# A RESEARCH PAPER ON ANALYSIS OF DE-LAVAL NOZZLE ON ANSYS WORKBENCH

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**Abstract -** *A rocket requires high thrust with which it could fly in the sky and outer space which is achieved by convergent-divergent nozzle. A convergent-divergent nozzle is a prominent part of rocket such that to provide optimum thrust to drive it into the skies with high velocity. Exhaust gases coming out of the nozzle have supersonic flow i.e., their Mach number is greater than 1. The objective of this paper is to interpret and analyze how the change in throat diameter changes the thrust of convergent divergent nozzle. This study computes the flow of gases inside the convergent divergent nozzle using commercially available computational fluid dynamics (CFD) tool ANSYS FLUENT. Different models are taken which differ in their throat diameter and the material used and the outcomes has been compared to the standard ones currently used.*

***Key Words*: : Convergent-Divergent Nozzle, De-Laval Nozzle, ANSYS WORKBENCH, Thrust, Pressure and Velocity analysis, Face Meshing.**

## 1. INTRODUCTION:-

**Nozzle: -**A nozzle is a gadget used to control the speed of the liquid stream, headings, and stream qualities. The structure of the nozzle is viewed as a pipe with shifting cross-sectional zones all through the length for modifying and controlling the mass stream rate, speed, course of a stream, weight proportion, and so forth. The variety of weight contrast at the channel and outlet of the nozzle area brings about the difference in stream qualities. Nozzles can be classified as the convergent, divergent or both as convergent and divergent nozzles. The first ever nozzle was invented by German engineer named Ernst Korting in the year 1878 and Gustaf de laval, who is a Swedish inventor and thus named after him. [1-4]

1. Conversion nozzle
2. Convergent-Divergent nozzle

**Convergent nozzle:** The convergent nozzle is a spout that starts huge and gets littler, a decrease in the cross-sectional district. As a fluid enters the littler cross-territory, it needs to quicken in light of the generation of mass. To keep up a predictable proportion of fluid going through the limited piece of the spout, the fluid must move quicker. The energy to make this fluid speed up has to come from somewhere. Some energy is in the random motion of molecules, which we observe as pressure. The energy in this random motion is converted into faster forward motion, known as stream flow.

This change makes the pressure drop. In other word a convergent nozzle, there is an increase in velocity and a decrease in pressure, but we know that pressure is inversely proportional to area. [1-4]

**Convergent-Divergent nozzle:** This type of nozzle firstly developed by Swedish engineer named Carl Gustaf De Laval in the year 1888, thus it is also called as a De Laval Nozzle.

This type of nozzle consists three different type of sections called:

    i.   Converging section
   ii.   Throat section
  iii.   Diverging section

The combustion chamber in which fluid present the convergent section of De Laval Nozzle is connected to it. In this section the fluid gains the kinetic energy and loosed pressure energy due to Bernoulli's principle and the law of conservation of mass. The acceleration of fluid takes places from convergent to throat section. **As the force of incoming flow is greater than throat mass flow rate, the rate of flow from the convergent section increases rapidly**. The throat section is present between convergent and divergent section its smallest in size as compare both section. This section reason of change in velocity in engine. To provide subsonic flow (0<M<1), Supersonic flow, Sonic flow, the increase in velocity of fluid is directly proportional to decrease in area of the duct. [5-6]

Concurrent Divergent supersonic nozzles are fundamentally utilized for rapid rockets and for rocket nozzles. Contingent upon the nozzle applications various shapes are utilized. The unique piece of nozzle assumes an imperative job in development qualities. The capacity of CD nozzle is to change over warm vitality into dynamic vitality to rapid fumes. The significant significance of a CD nozzle in the business is to improve the motor vitality of the streaming medium to a detriment of interior vitality and the weight. Rockets regularly utilize a fixed united segment pursued by a fixed dissimilar segment for the structure of the nozzle. This nozzle arrangement is known as a focalized unique, or Album, nozzle. In a Compact disc rocket nozzle, the hot fumes leave the burning chamber and join down to the base territory, or throat, of the nozzle. The throat size is picked to gag the stream and set the mass stream rate through the framework. The stream in the throat is sonic which means the Mach number is equivalent to one in the throat.

