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# DESIGN AND ANALYSIS OF A MICRO CD-NOZZLE FOR GENERATING SUPERSONIC FLOW

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**Abstract**— This paper aims at design and analyses of a Convergent–Divergent nozzle in order to attain a supersonic flow at the exit of the nozzle which produces shock diamonds. Area ratios, diameters, and lengths for inlet, throat and exit are calculated mathematically with respect to a standard compressor and corresponding Mach numbers are calculated. Based on analytical results a Convergent –Divergent nozzle is designed in Catia V5 and the flow field analysis of CD nozzle is carried using Ansys fluent work bench. Both fluent results and analytical results are compared to quantify.

**Keywords**—Convergent-Divergent nozzle, supersonic flow, shock diamonds

## I. INTRODUCTION

The nozzle is basically designed to increase the velocity of the fluid flow across it by converting heat and pressure into kinetic energy of fluid. In Aero-engines, it is used to produce efficient thrust. The fluid from subsonic velocity is accelerated to supersonic velocity using a Convergent- Divergent nozzle.

A Convergent-Divergent nozzle is a duct that is nipped 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.

If the pressure & the mass flow rate through the nozzle are sufficient to reach the sonic speeds then choking occurs at the throat of a Convergent-Divergent nozzle and it produces supersonic flow downstream of throat. It means the entry pressure to the nozzle to be significantly more than the ambient at all the times. In addition, the pressure of the gas at the exit of the expansion portion of the exhaust of a nozzle must not be low. The exit pressure can be significantly below ambient pressure it exhausts into, but if it is too far below ambient, then the flow will cease to be supersonic. In practice, the nozzle exit pressure must be-around 2-3 times higher than the ambient pressure to attain supersonic flow.

The flow in the throat is sonic which means the Mach number is equal speed of sound. Downstream of the throat, the geometry diverges and the flow is isentropically expanded to a supersonic Mach number that depends on the nozzle area ratio.

If the flow is over expanded, at the nozzle exit shock diamonds are formed where as if the flow is under expanded then the expansion fans with shock diamonds will be formed.

## II. METHODOLOGY

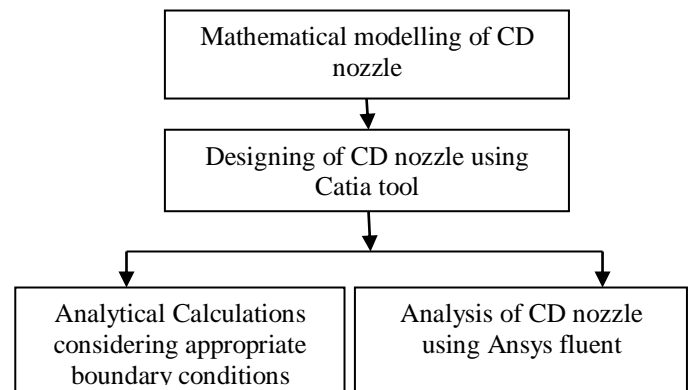


Fig.1 Methodology

Research starts with considering the capacity of a compressor of 8 bar and based on its pressure input design parameters are calculated for a Convergent-Divergent nozzle like nozzle dimensions and inlet mass flow rate, velocity and pressure. After that Convergent-Divergent nozzle is modelled using catia software.

The area relation for a given Mach number is given below:

## III. INPUT AND DESIGN PARAMETERS CALCULATIONS

a) Effect of Compressors Mass Flow Rate on Design Parameters

$$\text{Mass Flow Rate, } \dot{m} = \frac{p_0 \dot{A}}{\sqrt{T_0}} (0.0414)$$

Where,  $\dot{m}$  = mass flow rate in Kg/s

$p_0$  = Inlet Pressure in Pa

$T_0$  = Absolute Temperature in Kelvin

$\dot{A}$  = Throat Area in m<sup>2</sup>

b) Specification of Compressor

<b>Model Number</b>	<b>TS 03 120 HN</b>
<b>Piston displacement</b>	<b>311 lpm</b>
<b>Free air delivery</b>	<b>250 lpm</b>
<b>Motor power</b>	<b>3 HP, 2.2 kW</b>
<b>Compressor rpm</b>	<b>925 rpm</b>
<b>Number of cylinders</b>	<b>2</b>
<b>Air receiver capacity</b>	<b>160 litres</b>
<b>Dimensions in mm</b>	<b>1595*500*1000</b>

