RV COLLEGE OF ENGINEERING
Bengaluru-560 059

REPORT ON
EXPERIENTIAL LEARNING / PROJECT BASED LEARNING
ACY 2023-24

THEME

Energy

Title of the Project
Field Analysis of Varying Rocket Propellants

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Field Analysis of Various Rocket Fuel Compositions

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ABSTRACT (INTRODUCTION)

This project investigates a new type of solid rocket fuel which could be a potentially better alternative for sugar-based fuels in the field of rocketry. With the current propellant chemicals being Ammonium Perchlorate, which is highly restricted in India, we came up with **KNDX and Alumina Nanoparticles** as a potential alternative, which is a greener, safer, and much cheaper formula as a replacement. This can be used in various equipment, such as ejection seats, flare guns and further vehicular launches. Another problem we took up was of developing a cheaper, safer and universal alternative to test the characteristics of solid propellants which can be easily made available for target groups of college students and other independent entities which cannot afford buying and maintaining expensive apparatus.

Keywords: Aluminum Oxide Nanoparticles, Solid Rocket Fuel, Sugar Rockets, Propellant Characterization

I. PROBLEM DEFINITION

A**. Problem Statement**

1. Solid Rocket Propellants in India are highly regulated unlike other countries where they are available for rocketry. The ones that do exist like KNDX have a very low specific impulse in comparison to APCP.
2. The testing apparatus to characterize propellants is very rare to come by and expensive to make and maintain.

B. **Background Info**

Solid rocket propellants have been used for centuries, with significant advancements occurring over the past few decades. The most common types of solid propellants are composite propellants, which typically consist of an oxidizer, a fuel, and various additives to enhance performance. Potassium nitrate and dextrose (sugar) propellants, known as "sugar rockets," have been popular in amateur rocketry due to their simplicity and cost-effectiveness. However, these propellants often suffer from lower performance compared to more advanced formulations.

These types of propellants can be used while researching/designing equipment pertaining to solid rocket motors as these are very cost-effective.

II. OBJECTIVES

A. **Primary Objectives**

1. Formulate and produce a new solid rocket propellant comprising of Alumina Nanoparticles
2. Design a testing apparatus for the solid rocket motor which has live telemetry.
3. Design and test a H-Class solid rocket motor while keeping the factor of safety above two.

B. Secondary Objectives

1. Characterize the burn surface of the propellant.
2. Developing a Python Program to help with rocket motor design.
3. Run CFD Simulations on the Nozzle.

III. METHODOLOGY

A. Approach

The entire process consisted of 6 major steps which were, Simulation, Prototyping, Coding, Manufacturing Hardware, Manufacturing Fuel and Testing.

