Design And Analysis of Conical Nozzle For Various Semi-Divergent Angle

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Abstract- *In this project with the help of software program we ran a simulation of conical nozzle for various semi divergent angle and analyzed which increases the efficiency of the rocket propulsion. Nozzle efficiency is affected by operation in the atmosphere because atmospheric pressure changes with altitude; but due to the supersonic speeds of the gas exiting from a rocket engine, the pressure of the jet may be either below or above ambient, and equilibrium between the two is not reached at all altitudes We drafted the 3D models of three different semi-divergent angles using CATIA. We also changed the input pressure with three different conditions for all three angles. A 2D graphical representation of the nozzle is plotted and co-ordinates of the plotted lines have also been displayed. This project aims in determining the most efficient nozzle type with certain parameters which thereby provides maximum efficiency.*

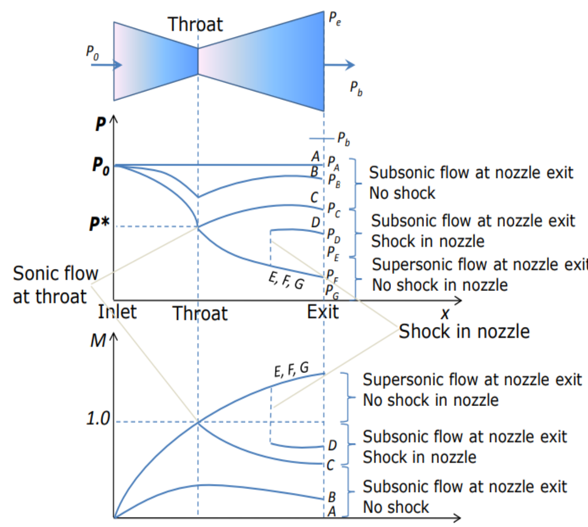
Keywords- Propulsion, Conical nozzle, semi-divergent angle, aeronautical.

I. INTRODUCTION

NOZZLE :

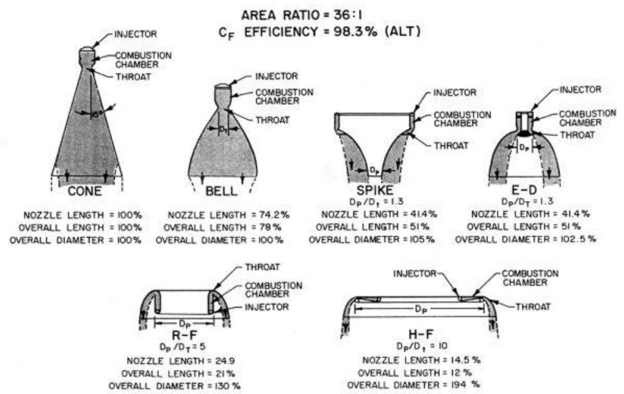
- Maximum Mach number achievable in a converging nozzle is unity.
- For supersonic Mach numbers, a diverging section after the throat is required.
- However, a diverging section alone would not guarantee a supersonic flow.
- The Mach number at the exit of the converging-diverging nozzle depends upon the back pressure.
- The flow through nozzles is normally assumed to be adiabatic as the heat transfer per unit mass is much smaller than the difference in enthalpy between the inlet and outlet.
- The flow from the inlet to the throat can be assumed to be isentropic, but the flow from the throat to exit may not be due the possible presence of shocks.

$$\frac{A^*}{A_e} = \frac{P_{0e} M_e}{P^*_{0i}} \left[\frac{(\gamma+1)/2)}{1+((\gamma-1)/2)M_e^2} \right]^{(\gamma+1/2(\gamma-1))}$$



Conical Nozzles:

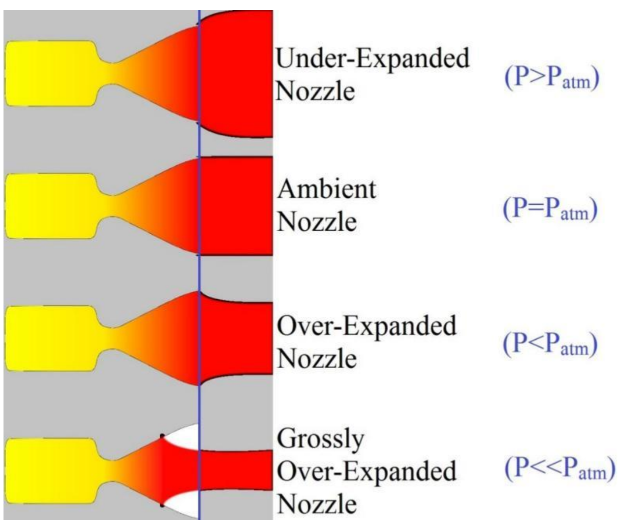
The conical nozzle is the oldest and the simplest configuration.It is ease to fabricate.The cone gets its name from the fact that the walls diverge at a constant angle. A small angle produces greater thrust, because it maximizes the axial component of exit velocity and produces a high specific impulse (a measure of rocket efficiency). Small nozzle divergence angle means long length and axial momentum and thus high specific impulse.It has penalty in rocket propulsion system mass, vehicle mass due to its long length.



Large divergence angle reduces size and weight. But, results in performance loss at low altitude as the high ambient pressure causes overexpansion andflow separation.

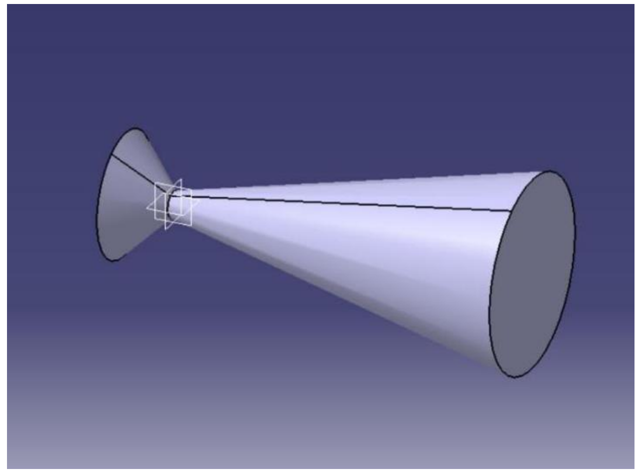
In practice the thrust, exist velocity, etc obtained from the ideal rocket equations are not the same. So, some correction factor has to be applied to this equations.The correction factor applied is called divergence factor and is denoted by Greek alphabet Lambda(λ).

λ= 1/ 2* (1+ cosα)
The expression for the divergence factor is given by
α is the half cone angle. λ = 1 for ideal rocket.
For a nozzle with divergence angle of 30 deg. The value of α i s 15 deg.



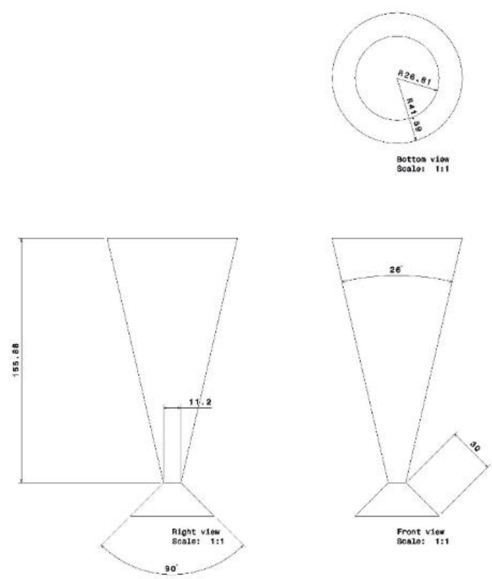
II. DESIGN

The initial work we did was started with the design of the nozzle where the basic idea of the design was referred from our base paper in which we had our own few modifications to improve the flow properties. It is also important to note that the variation in design had created problems in flow which were rectified accordingly. We designed the 3D model for various semi-divergent angles (12°,13°,15°,17°).



