International Journal of Architecture, Engineering and Construction ISSN (online) 1911-1118
Vol 12, No 2, June 2023 (UGC CARE 1) ISSN (print): 1911-110X

Optimal Design and Fabrication of Sharp Throat De Laval Rocket Nozzle Prototype

Dr. K. Kalyani Radha, Associate Professor
JNTUACEA, Ananthapuramu, Andhra Pradesh, India.
*Corresponding Author Email: radha.mech@jntua.ac.in

Abstract: **Nowadays the nozzles play a key role in rocket science and missile technology as we know that nozzles are used to convert high pressure energy into kinetic energy in order to produce maximum thrust force. This project deals with the optimal design and fabrication of sharp throat De Laval rocket nozzle in order to attain acceralated supersonic velocity from subsonic velocity and to obtain maximum thrust force at the divergent section of the nozzle without any flow separation and choking due to shock waves at the exit portion of the nozzle.**

The sharp throat De Laval rocket nozzle is designed using AutoCAD and the prototype modeling is done with solid works. The simulation work is carried out with the help of computational fluid dynamics (CFD) i.e. ANSYS CFX software such that the optimum performance characteristics based upon various flow conditions are simulated.

An experimental study has been conducted with the prototype which is fabricated by using CNC lathe machine and the nozzle performance characteristics are tested with the help of an air compressor at various nozzle pressure ratios (NPR). Finally a comparative study is done with the experimental and simulated values to confirm the exact results.

I. INTRODUCTION

De Laval nozzle is the device which is used to convert highpressure energy into kinetic energy in order to produce maximum thrust force. De Iaval nozzles are also called as convergent-divergent nozzle(C-D) which is used to convert the flow from low velocity into high velocity.

The present paper deals with the optimal design and fabrication of sharp throat De Iavalrocket nozzle. Initially the basic sketch of the nozzle is developed according to design requirement through free hand sketching and then modeling work of nozzle is done using solid works software as shown in the figure 1.1. After the completion of the modeling work the analysis work of the model is done using computation fluid dynamics (CFD) method i.e. ANSYS CFX software. The model is tested at various working conditions by varying various input and output parameters in order to obtain the optimum results. Then the fabrication of the Prototype is done using CNC lathe machine with INCOLOY 825 as the work material, the fabricated prototype is tested by conducting an experiment by using Air compressor test rig to obtain the results and finally the results are compared with the experimental and analytical results which obtained using the software.

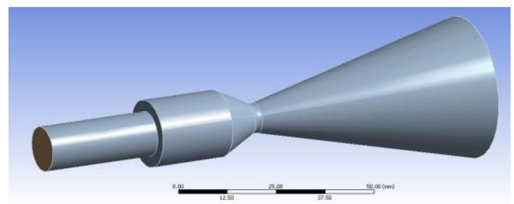

Figure 1.1 Design of Prototype using Solid works

II. DESIGN & MODELLING

The Design is modeled by the using Solid works software and the mesh of the model is generated for the simulation purpose and checked twice in order to eradicate the errors for the purpose to obtain optimum Analysis results using computational fluid Dynamics(CFD) i.e. ANSYS CFX software. The figure 2.1 and figure 2.2shows the Prototype which is modeled by using solid works.

