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# Mathematical Modeling and Analysis of Different Type of Fuel Injector in Scramjet Engine Using CFD Simulation in Fluent

Santosh Kumar Dixit[1], Rohit Kumar Choudhary[2], Suresh Badholiya[3]
*Department of Mechanical Engineering, B.I.T.S college, Bhopal.*

***Abstract : At Present the most promising propulsive systems, the scramjet engine has drawn the attention of many researchers. The two-dimensional coupled implicit NS equations, the standard k-ε turbulence model and the finite-rate/eddy-dissipation reaction model have been applied to numerically simulate the flow field of the hydrogen fuel scramjet combustor with a different type of fuel injector like single wall, double wall and Pylon structure is compare with the basis of Temperature, Pressure and velocity variation, Mass fraction of H2, O2 & H2O and total energy. The results obtained by CFD simulation shows that the numerical method used in this study is suitable to simulate the flow field of the scramjet combustor. At last we analyse the pylon type fuel injector and conclude that this type of injector give the best results as compare to other. Temperature is increased by almost 35% as compared to previous one. Pylon injector provides better mixing of air-fuel and complete combustion in efficient manner due to this energy is increased and emission is reduced. From this study we can conclude that Pylon type of injector may solve the recent problem of scramjet combustor in use and this analysis shows the solution regarding stabilized flow. From flow phenomenon we can see the stability of flow which is the major problem with planer strut injector as which provide limitation in Mach no of engine but may give continuous flow and combustion through the flight. The eddy generated in the pylon acts as a flame holder in the combustor, and it can prolong the residence time of the mixture in the supersonic flow.***
***Keywords - CFD, Scramjet Engine, Mach number, Pylon Injector, Wall Injector, Strut Injector, Ansys etc.***

## I. INTRODUCTION

A. Mixing, Ignition and flame holding in a scramjet combustor Among the critical components of the scramjet engine, the combustor presents the most formidable problems. The complex phenomenon of supersonic combustion involves turbulent mixing, shock interaction and heat release in supersonic flow. The flow field within the combustor of scramjet engine is very complex and poses a considerable challenge in design and development of a supersonic combustor with an optimized geometry. Such combustor shall promote sufficient mixing of the fuel and air so that the desired chemical reaction and thus heat release can occur within the residence time of the fuel -air mixture. In order to accomplish this task, it requires a clear understanding of fuel injection processes and thorough knowledge of the processes governing supersonic mixing and combustion as well as the factors, which affects the losses within the combustor. The designer shall keep in mind the following goals namely, •Good and rapid fuel air-mixing •Minimization of total pressure loss •High combustion efficiency. Hydrogen should be injected in such a way that a good mixing is achieved over a short length resulting in a homogeneous temperature distribution. Local temperature peaks have to be avoided as to keep dissociation losses and nitrogen oxides low. An important issue at low Mach numbers of a scramjet is auto-ignition. Due to relatively low air static temperatures this may become a problem for axial strut injectors which only induce weak shock waves and small recirculation zones down normal shock waves may cause problems for a stable ignition. Four different modes of combustion may be distinguished for strut injectors:

### *A. cramjet engines*

A scramjet (supersonic combustion ramjet) is a variant of a ramjet air breathing jet engine in which combustion takes place in supersonic airflow. As in ramjets, a scramjet relies on high vehicle speed to forcefully compress and decelerate the incoming air before combustion (hence ramjet), but whereas a ramjet decelerates the air to subsonic velocities before combustion, airflow in a scramjet is supersonic throughout the entire engine. This allows the scramjet to operate efficiently at extremely high speeds: theoretical projections place the top speed of a scramjet between Mach 12 (9,100 mph; 15,000 km/h) and Mach 24 (18,000 mph;

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29,000 km/h).

The scramjet is composed of three basic components: a converging inlet, where incoming air is compressed and decelerated; a combustor, where gaseous fuel is burned with atmospheric oxygen to produce heat; and a diverging nozzle, where the heated air is accelerated to produce thrust. Unlike a typical jet engine, such as a turbojet or turbofan engine, a scramjet does not use rotating, fan-like components to compress the air; rather, the achievable speed of the aircraft moving through the atmosphere causes the air to compress within the inlet. As such, no moving parts are needed in a scramjet.

In comparison, typical turbojet engines require inlet fans, multiple stages of rotating compressor fans, and multiple rotating turbine stages, all of which add weight, complexity, and a greater number of failure points to the engine.

