



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 3, March 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**

9940 572 462

6381 907 438

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# Design Anatomization and Simulation of Nozzle with Varying Exit Deflection Angle in Scramjet

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**ABSTRACT:**Supersonic Combustion Ramjet (SCRAMJET) is a hypersonic flight speed engine where the combustion takes place supersonically. Flow analysis is done in the nozzle section as well as at the exit section with varying design. A baseline Convergent Divergent nozzle (CD nozzle) model is taken in account and the modifications are done at the divergent portions by varying the exit angles in forward direction as per expansion zone goes on. Certain angles are chosen to get the increment in expansion section of the nozzle exit and computational analysis is carried out with commercial Computational Fluid Dynamics (CFD) tool - Ansys Fluent which solves Density Based Navier Stokes (DBNS) equations and simulation is done to get the values of Pressure, Density, Temperature and Mach number by considering the flow inside the nozzle and domain to be ideal gas. A Rectangular domain is created to visualize the nozzle jet exit plume connecting with the nozzle exit. Stimulation shows the change of the flow parameters with specific modifications in Nozzle expansion zone parameters.

**KEYWORDS:** Scramjet, Supersonic Nozzle, Varying Angle, ANSYS FLUENT.

## I. INTRODUCTION

A scramjet 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 compress the incoming air forcefully before combustion (hence ramjet), but whereas a ramjet decelerates the air to subsonic velocities before combustion, the airflow in a scramjet is supersonic throughout the entire engine. That allows the scramjet to operate efficiently at extremely high speeds. The nozzle in scramjet is a divergent duct where supersonic flow is achieved by acceleration and reduced the static temperature and pressure. Lower velocity, higher pressure and higher temperature flow from combustor converts to higher velocity, lower pressure and lower temperature flow in divergent section of the nozzle respectively. The scramjet can fly to much higher speed due to supersonic stream flow. The top Mach of scramjet lies in a range of Mach 15 to Mach 24.

## II. RELATED WORK

[1] The numerical fluid dynamics can be effectively used for the jet core prediction of a CD nozzle. For flow analysis in CFD using density based Navier Stokes equation and standard k-epsilon turbulence model and putting the boundary conditions of pressure at the inlet and exit of nozzle, achieved the higher Mach at 15°. [2] The research paper is conforming Method of characteristics (MOC) for designing the supersonic nozzle contour and analysed the flow with varying Gamma ( $\gamma$ ) & nozzle length. [3] By varying the nozzle exit angle the performance of the nozzle can be improved. i.e. At 12° & 15° the Mach was greater than 2.5 and 2 KN of Thrust was generated. [4] At the divergent section, the velocity distribution is found to be increasing with increase in divergent angle. The static pressure decreased with increase in divergent angle at exit section. Optimum Mach number has been achieved at 15°. [5] Single Expansion Ramp Nozzle (SERN) is used to achieve higher Mach number with increase in altitude. With the change in 4.29° angle,

increment of 10.68% in thrust compare to conical Single Expansion Ramp Nozzle [6] By comparing the Conical shape nozzle, Bell shape nozzle and Triangular shape nozzle they have found that in Triangular shape nozzle, the Mach number at inlet (0.172), throat (1.09) and outlet (2.8).

