University of Petroleum and Energy Studies
Dehradun, Uttarakhand

Experimental Sounding Rocket Project

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Design and Fabrication of Sounding Rocket

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ABSTRACT

Team Garud (Official Rocketry Division of UPES) is going to take part in International Intercollegiate Rocket Engineering Competition (IREC). It is the world's largest rocketry competition hosted by ESRA (Experimental Sounding Rocket Association), which is going to be held at Spaceport America. The main objective of the competition is to launch a Sounding Rocket to a fixed Apogee and to deploy a scientific payload at that altitude.

A Sounding Rocket is used for conducting scientific experiments during its sub-orbital flights. The sounding rocket has so far proved to be a productive tool in enlightening scientists in research of the earth's atmosphere and its other geological features. It has helped in obtaining useful information and measurements catering to needs of current space organizations in various countries around the world. The Team is building a Sounding Rocket according to the requirements of Basic category of the competition.

The primary aim of this project is to design and build a rocket capable of achieving an Apogee of 10,000ft. It will be carrying a functional payload with a minimum weight of 10 lbs. The material that is used for the fabrication of rocket body is carbon fiber. Simulations are carried out using the Open Rocket v15.03 software and the results are verified through manual calculations. Ground and flight-testing will be performed at the later stages.

A single stage solid fuel propulsion system is used in the rocket. The Rocket is using the parachute for the recovery system. The rocket has a height of 285 cm and external diameter of 15 cm.

Flight Control board is programmed on Arduino equipped with some basic sensors. A main as well as a redundant electronics system will be present for recovery of the rocket. Certain design experiments shall be carried out and a final inflight testing might include some innovative design elements.

The team will follow all the safety measures as per the guidelines of amateur rocketry during this project. Safety devices shall be used by the team wherever and whenever required.

Introduction

Sounding Rockets take their name from a nautical word “to sound” that means to take measurements. They are sometimes called as research rocket, which are instrument-carrying rockets designed to take measurements and perform scientific experiments during its sub-orbital flight. They are used to test and calibrate satellite and spacecraft instrumentation. They are particularly useful for research in the far ultraviolet, X-ray or gamma and infrared, as they travel above the atmosphere and eliminate the problem of atmospheric opacity in these wavebands. Sounding rockets can also be used to make geological and meteorological observations.

Team Garud is formed under the guidance of Dr. Ugur Guven in 2014 and mentored by Dr. Gurunadh Velidi. Team Garud, Official Rocketry Division of UPES, is designing a sounding rocket, which is going to take part in ESRA’s Intercollegiate Rocket Engineering Competition (IREC). It is the world’s largest rocketry competition, which is to be held in Spaceport America, New Mexico.

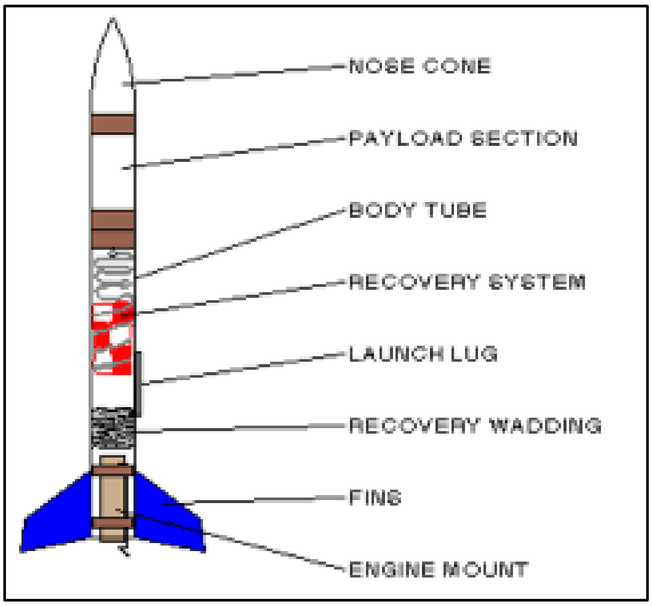
ESRA has been an organization for 13 years and has been hosting the IREC competition for the past 12 in Green River, Utah. The competition has two categories, advanced and basic. Each category must make a ten pound payload experiment and launch it to a predetermined height depending on the rocket category, 10,000 feet for basic and 25,000 feet for advanced. The rockets that are used in these competitions can be propelled in one of three different methods, solid, liquid, or hybrid fuel. The design teams are judged in a number of categories including, novelty of payload, accuracy of apogee and craftsmanship. Our team is going to compete in ‘Basic’ Category of this International competition with the renowned universities from around the globe. The objective of the ‘Basic Category’ is to send the rocket to 10,000 ft. AGL and recover it safely using an automated deployment system, along with the payload of the main competitions

