IITK Rocketry and Space Exploration Team

Proposal and Technical Report

April 2023

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Why “Rocketry and Space Exploration Team"?

1.1. Mission

Our mission to build a team of students from various academic fields who are driven to collaborate on projects aimed at the frontier of space exploration. We wish to develop a platform that bridges the gap between theory and practice.

1.2. Vision

To become India’s first student team which explores several multi-disciplinary areas related to space technology, be it model rockets, satellites, rovers, instrumentation etc. and pave the way for future students to build upon the initial progress and achieve greater and tougher feats.

We see ourselves as a **competitive research team**, which works on student-researched projects and at the same time tests the robustness of its work via competing with some of the best college students working in similar areas in different parts of the world. We also aim to devise novel methods to approach our problem statements while building upon the existing literature and contributing positively to the scientific community.

1.3. Introduction

Space exploration is a domain that fascinates a large number of people. This field is already witnessing significant advances in the present time, and there is much to come in the near future. The team consists of members who came together with a similar concern of not having the opportunity to work in this fascinating field at IITK. We felt that it was necessary for IITK to have a team that dedicatedly works in the area of Space Technology, a team that lays the foundation for IITKs leap into this domain.

Every big aim starts off with fulfilling smaller targets along the way. We thought that building a model rocket can be a great first project for the team, after all, payloads like satellites, rovers or spacecraft cannot reach their desired destination without escaping the earth’s gravitational field.

We plan to begin building small rockets, test out several permutations and combinations, learn from experiments, mistakes and take constant guidance from individuals highly experienced in this area. A long-term vision would be to eventually build a rocket capable of reaching the Kármán Line, a feat which has already been achieved by USCRPL, a student-research group from the University of Southern California working on experimental rocketry.

We have set **Spaceport America Cup**, an International Rocketry Challenge, in which university teams from all parts of the world, like MIT, Cornell, UCLA, etc. take part, as our initial target. This will help us begin with our initial rocket models and eventually help us gain experience and make connections at an international level. We hope to learn a lot from students who already have successful teams established in their institutions. Such activities will help increase our confidence to work on more prominent projects in the coming time. As the team matures in the manufacturing and development of model rockets, we intend to lay the groundwork for several other inter-related necessities of a Student Space Program, like cube-sat projects and rover projects (via competitions like the University Rover Challenge).

We look forward to progress ahead in our mission, having discussions and constantly updating ourselves with events going on around the world. From the perspective of students, SnT Council teams have always been the first choice to explore a particular domain, be it Autonomous Robotics or UAVs. We wish to give a similar opportunity to the future batches of IITK, to pass on this culture and knowledge and provide them with a platform to achieve goals in this particular domain of interest as well.

1.4. Importance of the Team

These are the times that we are seeing a strong revival of the space-tech community, amidst the second commercial "space race" among the big organisations, we also see several small players coming into the domain. The awareness in the student community is definitely propelled by the future prospects of the space industry.

We observe students team/clubs popping up at many different colleges around the world, and each one of them getting more and more experimental. India, is no different in this matter. Though legally at this point of time, the laws are not very well codified, the space sector still promises a tremendous opportunity to skilled people in the field.

The **Indian National Space Promotion and Authorization Centre (INSPACe)** has been setup by the Indian Government to act as a medium between ISRO and the private space sector in India. In the future, we can try to pitch our problems and requirements to IN-SPACe as a student group, asking for their support.

Several colleges in India already have their collegiate teams working on model rockets, rovers, satellites etc.:

1. IIT Bombay Rocket Team
2. Team Abhyuday, IIT Madras
3. ThrustMIT, Manipal University
4. SEDS BPHC, BITS Pilani
5. PEC Aerospace: Punjab Engineering College
6. IIT Bombay Student Satellite Program
7. IITB Mars Rover Team
8. Team Anveshak, IIT Madras
9. Team Anant, BITS Pilani

In the light of the emergence of so many student endeavours, it seems only appropriate that IIT Kanpur, try and make a conducive effort in the field of rocketry and other related areas. This can be enabled, and is far more favourable now than it ever has been, as we perceive a growing student base likely to participate in such an establishment if achieved. Also, the entrepreneurial sentiments have been on the rise within our generation, which are very supportive of such an ambitious field.

> We believe in IITK's inquisitive and entrepreneurial environment, and strongly hope that we will receive substantial support for our endeavours from the faculty at IITK and the Administration alike.

1.5. Team Structure

The team aims to function as a **Competitive Research Team**, under the guidance of a Professor or a group of Professors who are quite experienced in their respective domains of interest. Rocketry in itself is a multidisciplinary area, we therefore look forward to get guidance from professors who are willing to support this endeavour. We also propose to become a student team registered with the Science and Technology Council of IITK.

Currently, three professors have agreed to be our Faculty Advisors:

1. Prof. Abhijit Kushari, Department of Aerospace Engineering
2. Prof. Ashoke De, Department of Aerospace Engineering
3. Prof. Srinivas Dharavath, Department of Chemistry

We aim to structure the team via different subsystems such as:

1. Propulsion
2. Aerodynamics and Structures
3. Avionics and Recovery
4. Payload
5. Software
6. Business

1.6. Student Recruitment

We, as a group are looking forward to recruit students from the IITK student community irrespective of their year of study, based on their interest, creativity and willingness to learn and work hard.
Every member in the team is supposed to have a say in majority of the decisions. Though, Team Heads will be responsible for an efficient planning and management of the team.
The recruitment process shall work in an application-interview fashion. The applications will be open to **all students of IIT Kanpur**, the UG and the PG. We would encourage the participation of students based on their genuine interest, regardless of their background or subject of study at the campus.

