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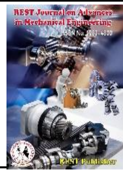

Experimental and Computational Investigation of Sounding Solid Rocket Motor

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Abstract. Experimental sounding rockets are important contributors to aerospace engineering research. However, experimental-sounding rockets are rarely used for student research projects by institutes in India. The unavailability of rocket motors, which require complex machining and explosive propellants, is a major barrier to the use of sounding rockets in student research projects. We ran into this problem while developing a sounding rocket motor for project and learning purposes. The project focuses on designing and constructing a solid rocket motor that researchers can use as the primary propulsion unit in experimental sounding rockets. Initially, basic designs were evaluated, as various concepts of observations of propellant configuration. The accessibility and ease of use of manufacturing and casting of propellants played a significant role in determining the best propellant based on these findings, the theoretical values for combustion chamber parameters were obtained. Also, materials were chosen accordingly, and a fundamental small-scale experimental design was built and extensively tested. This small-scale motor was created by combining all of the analysis and theoretical data.At experimental testing, we got to know the thrust generated is 763.47N and the motor runs for 4.1 sec, the total mass of the propellant is maxed at 1500g which gives us the max mass flow rate of 0.65Kg/sec this is the output for our solid rocket motor.
Keywords: Burn Rate, Propulsion, Solid Rocket Motor, Thrust

1. Introduction

Rocket motors square measure a non-air respirator, which suggests they do not want atomic number 8 from the atmosphere to burn the fuel held on within the rocket. A rocket motor may be a customary power gear mechanism. The energy within the fuel is born again into thermal energy by the combustion method. By this method "the internal energy of a gas is born-again into mechanical energy of the exhaust flow and also the thrust is made by pressure level within the exposed areas of the gas". The solid-propellant rocket motor is the most generally used compared to different rocket motors thanks to its easy style, high responsibility, simplicity, ability to use wherever needed, etc. Since robust rockets will behold on for a protracted time, and so dependably delivered with a brief notice, they're usually utilized in military systems like arrows. Solids, however, a square measure usually used as strap-on boosters to extend loading capability or as stable add-on elements once over traditional speed is needed.Solid Rocket Motor will be used for a spread of applications that need a good range of casting. This project focuses on the event of solid rocket victimization of commercially accessible building materials and chemicals and can function as an alternative to common issues like the acquisition of propellants, costly instrumentation, and sophisticated machinery. The analysis of the flow of the nozzle makes it roofing the key elements of a solid rocket motor and its analysis development perform. Unlike def. liquid rocket engines, solid rockets, and their key part can't be tested before, as testing can cause nozzle throat erosion and particle congestion, jeopardizing performance. It will be accustomed to simulating the interior combustion characteristics and visualize the combustion flow similarly to predict the performance. By doing this, motor performance improvement will be relinquished having to create and check innumerable real rocket motors.

Thus, a significant cost-saving will be achieved. A brand-new technique that is that the IR experimental approach has additionally been developed. The nozzle style is conducted by victimization Solid Works 2019.

2. Literature review

Solid propellant rocket motors (SRM) are commonly employed in satellite launch vehicles, according to reports. SRMs are made up of three separate structural materials: solid propellant, liner, and casing materials, Marimuthu R et.al [1]. Ogawa S et.al explained the construction of tiny spacecraft, the solid rocket motor (SRM) plays a crucial role. However, vertical flows can sometimes be caused by a propellant inhibitor, which produces pressure oscillation [2]. Shaheen S. et.al explained the rocket motor case is a non-energy-contributing missile component; the design goal is to make the case as light as possible while staying within technological and economic constraints [3].

The propellants in the motor are 98% hydrogen peroxide and hydroxyl-terminated polybutadiene. The flow field structure in the pre-combustion chamber and front half of the fuel grain port is mostly influenced by oxidizer flow distribution, according to a numerical study which is given by Tian H et.al [4]. Structures should be light, for example, key components should be made of composite and alloy materials with a low weight-to-strength ratio. The rocket motor casing is subjected to the 3-Dimensional finite element-based static structural analysis and modal analysis employing aluminum alloy, titanium alloy, alloy steel, carbon epoxy, and e-glass epoxy in this study. To undertake static structural and modal analysis, rectangular, semi-circular, semi-hexagonal, and triangular stiffeners are inserted into the rocket motor case which is explained by Barla et al [5]. Yildirim et.al told that thermal and pressure loads that occur during shipment, storage, and firing are thought to be the most important in defining the motor's long-term behavior. Under these loading conditions, the stress and strain distribution of the rocket motor is determined. Maximum hoop strain at the propellant surface and bond stresses at the liner–insulator interface is assessed as indicators of cracking in the propellant grain and deboning at the liner–insulator interface, respectively [6].

