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Simulative Study of Jet Combustor with Geometrical variation in Injector using Computational Method

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Abstract: In Current study we simulate the Scramjet combustor with double Wall Injector for rapid mixing of hydrogen fuel and air so that the total energy is increased of combustion. Finally we conclude that double wall type of injector may solve the recent problem of scramjet combustor in use and the analysis shows solution for stabilized flow. From tangential velocity contours 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. We analyse the double wall injector from CFD simulation and it shows that (due to rapid mixing and penetration) better results as compare to single wall injector. Temperature is increased by 25%, hence energy is increased by large amount and fuel efficiency is increased.
Keywords: CFD, Scramjet Engine, Mach number, Double Wall Injector, Strut Injector, Ansys etc.

I. INTRODUCTION

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. Scramjet 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; 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.
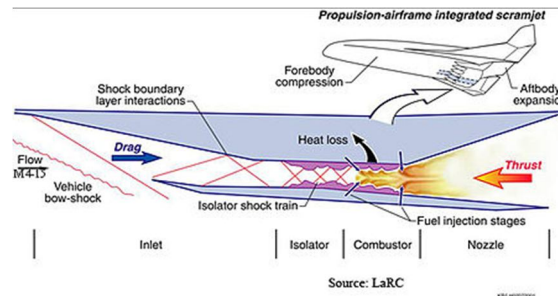
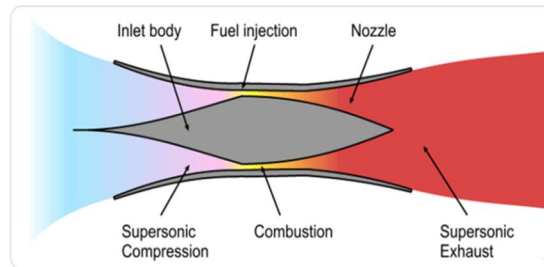Fig.1.1 – Integral Parts of a Scramjet   Propulsion system

Fig.1.2- Basic Components of Scramjet

1) *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.

2) *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,
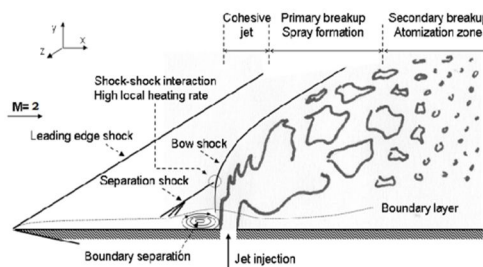

Fig1.3 - Wall Injector

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, when contrasted with fuel infused regularly with the wind

3) *Strut injectors:* 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.
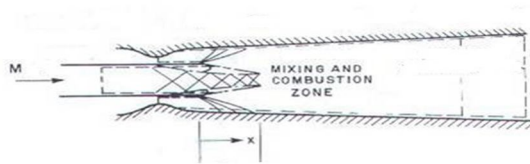
Fig.1.4. Strut Injector

II. LITERATURE

Shigeru Asoet.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 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 increase the fuel efficiency by rapid mixing of fuel and air using double wall injector. In present study we use Hydrogen as fuel and double wall injector is used which is Single wall injector, Double wall injector. Simulation will be done by FLUENT14.5. Conclusion will be done with the basis of simulative results like Temperature, Pressure, Velocity Variation, Turbulent kinetic energy, Total energy, Mass fraction of H2, O2 & H2O 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) *Preprocessing*

a) *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.

b) *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.

c) *Type of Solver:* Choose the solver for the problem from Pressure Based and density based solver.

d) *Physical Model:* Choose the required physical model for the problem i.e. laminar, turbulent, energy, multiphase, etc**.**

e) *Material Property:* Choose the Material property of flowing fluid.

f) *Boundary Condition:* Define the desired boundary condition for the problem i.e. velocity, mass flow rate, temperature, heat flux etc.

2) *Solution: Solution Method:* Choose the Solution method to solve the problem i.e. First order or 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**.**

3) *Post processing:* For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

B. *CFD Analysis of hydrogen combustion using Ansys Fluent*

1) *Preprocessing*

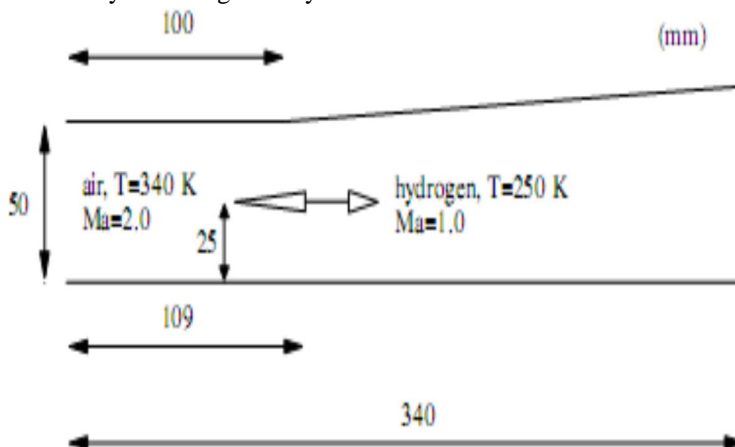a) *CAD Model:* Generation of 2d ax symmetric geometry in Fluent.