Currently, we are a group of 3 Y20 UG students and 2 Y21 UG students. We aim to recruit around 25-30 Y22 UG students and divide them into different subsystems. We also have 4 Y21 UG students joining us to take the progress ahead with the current members.

1.7. Workspace

The team does not have a dedicated workspace as of now. However, we are in an active search of a place where we can safely work on our model rocket project, which will help us assemble and safely keep the components, and use it as a meeting and discussion spot.

The team would be highly grateful to the Professors who support our initiative by allowing us to develop our custom parts/components in their well-equipped laboratories.

We aim to develop our propulsion system from scratch. Though, the initial project would utilise only sugar-based propellants which are comparatively safer to work with. But with time, we would need a bigger space where we can take all the necessary precautions to store the chemicals, and work on them in a safe and controlled environment, while taking all the precautionary measures and using proper safety equipment.

1.8. Future Competitions

- **Spaceport America Cup** is an international rocket engineering competition organised by ESRA (Experimental Sounding Rocket Assosiation). Spaceport America Cup is the flagship event of IREC (Intercollegiate Rocket Engineering Competitions) and has had Indian University teams participating in the past few years.
- **Latin America Space Challenge** is another international rocketry competition based in Brazil. We had registered for the 2023 edition of the competition but could not go ahead due to funding issues. We will try to target the next edition of this competition.
- Teams like **IITB Rocket Team**, **Team Abhyuday** of IITM, **ThrustMIT** of Manipal Institute of Technology, and several others are planning to take part in the competition. We hope that we will be able to develop our expertise in this area soon and target a later edition of the competition.

2 Roadmap

2.1. Development Map

As a team, it is important for us to have a set of well defined goals to achieve. In the previous sections, we discussed our long term-goals. Here, we list our short-term goals on which we will work in the immediate future:

1. Approach interested professors who would be willing to provide us their valuable guidance
2. Design, build and test a solid propellant rocket motor on our own
3. Exhibit the motor to the campus community and recruit interested people to work on the team
4. Approach the SnT council for the official recognition of our team on the basis of our theoretical research and practical work
5. Build and test other parts of the rocket in our workspace such as:
   - Body tube
   - Fins and nosecone
   - Avionics bay with the electrical components housed in it
   - Recovery system
6. Successfully launch a model rocket using our own propulsion system and collect the necessary data for improving future launches.
7. Utilise the knowledge and experience to build a rocket capable of competing in international competitions such as the Spaceport America Cup.
8. Create an archive to maintain the records of designs,experiments, obtained data, student research projects and any other relevant information.
9. To make sure that the knowledge gained is passed on to successive batches.

2.2. Future prospects

Keeping the long-term objectives in mind, we list down all the possible projects we can pursue in the future. Needless to say, we shall remain open to any new ideas we get.

1. Staging in series
2. Staging in parallel
3. Flight control using Gyroscopes
4. Liquid-Propellant Rocket Engine
5. Hybrid Rocket Engine
6. Thrust Vector Control
7. A rocket capable to cross the Kármán Line and enter space
8. Design a Cube-Sat which can be launched into the space
9. A mini-payload to be landed on Earth using cushion-landers

3

Propulsion System — Technical Report

3.1. Why propulsion?

The propulsion system is one of the basic necessities for an object needing to change its motion w.r.t. an inertial reference frame. A rocket requires some mechanism to push it against gravity while also overcoming the viscous drag caused due to the atmosphere. This is where its propulsion system plays a key role. It utilises the chemical energy of a propellant to release exhaust gases out of the rocket at very high speeds. Thus, an opposite force acts on the rocket as given by Newton's third law. Hence, to build a rocket, the first step is to build a reliable propulsion system.

Many competitions require off-the-shelf motors. However, there are many student rocketry teams around the world who develop their own solid and liquid based propulsion system. We intend to do the same so that we can develop novel methods to approach rocket motor design and development.

3.2. Safety considerations

Developing a solid rocket motor is not unsafe if proper precautionary measures are taken. Knowledge and awareness of hazards and dangers involved must be ensured prior to starting every step in the development process. Hence, precautions and hazards of specific chemicals thatd be used are also necessary. These are covered as follows:

1. **Potassium Nitrate**

    - **Hazards**
      Contact can cause eye and skin irritation
      Potassium Nitrate can affect one when breathed in
      Breathing Potassium Nitrate can irritate the nose and throat causing sneezing and coughing
      High levels can interfere with the ability of the blood to carry Oxygen causing headache, fatigue, dizziness, and a blue colour to the skin and lips (methemoglobinemia).
      Higher levels can cause trouble breathing, collapse and even death.
    - **Clothing**
      Skin contact must be avoided.
      Protective gloves and clothing must be worn. These must be cleaned, and available each day to be put on before work.
    - **Eye protection**
      Goggles or face-shields must be worn for eye protection.
      A face shield along with safety-glasses may be worn while working with other similar corrosive, irritating and toxic substances.
    - **General precautions**
      Wherever possible, local exhaust ventilation should be used at the site of chemical release. If local exhaust ventilation or enclosure is not used, respirators must be worn.
      In case of exposure to Potassium Nitrate, water should be used for immediate washing and one should be checked by a medical practitioner.