Material failure is the most concerning of the numerous modes of rocket motor failure. This could be due to minute fissures in the material or something that happened during the production process. The characteristics that cause structural failure include ultimate tensile strength and material thickness. The square root of the crack length is inversely proportional to the fracture strength of classical brittle material. When the material's stress intensity factor reaches a critical value, known as the critical stress intensity factor, it fails as a brittle fracture. It is a material attribute that determines which material is best for a rocket motor. It lowers as the thickness of the material increases.

The maximum circumferential stress caused by propellant gas pressure should be less than two-thirds of the material's yield strength. The governing factor in determining the appropriate material for a rocket motor is the critical stress intensity factor Kc. It is also beneficial to choose a material thickness that will not fail under plane strain and will only fracture under plane stress [7]. The magnitude of the vortex-shedding frequency in the combustion chamber is the most important factor, while the pressure amplitude is largely influenced by the mean Mach number. The link between thrust amplitude and pressure amplitude is described using an integrated formula by Zhang Q et.al [8]. During the simulations, a coupling component is also used to control the fluid-structure–combustion relationship. The numerical simulation results show an excellent correlation with experimental results involving the actual operational performance of a similar motor, resulting in a better physical understanding of the FSC interaction intrinsic to SRMs by Montesano et .al [9]. Marimuthu R et.al analyzes the structural integrity of solid rocket motor propellant grains; 20-node brick element (BH20), 8-node quadrilateral plane strain element (PH8), and 8-node quadrilateral ax symmetric solid of revolution element (AH8) have been created based on the Herrmann formulation [10].

Li. Q et.al explained an integrated framework for the combined simulation of propellant burning surface regression and internal fluid flow in a solid rocket motor described in this research. The results reveal that, although being serial versions, the given re-meshing algorithms are capable of effectively maintaining and improving mesh quality [12]. An in-house high-order numerical solver can estimate propellant combustion about acoustic pressures, with the numerical fluxes reconstructed using the fifth-order WENO 8 Department of Aerospace Engineering, Sandip University, Nashik (MH), India scheme and the viscous terms discredited using a sixth-order compact scheme. The pressure-coupled response function, the pressure index, and the reaction heat of the propellant, as well as the specific heat ratio of the burnt gas, are shown to promote the pressure oscillation growth process, but the magnitude and imposed region of burning rate pulses have less of an effect [13].

The addition of a burn rate-limiting coefficient was initially necessitated by numerical model stability concerns, but this, in combination with adjusting the net surface heat of reaction value, allows one to potentially align the model's response behavior with that observed experimentally for a given solid propellant, by Greatrix [14].

Ankit et.al resented a study on nozzle flow partition that is carried out by simulation of rocket nozzle designed Fusion 360 and ANSYS to inspect the laminar as well as turbulent regime for deviating section of nozzle [21]. Ankit et.al paper discussed a theoretical and conceptual design for compact size 2 stage sounding rocket by focusing on structural optimizations at various levels. The aim of the paper is to develop a two-stage sounding rocket with overall length constrained to 1 meter [22]. The aim of paper is to design a two-stage sounding rocket and its nozzles using fusion 360 and analysis of different properties using simulation on ANSYS software. The rocket is designed to reach maximum apogee to perform scientific experiments and can be recovered safely after use as described by Ankit et.al [23]. Theoretical study has also been presented which highlights the propellants being used in the solid rocket motor. The performance parameters are also being described along with the material selection as described by Ankit et.al [24]. Ankit et.al describes about a sounding rocket which is developed to perform certain scientific experiments in low earth orbit. The propulsion characteristics and calculations related to nozzles for both the booster stage and the sustainer stage of two-stage sounding rocket have been discussed and calculated using isentropic relations [25].

3. Model description

The figure plotted below presents an available SRM nozzle layout of the preliminary configuration based on mission requirements. The hollow cylinder grain configuration and the conical nozzle were adopted for the motor. The conical nozzle is historically the most common contour for SRM with low expansion ratios since it is simple and usually easy to fabricate at the expense of divergence losses. The contour of the present axisymmetric conical nozzle with an expansion ratio of 5.75 and a converged half-angle of 45 deg and diverge half-angle is 15 deg illustrated in Figure 1.

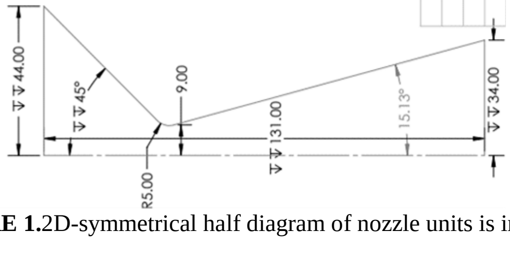

FIGURE 1.2D-symmetrical half diagram of nozzle units is in mm

The above figure shows the 2D representation of the model nozzle with all the parameters which has a throat length of 18mm and the total length of 131mm. The above figure shows the 2D representation of the model nozzle with all the parameters which has a throat length of 18mm and the total length of 131mm.