Downstream of the throat, the geometry veers, and the stream is isentropic ally extended to a supersonic Mach number that relies upon the zone proportion of the exit to the throat. The development of a supersonic stream makes the static weight and temperature decline from the throat to the exit, so the measure of the extension additionally decides the left weight and temperature. The leave temperature decides the leave speed of sound, which decides the leave speed. The leave speed, weight, and mass course through the nozzle decides the measure of push delivered by the nozzle. In fig. 1[a], [b] shown use of CD nozzle in jet engine to boosting the thrust output. [6-8]



[a]



[b]

Fig: 1 [a] Application of CD nozzle in Jet engine, [b] Application of bell shape nozzle.

The CD nozzle is also use to control input of engine in different international and national automotive championships. By using this type of nozzle equal the power of all engine so all participates having equal opportunity to win the championship. As shown in fig 2[a] and fig 2[b]





Fig;2 [a], [b]application of CD nozzle in automotive engine.

## 2. LITERATURE SURVEY: -

TrongBui [9] had performed experimentation on "CFD analysis of nozzle jet", in which the experiment resulted in the difference in the strength of the tail stock of nozzle between under expanded and over expanded flow. The observation recorded was based on the change in flow viscosity and type of grid.

K.P.S.S. Narayana and K.S. Reddy [10] had worked on the topic of "simulation of convergent-divergent rocket nozzle using CFD analysis" in which it had been observed that by changing the quality of mesh and number of divisions i.e., with refinement in mesh Mach number is increased and also pressure, temperature, velocity, density and also shockwave is varied.

Y.R.Maddu, S.Saidulu, Md.Azeem and S. Jabiulla[11] had worked on "Design and fluid flow analysis of Convergent-divergent Nozzle" in which it was observed that pressure, temperature, velocity, density and also variation in shockwave had been observered based on changing in the mesh quality and related iterations.

M.Srinivas, A.L. Suresh and Harish [12] had done research on "Thrust enhancement of a convergent-divergent nozzle by using CFD" in which the observations recorded was that the Mach number at throat=1 and at exit>1 and no formation of shock takes place. They had also found out that radius of throat cannot exceed 0.75 timed the diameter of throat.

Wei, Lee, Y. Chien T.H. Chou, J.S. Wu [13] had done investigation on "Effect of nozzle throat diameter on performance of hybrid rocket motor" in which it had been concluded that Thrust of the engine could be controlled up to certain extent by oxidizer even though if the nozzle is eroded.

Pandey et al [14], has worked on rocket engine design, in that research paper authors said that space of combustion in world today is very extensive, as straight we use combustion applications directly or indirectly, their key task was to equate the productivities of rocket engines with two inlets in case of low thrust orbit to orbit transfers. At their analysis authors observed air and fuel towards the inside the combustion chamber it starts burning because high velocity and temperature so that the pressure rises in combustion chamber and then vigor on decreasing to convergent portion and at throat the total pressure was a negative value. The temperature increases in combustion chamber followed by convergent portion of nozzle but as it reaches the divergent portion temperature start decreasing.

Gustaf De Laval [15], Swedish engineer De Laval recognized the concept of impulse steam turbine after that Laval success to build a prototype of steam turbine to establish that such devices can be set up on scale. He enrooted a nozzle that increase steam jet to supersonic speed and used in rocket engine nozzles.

## 3. MODELING AND ANALYSIS:

Software which are used for modeling 2D or 3D models are such as CREO, CAD, SOLID WORKS, and CATIA. All tools present in these software's helps user in designing the model. This software's are very useful to get accurate results during analysis. This software's are largely recognized for their flexibility and functionality.

