Design and Analysis of Missile Nozzle

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Abstract In this paper CFD analysis of pressure and temperature for a rocket nozzle with two inlets at Mach 2.1 is analyzed with the help of fluent software. When the fuel and air enter in the combustion chamber according to the x and y plot, it is burning due to high velocity and temperature and then temperature increases rapidly in combustion chamber and convergent part of the nozzle and after that temperature decreases in the exit part of the nozzle. It is concluded in this paper that two inlet rocket nozzle is having better performance than single inlet. We know that the driving forces such as conversation, pressure and temperature gradient can causes species transport, momentum transport and energy transport respectively. Scientist have been worked on “Comparison of the rocket engines efficiency in the case of low thrust orbit-to-orbit transfers” and their findings are the following: The main task of this paper is to compare two types of low thrust rocket engines: constant thrust vs. variable-thrust engines. They are concerned with efficiency, where efficiency is evaluated in the case of the orbit-to-orbit transfer with maximum payload mass in the central Newtonian gravity field.

1. Introduction
The use of a better performing supersonic nozzle will help rocket propulsion and the space industry to reach further into the unknown. The following project presents this design team with a number of complex challenges including: design, calculations, and testing. Firstly, the design team must expand its knowledge on fluid mechanics namely in the area of supersonic flow [for this report Mach 1 through 4], de Laval nozzles [convergence-divergence], shock wave formation, and pressure distribution inside the nozzle. Additional considerations and solutions must be found with respect to the testing of this design which includes: supersonic wind tunnel testing, machining of nozzle [according to tolerances and standards consistent with aerospace applications], operation of various temperature and pressure probes [to obtain quantitative measurements to validate data], and finally scaling considerations and dimensional analysis to accurately translate scale model calculations to full scale testing results.

A computational consideration such as appropriate software choice is imperative. Simulation software whose capabilities include high velocity flows [greater than Mach 1] and the ability to calculate high pressures and shock wave formation associated with such flows. Such capabilities must extend to handling complex geometries associated with differing initial designs and their optimized shape. LOCI, a family of codes specifically designed for this purpose, are used for computational modeling in
this report. The second consideration, the machining of the nozzle, must be done according to tolerances and standards which are common to the aerospace industry, including AS9100 and ASME Y14.5.

2. Basic design of Nozzle

Nozzle is the part of a rocket, rocket or air-breathing motor that produces push. Changing over the weight vitality of the hot chamber gasses into active vitality and coordinating that vitality along the Nozzle pivot. The force is made out of a fuel, regularly fluid hydrogen (H2), and an oxidizer, commonly fluid oxygen (O2). The force is drawn into an ignition chamber at some rate (m) where the fuel and oxidizer are blended and consumed. The fumes gasses from this procedure are pushed into the throat locale of the Nozzle. Since the throat is of less cross-sectional zone than whatever remains of the motor, the gasses are compacted to a high weight. The Nozzle itself continuously increments in cross-sectional territory permitting the gasses to extend. As the gasses do as such, they push against the dividers of the Nozzle making push. Numerically, a definitive reason for the Nozzle is to extend the gasses as productively as conceivable in order to boost the leave speed (V exit).

![Figure 1 Rocket nozzle](image1)

Simply Nozzle is a device designed to control the direction or characteristics of a fluid flow as it exits an enclosed chamber or pipe. It has varying cross section area, nozzle are used to control the rate of flow, speed, direction, mass, shape and pressure of the stream that comes out of the nozzle. The velocity of fluid increases at the expense of its pressure energy.

2.1 Types of nozzle

There are many types of nozzles like Conical Nozzle, Bell shaped nozzle, Aerospace nozzle, jet nozzle, High velocity nozzle, Propelling nozzle, Magnetic nozzle, Spray nozzles in which we are using Conical Nozzle, Bell shaped nozzle.

2.1.1 Conical nozzle:

Most military stream air creates utilize the basic cone like Nozzle with customizable cone shaped edge as their propulsive gadget. In this cone shaped Nozzle outer supersonic extension occurs.

![Figure 2 Conical nozzle](image2)
2.1.2 Bell Shaped Nozzle:
The Bell-formed or Contour Nozzle is presumably the most ordinarily utilized molded rocket motor Nozzle. It has a high edge extension area (20 to 50 degrees) directly behind the Nozzle throat; this is trailed by a steady inversion of Nozzle shape slant with the goal that the Nozzle leave the difference edge is little, typically not as much as a 10 degree half edge. Preferably a Nozzle is wished to coordinate the majority of the gasses produced in the burning chamber and quickened by the throat to leave the Nozzle voyaging straight out the Nozzle. That implies the energy of the gasses are hub, bestowing the most extreme push to the rocket. Indeed, there are some non-hub parts to the energy. Regarding an energy vector, there is an edge between the hub of the rocket motor and the gas stream. Accordingly, the push is brought down by shifting sums. The Bell or Contour shape is intended to give a vast point extension for the gasses directly after the throat.

