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Design and Computational Analysis of Scramjet Inlet

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ABSTRACT- Scramjet inlets are a critical component in its function and their design has significant effects on the overall performance of the engine. Thus, the forward capture shape of the engine inlet should conform to the vehicle body shape. These geometric changes have remarkable influence on the flow in several aspects. A computational study for scramjet inlet with different ramp angles are studied to compress the air by rounding leading edge, moving the whole cowl up and down, rotating the cowl lip and axisymmetric inlet with rounded edge. However, the performance of the inlet tends to degrade as Mach number range increases .An air intake consisting of various ramps producing oblique shocks followed by a cowl shock is chosen in order to increase air mass capture. An impinging shock may force the boundary layer to separate from the wall, resulting in total pressure recovery losses and a reduction of the inlet efficiency. Design an inlet to meet the requirements such as Low stagnation pressure loss, High static pressure and temperature gain and deceleration of flow to a desired value of Mach number. A two dimensional analysis is carried out in this project. CATIA is used to create the model. GAMBIT is used to create the mesh. FLUENT is used to cover the flow analysis.

KEYWORDS: scramjet inlet, contraction ratio, ramp, cowl lip, normal shock

INTRODUCTION

A supersonic combustion ramjet (scramjet) is a variant of a ramjet air-breathingcombustion jet engine. The definition of a ramjet engine is first necessary, as a scramjet engine is a direct descendant of a ramjet engine. Ramjet engines have no moving parts, instead operating on compression to slow free stream supersonic air to subsonic speeds, thereby increasing temperature and pressure, and then combusting the compressed air with fuel. Finally, a nozzle accelerates the exhaust to supersonic speeds, resulting in thrust. Due to the deceleration of the free stream air, the pressure, temperature and density of the flow entering the burner are "considerably higher than in the free stream". At flight Mach numbers of around Mach 6, these increases make it inefficient to continue to slow the flow to subsonic speeds. Thus, if the flow is no longer slowed to subsonic speeds, but rather only slowed to acceptable supersonic speeds, the ramjet is then termed a 'supersonic combustion ramjet,' resulting in the acronym scramjet.

To study the inlet performance, multiple standard parameters need to be evaluated. This study involves comparison of performance parameters for scramjet inlet which are evaluated as a result of FEM computation of 2-D turbulent flow field around six different scramjet inlet geometries. The salient geometrical parameters which are varied are; inlet ramp angle and length, cowl lip angle, leading edge and axisymmetric inlet [1].

The 2-D computation of turbulent flow is obtained by implementing high Reynolds number k-omega compressible turbulent formulation. The boundary and initial conditions are carefully selected to the free stream conditions that pertain to a cruise altitude of 25km. The simulations were performed for two free stream Mach number 8. Thus from the obtained result, comparative studies of performance parameters are carried out by parameterising geometrical variables and free stream Mach number. It is necessary to simulate the inlet design to obtain the appropriate inlet performance. Computational Fluid Dynamics (CFD) is used to study flight simulations in both steady and un-steady flow. A time-averaged, viscous, 2 Dimensional, CFD scheme used to compute aero-thermo dynamic quantities including boundary layer effects.[3,4] A variety of turbulent models available ranging from one to three equations transport models. Oblique shock waves, expansion waves and shock wave interactions are mainly considered. Accuracy of the solution is dependent on many parameters like size of the control volume, orientation of boundaries, discretizationand its order of accuracy.

SCRAMJET INLET

Intake is the most vital component of the engine. It converts the K.E of the air flow into a static pressure rise that helps in deceleration of flow at lower speeds. This deceleration takes place as the flow passes through a series of oblique shocks that are formed due to the presence of ramps in the inlet, also called as staged compression [7,8].

The internal inlet compression provides the final compression of the propulsion cycle. The forebody along with the internal inlet is designed to provide the required mass capture and aerodynamic contraction ratio at maximum inlet efficiency. The air in the captured stream tube undergoes a reduction in Mach number with an attendant increase in pressure and temperature as it passes through the system of shock waves in the fore body and internal inlet. It typically contains non-uniformities, due to oblique reflecting shock waves, which can influence the combustion process. 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.

