DESIGN AND ANALYSIS OF NOZZLE ASSEMBLY OF MISSILE

Kiran.G[1], K.Sambasivarao[2]

[1]*M.Tech, Student (MachineDesign),* [2]*Assistant Professor, Mechanical Engineering Dept, Swami Vivekananda, Engineering, College, Bobbili (India)*

ABSTRACT

Nozzle is the component of a missile, rocket or air breathing engine that produces thrust. Converting the pressure of the hot chamber gases into kinetic energy and directing that energy along the nozzle axis.The nozzle considered for analysis in this project work is designed for short range missile and is made of marging steel 250 alloy. In this work stress analysis of this nozzle under the different static test pressures are considered. Thermal analysis is also carried out at temperature 2023K.Nozzle is modeled in CATIA V5 R15 and analysis is carried out in ANSYS 14.0. Finite Element Analysis is carried out to find the stresses, thermal flux and displacement in nozzle components. Finally, from the results it is concluded that the structure is safe and has adequate margin of safety in components of nozzle assembly.

Keywords: CATIA V5 R15, ANSYS, Nozzle, Missile.

I. INTRODUCTION

Nozzle is the component of a missile, rocket or air-breathing engine that produces thrust. Converting the pressure energy of the hot chamber gases into kinetic energy and directing that energy along the nozzle axis. The missile is

Shown in fig 1.1

FIG1.1: Missile The propellant is composed of a fuel, typically liquid hydrogen (H_2), and an oxidizer, typically liquid oxygen (O_2). The propellant is pumped into a combustion chamber at some rate (m) where the fuel and oxidizer are mixed and burned. The exhaust gases from this process are pushed into the throat region of the nozzle. Since the throat is of less cross-sectional area than the rest of the engine, the gases are compressed to a high pressure. The nozzle itself gradually increases in cross-sectional area allowing the gases to expand. As the gases do so, they push against the walls of the nozzle creating thrust.Mathematically, the ultimate purpose of the nozzle is to expand the gases as efficiently as possible so as to maximize the exit velocity (V exit). This process will maximize the thrust (F) produce by the system since the two are directly related by the equation Where F=

Thrust force, M=Mass flow rate, V=Exit exhaust gas velocity at nozzle exit,p= Exit pressure of the exhaust gases at the nozzle exit,P= Ambient pressure of the atmosphere A= Exit cross-sectional area of the nozzle exit.

1.1 Expansion Area Ratio

In theory, the only important parameter in missile nozzle design is the expansion area ratio (e), or the ratio of exit area (A exit) to throat area (A Throat).Fixing all other variables (primarily the chamber pressure), there exists only one such ratio that optimizes overall system performance for a given altitude (or ambient pressure). However, a missile typically does not travel at only one altitude. Thus, an engineer must be aware of the trajectory over which a missile is to travel so that an expansion ratio that maximizes performance over a range of ambient pressure can be selected. Nevertheless, other factors must also be considered that tend to alter the design from this expansion ratio-based optimum. Some of the issues designers must deal with area nozzle weight, length, manufacturability, cooling (heat transfer), and aerodynamic characteristics.

1.2 Material

The nozzle is critical component of the missile. Material used to manufacture nozzle should posses high strength, high temperature resistant, good machinability. The nozzle components are made of 18 Ni marging steel 250 (ASTM A579 Code 72). This material used in annealed condition to acquire high strength, good machinability and resist the high temperature.

1.3 Design Consideration

Nozzle consists of three parts they are:

1.3.1 Nozzle End Dish Nozzle end dish is fixed to combustion chamber (schematic diagram of missile is shown in figure-1). So the left end of the nozzle end dish is constrained i.e., translation and rotational movements are arrested (ux=uy=uz=o)

1.3.2 Nozzle Neck Nozzle neck is fixed to nozzle end dish. Hot gases from hot chamber flows to nozzle neck through the end dish. The diameter of nozzle decreases from end dish to neck

1.3.3 Nozzle Cone Nozzle cone left end is fixed to the nozzle neck and the other end is free. From nozzle cone high pressure gases extruded to outside by this pressure only missile can move with high velocity.

