Critical Design Review
CanSat

Team Titans
2022-ASI-020
R V College of Engineering

Preface

Team Titans is a student CanSat team of RV College of Engineering. It is a team of dedicated undergraduate engineers from various disciplines of engineering working towards the success of the CanSat for the IN-SPACe CanSat Challenge 2022. The Payload of the CanSat aims to demonstrate active descent control during the recovery phase of the mission. The team also is working on passive innovative gyro control mechanism to stabilize the CanSat recovery. The payload also houses a live video feed as a testimony for CanSat stabilisation. Finally, we thank our Faculty Advisor and the mentors for their constant support and guidance to make this project realizable. A special mention of the hard work put by all the team members of Team Titans to design the CanSat. The selection of CanSat of Team Titans will allow Indian students to represent the nation on an international platform and provide a basis for further research in recovery mechanisms for human space missions.

- Project Head, Team Titans

Acknowledgements

We express our heartfelt gratitude to the Department of Electronics and Communication Engineering and the Department of Aerospace Engineering of R V College of Engineering for providing the arena for exchange of knowledge and personal creativity development. All the mentors and the resources provided by the college has been crucial in our vision that we present today. Innovative projects are at the core of engineering and development of the society. This project will build necessary maturity in students to handle real world projects in future.

We extend our special gratitude to Dr K N Subramanya, Principal, RVCE, Dr K S Geetha, Vice Principal, RVCE, Dr H V Ravish Aradhya, Head of the Department of Electronics and Communication Engineering at RVCE, Dr. Ravindra S Kulkarni, Head of the Department of Aerospace Engineering at RVCE and Dr Mahesh A, Faculty Advisor and Associate Professor at ECE Department, RVCE for Team Titans and the Management of RVCE for providing us with the necessary guidance and help in our endeavour.

This project would not have reached this stage without the exceptional dedication by all the hardworking budding engineers who have been a part of this team since the inception of this project. Hence, we extend our appreciation to the members of our team Titans.

Contents

List of acronyms

ADC	Analog to Digital Converter
AGL	Above Ground Level
ASCII	American Standard Code for Information Interchange
BoM	Bill of Materials
C&DH	Communication and Data Handling
CAD	Computer Aided Design
CDR	Critical Design Review
CG	Centre of Gravity
CIE	Continuous Internal Evaluation223
CMS	CanSat Mobile Support
DMP	Digital Motion Processor
EEPROM	Electrically Erasable Programmable Read only Memory
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSS	Ground Station Support
GUI	Graphical User Interface
HITL	Hardware In The Loop
I^2C	Inter-Integrated Circuit
IIR	Infinite Impulse Response
IMU	Inertial Measurement Unit
ISM	Information Security Management
LED	Light Emitting Diode
LKM	Link margin
LoS	Line of Sight
NTSC	National Television Standards Committee
PDR	Preliminary Design Review
PLA	Polylactic Acid
RAM	Random Access Memory
RSSI	Received Signal Strength Indicator
RTC	Real Time Clock
SITL	Software In The Loop
SMA	Sub Miniature Version A
SMP	Sponsorship, Marketing and Promotion
SPI	Serial Peripheral Interface
SRAD	Student Research and Development
TRL	Technology Readiness Levels
USB	Universal Serial Bus

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1 Mission overview

The CanSat project is a culmination of multiple subsystems working interdisciplinary to achieve the common goal of successfully launching and recovering a can-shaped payload that shall be sent to an apogee of about 800-900 meters.

1.1 Specifications of CanSat

- Name: CanSat –Team Titans
- Payload Objective: Innovative Descent Control Mechanism Illustration
- Altitude: 800 – 900 m Above Ground Level (AGL)
- Dimensions: 0.125 m (diameter) and 0.310 m (height)
- Estimated Weight: 749.72 g

1.2 Vision

To inspire young budding engineers of the nation to confidently take up challenges in the field of rocketry and satellite design. India being potentially capable of developing indigenous designs and excelling in the small satellites segment, we aim to promote opportunities in space technology among students right from their under graduation.

1.3 Mission

To design a CanSat weighing under 0.700 kg (+/- 0.050 kg), with dimensions not more than 0.125 m diameter and 0.310 m height and capable of withstanding shock loads of launch. The entire CanSat must be an SRAD component that is to be completely developed by the students and must have 2 descent control mechanisms out of which the secondary is an innovative descent control mechanism. A control gyroscope is to be incorporated as part of the payload and must be able to control the attitude of the CanSat during secondary descent. To provide live video feed of all ops on the CanSat simultaneously recording the same onto local storage on board the CanSat.

1.4 Statement of need

With advancements in space technology, there are a lot of opportunities for designing and testing prototypes related to various aspects of space missions. The technology has now enabled the space travel missions to be quick and reusable. Human missions into space are one of the most promising methodologies to scientifically explore non-terrestrial surfaces.

Launch and recovery are two most critical phases during the entire mission. Launch assists in placing the payload into its orbit while the recovery brings the astronauts back to earth, safe and sound. Concentrating on the recovery phase, re-entry into earth's atmosphere at uncontrolled descent rates have ended up in catastrophes, friction between the atmospheric molecules and the payload body being a major design challenge to safely overcome for human rated spaceflight.

Even with the payload body walls being sufficiently smooth to reduce the friction, the parachutes to control the descent rate, there is abundant scope for innovation as the main parachute mount cannot be at the geometric centre of the payload as such missions have latches that open up for human movement. This leads to drifting of the payload by large distances as it paves its way through the atmosphere. The stability of the payload is also affected due to the imbalance in centre of pressure and gravity induced by the asymmetrically placed parachute.

We, Team Titans intend to make the right use of the opportunity provided by the CanSat challenge 2022 hosted by IN-SPACe to miniaturise such payloads by making use of CanSat, design and illustrate innovative supervised glider mechanism to control the descent rate of the CanSat. To utilise this competition to the fullest, the team has designed a two-axis gyroscopic stabilisation mechanism to control the stability of the CanSat.

1.5 Team details

The team mainly consists of undergrad students from different streams of engineering to realise the mission objectives. All the team members are from the graduating batch of 2024.

Name	Branch	Role in the team
Amogh G	Electronics and communication	**Project manager**
Dheeraj G	Electronics and communication	**Technical head**
Bhuvan Bharadwaj	Electronics and communication	Sensors subsystem engineer
Jahnavi K P Urs	Electronics and communication	Communication and Data Handling subsystem engineer
Dharshan S Hegde	Aerospace	Mechanical subsystem engineer
Sanjay R	Aerospace	Payload subsystem engineer
Vageesha Sharma	Aerospace	Recovery subsystem engineer

Table 1: Team members and details

1.6 Mission success criteria

The mission success is measured as per the successful functioning of the critical components of the CanSat as described in Table 2

Criteria	Percentage
Design of primary and secondary descent control mechanism	20
Prototype Design & Testing of Descent Control mechanism	50
Design of Gyro mechanical control for stabilisation	60
Prototype Design & Testing of Stabilisation	70
Testing of Telemetry & Ground Station design	80
Assembly and Integration of Flight Model	85
Achieving descent rate less than 20 m/s after primary parachute deployment and less than 3 m/s after secondary mechanism deployment	90
Landing of the CanSat close to the designated GPS co-ordinates	95
Successful compilation of real-time telemetry data	100

Table 2: Success criteria of the mission

These percentages indicate the percentage of the mission successfully completed after every major milestone of the mission. The above points are described in detail for clear definitions

1. Design of primary and secondary descent control mechanism
   The initial ideation and design of the descent control mechanisms decide the strategy employed to achieve the mission objectives. The first phase involves the design of the first deployment parachute to bring down the descent rate below 20 m/s referred to as drogue parachute. The next phase involves brainstorming, ideation and design of the secondary descent control mechanism to further restrict the descent rate under 5 m/s while demonstrating active control referred to as the main parachutes.

2. Prototype Design and Testing of Descent Control
   The prototype design and testing contribute majorly towards the suc-

cess of the mission. The prototypes for both the primary and secondary descent control mechanisms would be fabricated/ manufactured and validated by performing 'drop tests' and 'ejection tests' while constantly updating the code using Software In The Loop (SITL) and Hardware In The Loop (HITL) simulations to better detect the ejection points during flight. The designs would be validated for robustness, durability and performance.

3. Design of Gyro mechanical control for stabilization
   The stabilisation of the CanSat after its deployment is very important to ensure the success of the mission. The design of an innovative mechanical gyroscopic mechanism that can demonstrate active roll control of the CanSat while keeping it within mass constraints is one of the key milestones for the mission.

4. Prototype Design and Testing of Stabilisation
   The flight model after integration is checked for stability and structural integrity by inspection and the stability of the design must be validated by physical tests and all the actuating parts' integrity that can qualify the CanSat, will be an important milestone to accomplish.

5. Testing of Telemetry and Ground Station design
   This is another major factor which dictates the success criteria. The data collected from the on-board sensors has to be down linked to the ground station to validate the success of flight and recovery. The team is evaluated based on the real time plots of telemetry data handled by the Ground Station Graphical User Interface (GUI). This takes place in two phases. The first phase involves the testing of CanSat and Ground Station Antennas for faithful communication link between them with sufficient link margin. The second phase is the development of Ground Station GUI.

6. Assembly and Integration of Flight Model
   After the completion of various tests and validation, a full scale model with integration of all the subsystems will be realized. The flight model will be subjected to all the tests mandated by IN-SPACe to validate its reliability for integration aboard the launch vehicle. Once cleared, the model is declared to be flight ready.

7. Achieving descent rate less than 20 m/s after primary parachute deployment
   The first parachute deployment at the apogee is the first crucial step once the recovery phase starts. This parachute, designed and validated to suit the mission requirements, is expected to reproduce the tested results to ensure success rate. This marks partial success of the entire recovery

phase.

8. Achieving descent rate less than 3 m/s after secondary mechanism deployment
   The active control of the secondary parachute by use of servos and GPS to guide it to a designated spot for landing or to home position based on launch day conditions. On demonstrating that the control is possible and predictable based on the landing spot we can draw sufficient conclusions.