4. Methodology

Manufacturing methods for solid rocket motors used in small, fast-flight vehicles were developed using the KNO3 (Potassium Nitrate) & Sorbitol test motor this chapter will describe the methods used for manufacturing the propellant and liner for this configuration. Additional considerations for extending the motor manufacturing process to cast multi-segment propellant grains and flight-like motor geometries are then described. In this paper, the missile is designed using Dassault Systems (SolidWorks 2019) software (Open Source). The first step was to create a 2D. For the first draft design, we created a rough nozzle to kick-start the project work this design made us realize the errors and the calculation behind the design. As the nozzle was going to be manufactured on LATHE there were so many restrictions on the nozzle model. So, we created the nozzle part separate and the nozzle part separately so that there is no harm to the model. After creating the parts, the flange and the nozzle were welded with TIG welding. The motor case was also manufactured the same way a pipe GI was taken separately and the flange was welded separately to avoid any harm to the case. The parameters were put in the open-source like Open Motor to know the capability of the (SRM) solid Rocket Motor after finalizing the nozzle. To cross-check we have tested with another software named Meteor. Finally, after the simulation process, we compared obtained graphs for the desired output and results. An innovative manufacturing process is required for manufacturing motors to enable small, fast aircraft. The manufacturing procedures and hardware were developed to produce consistently dense propellant grains and liners with a robust propellant-to-liner bond to prevent edge-burning.

5. Results and discussion

Before proceeding to the manufacturing of the nozzle & motor we tested the results with the help of software like Open motor, Meteor, and Ansys for different parameters like thrust time, max thrust, total impulse, specific impulse, max pressure, and so on. Given below are the optimum values with design variables.

Meteor software results: Parameters obtained from Meteor software for motor performance are as given below: -We have obtained the graph for a visual understating of the above parameters it clearly shows how the pressure, mass flow rate, and trust gradually increase with the time when it reaches the peak it drops down which shows the end of the motor

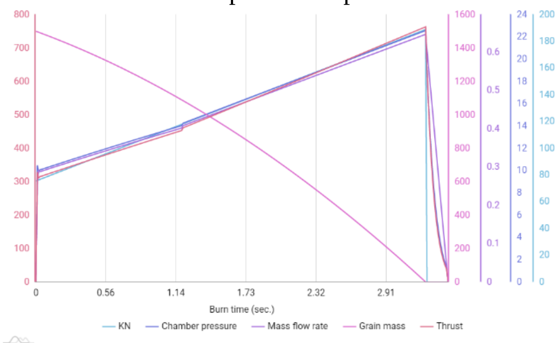

FIGURE 2. Performance Curve

A thrust curve typically referred to as a "performance curve" or "thrust profile" could be a graph of the thrust of AN engine or motor, (usually a rocket) regarding time. Most engines don't turn out linear thrust (thrust that will increase at a continuing rate with time). Instead, they turn out a curve of some kind, wherever thrust can slowly rise to a peak, and so fall, or "tail off". Rocket engines, significantly solid-fuel rocket engines, turn out consistent thrust curves, creating this a helpful metric for judging their performance.

This info is important when planning rockets and orbiters, significantly multi-stage orbiters since it's going to be advantageous to separate the engine and its associated fuel tanks and machinery before the fuel has been exhausted. this can be because even if the engine remains manufacturing thrust throughout the tail-off section, it's going to be therefore very little that the rocket would be economic.

Open motor results: Parameters obtained from Open Motor software for motor performance are as given below:

TABLE 3. Parametric Values

Variables	**Units**	**Values**
Impulse	Ns	1627.81
Peak pressure	Psi	326.11
Avg pressure	Psi	262.34
Burnt time	Sec	3.48
Port/Throat Ratio	--	4