Figure-4.1: Reference model detail

b) *Mesh*

Type of Injector	Element length (m)	No. of Nodes	No. of Elements
Double Wall	3.0e-004	13524	8546

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

C. Boundary Condition: Operating Condition: Pressure = 101325 Pa

Variables	Air	H$_2$
Ma	2.5	1.0
U (m/s)	750	1300
T (K)	340	250
P (Pa)	101325	101325
Density	1.002	0.097
Y$_{O2}$	0.232	0
Y$_{N2}$	0.736	0
Y$_{H2O}$	0.032	0
Y$_{H2}$	0	1
Mass flow Rate (kg/s)	2.5	0.02

1) Solution: Solution Method: Pressure- velocity coupling-Scheme–SIMPL,-Pressure–Standard
a) Momentum: Second order, Turbulent Kinetic Energy (k) Second order, Turbulent Dissipation Rate (e) second order Solution
b) Initialization: Initialized the solution to get the initial solution for the problem.
2) Run Solution: Run the solution by giving 500 no of iteration for solution to converge
3) Post Processing: For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.
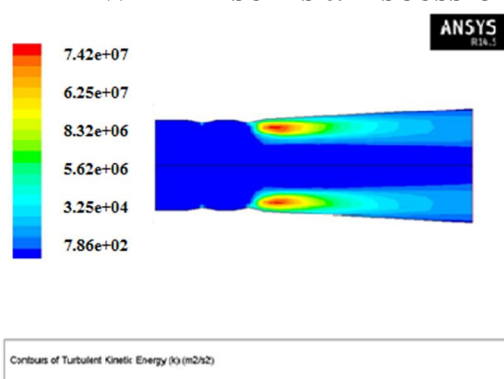
V. RESULTS & DISCUSSION

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 7.42e+07k-m2/s2
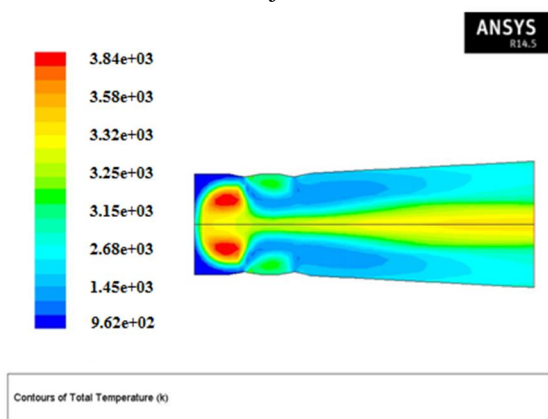

Figure-5.2 Contours of Total Temperature

The total temperature is increased at the time of injection and near the surface of injection but its temperature is in between 3840k near the region of injector after fuel injection done.
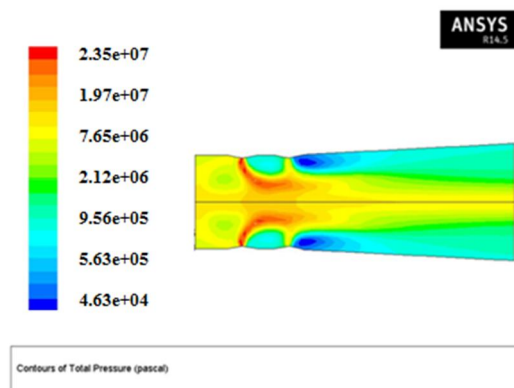

Figure-5.3 Contours of Total Pressure

The total pressure increases after fuel injection from wall injector and total pressure is maximum at the area of injection which is near 2.35e+07 pa and the total pressure remains near same through the axis after ignition.
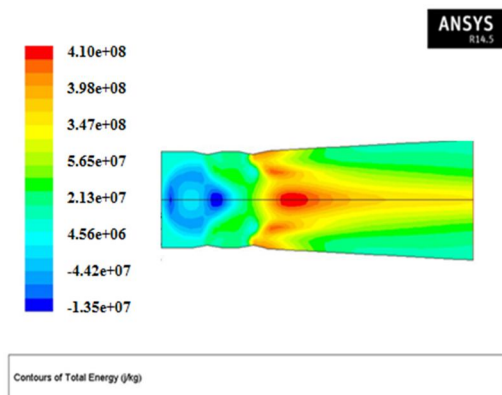

Figure-5.4 Contours of Total Energy

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 4.10e+08 j/kg at centre after injection.
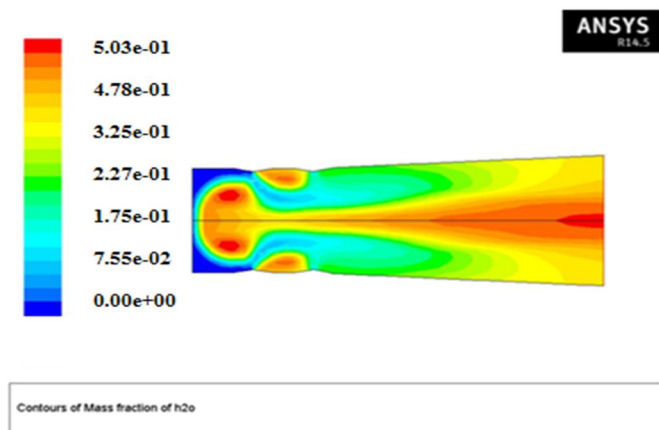

Figure-5.6 Contours of Mass fraction of H2O

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.

VI.   CONCLUSION

In the current study, double wall injectors are used for better mixing of fuel and air so that full combustion can be obtained. From this study, we can conclude from the same findings that the use of this type of injector can solve the recent problem of the Scorpion blanket and the current analysis shows the solution about the steady flow. From tangential velocity contours we can see the stability of flow which is the major problem with 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 this wall 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. From this study we conclude that scramjet combustor using wall injector is more stable and increase the temperature almost 12 times to the inlet temperature which shows that this type of injector increase the rapid mixing of fuel and air and release the high amount of energy which is required in jet engines.

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