International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 1, January- 2013

Analysis of Scramjet Engine With And Without Strut

S. Ramkumar[1], M. S. Vijay Amal Raj[2], Rahul Mahendra Vaity[3]
1.Assistant Professor NIT Coimbatore,
2. U.G.Student, NIT Coimbatore
3.U.G.Student MVJ College of Engineering, Bangalore

Abstract

The major challenge in scramjet engine is the flame holding as the engine is operated at higher Mach number. This is intended to stabilize the flame for the scramjet combustor by using a strut. The strut is designed using GAMBIT and the designed strut is of aerodynamic shape so that there will be some interaction of shocks which will leads to a good mixing of fuel. The fuel used here is having the ability to be auto ignited at certain temperature so there is no need of separate igniters to be used. The deceleration of the flow needed for combustion is achieved through this strut. During this process, a localized subsonic region is formed and holds the flame through the strut. The designed strut is then analyzed in fluent in finding out the proper region for the fuel to be injected. The combustion analysis is done during injection, with combustion, without combustion and their temperature, pressure and Mach number also analyzed to check whether the designed strut is able to sustain the combustion

1. Introduction

The desire for faster response times or cheap access to space drives both government program requirements and industry driven innovation in propulsion. Applications such as rapid transportation, ballistic missile defiance, long range strike, or air breathing access to space continue to push the envelope in terms of altitude and airspeed. Today, turbine engines power most high speed aircraft, but they can no longer be expected to provide the primary source of air-breathing propulsion as speed and altitude requirements increase [36].

There are several key issues that must be considered in the design of an efficient fuel injector. Of particular importance are the total pressure losses created by the injector and the injection processes that must be minimized since the losses reduce the thrust of the engine. The injector design also must produce rapid mixing and combustion of the fuel and air. Rapid mixing and combustion allow the combustor length and weight to be minimized, and they provide the heat release for conversion to thrust by the engine nozzle. The fuel injector distribution in the engine also should result in as uniform a combustor profile as possible entering the nozzle so as to produce an efficient nozzle expansion process. At moderate flight Mach numbers, up to Mach 10, fuel injection may have a normal component into the flow from the inlet, but at higher Mach numbers, the injection must be nearly axial since the fuel momentum provides a significant portion of the engine thrust. Intrusive injection devices can provide good fuel dispersal into the surrounding air, but they require active cooling of the injector structure. The injector design and the flow disturbances produced by injection also should provide a region for flame holding, resulting in a stable piloting source for downstream ignition of the fuel. The injector cannot result in too several local flow disturbance, that could result in locally high wall static pressures and temperatures, leading to increased frictional losses and severe wall cooling requirements. A number of options are available for injecting fuel and enhancing the mixing of the fuel and air in high speed flows typical of those found in a scramjet combustor.

Two-dimensional coupled implicit NS Equations and the standard k- turbulence Equation was analyzed by K.M.Pandey and K.Sivasakthivel model and they also analyzed finite-rate/eddy-dissipation reaction model to simulate numerically the flow field of the scramjet combustor and have applied to the flow field of the hydrogen fuelled scramjet combustor with a planer strut flame holder under two different working conditions, namely, cold flow and engine ignition. The obtained results show that the numerical method used in this paper is suitable to simulate the flow field of the scramjet combustor.

Takashi Niioka et.al has studied on flame holding using strut and he worked on it, the strut is divided into two parts and he established that the flame stabilization is possible in the subsonic region in between the gap of the struts.

The detailed study of the journal “Hypersonic air breathing propulsion” of AIAA education series shows that the perpendicular fuel injection increases the mixing efficiency of the scramjet combustor in scramjet engine

Work carried out on scramjet combustor by Kyung Moo Kim et.al on Numerical study on supersonic combustion with cavity-based fuel injection”, and their findings are,”When wall angle of cavity increases, the combustion efficiency is improved, but total pressure loss increased. When the offset ratio of upper to downstream depth of the cavity increases, the combustion efficiency as well as the total pressure loss decreases”.

Detailed analysis done by Yuan shengxue on the topic of “supersonic combustion”, and his findings are – “The calculation of deflagration in supersonic flow shows that the entropy increment and the total pressure loss of the combustion products may decrease with the increase of combustion velocity. The oblique detonation wave angle may not be controlled by the wedge angle under weak under driven solution conditions and be determined only by combustion velocity”.

2. Strategy of CFD

Broadly, the strategy of CFD is to replace the continuous problem domain with a discrete domain using a grid. In the continuous domain, each flow variable is defined at every point in the domain. For instance, the pressure p in the continuous 1-D domain would be given as

$P = p(x), 0 < x < 1$ [44]

In the distance domain, each flow variable is defined only at the grid points. So, in the discrete domain shown below, the pressure would be defined only at the N grid points.