Team Garud’s this year’s competition is named as ‘Kalam’ to pay tribute to missile man of India, Dr. A.P.J. Abdul Kalam. He was called as the ‘missile man’ as he was no less than a missile. His achievement and success carried India to a height in space research and development. The project is divided into various domains of engineering like Aerospace, Electronics, Mechanical and Computer Science.

Figure: Last year's Rocket Launch

The Team Garud consists of four separate sub-teams: Aero Structure, Recovery, Payload and Avionics. Each sub-team must operate cooperatively amongst the groups in order to achieve a successful design.

- Aero Structural Design- It is the main body of the Rocket.
- Payload- Which carries the instruments for experimentation and data collection.
- Avionics- Which carries the electronics required for the Rocket
- Recovery- It contains the recovery system of the Rocket, ex. Parachute system.
- Propulsion- It carries the Rocket motor which propels the Rocket.



- **Figure:** components of a rocket

Structural Design

The purpose of the structure team is to design an effective system to in-capture the internals during flight. The structure must secure these parts while at the same time allowing these components to operate as intended. Each group puts out specific restrictions, which must be taken into consideration. After a comprehensive study of various suitable materials, our team short listed three materials: Aluminum (6061 to 6065), Carbon fiber and Fiber glass in which Carbon fiber is found to be appropriate for the fabrication of the Rocket.

Carbon Fiber is light weight. It is corrosion resistant. Its specific strength is higher than that of aluminum. It has a high fatigue limit. Slightly stronger than fiber glass.