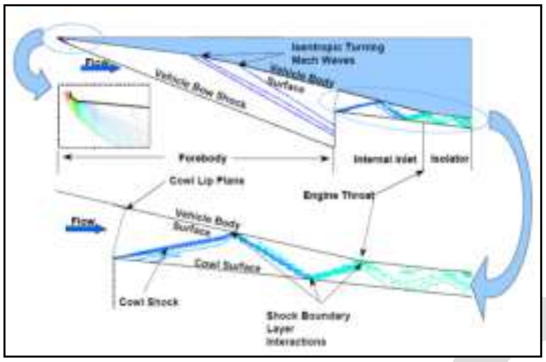

Fig .1: Summary of Important Forebody and Internal Inlet Physics

The design of this type of critical inlet component alters the overall performance of the engine. The major purpose of the air inlet is to compress the supersonic flow into subsonic flow and to diffuse the condition such that proper combustion takes place. Also to provide required amount of air to engine ensuring a stable flow and to keep the total pressure loss minimum. In hypersonic case inlets are often called as Inlet diffusers [9]. Here the compression is performed by shocks both external and internal to the engine, and the angle of the external cowl relative to the free stream can be made very small to minimize external drag. These inlets are typically longer than external compression configurations, but also spill flow when operated below the design Mach number. Depending on the amount of internal compression, however, mixed compression inlets may need variable geometry in order to start.

MODELLING OF SCRAMJET INLET IN CATIA

Geometry creation in CATIA is done with the required commands from the geometry creation tool pad. The geometry creation tool pad contains specification of scramjet inlet with leading edge, ramps, ramp angle and length, cowl deflection and contraction ratio (CR) to design a seven models of scramjet inlet with different specifications.

A. Create Of Inlet Geometry

The inlet to be optimized in this paper comprises six models,

- Rounded and sharp leading edge with three ramps and without deflection.
- Four Ramped Inlet model with deflection.
- Two Ramped Inlet model with deflection.
- Axisymmetric Inlet model with rounded and sharp leading edge.

The internal geometry is represented by five parameters: the leading-edge, ramp lengths, ramp angle, ramp angle increments, and exit radius.For rounded leading edge the inlet radius is fixed at 0.6mm to ensure constant mass flow entry, which effectively makes one of the ramp parameters dependent on the others for a given value of the combustor radius. Also fixed is the leading edge nose-tip radius 0.6mm in order to focus on the influence of ramp geometries by freezing the entropy layer effect originating from the leading edge. For axisymmetric inlets are two models are sharp and rounded leading edge with three ramps different angles. These assumptions, in effect, leave these parameters as design variables, or decision variables for optimization.

Table 1: Scramjet inlet 1 Specification

Leading edge	Rounded
No.of ramps	Three
Ramp angles	5.5˚,10.8˚,14.1˚
Ramps length (mm)	75,69,35
Cowl angle	0˚
Throat area (mm)	35

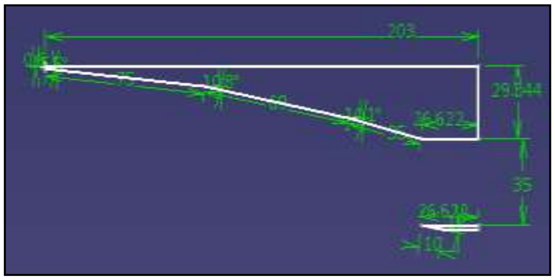

Fig 2: Rounded leading edge with three ramps and without deflection

Table 2: Scramjet inlet 2 Specification

Leading edge	sharp
No.of ramps	Three
Ramp angles	5.5˚,10.8˚,14.1˚
Ramps length (mm)	75,69,35
Cowl angle	0˚
Throat area (mm)	35

