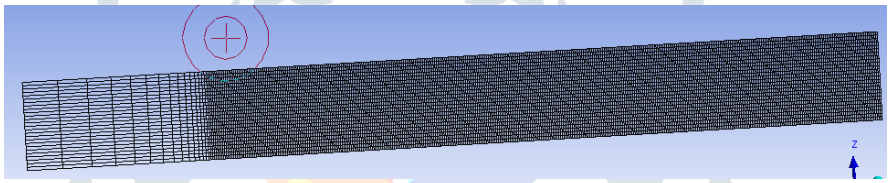


Figure 2. Mesh over the domain

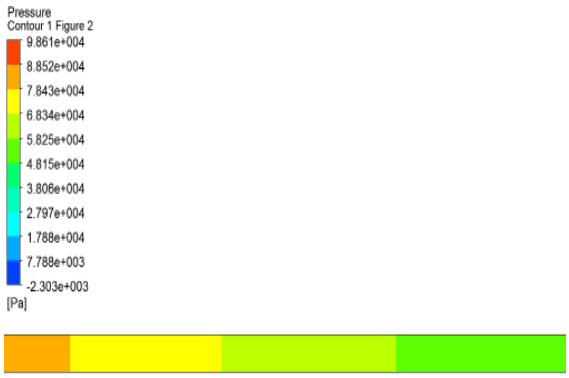
To solve numerically, the meshed model was imported in to CFX. The model of the solver formulation turbulence is k-epsilon, control parameters of the boundary condition solution and defining the material properties. After defining all of the parameters the code was initialized. The findings achieved have been checked and evaluated.

Results and Discussions

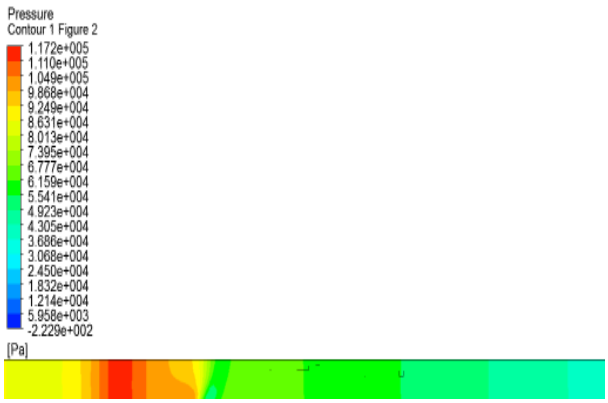
The effect of bleed air isolator is measured without bleed air to the insulator. The debates centered primarily on the transfer of energy within the isolator. The test was carried out with three different inlet Mach number numbers as 0.3, 0.35, 0.4 with two different versions.