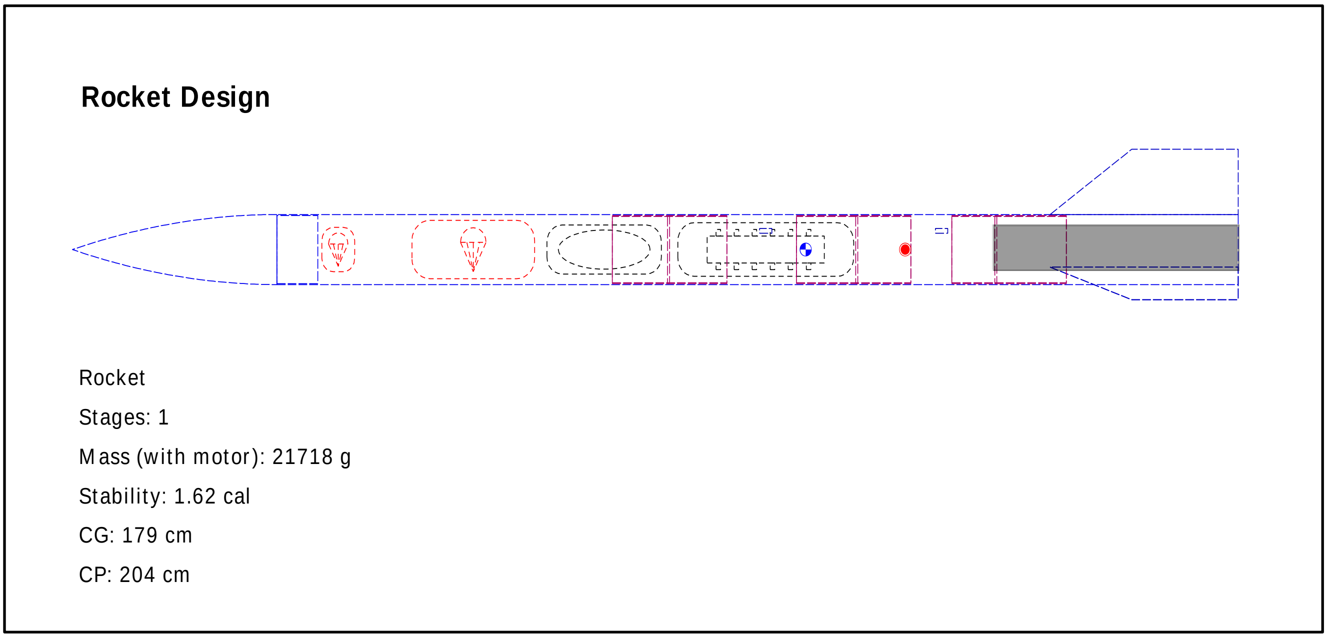


Figure: Rocket Design

M1845-P

Altitude	3260 m
Flight Time	122 s
Time to Apogee	24.7 s
Optimum Delay	20 s
Velocity off Pad	30.3 m/s
Max Velocity	315 m/s
Velocity at Deployment	79.2 m/s
Landing Velocity	7.58 m/s

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
M1845	1822 N	4.44 s	2434 N	8093 Ns	8.56:1	3772 g	98/597 mm

Figure: Design Constraints

Parts Detail

Sustainer

Nose cone	PLA (1.85 g/cm^3)	Parabolic series	Len: 50 cm	Mass: 1188 g
Body tube	Carbon fiber (1.78 g/cm^3)	Dia$_{in}$ 14.6 cm Dia$_{out}$ 15 cm	Len: 235 cm	Mass: 3890 g
payload		Dia$_{out}$ 10.5 cm		Mass: 5500 g
drogue chute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 30 cm	Len: 8 cm	Mass: 7.98 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 30 cm	
main chute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 300 cm	Len: 30 cm	Mass: 477 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 30 cm	
avionics bay		Dia$_{out}$ 11.5 cm		Mass: 2000 g
Trapezoidal fin set (3)	Cardboard (0.68 g/cm^3)	Thick: 0.3 cm		Mass: 308 g
Engine block	Aluminum (2.7 g/cm^3)	Dia$_{in}$ 14.6 cm Dia$_{out}$ 14.6 cm	Len: 0.5 cm	Mass: 0 g
Bulkhead upper	Fiberglass (1.85 g/cm^3)	Dia$_{out}$ 14.6 cm	Len: 0.5 cm	Mass: 155 g
Bulkhead lower	Fiberglass (1.85 g/cm^3)	Dia$_{out}$ 14.6 cm	Len: 0.5 cm	Mass: 155 g
Tube coupler upper	Carbon fiber (1.78 g/cm^3)	Dia$_{in}$ 14.2 cm Dia$_{out}$ 14.6 cm	Len: 28 cm	Mass: 451 g
Tube coupler middle	Carbon fiber (1.78 g/cm^3)	Dia$_{in}$ 14.2 cm Dia$_{out}$ 14.6 cm	Len: 28 cm	Mass: 451 g
Tube coupler lower	Carbon fiber (1.78 g/cm^3)	Dia$_{in}$ 14.2 cm Dia$_{out}$ 14.6 cm	Len: 28 cm	Mass: 451 g
Launch lug	Fiberglass (1.85 g/cm^3)	Dia$_{in}$ 0.8 cm Dia$_{out}$ 1 cm	Len: 3 cm	Mass: 1.57 g
Launch lug	Fiberglass (1.85 g/cm^3)	Dia$_{in}$ 0.8 cm Dia$_{out}$ 1 cm	Len: 3 cm	Mass: 1.57 g

Figure: Components Dimensions

Payload

The Payload borne by our sounding rocket Kalam is an off the shelf design idea to fabricate the first-of-its-kind combination of a Hexapod and a Hexacopter, a Hexapodopter as we've come to call it.