### III. GEOMETRIC MODEL

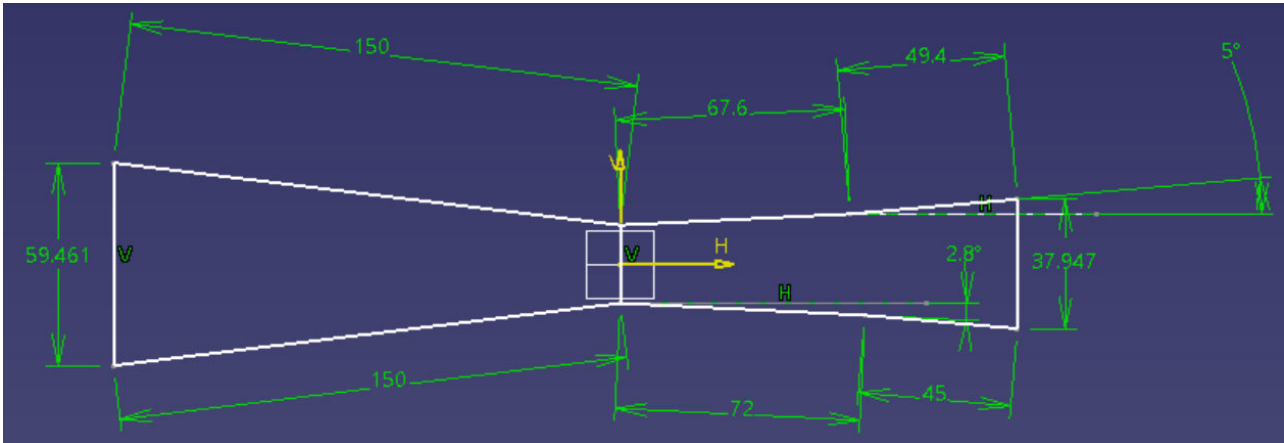


Fig 1. Configuration of 5 Deg nozzle model (in mm)

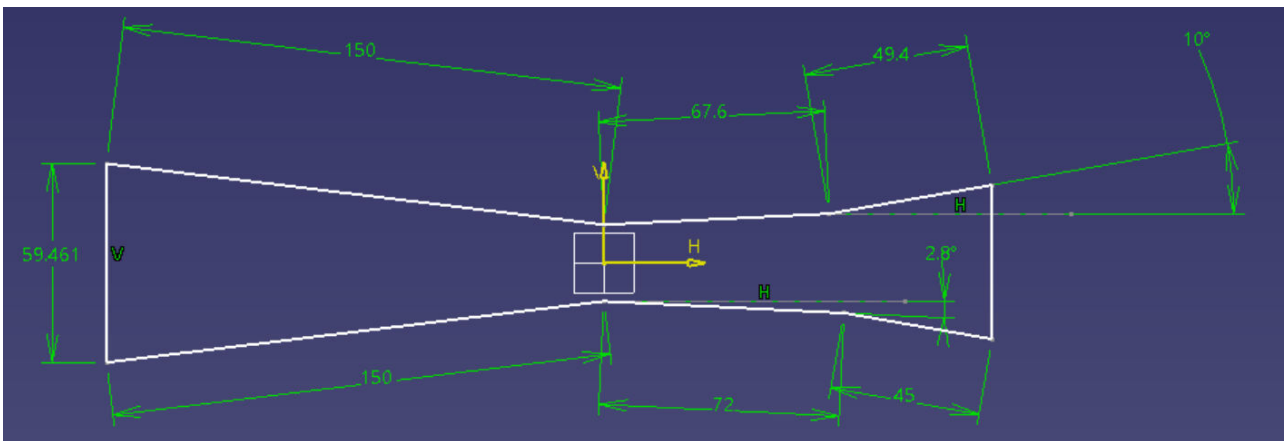


Fig 2. Configuration of 10 Deg nozzle model (in mm)

### IV. MESHING (DISCRETIZATION)

Fig 3,4. show the Two-Dimensional Grid meshing used for 5° and 10°. The mesh type was Quadrilateral for both 5° and 10°, with the elements (366142) and nodes (366782) & elements (404908) and nodes (405580) respectively.

