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Parametric flow study inside convergent-divergent nozzle using CFD method

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ABSTRACT

Computational fluid dynamics is a branch of fluid mechanics that deals with problems related to fluid flow and solves numerical methods and algorithms. Computational methods are used to perform the simulation to observe the interaction of fluids with the surface defined by boundary conditions. The objective of the current study is to determine the variation of the flow parameters like density, velocity, pressure, and temperature. The analysis software considered for computational findings are done using ANSYS (Fluent).

Keywords: Aerodynamics, CD Nozzle, CFD, Flow, Properties

1. INTRODUCTION

CD nozzle which is also known as a De-Laval nozzle is a tube that is pinched in the middle, makingan hourglass-shape. It is used as a means of accelerating the flow of a gas passing through it to asupersonic speed. It is widely used in some types of steam turbine and is an essential part of themodern rocket engine and supersonic jet engines. The one-dimensional inviscid isentropic flow in aconvergent-divergent (CD) nozzle is a classical textbook problem, which has different flow regimesdepending upon the nozzle pressure ratio (NPR). The inviscid theory predicts a simple shockstructure consisting of a normal shock followed by a smooth recovery to exit pressure in thedivergence part of a choked nozzle for the nozzle pressure ratios corresponding to the over-expanded flow regime. But, in reality, multi-dimensionality and viscous effects like wall boundarylayer and flow separation drastically alter the flow in a CD nozzle. The over-expanded flow regime inCD nozzles of different shapes and sizes has been a subject matter of numerous investigationsbecause of their wide range of applications. The CD nozzle plays a vital role in the case of asupersonic version of the missile, jet engines, wind tunnel, ramjets, scramjets and rocket science aswell. A CD nozzle is used frequently to proselytize chemical energy into kinetic energy in a thermalchamber and vice versa.

2. LITERATURE REVIEW

Theoretical study has also been accessible which spots the propellants being used in the solid rocket motor. The performance parameters are also being described along with the material selection as described by Ankit et.al [8]. Ankit et.al presented a study on nozzle flow partition that is carried out by simulation of rocket nozzle designed Fusion 360and ANSYS to inspect the laminar as well as turbulent regime for deviating section of nozzle [1]. Ankit et.al reviewed about pintle injector used in rocket nozzle along with motor combination for generating higher amount of thrust. It show the influence of spray angles and characteristics such as flow as well as combustion on spray images, droplet size, momentum ratio, opening distance and SMD distributions which affect the injector geometry [2]. Ankit et.al paper discussed a theoretical and conceptual design for compact size 2 stage sounding rocket by focusing on structural optimizations at various levels. The aim of the paper is to develop a two-stage sounding rocket with overall length constrained to 1 meter [3].The aim of paper is to design a two stage sounding rocket and its nozzles using fusion 360 and analysis of different properties using simulation on ANSYS software. The rocket is designed to reach maximum apogee to perform scientific experiments and can be recovered safely after use [4]. Ankit et.al described about different classification of propellants used for launch vehicles. The cryogenic propellants taken for comparison are liquid hydrogen, liquefied methane and for semi cryogenic fuels considered are RP-1 (kerosene) and UDMH with liquid oxygen as the oxidizer. The scope of this work addresses the comparison among the propellants, on their chemical properties, overall efficiency and fatigue life which is a major criterion for launch vehicles [5]. Aerodynamic thrust variation and performances play a key role in estimating forces along with the injected flow and their characteristics. This review paper deals with the aerodynamics characterization, its properties at different conditions inaddition with the performance analysis of the aerospike nozzle study carried by Ankit et.al [6]. Ankit et.al discusses about composition of chemical substances that affects the launch vehicle in ground station as well as atmospheric conditions is been presented. During the rocket-launching the large amount of inhalation of an exhaust gas released and it majorly affects the surface of the launch pad as well as the atmosphere [7]. Ankit et.al describes about a sounding rocket which is developed to perform certain scientific experiments in low earth orbit. The propulsion characteristics and calculations related to nozzles for both the booster stage and the sustainer stage of two-stage sounding rocket have been discussed and calculated using isentropic relations [8].Theoretical study has also been presented which highlights the propellants being used in the solid rocket motor. The performance parameters are also being described along with the material selection as described by Ankit et.al [9].The presented a work on aerodynamics for profile ofelliptical nose cone and especially improved flowing qualities that can be used in scheming aircrafts. Flow occurrencesobserved in numerical simulations for different AOA for elliptical nose cone profile are emphasized, critical design aspectsand performance features of selected nose cone are presented by Ankit et.al [12].