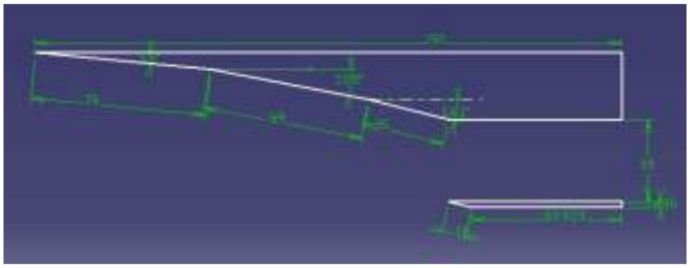

Fig 3: Four Ramped Inlet model with deflection

Table 3: Scramjet inlet 3 Specification

Leading edge	Sharp
No.of ramps	Four
Ramp angles (degree)	5.5,7.55,9.05,12.5
Ramps length (mm)	212,113,106,44
Cowl angle (degree)	12.5
Cowl lip length (mm)	44
Throat area (mm)	60

Fig.4: Four Ramped Inlet model with deflection

Table 4: Scramjet inlet 4 Specification

Leading edge	Sharp
No.of ramps	Two
Ramp angles (degree)	9,20.5
Ramps length (mm)	300,150
Cowl angle (degree)	10
Cowl lip length(mm)	20
Throat area (mm)	20.066

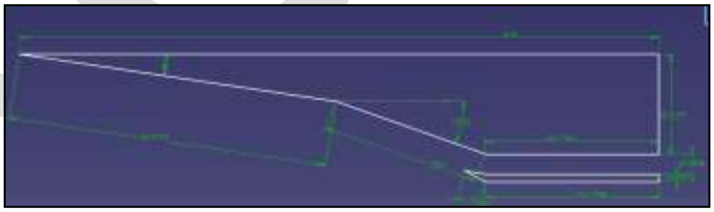

Fig.5: Two Ramped Inlet model with deflection

Table 5: Scramjet inlet 5 Specification

Leading edge	Rounded
Inlet type	Axisymmetric
No.of ramps	three
Ramp angles (degree)	5,10.6,13.6
Ramps length (mm)	75,69,39
Throat area (mm)	30

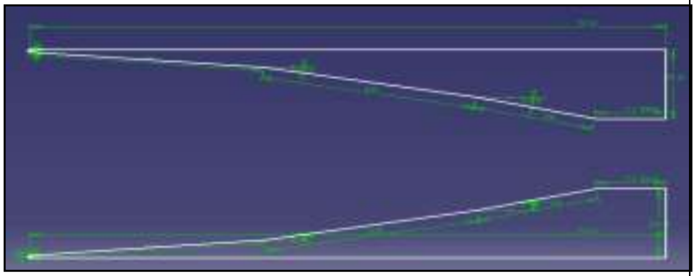

Fig.6: Axisymmetric Inlet model with rounded leading edge

Table 6: Scramjet inlet 6 Specification

Leading edge	sharp
Inlet type	Axisymmetric
No.of ramps	three
Ramp angles (degree)	5.5,10.8,14.1
Ramps length (mm)	95,75,40
Throat area (mm)	30

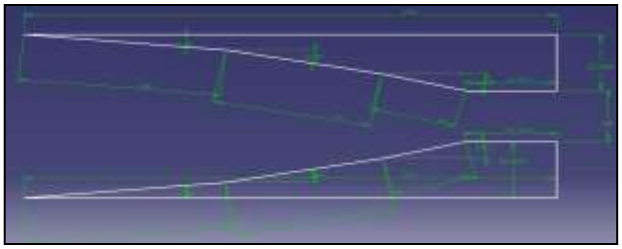

Fig.7: Axisymmetric Inlet model with sharp leading edge

GRID GENERATION

Meshing creation in gambit is done with the help of required commands from the meshing creation tool pad. The meshing creation tool pad contains command buttons that allows performing operations which include creating edge meshing, face meshing and boundary conditions. For the numerical study, inlet geometry parameters such as inlet ramps angles, length, number of ramps, cowl deflection and contraction ratio are varied. Axisymmetric inlets with sharp and rounded leading edge also meshing with rectangle domain can be create in this Chapter

A.Computational Domain

The 2D modeling scheme was adopted in GAMBIT. The structured grids were generated using ANSYS Gambit meshing tool.