   The success of secondary descent control mechanism marks the complete success of the recovery phase. The active control of the secondary parachute by use of servos and Global Positioning System (GPS) guides the CanSat to a designated spot for landing or to home position based on launch day conditions. The successful demonstration of controlled landing provides a 'proof of concept' for the innovation of the team in designing the descent control mechanism.

1.7 Technology Readiness Level(TRL)

The technology readiness levels of the project indicates the readiness of the individual subsystems and their work with reference to previously designed or flown designs that are proven in flight, lab conditions, etc. This sets a very good base mark as to how close the current mission is to achieve actual success. The TRL levels are indicated in the Table 3.

Parameter	**TRL level**	**Reason**
Gyroscope	7	Tested previously on space missions
Drogue parachute	6	Drop tests performed previously
Main parachute	4	Parachute characteristics tested in simulated environment
Actuation mechanism	3	Actuation mechanism validated in lab tests
Chassis	7	Design inspired by previous winning CanSats
Release mechanism	2	Idea formulated and discussed; initial designs discussed
Sensors stack	8	Similar sensor stack used & recovered on previous CanSats
C&DH	8	XBee S2C previously flown on CanSat missions
Antennas	4	Tested in Anechoic chamber for gain and radiation pattern
Ground station GUI	5	Validated on tests conducted in lab

Table 3: TRL levels of the various subsystems of CanSat

1.8 Changes since PDR stage

The team considered the suggestions from the judges carefully and after multiple iterations of design the following changes were deemed mandatory and have been discussed in brief here.

1.8.1 External body design

The design of the external body has been changed from the initial design of being a hexagonal lattice to having a triangular lattice in order for ease of 3D printing and also better reduction of mass that has been obtained.

1.8.2 Release mechanism of the main parachute

The release mechanism of the secondary descent control system is to be carefully designed keeping in mind the safe and timely release of the drogue chute and the bulkhead that the drogue is attached to. The current design includes a system that consists of servos axially in line with the yaw axis(X_C) of the CanSat at about halfway from the bottom.

The main chute is attached to the mount holding this servo and both are securely attached to the load bars. The top half of the CanSat housing the main descent control mechanism is designed to be removable and is such that on actuating the in-line servo, the few pins that are the only mechanical structures holding the two halves are retracted and the halves separate. This causes the top half of the housing to eject with the drogue still attached to it and lands safely while the lower half is steered by the main descent control mechanism. This method has the following advantages.

- It reduces the perturbance on the main descent control mechanism due to the drogue chute and bulkhead as in previous design it would still be attached to the body. This promises much more accurate results.
- The mass of the above half of the CanSat need not be accounted for in the main descent control steerable parachute, hence it reduces the parachute dimensions.

The upper half will have a separate beacon system that shall be responsible for helping locate it which would be activated on separation. The halves shall then be recovered successfully by the recon team and most importantly it does not damage or in any way harm the CanSat in a way that it diminishes its value Its functionality still is valid and is completely reusable unlike other string based mechanism or spring loaded mechanisms therefore is arguably better than most of the existing solutions under the guidelines and therefore this method of separation was chosen.

1.8.3 Parachute actuation mechanism

The steerable parachute is the main idea of the secondary descent mechanism. In order for this parachute to work, it has to be actively controlled by the system and the system must take constant input about the attitude and location of the CanSat and then actuate the parachute accordingly. As of now a single servo system is put in place to pull on the steering cords of the steerable parachute mechanism.

1.9 System level overview of CanSat

This section is introduced to highlight the interdependencies of the different subsystems of the CanSat and the respective tasks that those subsystems are concerned. This specifically helps in division of a given task and is particularly helpful to track a task's progress based on the individual subsystem's progress with respect to that task.

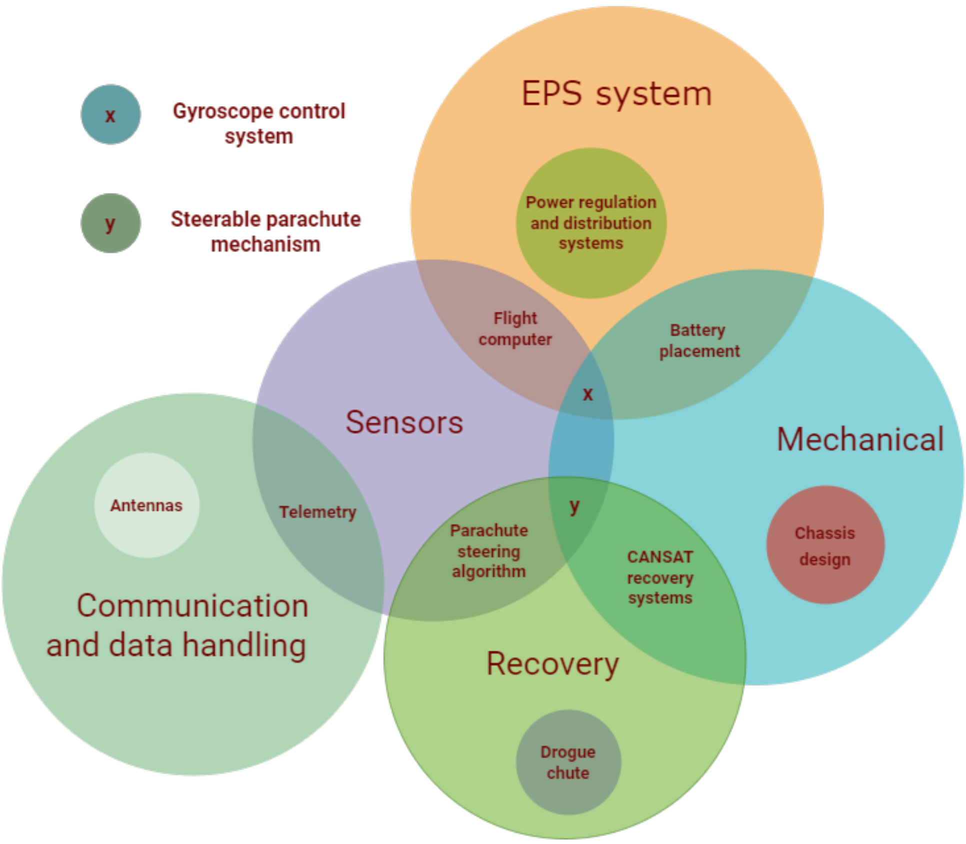


Figure 1: System level overview of CanSat

The Venn diagram indicates the major subsystems and the overlapping region corresponds to the tasks that concern multiple subsystems. The individual subsystem tasks can also be highlighted by the bubbles not overlapping with any of the other subsystems. The most interdependencies as per Figure 1 are

- Gyroscope control system that involves sensors, EPS and Mechanical subsystems.
- Steerable parachute mechanism that uses the recovery, sensors and mechanical subsystems.

A few other tasks that have fewer requirements but are more critical to the functioning of CanSat are

- Flight computer that utilizes EPS and Sensors subsystems.
- Telemetry that mainly concerns Sensors and Communication and Data handling subsystems.
- Parachute steering algorithm that mainly includes sensors and recovery subsystems.
- Secondary recovery mechanism that is the responsibility of Mechanical and Recovery subsystems.
- Battery placement to ensure Centre of Gravity is maintained by mechanical subsystem and looked over by EPS.

The following tasks are purely the responsibility of the concerned subsystem as these tasks hold importance at the whole system level and require the complete attention of a single subsystem to ensure the perfection required. These are

- Power regulation an distribution systems
- Chassis design
- Drogue chute design
- Secondary descent control ejection mechanism
- Antennas

1.10 CanSat project workflow

The project has been actively worked on since August 2022. In the initial days of the project the team was following an unorganized work plan but since the submission of the PDR in September 2022, the team realized the need for a Work Breakdown System(WBS) and has actively maintained one.
The WBS has been split up for understanding purposes into pre and post CDR phases and the pre CDR WBS has been indicated in the graphic as depicted in the Figure 2