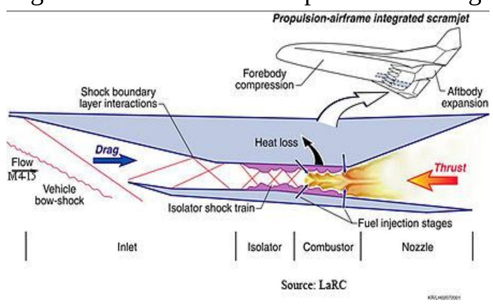


Fig.1.1 – Integral Parts of a Scramjet Propulsion system

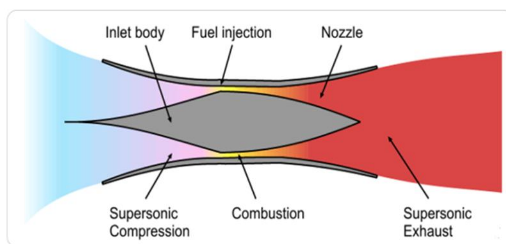


Fig.1.2- Basic Components of Scramjet

Scramjet injectors: Mixing, ignition and flame holding in combustor, ground test facilities and numerical simulation of Scramjet engine are the critical challenges in the development of scramjet engine.

Wall Injectors:- Where hydrogen is injected through the wall [18–20] (normal or oblique to the main flow) or by ramps [21–23] mounted to the wall,

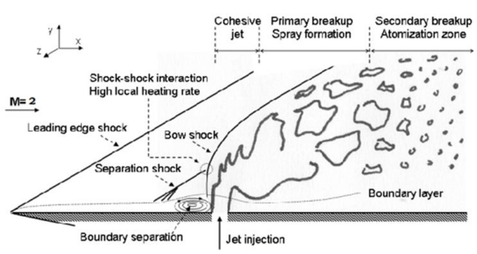


Fig1.3 - Wall Injector

Wall injectors are simpler to design then other injection methods, but result in a relatively complex flow pattern. It involves a round or elliptic hole through a flat plate though which fuel is injected into the air stream. However, one of the real issues of well infusion is the measure of gaps likewise assumes a part in deciding the ignition. On the off chance that openings are set too far separated from one another, the energy flux per unit frontal region diminishes, because of the inadequate aggravation from the infused fuel. On the other hand, if openings are set excessively near one another, there could emerge issues identifying with development of the stream owing to inadequate space. The range of the openings likewise have influence, with a grater clear bringing about a diminishing of power on the fuel plane stream ,while expanding the time and separate for accomplishing a given entrance stature,

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when contrasted with fuel infused regularly with the wind. At times, both sorts of injectors approach one another, e.g. on the off chance that an incline injector reaches out over a large portion of the channel stature [23]. A decent tight field blending can be accomplished by divider infusion. Then again transverse infusion frameworks cause a huge blockage of the stream bringing about irreversibility's because of stunning waves and push misfortunes [27]. Another concern is the case that the entrance of the fuel plane may be inadequate for genuine size combustors. In divider injectors no misfortunes altogether weight in the event that they are traded off. The last indicator is interestingly inclined or strut injectors which may not be expelled from the stream field if no hydrogen is infused.

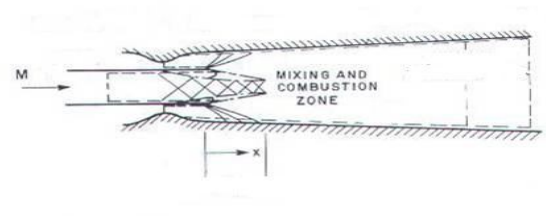


Fig.1.4. Strut Injector

Pylon injection is essentially injection behind a tall, narrow in-stream body, such as shown in Figure 1.2. Injection may be axial, normal, or at some other angle relative to the free stream. Many shapes and angles of injection have been investigated. Vinogradoff. al. [14] experimented with gaseous fuel injection far upstream behind a swept, thin pylon with a various cross sectional pylon shapes. The results showed much improved mixing and penetration, improved flame holding, and a lack of pressure losses and pronounced edge shocks. These results are not typical of earlier work referenced by Paull and Stalker [15], where an advantageous system of shocks from the pylon helped improve mixing but at the sacrifice of pressure losses.

