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Yogesh Bhawarker Mr.
Department of Aerospace Engineering, Sandip University, SOET, NASHIK, MH, yogeshbhawarker@gmail.com

Digambar Daware Mr.
Department of Aerospace Engineering Sandip University, digambardaware7@gmail.com

Krishna Yadav
Department of Aerospace Engineering Sandip University, krishnayadav8433@gmail.com

Vedant Akolkar
Department of Aerospace Engineering Sandip University, vedantakolkar9511@gmail.com

Pallavi Padalwar
Department of Aerospace Engineering Sandip University, padalwarpallavi@gmail.com

See next page for additional authors

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Authors

Yogesh Bhawarker Mr., Digambar Daware Mr., Krishna Yadav, Vedant Akolkar, Pallavi Padalwar, and Prakash Katdare

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Yogesh Bhawarker[1], Digambar Daware[1], Krishna Yadav[2], Vedant Akolkar[2], Pallavi Padalwar[3], Prakash Katdare[4]
[1,2,3]Department of Aerospace Engineering, Sandip University, Nashik India
[4]Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal India
Corresponding Author : yogesh.bhawarker@gmail.com

***Abstract*— The reduction of Earth-to-orbit launch costs in conjunction with an increase in launcher reliability and operational Efficiency is the key demands on future space transportation systems, like single-stage-to-orbit vehicles (SSTO). The realization of these vehicles strongly depends on the performance of the engines, which should deliver high performance with low system complexity. Performance data for rocket engines are practically always lower than the theoretically attainable values because of imperfections in the mixing, combustion, and expansion of the propellants. The main part of the project addresses different nozzle concepts with improvements in performance as compared to conventional nozzles achieved by Different Mach numbers, thus, by minimizing losses caused by over- or under expansion. The design of different nozzle shapes and flow simulation is done in gambit and fluent software's respectively for various parameters**

Keywords- CD- Nozzle, Bell shaped Nozzle, pressure, density, velocity.

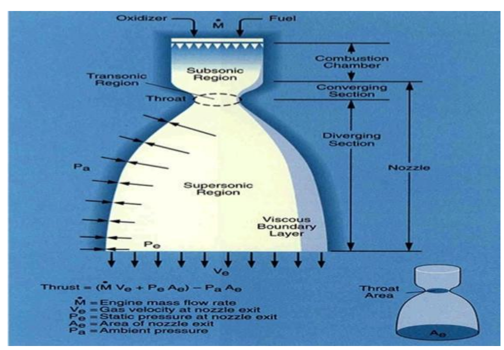
I. INTRODUCTION

A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber. A nozzle is often a pipe or tube of varying cross sectional area and it can be used to direct or modify the flow of a fluid (liquid or gas). Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. A jet exhaust produces a net thrust from the energy obtained from combusting fuel which is added to the inducted air. This hot air is passed through a high speed nozzle, a propelling nozzle which enormously increases its kinetic energy. The goal of nozzle is to increase the kinetic energy of the flowing medium at the expense of its pressure and internal energy. Nozzles can be described as convergent (narrowing down from a wide diameter to a smaller diameter in the direction of the flow) or divergent (expanding from a smaller diameter to a larger one). A de Laval nozzle has a convergent section followed by a divergent section and is often called a convergent-divergent nozzle ("con-di nozzle"). Convergent nozzles accelerate subsonic fluids. If the nozzle pressure ratio is high enough the flow will reach sonic velocity at the narrowest point (i.e. the nozzle throat). In this situation, the nozzle is said to be choked.

II. NOZZLES BASIC REVIEW

A rocket nozzle includes three main elements: a converging section, a throat, and a diverging section. The combustion exhaust gas first enters the converging section. The gas moves at subsonic speeds through this area, accelerating as the cross sectional area decreases. In order to reach supersonic speeds, the gas must first pass through an area of minimum cross sectional area called the throat. From here, the supersonic gas expands through the converging section and then out of the nozzle. Supersonic flow accelerates as it expands. The following are the features of nozzle,

- Nozzle produces thrust.
- Convert thermal energy of hot chamber gases into kinetic energy and direct that energy along nozzle axis.
- Exhaust gases from combustion are pushed into throat region of nozzle.
- Throat is smaller cross-sectional area than rest of engine; here gases are compressed to high pressure.
- Nozzle gradually increases in cross-sectional area allowing gases to expand and push against walls creating thrust.
- Mathematically, ultimate purpose of nozzle is to expand gases as efficiently as possible so as to maximize exit velocity.



