# AERODYNAMIC DESIGN AND PERFORMANCE OF NOZZLES WITH DIFFERENT MACH NUMBERS USING CFD ANALYSIS

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**Abstract—** *The exhaust nozzle system plays a flagship role in aircraft and the design of nozzle have a supersonic cruise mission is optimized for a cruise condition and in takeoff conditions it must give the required quantity of thrust action at other most lynchpin operating points. In contrast, for a vehicle the exhaust nozzle system is to an accelerating mission must provide limited action across the flight envelop as there is not a fixed cruise point were the operates of aircraft the majority of the time. The aerodynamic design and performance analysis of convergent and convergent –divergent nozzle with different lengths 110.236mm and 135.636mm with subsonic and supersonic flow conditions is analyzed using CFD analysis. The comparisons are made for pressure distribution, velocity and mass flow rates in 3D models are done in CATIA and CFD analysis*

***Key words*— Nozzles, Cad, Mesh.CFD analysis.**

## 1.INTRODUCTION

While choosing the nozzles make sure its capabilities with your current systems. The perform flow testing to ensure you get adequate water and also consider the penetration and reaction force on the firefighter.

To the extinguish a fire we will use the any nozzle, keep in mind that actual flow may be affected by many variables, such as differences in piping from the pump to the discharge point, augment friction loss, changes in the types and their individual friction loss, different pump pressures, water supply issues and debris passing through the water system. So be sure to test your nozzle under ideal conditions and under poor conditions to decide how it will works in both quality and inadequate of water-flow situations.

By the characteristics of nozzles there are many features are available and uses. The key point is determining which nozzle is right for your needs. To help you make that determination, here's a breakdown of some of the basic nozzle types, and the pros and cons of each. Typically, the smooth-bore nozzle produces the greatest reach/rpm combination of all nozzles while at the same time using the lowest engine pump

### 1.1 NOZZLE

**Fig-1:** Water nozzle

To control the direction of a fluid flow the device is used is called as nozzle it exits (or enters) an enclosed chamber or pipe.

### 1.2 AERODYNAMIC NOZZLE

We can metamorphose a gas turbine into a jet engine by utilizing the propelling nozzle. Power obtained from the gas turbine exited it can transfer into a high speed propelling jet by using the nozzles. Engines like turbofan may have spare and separated propelling nozzle which gives the high speed to propelling jet from the energy from the air is send through the fan. In addition, by using the nozzle we can determine how the gas generator and fan operate as it acts as a downstream restrictor.

Propelling nozzles are moving quickly the obtained gas to subsonic and transonic velocities rely on the power setting of engine. The Convergent-divergent (C-D) are the internal shape which can move quickly the jet to supersonic velocities within the divergent section, whereas a convergent nozzle cannot accelerate the jet beyond sonic speed.

### 1.3 Types of nozzle

***1)*** **Ejector nozzle**

Ejector type of nozzle is used for pumping action of the more scalding, high speed, engine exit entraining to an ambient air flow. Nozzle manipulates the expansion of the exhaust of engine.

***2)*** **Thrust vectoring nozzle**

Nozzles for vectored thrust include fixed geometry Bristol Snidely Pegasus and variable geometry

*3)* **Rocket nozzle**

Rocket motors also used convergent-divergent nozzles, but these are usually of fixed geometry, to minimize weight.

**1.4 MACH**

In compressible flow theory the mesh is most flagship parameter, and it comparing with the speed of sound in a fluid (excellent measure of compressibility effects) and the speed at which the fluid is flowing.

**1.5 MACH ANGLES**

This isentropic wave front is analogous to the oblique shock wave, and the angle between the wave front and the direction of the disturbance's motion is called the Mach wave angle or Mach angle.

**2. INTRODUCTION TO CAD**

As we know to design of an object in computer is difficult in computer in past days but now a day's it's so simple firstly we know Computer-aided design (CAD) it is software now a day's it's made so easy to draw 2D and 3D diagrams in computers. It's also called as computer-aided design and drafting (CADD).By the using of Computer Aided Drafting which explains the drafting process in computer. For many of design engineering CADD software is a flagship tool by using this software they shows the elegant designs of the objects as per the requirements. The output of CADD is in the form of print or machining operations.