### 3.1 Catia

CATIA is an abbreviation for Computer Aided Three-dimensional Interactive Application. Catia is leading software used by organizations in numerous industries extending from aerospace, automobile to consumer products. CATIA can be used at various stages of the design - ideate, draw, test and iterate. The software comes with various workbenches ("modules") that tolerate CATIA to be used across varied industries – from parts design, surface design and assembly to sheet metal design. CATIA can also be used for CNC.
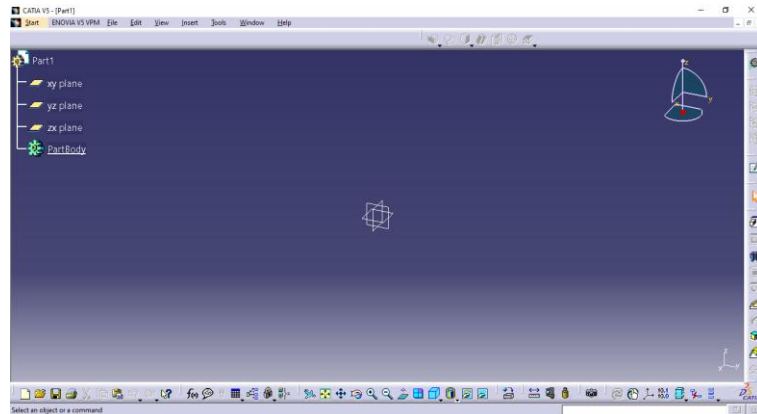


Fig: 3   Catia Interface

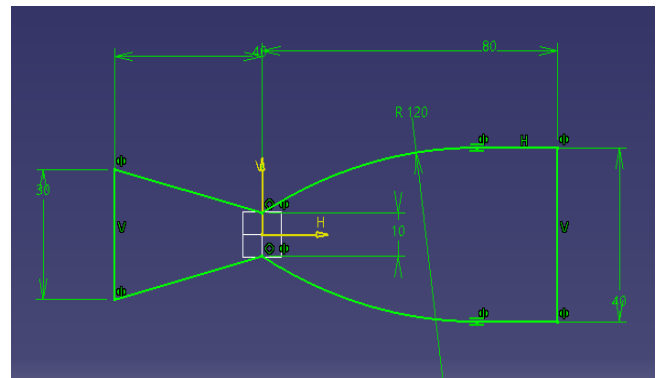ANSYS Workbench 18.0 had been used to create the geometry of CD nozzle:
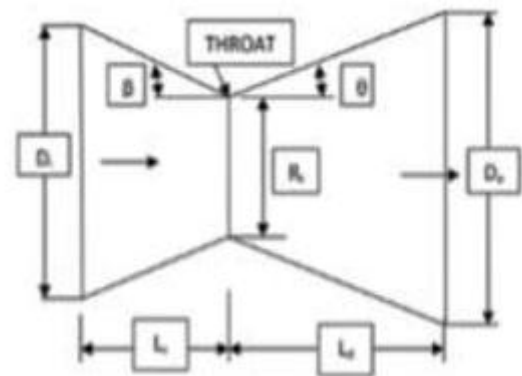


Fig: 4 Basic model of CD nozzle.



Fig: 5 Basic termology of CD nozzle

CATAIA V5 had been used to create model of 4 different types which vary in their throat diameter.

### 3.2 COMPUTATIONAL FLUID DYNAMICS ANALYSIS:

CFD (computational fluid elements) a branch that is generally utilized for settling administering conditions of fluid elements. Today we can discover its applications for all controls, for example, heat move, fluid elements and in any

event, for normal science, and so forth. Issues that are extremely confused to illuminate by methods for the general diagnostic technique can be effectively fathomed by CFD. Since the arrangement of conditions of coherence, force, the vitality of fluid elements is known as a Navier-stroke condition. There are numerous methodologies in CFD through which we can acquire a suitable outcome, yet the standard strategy utilized is the limited volume technique. For all of the volume, the conditions are illuminated and results are acquired. In this way after the finishing of cycles each point explicit some worth. Accordingly, through these outcomes, we can make a point on the conduct of the fluid stream. For investigation here we are utilizing ANSYS. This examination incorporates the subject of delta temperature, gulf weight, and outlet temperature and weight. [16-18]