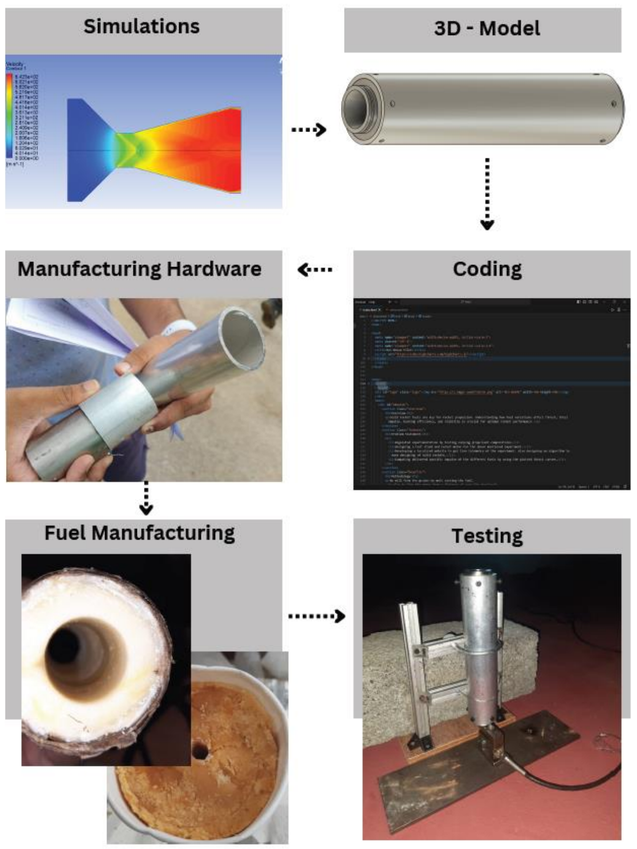


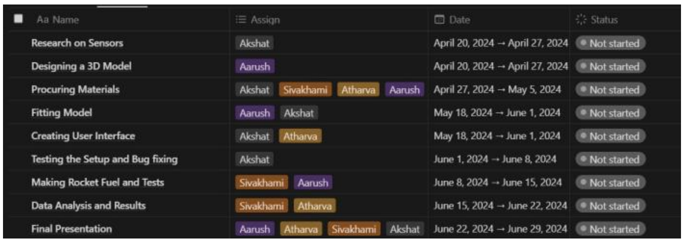
Figure 1 - Flowchart

B. Procedures

We hypothesized that alumina nanoparticles would function as both an oxidizer and a fuel. To test this, we began by experimenting with various compositions using a propellant simulation software called ProPEP. We performed several calculations and ran multiple simulations to determine the specific parameters for our rocket motor.

Next, we created a prototype 3D model of the rocket motor and the testing apparatus. Simultaneously, we developed a website capable of receiving thrust telemetry data. Afterward, we procured all necessary materials and sent our 3D designs for manufacturing.

Once we received the manufactured components, we prepared the alumina nanoparticles and formulated the rocket fuel. Finally, we tested the solid rocket motor and characterized the fuel surface to evaluate performance.



Aa Name	Assign	Date	Status
Research on Sensors	Akshat	April 20, 2024 → April 27, 2024	Not started
Designing a 3D Model	Aarush	April 20, 2024 → April 27, 2024	Not started
Procuring Materials	Akshat Sivakhami Atharva Aarush	April 27, 2024 → May 5, 2024	Not started
Fitting Model	Aarush Akshat	May 18, 2024 → June 1, 2024	Not started
Creating User Interface	Akshat Atharva	May 18, 2024 → June 1, 2024	Not started
Testing the Setup and Bug fixing	Akshat	June 1, 2024 → June 8, 2024	Not started
Making Rocket Fuel and Tests	Sivakhami Aarush	June 8, 2024 → June 15, 2024	Not started
Data Analysis and Results	Sivakhami Atharva	June 15, 2024 → June 22, 2024	Not started
Final Presentation	Aarush Atharva Sivakhami Akshat	June 22, 2024 → June 29, 2024	Not started

Figure 2 - Initial Timeline

IV. PROJECT EXECUTION

A. Planning and Design

Initially we planned to do a strand burner test for multiple propellant compositions instead of making our own testing apparatus but when we discovered that it was broken and no other college had one, we decided to make a cost-effective testing apparatus as well.

Since this project was a huge undertaking, we divided all major work into 4 major tasks and assigned them to each team member. The 4 major tasks being Solid Rocket Motor, Propellant, Testing and Code & Electronics. All 4 of us came up with the initial design/plan for all 4 tasks. We also came up with our own personal timelines to execute our individual tasks.

B. Implementation

The implementation phase began with the preparation of engineering drawings, circuit diagrams, and a detailed list of materials. After procuring all necessary materials, we moved on to manufacturing. Our designs were provided to a lathe operator in Peenya for fabrication. An initial fit of all the motor hardware revealed issues with the O-ring grooves, which we then returned to the manufacturer for correction.

With the motor ready, we proceeded with the procurement and preparation of chemicals. Using the campus chemistry lab, we synthesized 4 grams of alumina nanoparticles via the solution combustion method. Following this, we prepared the casting equipment through 3D printing.

The code for the microcontroller was done on Arduino IDE and the development of the Telemetry dashboard was done in the form of creating a localised website that was constructed using the languages HTML, CSS for frontend and Javascript for backend.

Finally, we assembled and soldered all circuits, launched the website for receiving telemetry data, and conducted a test with the rocket motor using KNDX as the propellant. This thorough and iterative process ensured that all components and systems were properly integrated and functional.

V. TOOLS AND TECHNIQUES

A. Tools

Software Tools

1) ProPEP: Propellant Evaluation Program -> Used to analyse the various theoretical propellant compositions.
2) Fusion 360: Used for designing the 3D Models and Engineering drawings of the test stand and rocket motor.
3) OpenMotor: Run rocket motor simulations to get an Ideal Thrust v/s Time Curve
4) Ansys Fluent: Used to perform fluid analysis on the nozzle to optimize the design.
5) Arduino-IDE: Used for coding the NodeMCU microcontroller and interfacing the Load Sensor.
6) Python: Used for developing an algorithm which helps design rocket motors.
7) JavaScript: Used to design the website on which the telemetry data was streamed.