Bearing a Hexagonal Shape, the Payload shall host 6 Propellers anti nadir, powered by a custom made Lithium Ion Battery that shall assist in Safe Decent. Besides the propellers, 6 ideally differentiated limbs fabricated mainly of Steel shall be incorporated by a folding mechanism into the body and which shall be released by the means of a spring system.

The Limbs shall serve as the pods for the hexapodopter ensuring stable landing. The Innovation being: the Hexapodopter as a 'MultiTerrain ExtraTerrestial Vehicle for Planetary Findings'.

The Hexapodopter shall be equipped with High End Gas, Temperature, Pressure, Altitude, GPS, and Accelerometer Sensors that shall be telemetering Sensory Data to our paired Ground Computer.
Each Sensor shall be powered by a sequence of Solar Wafers of Data Telemetry. The Data shall be visualized to ensure further processing and usage.

Once upon Stable Landing, the Hexapodopter shall initiate a certain Flight Time, for Terrain Mapping and land subsequently for battery relinquishing and repeat the procedure for another Terrain Segment to be mapped.

Figure: HexaCopter Recovery

Avionics

Electronics plays a crucial role in the design cycle of a sounding rocket. The overall design encompasses of three main roles:

- Rocket pre & post launch monitoring
- Scientific experimentation (payload)
- Rocket recovery.

An integrated embedded system comprising of avionics subsection is installed within the rocket body tube, which communicates continuously with the ground station by transmitting rocket data at the rate 1Hz. The sensors on-board such as accelerometer and gyroscope (MPU 6850) gives a clear indication of rockets orientation on the launch pad and during launch, IR-based flame sensors detect the possibility of fire hazard during launch due to rocket engine or batteries.

On board electronics also comprises of the following systems:

- A Pitot tube to measure rocket's maximum velocity
- A barometric altitude sensor (BMP280) a magnetometer
- A current sensor on-board power supply circuit (buck converter)
- Redundant electronics (back-up electronic circuit, in case main system fails)
- On-board data logger
- GPS (Ublox neo6MV)
- Communication antenna (Xbee-9km range with 2.1 dBi Dipole Antenna) and
- High dB electric buzzer.

