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# Design Analysis of Convergent-Divergent Nozzle

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**ABSTRACT:** Nozzle is a device designed to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that exhaust from them. Nozzles come in a variety of shapes and sizes depending on the mission of the rocket, this is very important for the understanding of the performance characteristics of rocket. By the proper geometrical design of the nozzle, the exhaust of the propellant gases will be regulated in such a way that maximum effective rocket velocity can be reached. Convergent divergent nozzle is the most commonly used nozzle since in using it the propellant can be heated in combustion chamber. After getting heated the propellant first converges at the throat of the nozzle and then expands under constant temperature in the divergent part.

**KEYWORDS:** Catia v5r1, CD nozzle, Analysis, design, convergent section, divergent section, throat section

## I. INTRODUCTION

A device that controls the speed of the fluid flow, directions, and flow characteristics is a Nozzle. The nozzle is designed like a pipe with a non-uniform cross-section. This design helps in controlling the velocity, flow rate, pressure ratio, direction, etc. Flow characteristics of the nozzle section can be varied with the variation in pressure difference at the outlet and the inlet sections. A CD nozzle or convergent-divergent nozzle is shaped like a tube with two bulging ends and a narrow section in the middle. This structure/design gives a balanced shape for the nozzle. Nozzle speeds up hot, pressurized gas passing through it in the axial (thrust) direction, by converting the heat energy of the flow into kinetic energy. A CD nozzle is of most importance to increase the kinetic energy of the medium. But, during this increase in kinetic energy, there is a drop in internal energy and pressure. Due to the demand for high-performance propulsion engines like the rocket has led to the critical assessment of its engine subsystems with the intent of minimizing losses. The main losses which are seen in this nozzle are flow rate, speed, pressure, etc. and these are controlled by the nozzle by sending this to the exhaust system. Thus, the main functions of the nozzle are to utilize waste energy and to use it to create pressure that lifts the body.

The nozzle's asymmetric configuration controls the direction and shape and also speeds up the outlet gases. The CD nozzle contains three parts, they are:

Converging section

Throat and

Diverging section

The **converging section** of the CD nozzle connects the gas or fluid chamber. At the converging part, the high-pressure gas loses its pressure energy and gains kinetic energy. The pressure drop is due to Bernoulli's principle and the law of conservation of mass. As we know, the force of incoming flow is greater than the throat mass flow rate which increases the flow rate at the convergent section.

The middle narrow section is the throat section. The throat is the narrowest and the smallest of all the sections in the nozzle.

The throat is the connecting part between the inlet and outlets of the CD nozzle. The Diverging section is for the outlet of the gas which comes out with high pressure and velocity which lifts the object and creates upthrust.



- For the converging section the change in area is negative ,  $M < 1$  (subsonic flow).
- for the flow near the throat change in area is zero ,  $M = 1$  (sonic flow).
- For the diverging section the change is area is positive ,  $M > 1$  (supersonic flow).

Subsonic Equation,

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2} \left[ \frac{2}{\gamma + 1} \left( 1 + \frac{\gamma - 1}{2} M^2 \right) \right]^{\frac{\gamma + 1}{\gamma - 1}}$$

Subsonic wave will exist if the mach number increased and  $A/A^*$  decreased.

De Laval Nozzle Formulation

$$\frac{dv}{v} = \frac{1}{1 - M^2} \frac{dA}{A} \rightarrow \frac{dA}{A} = (M^2 - 1) \frac{dv}{v}$$

de Laval Nozzle produces at Mach number  $M = 1$  where  $dA = 0$

Consider steady flow through nozzle with sonic throat;

$$\dot{m} = \rho v A = \rho^* v^* A^* \rightarrow \frac{A}{A^*} = \frac{\rho^* v^*}{\rho v}$$