EXPANSION AREA RATIO

Most important parameter in nozzle design is expansion area ratio, e. Fixing other variables (primarily chamber pressure) → only one ratio that optimizes performance for a given altitude (or ambient pressure). However, we have to keep in mind that rocket does not travel at only one altitude, so we should know trajectory to select expansion ratio that maximizes performance over a range of ambient pressures. Thus variable expansion ratio nozzles are preferred for space travel.

III. WHY NOZZLES ARE USED?

Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. A jet exhaust produces a net thrust from the energy obtained from combusting fuel which is added to the inducted air. This hot air is passed through a high speed nozzle, a propelling nozzle which enormously increases its kinetic energy. The goal of nozzle is to increase the kinetic energy of the flowing medium at the expense of its pressure and internal energy. Convergent nozzles accelerate subsonic fluids. If the nozzle pressure ratio is high enough the flow will reach sonic velocity at the narrowest point (i.e. the nozzle throat).Convergent nozzles accelerate subsonic fluids. If the nozzle pressure ratio is high enough the flow will reach sonic velocity at the narrowest point (i.e. the nozzle throat).

IV. WORKING OF ROCKET

A rocket engine, or simply "rocket", is a jet engine that uses only stored propellant mass for forming its high speed propulsive jet. Rocket engines are reaction engines and obtain thrust in accordance with Newton's third law. Since, they need no external material to form their jet, rocket engines can be used for spacecraft propulsion as well as terrestrial uses, such as missiles. Most rocket engines are internal combustion engines, although non-combusting forms also exist. Rocket engines as a group have the highest exhaust velocities, are by far the lightest, but are the least propellant efficient of all types of jet engines. Rocket technology can combine high thrust (mega Newton's), very high exhaust speeds (around 10 times the speed of sound in air at sea level) and very high thrust/weight ratios (>100) simultaneously as well as being able to operate outside the atmosphere, and while permitting the use of low pressure and hence lightweight tanks and structure.

V. TYPES OF NOZZLES

Types of nozzles are several types. They could be based on either speed or shape.

A. Based on speed The basic types of nozzles can be differentiated as

- Spray nozzles
- Ramjet nozzles

B. Based on shape The basic types of nozzles can be differentiated as

- Conical
- Bell
- Annular

CONICAL NOZZLES:

- Used in early rocket applications because of simplicity and ease of construction
- Cone gets its name from the fact that the walls diverge at a constant angle
- A small angle produces greater thrust, because it maximizes the axial component of exit velocity and produces a high specific impulse
- Penalty is longer and heavier nozzle that is more complex to build
- At the other extreme, size and weight are minimized by a large nozzle wall angle – Large angles reduce performance at low altitude because high ambient pressure causes overexpansion and flow separation
- Primary Metric of Characterization: Divergence Loss

VI. HOW NOZZLES ARE DESIGNED?

A rocket engine uses a nozzle to accelerate hot exhaust to produce thrust as described by Newton's third law of motion. The amount of thrust produced by the engine depends on the mass flow rate through the engine, the exit velocity of the flow, and the pressure at the exit of the engine. The value of these three flow variables are all determined by the rocket nozzle design. A nozzle is a relatively simple device, just a specially shaped tube through which hot gases flow. Rockets typically use a fixed convergent section followed by a fixed divergent section for the design of the nozzle. This nozzle configuration is called a convergent-divergent, or CD, nozzle. In a CD rocket nozzle, the hot exhaust leaves the combustion chamber and converges down to the minimum area, or throat, of the nozzle. The throat size is chosen to choke the flow and set the mass flow rate through the system. The flow in the throat is sonic which means the Mach number is equal to one in the throat. Downstream of the throat, the geometry diverges and the flow is isentropically expanded to a supersonic Mach number that depends on the area ratio of the exit to the throat. The expansion of a supersonic flow causes the static pressure and temperature to decrease from the throat to the exit, so the amount of the expansion also determines the exit pressure and temperature. The exit temperature determines the exit speed of sound, which determines the exit velocity. The exit velocity, pressure, and mass flow through the nozzle determine the amount of thrust produced by the nozzle.