The required output information is also important for CAD such as materials, processes, dimensions, and tolerances, according to specific applications. The design curves and figures in two-dimensional (2D) space and solids surface in three-dimensional (3D) objects are shown in CAD software.. The design of geometric objects for object shapes, in particular, is often called computer-aided geometric design (CAGD).

**3. 3D MODELING CONVERGENT MODEL**

Length 110.236 mm

2d Sketch

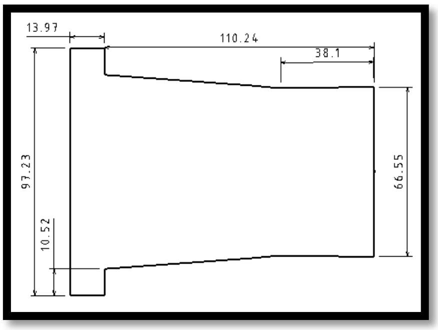



**Fig-2**: Surface model

Length 135.636 mm

3d Sketch

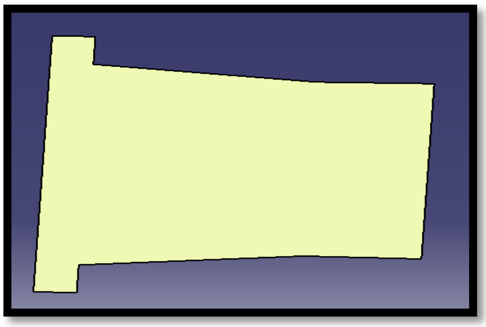


**Fig-3:** Surface model

**CONVERGENT DIVERGENT MODEL**

Length 110.236 mm

2d Sketch

Surface model

The mach numbers or taken from the national aeronautics and space administration

$$\text{Mach number} = \frac{\text{object speed}}{\text{speed of sound}}$$

THE SPEED OF SOUND C= 343 METERS PER SECOND (M/S)

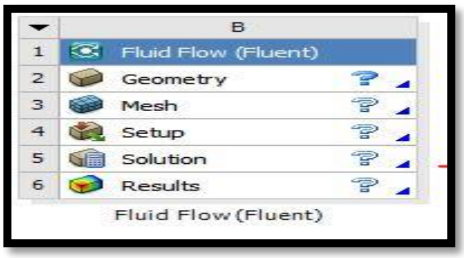
CFD ANALYSIS FOR AERODYNAMIC NOZZLE

CONVERGENT MODEL

FLUID –NITROGEN OXIDE

MODEL LENGTH – 110.236mm

FLOW- SUBSONIC FLOW (MACH NUMBER 0.4)