### 3.3 Meshing in Ansys Workbench: -

Meshing is process of formation of small grids to the surface of model in order to convert infinite domain into finite domain with the help of nodes and elements. Here Fluid Fluent had been used for meshing the model. The Equations used for governing the mesh are the following: This is an expression for physical coordinates and generalized co-ordinates:

$$\eta = \eta(x, y) \; \xi = \xi(x, y)$$

$$x = x((\xi, \eta) \; y = y(\xi, \eta)$$

Then the governing equations are transformed into partial derivate as follows: -

$$\frac{\partial T}{\partial x} = \frac{\partial T}{\partial \xi}\frac{\partial \xi}{\partial x} + \frac{\delta T}{\delta \eta}\frac{\delta \eta}{\delta x} \qquad \text{(eq.1)}$$

$$\frac{\partial T}{\partial y} = \frac{\partial T}{\partial \xi}\frac{\partial \xi}{\partial y} + \frac{\delta T}{\delta \eta}\frac{\delta \eta}{\delta y} \qquad \text{(eq.2)}$$

$$\frac{\partial T}{\partial \xi} = \frac{\partial T}{\partial x}\frac{\partial x}{\partial \xi} + \frac{\delta T}{\delta y}\frac{\delta y}{\delta \xi} \qquad \text{(eq.3)}$$

$$\frac{\partial T}{\partial \eta} = \frac{\partial T}{\partial x}\frac{\partial x}{\partial \eta} + \frac{\delta T}{\delta y}\frac{\delta y}{\delta \eta} \qquad \text{(eq.4)}$$

Grid Clustering is controlled by the predefined functions P and Q. In this analysis meshing is an important part of simulation since without proper meshing it won't give correct and accurate results. Meshing done here is clear and structured mesh is formed with the help of face mesh. [16-18]
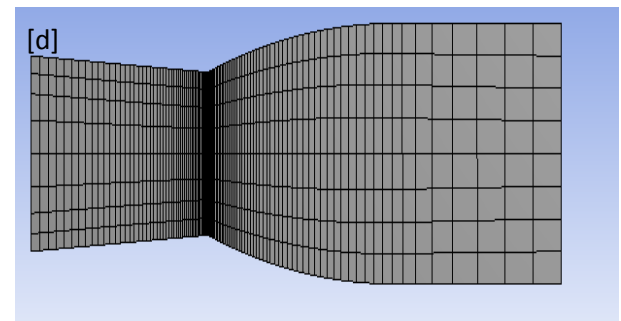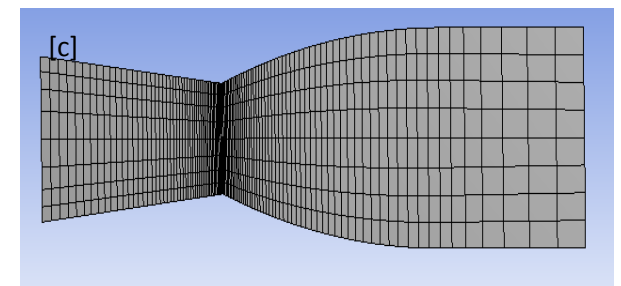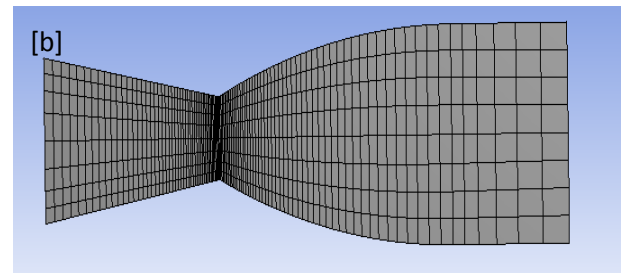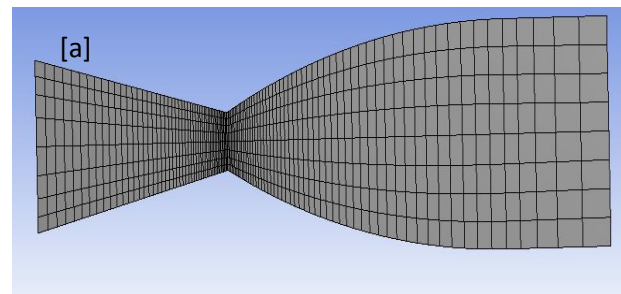
Fig:6 [a]Throat diameter=10 mm, [b]Throat diameter=15 mm, [c]Throat diameter=20 mm, [d]Throat diameter=25 mm