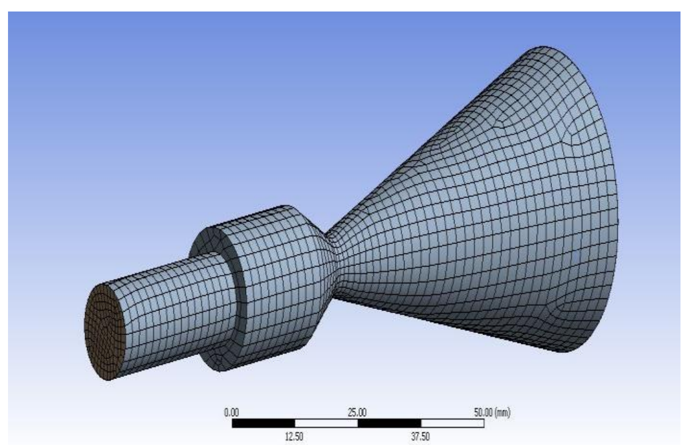

Figure 2.1 Meshing of the Prototype

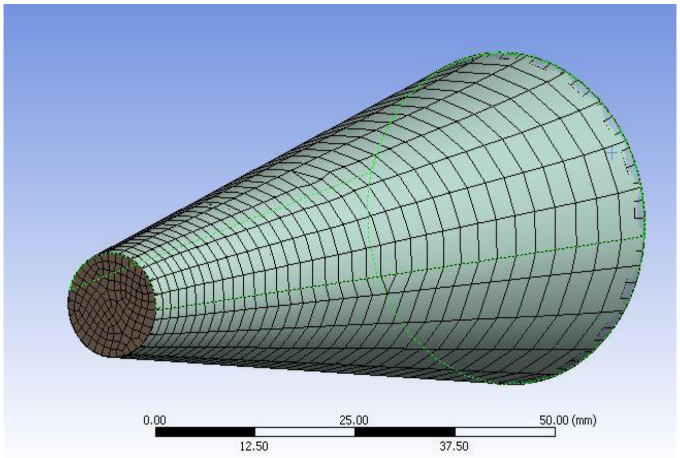

Figure 2.2 Divergent section of the Prototype

III ANALYSIS

The Analysis or the simulation work is carried out by computational fluid dynamic technique i.e. ANSYS CFX software.The simulation of the solid works model is done by taking mesh model which is generatedby using the solid works,the parameters such as inlet temperatures, inlet Pressure and inlet velocity parameters are taken as input characteristics to study the output characteristics such as Exit velocity, thrust force and volumetric efficiency as the required characteristics to be analyzed.The Incoloy material is selected as the material to the study the flow conditions and air is selected as the working fluid. The results that are generated after giving the input parameters are shown in below figures.

Velocity Contours:

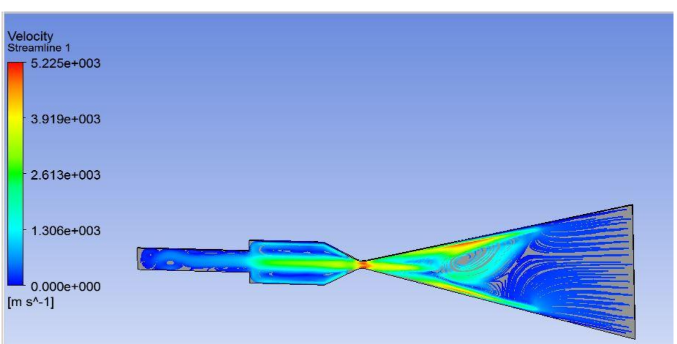

Figure 3.1 Distribution of Velocity

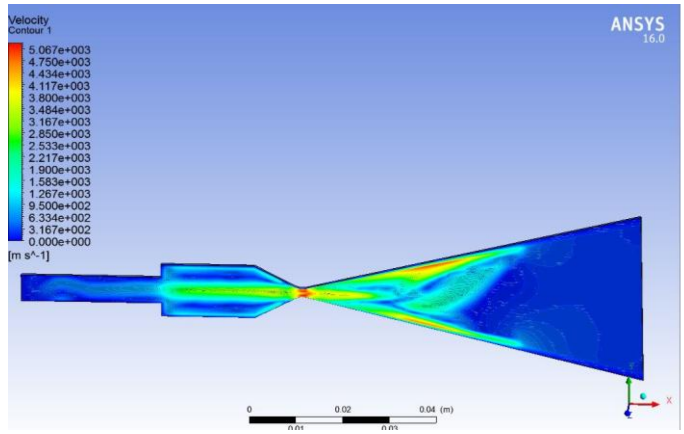

Figure 3.2 Velocity flow distribution of air

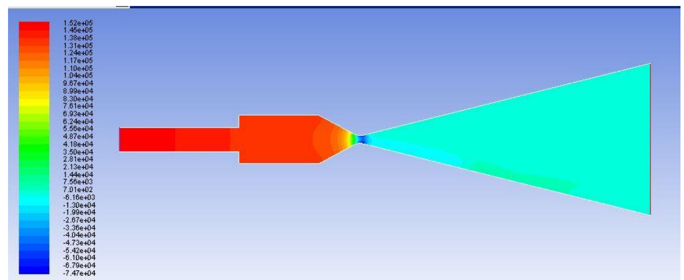

Figure 3.3 shows the velocity Contour

Pressure Contours

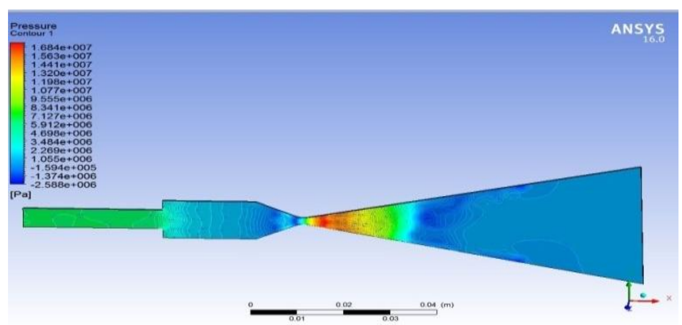

Figure 3.4 Pressure Distribution in model

*Temperature Contours***:**

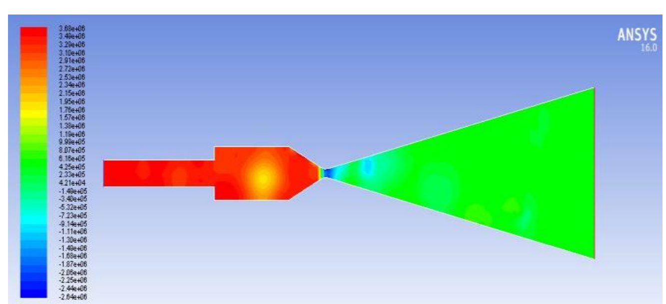

Figure 3.5 Distribution of the Temperature

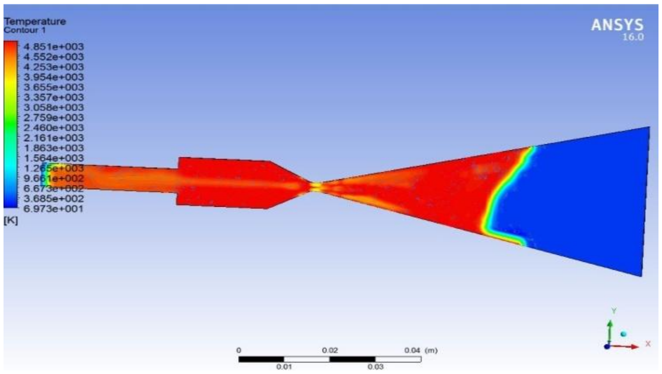

Figure 3.6 Distribution of Temperature of air in model

IV FABRICATION

Fabrication is the process of manufacturing a particular product or an object by using various methods of production with the help of machines depending on the characteristics of the material and its applications.

The fabrication work is done with Incoloy 825 as the work material using CNC lathe machine. The figure shown below is Incoloy 825 material, its properties and composition.

Figure 4.1 Incoloy 825 work material

Before Fabrication:

- Total Length of the Work Material=180 mm
- Total Diameter of the Work Material =60 mm
- Total Weight of the Work Material= 2.62 kg

TABLE 1

CHEMICAL COMPOSITION OF INCOLOY 825

S.NO	Material	Percentage of Composition (%)
1	Aluminum	0.2 max
2	Carbon	0.05 max
3	Chromium	19.5-23.5
4	Copper	1.5-3.0
5	Iron	36-42
6	Manganese	1 MAX
7	Molybdenum	2.5-3.5
8	Nickel	38-46
9	Phosphorous	0.03 MAX
10	Silicon	0.5 MAX
11	Sulphur	0.03 MAX
12	Titanium	0.6-1.2
13	Total	100

TABLE 2

PHYSICAL PROPERTIES OF INCOLOY 825

s.no	Property	Units
1	Density	8.14 g/cm^3
2	Melting point	1400°C
3	Coefficient of thermal expansion	14.0 µm/°C
4	Modulus of rigidity	75.9 kN/mm^2
5	Modulus of elasticity	196 kN/mm^2
6	Thermal conductivity	15.9 W/m-K

TABLE 3

MECHANICAL PROPERTIES OF INCOLOY 825

S.NO	PROPERTY	UNITS
1	Yield strength	338 MPa
2	Ultimate tensile strength	662 Mpa
3	Rockwell hardness	135-160
4	Charpy impact strength	106 J/m^2
5	Possion's ratio	0.32
6	Shear modulus	68 Gpa

TABLE 4

MACHINING PARAMETERS

S.NO	PARAMETER	UNITS
1	Spindle speed	900 rpm
2	Feed	0.8 mm/rev
3	Depth of cut	0.15 mm
4	Coolant	Mag cutting oil
5	Lubricant	Castrol 68 oil

Figure 4.2 shows the CNC Machine

After Fabrication:

The Prototype have been exactly obtained as per design requirements and it is ready for the Experimental Investigation in order to investigate its performance characteristics at different working conditions by conducting experimentation with the help of Air compression test rig

Figure4.2Prototype of De Laval Nozzle after Fabrication

V. EXPERIMENTAL INVESTIGATION

The Experimental investigation of the De Laval nozzle Prototype is carried out after the fabrication process. In order to study the various performance characteristics of the nozzle at different working conditions by varying different parameters, to obtain the results and conclusions of the fabricated prototype. The overall Experimentation is conducted by using the Air compressor test rig apparatus. The experiment is done by varying inputparameters to obtain the output characteristics such as velocity of air Thrust force and volumetric efficiency.