3. DESIGN AND MODELLING OF CD NOZZLE

Nozzles are used to produce thrust by accelerating the exhaust gases and are used to control the speed, characteristics, direction of the fluid flow. They are different types of nozzles but a convergent-divergent nozzle is mostly used because for this type of nozzle Mach number greater than 1 can be achieved. It comprises a convergent and divergent section connected by the throat

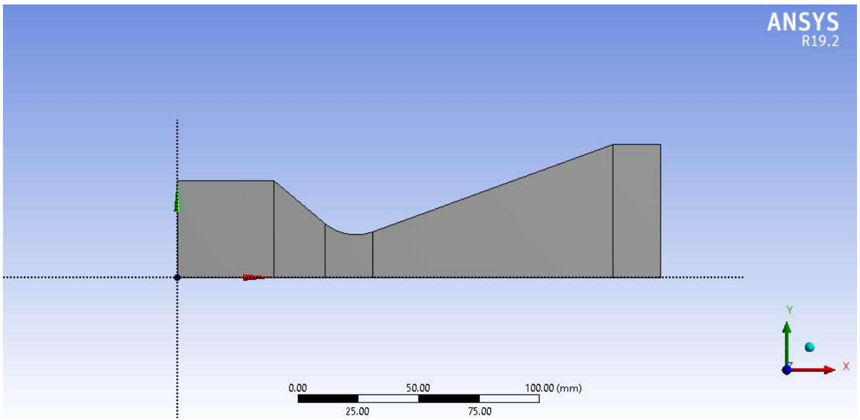

Figure 1. Half way view of CD Nozzle

General Setup

Table 1: Setup for nozzle

1.	**SOLVER TYPE**	Pressure Based
2.	**2D Space**	Planar
3.	**Time**	Steady

Meshing

The nozzle meshing has been done using selecting the edges inferiority, creating the five different splitting faces with face meshing along with the inflation. The pictorial representation of meshing for nozzle has been shown below-

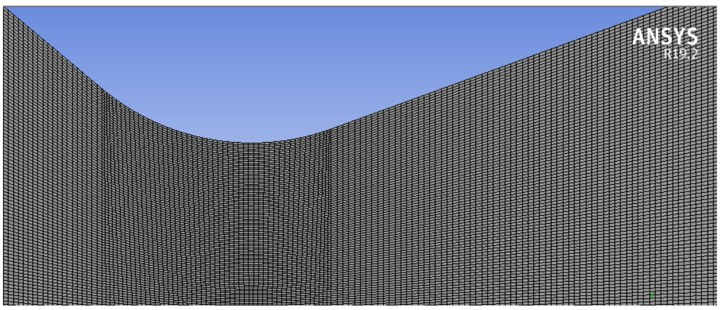

Figure 2. Meshing of CD Nozzle

Material Properties

In this type of CFD solution, one needs to specify the material properties of the fluid which will flow through the nozzle. Generally, the properties of the fluid resemble that of the fluids which are used for rocket propulsion. These types of fluids are highly effective when used in nozzles. Materials used for the section of the wall were set to default. The material properties of one such fluid for the nozzle are mentioned below which has been used for our CFD solution.

Table2. Material Properties of Nozzle

PROPERTIES	VALUE
Density	101325 kg/m^3
Viscosity	$1.81*10^{-5}$ Pa/s
Thermal Conductivity	0.02617 W/mK
Specific Heat	1006.45 J/kg K
Mean Molecular Mass	28.97 g/mol

Boundary Conditions

Whenever we do any type of simulation, we have to define some basic initial conditions so that our simulation goes in thedesired way and does not deviate from the course. Every option that we choose here will have some significant effect on thefluid flow through the nozzle that is why the user needs to have good knowledge of fluid mechanics and aerodynamics. In our CFD solution, we used various surfaces for different functions. Inlet, outlet, and walls were specifically named anddefined. While defining the wall no-slip condition wall with no roughness was selected to get proper results for this solution. In this particular solution, a pressure-based inlet and outlet were used and the properties are mentioned below.

Table 3. Pressure Inlet

Gauge Total Pressure	$5*10^6$ Pa
Initial Gauge Pressure	$496*10^4$ Pa
Turbulence Intensity	7%
Turbulence Viscosity Ratio	10

Table 4. Pressure Outlet

Gauge Pressure	101325 Pa
Pressure Profile	1
Backflow Turbulence Viscosity Ratio	10

4. RESULTS

The analysis results of CD nozzle for several variables such as velocity, pressure, temperature etc. are been computed and displayed below.