- **Fire hazards**
  Potassium Nitrate is noncombustible. However, being a strong oxidizer,it will accelerate burning when involved in a fire.
  For putting out fire, only water should be used. Dry Chemicals, Carbon Dioxide or Halogenated extinguishing agents must be avoided.
  It should be noted that poisonous gases would be produced in fire, including Nitrogen-Oxides.
- **First aid**
  Eye Contact: Should be immediately flushed with large amounts of water for at least 15 minutes, occasionally lifting upper and lower lids.
  Skin Contact: Contaminated clothing should be removed and skin should be washed with excess water.
  Breathing Exposure: Person should be removed from exposure and given rescue breath (if needed) using universal precautions.
  In all cases, the exposed person should be transferred to health-care facility at the earliest.
- **Spills and Emergencies**
  If Potassium Nitrate is spilled, following steps should be taken:
  - Evacuate persons not wearing protective equipment from the area of spillage until clean-up is complete.
  - Collect powdered material in the most convenient and safe manner and deposit in a sealed containers.
  - Ventilate and wash the area after clean-up is complete.
  - It may be necessary to contain and dispose of Potassium Nitrate as a Hazardous waste.

2. **Sorbitol**

- **Hazards**
  Specific Hazards Arising from the Chemical Thermal decomposition can lead to release of irritating gases and vapours. The chemical and its containers should be kept away from heat and sources of ignition.
- **Fire precaution**
  Suitable Extinguishing Media: Water spray, carbon dioxide (CO2), dry chemical, alcohol-resistant foam.
- **First aid**
  Eye Contact: Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes.
  Skin Contact: Rinse the skin with water.
  Inhalation: Move to fresh air.

3.3. Material and Equipment Required

1. Potassium Nitrate (Oxidiser)
2. Sorbitol (Fuel)
3. Liquid Laundry detergent (Surfactant)
4. Powdered Al, KNO_3 and Plasticised ethyl cellulose (Ignition Primer)
5. Epoxy spray (Inhibitor)
6. Black-Powder and Nichrome wire (Ignition fuel)
7. Iron Oxide Burn Rate enhancer
8. Opacifier
9. Skillet pan and Stove for cooking.
10. Digital weight scale
11. Motor and Container for continuous mixing
12. Open funnel and spatula
13. Casting tubes
14. Coring tool
15. Solid and hollow plungers
16. Digital thermometer with probe sensor

3.4. Procedure

The procedure for making the propellant grain is as follows:

1. **Mixing**

    i. Powdered sorbitol is passed through a flour sifter. Potassium Nitrate is grinded or milled to a fine texture.
    ii. Sorbitol is then placed in a shallow pan and put in a dessicator (tupperware container lined with a few centimetres of fresh calcium chloride) for several days.
    iii. The two constituents are carefully weighed, extra 20-25% of the material should be taken than desired as some is wasted during the casting process.
    iv. The mixture is put in a tumbler and mixed continuously making the composition consistent throughout. 30 rpm is suitable.

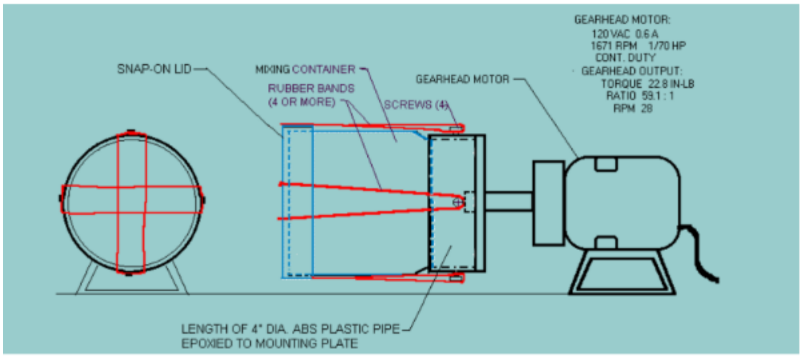

Figure 3.1: Tumbler rotated by a motor (reference: Richard Nakka rocketry site)

NOTE: Special care must be taken after Mixing, as the mixture becomes explosive at this stage. It should be kept away from any possible source of ignition. (Electric spark, fire, heat, friction etc.)

2. **Cooking and Casting**

    Heating the mixture is done using a thermostatically controlled electric deep fryer/skillet. Only a thermostatically controlled heating vessel with no exposed elements should be used for heating the propellant. The intent here being, no exposed heating surface should have temperature significantly higher than the melting point of the propellant.
    The mixture must be heated to just above the melting point of Sorbitol - about 95 řC for casting.
    To monitor the temperature of the heated slurry, a dial-type candy thermometer, a digital thermometer equipped with a probe sensor, or an infrared thermometer may be used.

    i. The skillet is first preheated to the required temperature and is maintained in this state.
    ii. About half of the propellant mixture is added and continuously stirred to assist melting. Once this melts, the remaining powdered mixture is added.
    iii. The melted slurry is initially colourless but begins to turn white as the mixture fully melts. Purer the oxidizer (Potassium Nitrate), purer the white colour obtained on melting.
    iv. After all the powdered mixture has been fully incorporated into the melt, an additional five to ten minutes of heating brings the slurry up to the casting temperature.
    v. Sodium Laureth Sulphate (SLS) may be simply added to the fully molten propellant and stirred. The viscosity of the slurry immediately decreases upon addition of only 0.1% surfactant mass relative to mixture mass.
    vi. For making casting tubes we plan to use 3 or 4 layers of papers or a poster board roll with a coating of oil-based (not water-based) polyurethane varnish (to make it more heat resistant) which will be allowed to fully dry.
    vii. The slurry is poured into the casting tube using a spatula. The mould is repeatedly tapped against a hard surface to remove any bubbles. The coring tube is then inserted.
    viii. For BATES configuration the outer surface acts as an inhibitor. The casting tube intimately bonds to the propellant and becomes a permanent part of the grain.

ix. The propellant is left to cure for a few days before demoulding. Full curing may take a week, however it is perfectly acceptable to fire the grain anytime before the demoulding.