$$\frac{\rho^*}{\rho} = \frac{\rho^* \rho_0}{\rho \rho_0} = \left( \frac{2}{\gamma + 1} \right)^{\frac{1}{\gamma - 1}} \left( 1 + \frac{\gamma - 1}{2} M^2 \right)^{\frac{1}{\gamma - 1}}$$

$$v^*/v = \sqrt{\gamma R T^*/T} = \sqrt{\gamma R T^*} \sqrt{T/T^*} = 1/M \sqrt{T/T_0} \sqrt{T_0/T} = 1/M \left( \frac{2}{\gamma + 1} \right)^{\frac{1}{2}} \left( 1 + \frac{\gamma - 1}{2} M^2 \right)^{\frac{1}{2}}$$

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

Dynamic Pressure Equation

$$P_{dynamic} = \rho \text{fluid} \frac{v^2}{2}$$

Equation to found the velocity from the pressure at inlet and outlet.

Mach Number Equation

$$M = \frac{v_{fluid}}{v_{sound}}$$

After the velocity is obtained, it should be easy to obtain the Mach Number.

## II. RELATED WORK

A CD Nozzle is a tube that is pinched in the middle, making a carefully balanced, asymmetric hourglass shape. It is used to accelerate a hot, pressurized gas passing through it to a higher supersonic speed in the axial (thrust) direction, by converting the heat energy of the flow into kinetic energy. the main functions of the nozzle are to utilize waste energy and to use it to create pressure that lifts the body. CFD and ansys analysis of different pressure in inlet and outlet parameters.

## III. METHODOLOGY

The design parameters and the boundary conditions are determined. The designing of CD Nozzle is done for desired outlet conditions. The modelling for both CD Nozzle and Cylindrical enclosure is done using CATIA V5 Software. Then later the meshing of Nozzle is done using ANSYS V.15 software. The fluid flow analysis is done using Ansys Fluent to obtain various velocity, Pressure, Mach number and Temperature conditions. The analysing of CD Nozzle is done and calculation is done in MATLAB to check errors whether it is coming here. Also theoretical analysis is done of CD Nozzle. Then results are then validated and comparison of both models will carried out and the result with least error will take into consideration.



PARAMETER	VALUE
Inlet diameter(D1)	6.25 cm
Outlet diameter(D2)	5.84 cm
Throat diameter(Dt)	9.5 cm
Static pressure(P1)	13 bar
Static pressure(P2)	1 bar
Stagnation pressure(P01)	17 bar
Stagnation temperature(T0)	303 K
Exit temperature(T2)	134.6 K
Exit Mach Number	2.5
Exit velocity	585 m/s
Mass flow rate	9.9 kg/s
Thrust F	5815.3 N
A2/A1	2.636
A1/At	1.435
Entry Mach Number M1	0.64

#### IV. EXPERIMENTAL RESULTS

From the research,

Stagnation pressure  $P_0 = 17$  bar

Stagnation temperature  $T_0 = 303$  K

Inlet Diameter  $D_1 = 6.25$  cm

Entry Mach number  $M_1 = 0.6$

Required,

Exit Mach number  $M_2 = 2.5$

Exit Temperature  $T_2 = 134.6$  K

For  $M_1 = 0.64$ , (from isentropic tables)