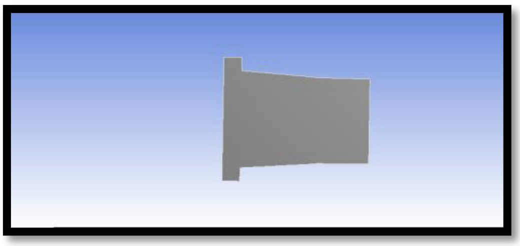



**Fig-4:** Import model

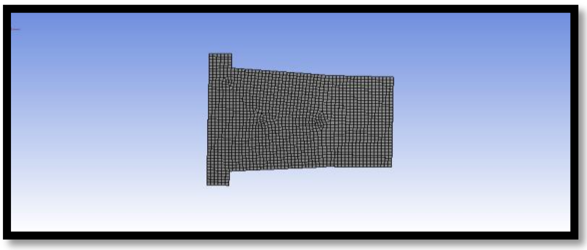


**Fig-5:** Meshed model

Specifying boundaries for inlet, outlet and wall

Select edge → right click → create named section → enter name → inlet

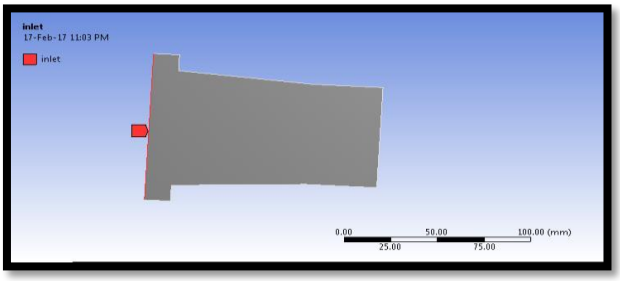



**Fig-6:** Inlet

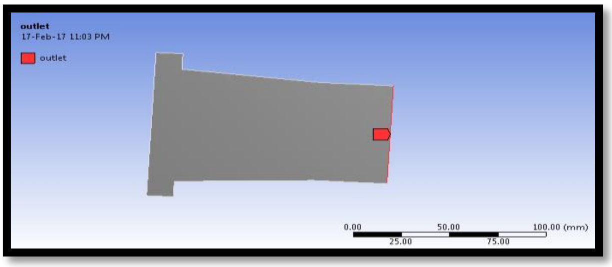



**Fig-7:** Outlet

Select edge → right click → create named section → enter name → outlet

Wall

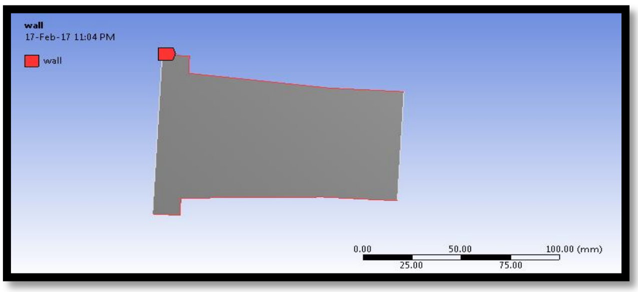



**Fig-8:** Inlet and outlet of wall

Select fluid nitrogen oxide

Boundary conditions → select air inlet → Edit → Enter Inlet Velocity → 171.5m/s

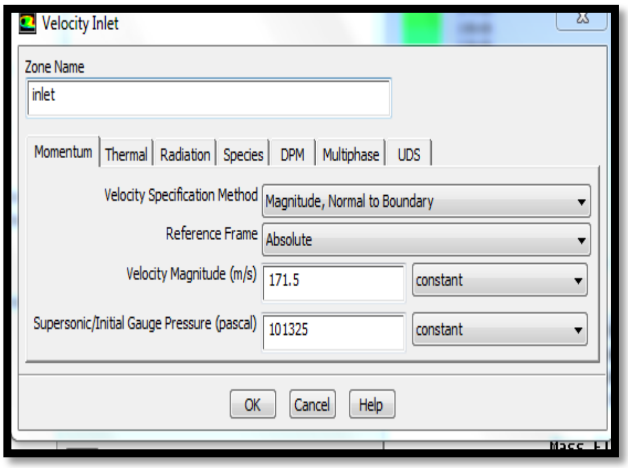



**Fig-9:** Velocity inlet

Solution → Solution Initialization → Hybrid Initialization →done

Run calculations → no of iterations = 30 → calculate → calculation complete as shown in Fig.9