In above mesh models there is only one difference i.e., difference in the throat diameters as mentioned. Sizing is done on the walls of nozzle which is biased such that meshing is obtained refine at the surroundings of throat, since we are interested at the areas of throat as the change in throat diameter affects the sonic flow. [19-20]

### 3.4 DESIGN PARAMETERS: -

All the design parameters had been considered in centimeter.

Table: 1 Design parameters

| PARAMETRES | MODEL-1 | MODEL-2 | MODEL-3 | MODEL-4 |
|---|---|---|---|---|
| Inlet diameter | 30 | 30 | 30 | 30 |
| Throat diameter | 10 | 15 | 20 | 25 |
| Outlet diameter | 40 | 40 | 40 | 40 |
| Total length of nozzle | 120 | 120 | 120 | 120 |

## 3.5 BOUNDARY CONDITIONS:

1.          Inlet

2.          Wall of nozzle

3.          Outlet

The boundaries assigned in the nozzle are the inlet of the nozzle, outlet of the nozzle and the walls. It is performed with the use of create name selection in the mesh section itself. [17]

## 4. ANALYSIS PROCEDURE:

The solving of the mesh is done when the commands are given in the setup feature of fluid fluent. The input parameter given are: The mesh is solved based on density-based.
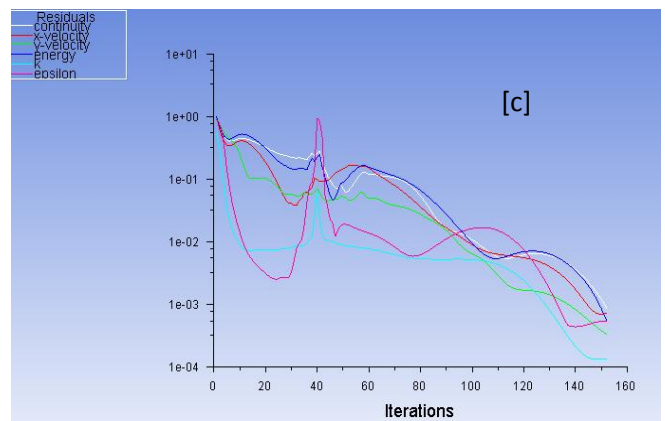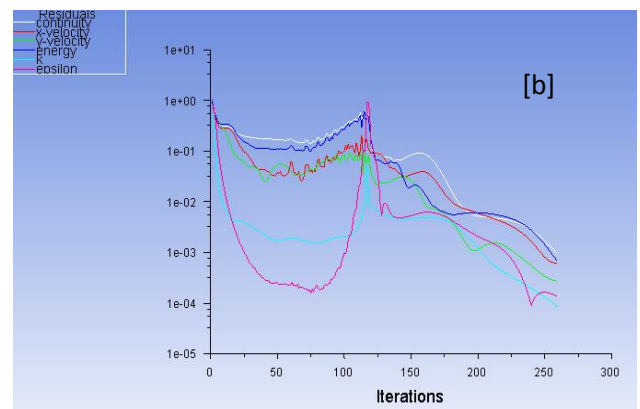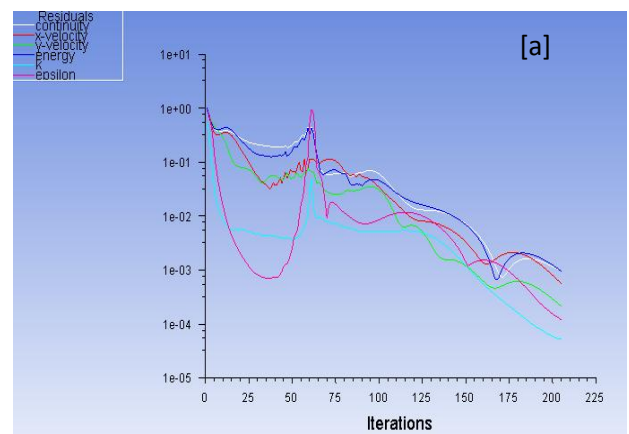
Table: 2 Analysis Procedure

