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# Design and Flow Analysis of Convergent -Divergent Nozzle

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***Abstract: A main purpose of nozzle is to increase the velocity or to accelerate the flow at exit of nozzle. Variation of parameters and fluid properties depend on design of that certain nozzle. To achieve better performance with less losses of fluid properties, nozzle should be satisfying better design requirements in every operating conditions. This research paper focuses on design, modelling and flow analysis of Convergent-Divergent nozzle. Objective of our research is to show variation of fluid properties like pressure, Mach number at exit of CD nozzle. Flow in the nozzle is considered as isentropic flow. The design parameters are inlet diameter, outlet diameter, throat diameter, length of convergent section and length of divergent section. Modelling is done in CREO PARAMETRIC 4.0 and fluid flow analysis is done in ANYSYS 17.1 FLUENT. We have chosen design of CD nozzle based on literature studies.***
***Keywords: Convergent-Divergent nozzle, isentropic, mass flow rate, pressure contour, Mach number contour, velocity, boundary conditions, meshing, inlet diameter, exit diameter, throat diameter, area velocity Mach relation, area ratio***

## I. INTRODUCTION

In this modern time, in every passenger aircraft and military aircraft we are using jet engine or gas turbine. In gas turbine nozzle is placed after turbine. The purpose for using nozzle is to increase velocity of flow at nozzle exit to produce thrust. Types of nozzle depends on application of that and exit velocity.

Nozzle efficiency affects whole system where we put nozzle. Application of nozzle is generally in aerospace and aeronautical field, in mechanical field, in chemical and medical field as well. The one type of nozzle is Convergent-Divergent nozzle or de laval nozzle.

When divergent section or duct is combined with conventional nozzle then it's called Convergent- Divergent nozzle. This nozzle mostly used in rocket engine and in some high-speed missile, which operates at supersonic Mach number. CD nozzles enhance kinetic energy of the fluid which is flowing through it. This is the primary purpose of CD nozzle. Basically, it works on Newton's third law of motion. Cd nozzle should be designed in such a way so it can receive more mass flow of fluid. There are various shapes are available in CD nozzle like rectangular, square, circular etc. We can get more thrust by using de laval nozzle. In convergent section we get subsonic flow, at the throat of CD nozzle there is sonic flow then flow accelerate in divergent section and becomes supersonic.

## II. METHODOLOGY

### *A. Design of CD nozzle*

In this study Method of Characteristics is used for designing the CD nozzle. This method is numerical method to solve 2-dimensional flow problem. Flow properties can be calculated by this method like direction and velocity of flow at various point. Supersonic nozzle can be divided into two parts, gradual-expansion, and minimum-length nozzle [1]. Gradual expansion is typically used where we need to

maintain high quality flow at exit of nozzle. (e.g., supersonic wind tunnel) and the second one that is minimum length nozzle, it can be used in rocket engine. We have designed minimum length nozzle.

### *B. Modelling*

Design and modelling of de laval nozzle is done in the CREO PARAMETRIC 4.0. Parameters are inlet diameter, outlet diameter, throat diameter, convergent section length, divergent section length. Table 1 shows the dimensions of CD nozzle.

Table I. Dimension of CD nozzle

| Sr. No. | Specifications | Dimensions (mm) |
|---|---|---|
| 2. | Inlet diameter | 3000 |
| 3. | Exit diameter | 5000 |
| 4. | Throat diameter | 700 |
| 5. | Convergent section length | 3000 |
| 6. | Divergent section length | 5000 |

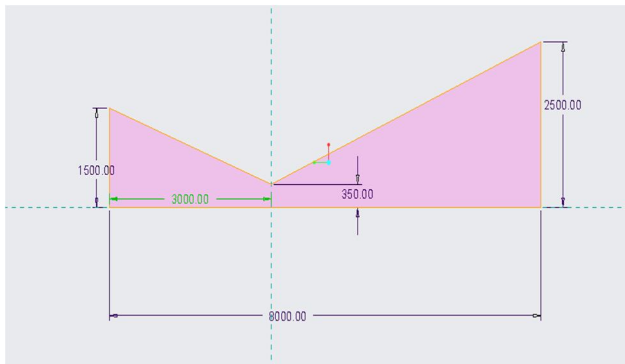

Figure 1. Sectional view of CD nozzle

*C. Analysis*

In this study analysis has been done in ANSYS 17.1 FLUENT. Energy equation and momentum equation are principal equations used in CFD to solve required solution [2]. Geometry which has been done in CREO PARAMETRIC 4.0 is imported to ANSYS WORKBENCH 17.1. There is no need of other domain construction in ANSYS as nozzle flow analysis is an internal flow type[2]. After that meshing has been done for input and output section. Next assigned boundary conditions.

