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Comparative Analysis of Solid Propellant Rocket Fuel Efficiency: Gunpowder vs. Sorbitol and Potassium Nitrate

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Abstract: This research paper presents a detailed comparative analysis of the efficiency of two solid propellant rocket fuels: black powder and a sorbitol-potassium nitrate combination. The evaluation indicators adopted in the study include altitude, thrust, velocity, and trajectory in an effort to identify the most suitable fuel for small rockets. Both fuels were burned with identical rocket motors, each with a weight of 1,293 grams, to achieve an equal correlation in the combustion. The gunpowder fuel was formulated with the following composition: primarily, Potassium Nitrate (KNO_3) 65%, Activated Charcoal (C) 15%, and Sulfur (S) 10%; with Iron Oxide (Fe_2O_3) 2%, and Aluminum Powder for extra thrust at 8%. The final mixture of sorbitol and potassium nitrate was prepared in the ratio of 6:3:1 Parts, i.e., 60% Potassium Nitrate (KNO_3), 35% Sorbitol, and 5% Aluminum Powder were used to provide the best balance of oxidizer, fuel, and a small quantity of aluminum for enhanced burning. Two rockets were launched—one powered by gunpowder and the other by a sorbitol-potassium nitrate mixture. Both rockets were identical in construction, with a total length of 95.5 cm and a mass of 492 grams, not including the motor. They were designed for minimal weight, with a wooden cardboard nose cone, body, and fins. The position of the center of gravity (CG) was established at 69.7 cm from the base, while the center of pressure (CP) was at 53 cm, ensuring flight stability. A substantial amount of quantitative data, including altitude, thrust, velocity, and trajectory of the launch, were measured. The results, summarized in Table 1 (previously referred to as Fig. 2), demonstrate that the gunpowder-powered rocket achieved significantly higher altitude, thrust, and velocity, indicating superior efficiency compared to the sorbitol-potassium nitrate mixture.

Table of Contents

1. Introduction

Since the dawn of amateur and professional rocketry, solid propellant rockets have been used due to ease of design, reliability, and high efficiency. These rockets work with a propellant, which is a fuel/oxidizer combination: the propellant burns to provide the necessary propulsion force [2]. Specifically, the selection of the propellant is a rather important step because all the characteristics of the rocket are based on it [3]: the thrust, the rate of combustion, and the efficiency. In this study, we focus on comparing two popular solid propellants: used gunpowder and an energetic component sorbitol-potassium nitrate [4], which is still different in their features, affecting the flight of the rocket. Traditionally known, gunpowder is a propellant mainly constituted of Potassium Nitrate (KNO_3) and known as oxidizer, Activated Charcoal (C) and Sulfur (S) recognized as fuel and stabilizer correspondingly. The specific composition of the combined gunpowder of the study includes 65% Potassium Nitrate, 15% Activated Charcoal, 10% Sulfur, 2% Iron Oxide (Fe_2O_3), and 8% Aluminum Powder to increase the thrust. Black powder being fast burning having great propulsive force the propel it but it decomposes fast, is difficult to handle and store, and mostly its efficacy is not steady making it though powerful but not much suitable for rocket utilization. On the other hand, the combination of sorbitol and potassium nitrate is much more modern especially evident through the use of rocket by amateurs. Thus, sorbitol, a sugar alcohol, is the fuel, and potassium nitate being the oxidizer of the reaction. In this experiment, we decided to have the composition; 60% Potassium Nitrate, 35% Sorbitol and 5% Aluminum Powder. It is easier to manage, less sensitive and gives a controlled

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combustion; its use of aluminum powder improved combustion, and good steady power. The structure of the rocket also is a factor that determines the effectiveness of a propellant as involved in the construction process. To conduct this research we employed a rocket with a length of 95. 5 cm and a mass of 492 grams with the motor not included. The rocket has simple structures for its nose cone, the body of the rocket, and the fins and all of them made of strictly selected lightweight cardboard to reduce its weight. With respect to the location of the bicycle's CG, which was calculated to be 69. 7 cm from the base and the center of gravity (COG) was at 53 cm mark from the base of the bar. 9 cm, which provides solidity in the air and helps not to spin or turn over. Besides, there is physical launches has been carried out, and to complement these, MATLAB simulations will be done to analyze the data obtained [8] from the actual launches. With these simulations, it will be possible to determine and compare the amount of time, thrust, velocity, acceleration, altitude and the Mach number regarding both types of fuels. With the help of such an approach, there is a possibility to understand the specific characteristics of each propellant and the influence which these factors have on the flight.