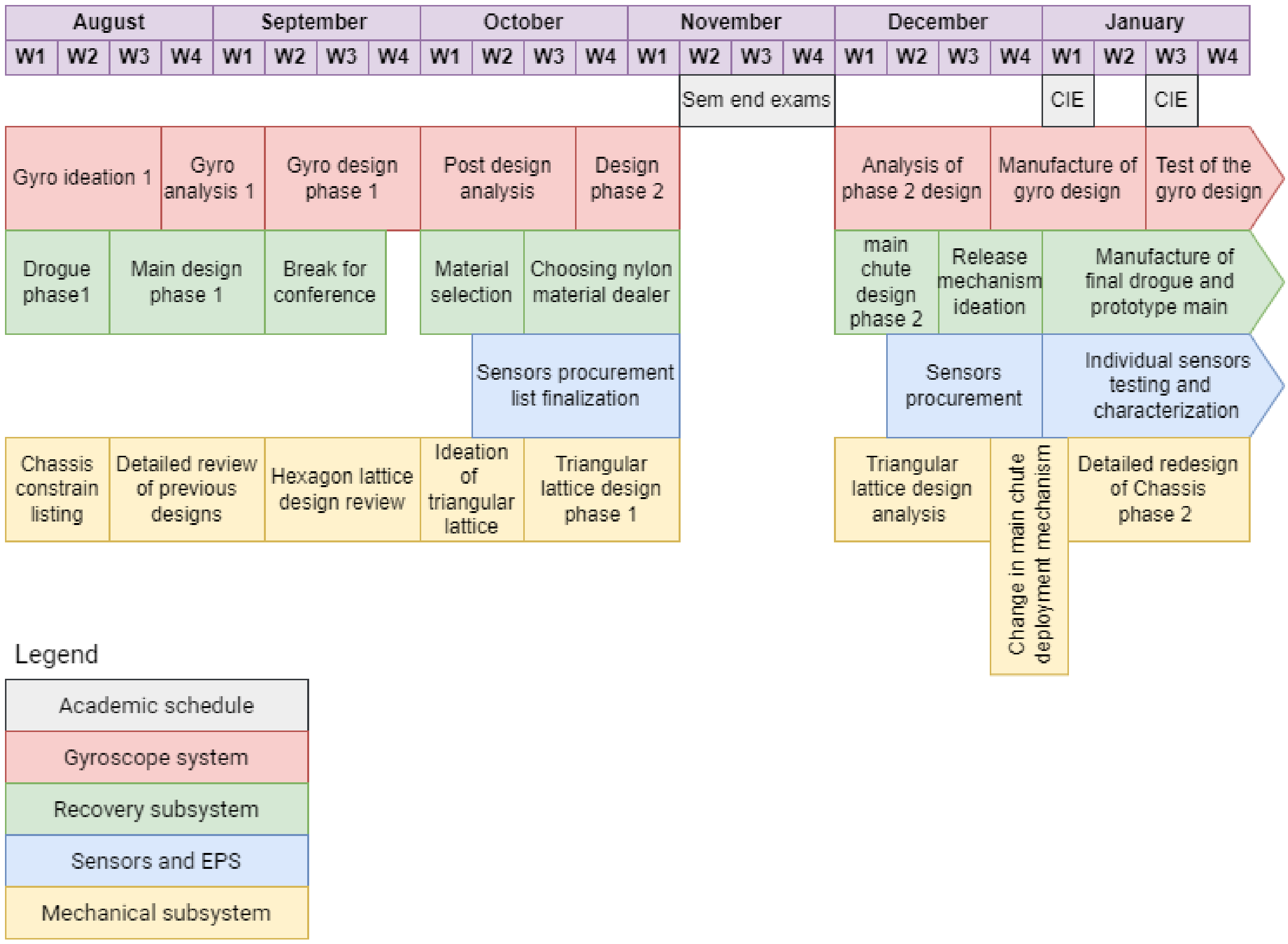


Figure 2: Pre-CDR WBS

Post CDR, the WBS has been planned out ideally and all the speculated dates of academic activities and the deadlines have been tentatively planned out and the same has been represented in Figure 3

These are all the tasks planned out in the WBS for the completion of the project. After the completion of the project, execution of a few set of tasks ensure the successful completion of the mission to reach its end goal. These on site tasks are mainly at 2 sites namely at the ground station and at the CanSat. Intuitively one can divide the team into 2 sub teams that perform their respective tasks.

These teams can be named according to the tasks they are required to carry out so Ground Station Support(GSS) dealing with all the operations concerning the Ground station and then the CanSat Mobile Support(CMS). These teams have a few tasks that concern them starting from Arrival to Landing. Each teams are expected to come together for a few system level tests that ensure the inter-working of the whole system and for information on the state of CanSat during and after launch.

Another team that shall work on recovery is a recon team that will contain

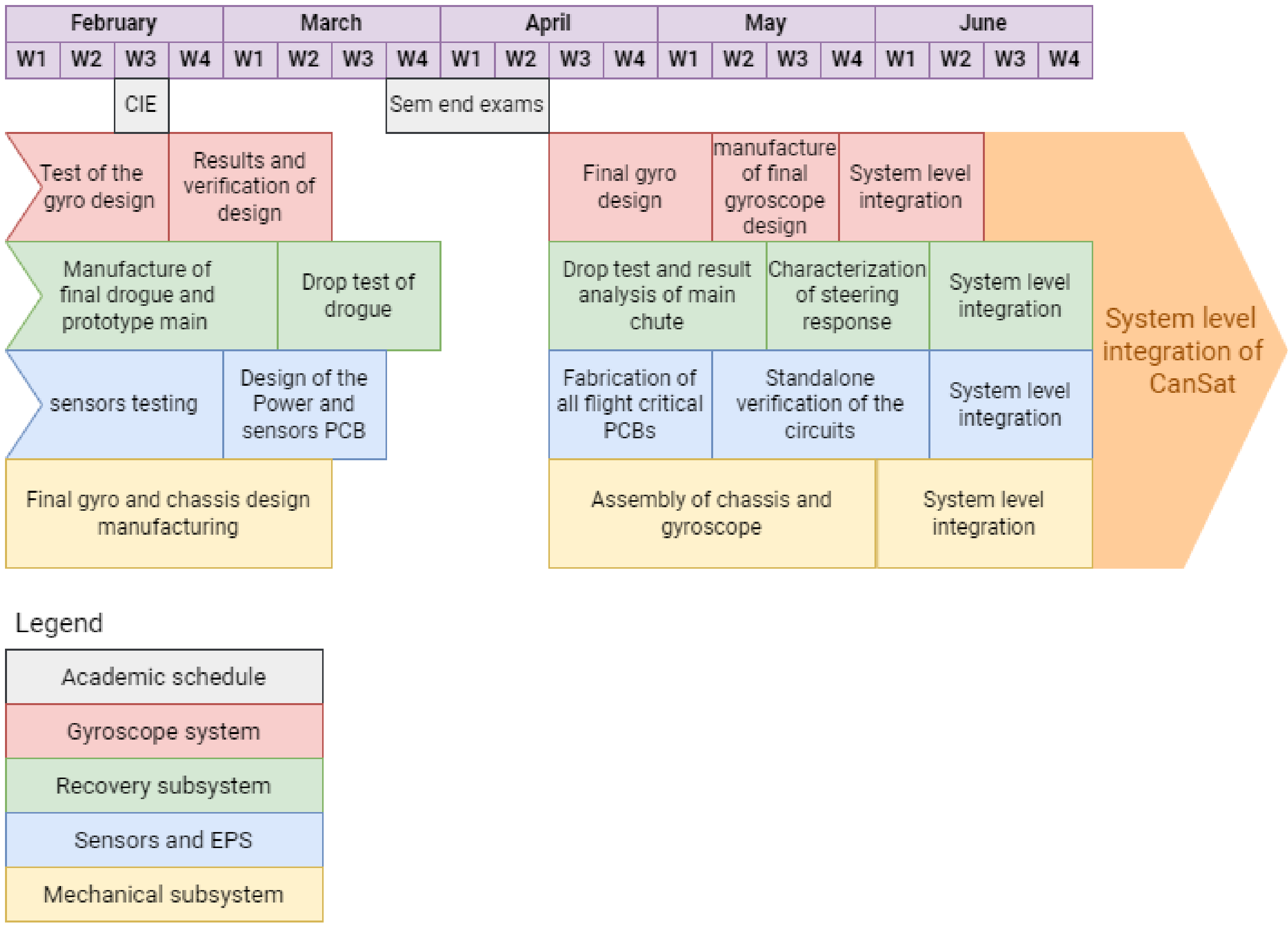


Figure 3: Post-CDR WBS

members from both GSS and CMS will coordinate search and recovery of the CanSat on landing. The reason for a specific recovery team is formulated is because data from the GSS in real time is also used to recover the CanSat by the CMS hence such interdependencies have to be resolved and hence this arrangement.

The on site tasks and operations on launch day are highlighted by the Figure 4

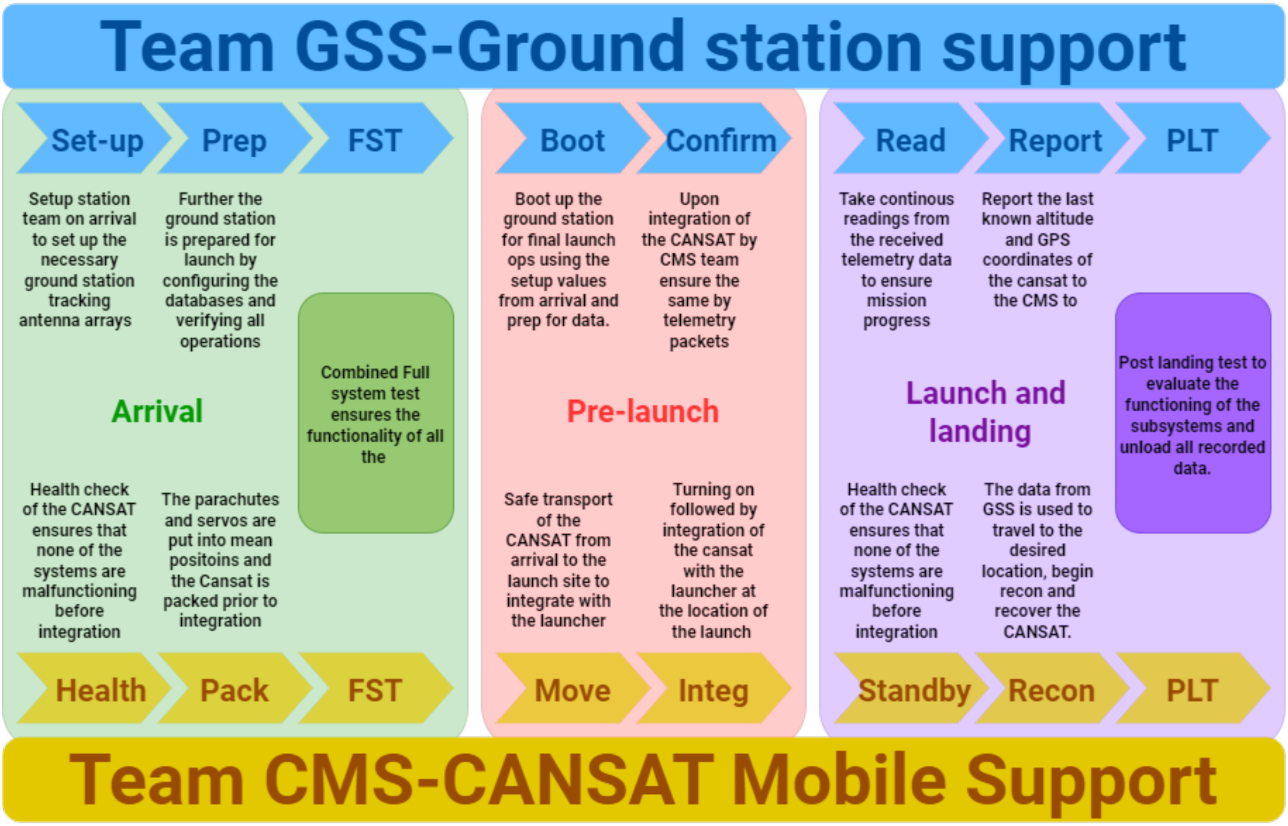


Figure 4: Ground operations on launch day

1.10.1 Ground Station Support

The ground station support team is tasked with the following tasks

- Upon Arrival
  - Setting up the ground station with all the antennae and XBees.
  - Preparations in order to configure the software and all the hardware-software interfaces.
  - Full system test along with the CMS team.
- Pre-launch
  - Boot up the ground station for the final launch and ensure data link.
  - Confirm the activity of the CanSat once the CMS boots up the CanSat for integration.
- Launch and landing operations
  - From the received telemetry read the states and values to ensure the CanSat has an ideal launch profile.
  - Report the findings to the CMS so that the whole team is updated

about the launch.