N1= Number of divisions at exit and inlet

N2= Number of divisions on wall

Table II. Boundary Conditions

| Boundary zone | Details of fluid properties |
|---|---|
| Inlet | Gauge total pressure: 3e5 Pa<br>Inlet temperature: 298 K |
| Outlet | Gauge total pressure: 0.12e5 Pa |
| Material | Fluid: Air<br>Density: Ideal gas<br>Ratio of specific heat: 1.4 |

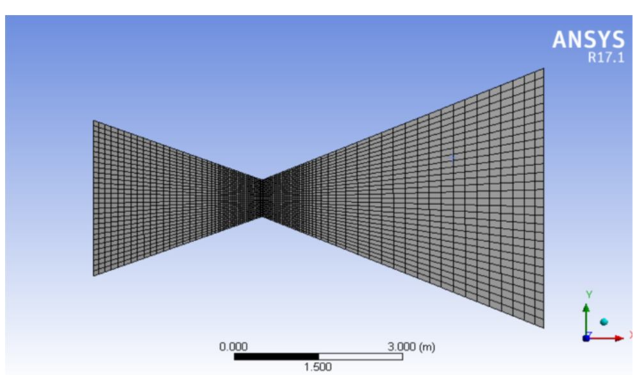

Figure 2. Meshing 1 of CD nozzle

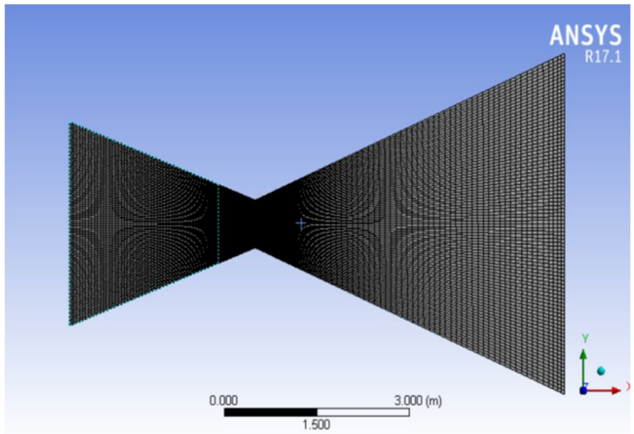


Fig. 3. Meshing 2 of CD nozzle

Here in figure 3 and 4 shows the contour of static pressure and Mach number for two various meshing respectively. From that contour we can conclude some results of flow properties.