Hardware

Hardware for this project included, aluminium extrusions, aluminium tubes, stainless steel and aluminium stock material, nylon rods, PLA, 12.9 grade alloy steel bolts, eyebolt, threading equipment, Buna-N O-rings, Machine Grease, Steel Mandril, PVC Pipes, RTV auto gasket maker and u-bolts.

B. Techniques

1. Lathing

   Lathing was used to create all the motor hardware since they were all cylindrical.

2. Surface Characterization

   Surface characterization of the propellant was done by taking thin samples of the propellant and placing them under an optical microscope at 50x and 20x magnification.

3. Liner Layup

   The thermal liner we have used are the ones manufactured out of kraft papers which are made by spirally binding layers of craft paper in opposite manners to bring about a rigid structure which is further solidified using either epoxy or a solution of glue.

4. Solution-Combustion Method for Alumina

   1. 5g of Aluminium nitrate [$Al(NO_3)_3$] was taken in a beaker.
   2. About 2g of Urea was added to $Al(NO_3)_3$.
   3.This mixture was dissolved in minimum water and then heated over a Bunsen burner until all the water evaporated.
   4.On continuing to heat, the mixture eventually caught flames, to leave behind a white powder.
   5. This white powder was Alumina nano particles.

   This process yielded about 1g of Al np. We used this method to produce about 5g of Al np.

5. Casting

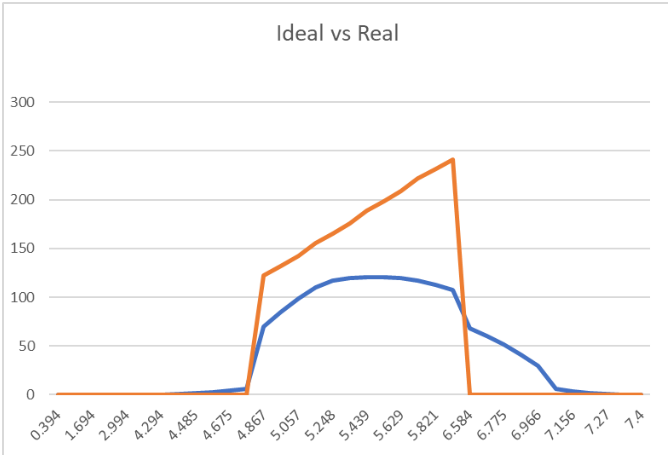
We have adopted the method of melt casting the process includes:

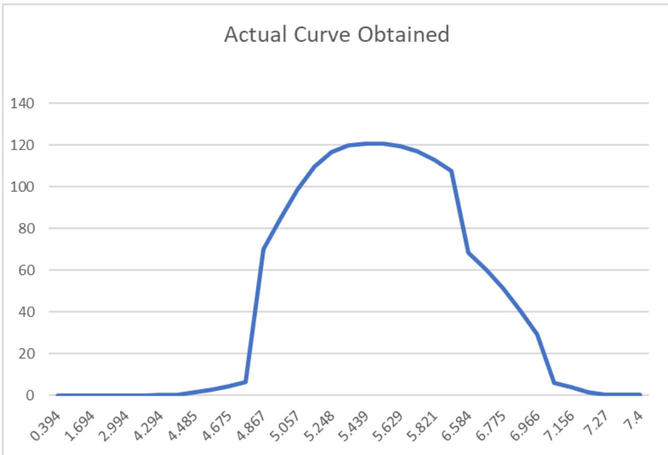
1. Both the oxidant and the fuel are taken separately and grinded into fine powdery state
2. These powders are then taken and thoroughly mixed in a 65:35 ratio, this mixture is hand mixed to assure that they are evenly mixed.
3. At this stage when the mixing is done any additive that needs to be added is added to the mixture.
4. WD-40 is added to the entire equipment to ensure that this mixture doesn't end up sticking to the equipment while casting.
5. The mixture is then taken to pan which is kept on an induction with the temperature being at the lowest. This is done to avoid caramelization.
6. Constant stirring is done to the mixture to ensure that while it gets heated none of it gets sticked to the pan. After some time, the mixture starts to clump up, further it starts to become gooey and at last it becomes a highly viscous fluid.
7. The casting equipment i.e. the liner and the coring are prepared beforehand, The liner is placed over the coming onto which this liquid fuel is poured and this is then sealed, the setup is then left to set for 30 minutes.
8. After 30 minutes are done u remove the grain from the coring and let it harden for another 3-4 hours in an airtight container.