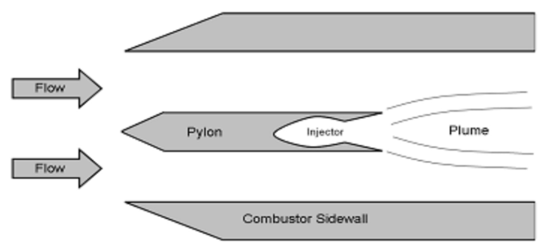


Fig-1.5. Central pylon injector

## II. LITERATURE

Shigeru Aso et.al [1] worked on the topic of “Fundamental study of supersonic combustion in pure air flow with use of shock tunnel”, and their findings are – The increase of injection pressure generated strong bow shock, resulting in the pressure loses. The shock generator is an effective method to accelerate the combustion. The increase of the injection total pressure raises the penetration of fuel; thus, the reaction zone expands to the centre of flow field. K.M.Pandey and Siva Sakthivel. T[2] worked on the topic of “Recent Advances in Scramjet Fuel Injection - A Review”, and their findings are – Fuel injection techniques into scramjet engines are a field that is still developing today. The fuel that is used by scramjets is usually either a liquid or a gas. The fuel and air need to be mixed to approximately stoichometric proportions for efficient combustion to take place. The main problem of scramjet fuel injection is that the airflow is quite fast, meaning that there is minimal time for the fuel to mix with the air and ignite to produce thrust (essentially milliseconds).Hydrogen is the main fuel used for combustion. Hydrocarbons present more of a challenge compared to hydrogen due to the longer ignition delay and the requirement for more advanced mixing techniques. Enhancing the mixing, and thus reducing the combustor length, is an important aspect in designing scramjet engines. There are number of techniques used today for fuel injection into scramjet engines. Kyung Moo Kim et.al [3] worked on the topic of “Numerical study on supersonic combustion with cavity-based fuel injection”, and their findings are – When the 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. Yuan shengxue [4] worked on the topic of “supersonic combustion”, and his findings are – The calculation of deflagration in supersonic flow shows that the entropy increment

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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. Gruenig and F. Mayinger [5] worked on the topic of "Supersonic combustion of kerosene/h2-mixtures in a model Scramjet combustor", and their findings are – The necessary temperature level is partly achieved by the oblique shock waves in the supersonic flow with increasing combustor area ratio. K. Kumaran and V. Babu [6] worked on the topic of "Investigation of the effect of chemistry models on the numerical predictions of the supersonic combustion of hydrogen", and their findings are – Multi step chemistry predicts higher and wider spread heat release than what is predicted by single step chemistry. The single step chemistry model is capable of predicting the overall performance parameters with considerably less computational cost. A better trade off between thrust augmentation and combustion efficiency can be achieved through staged combustion. T. Cain and C. Walton [7] worked on the topic of "review of experiments on ignition and Flame holding in supersonic flow", and their findings are – Low combustor entry temperature is desirable /essential due to intake and nozzle limitations. Hydrogen and hydrocarbon the optimum temperature /pressures are in regions in which ignition delay is very sensitive to temperature, varying from 0.1ms to >>10ms. At low Mach number and static temperatures but at these conditions combustion results in free subsonic regions with very high turbulence. Chemical initiators such as silane, fluorine and OTTO can be used but there are penalties in specific impulse, system complexity and handling hazards. G. Yu, J.G. Li, J.R. Zhao, et al. [8] worked on the topic of "An experimental study of kerosene combustion in a supersonic model combustor using effervescent atomization", and their findings are – The smaller kerosene droplet having higher combustion efficiency. A local high temperature radical pool in the cavity is crucial in promoting the initiation and the subsequent flame holding of the kerosene combustion in a supersonic combustor.

## III. OBJECTIVE OF STUDY

Our main objective of the study is to compare the different type of Fuel Injector in Scramjet combustor in supersonic model. In present study we use Hydrogen as fuel and three type of fuel injector is used which is Single wall injector, Double wall injector and Pylon Injector. Simulation will be done by FLUENT14.5. Comparison will be done with the basis of simulative results like Temperature, Pressure, Velocity Variation, Turbulent kinetic energy, Total energy, Mass fraction of $H_2$, $O_2$ & $H_2O$ etc. CFD model (Flow pattern) will also give the information about Stability of the model that model is stable or not.