Max Face Size	Max Tet Size
0.0041364	0.0082728

Table 1. Mesh Sizing

Sphere Radius	Element Size
0.13	0.0008

Table 2. Body sizing of Sphere

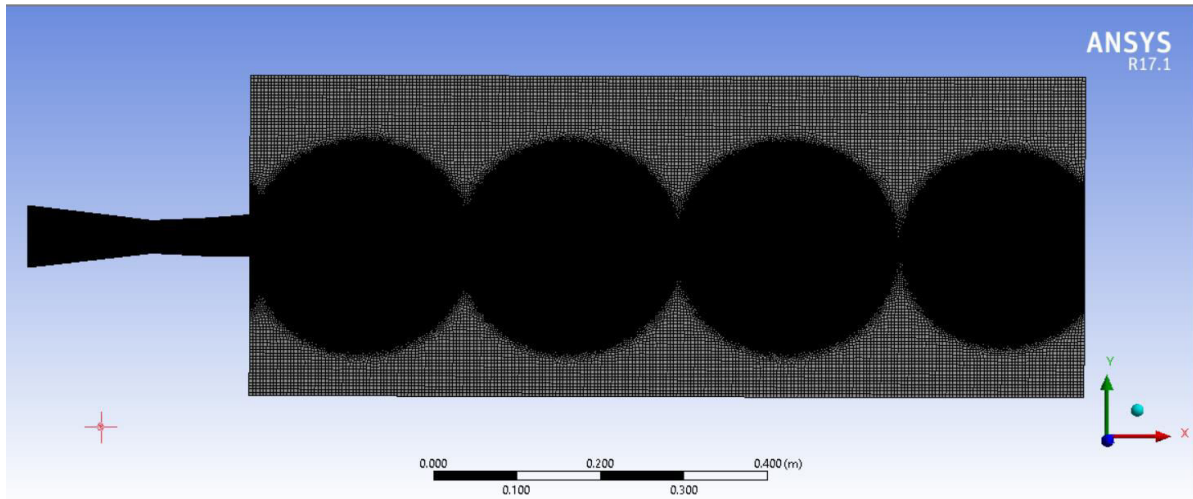


Fig 3. Meshing of 5°

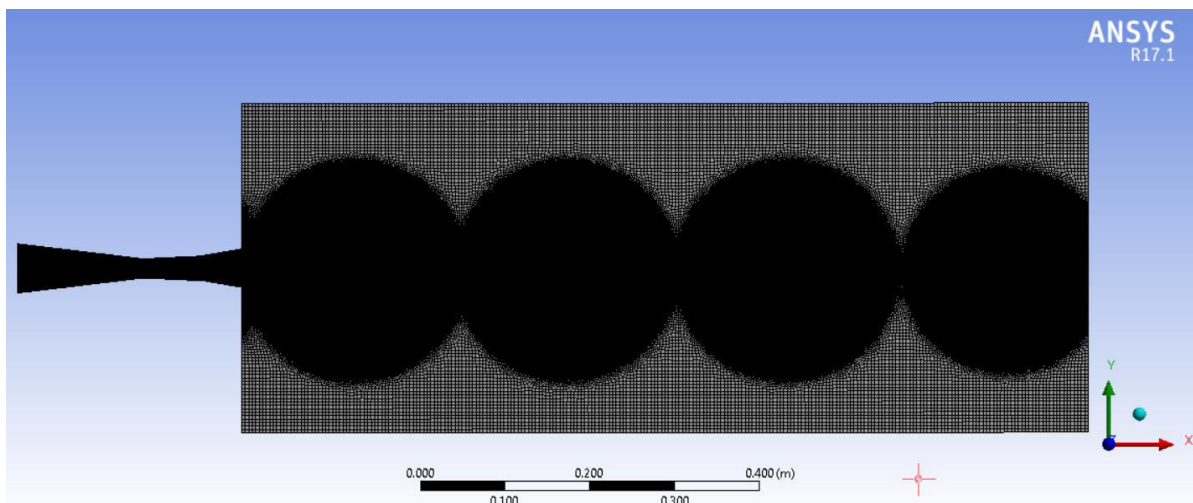


Fig 4. Meshing of 10°

### V. INPUT PARAMETERS

BOUNDARY CONDITION	VALUES
Inlet Total Pressure (Gauge)	500000 Pa
Supersonic Intel Pressure (Gauge)	300000 Pa
Inlet Total Temperature	300 K
Inlet Turbulent Intensity	5 %
Density (kg/m3)	Ideal Gas

Table 3. Boundary Parameters

Here we are using Computational Fluid Dynamics (CFD) tool - Ansys Fluent which solves on Density Based Navier Stokes (DBNS) equations. Model was Realizable K-epsilon (k-ε) in which we have selected Compressibility effect.