$$P_1/P_{01} = 0.759$$

$$A_1/A_1^* = 1.145$$

$$P^*/P_0 = (2/\gamma + 1)^{\gamma/\gamma - 1}$$

$$A/A^* = 1/M \sqrt{2/\gamma + 1 + \gamma - 1/\gamma + 1M^2}$$



Here,

$$A_1^* = A_t$$

$$P_{O1} = P_{O2} = P_0$$

Therefore,

$$A_t = A_1 / 1.145 = \frac{\pi}{4} D_1^2 / 1.145$$

$$A_t = 26.81 \text{ cm}^2$$

Throat Diameter,  $D_t = 5.84 \text{ cm}$

$$P_1 = 0.759 * P_0 = 0.759 * 17$$

Static pressure at inlet,  $P_1 = 13 \text{ bar}$

For  $M_2 = 2.5$

$$\frac{A_2}{A^*} = 2.636$$

$$\frac{P_2}{P_{O2}} = 0.0585$$

Here,  $A^*_2 = A_t$

Therefore,

$$A_2 = 2.636 * A_t = 2.636 * \frac{\pi}{4} D_2^2$$

$$A_2 = 70.15 \text{ cm}^2$$

Throat Diameter,  $D_2 = 9.5 \text{ cm}$

$$P_2 = 0.0585 * P_0 = 0.0585 * 17$$

static pressure at exit,  $P_2 = 1 \text{ bar}$

$$\text{Exit velocity } V_e = M_2 \sqrt{\gamma R T_2}$$

$$= 2.5 \sqrt{1.4 * 287 * 134.6}$$

$$V_e = 585 \text{ m/s}$$

Thrust,

$$F = m * V_e$$

$$= 9.9 * 585$$

$$F = 5815.3 \text{ N}$$

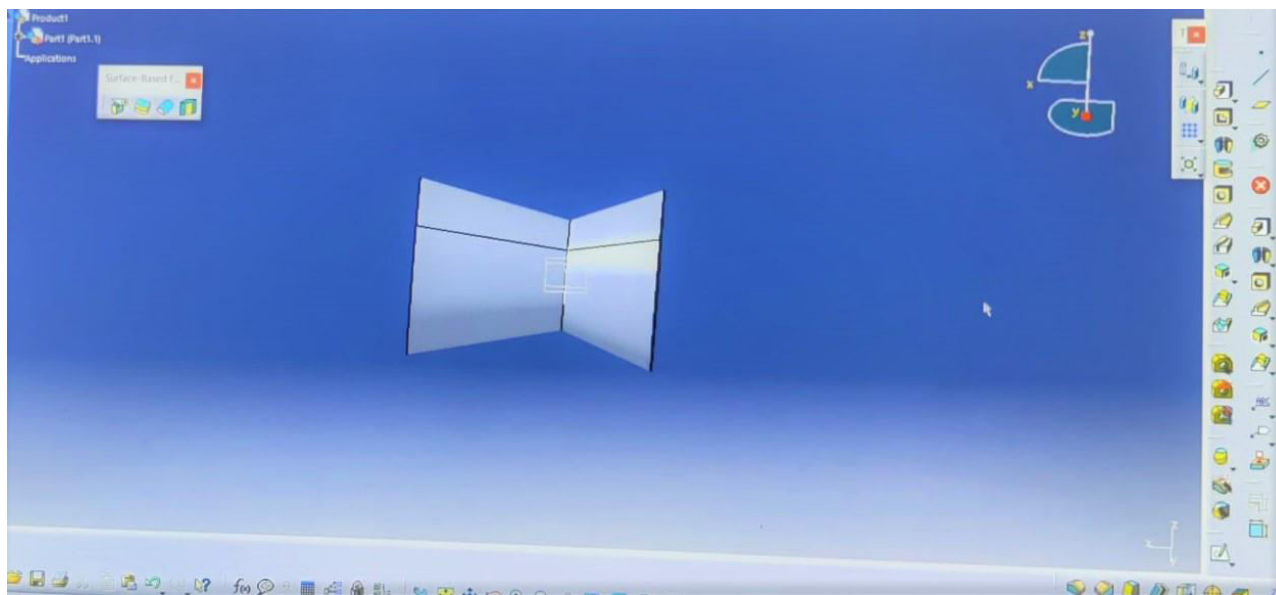


Figure 1: Convergent-Divergent Nozzle

## V. CONCLUSION

From this we can conclude that we are done with the introduction, working, advantages and calculated the values of required parameters like temperature, pressure, velocity, and mach number etc. And we have also gone through the mechanical features and inlet parameters, outlet parameters and dimensions to find out the required parameters. From this we will continue the design and analysis through the following information we got now.

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