Pressure contour

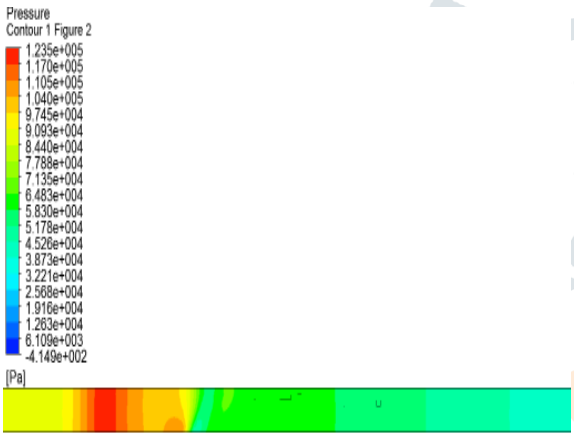
Without bleed air



With bleed air at M=0.3



With bleed air at M=0.35



With bleed air at M=0.4

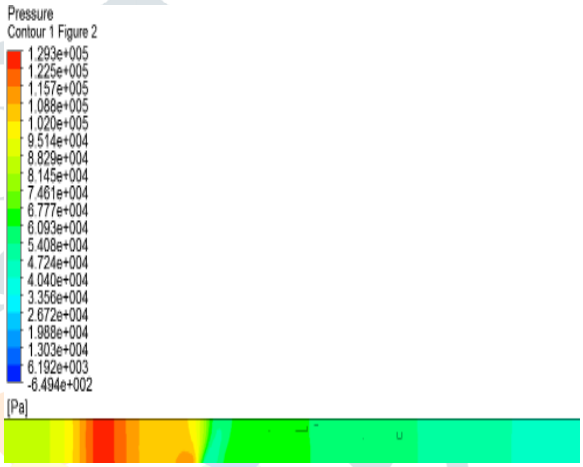


Figure 3. Pressure contour for Isolator for different Mach numbers

Pressure distribution inside the scramjet isolator is shown in figure 3. The figure shows the comparison between the with and without bleed configurations. There is very slight build up in pressure is observed for the without bleed configuration. But, with bleed configuration show considerable amount of increase in pressure in the flow direction near to the bleed inlets. N the downstream location there is no significant difference is observed. The magnitude of the pressure rise falls considerably with the bleed air Mach number. Although the introduction of bleed helps to increase pressure the Mach number has negative effect on the overall impact on the performance.

Mach number contour

Without bleed air

With bleed air at M=0.3

With bleed air at M=0.35

With bleed air at M=0.4

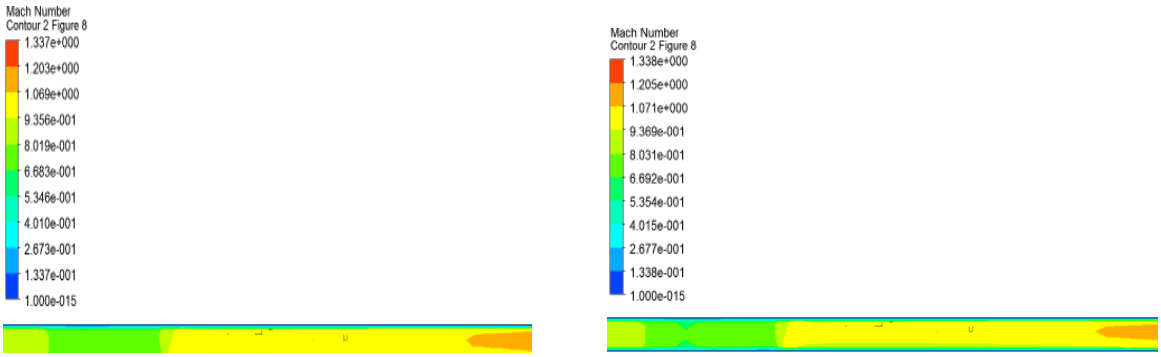
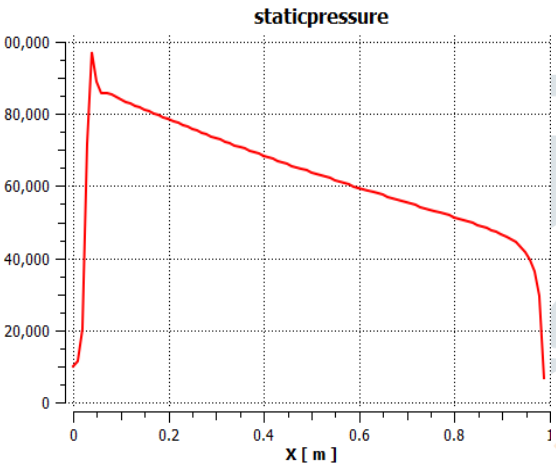