13° semi-divergent angle nozzle design

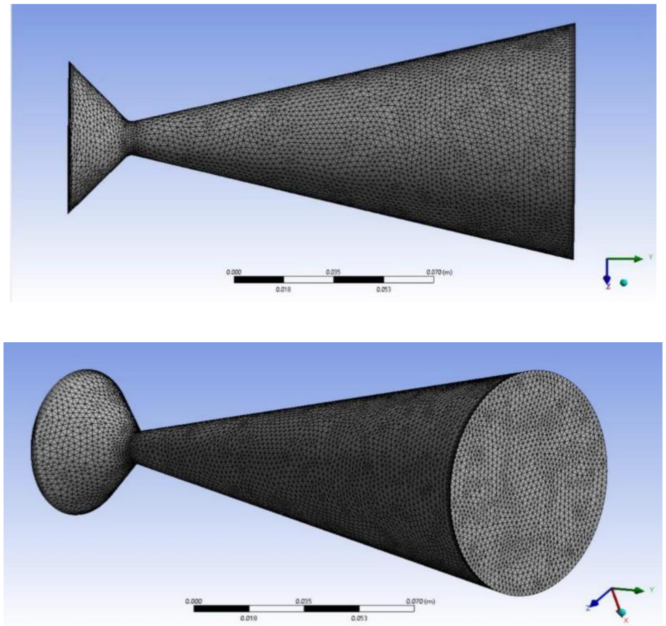
Using draft option we have converted 3D Nozzle diagram to 2D and the various values have been marked .The Draft for 13° semi-divergent angle nozzle is attached below. All other nozzles were designed and drafted similar to this nozzle varying the semi-divergent angle.



draft for 13° semi-divergent angle nozzle

III. MESHING

Ansys provides general purpose, high-performance, automated, intelligent meshing software that produces the most appropriate mesh for accurate, efficient multiphysics solutions from easy, automatic meshing to highly crafted mesh. Smart defaults are built into the software to make meshing a painless and intuitive task, delivering the required resolution to capture solution gradients properly for dependable results. Larger the number of nodes and elements, higher will be the accuracy of results. Similar to this meshing for 12°,15°,17° were done.



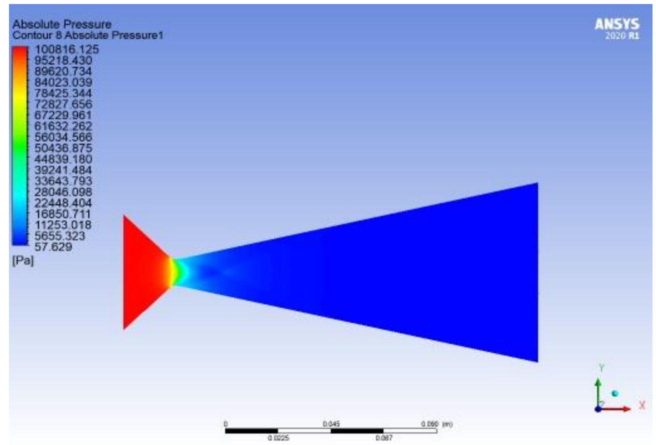
meshing of 13° semi-divergent nozzle

IV. OBSERVATION FROM ANALYSIS

We have analyzed the 13 degree semi-divergent angle conical nozzle mesh with an input pressure of 1 atmospheric pressure and a temperature of 300 kelvin. We then inserted a plane at x-y axis and various contours have been created and are displayed below.

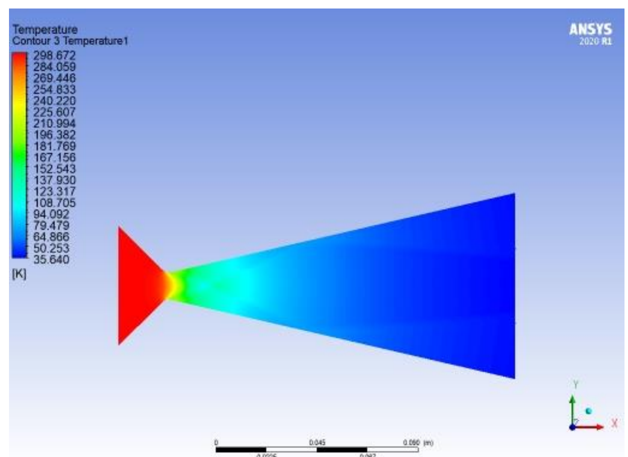
Since the entire process occurs in supersonic speeds the viscous flow has been set to K-epsilon and standard wall functions. The problem is solved using coupled algorithm in pseudo transient state which adds an unsteady term to the solution equation in order to improve the stability and its convergence behaviour. The solution has been run until it is converged.The analysis got converged at 624th iteration.