  - Post recovery by the Recon team, run tests to ensure the existence of data and offload all flight data off from the CanSat

1.10.2 CanSat Mobile Support

- Upon arrival
  - Check the health of the CanSat after transport and travel by first power up and verification. Ensure Indian flag, team name, mobile number and email-ID of the (Project Head , Technical Head) in English, Hindi and Gujarati.
  - Pack and stow the parachutes and recovery systems for integration into the launcher.
  - Full system test along with the GSS team.
- Pre-launch
  - Move to the integration site along with the CanSat and any tools required to integrate.
  - Integrate with the launcher and ensure the proper power up of the CanSat by coordinating wiht the GSS.
- Launch and landing
  - Standby during launch and receive timely updates from the GSS team.
  - Recon team to recover the CanSat and all its components from the landing site.
  - Post Landing Test along with GSS team.

2 Funding and procurement details

The required components for the tests and all other uses concerning the CanSat project is being carried out in 2 phases. The first phase of procurement called phase 1 consists of the following components and the prices and other details have been indicated in Table 4

Subsystem	Component	Price	Nos	Total(INR)
Sensor subsystem	XBee	2,399.00	2	4798
	Li-ion battery	1,500.00	2	3000
	IMU	249.00	1	249
	Teensy 4.1	3,199.00	1	3199
	BMP280	69.00	1	69
	INA219	299.00	1	299
	Jumper wires	72.00	1	72
	FP-260 motor	49.00	1	49
	Breadboard	70.00	1	70
Recovery subsystem	Ripstop Nylon	125.00	5	625
	Parachord 550	539.00	1	539
	Quick link	290.00	1	290
	Swivel hook	135.00	1	135
Mechanical subsystem	603 ZZ Bearing	190.00	2	380
	PLA filament	1,699.00	1	1699
	Carbonfibre rod	799.00	1	799
			Total(INR)	16272

Table 4: Phase 1 procurement details of CanSat

The components in this list have been procured and are used in all the described processes and tests.

The procurement has been divided into 2 parts mainly in order to facilitate the better use of allotted finances to all subsystems equally as the project was budget constrained in its initial phases. This forced the division of budget not to subsystems as a whole but as per their requirements to complete system level tasks. This method ensures that no subsystem is working on secondary systems and also ensures the quick completion of flight critical hardware that eases the workflow in tight budget cases.

The phase 2 procurement details are for components that have a higher price point or were unavailable at the time of phase 1 procurement. The following list highlights the same and is incomplete due to stock issues or is not of immediate concern. Components that have not been chosen yet are also left blank.

At the initial stages of the design phase after PDR selection, the team was in need of immediate financial assistance as the procurement list was generated and without any designs being realised the work was stalling. This was conveyed to the institution after reviewing the PDR documentation and understanding the enthusiasm of the team, an initial funding of about INR 20000 was sanctioned with which the team were able to purchase a few initial components

Subsystem	Component	Products	Price	Nos	Total(INR)
Sensor and EPS subsystem	Camera	Runcam split 3	6000	1	6000
	VTX	HGLRC Zeus	2000	1	2000
	Recording camera	Runcam thumb	10709	1	10709
	PCB	PCB power	5000	1	5000
	Silicon wires				0
	Buzzer	110 dB buzzer	269	2	538
	Battery	18500 cells	1500	2	3000
	Rotary sensor	Op-amp,IR LEDs	50	2	100
	Moxon antenna				
Recovery subsystem	Servos	6g micro servo	500	2	1000
	Laser cutting	Service	3000	1	3000
Mechanical subsystem	Servos	9g	500	2	1000
	Adhesives				0
				Total(INR)	32347

Table 5: Phase 2 procurement details of CanSat

for all the work to begin in design phase. Phase 1 procurement has been successfully completed with the received funding and the balance is to be carried over to the Phase 2 procurement.

After an interaction with a few officials of Ansys at a conference in December, the team along with the assistance of the faculty coordinator and mentors approached Ansys for a possible sponsorship where details of the competition and the team's main objectives were communicated through a drafted mail through the institution. The team requested for a funding of INR 80,000 keeping in mind the budget cap of the project as set by IN-SPACe and considering the previous funding received by the institution towards the project. As of February, Ansys is in the process of reviewing the documents.

This delay in funding affected the phase 2 procurement which is a critical phase as well. Although this is a major setback the progress of the project is unaffected as phase 1 procurements ensured every subsystem had the minimum requirements to not only maintain the technical work progress but also accelerate it towards the subsystem level tests. As it currently stands this delay has been communicated to the college which has reviewed the work done by the members and has agreed to release the full INR 80,000 to fill in for the delay and the team has also agreed to return the full sum to the institution in case Ansys decides to grant the funding and become sponsors of Team Titans.

3 Technical Details

3.1 Layout of the CanSat

The CanSat shall be laid out as follows, the main chute is housed in the top half that is designed to be ejected during secondary descent control system deployment. This is also attached to the drogue chute on the top. Under this lies the control servos for the parachute. This is above the ejection servos that have the pins laterally going into the 2 halves. Under this lies the main PCB which houses the sensors and the main controller.

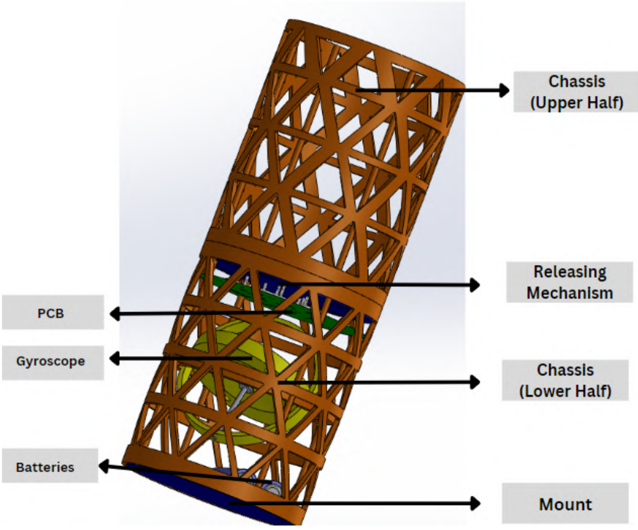


Figure 5: Assembly of the CanSat model

Directly under this lies the gyroscope assembly with the servos for actuating that consists of the camera setup around the bottom part of the gyroscope assembly. Under this the PCB responsible for the distribution of power from the batteries lies alongside with the batteries to enhance the accessibility.

3.2 Control system details of the CanSat

The innovative descent control is mainly the product of two components of the CanSat namely the Gyroscope yaw control and the roll control by the steerable parachute. These provide control in the Roll(Y_C) and Yaw(X_C) axis of the CanSat. The Gyroscope is a 2 frame gyro which shall be actuated by servos during descent.

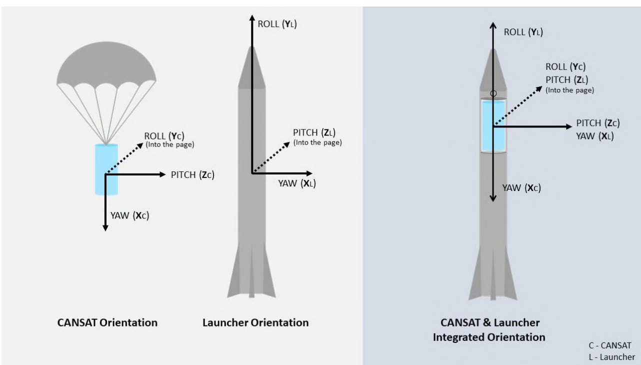


Figure 6: Axes of CanSat and launcher

Due to the steerable parachute having an airfoil profile, changing the Pitch(Z_C) will affect the angle of attack of this airfoil shaped parachute causing stalling or diving characteristics which complicates the control system. The gyroscope however is free of such variations as it remains spinning for the entirety of the mission and therefore it does not induce a lot of perturbations in the axes other than yaw.

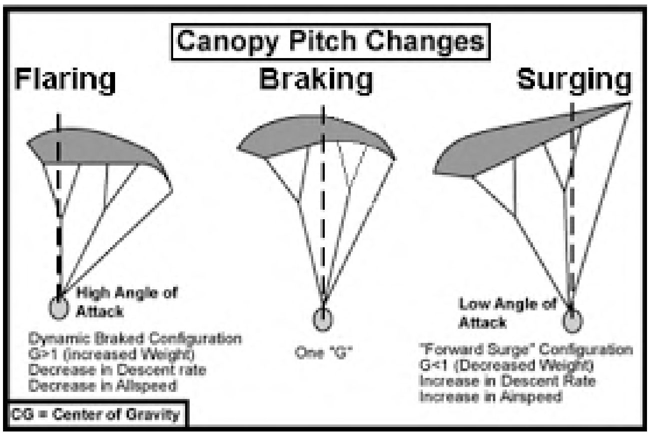


Figure 7: Angle of attack characteristics of steerable parachute

These characteristics with respect to the parachute are called Flaring and Surging respectively. Also, the main parachute is being manufactured and as of documenting, remains untested, therefore not a lot of solid data is available that the team can rely on to make any convincing assumptions on the Pitch axis.