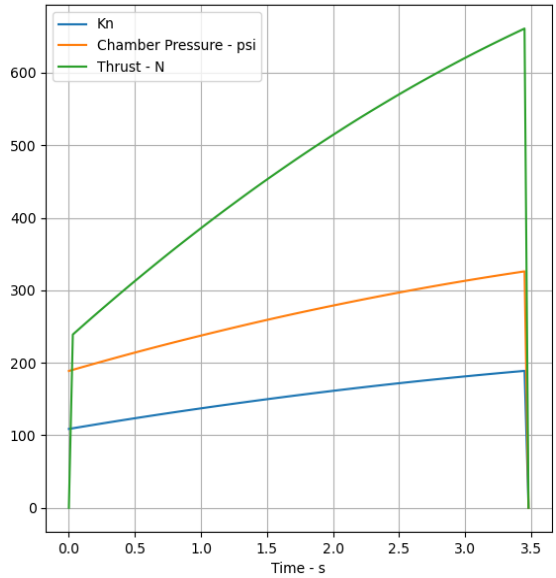

FIGURE 3. Variation of Chamber Pressure, Thrust with respect to time

From the table and graph, the square measure can compare the results that are nearly equivalent because of the modification within the propellant composition within the open motor a small modification within the results than from the meteor computer code however we can see the graph and recognize that the thrust curve of each computer code is almost an equivalent. Considering the mass rate equation, it seems that for a given space and a set density, we tend to might increase the mass rate indefinitely by merely increasing the speed. In real fluids, however, the density doesn't stay fastened because the speed will increase due to spontaneous effects. An account for the modification in density to work out the mass rate at higher velocities. If we tend to begin with the rate equation given higher than and use the physical property flow relations and also the equation of state, we can a compressible sort of the mass rate equation

$$\dot{m}\sqrt{\gamma} * P_c * A_t * \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} * \frac{1}{\sqrt{R}.T_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The above equation is a Max when M=1, At this condition, flow is chocked.

6. CFD (Computational Fluid Dynamics)

Computational fluid dynamics (CFD) may be a branch of mechanics that uses numerical analysis and knowledge structures to research and solve issues that involve fluid flows. Computers are accustomed perform the calculations needed to simulate the free-stream flow of the fluid, and also the interaction of the fluid (liquids and gases) with surfaces outlined by boundary conditions. With high-speed supercomputers, higher solutions are achieved and are usually needed to resolve the most important and most complicated issues. The in-progress analysis yields computer code that improves the accuracy and speed of complicated simulation situations like sonic or turbulent flows. Initial validation of such computer code is usually performed mistreatment of experimental equipment like wind tunnels. Additionally, antecedently performed analytical or empirical analyses of a specific downside are used for comparison. Final validation is commonly performed mistreatment all-out testing, like flight tests.

Design Specification: Design is one of the foremost necessary ideas in developing any product. It's also associated with the varying method that has a series of simulations up which a model is determined and so finalized. For this specific style, the tendency is to receive inputs from our mentor and this style is one in all the iterations that were provided with some alterations. When the look, we tend divided varied sections with lines and so the face split possibility through that we have a tendency, we were able to choose varied faces which might eventually facilitate us within the meshing section. The scale is as follows (Obtained from CAD).

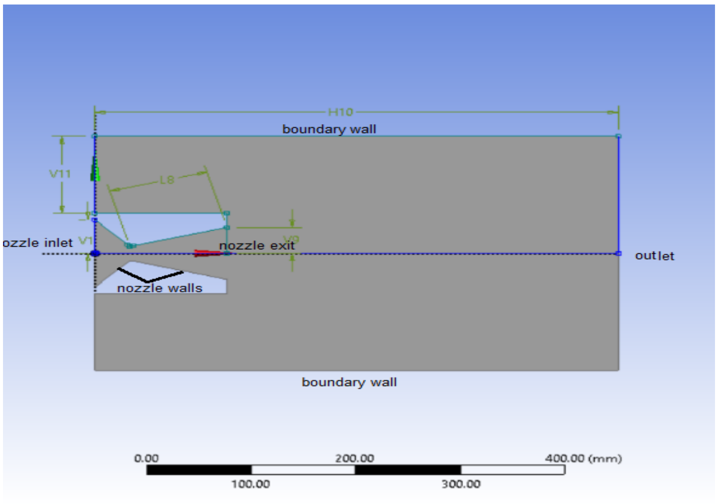

FIGURE 4.CFD setup with boundary condition

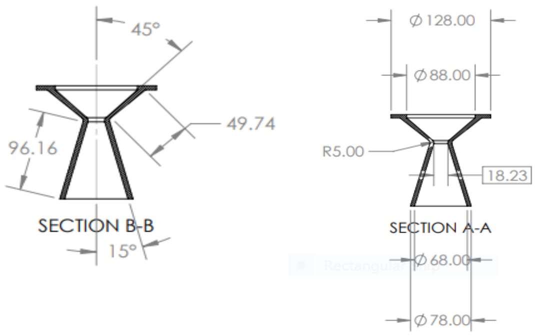

FIGURE5. Design Details of Nozzle (units in mm)

Meshing Conditions: Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into discrete geometric and topological cells. Usually, the cells partition the geometric input domain. Mesh cells are used as discrete local approximations of the larger domain. Meshes are created by computer algorithms, often with human guidance through a GUI, depending on the complexity of the domain and the type of mesh desired. The goal is to create a mesh that accurately captures the input domain geometry, with high-quality (well-shaped) cells, and without so many cells as to make subsequent calculations intractable. The mesh should also be fine (have small elements) in areas that are important for the subsequent calculations. The total nodes that were created through mesh were 146701 with 1mm of element size and the total elements were 145636 presents in the domain.