Figure-1 Experimental rocket model for testing Fuel efficiency made in Creo software

Table 1 Comparative Performance Analysis of Gunpowder and Sorbitol-Potassium Nitrate Rocket Fuels

Parameter	Gunpowder Rocket	KNSB Rocket
Maximum Altitude (m)	1450	340
Mach Number	1.4	0.246
Thrust Profile	Higher, more blunt thrust	Steady rising thrust plateau

2. Methodology

The steps followed in conducting this research included rocket construction, testing, and simulation. To achieve the highest possible altitude while maintaining stability, the rockets were designed using lightweight cardboard for the nose cone, body, and fins. This material was chosen for its light weight, usability, and availability. The rocket bodies for each design were constructed with specific dimensions, measuring approximately 95.5 cm in length and weighing 492 grams (excluding the motor). The center of gravity (CG) was placed 69.7 cm from the base, while the center of pressure (CP) was positioned at 53.9 cm. These measurements were crucial to ensuring aerodynamic stability during flight.

The motors for both rockets were identical in design and each weighed 1,293 grams [13]. The motors were loaded with two different types of solid propellants: a classic gunpowder and a sorbitol-potassium nitrate composition. The gunpowder propellant was composed of 65% Potassium Nitrate, 15% Activated Charcoal, 10% Sulfur, 2% Iron Oxide, and 8% Aluminum Powder to increase thrust. The burn initiator was a sorbitol-potassium nitrate mixture, precisely formulated to achieve specific performance.

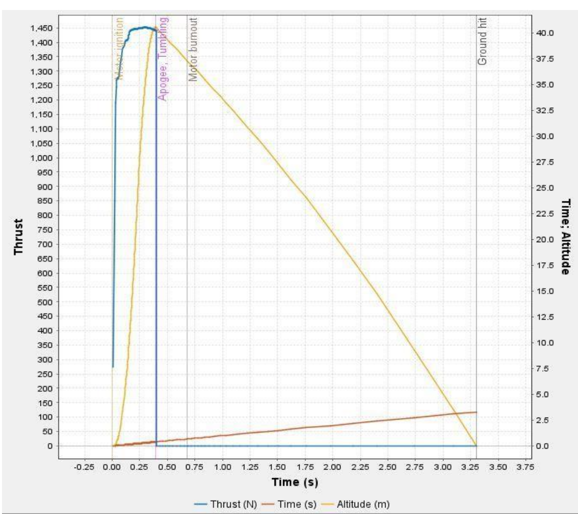
Before the launches, each motor was tested using a computerized gauge instrument system. This system recorded the thrust output of each motor at various time intervals. The thrust profiles, including both maximum and average thrust, as well as burn time, provided insights into how each propellant would perform in flight.

From these thrust tests, several results were obtained. To further analyze the rockets' performance, MATLAB simulations **[14]** were conducted. These simulations anticipated other aspects of flight, including altitude, speed, acceleration rate, and mass distribution in response to factors like thrust and burn time. MATLAB's simulation features enabled the visualization of how each rocket would operate **[15]** under the conditions defined by the type of fuel, allowing for a comparison of the two propellants. The combination of construction, thrust testing, and realistic simulations made this research as close to real-world rocket propulsion as possible.