Due to this, the control system of the CanSat consists of 2 PID loops that are constantly working in the closed loop control phase or descent phase 2 as indicated by figure9 and are interdependent due to the steerable parachute inducing Yaw(X_C) effects. This is not to be corrected by the gyroscope as this is desired motion and therefore the gyroscope has to not be active when the parachute is being steered by logic. This induces a paradoxical control authority where if the steering parachute is continuously being used, then the gyroscope does not have to be actuated in any part of the mission.

So the whole control authority must be divided between the Gyroscope and the Steerable parachute. Since the primary objective of the Steerable parachute is to enable control in the Roll(Y_C) axis, the disturbances it causes in the Yaw axis shall be corrected by using the Gyroscope. Also to prevent the problem of the gyroscope sitting idle due to the steerable parachute being in use, a certain amount of dead zone is allowed in the roll axis for the parachute to not actively control the characteristics so that the gyroscope can correct all yaw motions.

This dead zone can be programmed such that the switch is controlled by the threshold function, and when the roll error is less than threshold pass the yaw error as is to the Yaw control system but in order to disable the control system, when the roll error is greater than the threshold, it means that the roll control system is active and therefore passing a zero to the yaw control system locks it in the current position.

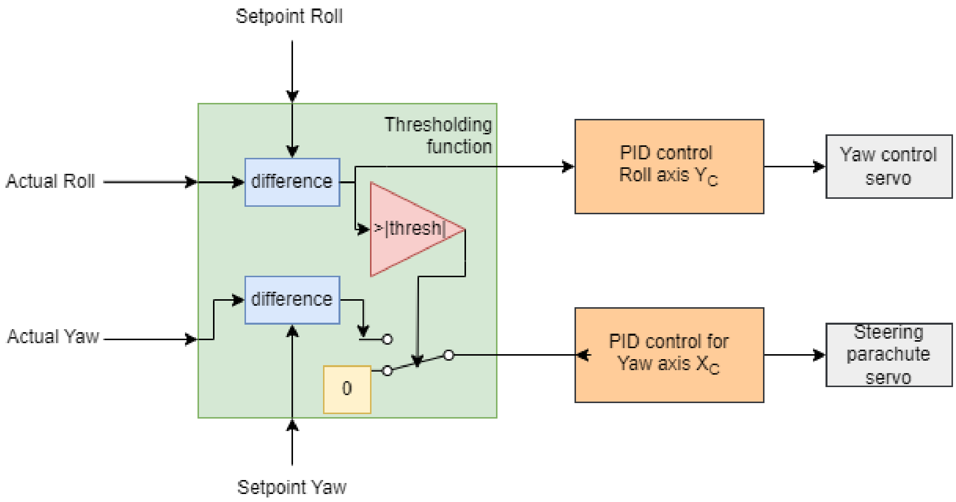


Figure 8: Angle of attach characteristics of steerable parachute

Figure 8 highlights the same put in terms of block diagrams and therefore forms the total control system of the CanSat. These P, I and D values are yet to be finalized based on the response of the system and the accuracy of the sensors.

The use of IIR filters on the sensor data is used to filter out high frequency noise during data logging. The control system requires noiseless data for which these IIR filter.

3.3 Flight software

The flight software mainly consists of a state machine with the sensor readings indicating the different stages of the flight of the CanSat to determine the required actuators and deployments that have to happen in sync to safely recover the CanSat. The state flow diagram is as indicated and has mainly 7 states.

Each mode has been discussed in detail keeping in mind the condition that triggers each state transition and the outputs that are triggered in the respective state.

1. State 0: BOOT_MODE/ START
   Trigger condition - reset / power up
   This mode is the default boot state that is used to initialize most of the variables, initiate hot/cold start for the GPS module, sync the RTC, initiate a self-test and verify all the components are working as expected. This mode does not actuate any outputs other than a few status LEDs.

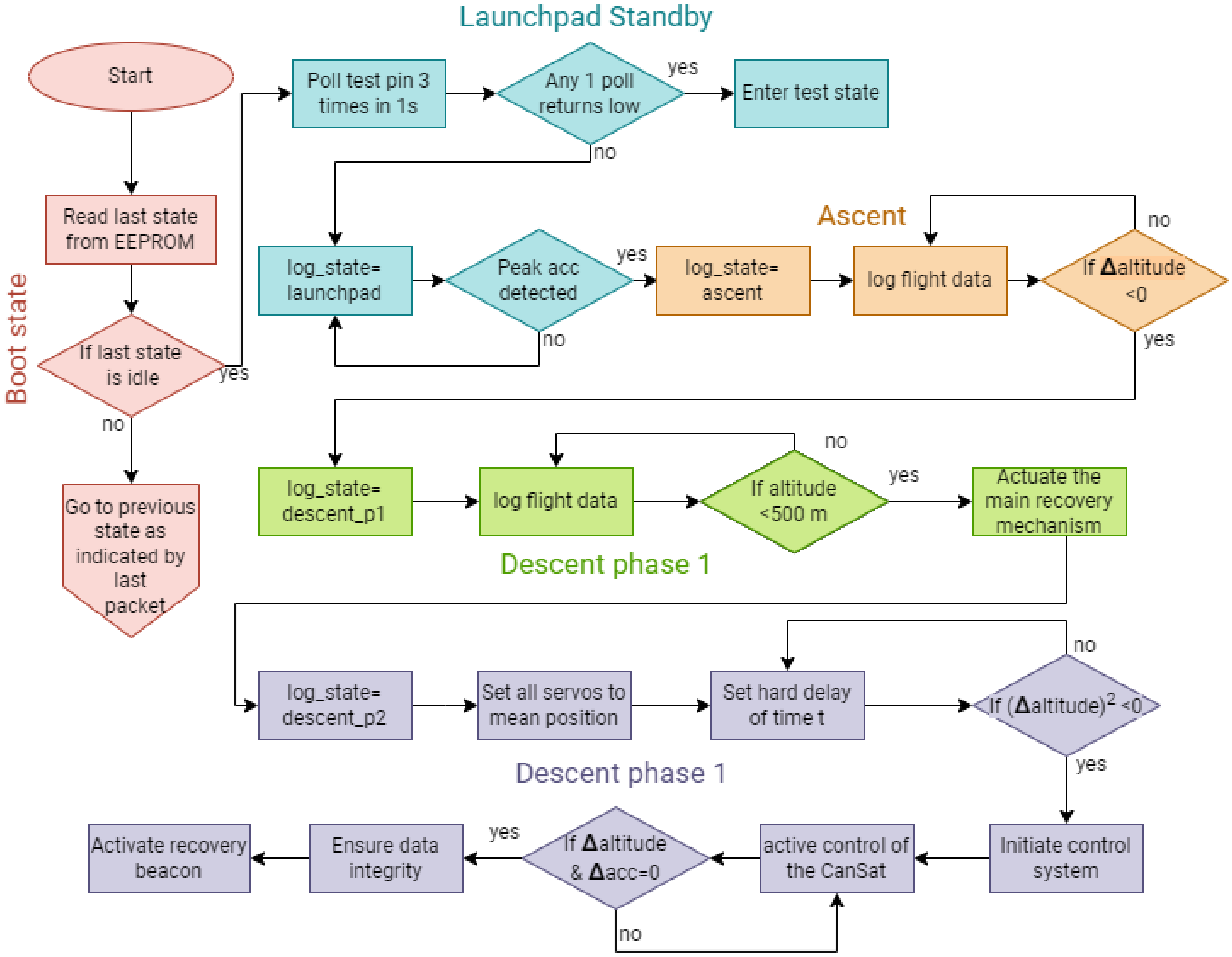


Figure 9: Flowchart of the state diagram of the CanSat

This is the default mode of the CanSat in case of any errors occur. All the internal register contents are stored to the EEPROM and the CanSat state is reverted to the BOOT_MODE.

2. State 1 - TEST_MODE
   Trigger condition - manual push button state on power up
   This test mode is necessary to debug the various sensors of the satellites in case of abnormal behavior or in other cases that involve just debugging to verify the operation of the sensors. This mode will mainly poll the sensors and utilize the telemetry link to send the values through to the ground station as to what tests have passed or raw values if need be.
   The test pin is polled to enter into the TEST_MODE. The pin is polled thrice in a second for redundancy and check for validity of the input to enter the TEST_MODE. If the test pin goes low atleast any of the three polls, the TEST_MODE is activated.

3. State 2 – LAUNCH_PAD
   Trigger condition: Manual command through the Telemetry link

When the rocket is resting on the launch pad before launch, it is put to this mode and it expects launch to occur when in this mode. This mode will use the IMU and the altimeter to detect the launch and certain conditions such as acceleration peaks and increase in altitude to determine the launch condition.
The LAUNCH_PAD mode will be exited only when there is steady peak in acceleration and constant increase in altitude are detected when the controller continuously polls IMU, altimeter and GNSS. Acceleration and altitude peak detection algorithms will be run on interrupt mode.

4. State 3 - ASCENT
   Trigger condition - peaking acceleration and increase of altitude of over 5m in under a fixed time interval.
   Once the interrupt from the acceleration and altitude peak detection is generated, the service routine marks the transition to ASCENT state. ASCENT state is mainly included for completeness of the state transitions as this state paves the way for all further state transitions. This state enables the IMU and a negative gradient of altitude (apogee detection) to trigger the next state. No actuation happens in this state but the transition is an important indication to proceed in the states.

5. State 4 - DESCENT_P1
   Triggering condition - the apogee detection algorithm that is enabled by the previous state.
   The drogue is in effect in this state and is therefore the terminal velocity is limited to 20 m/s and this has to be measured by the rate of change of altitude by using the altimeter and this may also be sent as a part of the telemetry data. The triggering condition of this state also begins the spin up of the gyroscope so active control can begin and be in effect throughout the descent phases. There is no control of the active parachute in this state as it is not deployed and the drogue is just working on slowing down the CanSat.
   Thus, the DESCENT_P1 state marks the deployment of the drogue chute and the altitude detection algorithm generates an interrupt to deploy the steerable parachute mechanism.

6. State 5 - DESCENT_P2
   Triggering condition - the altitude reading of 500m
   The start of this state triggers the ejection of the main parachute which is responsible for the main control of the lateral motion of the CanSat as it can be actuated by the use of servos. The servo is controlled by the flight computer and it guides the CanSat to a designated GPS location that is yet to be determined.
   DESCENT_P2 is the most crucial and critical state which activates the

controls by attitude correction algorithm to steer the main parachute using servos.