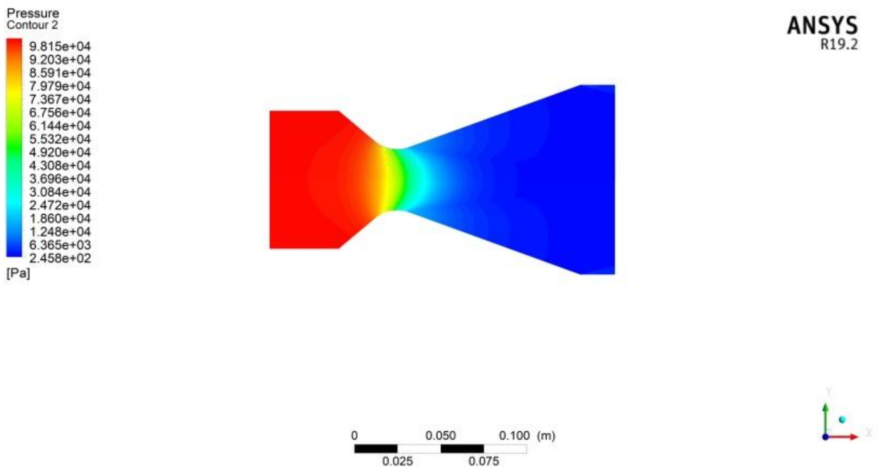

Figure 3. Contour variation for pressure

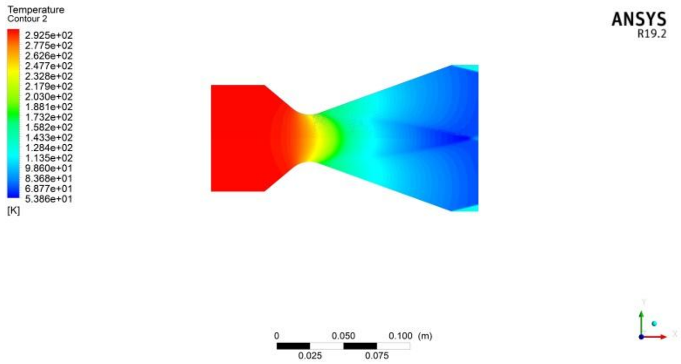

Figure 4. Contour variation for temperature

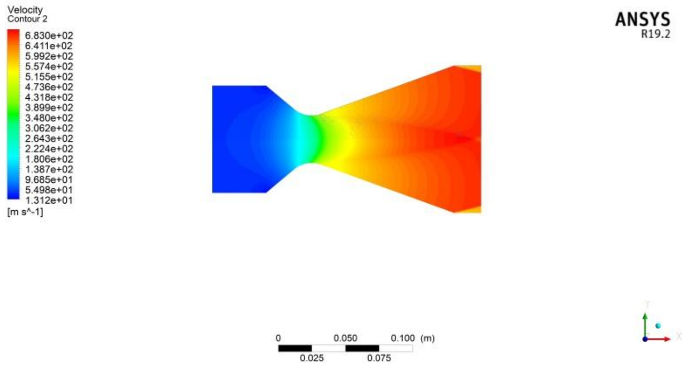

Figure 5. Contour variation for velocity

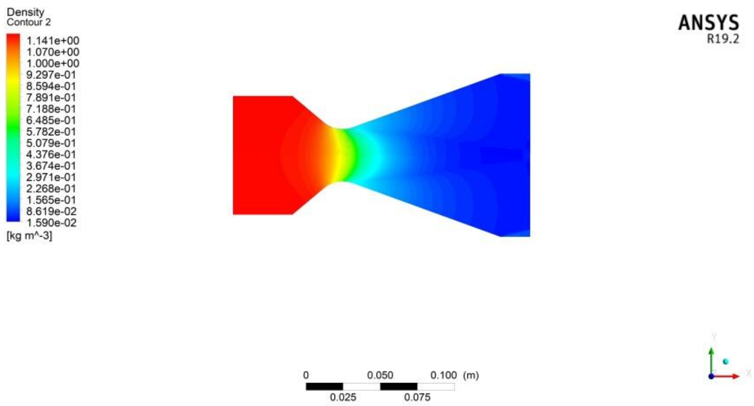

Figure 6. Contour variation for density

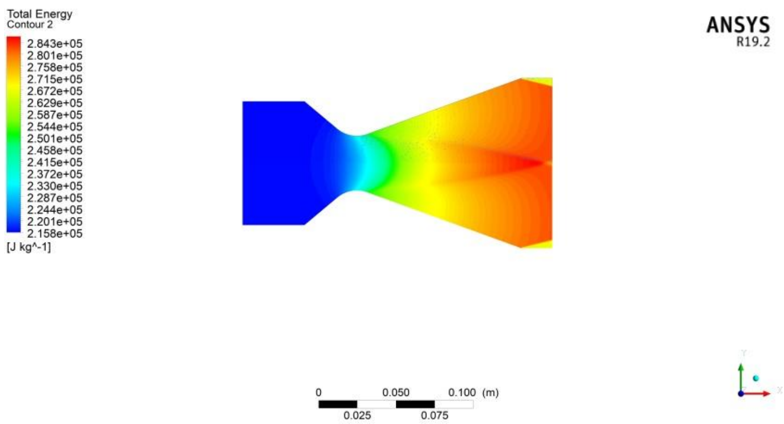

Figure 7. Contour variation for energy

CONCLUSION

The results were obtained using the software ANSYS fluent. From this study, we found that for supersonic combustion, the fuel shot should be done at supersonic speeds. The flow parameters like pressure, temperature, density, and velocity largely depend on the nozzle cross-sectional area, which affects the flow inside the nozzle and the extent of flow expansion. When pressure increases, the velocity will decreases this can be seen in our results. The indication inside the flow duct, the velocity increases after the throat section and there can be seen an impulsive rise in velocity till it reaches a high mach number.

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