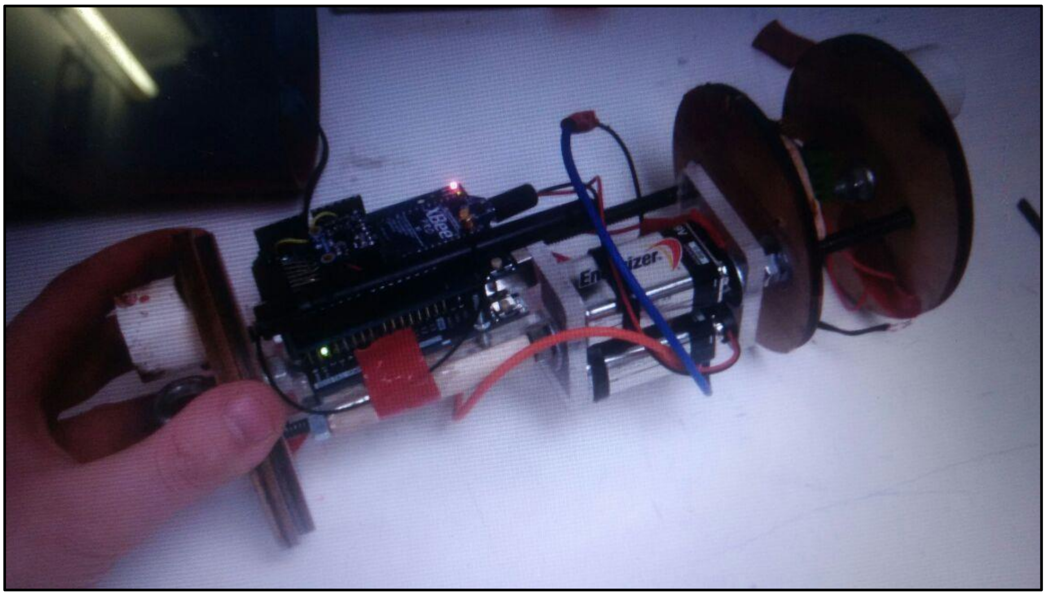


Figure: Electronics System 1

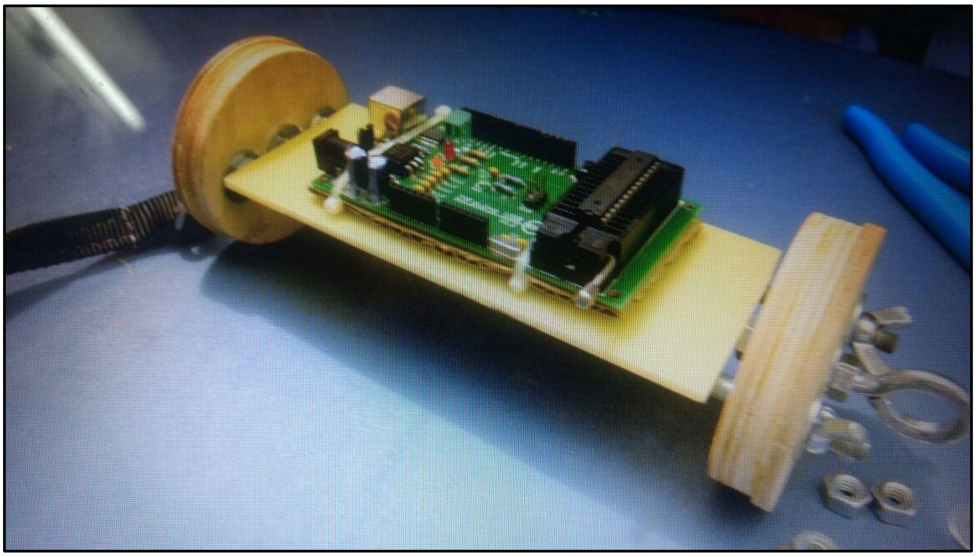


Figure: Electronics System 2

These along with nose cone ejection mechanism (altitude based CO2 cartridge puncturing mechanism) comprise of the rocket Avionics/Electronics system. These systems, along with ground station GUI (developed in MATLAB) will help track our rocket during launch stages (by comparing exact trajectory to the calculated trajectory) and also locate our rocket after landing (GPS and Electric buzzer aid in tracking down the rocket after launch). The on-board COTS (commercially available off-the-shelf) flight computer gives the official log of the apogee height above ground level (AGL), which is required to 10,000ft AGL.

The payload design comprises of electronics subsection, which would track the payload right from the point of ejection from the sounding rocket. Payload electronics comprises of separation mechanism of actual payload from its container as it descents via a parachute. Various sensors such as gas sensors, dust particle sensors, solar cells and actuators such as Brushless DC motors, servomotors, are controller using on-board system.
The power system is critically managed by using high current Li-Ion batteries along with a buck converter power supply for efficient power management.