VI. RESULTS

Fig 5. Show the various contour of afterbody of supersonic nozzle. The fig. 5(a) shows the Mach number variation from throat to the nozzle exit as well as it shows the variation in nozzle exit jet plume in afterbody. The maximum Mach number was 2.8442. The fig. 5(b) shows the velocity contour in the nozzle section up to the end of the atmospheric domain. The range of velocity goes up to 632.718 m/s whereas the outlet pressure is 475428 Pa (fig. 5(c)). The temperature contour in mention in fig 5(d). The density is varying between the range of 0.536 to 6.79 Kg/m<sup>3</sup> fig(5(e)).

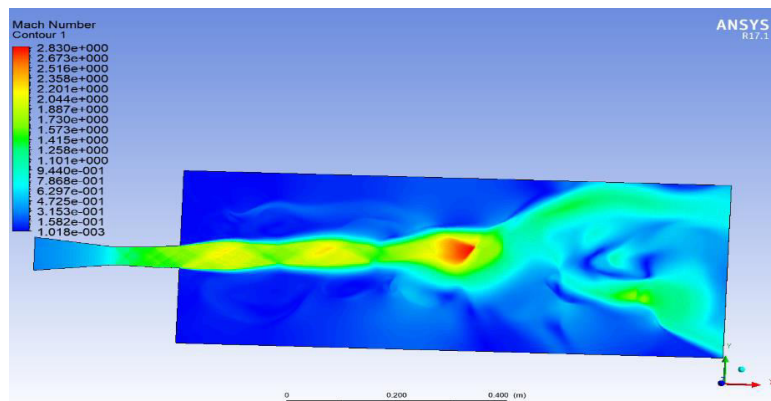


Fig 5 (a) Mach No contour of 5° nozzle

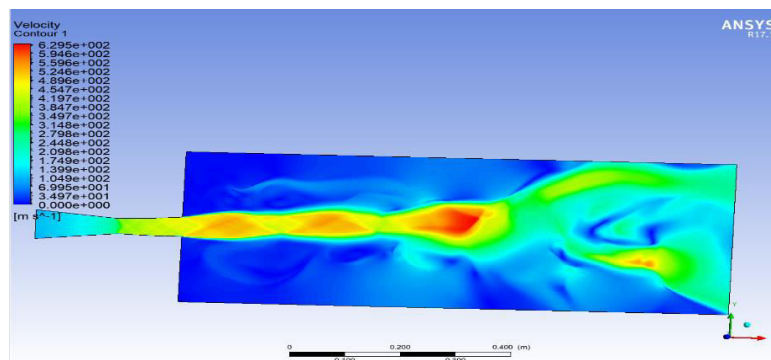


Fig 5 (b) Velocity contour of 5° nozzle

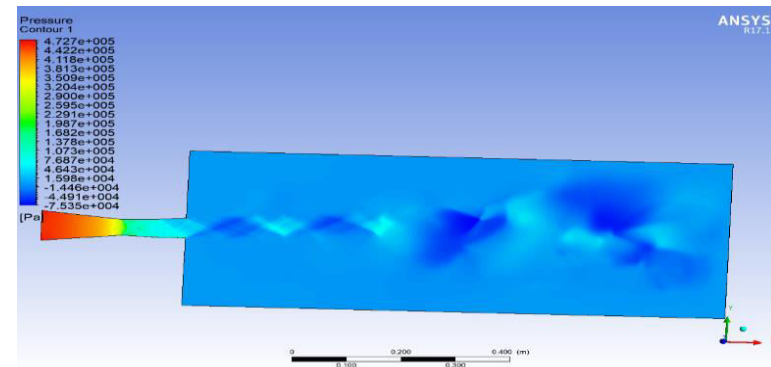


