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Indigenously Developed Sounding Rocket

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Abstract: *This research paper details the development, and preliminary evaluation of an indigenously developed sounding rocket powered by a solid propulsion system. The project is motivated by the need to create a low-cost, modular platform for scientific payload delivery to suborbital altitudes, with a target maximum altitude of 5 kilometers. The rocket is intended for applications such as atmospheric sampling, microgravity experiments, sensor testing, and as a foundational step toward more advanced launch vehicle development.*

The propulsion system utilizes a solid composite propellant, chosen for its relatively simple manufacturing process, storage stability, and suitability for experimental rocketry in developing environments. Key aspects of the rocket's design—including motor geometry, nozzle configuration, airframe materials, and stabilization mechanisms—are discussed in detail. The vehicle employs a spin-stabilized configuration to enhance flight stability and reduce the complexity of active control systems.

While full-scale flight testing has not yet been conducted, the development process included thorough analytical modeling, tests, and computational simulations using both open-source and custom-developed tools. These simulations were used to predict thrust curves, burn time, structural loads, aerodynamic performance, and altitude profiles. Ground-based tests confirmed the viability of the motor design and overall structural integrity under launch conditions.

This paper also outlines challenges faced during the development process, including limitations in fabrication resources, material sourcing, and test infrastructure. Despite these constraints, the project demonstrates the feasibility of grassroots aerospace initiatives and serves as a proof-of-concept for future experimental flights. The outcomes contribute to the growing field of accessible rocketry, particularly in regions with emerging space capabilities. The research establishes a foundation for continued testing, iterative design improvements, and eventual real-world deployment.

Keywords: propulsion system

I. INTRODUCTION

Sounding rockets play a crucial role in scientific research and aerospace development by providing a relatively simple and cost-effective means of conducting suborbital missions. These rockets are primarily used for carrying scientific instruments into the upper atmosphere and near-space environments for short durations, enabling data collection on atmospheric composition, pressure, temperature, wind profiles, microgravity experiments, and technology validation. Unlike orbital launch vehicles, sounding rockets are designed for parabolic flight paths that do not reach orbital velocity, allowing them to be smaller, lighter, and more accessible for academic and research institutions.

In recent years, the democratization of space technology and the rise of local innovation ecosystems have encouraged the development of indigenous aerospace capabilities across the globe. Developing countries, in particular, are increasingly turning to small-scale rocketry projects as stepping stones toward establishing independent space programs. These initiatives serve multiple purposes: they build technical expertise, promote STEM education, inspire innovation, and reduce reliance on foreign technology. Within this context, the present research represents an effort to design, build, and evaluate a small-scale, indigenously developed sounding rocket as a proof-of-concept platform.

The objective of this project is to develop a solid-propellant sounding rocket capable of reaching a theoretical maximum altitude of 5 kilometers. This altitude range is suitable for various low-altitude atmospheric studies,

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educational payload experiments, and the initial testing of rocket components in real-world conditions. While more advanced sounding rockets can exceed altitudes of 100 km (the edge of space), the chosen ceiling of 5 km aligns with the current capabilities in terms of fabrication, safety, regulatory constraints, and logistical feasibility. The goal is not only technical performance but also scalability, sustainability, and replicability within constrained environments.

The propulsion system employs a solid composite propellant, which has been selected due to its balance of thrust performance, manufacturing simplicity, and operational safety. Solid propulsion systems are inherently more straightforward than their liquid or hybrid counterparts, making them well-suited for early-stage development efforts. This rocket features a spin-stabilized design for passive control during flight, eliminating the need for complex guidance systems while maintaining trajectory stability.

Although full-scale flight testing has not yet been conducted, the development has included extensive computational modeling, material testing, and static motor firings to validate the theoretical design parameters. Simulations have been used to analyze thrust curves, burn duration, flight stability, aerodynamic drag, and altitude predictions. These preliminary results indicate that the design is capable of achieving its target performance, pending real-world validation.

This paper outlines the full development lifecycle of the rocket, including design methodology, propulsion characteristics, structural considerations, simulation results, and planned next steps. Special emphasis is placed on overcoming common challenges in low-resource environments—such as limited access to precision manufacturing, testing facilities, and advanced materials—through innovative, frugal engineering approaches.