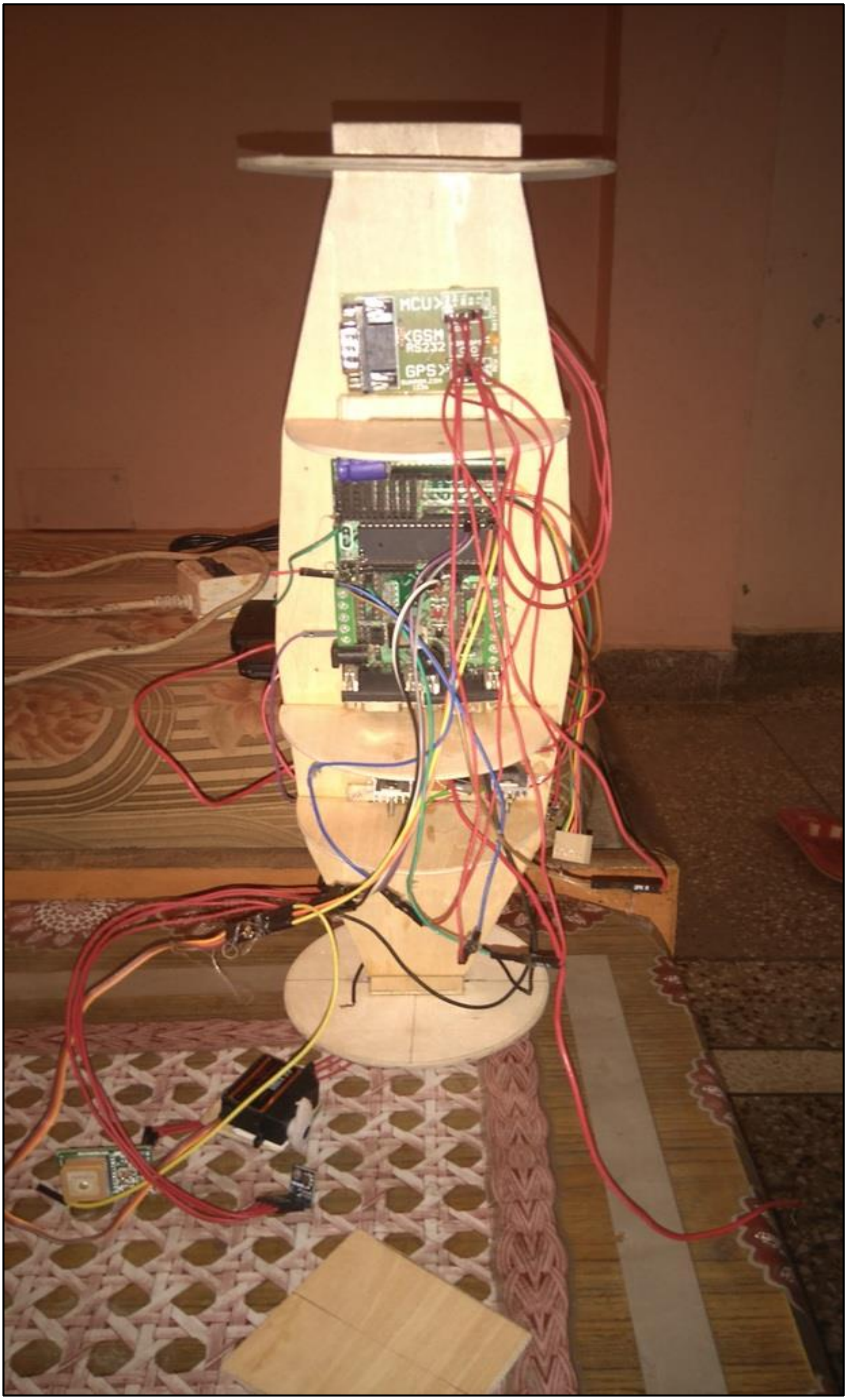


Figure: Final Avionics Bay

Recovery System

For our Rocket this year we are doing Nose Cone Deployment using CO_2 canisters. How the Co2 canister system will work is explained below:

The recovery section consists of a series of the combination of several complex and in-complex mechanisms working together to assure a stable and controlled recovery of the rocket.