Fig 5 (c) Pressure contour of 5° nozzle

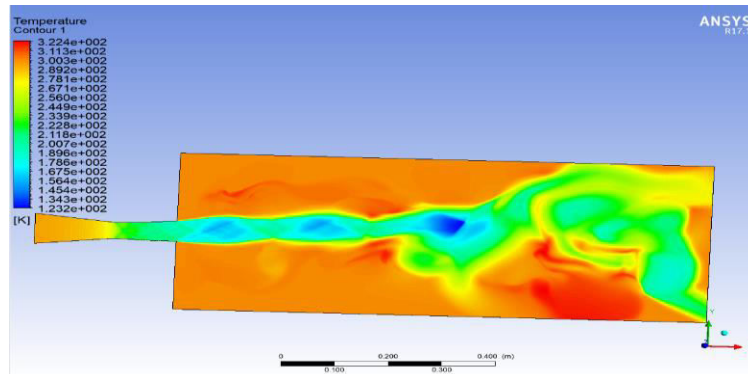


Fig 5 (d) Temperature contour of 5° nozzle

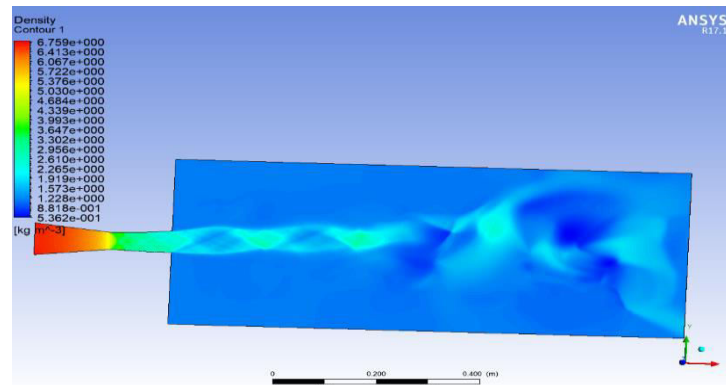


Fig 5 (e) Density contour of 5° nozzle

Fig 6. Show the various contour of afterbody of supersonic nozzle. The fig. 6(a) shows the Mach number variation from throat to the nozzle exit as well as it shows the variation in nozzle exit jet plume in afterbody. The maximum Mach number was 2.66. The fig. 6(b) shows the velocity contour in the nozzle section up to the end of the atmospheric domain. The range of velocity goes up to 708.265 m/s whereas the outlet pressure is 486943 Pa (fig. 5(c)). The temperature contour in mention in fig 6(d). The density is varying between the range of 0.645 to 6.87545 Kg/m<sup>3</sup> fig(6(e)).