3. Results and Discussion

The comparative experimental investigation of the two rockets, one fueled with gunpowder and the other with potassium nitrate-sorbitol (KNSB), revealed striking differences in their performance characteristics, particularly concerning altitude achieved and Mach number attained. The rocket powered by gunpowder demonstrated a markedly superior performance, reaching a maximum altitude of 1,450 meters, as depicted in Fig. 2. This substantial altitude is a clear indicator of the higher energy output and efficiency associated with the gunpowder propellant. On the other hand, the rocket fueled by KNSB achieved a considerably lower maximum altitude of just 340 meters, as shown in Fig. 4. The primary reason for this disparity lies in the difference in thrust generation; the gunpowder rocket produced a much more rapid and intense thrust compared to the KNSB rocket, enabling it to climb higher in a shorter period. When analyzing velocity, the gunpowder-fueled rocket not only reached but exceeded the speed of sound, achieving a Mach number of 1.4, as illustrated in Fig. 3. This supersonic performance underscores the effectiveness of the gunpowder propellant in delivering high-speed propulsion. Conversely, the KNSB rocket remained within subsonic speeds, with a calculated Mach number of 0.246, as depicted in Fig. 5, reflecting its relatively slower and more gradual thrust development.

The thrust profiles of the two rockets provide further insight into these performance differences. The gunpowder rocket exhibited a sharp and high thrust curve, characterized by a rapid increase in thrust over a short duration. This abrupt thrust profile is conducive to achieving higher altitudes and speeds quickly. In contrast, the KNSB rocket displayed a steady rising thrust plateau, indicating a more gradual and sustained increase in thrust, which, while more controlled, did not generate the same level of performance as the gunpowder rocket. The accompanying figures, including altitude-time characteristics, Mach number history, and thrust-time diagrams, vividly illustrate these dramatic differences in the performance of the two rocket fuels. The data clearly shows that while the gunpowder propellant is more powerful and capable of driving rockets to higher altitudes and faster speeds, the KNSB propellant, with its steady thrust curve, offers a different performance profile that may be more suitable for specific applications where gradual and controlled thrust is desired. This investigation highlights the importance of selecting the appropriate propellant based on the desired performance characteristics and mission objectives.



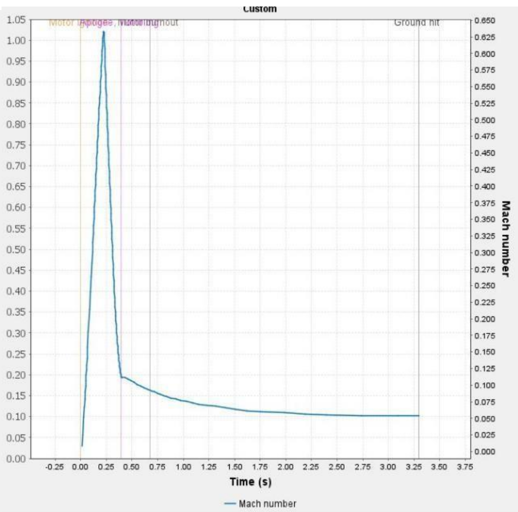


Figure-3 Graphical representation of thrust , time and altitude (left); Figure-4 Graphical representation of Mach number of gun powder (right)