Figure 5.1 Air compressor Test rig Equipment

TABLE 5

OBSERVATIONS OF THE READINGS

S. NO	Room Temperature of Air °c	Speed of the compressor RPM	Inlet Pressure Bar	Inlet Temperature °c	Inlet Velocity m/s	Exit Velocity m/s	Exit Pressure m/s
1.	33	943.5	6.15	31.5	186.5	337	3.35
2.	33.5	933.5	5	36	197.5	332	2.7
3.	35.5	934	3.65	34.5	207	309.5	3.9
4.	29.5	942	3.05	33.5	220.5	322.5	2.3

VII. RESULTS AND CONCULSIONS

Results obtained from the Experiment**:**

The results that are obtained after the completion of the experiment are as follows.

TABLE 6

RESULTS OF EXPERIMENT

S.NO	PARAMETER	RESULT
1	Exit velocity of nozzle	326.25 m/s
2	Thrust force at exit of nozzle	22511.33 KN
3	Volumetric efficiency of nozzle	60.04%

Results generated from ANSYS CFX (Software):

The results that are generated after the analysis of the model using ANSYS CFX software are as follows.

Velocity contours:

From the figure 3.1 and 3.2of velocity contour tells us that the velocity of air at the entrance portion of the designed Prototype model is initially less as soon as the air starts flowing towards the convergent section it starts increasing when it is nearer to the throat section of the model the velocity of the air is maximum and due to choking condition that is generated at the throat the velocity of air becomes gradually decreased and finally when it starts flowing towards the divergent section again the velocity of the air is slowly increased and reaches the optimum level.

Pressure Contours:

From the figure 3.4 The Distribution of Pressure of the air that is generated in the Prototype model, pressure contour tells us that during the entrance portion when the air enters the nozzle the Pressure is optimum at the entrance position of the nozzle and it gradually decreases during its travel towards the convergent portion of the nozzle and the Pressure reaches maximum level when it reaches the centre portion i.e. the throat portion of the nozzle and it gradually decreases when the air reaches the divergent section of the nozzle.

Temperature Contours:

The figure 3.5 and 3.6 tells us that there is optimum level of temperature of the air is at the entrance section of the nozzle and gradually it decreases towards the convergent section and reaches to the maximum point during the travel of air towards the throat and slowly the temperature of air starts decreasing when it reaches the divergent portion and finally at the exit portion of the nozzle the maximum fall in temperature takes place.

Comparison of Results:

The results that are obtained from the experiment and software are compared to get the exact range of the results of the designed De Laval nozzle prototype model. The below table shows the results of comparison between analysis and experimental results

TABLE 7
RESULTS COMPARISON

S.NO	Parameter	Analysis Result	Experimental Result
1	Exit velocity	358 m/s	326.25 m/s
2	Exit temperature	Decreases	Decreases
3	Exit Pressure	Decreases	Decreases

CONCULSION

The results which are generated from the software and experiment are successfully compared with each other to assess the exact range of the results.Theanalysis result of the exit velocity of the De Laval nozzle Prototype gives around 360 m/s which is Supersonic in nature while the exit velocity obtained from the experiment gives around 330 m/s.

This variation among the Analytical and Experimental results are because of the errors that are generated normally during the machining, the friction factor

And the human parallax error while notingdown theobservations during the experimentation process. The overall design of the De Laval nozzle Prototype and the material chosen for the fabrication gives optimum results.

REFERENCES

[1] Nikhil deshpande, Suyash s Viswas, Pratik Mahale, Rutuja S Joshi. Singhad institute of science & technology, Pune. "*Theoretical and CFD analysis of De Laval nozzle".*

[2] Mohan kumar.G, Dominale Xavier Fernando and R.Muthu Kumar Hindustan University of Aeronautical Sciences, Chennai. "*Design and optimization of De Laval Nozzle to prevent shock induced flow separation"*

[3] Md.Akhtar khan, Sanjay Kumar, D.Harika ChowdersGITAM University, Hyderabad. "*Design of supersonic nozzle using method of characteristics".*

[4] Kunal Pansari, S.A.K Jilani, Chhattisgarh swami Vivekananda University, Raipur. "*Analysis of the performance and flow characteristics of convergent –Divergent Nozzle*".

[5] Balakrishna, Sushma indana and P.Ravinder Reddy, Chaitanya Bharathi institute of technology, Hyderabad "*Investigation of supersonic flow through conical nozzle with various angles of divergence*".

[6] Sandhya.T, Shabhana Ahmed, Sandeep S K, J.Devi priya , Dr.Padmanaban, Tagore engineering college, Chennai."*Design, Fabrication and Testing of sharp throat characteristic supersonic nozzles flow visualization and study of shocks".*

[7] K M Pandey, Member of IACSIT"CFD Analysis of Conical Nozzle for *Mach 3 at various angles of Divergence with Fluent Software".*

[8] EricGambol, Dwain Terrell SPRITECH *Advance Products Inc. "Nozzle Selection and Design criteria".*

[9]Karla K Quinton, Florida International University, USA "*Design Optimization of Nozzle Shapes for Maximum uniformity of Exit flow".*