## IV. METHOD

### *A. Basic Steps to perform CFD Analysis*

*1)* CAD Modeling: Creation of CAD Model by using CAD modeling tools for creating the geometry of the part/assembly of which you want to perform FEA.CAD model may be 2D or 3d.
*2)* Meshing: Meshing is a critical operation in CFD. In this operation, the CAD geometry is meshed into large numbers of small Element and nodes. The arrangement of nodes and element in space in a proper manner is called mesh. The analysis accuracy and duration depends on the mesh size and orientations. With the increase in mesh size (increasing no. of element), the CFD analysis speed decrease but the accuracy increase. Type of Solver: Choose the solver for the problem from Pressure Based and density based solver. Physical model: Choose the required physical model for the problem i.e. laminar, turbulent, energy, multiphase, etc. Material Property: Choose the Material property of flowing fluid. Boundary Condition: Define the desired boundary condition for the problem i.e. velocity, mass flow rate, temperature, heat flux etc.
*3)* Solution: Solution Method : Choose the Solution method to solve the problem i.e. First order, second order. Solution Initialization: Initialized the solution to get the initial solution for the problem. Run Solution: Run the solution by giving no of iteration for solution to converge.
*4)* Post processing: Post Processing: For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

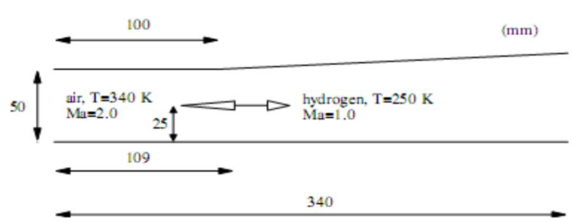

Figure-4.1: Reference model detail

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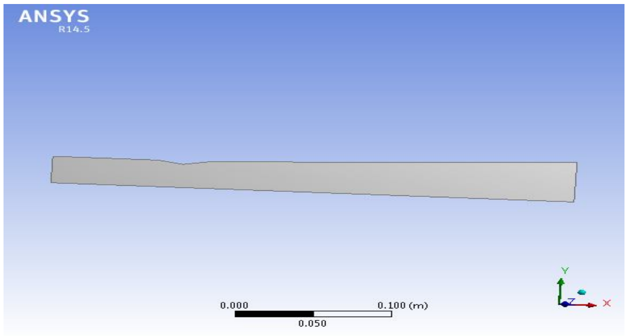