- Meshing can be done in forms namely edge meshing, face meshing.
- Meshed edge, faces can be copied, moved, linked or disconnected from one another.
- Structured grid cells are used for entire domain. Cells are clustered at the region.
- Grading schemes includes successive ratio. Double sided grading also can be performed.The interval count can be specified for the starting mesh based on the model. In face or 2D meshing the following parameters can be specified.Meshing schemes mesh node spacing and face meshing options.

The meshing schemes include the elements and the types. Quadrilateral can be used as the elements.The meshing type pave are used.

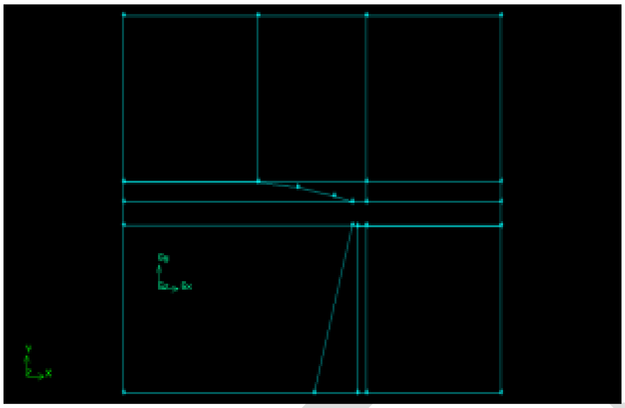

Fig .8: Rectangle domain created around model

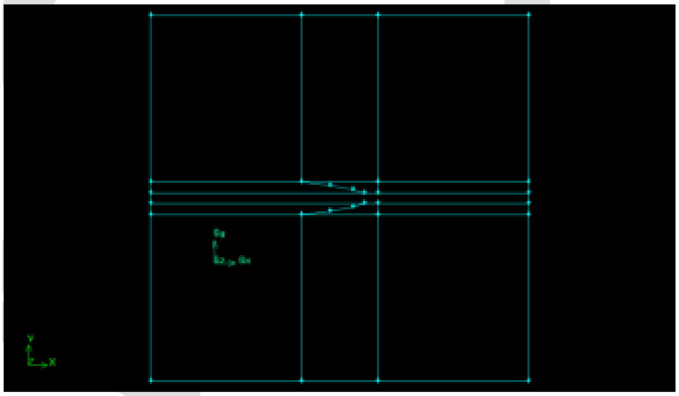

Fig .9: Rectangle domain created around axisymmetric inlet

Above figure show the rectangle domain into various section for meshing can be more around the scramjet inlet and axisymmetric scramjet inlet.