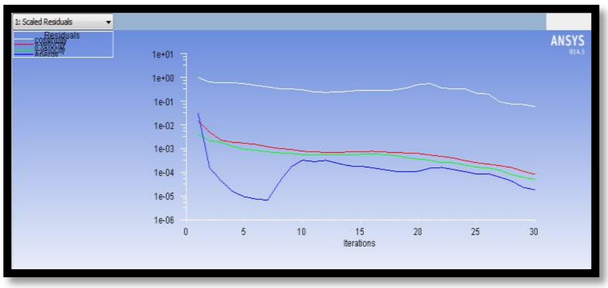



**Fig-10:** Pressure difference graph

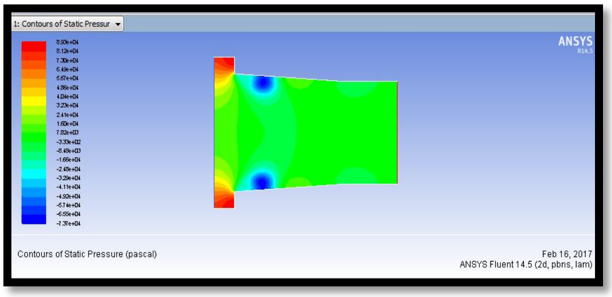



**Fig-11:** Velocity

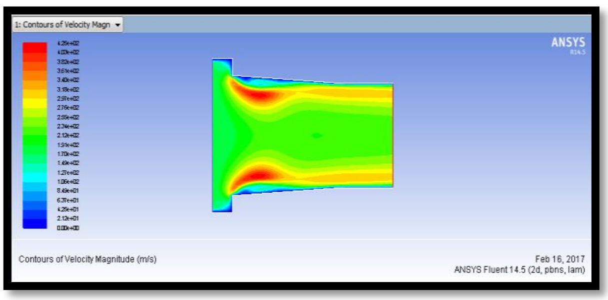



**Fig-12:** Reynolds number

**Mass Flow Rate (kg/s)**

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Inlet 20.427063

Interior-part_1 -411.77686

Outlet -20.436523

Wall 0

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Net -0.0094604492

MODEL LENGTH – 135.636 mm

FLOW- SUPERSONIC FLOW (MACH NUMBER 1.0)

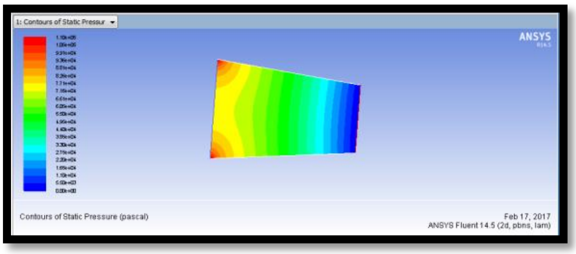


**Fig-13:** pressure

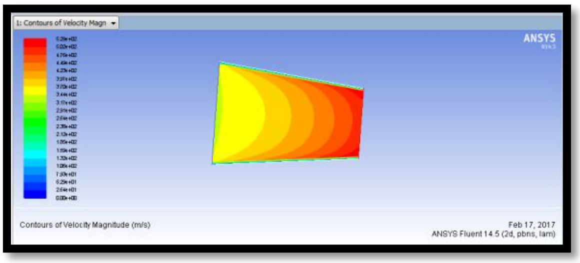


**Fig-14:** velocity

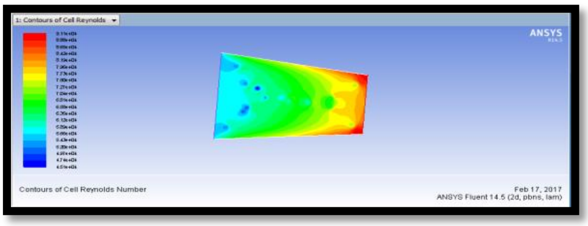


**Fig-15:** Reynolds number

Mass Flow Rate (kg/s)