VI. **RESULTS AND DISCUSSION**

We test fired our rocket motor in Krishnagiri, Tamil Nadu.

It had a max thrust of 120N and an specific impulse of 90 s





In order to compare and analyse the effect that Al np brought to the new combination, the surfaces of the two propellants were characterized under an optical microscope. The two combinations were Potassium nitrate (KNO3) + Iron oxide (Fe2O3) and Potassium nitrate (KNO3) and Alumina nanoparticles. At 20x magnification, the samples looked like:

By observing the two surfaces in the above pictures, we can conclude the following:

- KNDX + Iron Oxide has a more irregular surface than KNDX + Alumina np.
- Though KNDX + Alumina np has bigger pores than KNDX + Iron Oxide, yet it has more stability due to its smoother surface.
- Having a smoother surface ensures more even burning, leading to a better efficiency.
- Thus, the grain with Al np is much more efficient.

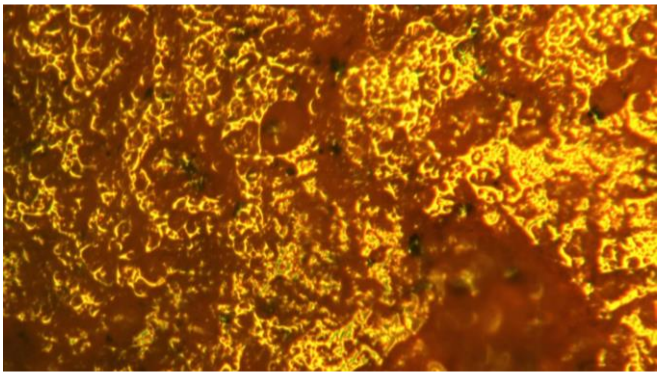


Figure 3 - KNDX+ Fe2O3

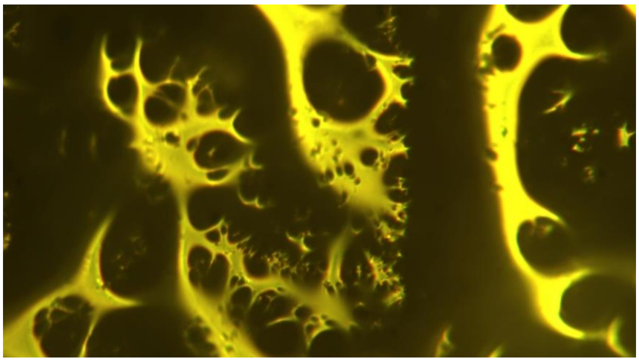


Figure 4 - KNDX + Alumina Nanoparticles

When a sugar based propellent is heated over a period of time it is observed that the propollent begins to caramalize this caramalization brings about a decrease in specifc impulse and also makes the grain softer.
When the powedered mixture of KNDX and alumina nanoparticles was heated at minimum temperature it had already begin to caramalize. The resulting grain from this compostion came out as too soft. When such soft Grains are used for testing in rocket motors under the excess pressure inside the casing they collapse and clumps up to the nozzle.

Since the nozzle is the only path from which the hot gasses can exit of, this causes all the hot gasses to be intrapped inside the casing and may lead to the explosion of the motor.
We believe that the reasoning for the soft grain and early caramalization is that the alumina nanoparticle hampers the binding of the fuel and oxidant, if a better binder is available there are chances that the composition might work and provide a better thrust.

VII. PROTOTYPE

A. Test Stand

A test stand is an integral part of the rocket motor test apparatus, it makes sures that the motor is held in place during its testing and couples the motor with the Load cell sensor. After much research we have opted for a Vertical Test stand design, The test stand consists of couple of U clamps to firmly hold the motor in its place and has a mechanism that allows us to encompass various sizes of rocket motor as well. The load cell is mounted on the bottom of the test stand onto which the motor is made to rested. To make sure that the motor doesn't get detached from the stand during its testing cinderblocks are placed.