VII. DIFFERENT TYPES OF SOFTWARE USED

We use variety of software to make our work easy, fast and accurate. The software required will be on two categories. They are designing and analysis. Recently we have many types of software for designing. We mainly use three types of software. They are

- CATIA
- Gambit
- ANSYS

VIII. DIMENSIONS AND BOUNDARY CONDITIONS ASSUMED

CD Nozzle dimensions and boundary conditions
Inlet diameter = 69cm

Exit diameter = 82cm
Inlet pressure = 210000 Pa
Temperature = 300 K

Bell Nozzle dimensions and boundary conditions
Inlet diameter = 48cm
Exit diameter = 68 cm
Inlet pressure = 210000 Pa
Total temperature = 300K

Double bell Nozzle dimensions and boundary conditions
Inlet diameter = 48 cm
Exit diameter = 91 cm
Inlet pressure = 210000 Pa
Total temperature = 300K

Expandable Nozzle dimensions and boundary conditions
Inlet diameter = 69 cm
Exit diameter = 100 cm
Inlet pressure = 210000 Pa
Total temperature = 300 K

APPLYING BOUNDARY CONDITIONS

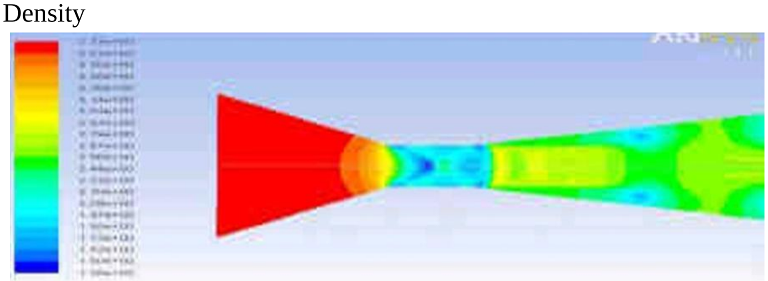
Applying boundary conditions indicate that we need to give boundary conditions to each and every face. For example, the inlet has to be given certain conditions like inlet pressure and inlet temperature. Likewise we need to give wall boundary conditions to the top surface. Similarly axis condition should be given to the axis.

IX. THE CFD RESULTS

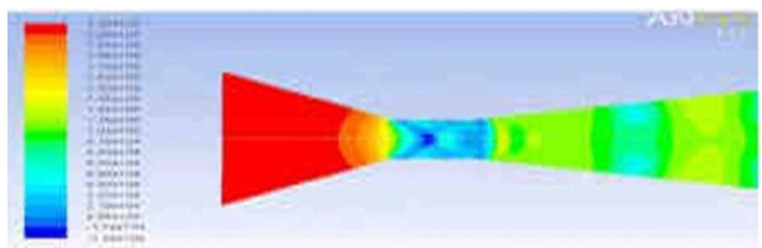
The CFD analysis of a rocket engine nozzle has been conducted to understand the phenomena of subsonic flow through it at various divergent angles. A two - dimensional axisymmetric model is used for the analysis and the governing equations were solved using the finite-volume method in ANSYS FLUENT® software. The variations in the parameters like the Mach number, static pressure, turbulent intensity are being analyzed. The phenomena of oblique shock are visualized and the travel of shock with divergence angle is visualized. Computational Fluid Dynamics (CFD) is an engineering tool that assists experimentation. Its scope is not limited to fluid dynamics; CFD could be applied to any process which involves transport phenomena with it. To solve an engineering problem we can make use of various methods like the analytical method, experimental methods using prototypes. The analytical method is very complicated and difficult. The experimental methods are very costly. If any errors in the design were detected during the prototype testing, another prototype is to be made clarifying all the errors and again tested. This is a time-consuming as well as a cost consuming process. Flow instabilities might be created inside the nozzle due to the formation if shocks which reduce the exit Mach number as well as thrust of the engine. This could be eliminated by varying the divergent angle. Here analysis has been conducted on nozzles with divergent angles and thus change in the external diameter 32, 34, 40, 44, 50, 55. Experimentation using the prototypes of each divergent angle is a costly as well as a time consuming process. CFD proves to be an efficient tool to overcome these limitations. Here in this work the trend of various flow parameters are also analyzed.