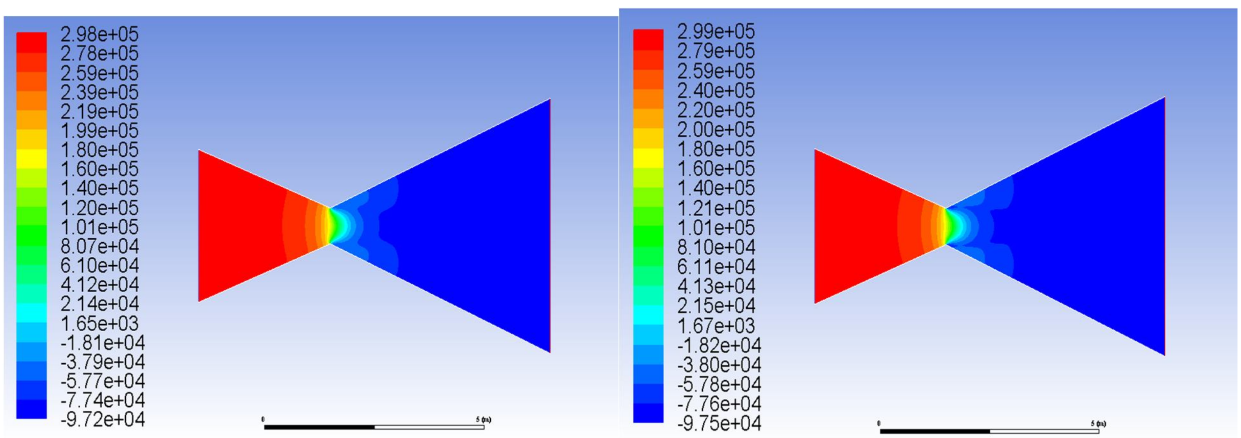


Fig. 4. Static pressure contour of CD nozzle

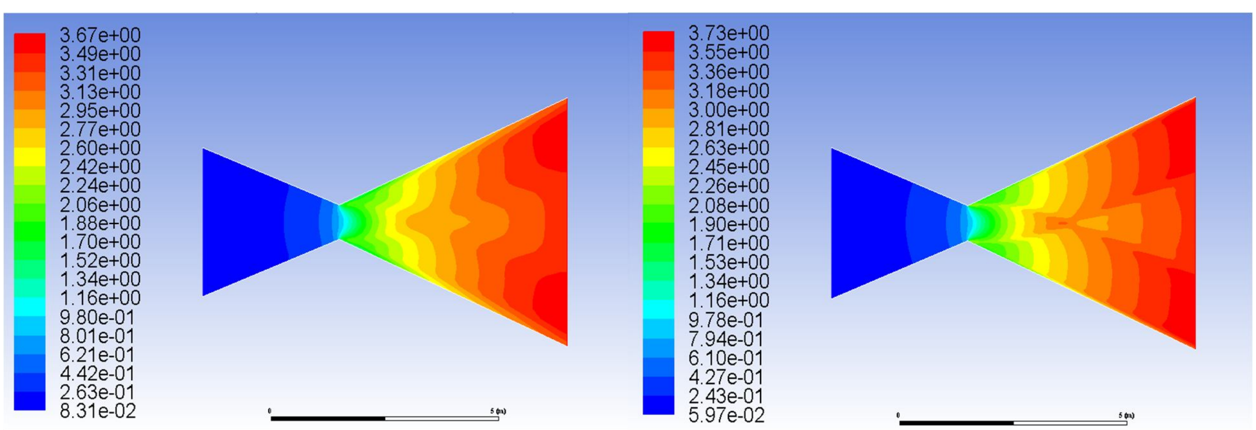


Figure 5. Mach number contour of CD nozzle

From above static pressure contour we can conclude that, red part is showing highest value of pressure that is 2.99e5 Pa at inlet, after that pressure is decreasing throughout the length, so we can say that according to Bernoulli's principal as pressure decreases then velocity increases. So, the highest value of pressure is 2.99e5 and the lowest value of pressure is -9.75e4 at exit.

From Mach number contour we can say that inlet Mach number is 0.0597 that is subsonic, after that Mach number is increasing and it will be close to 1 at throat, in divergent section Mach number increasing again and we get supersonic Mach number at exit of CD nozzle. Mach number is key parameter for the calculation.

*D. Numerical Calculations*

$$\frac{T0}{T*} = \left(1 + \frac{\gamma+1}{2}\right)(M*)^2$$

$$a* = \sqrt{\gamma RT*}$$

$$\frac{P0}{P*} = \left(\left(1 + \frac{\gamma+1}{2}\right)(M*)^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$\text{Exhaust Velocity} = \left(\frac{2\gamma}{\gamma-1}\frac{RT_0}{M}\left(1 - \frac{Pc}{130}\right)\frac{\gamma-1}{\gamma}\right)^{\frac{1}{2}}$$

Convergence area in nozzle = $A_c = 3A_t$

$$\text{Length of divergent section} = \sqrt{\frac{A_C}{\Pi}\left(\frac{1}{\tan\theta}\right)}$$

$$\text{Length of convergent section} = \sqrt{\frac{A_C}{\Pi}\left(\frac{1}{\tan\beta}\right)}$$

$$\frac{P2}{P*} = \left(\frac{\gamma+1}{2+(\gamma-1)Me^2}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{T0}{Te} = \left(1 + \frac{\gamma-1}{2}\right)(Me)^2$$

$$\text{Area ratio: } \left(\frac{Ae}{A*}\right)^2 = \left(\frac{1}{(Me)^2}\right)\left(\left(\frac{2}{\gamma+1}\left(1 + \left(\frac{\gamma-1}{2}\right)(Me)^2\right)\right)\right)^{\frac{\gamma+1}{\gamma-1}}$$

Throat area equation:

$$A* = \frac{\dot{m}V1}{C*(\rho*)^{\frac{1}{\gamma}}}$$

Critical pressure ratio:

$$r* = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

## III. CONCLUSIONS

Nozzle is most important part of the gas turbine engine because its playing vital role to produce thrust. So, by this research we got idea about the internal flow of nozzle, and the loss of energy. When area increase at that time velocity will increase, from that we can say that pressure decrease according to Bernoulli's principle. As velocity increases Mach number Increases. So, we can get more thrust.