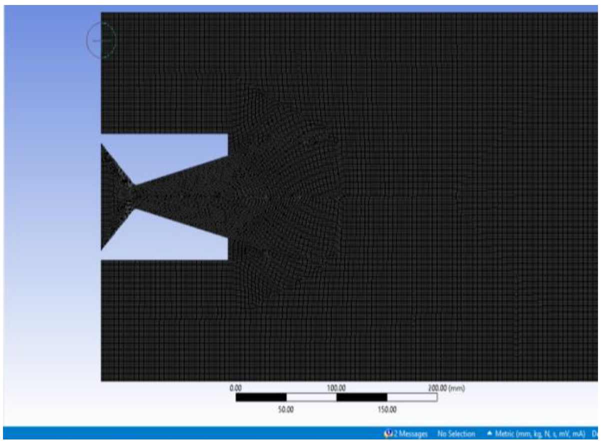

FIGURE 6. 1mm spaced Meshing in CFD analysis Meshing

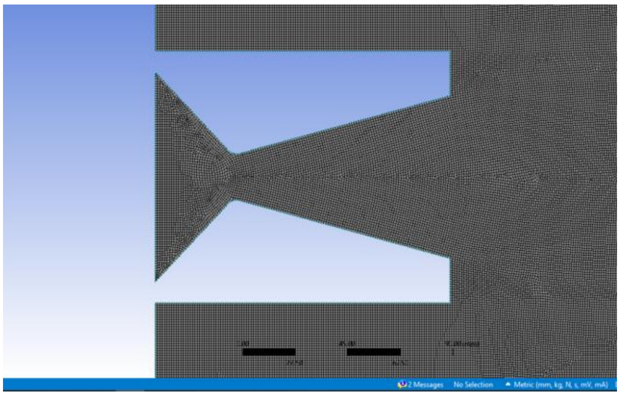

FIGURE 7. Zoomed view of1mm mesh of the nozzle

Setting up Physics: Whenever to do any type of simulation, we have to define some basic initial conditions so that our simulation goes in the desired way and does not deviate from the course. In the case of our Computational Fluid Analysis (CFD) problem we should follow some basic steps, which will be mentioned below. Every option that we choose here will have some significant effect on the fluid flow through the nozzle, which is why it's necessary to have good knowledge of Fluid Mechanics and Aerodynamics.

The steps taken for this CFD analysis are as follows,

In Boundary conditions mention the following inputs,

- For Pressure Inlet= Gauge total pressure =40 bars,
- Initial Gauge Pressure=39 bars, Total Temperature = 3200k.
- For Pressure Outlet = Backflow total Temperature to 2700k.

For Domain walls, Nozzle walls, and Surface walls = No-slip conditions. In Reference values, set the "Compute from" option to Pressure input and change the ratio of specific heats value (gamma) to 1.19. In methods set the Flow, Turbulent Kinetic Energy, and Turbulent Dissipation rate to Second order upwind for better accuracy. In Controls set the Turbulent kinetic energy and turbulent dissipation rate to 0.4 respectively. Set the iterations to 5000 and the time step size to 0.001.

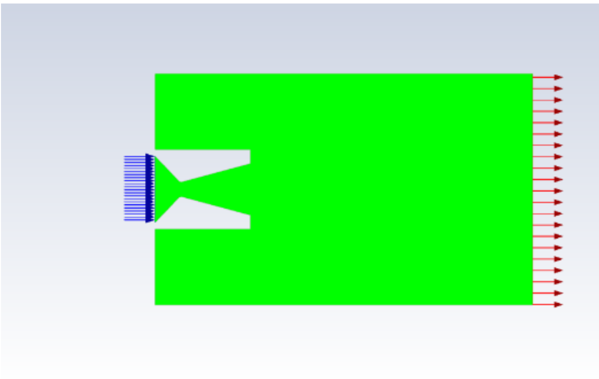

FIGURE 8. Setting up Physics for CFD

7. Results

Results of any CFD simulations provide a basic understanding of how the device can perform in sure given atmospheric conditions. It's going to not be as correct as the original experimentation however it'll offer some values which might be used as reference values in the original experimentation. During this specific CFD analysis, we are going to be specializing in specific results parameters that will so verify our results. The parameters we are going to be specializing in are going to be as follows,

- Pressure
- Temperature
- Mach No (velocity)

Preliminary results show that it is a rather over-expanded Nozzle because the pressure P at the outlet is a smaller amount than that of atm pressure.

