DESIGN AND DEVELOPMENT OF DE LAVAL NOZZLE

GOVARDHAN REDDY K S
Department of Mechanical Engineering, CMR College of Engineering & Technology, Hyderabad, India
17H51A0318@cmrcet.ac.in

MUTYALA KAMAL
Assistant Professor
Department of Mechanical Engineering, CMR College of Engineering & Technology, Hyderabad, India
kamalm@cmrcet.org

R KRISHNATEJA SARMA
Department of Mechanical Engineering, CMR College of Engineering & Technology, Hyderabad, India,
17H51A0345@cmrcet.ac.in

S TULASI NAIDU
Department of Mechanical Engineering, CMR College of Engineering & Technology, Hyderabad, India
17H51A0357@cmrcet.ac.in

P CHAITANYA PRASAD
Department of Mechanical Engineering, CMR College of Engineering & Technology, Hyderabad, India
17H51A0341@cmrcet.ac.in

Abstract

A nozzle is a device designed to control the characteristics of fluid. It is mostly used to increase the velocity of fluid. A typical De-Laval nozzle is a nozzle which has a converging part, throat and diverging part. This paper aims at explaining most of the concepts related to De Laval nozzle. In this paper the principle of working of nozzle is discussed. Theoretical analysis of flow is also done at different points of nozzle. The variation of flow parameters like Pressure, Temperature, Velocity and Density is visualized using Computational Fluid Dynamics.

Keywords *- De Laval Nozzle, Computational Fluid Dynamics, flow parameters.*

I. INTRODUCTION

Nozzle is a device designed to control properties of fluids like pressure, velocity, temperature etc. The major applications of nozzles are to increase the velocity by converting heat energy and pressure of the fluid. Nozzles are widely used in aerospace industries and automobile industries. A Nozzle plays a very important role in providing the thrust required for a Rocket to take off. The velocity of the fluid through the Nozzle is converted from subsonic to supersonic velocities upon various alterations to its design to obtain the highest magnitude of thrust possible. The design also depends on the operational conditions and working of the rocket.

II. THEORETICAL FORMATION

The operation of a De Laval Nozzle relies on different properties of the gas flowing at subsonic, sonic and supersonic velocities. The velocity of the gas will increase gradually as it reaches the throat of the Nozzle where the cross-sectional area is minimum. At this point the velocity becomes sonic (Mach Number=1.0), a condition where the flow is choked. The cross-sectional area of the nozzle increases from this point on, which causes the expansion of the gas and increase in the velocity. This speed recorded at the tail end of the nozzle is viewed to be supersonic (Mach Number>1.0).

A. *Basic Equations*

The Mach Number Variation is given by

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

The Temperature variation is given by

$$\frac{T_0}{T} = 1 + \frac{\gamma-1}{2}M^2$$

Keeping the temperature and inlet velocity constant, we can calculate the theoretically, the possible outcomes for a De Laval Nozzle with different throat diameters.

B. *Nomenclature of symbols used*

T – Temperature (K)

V – Velocity (m/s)

Ma – Mach Number

A – Area (m^2)

γ - Adiabatic index

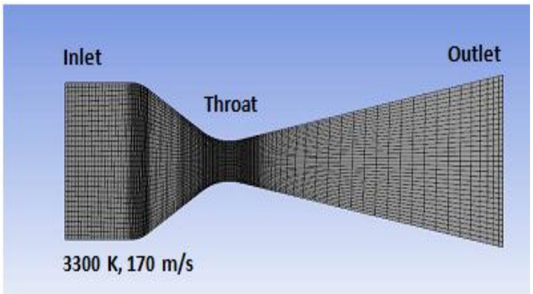

Fig. 1 Boundary Conditions of the Nozzle

TABLE I
THEORETICAL RESULTS OF DIFFERENT THROAT DIAMETERS OF DE LAVAL NOZZLE

Diameter of Throat	Parameters	Inlet	Throat	Outlet
38	T[K]	3300	2600	502
	V[m/s]	170	300	270
	Ma	0.5	0.8	0.7
34.5	T[K]	3300	2700	300
	V[m/s]	170	384	350
	Ma	0.5	1.1	1
30	T[K]	3300	2800	1700
	V[m/s]	170	386	1152
	Ma	0.5	1.1	3
26	T[K]	3300	2900	4700
	V[m/s]	170	392	720
	Ma	0.5	1.2	2

III. COMPUTATIONAL ANALYSIS

Treatment of engineering problems basically contains three main parts: create a model, solve the problem and analyse the results. Ansys, like many other FEA programs, is also divided into three main parts namely the processors which are called pre-processor, solution processor and post-processor.

The following are the steps performed for computational analysis of the nozzle using ANSYS: Modelling, Meshing, Pre-processing, Solution, Post-processing.

A. *Modelling*

The Nozzle is then designed, by generating a proper radius of curvature at the throat and fixing the throat diameter such that the temperature and pressure at that point decrease while velocity of the flow increases.