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Inlet 40.853596

Interior-fill.1__ 272.28693

Outlet -40.852173

Wall 0

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Net 0.001422882

**CONVERGENT DIVERGENT MODEL**

FLUID –NITROGEN OXIDE

MODEL LENGTH – 110.236mm

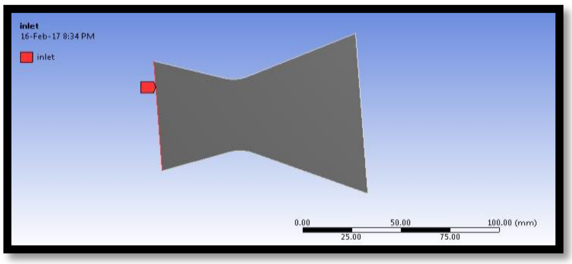


**Fig-16:** Inlet

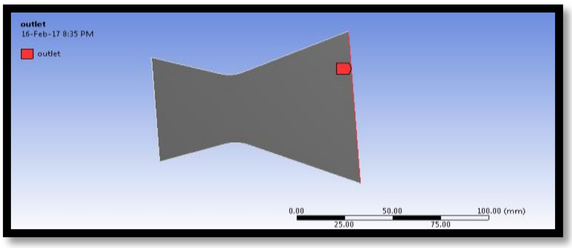


**Fig-17:** Outlet

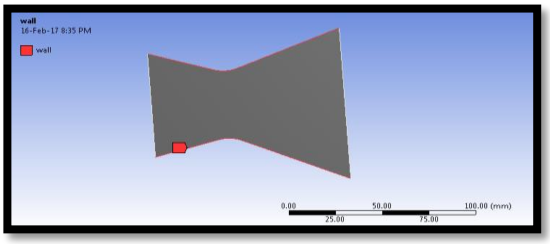


**Fig-18:** Wall

Select fluid nitrogen oxide

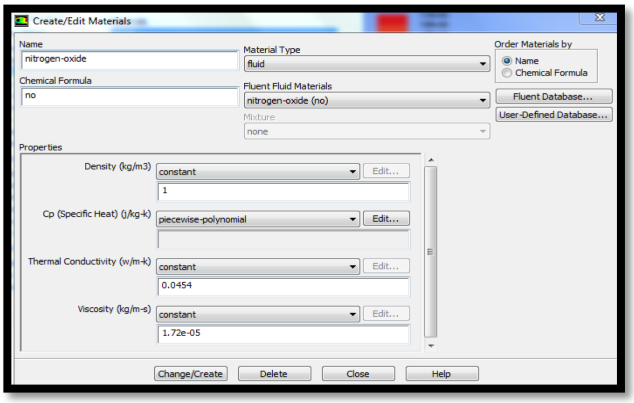


**Fig-19:** Select fluid nitrogen oxide

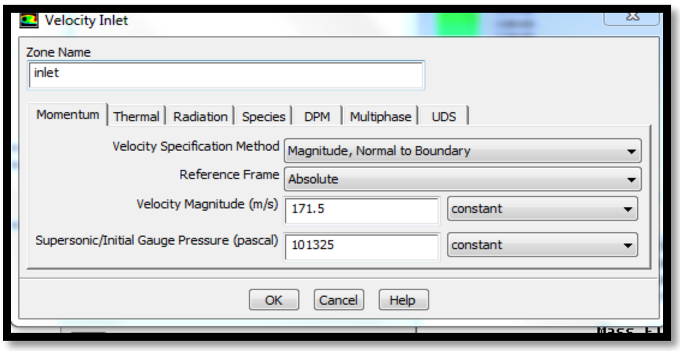


**Fig-20:** Velocity inlet

FLOW- SUBSONIC FLOW (MACH NUMBER 1.0)

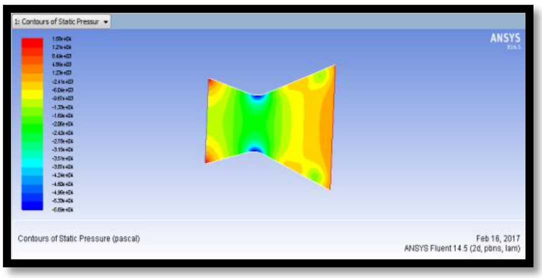


**Fig-21:** Pressure

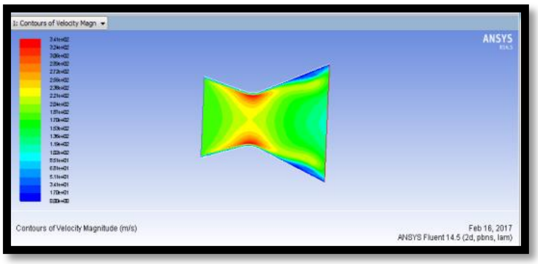


**Fig-22:** Velocity

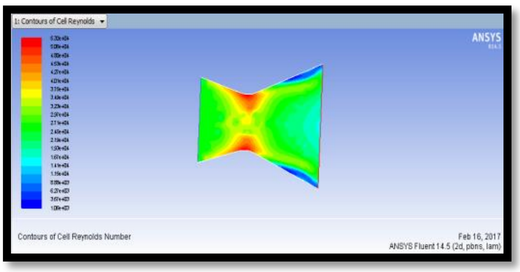


**Fig-23:** Reynolds number

Mass Flow Rate (kg/s)