3. Design Alternatives
Design specifications taken into consideration for this project were based upon simulation, optimization and manufacturing results. Simulations were based upon the modeling performed on three different nozzles (conical, bell, and dual bell shaped) using Solid works and an input program, LOCI. To accomplish the project objectives, the optimization goals are realized through calculations derived from mode Frontier and computation fluid dynamics (CFD) multi-platform programs. To validate simulated tests, considerations between the size of the theoretical optimized nozzle and prototype was strongly considered. Dimensional analysis was completed to obtain a prototype used to acquire testing results. A key specification for the supersonic nozzle was the ability to directly observe shock wave formation inside the divergent section.

The design of convergent-divergent supersonic nozzles for rocket applications has evolved from simple conical designs to several more advanced schematics. Each of these nozzle designs hold several advantages and disadvantages over the other depending on what rocket is used and what its designated goal is. For this project, several nozzle designs are considered for optimization. The selection, however, is limited by the difficulty of manufacturing and testing certain nozzle designs as well as the feasibility of running these designs with computational fluid dynamics analysis and optimization software. From the selected designs, simulation work was conducted and the parameters of each designed were optimized based on the optimization goals discussed in above chapter. The nozzle that achieved the optimization goals by the largest amount was considered for a final design for manufacturing and testing.

3.1 Design Alternatives 1 conical nozzle:
The cone shaped Nozzle configuration is the forerunner to every single other plan of merged different supersonic Nozzles. While different outlines hold more viable methods for managing the basic issues of rocket gas stream, this plan is the most straightforward. Figure 4.3 contains a schematic of the cone like Nozzle.
One interesting nature of this Nozzle is the consistent half point (symbolized as) of the cone in different area. The effortlessness of this parameter takes into consideration a cleaner improvement and a less expensive creation. The Nozzle, in any case, loses proficiency due to the non-hub speed segments of the leave stream speed. This happens due to the straightforward cone geometry.

3.2 Design Alternatives 2 bell nozzle:
The most well-known Nozzle configuration utilized is the ringer Nozzle. While not as straightforward as the cone like Nozzle, the Nozzle geometry gives a more productive plan as far as less length and non-pivotal stream lessening. The following figure demonstrates the geometry of the dissimilar segment of a ringer shape Nozzle.

![Figure 4: Schematic of Divergent Section of Bell Shaped Nozzle](image)

An observable contrast from the cone shaped outline is the changing half point of the cone in the disparate segment. The edge prompts an explanatory form which is the fundamental factor to the expansion in productivity. Having a changing edge, notwithstanding, makes investigation, enhancement and assembling more troublesome contrasted with the funnel shaped outline. One of the fundamental disadvantages to the ringer Nozzle is the absence of elevation remuneration. The leave spill out of the Nozzle can under grow or over extend contingent upon the distinction in weight between the exit and the encompassing. Weight changes at various heights influencing the ringer Nozzle to have misfortunes at the non-ideal elevations. Regardless of these misfortunes, the ringer Nozzle is generally utilized because it is so possible to fabricate and the effectiveness of the plan.

3.3 Design Alternatives 3 dual bell nozzle:
As an endeavor to enhance the ringer Nozzle configuration portrayed in the past segment, the double chime Nozzle is intended to adjust for the wide range of weights at various heights. The schematics of a double ringer Nozzle can be found in the figure underneath.

![Figure 5: Shape of Dual Bell Nozzle](image)

The disparate area of this Nozzle is partitioned into the accompanying three sections: the principal chime, divider expression, and second ringer. The principal chime is like the unique segment of the ringer Nozzle. The divider affectation is in the middle of the first and second ringers. The second ringer speaks to the bigger estimated chime. Because of this geometry, when the leave stream under
extends because of higher surrounding weight, the Nozzle carries on like a standard chime Nozzle. The stream does not touch the second chime because of the divider expression causing stream partition. On the off chance that the Nozzle is at a high elevation where weight is lower than the stream weight, the leave stream over grows at the main Nozzle exit and proceeds onto the second ringer.

While the double chime Nozzle has a more noteworthy general effectiveness in flights that arrangement with consistently evolving weights, the ringer Nozzle at its outlined ideal weight is more proficient than both two Nozzles of the double chime at their ideal weights. The double chime Nozzle is additionally the most troublesome of the three chose plans to make, recreate, and advance.

3.4 Feasibility Assessment:
The three nozzle designs selected for this project are the simplest to manufacture of the current convergent-divergent supersonic nozzles designs. Testing an optimal nozzle was done through cold gas. Hot flow testing was beyond the reach of this project due to a great deal of requirements. A few of these requirements were combustion chamber analysis, specific testing facilities, and obtaining the required permission for testing. For simulation, a 2-dimensional flow was assumed and an attempt to analyze 3-dimensional flow was conducted as well. Due to time constraints, running the optimization software using 3-dimensional flow analysis might not have yield desired results. For choosing a final design, optimization goals achieved were prioritized, however, only if it was not difficult to manufacture based on available facilities.