7. State 6 - LANDED
Triggering condition - Stable reading on IMU and altitude
Upon landing the buzzer will start beeping and the video system may be turned off after a set duration to conserve power. This time is also used to check the logged data and generate the telemetry file on the SD card that can be retrieved later and analyzed post launch. All the sensor data polling might be stopped and the beacon may be the only active system along with the XBee that can constantly transmit GPS coordinates to help find it by location and also by use of directional antenna and RSSI along with XCTU.

3.4 Ground station

The ground station is mainly a laptop connected to an XBee and a portable patch antenna designed and tested in house. The software uses the QtApplication package of Python to run the GUI while classes that are called as widgets by this application are handled by the matplotlib package backend is tightly integrated to incorporate the XBee. Python plugins for XBee and the XBee class have been used to configure, set up and communicate with the XBees. Figure 10 shows an example GUI that is being developed at the time of writing.

Figure 10: Illustration of the Ground station GUI

The figure shows the plots of basic parameters such as speed, IMU and battery voltage as of now. The buttons are available to start and stop storage that lead to a .csv file that is logging all the data that is coming through the

XBee link. A button to command the CanSat to start telemetry is still in progress.

The XBee are used in API mode where the data is sent in the form of frames which have the following components to them. The frames have a field indicative of what their functionalities are and also convey what the data contained in them mean. Mainly the frames used here are API frame[4], the transmit command frame and the receive frame. The transmit status frame is also used but only internally by the libraries that generate the correct errors that can be caught and rectified.

Length		**Frame data**									**Checksum**
1	2	3	4	5	6	7	8	9	...	n	n+1
0x7E	MSB	LSB	API-specific structure								Single byte

Table 6: XBee API frame structure

These frames are mainly used as the communication blocks between the XBees in such a way that these frames are in correct order in which the receiver XBee is able to decode the transmitted packets. This is also done internally by the libraries by using the predefined functions that allow the correct frame patterns to be generated and then sent to the XBee through the serial communication.

The received data is handled by the ground station code by the method of polling. As data comes in at a particular frequency say 1 Hz, if the polling happens at a frequency higher than this rate multiple copies of a single data block is received causing duplicates, on the other hand if the polling happens at a rate slower than this, the data blocks are skipped. This is known as the aliasing problem and is common in most communication systems. This was also observed during testing.

In order to solve the aliasing problem the program is configured such that a timer is set that polls the input from the XBee exactly every 1 second thus solving this issue and making sure that all the data coming in was actually correctly received and interpreted.without any shift in the frames.

The antennas tested were having a radiation pattern as indicated in Section 5.5.3. The ground station antennas were designed and tested in house and consist of a 2x2 array of single feed patch antenna designed for 2.4 GHz. This is connected to the ground station using 4:1 RF power dividers.

4 Payload subsystem

4.1 Camera setup

The number of cameras on the CanSat currently stands at 2 and are mainly the live feed analog camera and the digital camera that shall be used to record the flight in high resolution.
Since these are off the shelf components, they are left to be procured in procurement phase 2 as highlighted in Table 5 and are bound to be changed if better alternatives are found later on. The current setup utilizes the following components.

4.1.1 Runcam Thumb

This is a digital camera responsible to capture the flight of the CanSat. It is capable of recording at up to 1080p at 60 fps. The camera also has a UART interface that allows it to be interfaced with the On board computer to turn recording on and off. This camera was specific built for the drone community and boasts the following features

- Resolution: 1080p 60FPS.
- Built-in Gyro (for Gyroflow)
- Powered by 5.0V (from USB or Power Port)
- Support Micro SD Card with up to 128GB capacity.
- Micro USB Port.
- Power consumption: At 5V, 200mA when standby, 280mA when recording.
- File format: MP4.

The excellent specifications make it an ideal choice for purposes such as this. This provides a very versatile camera that has a small form factor and is capable of excellent video footage.

4.1.2 Analog camera and video transmitter

The analog camera will be used to record the video that shall be transmitted to the ground station live on the 5.8GHz band. This camera is a COTS system that will be integrated onto the CanSat in the coming days. A suitable choice is yet to be finalized and is currently only ideated. An omnidirectional antenna shall be used to transmit the same. The interference that this might cause with the CanSat's telemetry link is scheduled to be characterized and is yet to be tested.

4.1.3 Runcam Split

This is a camera that is made to cater to both needs. It is capable of recording locally at 1080p 30 fps and at the same time, generate an analog feed to be transmitted to the ground station via the video transmitter.

4.2 Video transmitter

The video transmitter is the most critical component in the live video on the ground station. This component takes in the analog video signals and modulates them with a carrier in one of the channels from the 5.8GHz band.

The power of transmission can be controlled by setting the appropriate power level on the video transmitter. This is paired with an appropriate omni directional antenna ensures stable signal transmission from CanSat. Similarly high gain patch antenna on the ground station for video reception is described in section (add section here).

4.3 Gyroscope

A gyroscope is a large rotating mass that makes use of the properties of gyroscopic rigidity and gyroscopic precession. When an external torque is applied, the rigidity in space causes it to tend to stay in the same position. Gyroscopic rigidity is directly proportional to the moment of inertia I and to the angular velocity ω and it is therefore a function of the product $I\omega$. This product is termed "angular momentum ". When a torque is applied to the gyroscope in a plane perpendicular to the rotor, the spin axis acquires precession and counters the applied torque. The concept of a 2-frame gyroscope which was mentioned in the PDR stage is being used with a few design optimizations with complete clarity about the mechanism of working. Higher the rigidity of the gyroscope, lower is the precession. As maintaining stability is the main aim of the gyroscope in this case, we need to decrease the precession angular velocity. The precession by a gyroscope is given by the formula [2]

$$\Omega_z = \frac{\tau_{roll}}{I_r \omega_r}$$

here,
Ω_z is the precession angular velocity
τ_{roll} is the external torque
I_r is the moment of inertia of the flywheel
ω_r is the spin angular velocity of the flywheel

4.3.1 Design changes and updates from PDR stage

- A major change in the gyroscope from the PDR stage is the material used for the flywheel, gimbal ring, and the mount. Previously aluminum was chosen for its density which is neither too low nor too high. But considering the ease of machinability and flexibility for design optimization, Poly-lactic acid (PLA) is chosen as the material. With PLA, the components of the gyroscope can be easily manufactured by Fused Deposition Moulding (FDM) or 3D printing for any complex design.

- The previous design of the flywheel had a stepped type of cross-section which was not the most optimized design. The new design has a linear cross-sections from the center to the edge. The diameter of the flywheel continues to be 84mm. At the center, the wheel has a thickness of 3mm extending to a diameter of 20mm. Near the edge, the wheel has a thickness of 10mm extending from a diameter of 54mm to 84mm. The region between the thin and thick sections has a linearly increasing thickness from 3mm to 10mm which connects the thin and thick sections.

- With more thickness at the circumference, the Moment of Inertia of the flywheel increases, increasing the rigidity. The intermediate region is made linearly increasing so as to increase the stability of the gyroscope.

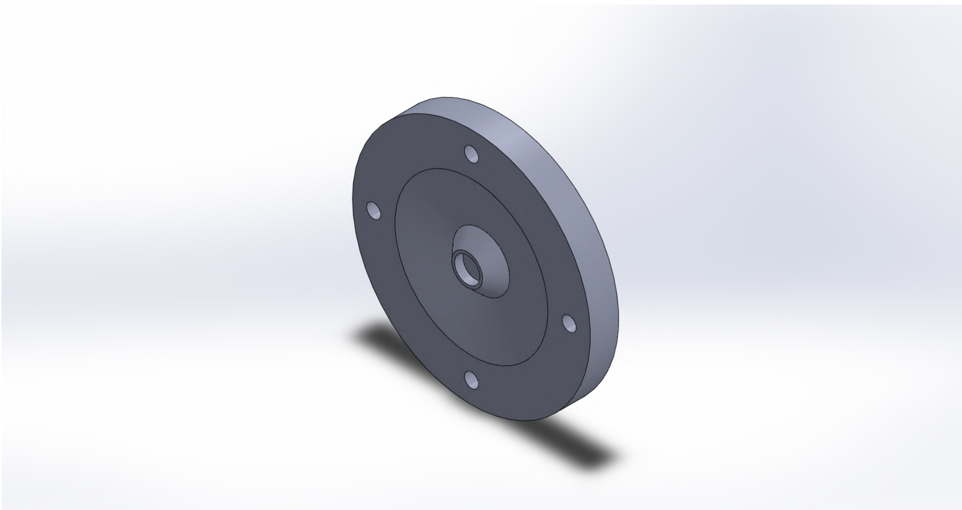


Figure 11: Isometric view 1

- As PLA has a low density of 1.2 to 1.24 g/cc, 4 metallic nuts and bolts will be fixed near the circumference to increase the Moment of Inertia. Holes for the same purpose are made on the flywheel which will be 3D printed. The moment of inertia obtained was 99245.62 gmm^2.