Pressure: For an ideal nozzle, the pressure at the exit should be equal to the atmospheric pressure, if the above-mentioned property is satisfied then the nozzle is called the optimum (ideal) nozzle. Similarly, if P exits< P atm then it is called an Under Expanded Nozzle.

Similarly, if P exits > P atm then it is called a grossly over-expanded nozzle.

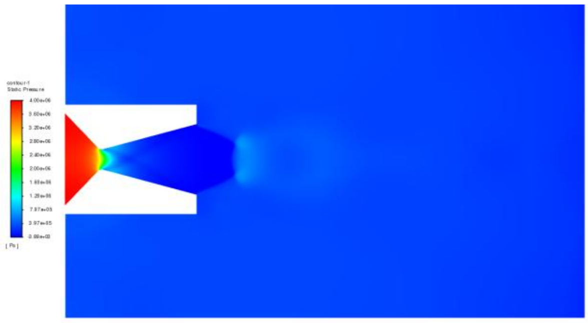

FIGURE 9. Static Pressure

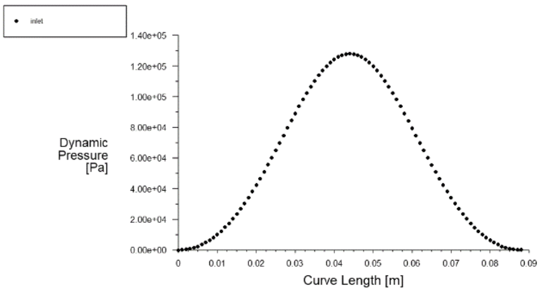

FIGURE 10. Graph plots for dynamic pressure

Temperature: The below graph shows the temperature variation at various positions of the nozzle. We can see that the temp at the inlet is about 3200k and as it moves towards the exit section it drops below 2900k.

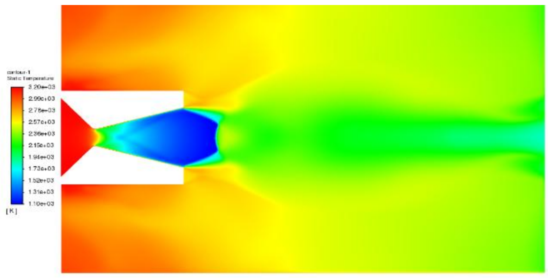

FIGURE 11. Temperature Contour

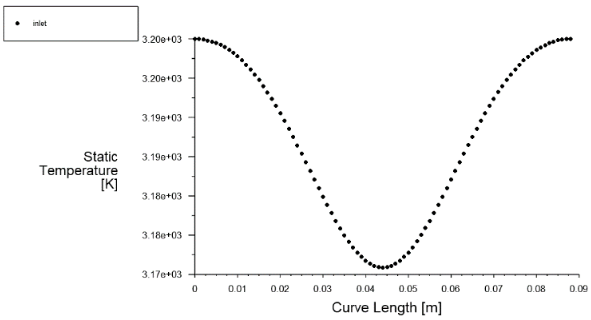

FIGURE 12. Graph plots for static temperature

Velocity: This equation tells however the speed V changes once space changes, and therefore the results rely on the Mach number M of the flow. If the flow is subsonic then ($M < 1$) and therefore the term multiplying the speed amendment is positive ($1 – M^2> 0$). A rise within the space (dA>zero) produces a negative increase (decrease) within the rate. For our CD nozzle, if the flow within the throat is subsonic, the flow downstream of the throat can decelerate and keep subsonic. Therefore, if the convergence section is simply too giant and doesn't choke the flow within the throat, the exit rate is extremely slow and does not manufacture a lot of thrusts. On the opposite hand, if the convergence section is little enough so the flow chokes within the throat, then a small increase within the space causes the flow to travel supersonically. For a supersonic flow ($M > 1$) the term multiplying rate amendment is negative ($1 – M^2< 0$). Then a rise within the space (dA> 0) produces a rise within the rate (DV > 0). This result is exactly the other of what happens sub-sonically. Because, to conserve mass in an exceedingly supersonic (compressible) flow, each density and therefore the rate is ever-changing as we modify the realm. For subsonic (incompressible) flows, the density remains fairly constant, and the increase at intervals in the area produces exclusively a modification in speed. But in supersonic flows, there square measure two changes; the speed and thus the density the equation

$(m2) \times dvv = drr$ tells that for M > 1 ……………………………………….. (2)

The amendment in density is way bigger than the amendment in speed. To conserve mass and momentum in an exceedingly supersonic flow, the speed will increase, and therefore the density decreases because the space will increase.