Fig-4.2: 2d ax symmetry model of Single wall Injector

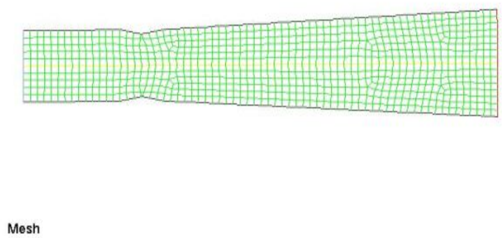


Figure-4.3: Mesh model of single wall Injector

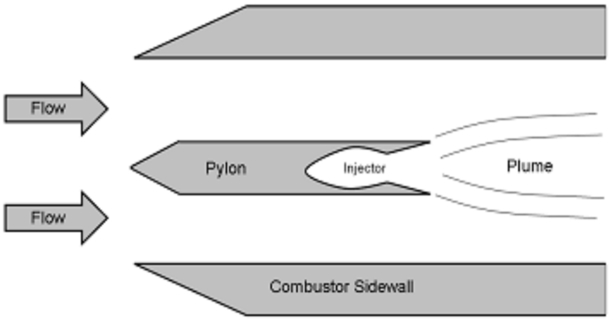


Figure-4.4: Pylon structure

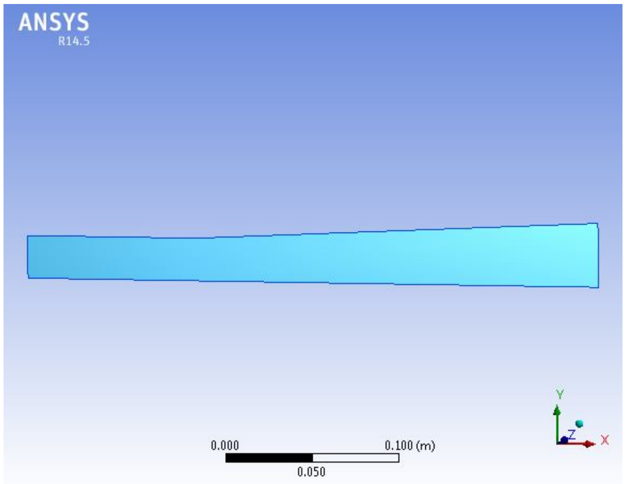


Figure-4.5: 2d Axisymmetry model of Pylon Injector

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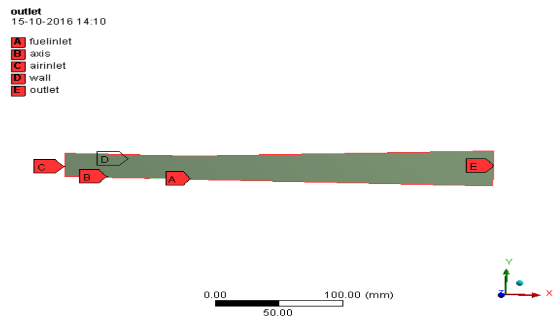
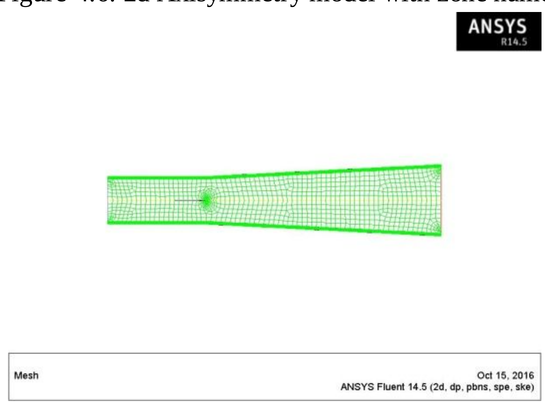



Figure-4.6: 2d Axisymmetry model with zone name




| Type of Injector | Element length (m) | No. of Nodes | No. of Elements |
|---|---|---|---|
| Single Wall | 3.0e-004 | 12356 | 8256 |
| Double Wall | 3.0e-004 | 13524 | 8546 |
| Pylon | 3.0e-004 | 14052 | 8956 |

Table-1: Mesh detail

Mesh Type: grid meshing

Fluent setup: After mesh generation define the following setup in the Ansys fluent. Problem Type : 2D ax symmetric ,Type of Solver: Pressure-based solver.

Physical model: Viscous: K-epsilon two-equation turbulence model. We Use P1, Finite rate/ Eddy dissipation model, Material Property: Flowing fluid is air Density of air = 1.225 kg/m$^3$ Viscosity = 1.7894e-05

Boundary Condition: Operating Condition: Pressure = 101325 Pa

| Variables | Air | $H_2$ |
|---|---|---|
| Ma | 2.0 | 1.0 |
| U (m/s) | 730 | 1200 |
| T (K) | 340 | 250 |
| P (Pa) | 101325 | 101325 |
| Density | 1.002 | 0.097 |
| $Y_{O2}$ | 0.232 | 0 |
| $Y_{N2}$ | .0.736 | 0 |

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| | | |
|---|---|---|
| $Y_{H2O}$ | 0.032 | 0 |
| $Y_{H2}$ | 0 | 1 |
| Mass flow Rate (kg/s) | 1.5 | 0.004 |

*B. Solution*

Solution Method: Pressure- velocity coupling – Scheme–SIMPL, Pressure–Standard, Momentum – Second order, Turbulent Kinetic Energy (k) Second order, Turbulent Dissipation Rate (e) Second order Solution Initialization: Initialized the solution to get the initial solution for the problem.

Run Solution: Run the solution by giving 500 no of iteration for solution to converge. **Post Processing**: For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

## V. RESULTS & DISCUSSION

*A. Pylon Structure*

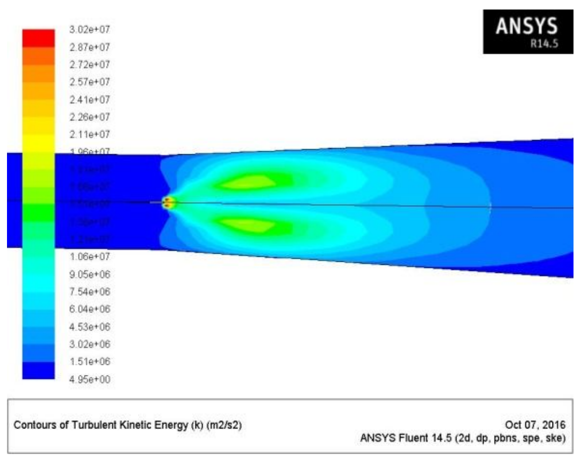


Figure-5.1 Contours of Turbulent Kinetic Energy

As shown in figure the kinetic energy of air gets increase after injection and here the kinetic energy gets increase by oblique shock wave and maximum at injection start and after 25mm after injection as shown near the wall surface which is near 6.42e+07k-m2/s2