1.4 Problem Specification

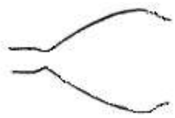
Nozzle is attached to combustion chamber and it exerts high pressures and temperature. It consists of three components end dish, neck and cone as shown in fig 1.2. The end dish is subjected to both radial pressure and thrust. Neck and cone subjected to radial pressure. The components are analysed for strength considering material properties at elevated temperature 2023K. Also temperature fluxes are calculated for the nozzle. Four load cases viz: load case 1(10MPa, 5MPa, 2MPa) load case 2 (13.5MPa, 7MPa, 2MPa) load case 3(17MPa, 10.5MPa, 5MPa) and load case 4 (35MPa, 20MPa, 10MPa).Right end component shows the end dish, left end component shows the cone and middle component is neck.

II. LITERATUREREVIEW

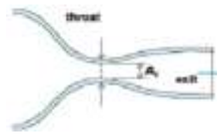
2.1 Types of Nozzles

2.1.1 Conical nozzle:Most military jet air craft employ the simple conical nozzle with adjustable conical angle as their propulsive device. In this conical nozzle external supersonic expansion occurs.Conical nozzle

2.1.2 Bell shaped nozzle:In this nozzles exhaust gases are forced into a converging throat region of low area before expand in bell shaped nozzle. In this nozzle expansion occurs internally. Bell shaped nozzle



2.1.3 Convergent-divergent nozzleThe Engineering hand book was presented by Ed. Richard C. Dorf [1]: This nozzle has convergent section followed by a divergent section so called as convergent divergent nozzle. From inlet heat gases to the throat (minimum area) and then decelerates. As pressure is lowered the flow eventually chokes.



Convergent divergent nozzle

FIG: 2.1 Different Types of Nozzles

Above nozzles are modelled as methods of reducing the length of spike nozzle centre body by replacing the ideal spike with a conical spike. While this method does indeed result in much shorter nozzle length, we can go even further by removing the pointed spike altogether and replacing it with a flat base.Influence of large scale pressure changes on nozzles paper was presented by Venkateshwarn, S. Merle [2]: As any fluid dynamics recognizes, the significant disadvantage of the "flat" plug is that a turbulent wake forms aft of the base at high altitudes result in high base drag and reduced efficiency. However, this problem can be greatly alleviated in an improved version of the truncated spike that introduces a "base bleed", or secondary subsonic flow, into the region aft of the base.The circulation of this secondary flow and its interaction with the engine exhaust creates an "aerodynamic spike "that behaves much like the ideal, isentropic spike. In edition, the secondary flow re-circulates upward pushing on the base to produce additional thrust. It is this artificial aerodynamic spike for which the aero spike nozzle is named linear aero spike. All of these nozzles are far been annular, or circular when viewed from below. Still another variation, of the aero spike nozzle is not an annular nozzle at all. A second approach pioneered by the "Missile Dyne Company (now division Boeing) in the 1970's, places" the combustion chambers in a line along two sides of the nozzle.This approach results in a more versatile design allowing the use of lower-cost modular combustors. These modules can be combined in varying configurations depending on the application.

2.2 Radial Nozzle

Thermal engineering by Ballaney. P. L [3]: The second major variety of annular nozzles is the radial in-flow type, exemplified by the spike shown below.

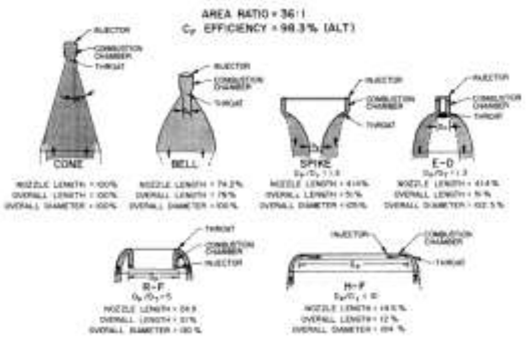


FIG-2.2: Size comparison of optimal cone, bell, and radial nozzles for a given set of conditions

This type of nozzle, named for the prominent spike center body, is often described as a bell turned inside out. However, the nozzle shown in fig-2.2 is only one of many possible spike configurations. Variations of this design shown below include(a) A traditional curved spike with completely external supersonic expansion(b) A similar shape in which part of the expansion occurs internally (c) A design similar to the expansion – deflection nozzle in which all expansion occurs internally.

Note that each of the above spike nozzles features are curved, pointed spike, the most ideal shape. This spike shape allows the exhaust gasses to expand through isentropic or constant entropy, process. In so doing, the nozzle efficiency is maximized and no energy is lost because of turbulent mixing in the exhaust flow. While the isentropic spike may be most efficient, it also tends to be prohibitively long and heavy. However, theoretical studies have shown that replacing the curved shape by a much shorter and easier to construct cone results in very little performance loss.