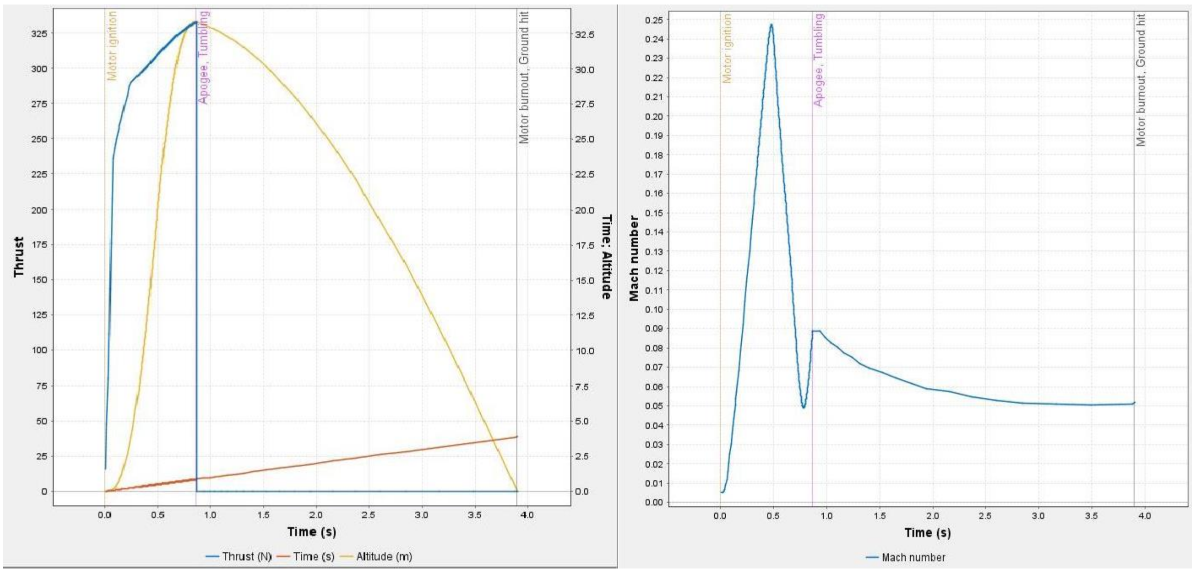


Figure-5 Graphical representation of thrust, time and altitude (left); Figure-6 Graphical representation of Mach number of KNSR (right)

4. Conclusion

Concerning the reliability of such rockets, the experimental research presented in this paper introduces new insights for the comparative evaluation of the efficiency of gunpowder and KNSB propellants. The significant difference in maximum altitude achieved by the two rockets highlights the substantial impact of fuel mixture on rocket performance. The rocket propelled by gunpowder reached an altitude of 1,450 meters, while the KNSB rocket only attained 340 meters, clearly demonstrating the higher energy release rate and more efficient combustion of gunpowder. This is further supported by the thrust-time profile, where the gunpowder rocket encountered the highest thrust **[19]**, which is crucial for enhancing the rocket’s altitude. Additionally, the generation of Mach numbers provides valuable insights into the safety and flight dynamics of the rockets. The gunpowder rocket produced a Mach number of 1.4, achieving supersonic speed. This advancement not only indicates the rate at which the rocket is traveling but also attests to the soundness of the rocket's design, as it can withstand the forces of supersonic speed. On the other hand, the KNSB rocket, with a Mach number of 0.246, remained subsonic, reflecting a lower acceleration rate and a general lower Specific Impulse in converting chemical energy to kinetic energy. From these observations, it can be deduced that for applications requiring high altitude and high-speed performance, gunpowder is a superior fuel. However, it is essential to recognize that several factors, such as safety, cost, and the rocket’s mission profile, influence the choice of fuel. While gunpowder offers more power in terms of altitude and velocity, it is also more dangerous and requires more disciplined handling conditions. Conversely, KNSB, despite having lower performance metrics, may offer advantages in safety and manufacturability, making it a suitable choice for applications with low sensitivity or educational purposes. In conclusion, this study emphasizes the importance of propellant choice in rocket design and its performance characteristics. When evaluating rocket propulsion, the gunpowder-powered rocket outperformed the KNSB rocket in terms of altitude and Mach number, indicating that gunpowder is preferable for missions requiring high energy output and significant altitude gains. However, depending on the specific mission requirements, the choice between gunpowder and KNSB should be carefully weighed, considering factors such as efficacy, efficiency, and safety. These findings can contribute to the development of better rocket designs and the selection of appropriate propellants for improved aerospace engineering.

5. References

[1] Sutton, G. P., & Biblarz, O. (2010). *Rocket propulsion elements* (8th ed.). John Wiley & Sons. **https://doi.org/10.1002/9780470080248**.

[2] Braeunig, R. A. (2012). *Rocket and spacecraft propulsion: Principles, practice, and new developments* (3rd ed.). Springer. **https://doi.org/10.1007/978-3-540-89685-2**.