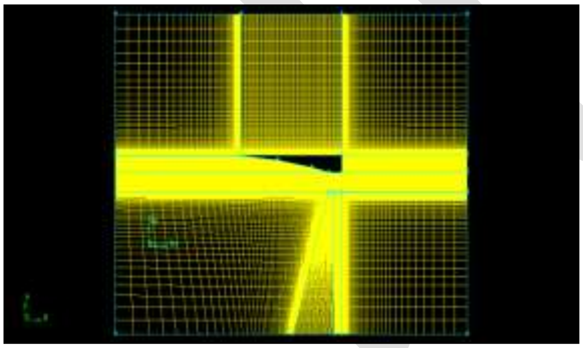

Fig .10: Two Ramped Inlet model without deflection

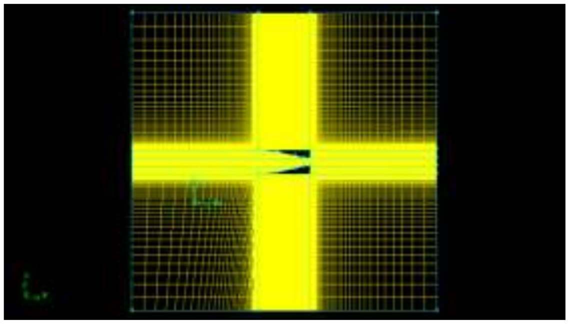

Fig .11: Axisymmetric Inlet model with rounded leading edge

The grid independence test is done which involves transforming the generated physical model into a mesh with number of node points depending on the fineness of the mesh. The various flow properties were evaluated at these node points. The extent of accuracy of result depended to a great extent on the fact that how fine the physical domain was meshed. After a particular refining limit the results changes no more. At this point it is said that grid independence is achieved. The results obtained for this mesh is considered to be the best. This mesh formation was done with GAMBIT

B. BOUNDARY CONDITIONS

For two dimensional computations over the model a structured grid consists of quadrilateral cells are made. The overall rectangular domain is made of several iterations were chosen for all models. Inlet exit was the part of the outlet boundary face whereas the model base was situated on the boundary which was assigned as wall boundary. The grid generation scheme is quad/tri type cells of volume meshing. Grid with approximately 20000 cells is made for every inlet models. The initialize boundary condition for all the scramjet inlet models after the meshing can be done.

Table 7: Boundary conditions for all models

Inlet	Velocity inlet
Outlet	Pressure outlet
Upper boundary	Wall
Lower boundary	Wall
Fore body	Wall
cowl	Wall
Fluid	Air

The grid for the scramjet inlet 2D models generated using the software GAMBIT and the other specification discussed. Grid independence study results in formation of fine grids to obtained desired results. Separated domains was selected based on several iterations were chosen. The initialize boundary condition for all the scramjet inlet models is given been chosen.

RESULTS AND ANALYSIS

Two dimensional simulations of the flow field using FLUENT are to be made. Computations validated through a simulation of hypersonic inlet at desired Mach number. Boundary conditions and properties of the model defined as reference to the literature.

ANALYSIS OF SCRAMJET INLET IN FLUENT

Table 8: Inlet Boundary Conditions for Mach 8

Gauge Pressure	1197 pa
Mach number	8
Reference temperature	226.5 k
Turbulent Viscosity	0.01
Turbulent Ratio	10
Altitude	30 km