$p_i = p(x_i), I = 1, 2, \ldots\ldots, N$ [44]

In a CFD solution, one would directly solve for the relevant flow variables only at the grid points. The values at other locations are determined by interpolating the values at the grid points.

The governing partial differential equations and boundary conditions are defined in terms of the continuous variables p, $\vec{V}$ etc. one can approximate these in the discrete domain in terms of the discrete variables p_i, $\vec{V_i}$ etc. the discrete system is a large set of coupled, algebraic equations in the discrete variables. Setting up the discrete system and solving it involves a very large number of repetitive calculations and is done by the digital computer.

This idea can be extended to any general domain.

printed material, including text, illustrations, and charts, must be kept within a print area of 6-1/2 inches (16.51 cm) wide by 8-7/8 inches (22.51 cm) high. Do not write or print anything outside the print area. All *text* must be in a two-column format. Columns are to be 3-1/16 inches (7.85 cm) wide, with a 3/8 inch (0.81 cm) space between them. Text must be fully justified.

A format sheet with the margins and placement guides is available as both Word and PDF files as <format.doc> and <format.pdf>. It contains lines and boxes showing the margins and print areas. If you hold it up to the light, you can easily check your margins to see if your print area fits within the space allowed.

3. Boundary conditions

The boundary conditions given in the GAMBIT were maintained and the input values were given. These values are given in the table below.

Table 1: boundary conditions

VARIABLES	AIR	HYDROGEN GAS
Mach number (M)	3	1
Total Pressure(Po) in pascal	20000	101325
Density (ρ) in kg/m3	1.002	.097
Mass flow rate in Kg/s	1.5	.004
Temperature in K	473	300

4. Analysing the strut without fuel injection

The strut is first analyzed without the injection of the hydrogen fuel. During this procedure, the boundary condition of the fuel inlet was changed from mass flow inlet to wall. This ensures that no fluid will pass through these faces. The flow was initialized with the air inlet and the coupled type of solving was used for the iteration, as this would decrease the convergence time.

The iterations were performed and the residuals for convergence was set to $1e^{-6}$. The following results were obtained when the solution converged. The contours of pressure and other entities are given in the figures below.

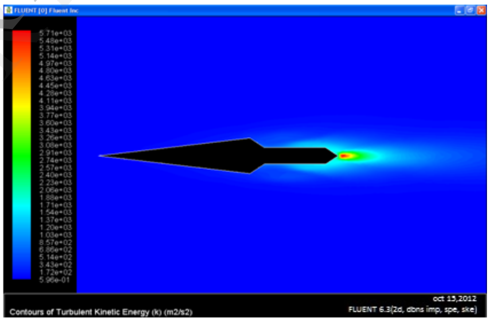


Figure 1: variation of turbulent kinetic energy

uthor names and affiliations are to be centered beneath the title and printed in Times 12-point, non-boldface type. Multiple authors may be shown in a two- or three-column format, with their affiliations italicized and centered below their respective names. Include e-mail addresses if possible. Author information should be followed by two 12-point blank lines.

5. Hydrogen injection without combustion

Second analysis of the strut was done by injecting the hydrogen fuel. This will enable us to compare the results from both the conditions. The boundary conditions of the fuel inlet were changed to mass flow inlet with a flow rate of .004kg/s in each of the fuel inlet faces.

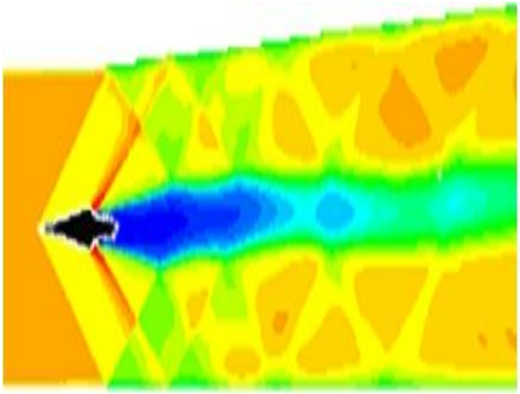
The cold flow (mixing) without combustion is investigated using k-ε model. Inert H2 injection adds significant complexity to the flow in the scramjet combustor since H2 has a considerably lower molar mass than air, which makes mixing an important process in establishing the conditions for scramjet combustion.