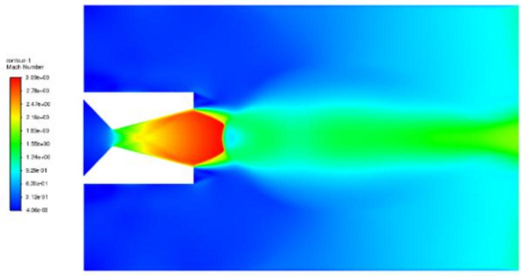

FIGURE13. Velocity contour

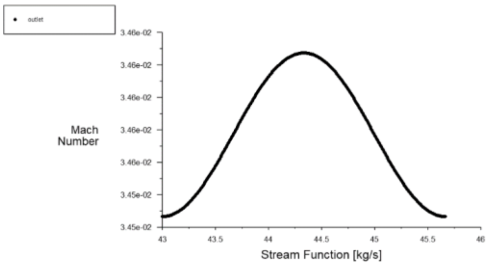

FIGURE14. Mach Result Plotted on Nozzle Exit

Experimental results: On the day of testing the final checking was done like looking after the fixture of the nozzle to the case, putting the inner liner of the hard heat-resisting sheet, and the case was coated with the grease for making the propellant slide in smoothly after all the preparation the nuts were fastened and the nozzle was placed on the motor case safely and we have made sure that no leakage was present. After doing this assembly of the motor we placed the motor on the test stand for the firing of the SRM, motor was placed on the test stand and buckled up with the clamps holding the motor weight and making it static stable. An igniter was placed in the motor and all the precautions and safety measures were taken so that no harm could be there to the surroundings as well as to the people After firing the SRM we got to know that the calculation is done to make the nozzle and the motor case was correct we got the thrust of almost 833.5 N to 980.6 N which was correct as given by the software and the total burn time was about 4.1 sec. After the test, we found the remains of the ashes of fuel all around the motor case and also the white nozzle, and inside the motor case, there was burnt fuel with the line The test was carried out successfully, and the desired results were found the thrust produced was 833.5 N, the total impulse was 1820.04 Ns, the specific impulse 117.18 s, and the max pressure built-in was 23.80 Bar with the nozzle exit speed of Mach 2.54 and the total grain mass burnt was 1583 g.

8. Conclusion

A numerical investigation of single and two-phase flow through the designed conical nozzle is conducted employing an Eulerian-Lagrangian description. The flow field results are to calculate the thrust and therefore the nozzle potency is additionally calculated. A designed round shape nozzle suggests that the particulates have important effects on the nozzle potency and lead to one percent lower potency than the only gas flow, therefore the particulates play a crucial role within the SRM nozzle style. The results indicate the requirement to use the next nozzle throughout the preliminary style optimization method of SRM.A solid rocket motor is successfully developed and might be utilized as a propulsion unit in experiments. Motor parameters are often varied according to the outputs required. The check results show that the overall Impulse and Specific Impulse generated by the motor are appropriate for test instrument vehicle applications.

All the calculation is done from the software i.e., meteor and open motor which seem to be correct, the total propellant was burnt in testing. All parameters of the motor seem to be accurate from the thickness to the C-D angle also the CFD has proven the stable flow.

References

[1]. Marimuthu, R., & Rao, B. N. (2013). Development of efficient finite elements for structural integrity analysis of solid rocket motor propellant grains. International Journal of Pressure Vessels and Piping, 111, 131-145.

[2]. Ogawa, S., & Sasaki, D. (2017). Two-dimensional computational fluid dynamics analysis of internal flow in a simplified solid rocket motor combustion chamber. Journal of Fluid Science and Technology, 12(3), JFST0023-JFST0023.

[3]. Shaheen, S., & Gupta, G. S. (2015). Design and analysis of carbon-epoxy composite rocket motor casing. International Journal of Innovative Research in Science, Engineering and Technology, 4, 7397-7740.

[4]. Tian, H., Jiang, X., Zhu, H., Yu, R., Zhang, Y., & Cai, G. (2021). Numerical analysis of the hybrid rocket motor with axial injection based on oxidizer flow distribution. Acta Astronautica.

[5]. Barla, K. S., & Krishna, C. S. R. (2021, September). Dynamic analysis of rocket motor case. In IOP Conference Series. Materials Science and Engineering (Vol. 1185, No. 1). IOP Publishing.

[6]. Yıldırım, H. C., &Özüpek, Ş. (2011). Structural assessment of a solid propellant rocket motor: Effects of aging and damage. Aerospace Science and Technology, 15(8), 635-641.

[7]. Pandey, K. M., & Bose, P. (2012). Structural failure analysis of Rocket motor. J. Environ. Res. Develop, 6, 869-872.

[8]. Zhang, Q., Wei, Z. J., Su, W. X., Li, J. W., & Wang, N. F. (2012). Theoretical modeling and numerical study for thrust-oscillation characteristics in solid rocket motors. Journal of Propulsion and Power, 28(2), 312-322.