CD NOZZLE RESULTS:

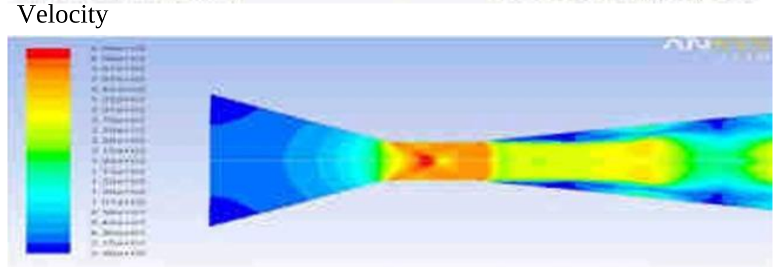
Density



Pressure

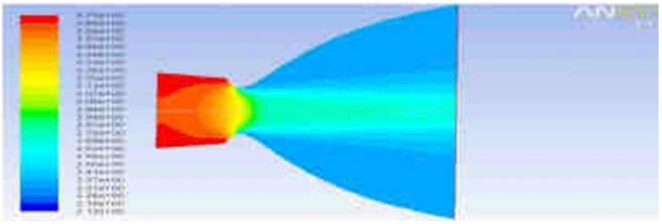


Velocity

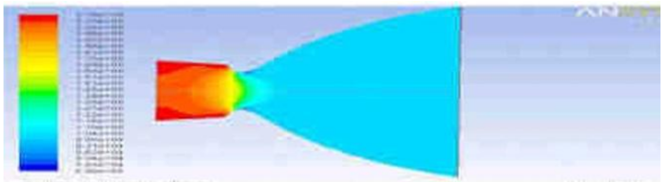


BELL SHAPED NOZZLE RESULT

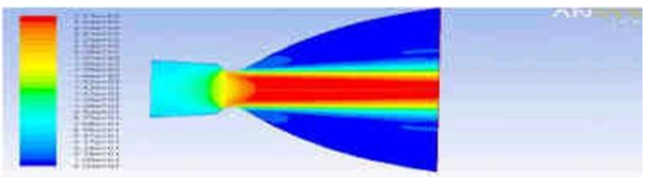
Density



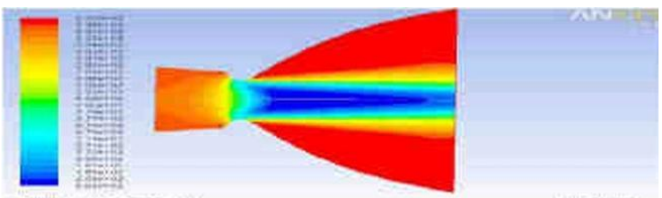
Pressure



Velocity



Temperature



CONCLUSION

Because of greater value for exit velocity, we can conclude that convergent divergent nozzle can show better performance than bell nozzle, dual bell nozzle and expandable nozzles. Although benefits in performance were indicated in most of the available publications, not many of these nozzle concepts has yet been used in existing rocket launchers. It is shown that significant performance gains results from the adaptation of the exhaust flow to the ambient pressure. All of the advanced nozzle concepts have been to the subject of analytical work and gave much satisfactory results, but Convergent divergent nozzle stands as best among the nozzles we analyzed.

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