Species and transport was turned on in the Define menu and the conditions of the hydrogen injection were given in the mass flow inlets. The mixture was taken as hydrogen-air in the mixture template. All the other species such as CO_2, NOX and H_2O were removed from the fluid and mixture template. The density was changed from incompressible gas to ideal gas for both the fluids. The flow was initialized from the air inlet. The iterations were performed and the residuals for convergence were set to $1e^{-6}$. The following results were obtained when the solution converged. The contours of pressure and other entities are given in the figures below.

Figure 2: Mach No variation over strut and combustor wall

6. Hydrogen injection with combustion

Mixing of fuel and air is described in the previous section, it forms a combustible mixture, which is ignited, leading in turn to the combustion of the fuel. The exothermicity resulting from the chemical reactions will likely alter the flow field due to density and temperature changes. Fig below shows the combustion by means of a velocity, blue streamlines representing the hydrogen injection and pressure gradients for the shocks.



Due to combustion the recirculation region behind the wedge becomes larger as compared to mixing case and it acts as a flame holder for the hydrogen diffusion flame.The leading edge shock reflected off the upper and lower combustor walls facilitatesthe on setting of combustion when it hits the wake in a region where large portions of the injected fuel have been mixed up with the air.

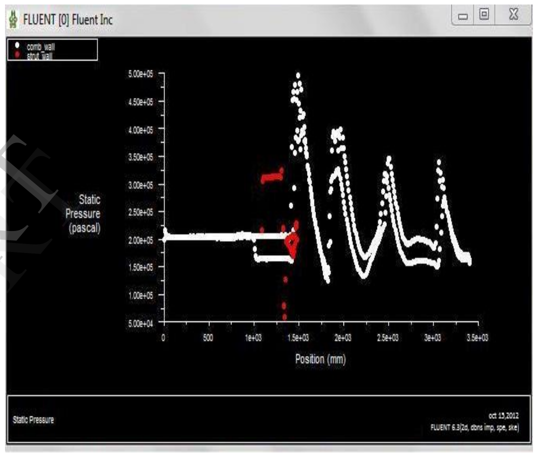


Fig 4: static pressure over strut and combustor wall

6. Results and conclusion

The results obtained from the analyses done in FLUENT for the strut which is drawn in GAMBIT to stabilize the flame in scramjet combustor are compared in the section below.

The two-dimensional coupled implicit RANS equations, the standard k-ε turbulence model and the finite-rate/eddy-dissipation reaction model are introduced to simulate the flow field of the hydrogen fueled scramjet combustor with a strut flame holder under different conditions, namely the cold flow and the engine ignition. We observe the following:

The numerical method employed in this paper can be used to accurately investigate the flow field of the scramjet combustor with planer strut flame holder, and capture the shock wave system reasonably.

PRESSURE:

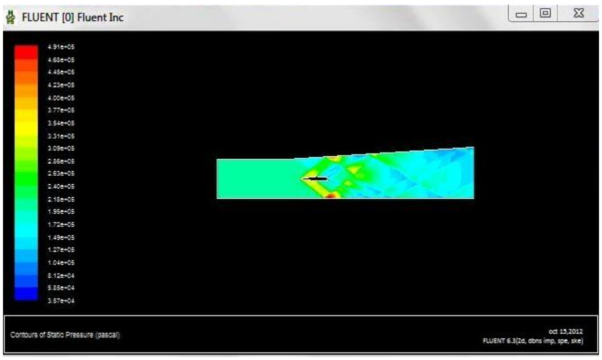


Fig.5: static pressure contour under cold flow mixing

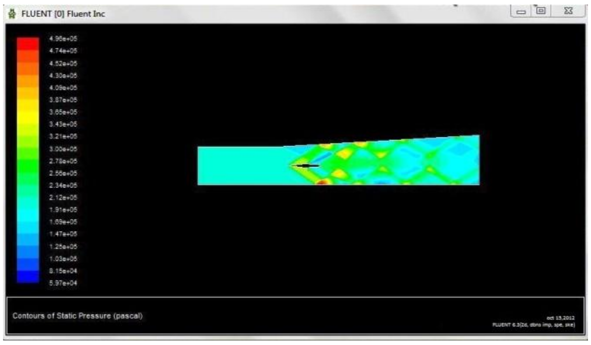


Fig.6: static pressure under the hydrogen combustion

The static pressure of the case under the engine ignition condition is much higher than that of the case under the cold flow condition due to the intense combustion process.

TEMPERATURE

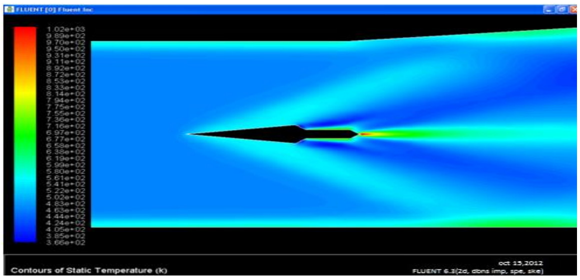


Fig.7: Contours of static temperature before fuel injection.