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Inlet 13.980276

Interior-fill.1__ -55.600498

Outlet -13.953549

Wall 0

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Net 0.026726723

FLOW-SUPER SONIC FLOW (MACH NUMBER 1.0)

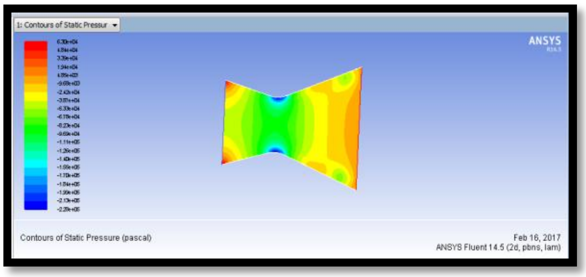


**Fig-24:** Pressure

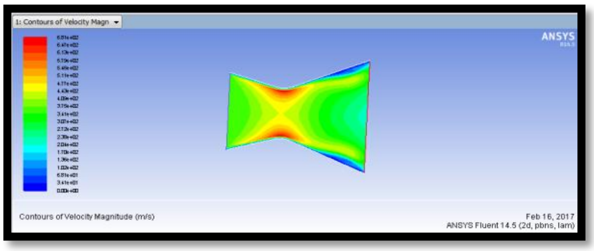


**Fig-25:** Velocity

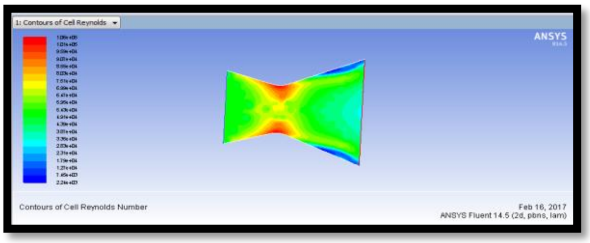


**Fig-26:** Reynolds number

Mass Flow Rate (kg/s)

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Inlet 27.960552

Interior-fill.1 -111.17674

Outlet -27.895111

Wall 0

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Net 0.065441132

MODEL LENGTH – 135.636mm

**RESULTS TABLE**

**CONVERGENT**

**Table-1:** Subsonic flow

| Length (mm) | Pressure (Pa) | Velocity (m/s) | Reynolds number | Mass flow Rate (kg/s) |
|---|---|---|---|---|
| 110.23 | 89330.5 | 424.63 | 67365.2 | 0.000631 |
| 135.63 | 27530.2 | 264.28 | 45528.8 | 0.00944 |

**Table-2:** Supersonic flow

| Length (mm) | Pressure (Pa) | Velocity (m/s) | Reynolds number | Mass flow Rate (kg/s) |
|---|---|---|---|---|
| 110.236 | 357324.3 | 849.31 | 134740.1 | 0.0014228 |
| 135.63 | 110088. | 528.76 | 91133.5 | 0.018939 |

**CONVERGENT DIVERGENT**

**Table-3:** Subsonic flow

| Length (mm) | Pressure (Pa) | Velocity (m/s) | Reynolds number | Mass flow Rate (kg/s) |
|---|---|---|---|---|
| 110.236 | 15753.44 | 340.543 | 53163.89 | 0.026726 |
| 135.63 | 17902.6 | 372.201 | 66907.4 | 0.01281 |

**Table-4:** Supersonic flow

| Length (mm) | Pressure (Pa) | Velocity (m/s) | Reynolds number | Mass flow Rate (kg/s) |
|---|---|---|---|---|
| 110.23 | 62972.7 | 681.19 | 106358.4 | 0.0654 |
| 135.636 | 71.557.2 | 747.09 | 133843.5 | 0.0266 |