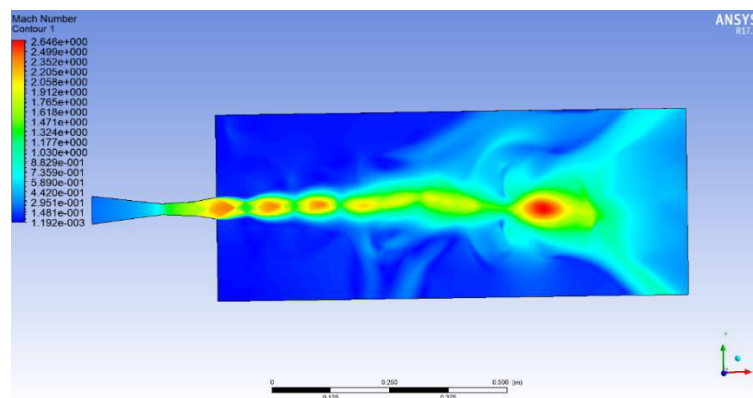


Fig 6 (a) Mach No contour of 10° nozzle

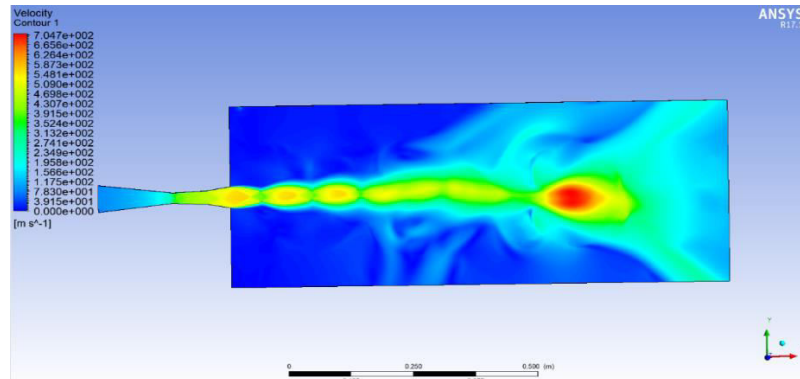


Fig 6 (b) Velocity contour of 10° nozzle

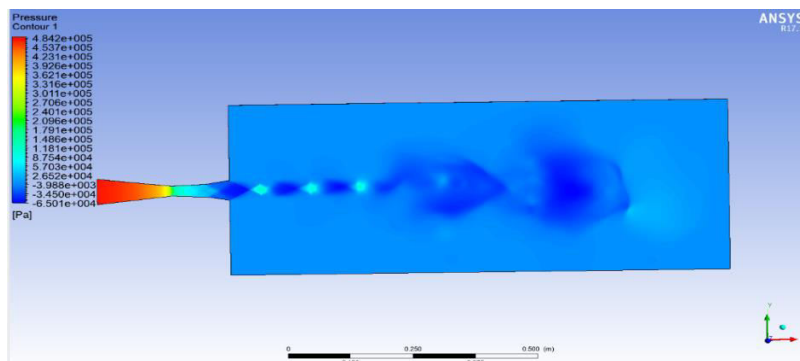


Fig 6 (c) Pressure contour of 10° nozzle

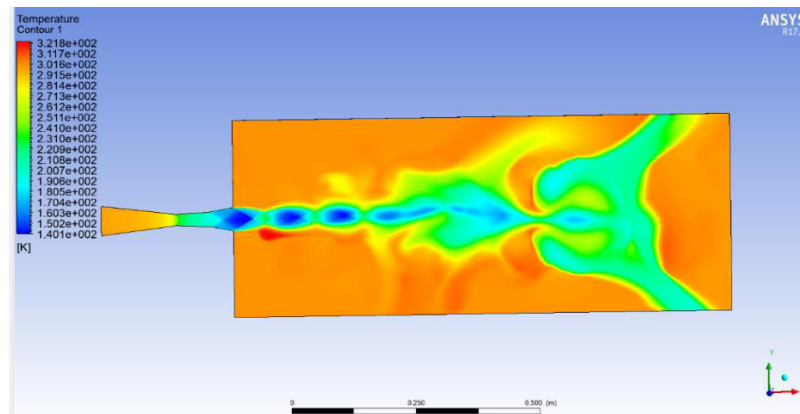


Fig 6 (d) Temperature contour of 10° nozzle

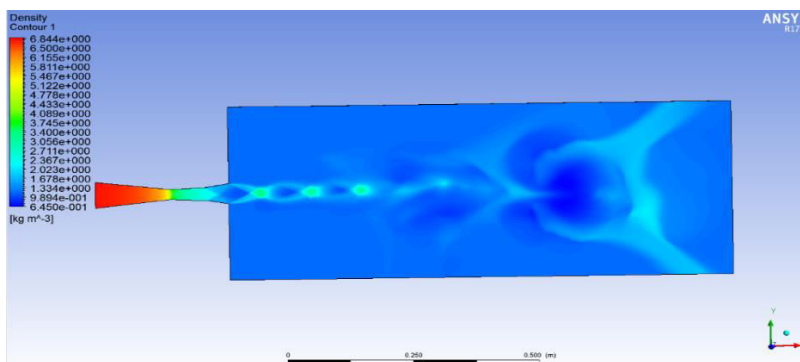


Fig 6 (e) Density contour of 10° nozzle



## VII. CONCLUSION

From the Analysis, it is clearly observed that nozzle with  $5^\circ$  angle has achieved higher Mach number compare to  $10^\circ$  angle configurations. The thrust force found at  $5^\circ$  angle is 8.11 KN which is higher compare to the  $10^\circ$  nozzle configuration. The value of pressure and density value is higher in the second model nozzle configuration. From above result it is concluded that the  $5^\circ$  angle nozzle configuration is achieving good Mach number.

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**ISSN** INTERNATIONAL  
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