B. **Website for Telemetery**

The first challenge was quite straightforward, selection of the most relevant libraries to be used for the code. We started with the SPIFFS library for the website upload to the flash memory of the controller only to find out it had delays in the power of 10-6 seconds. As such the LittleFS library was selected for the upload. To host a live website, the library ASyncWebServer was used which can update the url of the controller to request or upload data across the internet. The website was created using HTML (HyperText Markup Language) as the basic framework with CSS (Cascading Style Sheets) to give it the aesthetically pleasing GUI. Functionality to the website was added using Javascript which was linked to the AsyncWebServer requests to create the live graph.
During the first prototype test, we realised that due to wifi network speeds being limited, some dataloss was inevitable. We remedied it with the use of a SD card connected to the microcontroller to save the redacted values.

C. **Grain Geometry**

The propellant can be cast into different shapes. These shapes are known as Grain Geometry and they affect the burn rate of the fuel and eventually, its efficiency.

The standard grain geometry used is Cylindrical, which is also known as BATES (Burning Area Throats Erosion). A cylindrical grain ensures uniform burn rate and produces a neutral thrust curve.
Other grain geometries include star-shaped, which burns from all ends, giving high thrust in the beginning and then tapers off. It produces a progressive thrust curve. A cored grain is a hollow shaped grain, whose burn rate cn be controlled as desired.

VIII. Conclusion

Summary –

The rocket motor design we built, successfully worked along with the testing apparatus. To conclude we think alumina nanoparticles can act as a better solid rocket fuel additive if there is a better binder which we will develop in our next iteration.

Personal Reflections –

A. **Akshat Gupta**

Completing a coding project is always a mix of relief, pride, and a bit of nostalgia. As I reflect on the journey, several key thoughts and lessons stand out.

First and foremost, the project was a significant learning experience. I started with a clear goal but quickly realized the complexities involved in reaching it. Every roadblock became an opportunity to learn and grow. Debugging, which often felt frustrating, turned into a powerful teacher. Each bug fixed was a small victory, reinforcing the importance of patience and persistence.

Collaboration played a crucial role in the project's success. Working with my team taught me the value of diverse perspectives and skills. As the project was distributed over multiple industries, working with my team which comprised of students from multiple branches bringing their specialties into the mix simplified the tasks we needed to do. This made completing the project on time possible as we focused on what was needed of us.

B. Atharva Srivastava

Personally as someone who has never much thought deep into what goes into making a rocket or perhaps even a motor, This project was a really good way for me to learn new concepts and widen my horizons. From learning how a motor functions to how every individual part is designed and manufactured helped me understand greatly the working of the rocket motor. Characterizing surfaces of a fuel grain was really an amazing experience for me as i got to know how it looks at the micro level, Making a fuel grain from scratch, manufacturing a self made liner, making a test stand and much more are many of the things i will take back from being part of this project.
Manufacturing Alumina nanoparticle is part of the curriculum of the mechanical cluster, this project helped me gain practicality of what is being thought by allowing me to extract alumina nanoparticles from solution-combustion method to test in our fuel grains. Working with a team of various other branches helped the team to further branch out our research even though each one of us had our own parts to play we still were able to understand the other members part helping us to accumulate the required knowledge in a greater rate.
I'm very satisfied and proud of what we as a team have done for the past few months resulting to the success of this project, I hope for more inter-branch project opportunities like this so that all the branches can expand their horizons and experience new ideas and concepts like i have.

C. N Sivakhami

Initially, the topic we chose seemed hard to execute, but after planning it out and actually starting to work on it, it seemed more doable. Though it became hard at times, due to a helpful team, I was able to overcome them and contribute to the project. I was reminded the joy of working as a team, where each of us learned different skills and techniques from each other. Since, we manufactured most of the required parts/chemicals, there was a lot of that I learnt as well. Overall, I had a lot of fun working in this project.

D. **Aarush Jaiswal**

This project was one of the most challenging undertakings I have ever taken as designing a solid rocket engine from scratch that too with a new propellant formulation comes with a lot of risks but we managed to navigate through that while producing fruitful results and successful tests that too under high pressure. I am glad to have worked on this and will go on to publish this as a study.