3. **Curing under pressure**
   Curing under pressure is achieved by the use of a mould casting apparatus that utilises a compression spring to apply a force to the top surface of the propellant. This force generates a hydrostatic pressure in the propellant, pressing it against its enclosures, consisting of a top cap, a bottom cap and the casting tube.
   Initially, when the propellant is still hot, only light spring pressure is applied to squeeze out any trapped air. After the propellant has cooled, full spring pressure is applied and left until the propellant has fully cured.

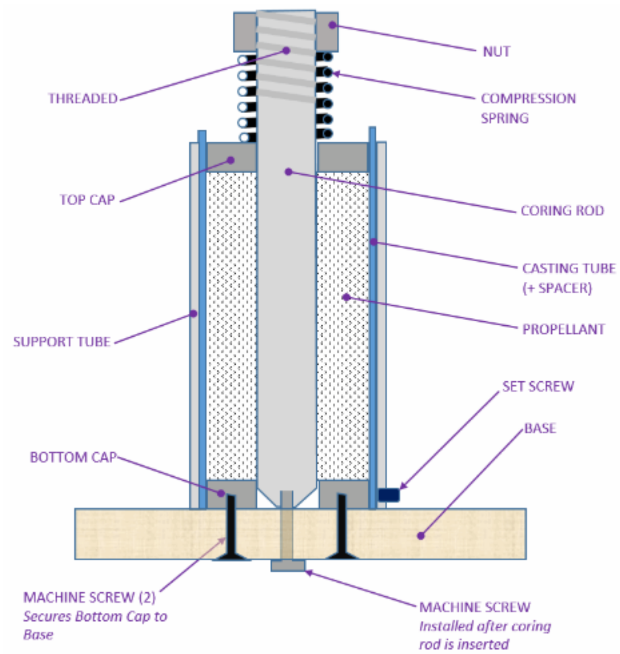

Figure 3.2: Apparatus for curing under pressure(reference: Richard Nakka rocketry site)

3.5. Motor design

We take in account the following parameters while designing our motor:

1. **Grain configuration**
   The grain configuration directly affects the motor performance. The amount of propellant being burned, the rate at which it is being burned depends on the burning surface area of the grain. We will be using a **BATES** grain configuration for our motor as it gives a neutral thrust curve, steady chamber pressure and is easy to manufacture.
2. **Steady State chamber pressure**
   When the amount of gases being produced by propellant combustion and being ejected out of the nozzle are equal, the chamber is said to be in steady state.
   If we have insufficient chamber pressure, then our grains may not burn properly and our rocket will not take off. If there is high chamber pressure then there is a risk of CATO (catastrophe at take off).
   The chamber pressure at steady state is given by:

$$P_0 = [(K_n a\rho)/\alpha]^{1/(1-n)}$$

where,

P_0 is the chamber pressure

K_n is the ratio of burning surface area to nozzle throat cross section area

a is the burn rate coefficient

α is a conversion factor

ρ is the propellant mass density

c is the characteristic exhaust velocity

n is the burn rate pressure exponent

3. **Characteristic exhaust velocity**
   The characteristic exhaust velocity is calculated as follows:

$$c = \sqrt{(RT_0/Mk)[(k+1)/2]^{(k+1)/(k-1)}}$$

where,

c is the characteristic exhaust velocity

R is the universal gas constant

T_0 is the chamber temperature

M effective molecular weight of the products

k is the ratio of specific heats

4. **Kn determination**
   It is the ratio of burning surface area of the grains to the cross section area of the nozzle throat. usually a minimum value of 220 is preferred for initial Kn. For very energetic fuel it can be kept around 180-200 and for low energy fuels, it can be kept around 240.
   Kn is important as it directly affects the chamber pressure which will in turn affect the burn rate.

3.6. Motor dimensions

We used a simulator **Openmotor** to simulate and find out the dimension of the grain and the nozzle needed for our motor and we came up with the following dimensions:

1. **Grain dimensions:**
   - 1.5 inch outer diameter (38.1mm)
   - 1 inch core diameter (25.4mm)
   - 2.25 inch length (57.15mm)
   - 5 grains in series (Total length 315.75mm)
2. **Nozzle dimensions:**
   - 0.7 inch throat diameter
   - 30 degrees converging angle
   - 15 degrees diverging angle
   - 1.5 inch exit diameter

Following were the results of our simulation:

3.7. Material Selection

The motor casing in a rocket serves two purposes: Enclosing the propellant grain and Acting as a pressure vessel. Its dimensions may be determined by simple stress analysis on a cylindrical vessel.