Model 1: Rounded leading edge with three ramps and without deflection

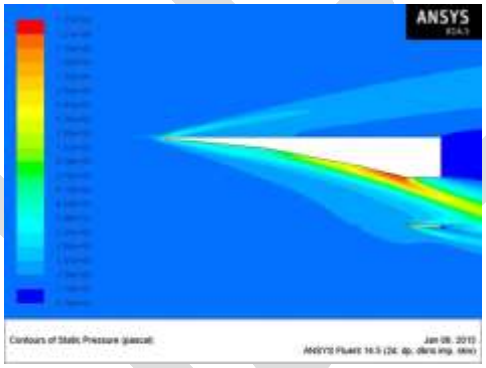

Fig 12: Pressure Contour

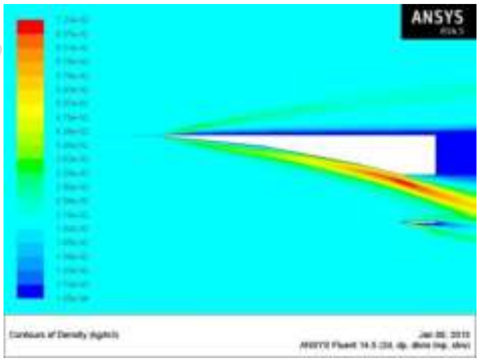

Fig 13:Density Contour

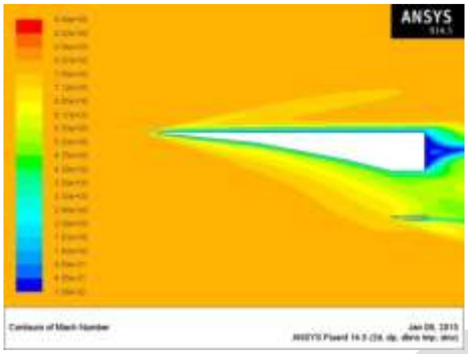

Fig 14: Mach Contour

Mode 2: Sharp leading edge with three ramps and without deflection

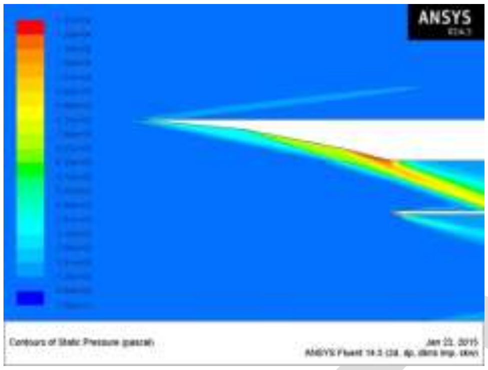

Fig 15 Pressure Contour

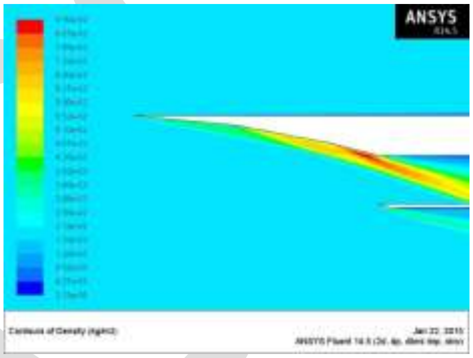

Fig 16 Density Contour

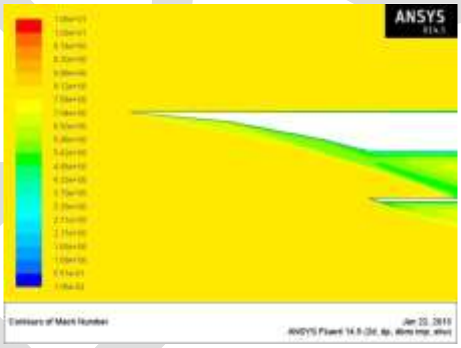

Fig 17 Mach Contour

Model 3: Four Ramped Inlet model with deflection

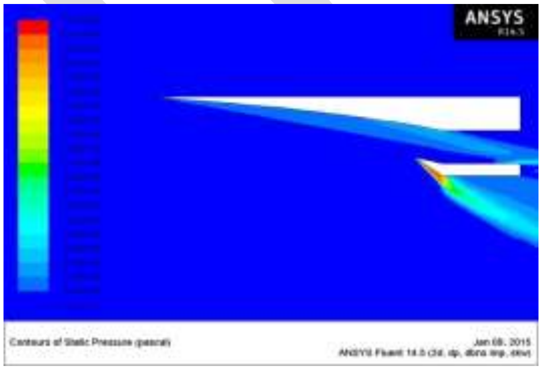

Fig 18 Pressure Contour

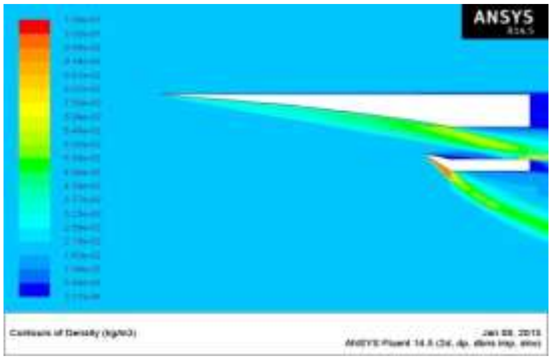

Fig 19 Density Contour

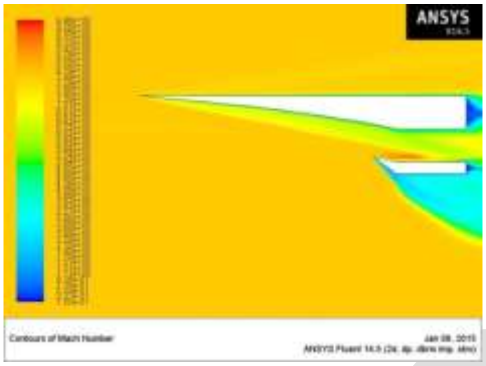

Fig 20 Mach Contour

Model 4: Two Ramped Inlet model with deflection