**Convergent model**

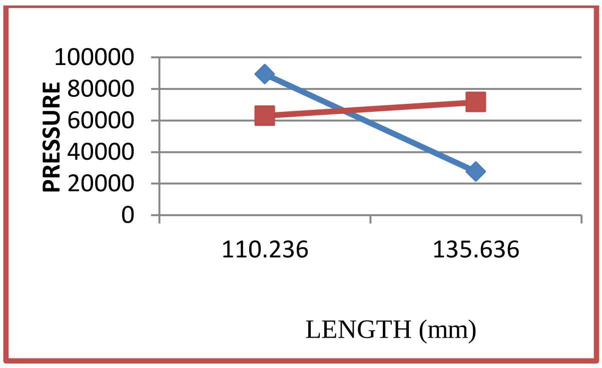


**Chart-1:** Comparison of pressure values for different flows and lengths

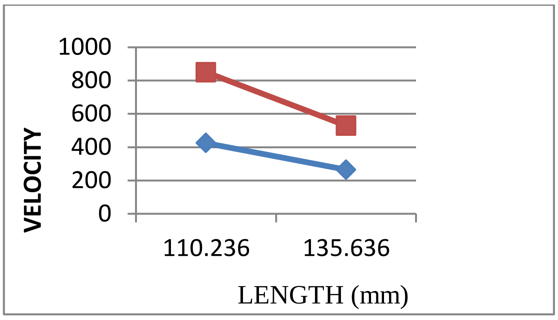


**Chart-2:** Comparison of velocity values for different flows and lengths

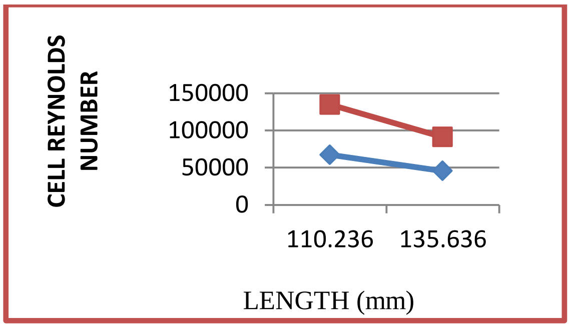


**Chart-3:** Comparison of cell Reynolds number values for different flows and lengths

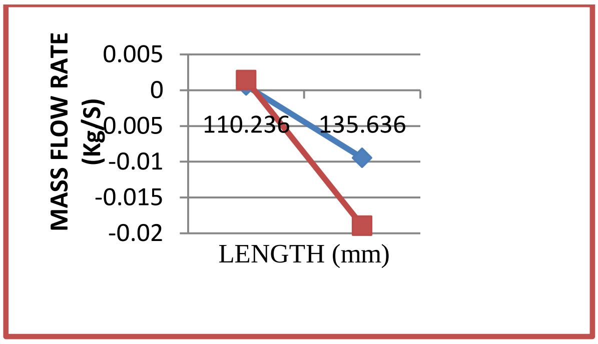


**Chart-4:** Comparison of mass flow rate values for different flows and lengths

**Convergent divergent model**

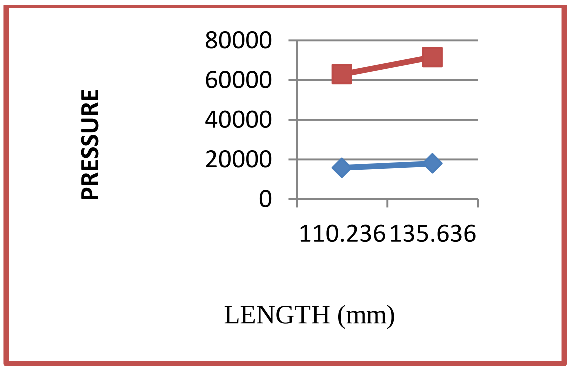


**Chart-5:** Comparison of pressure values for different flows and lengths

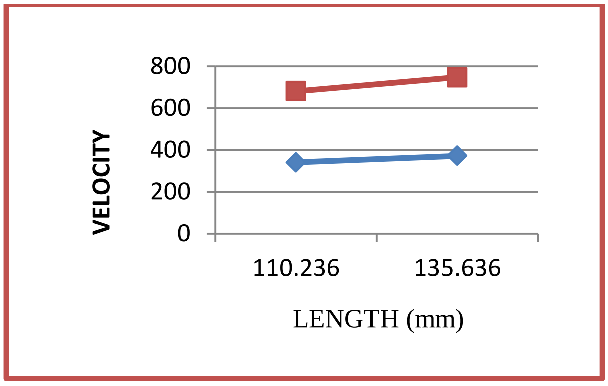


**Chart-6:** Comparisons of velocity values for different flows and lengths

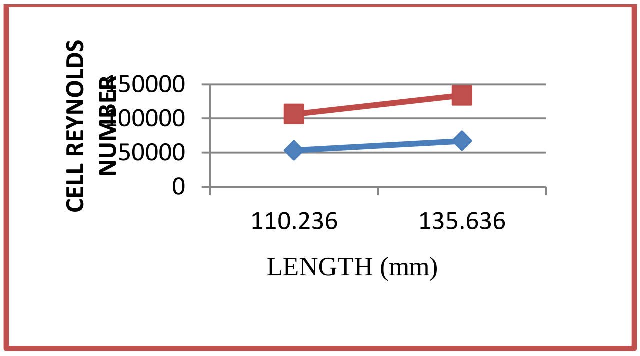


**Chart-7:** Comparison of cell Reynolds number values for different flows and lengths

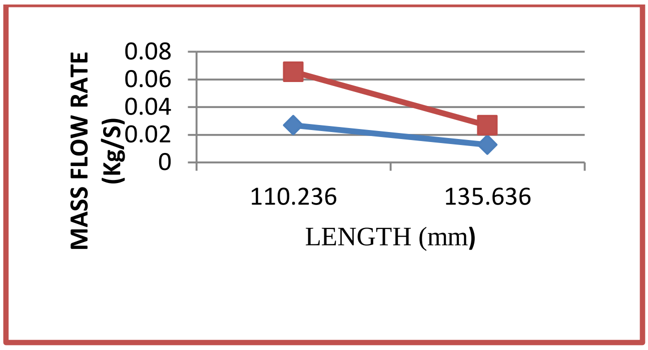


**Chart-8:** Comparison of mass flow rate values for different flows and lengths

## CONCLUSIONS

The aerodynamic design and performance analysis of convergent and convergent – divergent nozzle with different lengths 110.236mm and 135.636mm with subsonic and supersonic flow conditions is analyzed. The comparisons are made for pressure distribution, velocity and mass flow rates.

3D models are done in CATIA and CFD analysis is done in Ansys.