Influence of nozzle design and radial mass distribution paper by Coleman.P [4]: Two major types of plug nozzles have been developed to date. They are distinguished by the method in which they expand the exhaust, outward or inward. The radial out -flow nozzle was subject of much research in olden days.The name of these nozzles indicates how it functions. The expansion-deflection nozzle works much like a bell nozzle since the exhaust gases are forced into a converging throat region of low area before expanding in bell-shaped nozzle. However, a plug, or centre body, that forces the gases away from the center of the nozzle, deflects the flow. Thus, the E-D is a radial out flow nozzleThe reverse-flow nozzle gets its name because the fuel is injected from underneath, but the exhaust gases are rotated 180^0 the by reversing their direction. Similarly, the fuel in the horizontal-flow nozzle is injected sideways, but the exhaust is rotated 90.judging by the amount of literature obtained on this subject, little work has been done on the R-F and H-F nozzles, and they will not be considered further. The E-D, on the other hand, has been one of the most studied forms of annular nozzles .While similar in nature to the bell nozzle, the most notable difference is the addition of a center body.

2.3 Developments in Missile Nozzle

Through the concept of the nozzle has been around for many years, little actual flight or test experience has been available until recently. Nonetheless, it will take brief look at the develop and test spike nozzles.

2.4 Early Development

The first serious studies of nozzles were performed in Germany in conjunction with the development of the turbojet engine. Engines like those used on the Messer Schmitt me 262, utilized a plug center body to vary the throat area for better performance. Jeffry J. Berton [5] scientist of NASA said that the United States air force and missile dyne together spent over $500 million on the development of engines during the 1950s, 1960s, and 1970s. The development effort conducted by the NASA Lewis Research Center (now known as NASA Glenn) in Cleveland, oh, and by Missile dyne's Nevada testFacility, tested aero spike engines ranging in size from subscale cold-flow models to a full-scale 250,000lb thrust engine. These tests included 73 ground tests of full-sized engines totalling over4000 seconds of operation. Similar work was underway in West Germany from1965 to the early 1970s in support of a heavy lift launch vehicle called Neptune. The propulsion arrangement for this concept consisted of a "toroidal plug nozzle "that behaved much like an aero spike with primary and secondary flows.

III. NOZZLE MATERIAL AND ITS PROPERTIES

3.1 High Temperature Materials and Their Requirement

Recent developments in nuclear power, jet aircrafts, ballistic missiles and rocketry have increased the demand for materials that have good corrosion resistance, strength characteristics and particularly, creep resistance at high temperatures. High temperature use of materials can give rise to several problems such as:1.Accelerated oxidation and/or corrosion.2.creep3. Grain boundary other weakening4. Allotropic and other phase changes 5.Modification of conventional properties.Therefore, the material for high temperature use must be such that it can withstand these difficulties and perform its functions satisfactory during service.The nozzle components are made of 18 Ni marging steel 250 (ASTM A579 Code 72). This material used in annealed condition to acquire high strength, good machinability and resist the high temperature. The composition used for this material is given in table 3.1.

3.2 Compositions

TABLE-3.1: Chemical Composition of Maraging Steel-mdn250.

Constituent	C	Al	Ni	Cu	S	Mo	Mn	Si	Ti	P
	0.01		18	8	0	4.9	0.04	0.05	0.4	0
Weight. %	Max	0.1	To	To	Max	To	To	Max	To	5
			18	8		5	0.04		0.5	Max

In order to withstand high pressure and temperatures, its strength is acquired by the composition of these materials like Carbon, Nickel, Sulphur, Manganese, Titanium, Silicon and Molybdenum etc.

3.2.1 Nickel

It increases the strength and toughness of the steel. Nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion. An alloy containing 25% of nickel possesses maximum toughness and offers greater resistance to rusting, to rust in corrosion and burning high temperature. It has zero coefficient of expansion.

3.2.2 Manganese

It improves the strength of the steel in both the hot rolled and heat treated condition.

3.2.3 Silicon

It behaves like Nickel it has high elastic limit as compared to ordinary carbon steel.