4 ANSYS Simulations
ANSYS is a business programming bundle that was utilized to demonstrate and recreate the two geometrical setups for this task. One other reason this product was utilized as a part of conjunction with the LOCI programming was to approve the outcomes that the LOCI program created. As LOCI is a non-popularized programming, it was clear to have the capacity to reflect the outcomes in view of a basic geometrical setup and symmetrical limit conditions that the ANSYS programming could handle.

Figure 6: Mesh Model and Mach Number of 2-Dimensional Conical Nozzle (ANSYS)
Figure 7: Density and Temperature of Conical Nozzle (ANSYS)

The 2D cone like Nozzle above was mimicked utilizing ANSYS 14.5 CFX and presentations the Mach number for this recreation. The most extreme Mach number acquired was 1.927, which contrasted with a similar recreation from LOCI (M=2.573), is a 36% distinction. One can watch a typical shockwave framing at the Nozzle exit.

![Density and Temperature of Conical Nozzle (ANSYS)](image)

Figure 8: Velocity Contour and Pressure Distribution of the Conical Nozzle (ANSYS)

As observe from the figure above, we have conditions at the inlet that resemble typical sea surface temperatures (T=300K) on average.

The weight dissemination appeared in the above figure is a prime case of the stream's execution considering the underlying conditions put forward in ANSYS at 5 bars at the delta and the outlet state of a normal static weight of 1 bar. Again as illustrated, a shockwave frames close to the highest point of the outlet area.

The two past figures are essential to comprehend since they help characterize how the Mach number changes and aid the perception of the particles that stream all through the cone shaped Nozzle. Under these geometrical arrangements, we don't perceive any stream detachment on the mass of the Nozzle appeared by the figure with speed streamlines. The disparate area, where the speed achieves the most extreme of 527 m/s, the wandering edge assumes a key part on stream division. Since the veering point is steady in a cone shaped Nozzle, stream division is uncommon however may happen.

5. Results

| Property                        | Value       |
|---------------------------------|-------------|
| Mach Number                     | 1.972 e+0000|
| Density (kg m^3)                | 6.740 e+0000|
| Temperature (K)                 | 2.971 e+002 |
| Pressure Distribution (P)       | 4.907 e+005 |
| Velocity (m/s)                  | 5.229 e+002 |

6. Conclusion

Not all the task destinations were finished. As far as results, just the cone shaped Nozzle was improved and more trials for the advancement could have been rush to approve the enhancement procedure. Because of this outcome, the funnel shaped Nozzle geometry was chosen as the last plan.
The trial comes about did not concur with the recreation comes about; be that as it may, the outcomes for reenactment met extremely well. For this undertaking, just 2-D isentropic reenactments were run.

Reference
[1] Neilson, Robert M. The Steam Turbine. 1903: Longmans, Green, and CO, 1903.
[2] Dinavahi, Surya, Champagne, Victor and Helfritch, Dennis Correlation of Empirical and Theoretical Computations of Velocity for a Cold s.l.: IEEE, 2010.
[3] http://www.tessonics.com/items chilly spray.html. Icy Gas Spray Coatings. [Online] 2013. [Cited: March 17, 2015.]
[4] Mbuyamba, Jean-BaptisteMulumba, Estimation and Design of Supersonic Nozzles for Cold Gas Dynamic Spraying utilizing MATLAB and ANSYS Fluent [2013]
[5] Quintao, Karla K., Outline Optimization of Nozzle Shapes for Maximum Uniformity of Exit Flow[2012]. FIU Electronic Theses and Dissertations. Paper 779.
[6] Colaco, ColacoJ, Helcio RB Orlande and George S DulikravichReverse and Optimization Problems in Heat Transfer J. of the Braz. Soc. of Mech. Sci. and Eng. XXVIII. No.1 (2006).
[7] Sobol,I.M. (1967), Circulation of focuses in a shape and estimated assessment of integrals Zh. Vych. Tangle. Tangle. Fiz. 7: 784–802 (in Russian); U.S.S.R Comput. Maths. Math. Phys. 7: 86–112 (in English).
[8] Colaço, Marcelo J., Dulikravich, George S. what's more, Sahoo, Debasis(2008)‘A reaction surface technique based half breed optimizer’,Inverse Problems in Science and Engineering,16:6,717 — 741
[9] Hagemann, Gerald, Hans Immich, Thong Nguyen, and Gennady Dunmov Advanced Rocket NozzlesJournal of Propulsion and Power 14.5 (1998). Print.
[10] Sutton, George, and Oscar Biblarz. Rocket Propulsion Elements seventh ed. John Wiley and Sons, 2001. Print.