We have assumed the fluid as air and solid wall as aluminium.



Absolute pressure contour for 13° semi-divergent nozzle

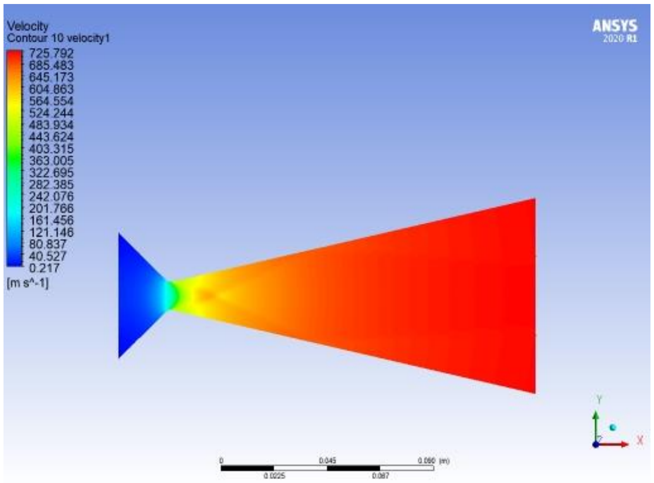
Fromthe above figure we can see that the absolute pressure is maximum at the inlet and minimum at the outlet. It indicates the reduction in the pressure and since pressure is indirectly proportional to the velocity, at the end of the nozzle we can get high velocity and low pressure.



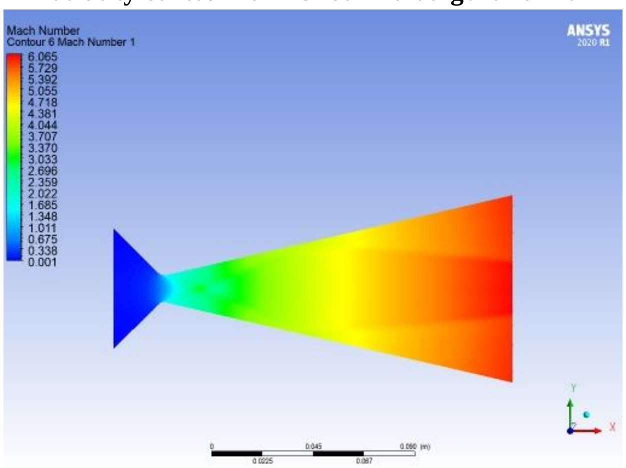
temperature contour for13° semi-divergent nozzle

The temperature contour shown in the above figure shows the temperature attained during the combustion process that is distributed along the lower section of the divergent nozzle.

We can see the presence of shock waves, they are due to a sharp change of pressure in a narrow region travelling through a medium, especially air, caused by a body moving faster than sound.



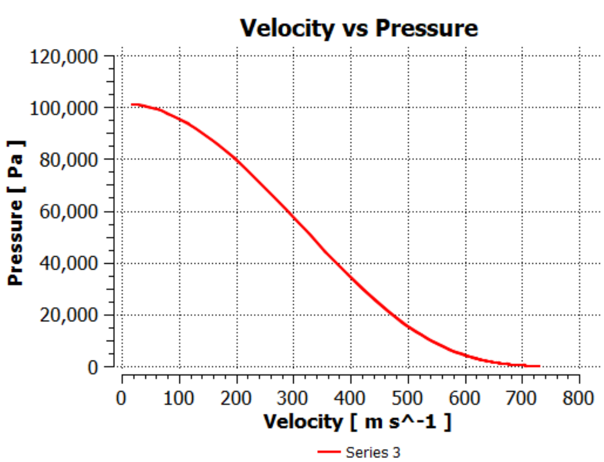
velocity contour for 13° semi-divergent nozzle