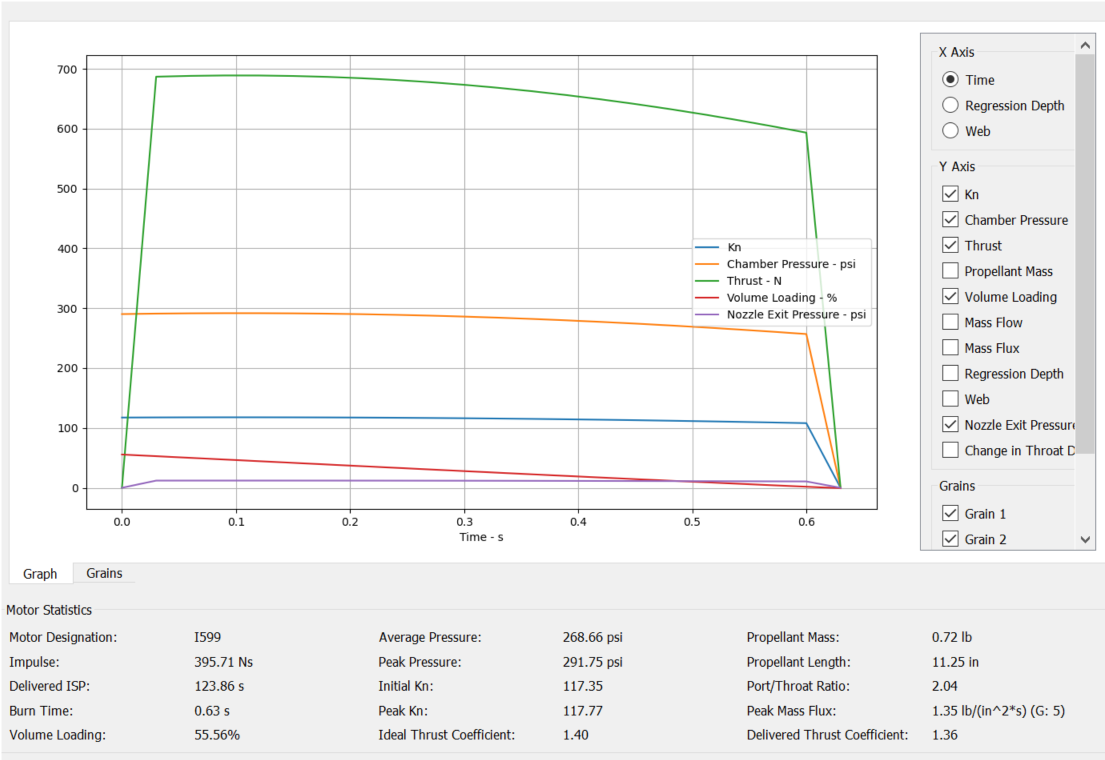

Figure 3.3: Simulation results from openmotor

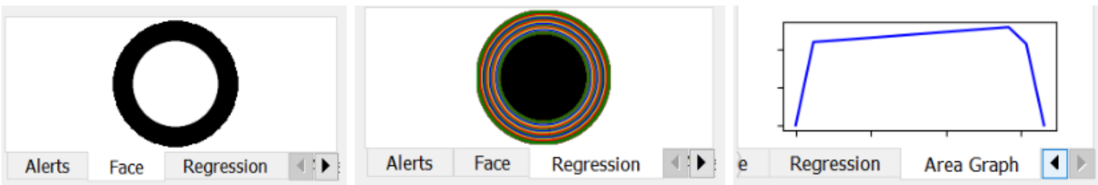

Figure 3.4: Propellant grains

3.7.1. Stress Analysis

Assuming that the vessel is thin, (wall thickness < 10% of Diameter.) simple analysis shows that Longitudinal (σ_l) and the hoop-stress (σ_θ) are given by:

$\sigma_l = \frac{Pr}{2t}$ $\qquad$ $\sigma_\theta = \frac{Pr}{t}$

Here, P is the internal pressure of the vessel, r is its internal radius and t is the wall-thickness.

Since both these stresses are perpendicular in direction, they respective determine the working condition of the vessel. The total stress must be less than the working stress of the material used for constructing the motor casing. Some additional complications are present near the ends. The ends of cylindrical casing may be spherical or ellipsoid, these configurations will be further analysed but for simplicity, a circular end is taken.

The extreme conditions within the motor chamber require suitable material to withstand high pressure and temperature conditions. For withstanding pressure, we analysed different materials using basic stress analysis. For withstanding high temperatures, we can insulate the inner wall of the chamber with suitable materials to increase thermal resistance.

Mild Steel

This is an easy to machine ferrous material made from iron and carbon. Is also low-priced and suitable for most engineering applications.

- Density = $7.85 \frac{g}{cm^3}$
- Yield Strength = $250 MPa$

For this material, the minimum thickness of the wall as required for chamber pressure of 50 Barr and internal radius 38mm is 0.85mm 1mm.
For a 15cm long vessel, this would mean a steel quantity of $36.5cm^3$ or roughly 290gm of motor casing weight.

Aluminium
Aluminium 6061 is one of the most common aluminium alloys for machining in the 6xxx series. It is also one of the most versatile of all machinable alloys making it a top choice in CNC machining.

- Density = $2.7\frac{g}{cm^3}$
- Yield Strength = 241MPa

For aluminium, minimum thickness of the wall as required for chamber pressure of 50 Barr and internal radius of 38mm is again around 0.88mm 1mm.
For a 15cm long vessel, this would require an aluminium quantity of $36.3cm^3$ $36.5cm^3$.Hence, the mass of the motor casing is about 100 gm.
Further complications may arise while machining these thin metal cylinders.

3.8. Motor Performance Evaluation

The effectiveness of a motor also depends on how well it performs compared to our expected results obtained from simulations. Hence, after making a solid propellant rocket motor, its performance must be analysed before any actual blast-off. We shall evaluate our motor on the basis of the following two parameters:

i. **Thrust:** We will use load cells for measuring thrust generated by the motor and digitally acquire the readings through an electrical circuit involving Arduino.
ii. **Pressure:** We will use a pressure transducer to digitally record the pressure in the combustion chamber.