The mechanisms included in the same are:-

- Nose Cone Deployment
- Parachute Deployment
- Payload Deployment

The nosecone will be deployed using pressurized CO_2, which will be released out of a pressure vessel in a pressure chamber situated at the top of the body tube separated by a removable bulkhead and cover with the nose cone itself. The pressure vessel will be a CO_2 cartridge, which will be subjected to get punctured at a definite time (at the apogee) using a puncturing mechanism called PCP Valve, which will get triggered using a linear articulator. As the linear articulator will trigger the PCP valve mechanism the CO_2 cartridge will get punctured. Leading to a high pressure CO_2 gas in the pressure chamber. As the pressure in the chamber will increase the nose cone will be deployed.

Once the nose cone gets ejected it will pull the bulkhead out of the body tube and as a chain the Drogue Chute and Main Chute will be ejected as the same time followed buy the payload.

Based on our calculations considering the Rocket, 32 grams of CO_2 is needed to do the same.

Propulsion

The word is derived from two Latin words: *pro* meaning before or forwards and *peller* meaning to drive. Propulsion means to push forward or drive an object forward. A propulsion system is a machine that produces thrust to push an object forward

The rocket motor is the device in the model that creates the thrust force that propels the rocket into the air. They create the fire, smoke, and noise that make rocketry so exciting to watch. Since they need no external material to form their jet, rocket engines can perform in a vacuum and thus can be used to propel spacecraft and ballistic missiles.

This time we are using Aerotech M1845 Rocket Motor. The M1845 is a 55% M reloadable composite motor from Aerotech. This reload fits an RMS 98/5120 motor case.

Aerotech's Blue Thunder propellant produces a bright violet-blue flame with a minimum of exhaust smoke. These motors provide a higher level of thrust than White Lightning or Black Jack motors of the same total impulse.

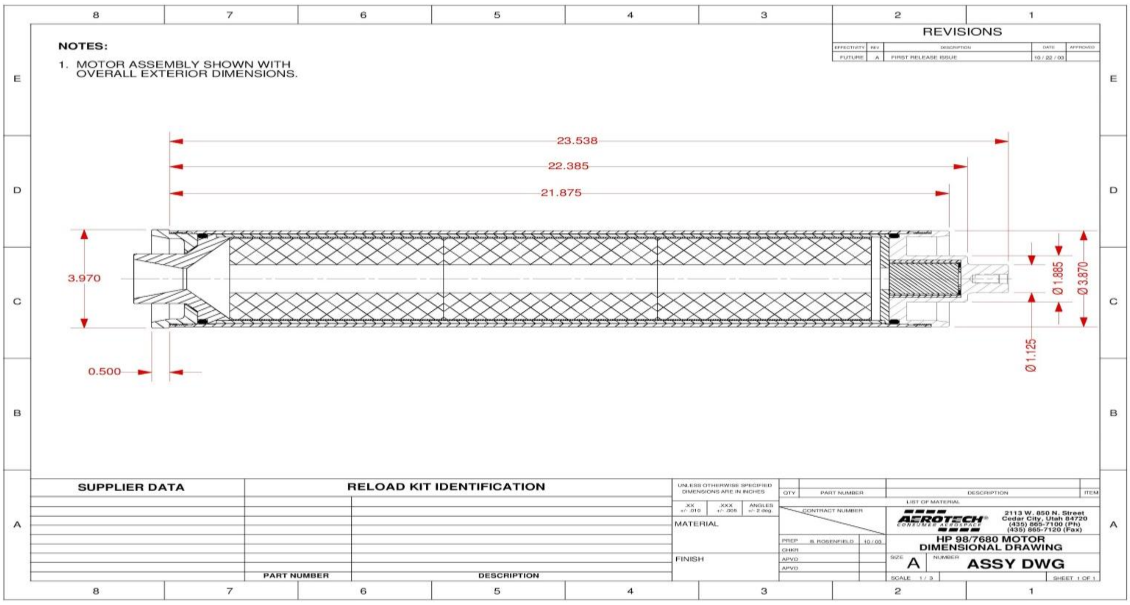


Figure: Rocket Motor Assembly (AeroTech M1845)