MACH NUMBER

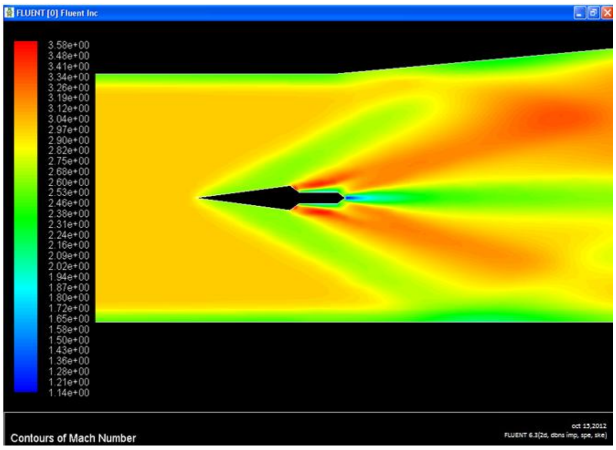


Fig.8 : Mach no contour without fuel injection

In the above contour we can clearly see that no subsonic regions are created in the flow over the strut. Only low supersonic velocities are created.

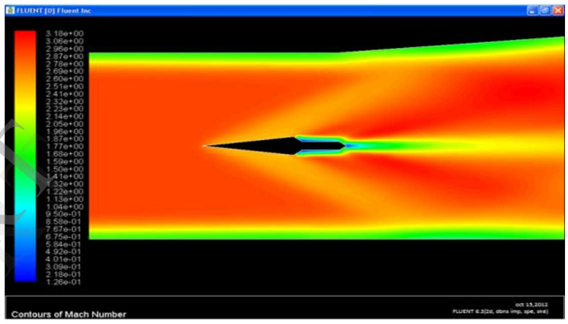


Fig.9: Contours of mach no with fuel injection

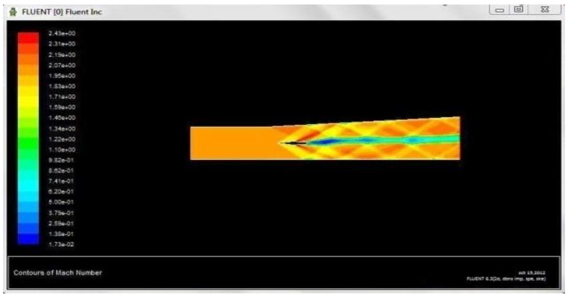


Fig.10: contours of mach no when hydrogen is ignited.

From the above figure we can notice subsonic region of extremely low velocities. The creation of these subsonic velocities may be due to the shock and hydrogen stream interaction, this also creates high temperature after fuel injection due to the localized deceleration of the flow. Subsonic velocity is needed for flame holding in a supersonic combustor. Here subsonic regions are created. This subsonic region does not affect the remaining parts of the flow.

Combustion efficiency:

$$\eta = \frac{\text{mass flow rate of fuel given at the inlet in (g/s)}}{\text{mass flow rate of fuel burned during combustion in (g/s)}}$$

$$\eta = 0.0015/0.0037 = 40.5\%$$

The results show that both high temperature and subsonic regions are created in the same region behind the strut. And fine mixing of the hydrogen particles are also in the same region. This clearly shows that the region beyond the strut is well suitable for the auto ignition.

During combustion the recirculation region behind the strut becomes larger as compared to mixing case and it acts as a flame holder for the hydrogen diffusion flame.

Hence the designed strut will hold the flame and sustain the ignition.

7. References

REFERENCES

[1]“Cavity Flame-Holders for Ignition and Flame Stabilization in Scramjets”: An Overview Adela Ben-Yakar and Ronald K. Hanson, “Journal of propulsion and power”

[2]“CFD Analysis of Mixing and Combustion of a Scramjet Combustor with a Planer Strut Injector” by K.M.Pandey and Sivasakthivel.

[3]“Scramjet combustor development” Dr. Satish Kumar & Team HSTDV,DRDL, Hyderabad.

[4]“Hypersonic Aerothermodynamics” by John J. Bertin, AIAA Education series.

[5]“Hypersonic Airbreathing Propulsion” by William.H. Heiser and David.T.Pratt, AIAA education series.

[6] “Flame stabilization Characteristic of strut divided into two parts in supersonic flow”, by Takashi Niioka et al., Journal of propulsion and power, Vol 11 1995

[7]“Modern compressible flow” by John.D.Anderson