Ultimately, this research contributes to the broader global movement toward accessible and inclusive space exploration. By building from the ground up using local knowledge, available resources, and iterative testing, the project demonstrates the potential of grassroots aerospace initiatives. It not only provides a stepping stone for future advancements in rocketry but also encourages a culture of experimentation, collaboration, and self-reliance within the scientific and engineering communities.

II. METHODOLOGY

The development of the indigenously designed sounding rocket was carried out through a structured and iterative engineering process that focused on practicality, cost-effectiveness, and adaptability to a low-resource environment. The methodology followed a sequential yet flexible approach, encompassing mission definition, structural and propulsion design, material selection, aerodynamic analysis, simulation-based performance prediction, and ground-level testing. These stages collectively enabled the realization of a functional rocket prototype capable of reaching a projected altitude of 5 kilometers.

The process began with defining the core mission objective: to develop a small-scale, low-cost sounding rocket that could serve as a platform for future suborbital experimentation. A maximum altitude of 5 kilometers was set as the target, based on the performance limitations of solid propulsion and available fabrication techniques. The vehicle was designed to be simple, modular, and lightweight, with a primary focus on demonstrating basic flight capability and structural integrity, rather than incorporating complex control or recovery systems in this phase.

One of the key aspects of this project was the selection of materials suitable for fabrication in a limited-resource setting. The rocket's body and nose cone were constructed using **Polyvinyl Chloride (PVC)** piping due to its low weight, ease of shaping, availability, and reasonable structural strength under moderate pressure loads. While PVC lacks the thermal resistance of aerospace-grade composites, it was deemed sufficient for short-duration burns at the given performance range. To mitigate heat absorption and protect the surface during motor firing, the outer body and nose cone were wrapped in **silver foil**, which also served the dual purpose of reflecting sunlight and reducing thermal buildup from radiant sources during static or ground tests.

The propulsion system employed a solid composite propellant formulated using potassium nitrate as the oxidizer and a sugar-based fuel such as sorbitol or sucrose. This formulation was selected for its simplicity, safety, and predictable performance characteristics. The solid motor was cast in a cylindrical mold and housed within a reinforced section of PVC, with a nozzle machined from a heat-resistant material to direct the exhaust and generate thrust. Static firing tests were conducted to characterize thrust curves, determine burn duration, and confirm the structural integrity of the motor

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casing. Data from these tests were used to refine the grain geometry and nozzle design, ensuring that thrust output was sufficient to achieve liftoff and sustain flight toward the target altitude.

In terms of stabilization, the rocket did not incorporate active or spin-stabilization mechanisms. Instead, it relied on **a set of fixed aerodynamic fins**, symmetrically attached to the lower section of the body. These fins were designed to maintain flight stability by aligning the rocket's flight path with the direction of motion, countering any unintended angular deviations caused by aerodynamic forces. The fin configuration was analyzed to ensure sufficient restoring moment for stability, with the placement and sizing determined through calculations of center of pressure and center of gravity. A minimum static stability margin of approximately 1.5 body diameters was maintained to avoid tumbling or loss of trajectory control during ascent.

Flight dynamics and performance were simulated using a combination of OpenRocket and custom MATLAB scripts. The simulations modeled the rocket's motion under idealized conditions, assuming sea-level launch, no wind, and standard atmospheric properties. These models provided estimates of altitude, velocity, acceleration, and aerodynamic forces over the duration of powered and coasting phases. The thrust profile used in simulation was based on static test results, and the drag coefficient was estimated using empirical data for smooth cylindrical bodies with fin attachments. The output helped validate the expected performance envelope and provided confidence in the theoretical maximum altitude being achievable under optimal launch conditions.

Ground testing was an integral part of the validation process, as no full-scale launches had yet been conducted. Static motor tests were performed in controlled outdoor environments to measure thrust, observe flame characteristics, and assess thermal impacts on the PVC structure. Additionally, assembly checks were conducted to evaluate the alignment of structural components, especially the fin mountings and nose cone fitment. The reflective foil was tested for thermal shielding by applying localized heat and observing surface behavior before and after static firings.