3.2.4 Cobalt

It gives red hardness by retention of hard carbides at high temperatures it tends to the decarburize steel during heat-treatment. It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

3.2.5 Molybdenum

It posses extra tensile strength and is used for air-plane fuselage and automobile parts. It can replace in high speed steel

3.3 General Characteristics

This composition has following characteristics 1. Good machinability 2. Good surface finish 3. High strength4. Excellent corrosive resistance

3.4 Properties

This composition has the following physical properties and mechanical properties

3.4.1 Physical Properties

Density : 8e3 Kg/m^3Specific heat : 0.11 Kcal/Kg K

Thermal conductivity : 38.4W/m-K

3.4.2 Mechanical Properties

Tensile strength, yield :650MPa

Modulus of elasticity :1.85e5MPa

Poisson's ratio : 0.3 Ultimate tensile strength : 965 MPa

IV. MODELLING OF NOZZLE

4.1 Analysis of Nozzle

Analysis of the Nozzle is carried over in the following steps:

4.1.1 Building the Model: Where the geometry of nozzle is specified and model is created in CATIAV5R15

4.1.2. Applying the Load: This is carried out in ANSYS14.0.Meshed model is imported to ansys and pressures are applied.

4.1.3 Viewing the Results: This is also carried out in ansys. In this we can view stresses and deformations.

4.2 GEOMETRIC MODELLING: Modelling has been carried over in CATIA V5 R 15 software is very easy modelling critical components. CATIA is very user friendly and parametric.

4.3 Nozzle Has Three Components

1.Nozzle end dish2.Nozzle neck3.Nozzle cone

4.3.1 Nozzle End Dish: Nozzle end dish is the critical part of the model. Nozzle end dish inner wall has two different curvature and outer wall with different curvature, where it becomes complicated to model. Nozzle end dish is cylindrical object. The detailed drawing of the nozzle end dish is given the Fig 4.1detailed drawing of nozzle end dish.Nozzle end dish is modelled by the following procedure:1. The sectional drawing of the nozzle end dish is revolved to 360^0 about the central axis as shown in the fig 4.1 sectional drawing is revolved to obtain the 3 D model of nozzle end dish

4.3.2 Nozzle Neck: Nozzle neck is the critical part of model, and its inner wall has a curvature with inclined angle of 48^0 and outside curvature with an angle of123^0, which makes it complicated to model. Nozzle neck is cylindrical object. The detailed drawing of the nozzle neck Nozzle neck is modelled by the following procedure: The sectional drawing of the nozzle neck is revolved to 360 ^{0}about the central axis . The sectional drawing is revolved to obtain the 3 D model of nozzle neck

4.3.3 Nozzle Cone: Nozzle cone is easy to model, and its inner wall is inclined angle of 9^0 nozzle cone is cylindrical object. The detailed drawing of the nozzle cone .Nozzle cone is modelled by the following procedure:The sectional drawing of the nozzle cone is revolved to 360^0 about the central axis . The sectional drawing is revolved to obtain the 3 D model of nozzle cone

4.4 Nozzle Assembly Assembly is done in the assembly module of the CATIA V5 R 15. Nozzle consists of the three components 1.Nozzle end dish, 2. Nozzle neck, 3. Nozzle cone.Nozzle model has been modeled in the CATIA V5 R15 . For performing the analysis over the nozzle a finite element model is necessary. In ansys, the meshing of the nozzle components is difficult and even the mesh quality is not maintained for acquiring the results.

4.4.1 Pressure Loads

components	Pressure load case in MPa			
	Load case 1	Load case 2	Load case 3	Load case 4
Nozzle end dish	10	13.5	17	35
Nozzle neck	5	7	10.5	20
Nozzle cone	2	2	5	10

Pressure loads are used for structural analysis. Temperature 2023K is also applied to perform the thermal analysis.

4.5 Boundary Conditions

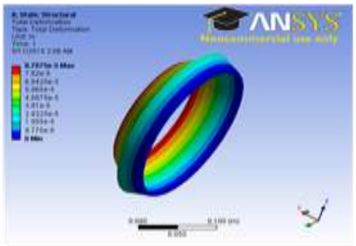
Meshed model is imported to ansys14.0 .In ansys 3D 20 noded solid element (solid 95) is defined. Solid 95 is higher order element.

4.5.1 Applications of Boundary Conditions

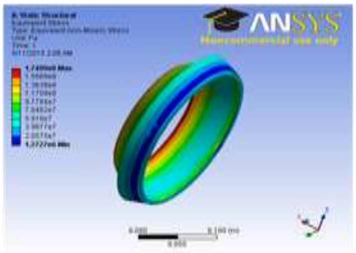
Nozzle end dish is fixed to combustion chamber .So the left end of nozzle is constrained that is translation and rotational movements are arrested (ux=uy=uz=0). Pressure loads applied on the components are given in table. These pressure loads are applied to the inner walls of nozzle and temperature distribution also calculated for 2023K.