| PROCEDURE | DETAILS |
|---|---|
| **Problem Setup** General-Solver | **Type:** Density based **Velocity :** Absolute **Time:** Steady **2D space:** Planar |
| **Models** | **Energy**: On **Viscous**: Realizable k-e, Enhanced wall treatment |
| **Materials** | **Fluid :**Air **Density:** Ideal Gas **Viscosity:** Sutherland |
| **Boundary conditions** | **Inlet :** Pressure Inlet **Gauge Total Pressure (pa):** 300000 **Outlet :** Pressure Outlet |
| **Reference Values** | **Compute from :** Inlet **Reference Zone :** Solid Surface body |
| **Initialization** | **Standard Initialization** |

| | **Compute** from Inlet. |
|---|---|
| **Solution** | **Run Calculation:** Enter the Number of iterations, Click calculation. |

## 5. RESULT AND DISCUSSION:

A.          Covergence history:

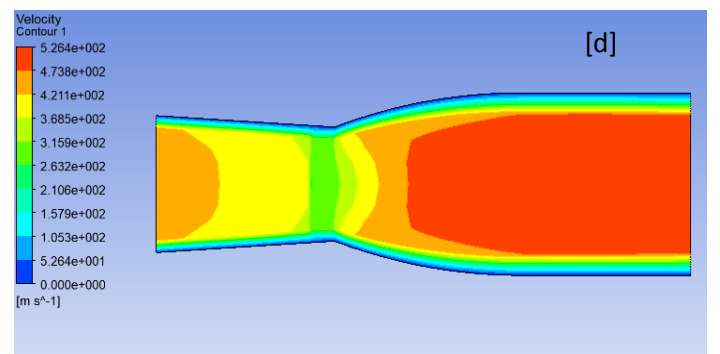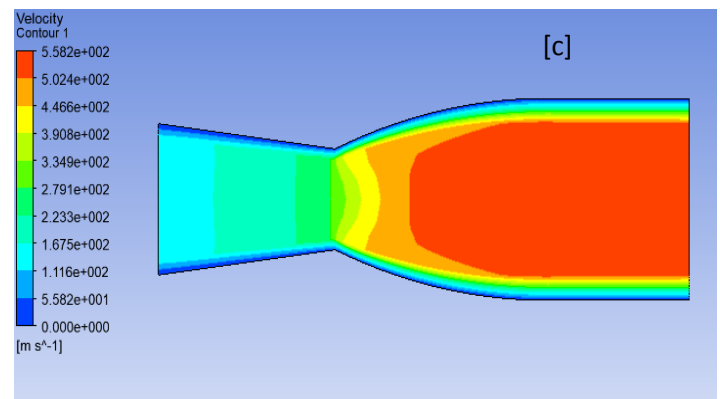The histroy where the graphs converged is shown in the below figures:-
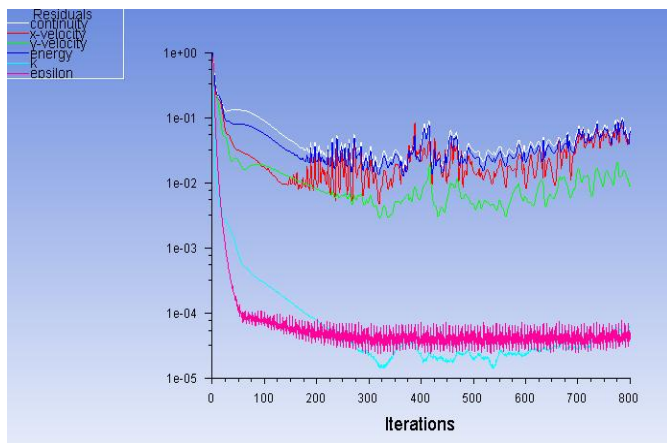