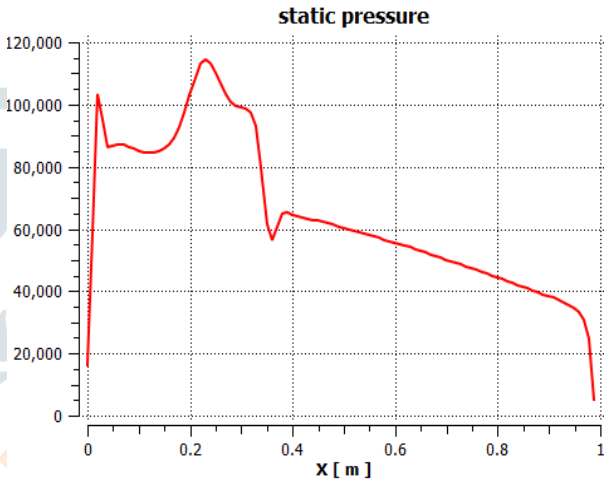
Figure 4. Mach number contour for Isolator for different Mach numbers

Static Pressure curve

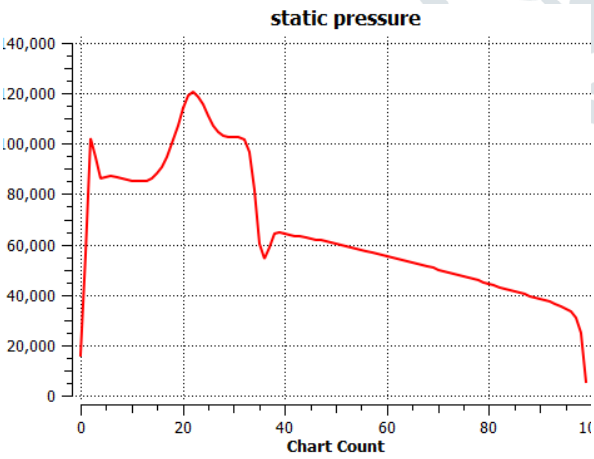
Without bleed air



With bleed air at M=0.3



With bleed air at M=0.35



With bleed air at M=0.4

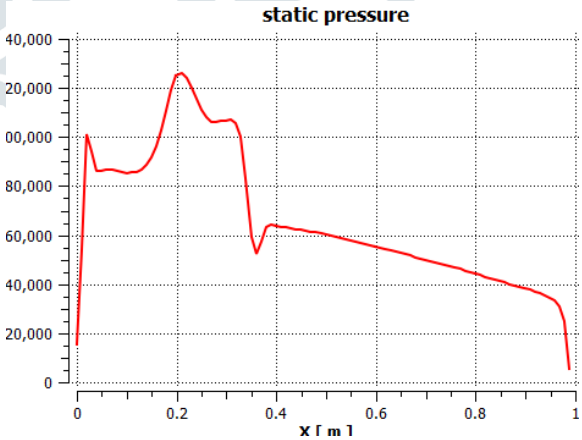


Figure 5. Static Pressure chart for Isolator with different Mach numbers

Mach number contours are shown in figure 4. It shows the effect of bleed air on the flowfield. It can be seen that the introduction of bleed air reduces the Mach number of the internal flow at the immediate upstream location. But, later in the far downstream location there is small expansion region is observed. This expansion region balances the Mach number reduction and reaccelerate the flow to higher Mach number. It also ensures that at the exit there will be no loss of Mach number to the flow.

The static pressure distribution along the centerline of the isolator presents a great insight into the flow field that is shown in figure 5. The maximum static pressure achieved for the non-bleed isolater 80KPa. But due to the introduction of bleed air there is a huge increase in maximum pressure is obsereve. The maximum pressure achieved with bleed 0.3 Mach number is closer to 180KPa. But in the case of 0.35 and 0.4 Mach case the maximum pressure achieved is 120KPa and 123KPa respectively. This concludes that the increase in Mach number of the bleed flow has a negative impact on the static pressure rise achieved inside the isolator.

Conclusions

This proposal suggests solutions for raising the insulator's length without compromising the isolator's original function. By reducing the isolator length we can reduce weight gain in the scramjet motor. From the findings it is inferred that the surface pressure residual temperature and density decreases across the shock line. In addition the number of Mach diminishes. The shock train gets disturbed while introducing bleed air into the isolator, and thus the number of Mach is reduced after that area. These achieve the subsonic velocity required for combustion.

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