RESULTS AND DISCUSSIONS

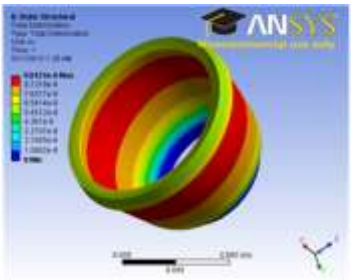
RESULTANT DISPLACEMENT AND VON-MISES STRESS CONTOURS FOR LOAD CASE1



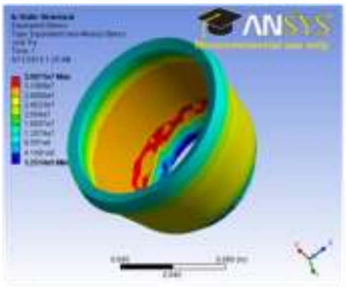
Resultant displacement of end dish for load case1 (10MPa)



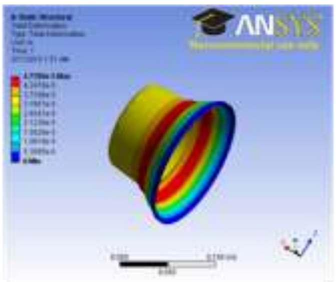
Von-mises stress of end dish for load case 1 (10MPa)



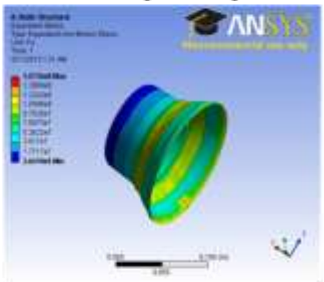
Resultant displacement of cone for load case 1(2MPa)



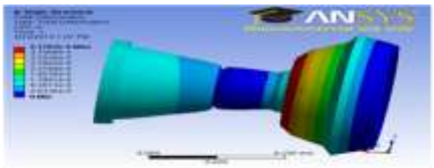
Von-mises stress of cone for load case1 (2MPa)



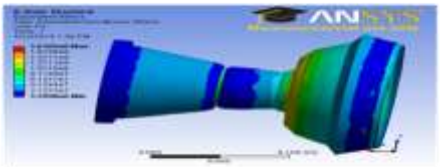
Resultant displacement of neck for load case 1(5MPa)



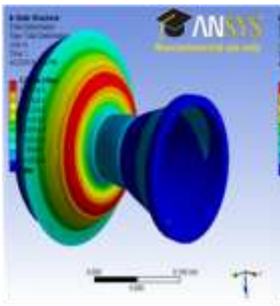
Von-mises stress of neck for load case 1(5MPa)



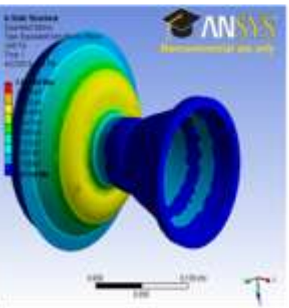
Resultant displacement contour of nozzle assembly for load case 1



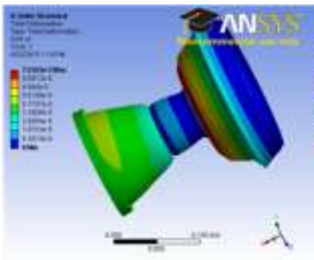
Von-mises stress counter of nozzle assembly for load case 1



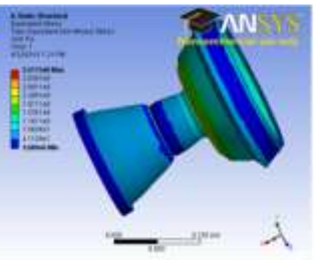
Resultant displacement contour of nozzle assembly for load case 2