[d]

Fig: 7 [a] Results of Throat diameter=10 mm, [b] Results of Throat diameter=15 mm, [c] Results of Throat diameter=20 mm, [d] Results of Throat diameter=25 mm,

The model-1 had converged at 153 iterations, model-2 had converged at 208 iterations, model-3 had converged at 220 iterations and model-4 had not converged and had deviating graph.
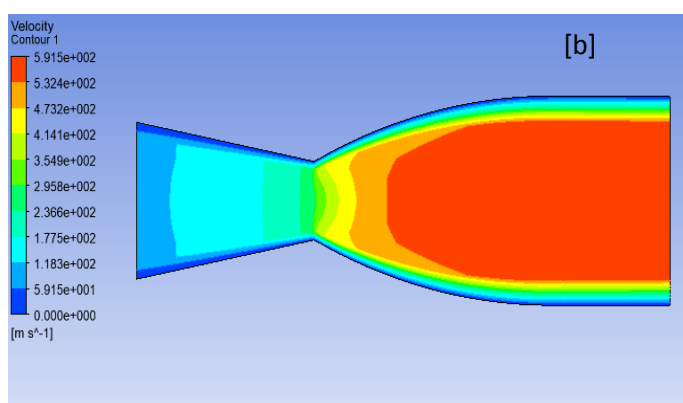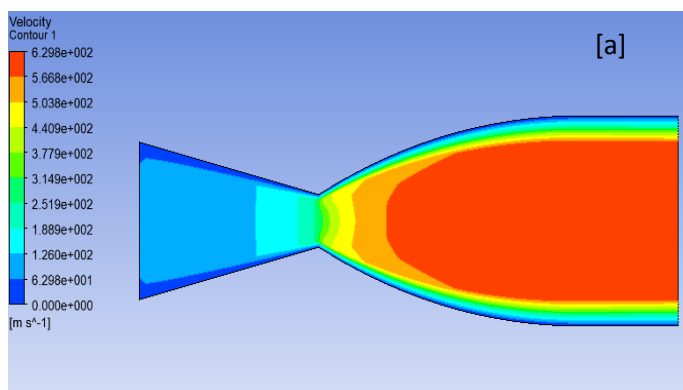
B.    Velocity:









Fig: 8 [a] Velocity Results of Throat diameter=10 mm, [b] Velocity Results of Throat diameter=15 mm, [c] Velocity Results of Throat diameter=20 mm [d] Velocity Results of Throat diameter=25 mm

The obtained velocity values for the mesh are as follows:

Table 3: Velocity values for the mesh

| Mesh | Minimum value (m/sec) | Maximum value (m/sec) |
|------|------------------------|------------------------|
| 1 | 0.00 | 6.298e+002 |
| 2 | 0.00 | 5.915e+002 |
| 3 | 0.00 | 5.324e+002 |
| 4 | 0.00 | 5.264e+002 |

## 6. CONCLUSION:

A nozzle is basically used to vary the flow characteristics of fluid or air. In convergent divergent nozzle the pressure and velocity are inversely proportional to each other. As the pressure moves in the cd nozzle it decreases whereas the velocity increases. Velocity at the inlet of the nozzle is sonic flow, at the throat is sub-sonic flow and at the exit is supersonic flow which is the reason for the shock formation (of diamond shape) at the outlet. This experiment concludes that as the throat diameter increases in the 4 models it had been noticed that the maximum value of velocity is reduced. Hence it is suggested to have a nozzle as of model-2 as flow must be withstand the exit temperature without melting the metal of nozzle.

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