- The wheel will be driven by a DC motor which has a shaft of 2 mm diameter. On the other end, the wheel will be connected to the gimbal ring through a shaft. Ball bearings of 9 mm outer diameter and 3 mm

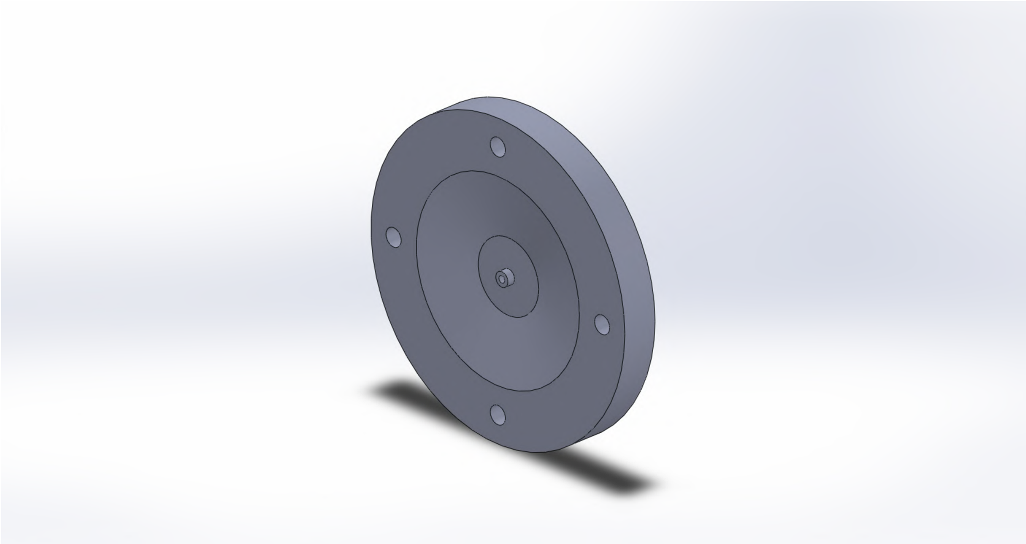


Figure 12: Isometric view 2

inner diameter will hold the shaft and the wheel and allow the wheel to rotate freely.

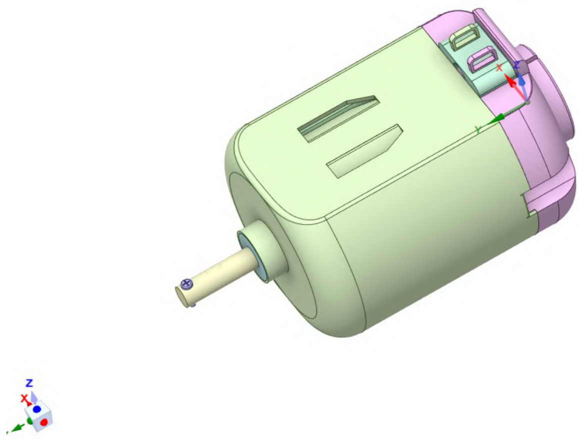


Figure 13: Motor CAD model

- The shafts used everywhere in the gyroscope setup have a standard 3 mm diameter and carbon fiber rods are used for the same.
- The same goes with ball bearings with 9 x 3 x 5 mm dimensions.
- The motor will be held by a motor holder which is also 3D printed.
- In order to actuate the gyroscope, the gimbal ring will be held by a string and will be pulled by a servo motor to actuate the gyroscope during flight. A small extension with a hole is given for the same on the gimbal ring.

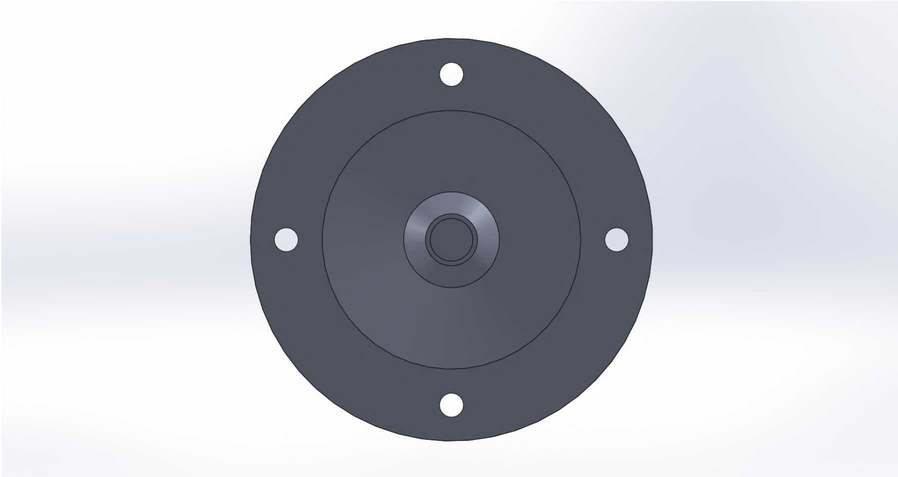


Figure 14: Front view

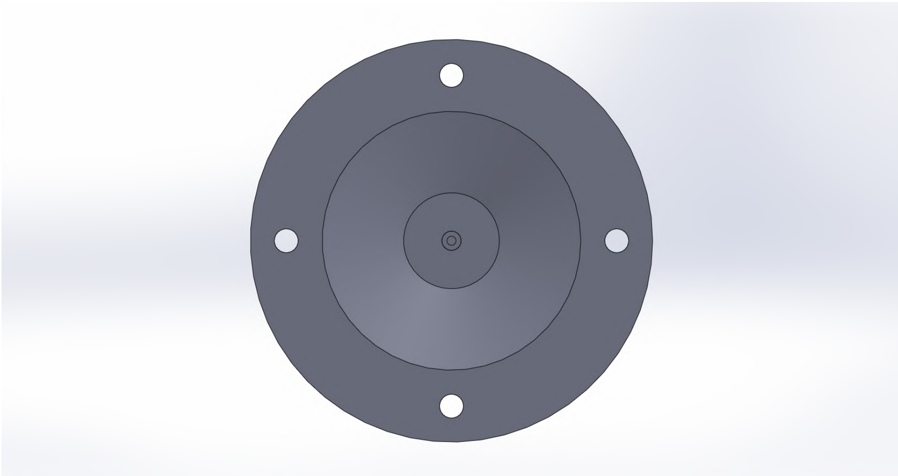


Figure 15: Back view

4.3.2 Dimensions

- Outer part thickness = 10 mm
- Inner part thickness = 3 mm
- Shaft diameter and bearing inner diameter = 3 mm
- Bearing outer diameter = 9 mm
- Diameter of holes for screws = 5 mm
- Inner part diameter = 20 mm
- Outer part diameter = 54 mm - 84 mm
- Gimbal ring thickness = 3 mm
- Moment of inertia = 99245.62 g mm^2

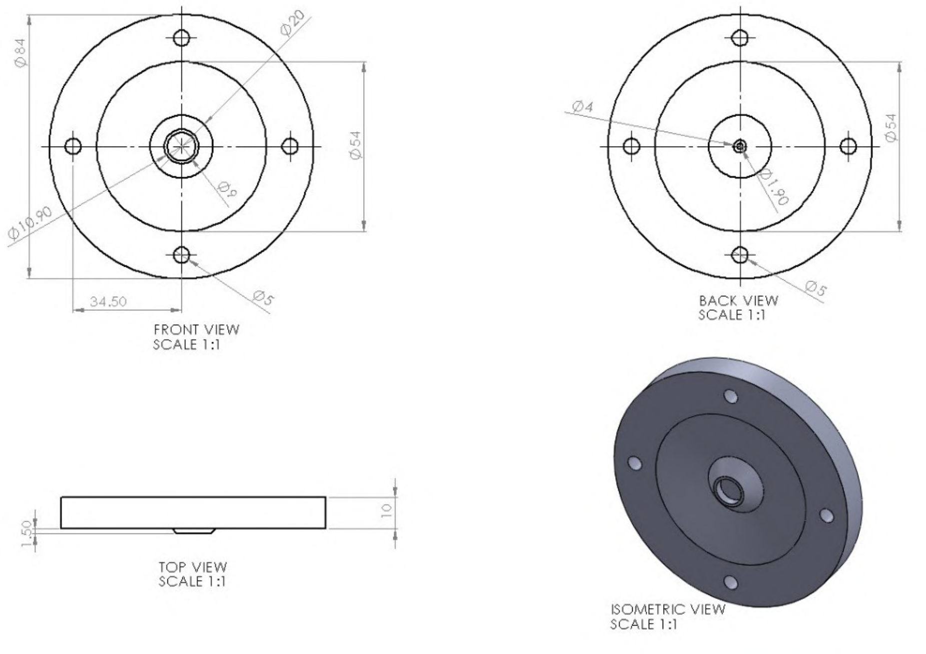


Figure 16: Flywheel dimensions

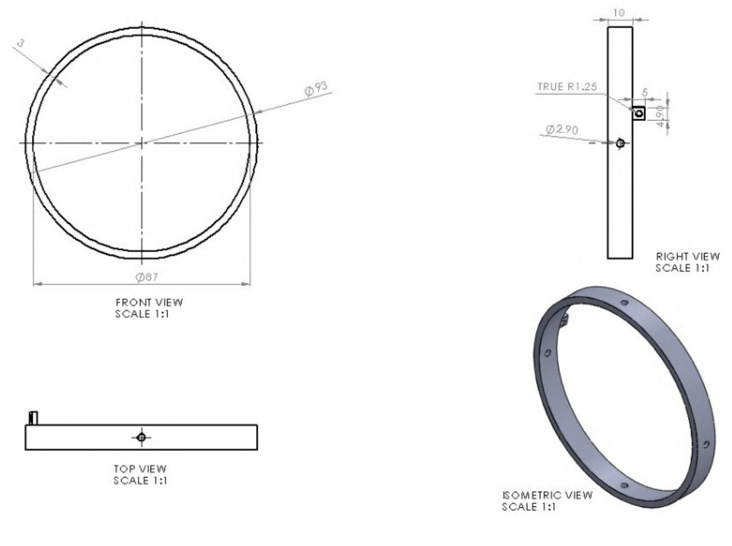


Figure 17: Gimbal ring dimensions

4.3.3 Design constraints

The mass and space limitations must be taken into consideration when designing a high rigidity gyroscope for the CanSat. Another limitation is the number of times the gyroscope can be produced with various designs to iterate various cases.

4.3.4 Subsystem tests

To test the working of the designed gyroscope mechanism, the flywheel, gimbal ring, gyroscope mount, and motor holder were manufactured using 3D printing with PLA as the material. One of the participants in the team owns a small-scale 3D printing machine which helps in increasing the rate at which we can manufacture prototypes and iterate for different design cases. The assembly of all the components was done using Carbon Fibre rods as the connecting rods and shafts. The ball bearings were fixed wherever required.