mach number contour for 13° semi-divergent nozzle

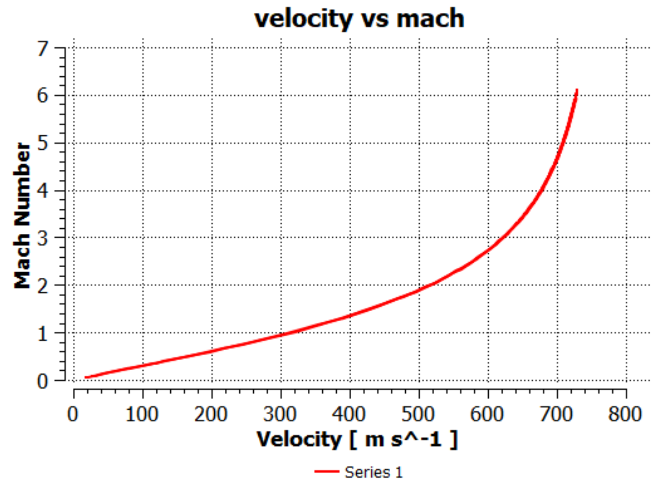
V. GRAPHICAL REPRESENTATION

Various graphs have been plotted and have been attached below. In the figure given below a graph is plotted in which pressure is plotted against velocity. They are indirectly proportional to each other.



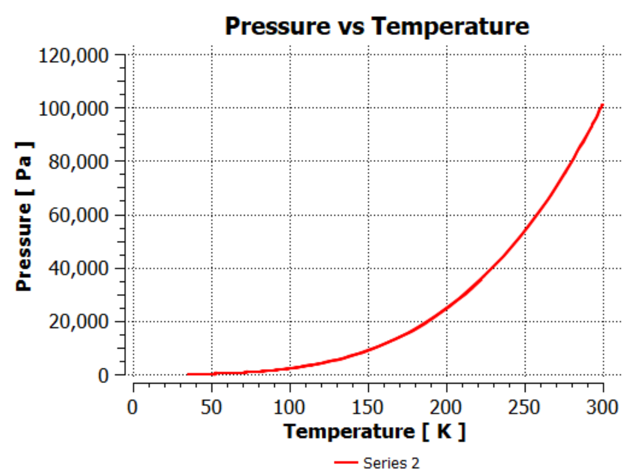
velocity vs pressure graph 13° semi-divergent nozzle

From the figure given below it can be noted that the maximum mach number achieved in this nozzle is mach 6.2 and from the figures 4.19 and 4.21 we can observe the velocity and the temperature at the end of the nozzle, they are 735m/s and 33k respectively.



velocity vs mach graph 13° semi-divergent nozzle

The graph below is plotted with pressure against temperature. In the nozzle both the pressure and temperatures are higher at the beginning, and are reduced at the nozzle outlet which implies that they are directly proportional to each other. Similar analysis and observations were done for 12°,15°,17° semi-divergent conical nozzles.



pressure vs temperature graph 13° semi-divergent nozzle

VI. COMPARISON

The temperatures, velocities and mach numbers of various semi-divergent angle nozzles that we designed are tabulated.

Semi-divergence angle	Temperature at the end of the nozzle	velocity at the end of the nozzle	Mach number at the end of the nozzle
17°	39K	724m/s	5.8
15°	37K	728m/s	6
13°	33K	735m/s	6.2
12°	36K	730m/s	6.1

The 13° semi-divergent angled nozzle was better in all the aspects and is highlighted above.

VII. RESULTS AND CONCLUSIONS

All the four angle semi-divergence (I.e)., 17 degree, 15 degree, 13 degree and 12 degreewas successfully computed. The desired results were observed. The velocity and the pressure contours results were attached. The modelling was conducted in the Catia V5. Then the model exported to ANSYS workbench and the meshing, solving and further observation of results are successfully conducted in ANSYS fluent.

The meshing were completed with as many nodes and elements as possible to get more accurate results. The nozzles were analyzed and various contours were taken and were attached. With the graphs we had listed we can come to the conclusions that the mach is greater in 13° semi-divergent angle conical nozzle than 17°,15° and 12° semi-divergent angle.

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