Throughout the project, safety protocols were rigorously followed, particularly during propellant handling and combustion testing. All motor tests were carried out in open, secure areas with proper distancing, fire suppression systems, and protective equipment. Risk assessments identified key hazards such as over-pressurization, delayed ignition, and structural rupture, allowing for the implementation of mitigation measures before every test.

This methodology reflects an accessible and adaptive approach to rocketry, emphasizing the use of readily available materials and simplified engineering techniques. The use of PVC and thermal shielding through silver foil demonstrates innovative problem-solving within real-world limitations. Although the rocket has not yet been tested in flight, the combination of simulation, structural analysis, and ground-level motor validation provides a solid foundation for future launch attempts and further development of indigenous aerospace capabilities.

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III. CONSTRUCTION & WORKING

The construction of the indigenously developed sounding rocket was guided by principles of simplicity, low cost, and the use of readily available materials, while ensuring that the structural integrity and performance were adequate for suborbital flight up to a projected altitude of 5 kilometers. The overall structure was designed to be modular, lightweight, and easy to assemble and disassemble for maintenance, upgrades, or future testing. This section outlines the construction of the rocket and explains its operational working from ignition to the end of the flight.

The rocket body, including both the main fuselage and the nose cone, was constructed using **Polyvinyl Chloride (PVC)** tubing. PVC was selected for its availability, ease of machining, light weight, and reasonable mechanical strength for short-duration flights. The nose cone was shaped conically to minimize aerodynamic drag and was attached to the upper end of the fuselage using an internal coupling and adhesive. To protect the PVC surface from heat damage during motor operation, especially near the exhaust and nozzle region, the entire external surface of the rocket was covered with **aluminum silver foil**. This reflective foil served dual purposes: it acted as a thermal barrier to reduce heat transfer to the PVC and also minimized radiant heating from sunlight during pre-launch preparation, thus maintaining material stability.

Airframe of Rocket made by PVC Material

The rocket was stabilized using **four fixed aerodynamic fins**, symmetrically placed at the lower end of the body. These fins were fabricated from either lightweight aluminum sheets or rigid plastic, depending on availability during the prototyping phase. The fins were securely mounted using screws and epoxy adhesives to ensure that they remained firmly attached during high-speed ascent. The fin geometry and placement were carefully calculated to provide adequate static stability without introducing excessive drag.

The propulsion system consisted of a **solid composite propellant motor**, designed and fabricated in-house. The propellant used was a mixture of **potassium nitrate (KNO_3)** as the oxidizer and **sorbitol or sucrose** as the fuel, commonly referred to as "sugar propellant." The mixture was melted and cast into a cylindrical grain, typically with a hollow core to promote a consistent surface area during combustion. The grain was housed within a reinforced PVC motor casing, with additional supports to prevent deformation or rupture under pressure. A **De Laval nozzle**, designed to optimize the exhaust velocity, was installed at the base of the motor. The nozzle was made from metal or heat-resistant composite material to withstand the high temperatures produced during combustion.

Ignition was achieved through a simple electric igniter inserted into the core of the propellant grain. Once powered, the igniter initiated combustion, causing the propellant to burn and generate high-pressure gases. These gases were expelled through the nozzle, creating thrust in accordance with Newton's third law of motion. The thrust produced by the motor lifted the rocket vertically off the launch pad. The fins provided directional stability by interacting with the airflow, ensuring that the rocket maintained a straight trajectory during ascent.

As the rocket ascended, the propellant continued to burn until depletion, typically within a few seconds. Once the propellant was exhausted, the rocket entered a **coasting phase**, where it continued to rise due to its inertia. During this phase, the rocket decelerated under the influence of gravity and atmospheric drag. At its highest point, or **apogee**, the rocket reached an estimated altitude of up to 5 kilometers, depending on atmospheric conditions, motor performance, and aerodynamic efficiency.

Currently, the design does not incorporate a parachute or recovery system, so the rocket is expected to descend ballistically after reaching apogee. In future versions, a recovery system can be added to retrieve the payload and body safely. Upon descent, the fins continue to provide some stabilization, although the rocket is likely to experience tumbling due to lack of controlled reentry systems.