We will use the following integrated setup for measuring both thrust and chamber pressure simultaneously:

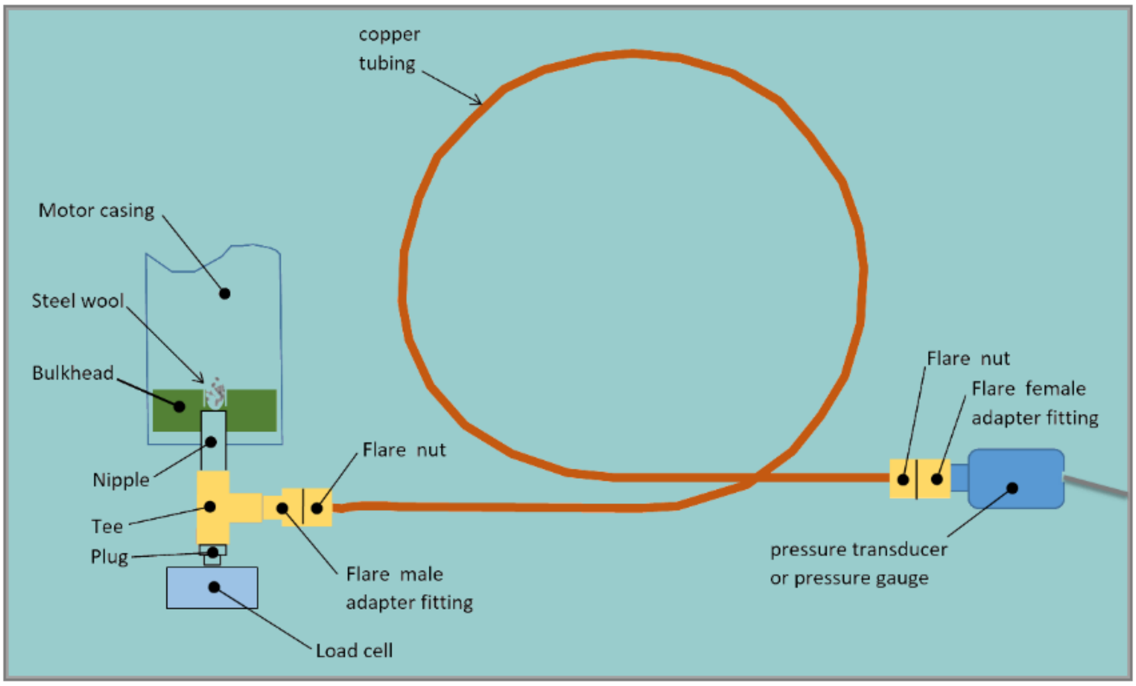

Figure 3.5: Apparatus for measuring thrust and pressure (Reference: Richard Nakka Rocketry)

After taking the readings, we can calculate the following values:

1. **Characteristic Velocity:**

$$c = \frac{A_t \Delta t}{m_p} \sum_{i=1}^{n} P_i$$

where,

c is the characteristic exhaust velocity

A_t is the throat area of nozzle

Δt is the time interval

m_p is the mass of the propellant

P_i is the discrete pressure value

n is the number of readings in the given time interval

2. **Thrust coefficient:** $C_f =, \frac{F}{A_t P_0}$ where,

C_f is the coefficient of thrust

F is the thrust produced

A_t is the throat area

P_0 is the chamber pressure

3.9. Motor components and Assembly

After producing our propellant grains successfully, our next step would be to build the components of the rocket motor in which we would be housing the propellant grains with the nozzle. This final motor will be placed inside the body tube of the rocket and attached via screw-nut mechanism.
Following are the list of components of the rocket motor:

1. **Propellant grain**

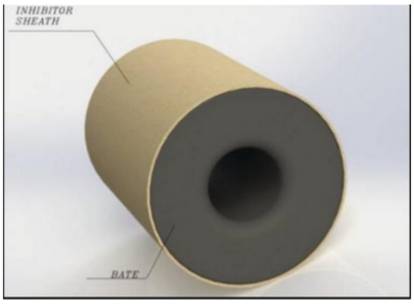

Figure 3.6: Reference: IntechOpen

2. **Liner tube**

Figure 3.7: Reference: rocketmotorparts.com

3. **Motor Case**

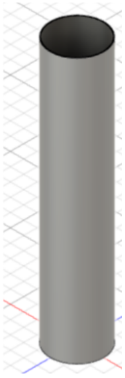

Figure 3.8: Software: Fusion 360

4. **Forward retainer**

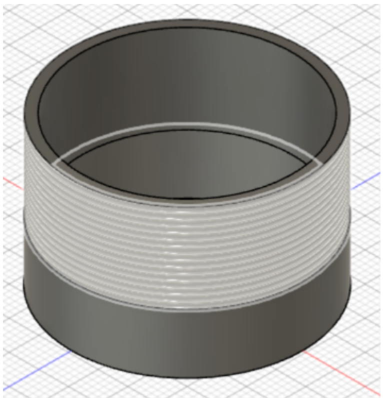

Figure 3.9: Software: Fusion 360

5. **Rear retainer**

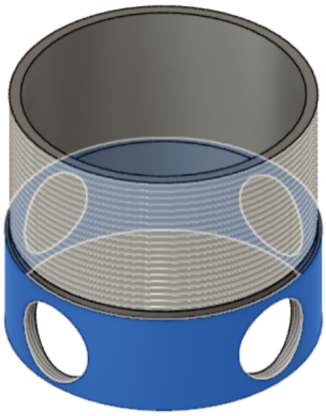

Figure 3.10: Software: Fusion 360

6. **Forward closure with groove for O-ring**

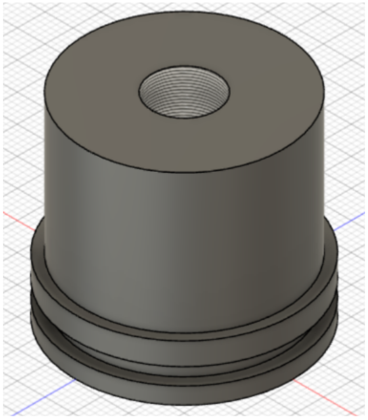

Figure 3.11: Software: Fusion 360

7. **Conical nozzle with groove for O-ring**

Figure 3.12: Software: Fusion 360

8. **Aeropack/bulkhead**

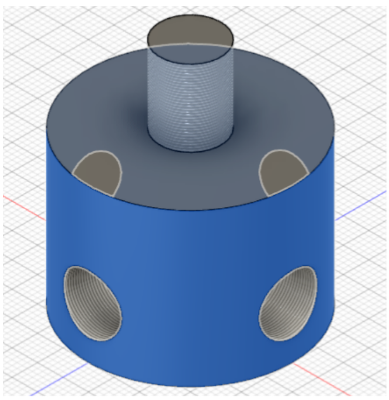

Figure 3.13: Software: Fusion 360

Following is the assembly procedure of the motor:

1. You insert the grains into the liner tube after painting their inhibiting surfaces (outer surface in this case) with epoxy paint.You insert the grains into the liner tube after painting their inhibiting surfaces (outer surface in this case) with epoxy paint.

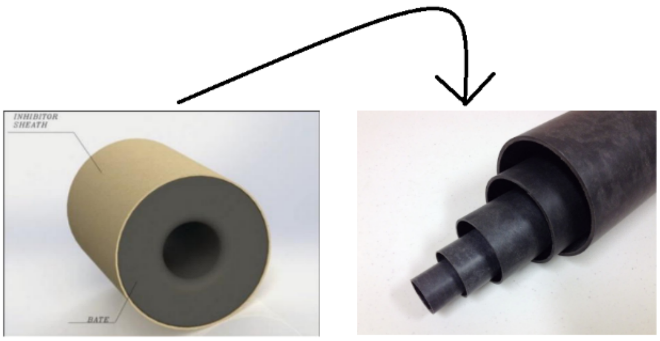

Figure 3.14

2. Apply lubricant on the outer surface of the liner and insert it into the motor case.Apply lubricant on the outer surface of the liner and insert it into the motor case.

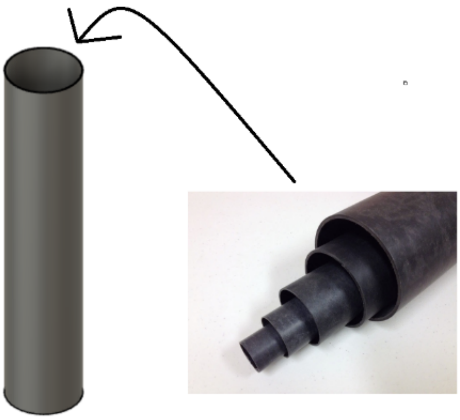

Figure 3.15

3. Insert forward closure on the top part of the motor case.Insert forward closure on the top part of the motor case.

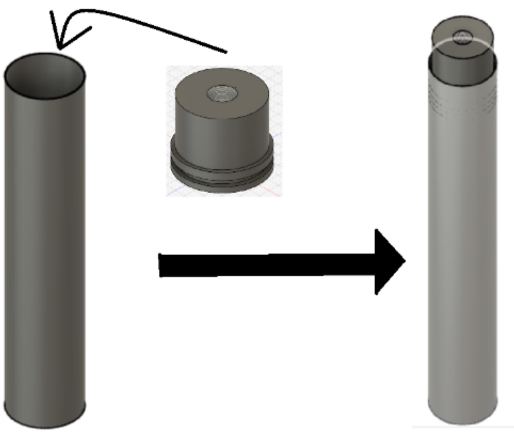

Figure 3.16: Software: Fusion 360

4. Thread in the forward retaining ring on top of the forward closure.Thread in the forward retaining ring on top of the forward closure.

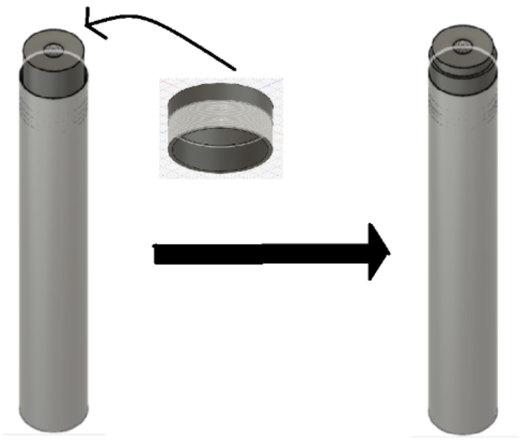

Figure 3.17: Software: Fusion 360

5. Screw in the aeropack/bulkhead on the top of the forward retaining ring.Screw in the aeropack/bulkhead on the top of the forward retaining ring.