The specifications of the Rocket are:

- Casing: RMS 98/5120
- Class: 51-75% M
- Diameter: 98.00 mm
- Length: 597.00 mm
- Formula: Blue Thunder
- Propellant: APCP
- Type: Reloadable
- Propellant Weight: 3772.00 g
- Total Weight: 6682.00 g
- Average Thrust: 1,675.4462 N
- Peak Thrust: 2,433.8300 N
- Total Impulse: 7923.1850 N

Simulator Data

Motor: AeroTech M1845
Contributor: John Coker
Submitted: Nov 10, 2009
Last Updated: Nov 10, 2009
Data Format: RASP
Data Source: Manufacturer
License: Unknown

Statistics	*Declared*	*Calculated*	*Official*
Diameter (mm):	98.0		98.0
Length (cm):	59.7		59.7
Prop. Weight (g):	3,772.0		3,772.0
Total Weight (g):	6,682.0		6,682.0
Avg. Thrust (N):	—	1,824.2	1,875.0
Max. Thrust (N):	—	2,433.8	3,081.0
Tot. Impulse (Ns):	—	8,093.5	8,307.0
Burn Time (s):	—	4.4	4.4

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Data Graph

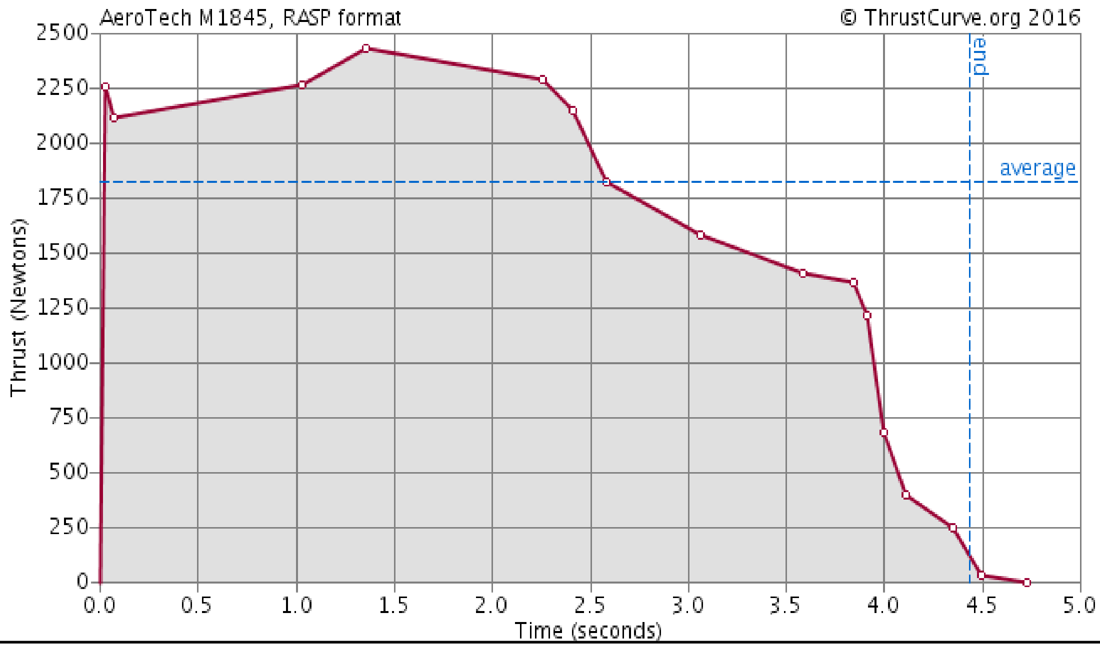

Figure: Thrust vs Time graph of M1845