Table.1 A two-stage reciprocating compressor specifications

c) Calculation for Throat Diameter

$$0.00936 = \frac{8 * 10^5 \dot{A}}{\sqrt{300}} (0.0414)$$

$$\dot{A} = 3.915 * 10^{-6} \text{ m}^2, \dot{A} = \text{Throat Area in m}^2$$

$$D = 2.49 \text{ mm}$$

d) Calculation for Exit Diameter and Area Ratio

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

Where A= Exit area in m<sup>2</sup>

$\gamma$  = Specific heat ratio

M= Mach number

$$\left(\frac{A}{3.915 * 10^{-6}}\right) = \left(\frac{1.4 + 1}{2}\right)^{-\frac{1.4+1}{2(1.4+1)}} \left(\frac{2 + (1.4 - 1)1.5^2}{2 * 1.5}\right)^{\frac{1.4+1}{2(1.4+1)}}$$

$$A = 7.23 * 10^{-6} \text{ m}^2 \quad D = 3.041 \text{ mm}$$

e) Calculation of Nozzle Pressure Ratio (Npr)

$$\frac{p_0}{p_t} = \left(1 + \frac{\gamma - 1}{2} (M_t)^2\right)^{\frac{\gamma}{\gamma - 1}}$$

$$\frac{p_t}{p_0} = 0.2724$$

f) Calculation of Temperature Ratio

$$\frac{T_0}{T} = \left[1 + \frac{\gamma - 1}{2} m^2\right]$$

$$\frac{T_0}{T} = 1.45$$

#### IV. MODELLING

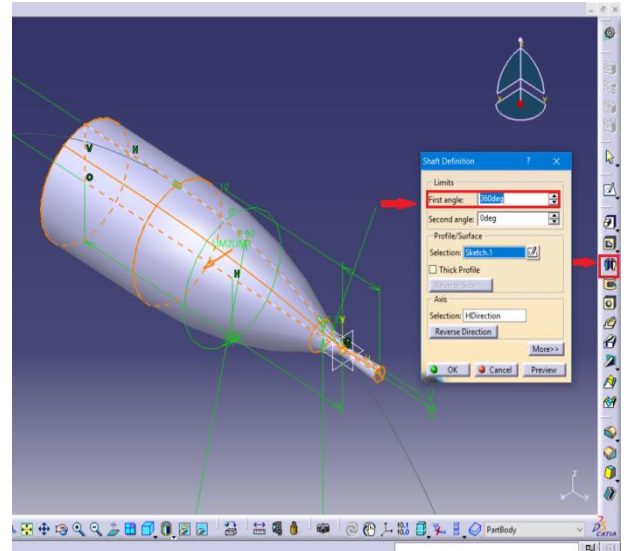


Fig. 2 Catia model of Convergent-Divergent Nozzle

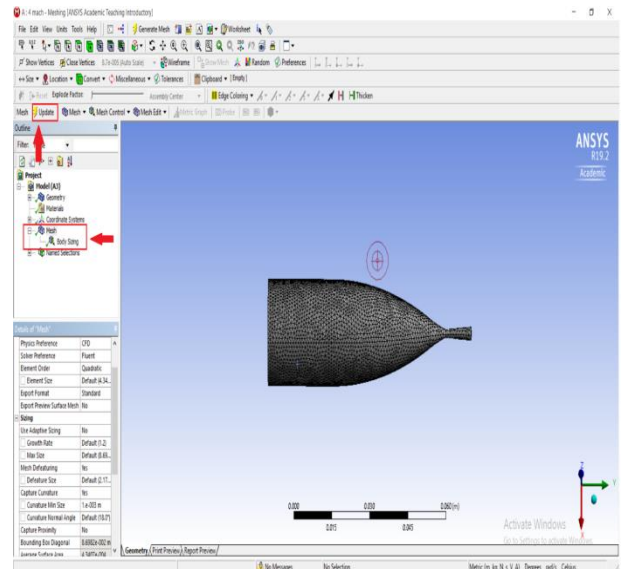


Fig. 3 Meshed Convergent-Divergent Nozzle

An unstructured mesh is generated with mesh size of 0.01mm with effective grid independent studies.