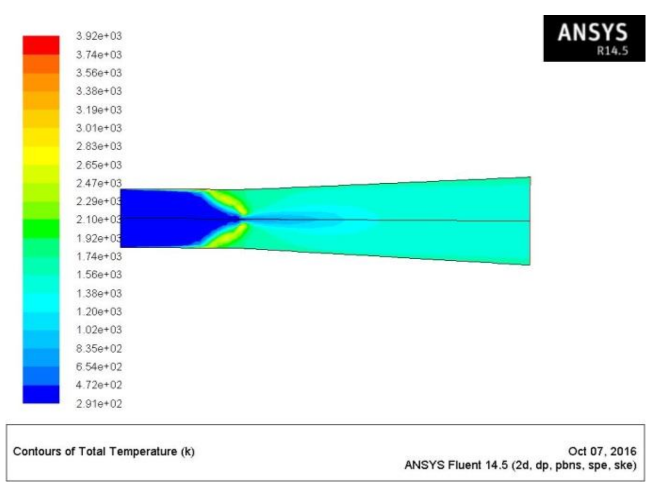


Figure-5.2 Contours of Total Temperature

The total temperature is increased at the time of injection and near the surface of injection but its temperature is in between 3590k near the region of injector after fuel injection done

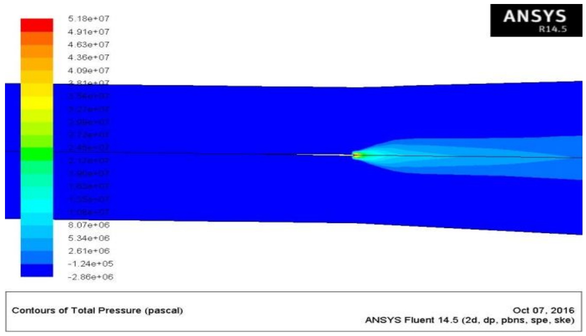


Figure-5.3 Contours of Total Pressure

The total pressure increases after fuel injection from wall injector and total pressure is maximum at the area of injection which is near 2.12e+07 pa and the total pressure remains near same through the axis after ignition.

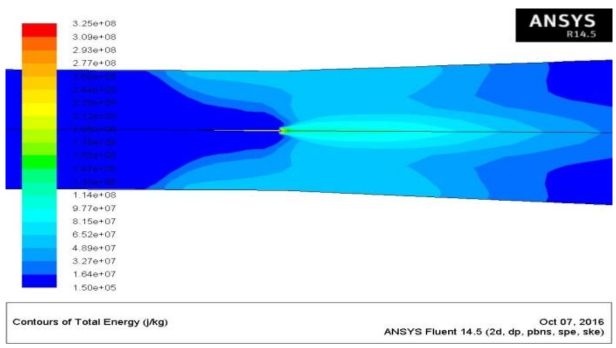


Figure-5.4 Contours of Total Energy

From figure we can see the total energy changes are same in axial direction and which is near same after injection of $h_2$ from wall injector. We find maximum energy of 3.30e+08 j/kg at centre after injection.

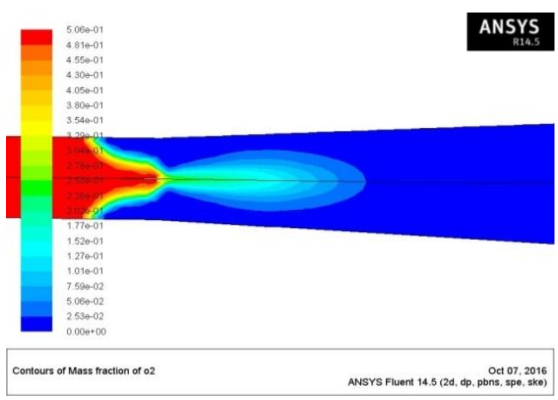


Figure-5.5 Contours of Mass fraction of O2

As analysis shows the O2 mass fraction Increase near the fuel injector and after injection it's the same after injection through the surface from axis through the wall surfaces.  Mass fraction is near the 2.17e-01 through flow.