By observing the results, the augment of velocity and diminish of Pressure along the length of the nozzle accepts little bit increasing during the shocking. However, the augment will not show any significant to the total pressure decreases. As per the Bernoulli's equation the diminish of pressure as augment of velocity. Mass flow rates are increasing by increase of mach numbers and increase of lengths. The values are increasing by increasing the length of the nozzle. This is due to fact that by increasing the lengths the fluid is compressed inside the nozzle. The pressure distribution, velocities are more under supersonic flow conditions due to high inlet velocities. So it can be concluded that increasing mach numbers and lengths yields to better performance of nozzle.

## REFERENCES

[1] Deng Qingfeng, ZhengQun, Yue Guoqiang, Zhang Hai, Luo Mingcong, "Using a Pressure Controlled Vortex Design Method to Control Secondary Flow Losses in a Turbine Stage", Chinese Journal of Aeronautics, 2013, 26(5), pp 1125–1134

[2] John D Denton, "Some Limitations of Turbo machinery CFD", Proceedings of ASME Turbo Expo 2010: Power for Land, Sea and Air, 2010, PaperGT2010-22540

[3] Prathapanayaka ET. al, "Design and Development of 385kW turbine stage for Small Gas Turbine Engine", Project Document, PD-PR/2015/1000, 2015, Propulsion Division, National Aerospace Laboratories, Bangalore.

[4] Hany Moustapha, Mark F.Zelesky, Nicholas C.Baines, David Japikse; Axial and Radial Flow Turbines, Published by Concepts NREC, 2003

[5] NASA SP-290, "Turbine Design and Application", 1994

[6] Anderson JD, [2001], Fundamentals of Aerodynamics, 3rd Edition, pp.532-537, pp.555-585.

[7] Anderson JD, [1982], Modern Compressible Flow with Historical, pp.268-270, pp.282-286.

[8]Shapiro, AH, [1953], the Dynamics and Thermodynamics of Compressible Fluid Flow, Vol.1, pp. 294-295.