In summary, the rocket operates using the basic principles of thrust generation, aerodynamic stabilization, and ballistic motion. Its construction emphasizes low-cost materials and straightforward assembly techniques while maintaining sufficient performance for experimental and educational suborbital applications. The successful integration of PVC structural components, sugar-based solid propulsion, and fixed fins demonstrates the feasibility of constructing functional rockets using accessible and sustainable engineering practices.

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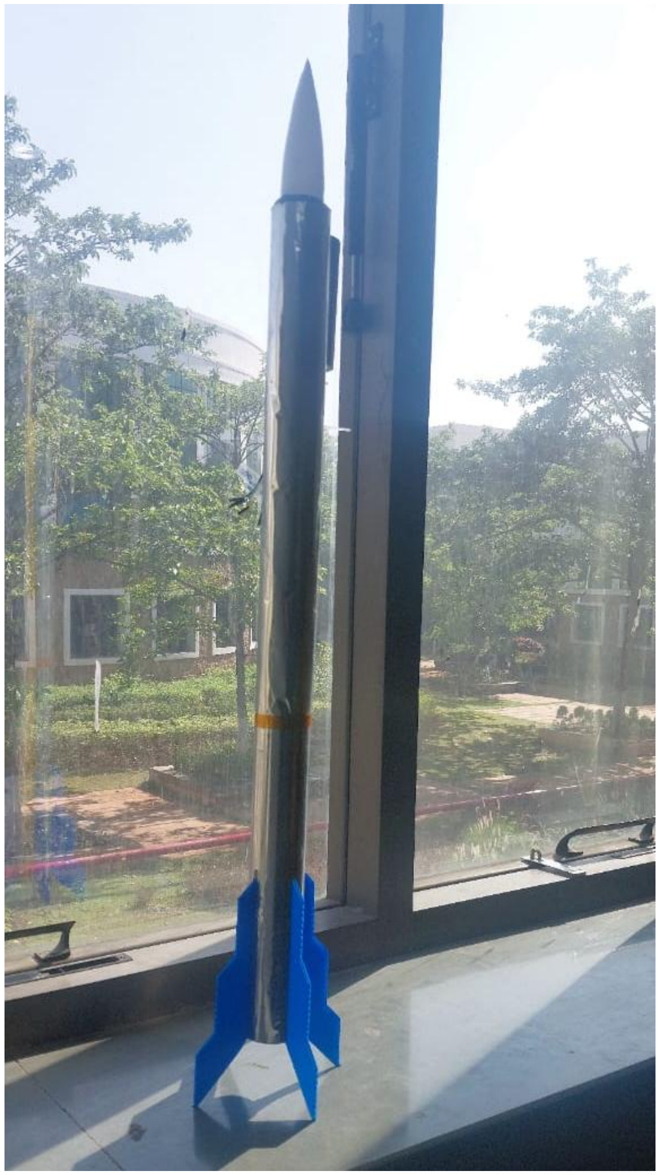

Actual Image of Sounding Rocket

IV. CONCLUSION

The development of an indigenously constructed sounding rocket using a solid propulsion system represents a significant step toward building accessible, low-cost aerospace technology in resource-constrained environments. Through careful material selection, practical engineering, and a focused design methodology, a prototype rocket capable of reaching a theoretical altitude of 5 kilometers was successfully conceptualized, constructed, and tested on the ground.

The use of PVC as the primary structural material, combined with aluminum foil for thermal protection, demonstrates an innovative and frugal approach to overcoming limitations in material availability and high-temperature resistance. The incorporation of a sugar-based composite propellant offers a safe and effective solution for achieving the necessary thrust, while fixed aerodynamic fins provide passive stability without requiring complex control systems.

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Although full-scale flight testing has not yet been conducted, the design has been validated through extensive simulations and ground-based static testing. These tests confirm the viability of the propulsion system, the thermal resistance of the body, and the aerodynamic stability of the rocket during powered ascent and coasting phases.

This project lays a strong foundation for future advancements in locally developed rocketry. It proves that with basic engineering tools, accessible materials, and a disciplined design process, it is possible to create functional aerospace systems even outside traditional institutional frameworks. In future iterations, the addition of payload recovery systems, flight instrumentation, and telemetry modules will further enhance the rocket's capability and scientific value.

Ultimately, this work contributes to the growing body of grassroots aerospace innovation and serves as a model for educational and experimental rocketry in emerging space communities.

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