## IV. ACKNOWLEDGMENT

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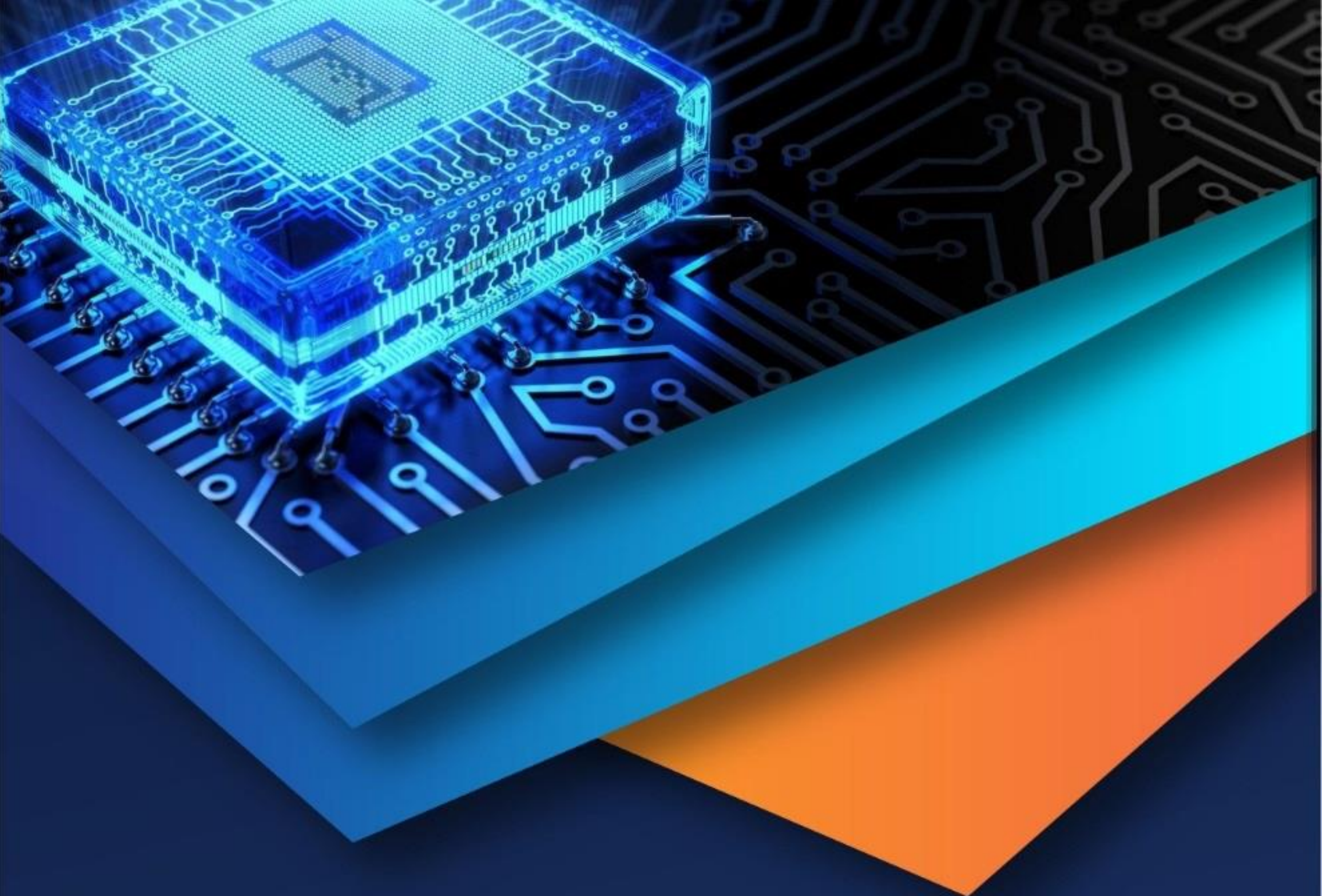


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