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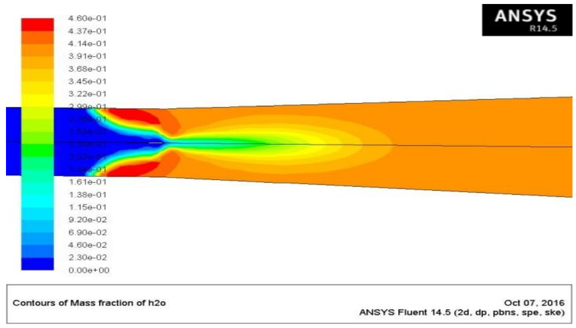


Figure-5.6 Contours of Mass

RESULTS TABLE

TABLE No . 1

| Type of Fuel Injector | Total Temperature (K) | Total Pressure (Pascal) | Turbulent kinetic energy (k-m2/s2) | Total energy (j/kg) | Mass flow rate (Fuel) (kg/s) | Mass flow rate (Air) (kg/s) | Fuel inlet Temp. (K) | Air Inlet Temp. (K) |
|---|---|---|---|---|---|---|---|---|
| Single wall Injector | 3200 | 1.04e+07 | 3.87e+07 | 2.93e+08 | 4.0 | 1.5 | 250 | 340 |
| Double wall Injector | 3590 | 2.12e+07 | 6.42e+07 | 3.30e+08 | 4.0 | 1.5 | 250 | 340 |
| Pylon Injector | 3920 | 5.18e+07 | 3.02e+08 | 3.55e+08 | 4.0 | 1.5 | 250 | 340 |

*B. fraction of H2O*

After $h_2$ gets injected and combustion takes place we find maximum mass fraction of $h_2o$ at the surface near the injector and its near 5.4e-01pbns which shows maximum mass converted to $h_2o$ with reaction to atmospheric air. The mass fraction near the axis after injection is near 7.83e-01pbns which is half the maximum amount of mass fraction in analysis.

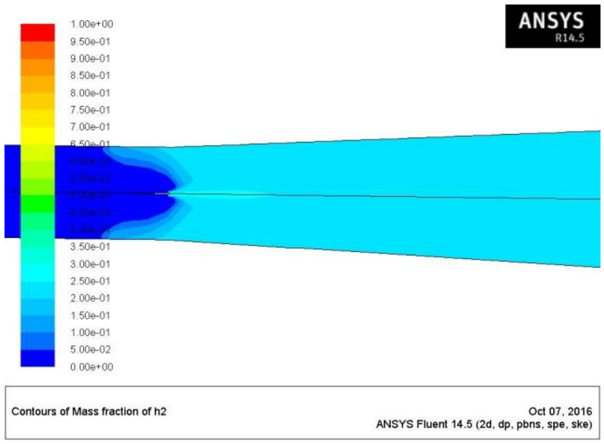


Figure-5.6 Contours of Mass fraction of H2

As analysis shows the h2 mass fraction Increase near the fuel injector and after injection it's the same after injection through the surface from axis through the wall surfaces. Mass fraction is near the 3.50e-01 through flow.

## VI. CONCLUSION

In Present Study we compare the different Geometry of Fuel Injector for Scramjet Engine based better mixing and Combustion of Hydrogen fuel which is analysed by Pressure, Temperature and Velocity variation, mass fraction of H2, O2 & H2O, Turbulent Kinetic Energy ,and Total Energy outcomes. From simulation results we conclude that when we change the geometry from central Injector to single wall injector Temperature is increased and pressure is decreased and total energy is also increased due better mixing and increased combustion rate. In next step we analyse the double wall injector from CFD simulation and conclude that it will give better results as compare to single wall injector. Temperature is increased by 20% , hence energy is increased by large amount and fuel efficiency is increased. At last we analyse the pylon type fuel injector and conclude that this type of injector give the best results as compare to other. Temperature is increased by almost 35% as compared to previous one. Pylon injector provides better mixing of air-fuel and complete combustion in efficient manner due to this energy is increased and emission is reduced.