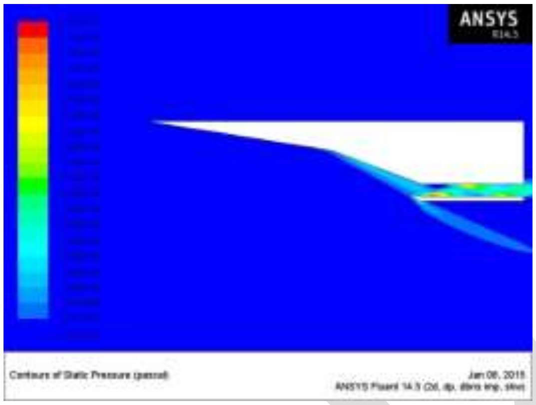

Fig 21 Pressure Contour

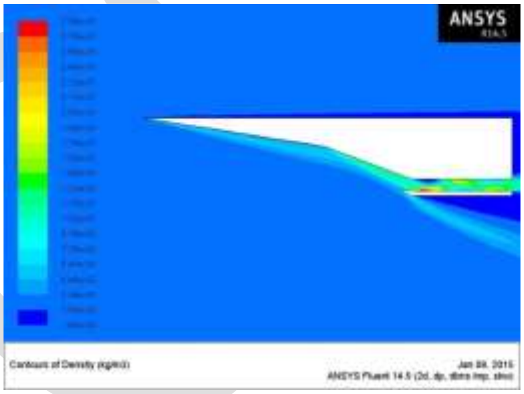

Fig 22 Density Contour

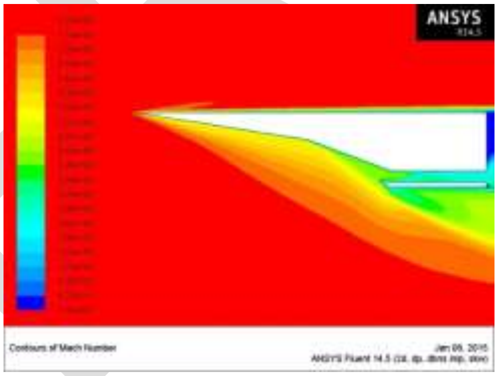

Fig 23 Mach Contour

Model 5: Axisymmetric Inlet model with rounded leading edge

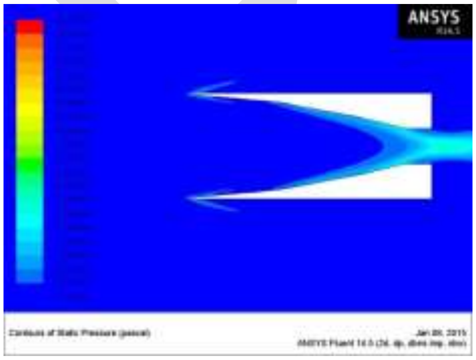

Fig 24 Pressure Contour

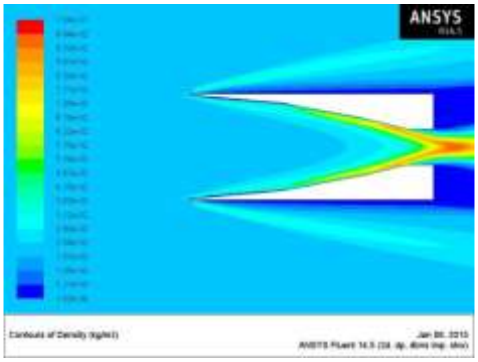

Fig 25 Density Contour

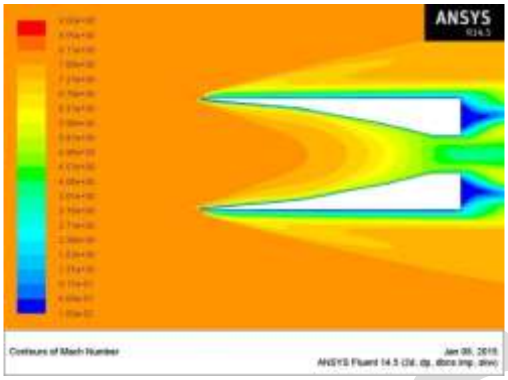

Fig 26 Mach Contour

Model 6: Axisymmetric Inlet model with sharp leading edge

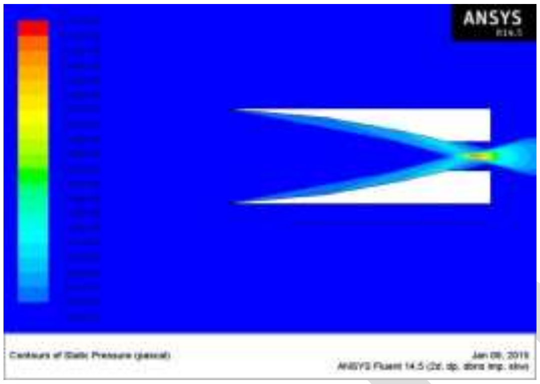

Fig 27 Pressure Contour

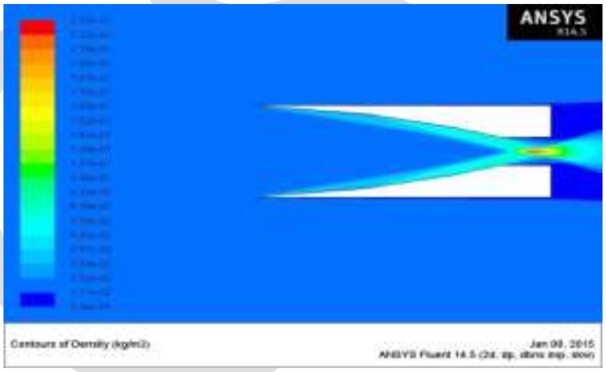

Fig 28 Density Contour

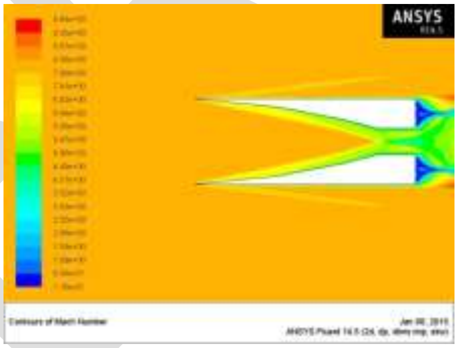

Fig 29 Mach Contour

CONCLUSION

The purpose of this paper was to determine which model is best when compared to other model with higher Mach number. Hence, a Scramjet engine was then modeled in GAMBIT and analysis was carried out in FLUENT for the same with different design models. Amongst all designs, a design with four ramps yielded better results than the other designs. By this Analysis we can conclude the "K-omega turbulence model exactly simulates the flow field characteristics in hypersonic conditions" in capturing shocks at leading edges. The result obtained in the present study and its analysis is applicable only to a similar or a congruent geometry to the geometry that has been proposed in this work. Thus the vital performance parameters obtained from the FEM numerical simulation are compared and analyzed by parameterizing various inlet ramp contour, Mach number and cowl angle at hypersonic limits.

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