TABLE II
Dimensions of the Nozzle

Parameter	Dimension
Total Length of the Nozzle (mm)	484
Inlet Diameter (mm)	166

Outlet Diameter (mm)	183
Throat Diameter (mm)	38/34.5/30/26
Convergence angle (Deg)	32
Divergence angle (Deg)	11

B. *Meshing*

The model created by the above dimensions was meshed in mesh mode of Ansys component systems. The relevance of meshing was set to 100. The proximity and curvature option were selected, since nozzle is a curved object. The smoothing was high and num cells across gap were set to 50.

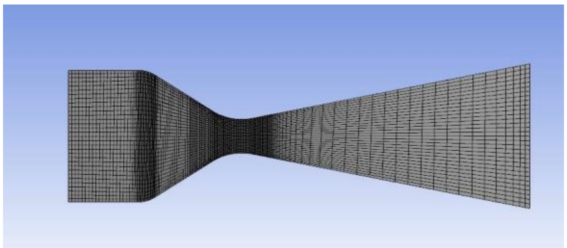

Fig 2 Mesh View of the Nozzle

C. *Pre-Processing*

The next step of the CFD after meshing is pre-processing. In pre-processing appropriate boundary conditions are applied to the meshed model. The pre-processing was done in Ansys Fluent.

TABLE III
PROCESSING DETAILS

General	Solver Type = Density Based 2D Space = Planar Time = Steady
Materials	Density = Ideal Gas Cp = 1006.43 J/kgK k=1.4 Viscosity = 1.81*10-5 Pas Mean Molecular Mass = 28.966 g/mol
Boundary Conditions	Inlet Temperature = 3300 K Outlet Temperature = 1900 K

D. *Solution*

In solver the solution is initialized and calculation is proceeded with the desired number of iterations. It is the most important port of CFD analysis.

TABLE IV
SOLVER DETAILS

Solution Control	Courant Number = 5
Solution Initialization	Compute from = inlet
Run Calculation	Number of Iterations = 2000

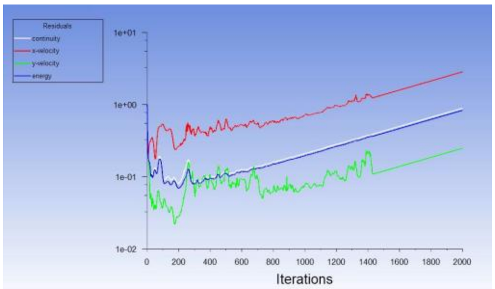

Fig 3 Iterations of Solution

E. *Results*

The results for De Laval Nozzle with various throat diameters are as follows:

1) *38 mm Throat Diameter:* The velocity reaches sonic state at the throat in this condition but the velocity at outlet is not as aspired.

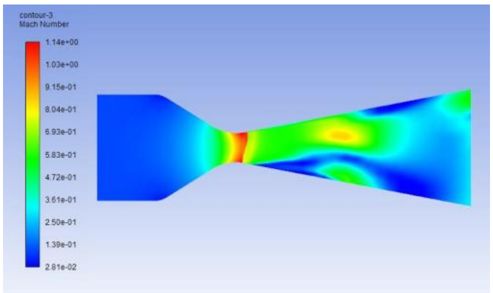

Fig 4 Contour of Mach Number Analysis for 38mm Throat Diameter

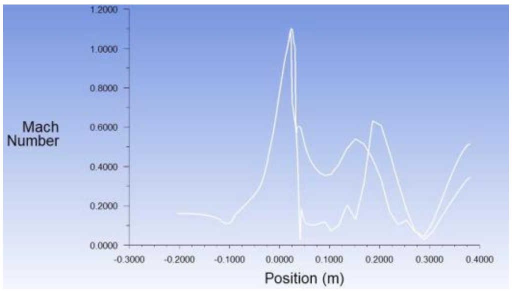

Fig 5 Mach Number Vs Position Graph

2) *34.5 mm Throat Diameter:* The velocity at the throat reaches sonic state in this condition but the outlet velocity is not supersonic.

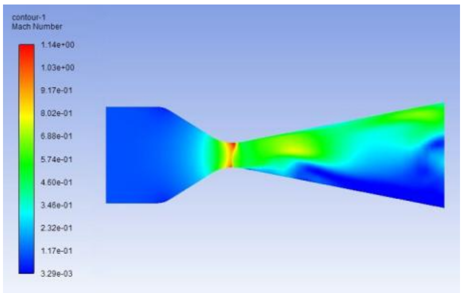

Fig 6 Contour of Mach Number Analysis for 34.5mm Throat Diameter

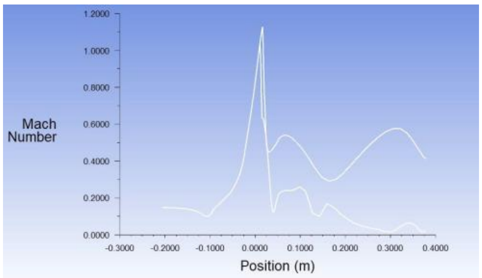

Fig 7 Mach Number Vs Position Graph

3) *30 mm Throat Diameter:* The velocity at the throat reaches sonic state in this condition and the supersonic velocity is achieved at the outlet.