From this study we can conclude that this type of injector may solve the recent problem of scramjet combustor in use and this analysis shows the solution regarding stabilized flow. From flow phenomenon we can see the stability of flow which is the major problem with planer strut injector as which provide limitation in Mach no of engine but may give continuous flow and combustion through the flight. From pressure and temperature analysis we can decide that Pylon injector provide stability in variation in pressure and temperature though the flow condition. This work may give solution of scramjet research vehicle in terms of correction in stability of combustion and Mach no of engine.

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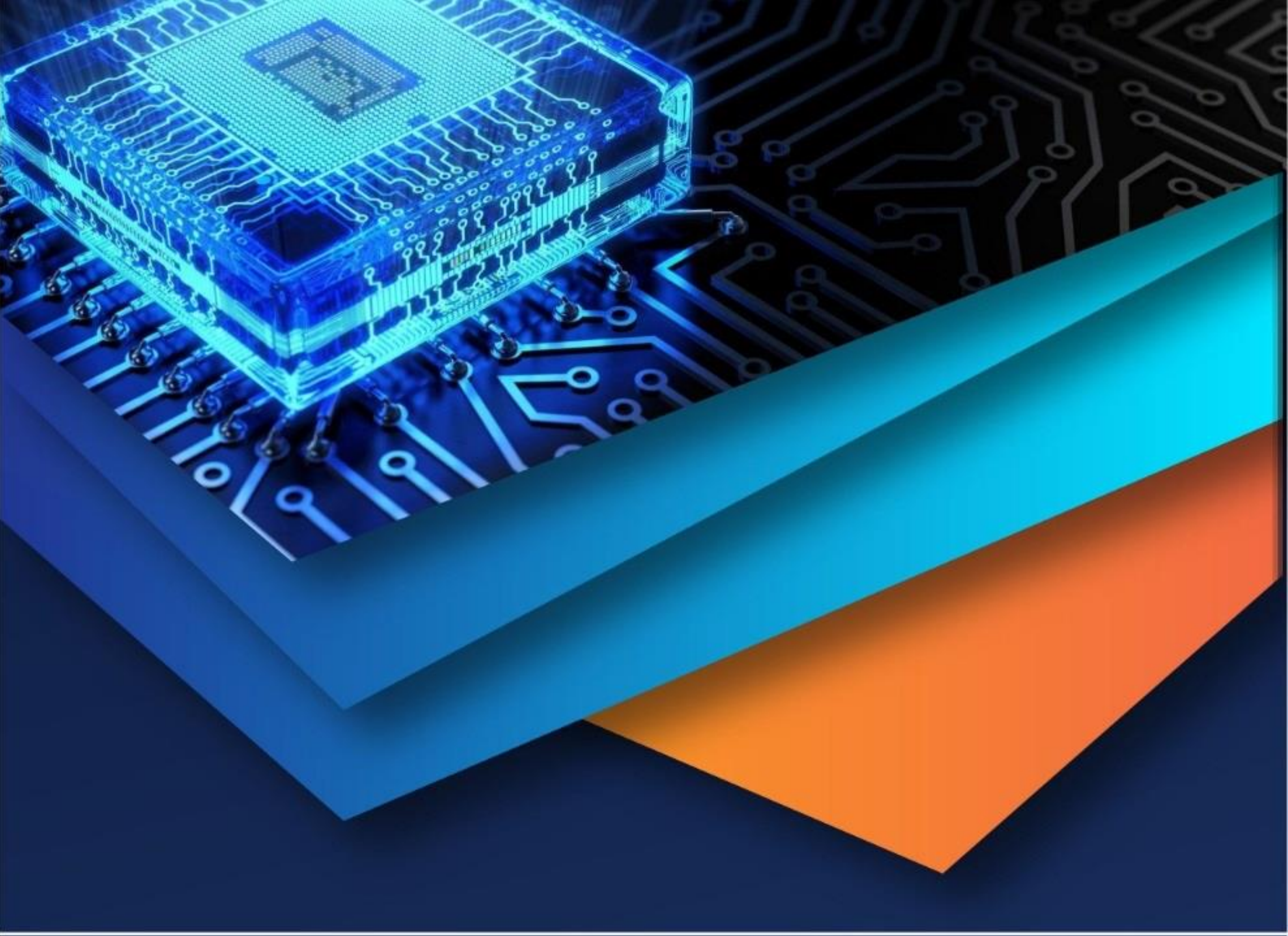


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