Von-mises stress counter of nozzle assembly for load case 2



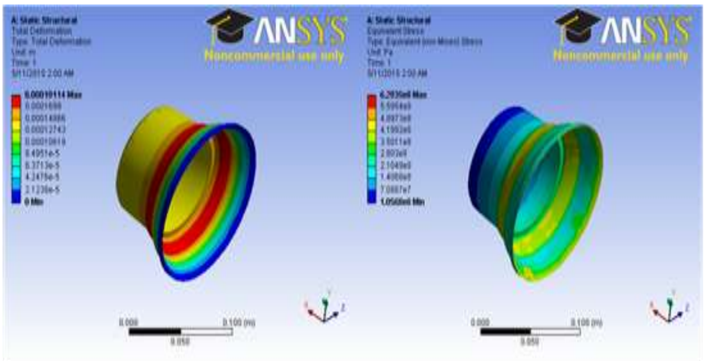
Resultant displacement contour of nozzle assembly for load case3



Von-mises stress contour of nozzle assembly for load case3

RESULTANT DISPLACEMENTS AND VON-MISES STRESS ACCORDING TO THE RESPECTIVE LOAD CASES

LOAD CASE	U-SUM(m)	VON-MISES(MPa)	REMARKS
1	4.17e-5	181.05	SAFE
2	5.77e-5	241.64	SAFE
3	7.51e-5	341.11	SAFE
4	15.5e-5	699.56	FAILED



Resultant displacement of neck for load case 4(20MPa)

Von mises stress of neck for load case 4(20MPa)

The Nozzle is analyzed for different inertia load cases in addition to test pressure. A global final element analysis (FEA) (static analysis only) is carried out to arrive at the stresses and deformations in critical components. Finally from the results obtained, it is concluded that all the stresses induced are well within the allowable limits and the structure is safe.

V. CONCLUSION

- The nozzle is analyzed for 4 pressure load cases they are load case -1(10MPa. 5MPa, 2MPa) load case-2(13.5MPa, 7MPa, 2MPa) load case-3 (17MPa, 10.5MPa,5MPa), load case -4(35MPa, 20MPa, 10MPa)Thermal analysis is carried out for 2023KThe nozzle assembly Maximum displacement 15.5e-5m occurs in load case 4Maximum stress 699.56MPa occurs in load case 4. This concludes that missile can with stand up to loadcase 3.Maximum deformation is occurred in the nozzle end dish curvature. ecause it have low thickness.From thermal analysis concluded that temperature distribution is 35.591W/m-k . This is less than material thermal conductivity so that nozzle design is safe for 2023K. Finally from the results obtained, it is concluded that all the stresses induced are well within the allowable limits and the structure is safe. But the stresses are very low in some components like nozzle cone, nozzle neck.

VI. FUTURE SCOPE

The above FEA analysis can be taken for different structural metallic materials like 15cdv6(low carbon steels used in rocket motor case),(Ti-6Al-4v) Titanium alloy and composite material like carbon c/silica c-phenolic Resin(used in ablatinliners,nozzle throat etc)&Sic_f/Sic(ceramic matrix composite used in high temp/hot structural) for rocket and missiles design. these components are optimized with respective their future work

REFERENCES

[1]. Ed. Richard C. Dorf(2000) “engineers hand book”, page no535-537.

[2]. Venkateshwaran ,S., merkle .C.L.,Zeing , X and Li, D(2002) .,”Influence of large scalepressure changes on nozzles ,”AIAA pp2002-2957, 32 nd Fluid Dynamic conferences ,St.Louis, MO, June 24-26,2002.

[3]. Bathe, K.J.(1981), Finite Element Procedures in Engineering Analysis. Engle wood Cliffs, NJ: Prentice Hall, .

[4]. Coleman, P., ETC.(2002)"Influence of nozzle design and radial mass distribution on Argaon K- , "ICOPS, May.

[5]. Jerry J. Berton(1991)" Developments and divergence thrust calculation in convergentand divergent nozzle"NASA

[6]. T.rChandrapatla& Ashok Belegundu(2003), Introduction to finite Elements in Engineering, Pearson Education, Third Edition.

[7]. Ballaney, P.L, (1991)Thermal Engineering, Khanna Publishers, Delhi, 18 th Edition, Pg no: 790-827.

[8]. www.matweb.com (materials specifications)

[9]. Exhaust Nozzles for Propulsion Systems with Emphasis on Supersonic Cruise Aircraft, L.E. Stitt, NASA Reference Publication 1235, May 1990

[10]. Nozzle selection and criteria by Eric gamble pageno12-20.

[11]. Missile history www.bharat-rakshak.com

[12]. Nozzle specification and design www.grc.nasa..gov

[13]. www.pdfsearch.com

[14]. Types of Nozzles www.aerospaceweb.org

[15]. ANSYS Elements Manual