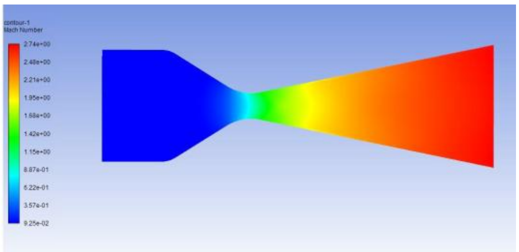

Fig 8 Contour of Mach Number Analysis for 30mm Throat Diameter

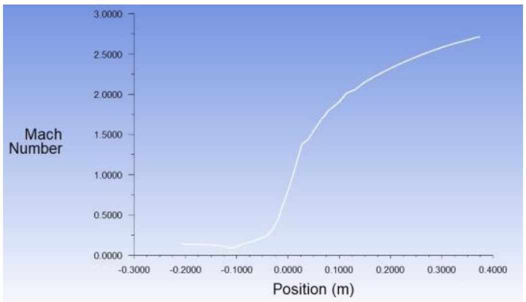

Fig 9 Mach Number vs Position Graph

4) *26 mm Throat Diameter:* The velocity at the throat reaches above sonic state in this condition and the supersonic velocity at the outlet is diverged.

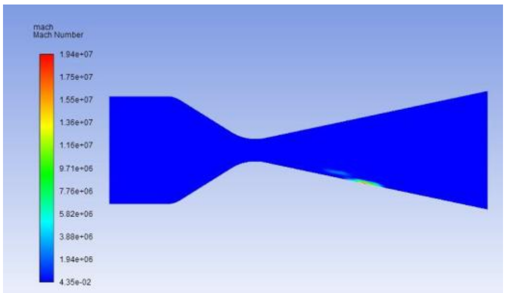

Fig 10 Contour of Mach Number Analysis for 26mm Throat Diameter

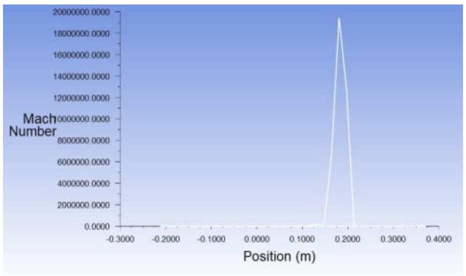

Fig 11 Mach Number vs Position Graph

TABLE V

RESULTS OF COMPUTATIONAL ANALYSIS

Diameter of Throat	Parameters	Inlet	Throat	Outlet
38	T[K]	3300	2730	322
	V[m/s]	170	345	240
	Ma	0.5	1	0.6
34.5	T[K]	3300	2730	283
	V[m/s]	170	355	300
	Ma	0.5	1	0.8
30	T[K]	3300	2770	1980
	V[m/s]	170	384	1200
	Ma	0.5	1.1	3.1
26	T[K]	3300	2830	5000
	V[m/s]	170	390	1100
	Ma	0.5	1.2	2.8

CONCLUSION

The results obtained by computational analysis and the theoretical derivation are almost identical. In view of this comparison, it can be stated that,

[1] when the throat diameter of the nozzle decreases, the velocity at the output increases to achieve the supersonic state.

[2] It is also understood that, these dimensions can be effective for a real time working conditions of a rocket Nozzle.

[3] It can also be stated that, the 1 dimensional or 2 dimensional analysis is sufficient to analyse the performance of a nozzle.

The following tables show the comparison between velocities achieved in Nozzles with different throat diameters:

TABLE V
VELOCITY COMPARISON FOR DIFFERENT THROAT DIAMETERS

Diameter of Throat	Velocity at outlet [Mach Number]	
	Theoretical	Computational
38 mm	0.6	0.7
34.5 mm	0.8	1.0
30 mm	3.1	3.o
26 mm	2.8	2.0

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REFERENCES

[1] Theoretical and CFD Analysis of De Laval Nozzle" by Nikhil Deshpande and Suyash Vidwans. In this paper total CFD analysis of a model of De Laval nozzle has been done.

[2] Modelling and simulation of Supersonic nozzle using computational fluid dynamics, by Venkatesh V and C Jayapal Reddy.

[3] A Review on CFD Analysis of Effects of Convergence and Divergence Angles on the Performance of a Nozzle MTech. Scholar Vishwajeet Yadav, Prof. Pawan Kumar Tiwari

[4] Analysis of convergent divergent nozzle with respective to the position of fluid flow in standard and realizable turbulent model" Devendra Kumar Lohia, Navneet Singh.

[5] Trong Bui had performed experimentation on "CFD analysis of nozzle jet".

[6] K.P.S.S. Narayana and K.S. Reddy had worked on the topic of "simulation of convergent-divergent rocket nozzle using CFD analysis".

[7] Y. R. Maddu, S. Saidulu, Md. Azeem and S. Jabiulla had worked on "Design and fluid flow analysis of Convergent-divergent Nozzle".