[9]. Montesano, J., Behdinan, K., Greatrix, D. R., & Fawaz, Z. (2008). Internal chamber modeling of a solid rocket motor: Effects of coupled structural and acoustic oscillations on combustion. Journal of Sound and Vibration, 311(1-2), 20-38.

[10]. Marimuthu, R., & Rao, B. N. (2013). Development of efficient finite elements for structural integrity analysis of solid rocket motor propellant grains. International Journal of Pressure Vessels and Piping, 111, 131-145.

[11]. Sun, L., Bao, F., Zhang, N., Hui, W., Wang, S., Zhang, N., & Deng, H. (2016). The thermos-structural response is caused by the structure gap and gap design for solid rocket motor nozzles. Energies, 9(6), 430. [12] Li, Q., He, G. Q., Liu, P. J., & Li, J. (2014). Coupled simulation of fluid flow and propellant burning surface regression in a solid rocket motor. Computers & Fluids, 93, 146- 152.

[12]. Ji, S., Wang, B., & Zhao, D. (2020). Numerical analysis on combustion instabilities in end-burning-grain solid rocket motors utilizing pressure-coupled response functions. Aerospace Science and Technology, 98, 105701.

[13]. Greatrix, D. R. (2008). Transient burning rate model for solid rocket motor internal ballistic simulations. International Journal of Aerospace Engineering, 2008.

[14]. MĂRMUREANU, M. I. (2014). Solid rocket motor internal ballistics simulation using different burning rate models. UPB Scientific Bulletin, 76, 51-56.

[15]. Adam Okninskia, BlazejMarciniaka, Bartosz Bartkowiaka, Damian Kaniewskib, Jan Matyszewskia, Jan Kindrackib, Piotr Wolanski(2015, April). Development of the Polish Small Sounding Rocket Program. https://doi.org/10.1016/j.actaastro.2014.12.001

[16]. Karl W. Naumann, Matthias Berndl, Ludwig Eineder, Raphael Esterl, Guenter Fechler, Andreas Hacker, Tobias Meyer, Sebastian Rest, Ludwig Stadler, Dominik Stangl, Holger Steinfeld, Martin Vetter, Alexander C. Weigand, Rainer Kirchhartz and Frank Scheuerpflug (2021, July). A First Stage Solid Propellant Rocket Motor for Sounding Rockets. https://doi.org/10.2514/6.2021-3692

[17]. NickolayZosimovych (2021, February). Sounding Rocket Preliminary Design. https://doi.org/10.24018/ejeng.2021.6.2.2368

[18]. ThadaSuksila (2018, December). Experimental investigation of solid rocket motors for small sounding rockets.DOI-10.1088/1757-899X/297/1/012009

[19]. Alexander C. Weigand, Axel Ringeisen, Tobias Meyer, Karl W. Naumann, Rainer Kirchhartz, Wolfgang Jung and Frank Scheuerpflug (2020, August). A Solid Propellant Rocket Motor for a Sounding Rocket. https://doi.org/10.2514/6.2020-3936

[20]. Ravikiran, Mohd, Jawad Shariff, H. Kaushil, S. Likhitha, Nikhil Bhootpur& Sreejith Mohan (2020, September). Design and Development of a Cost-Effective Reloadable Motor for Sounding Rocket. DOI: 10.1007/978-981-15-6619-6_48.

[21]. Ankit Kumar Mishra, Rishi SuhasKarandikar, Janani Kavipriya. S, Ashutosh kumar, “Study of nozzle flow separations in divergent section of nozzle”, International Journal of Universal Science and Engineering, Vol.No. 7, Jan-Dec, 2021.

[22]. Ankit Kumar Mishra, Madhumitha M, Vaishnavi Shenoy “Numerical and Computational Analysis on TwoStage Sounding Rocket”, International Journal of Science, Engineering and Technology, vol. 9(4), pp. 01-06, 2021.

[23]. Ankit Kumar Mishra, Kshitij Gandhi, Kuldeep Sharma, Neerumalla Sumanth, “Conceptual design and analysis of two stage sounding rocket”, International Journal of Universal Science and Engineering, vol.7(1), pp. 52-72, 2021.

[24]. Ankit Kumar Mishra, Shruti Jadhav, MasettyAkshay, “Theoretical Aspects on Design and Performance Characteristics of solid rocket motor”, International Journal of All Research Education and Scientific Methods, Vol.10, No.2, pp. 894-898, 2022.

[25]. Ankit Kumar Mishra, Janani Kavipriya VS, Prasannalakshmi Thota "Theoretical and Numerical Investigation on Propulsive Configuration and Performance Characteristics for a Sounding Rocket", International Journal of Enhanced Research in Science, Technology and Engineering, Vol.11, No.3, 2022, pp. 46-53.