#### V. RESULTS

Analytical Results		
Mach number	P/Po	Poutput in Pascal
1.2	0.412	329600
1.5	0.272	217600
2	0.127	101600
2.2	0.093	74400
2.5	0.058	46400
2.7	0.042	33600
3.0	0.027	21600
3.2	0.020	16000
3.5	0.013	10400
4	0.0065	4800

Table.2 Mach number with respect to pressure ratios

0.412	329600	1.49
0.272	217600	1.81
0.127	101600	1.907
0.093	74400	2.02
0.058	46400	2.52
0.042	33600	2.60
0.027	21600	2.97
0.020	16000	3.02
0.013	10400	3.48
0.0065	4800	3.81

Table.3 CFD Obtained Mach numbers

### CFD COUNTER PLOTS

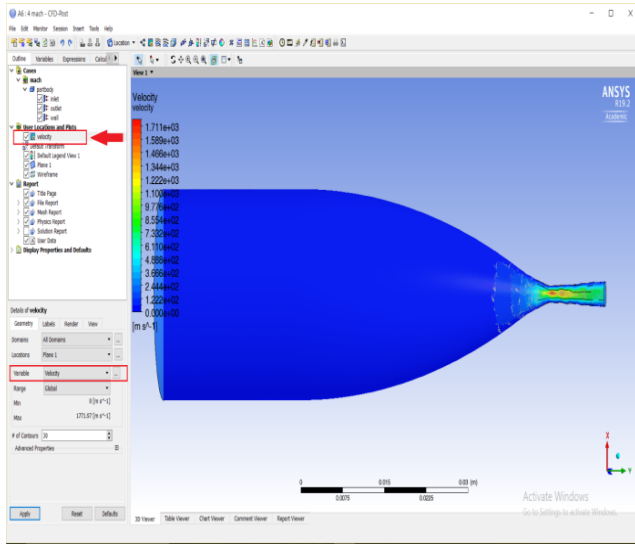


Fig. 4 Velocity contours

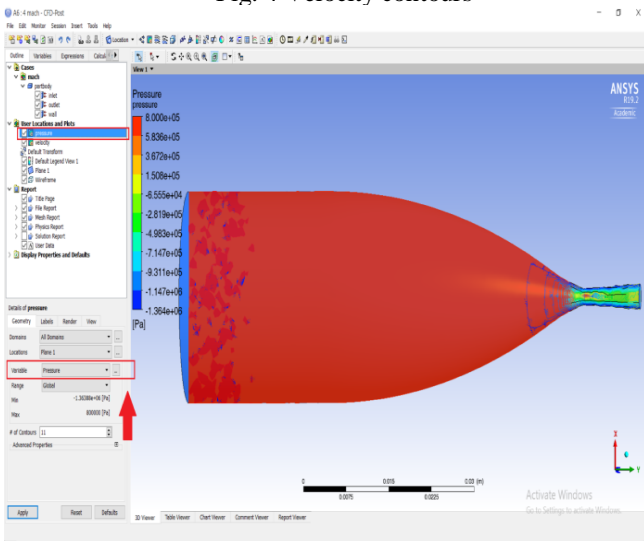


Fig. 5 Pressure contours

Analytical Results		CFD Results
P/Po	Poutput in Pascal	Mach number

### VI. CONCLUSION

By calculating analytically and solving through ansys fluent software it is found that both values are matching with little deviation but the design of Convergent-Divergent nozzle was able to achieve supersonic speed with taken conditions. And also its recommended to fabricate and test the Convergent-Divergent nozzle with above said dimensions.

### VII. ACKNOWLEDGEMENT

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