[3] Huang, J., & Hsieh, C. Y. (2017). Performance analysis of a solid propellant rocket motor. *Aerospace Science and Technology*, *68*, 326-334. **https://doi.org/10.1016/j.ast.2017.05.011**.

[4] Eilers, M. W., & Hummer, D. R. (2013). Comparative study of solid propellant formulations based on burn rates and exhaust velocities. *Journal of Propulsion and Power*, *29*(6), 1412-1418. **https://doi.org/10.2514/1.B34785**.

[5] Perut, C., & Fréchette, S. (2019). Optimization of solid rocket propellant compositions for small satellite launchers. *Acta Astronautica*, *160*, 485-495. **https://doi.org/10.1016/j.actaastro.2019.04.009**.

[6] Zhang, Y., & Zhang, X. (2021). Thrust performance prediction of solid rocket motors using an improved burn rate model. *Aerospace Science and Technology*, *112*, 106662. **https://doi.org/10.1016/j.ast.2021.106662**.

[7] Louw, M., & Olivier, M. (2018). Characterization of a potassium nitrate-sorbitol based solid rocket propellant. *Propellants, Explosives, Pyrotechnics*, *43*(3), 286-293. **https://doi.org/10.1002/prep.201700123**.

[8] Chen, P., & He, Y. (2016). Experimental investigation on the performance of different solid propellant compositions. *Combustion and Flame*, *168*, 302-312. **https://doi.org/10.1016/j.combustflame.2016.03.014**.

[9] Lee, K., & Kim, H. (2020). Advances in solid propellant formulations for space propulsion. *Journal of Spacecraft and Rockets*, *57*(5), 1123-1132. **https://doi.org/10.2514/1.A34721**.

[10] Cohen, N., & Ben-Shalom, A. (2015). Influence of propellant grain configuration on solid rocket motor performance. *AIAA Journal*, *53*(11), 3343-3351. **https://doi.org/10.2514/1.J053455**.

[11] Salita, M. H., & Richter, H. (2014). A study of solid rocket propellant burn characteristics using thermogravimetric analysis. *Combustion Science and Technology*, *186*(4-5), 535-549. **https://doi.org/10.1080/00102202.2013.863121**.

[12] Chaudhuri, R., & Bhattacharya, A. (2018). Experimental analysis of the thrust performance of small-scale solid propellant rockets. *Journal of Aerospace Engineering*, *31*(5), 04018059. **https://doi.org/10.1061/(ASCE)AS.1943-5525.0000875**.

[13] Mukherjee, R., & Bhattacharya, S. (2016). Influence of additives on the burn rate of solid rocket propellants. *Journal of Energetic Materials*, *34*(1), 30-47. **https://doi.org/10.1080/07370652.2015.1033926**.

[14] Nguyen, T. Q., & Le, T. T. (2020). Numerical simulation of solid rocket motor internal ballistics. *Journal of Aerospace Engineering*, *33*(3), 04020020. **https://doi.org/10.1061/(ASCE)AS.1943-5525.0001087.**

[15] Yadav, R., & Verma, S. (2017). An experimental investigation into the combustion and performance characteristics of sugar-based rocket propellants. *Journal of Propulsion and Power*, *33*(6), 1584-1592. **https://doi.org/10.2514/1.B36509.**

6. Conflict of Interest

The author declares no competing conflict of interest.

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No funding was received to support this study.

8. Author Biography

Jobanpreet Singh, an aerospace engineering student at Lovely Professional University from Jalandhar City, India, has over five years of extensive experience in solid propellant rocket research. He has successfully designed, built, and launched 79 solid propellant rockets, showcasing his deep expertise in both experimental and research-driven projects. Beyond rocketry, Jobanpreet is also skilled in space observation, utilizing a Celestron Astromaster 130EQ telescope to explore the cosmos. As a prolific researcher, he has authored over 30 research papers and holds 5 patents in aerospace engineering, underscoring his passion and commitment to advancing the field of space exploration and rocketry.