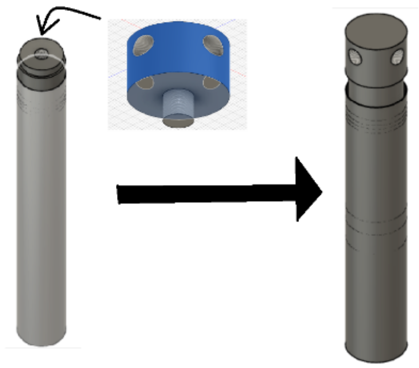

Figure 3.18: Software: Fusion 360

6. Insert the conical nozzle on the bottom of the case.Insert the conical nozzle on the bottom of the case.

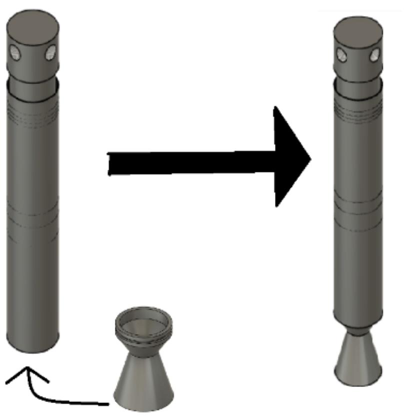

Figure 3.19: Software: Fusion 360

7. Thread in the rear retaining ring through the nozzle into the bottom of the case.Thread in the rear retaining ring through the nozzle into the bottom of the case.

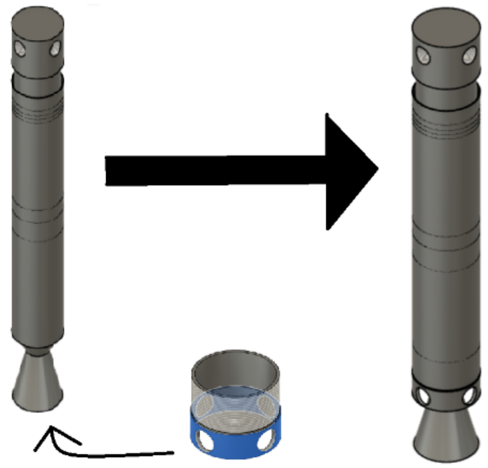

Figure 3.20: Software: Fusion 360

8. You have your motor ready! Put the airframe on the top of the motor and tighten screws through it on the bulkhead and the rear retaining ring.You have your motor ready! Put the airframe on the top of the motor and tighten screws through it on the bulkhead and the rear retaining ring.

3.10. Extra considerations

The following miscellaneous considerations will help us in our procedure:

1. **Surfactant:** We will use it when we pour our heated slurry into the casting moulds. Mix 0.1-0.3% by mass of the surfactant into the mixture. This greatly reduces the viscosity and eases in uniformly pouring and mixing the slurry.
2. **Ignition Primer:** KNSB does not easily ignite. It may not have high enough initial chamber pressure for ignition. As a result when our ignitor goes off in one region of the motor, only that region starts burning and all the surfaces do not which results in non uniform burning of our surfaces. This ends up affecting our desired neutral thrust curve. To tackle this issue, we paint all the burning surfaces with ignition primer, so that all the surfaces burn simultaneously and uniformly. This also helps in achieving the desired initial chamber pressure for ignition.

4

General Workspace Requirements

4.1. General Requirements

The workspace should be designed in such a manner, that everything be organised and easily accessible. The workspace will be divided in two major portions, one where all the paperwork and the software work will take place, and one where all the hardware processes will happen. This will be done to prevent damage to any delicate machinery or accidental destruction of documents. We will keep our storage area for the raw materials in the hardware zone and all the documents, archives, stationary in the software zone. We would also be needing a separate small space for conducting team meetings and discussions.
We would also need to have all the safety measures in suitable areas. These would include fire extinguishers, sand buckets, emergency exits near the hardware zone and the software zone, locked door system etc.

4.2. Storage

Safe storage is highly necessary for hazardous chemicals which will be used for the rocket propellant. We would need to store these chemicals in a separate corner where temperature remains low all the time. All students will be made aware of the hazards associated with these chemicals to ensure their safety. Further, the metal-components of our model rocket will also have to be stored safely in a moisture free environment to prevent oxidation etc.
For smaller projects, the storage and workspace may be at different locations because smaller components can be easily transported.

4.3. Machining Requirements

While smaller components may be manufactured and stored and different locations, the team will require a dedicated workspace where the materials may be readily machined and stored, in the future.
Most of the motors components, being cylindrical symmetrical, would be made on the lathing and drilling machines. These are readily available in TA202 Labs.
For complicated structures (like nose-cone etc) 3D printing (additive manufacturing) will be most suitable.

4.4. Metal Requirements

Machinable Metals are required for making motor body and other rocket parts. Aluminium and Mild Steel appear most suitable for the rocket body. The nosecone, which will be 3D printed, can be made of any lightweight material for smaller projects. For bigger projects, more thought will have to be given to thermal resistance of the material. Furthermore, for are primitive ignition system, a Nichrome wire will also be used.

4.5. Chemical Requirements

For making solid propellant, we require the chemicals mentioned in chapter 3. Furthermore, we require insulation between propellant grain and inner wall of ignition chamber. We may inhibit the outer surface of the propellant to further decrease thermal stress on the the ignition chamber. Epoxy resin or Phenolic resin may be used for this insulation. Further, Black-Powder (used in primitive ignition system) will also require safe storage. Hazardous substances should always be stored in a cool and dry space. Away from all possible ignition sources - switches, sunlight etc.