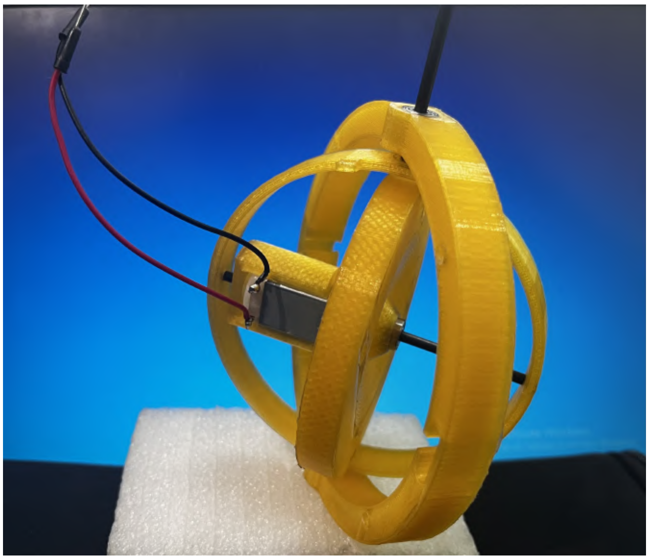


Figure 18: Assembled Gyroscope

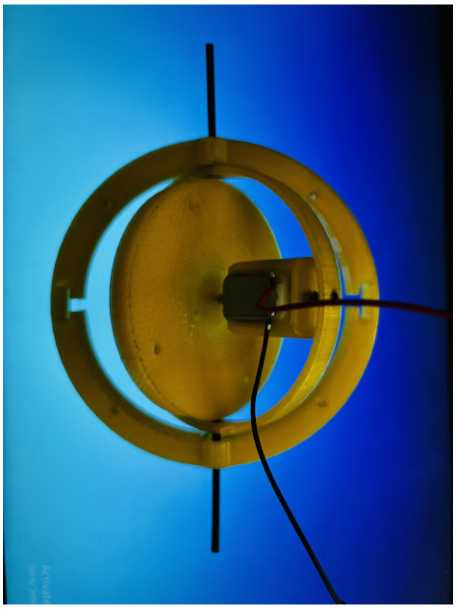


Figure 19: Assembled Gyroscope

The gyroscope was activated by running the motor and tested for its rigidity and resistance to rolling torque. The gyroscope successfully exhibits rigidity and reaction towards rolling torque. However, adding bolts in the holes provided in the flywheel and increasing the motor speed/rpm would yield better

results as the angular momentum of the gyroscope would increase.
Figure 20 shows the CAD model representation of the placement of the gyroscope in the CanSat body with the embedded mount.

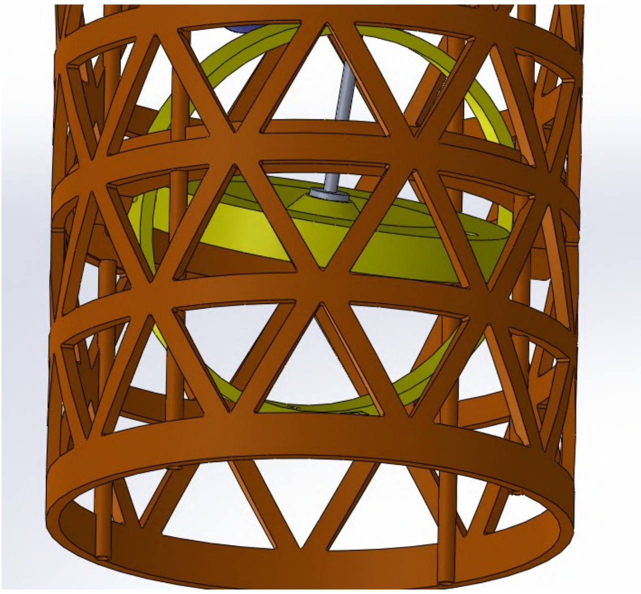


Figure 20: Gyroscope in CanSat body

5 Housekeeping subsystem

5.1 Recovery subsystem

Subsystem components: Recovery subsystem consists mainly of a drogue parachute, main parachute (Ram air), release mechanism and a main parachute actuating mechanism for descent control.

- Drogue parachute is externally connected to the CanSat main body, it is hemispherical and is made of ripstop nylon due to its tear resistance and high tensile strength.

- Main parachute is a Ram air parachute having an airfoil cross section for easy maneuvering. It is made of ripstop nylon.

- Release mechanism basically consists of a servo motor with four perpendicular columns passing through slots in the main CanSat body. When the right apogee is reached, the servo rotates the columns by 90 degrees unlocking the top and bottom half. This separation of the CanSat body into half will lead to deployment of the main parachute.

- Actuating mechanism consists of a servo motor connected to the control lines of the main parachute. The load bearing lines are connected to the bulkhead via u-bolt and the control lines are actuated by servo motor.

Theoretical Analysis

The tension from the drogue parachute shock cord will be used to bring about the deployment. At apogee of 500 m, the columns of the release mechanism will be rotated by 90 degrees which will prevent the load of tension being transferred to the bottom half of the structure. Due to gravity the bottom half will be pulled down, contrarily the top half of the CanSat will be pulled up by the the drogue chute, parachute being in between will be free to inflate. The drag equations for the drogue chute is given by Equation 1

$$F_D = 0.5 \times \rho \times A \times V^2 \times C_D \tag{1}$$

where,
F_D is the drag force (N)
A is the area of parachute (m^2)
V is the descent velocity (20 m/s)
C_D is the drag coefficient (1.5 for hemispherical shape)
ρ is the air density (kg/m^3)
m is the mass of CanSat (0.75 kg)
g is the acceleration due to gravity (9.8 m/s^2).

On calculation we get the area of the parachute as 0.02 m^2 and the diameter of the parachute is 0.16 m. Generally, the vent hole diameter is around 20% of the overall diameter of the parachute resulting in 0.032 m.

The drag equations for the main chute is given by the Equation 1 but in this case the area(A) is defined by the $l \times b$ of the parachute that has a rectangular cross section.

The aspect ratio of this main parachute is assumed to be 3, thus the length(l and breadth(b) are 0.96m and 0.32m respectively. This gives us a total area(A) of 0.3072 m^2.

Design Constraints

- The shock cords of the parachute have to bear almost 30g of acceleration during deployment.
- The drogue parachute should have a descent rate of around 20 m/s.
- The main parachute has to bring down the descent rate of the CanSat down to 3 m/s.
- The columns have to be strong enough to bear the tension of the drogue chute during descent.

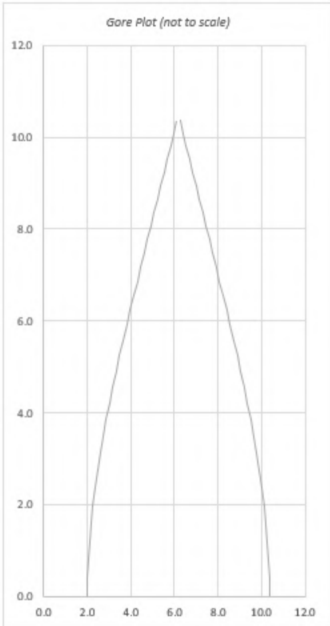


Figure 21: Gore plots of drogue parachute

- The servo has to bear the load of pulling out these pins. The servo exerts axial loads on the column while it is withstanding shear loads only.

Changes from PDR

- The main parachute shape has been changed to Ram air for easy maneuvering and accurate descent control.
- The CanSat will be split into two for main parachute deployment as discussed extensively before.

Subsystem level tests and results

- Drop test: the drogue parachute was manufactured using ripstop nylon and Paracord 550 suspension lines. A dummy payload of 700 grams was mounted to the parachute and was taken up to a height of 40m and then released. The time of descent was calculated which came up to 3.5s. It took around 2s to inflate and fell for 1.5s for a distance of 30m giving the drag coefficient to be around 1.65 which is very close to the assumed value of 1.5. The horizontal drift was about 20 m.
- Main parachute construction is being done and the dimensions of the parachute are checked with the ideal values and also for the airfoil shape.
- Once the construction of the main parachute is ready then the drop test has to be done again to validate the main parachute.
- The release mechanism has to be tested with and without tension.
- Actuating mechanism must be tested without any loads attached to it

and observe its ideal characteristics.

- Actuating mechanism with tension loads that shall test the strength and the reliability of the same.

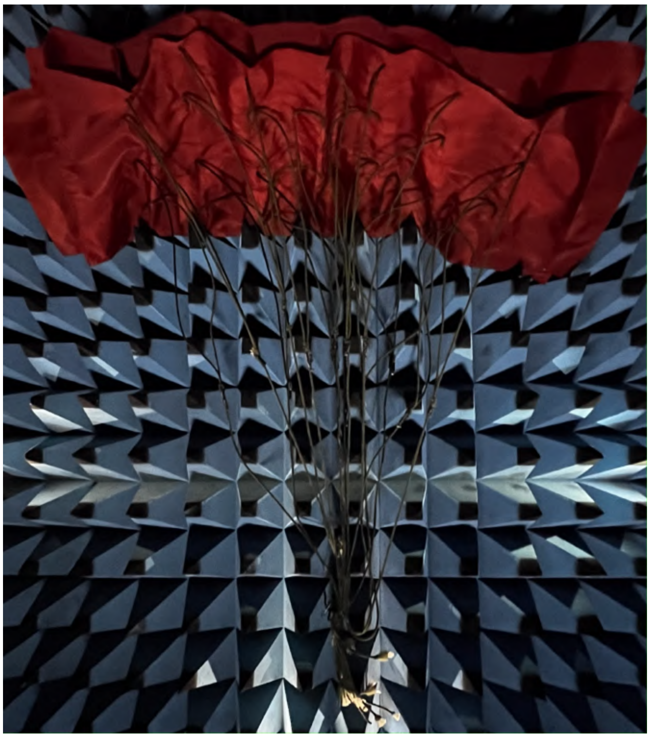


Figure 22: Parachute

5.1.1 Release mechanism

The main parachute is deployed by separating the CanSat into two halves. The mechanism to separate the two halves consist of a servo motor connected to the columns as shown in the figure 23. These columns are interlocked with the other section through extruded mounts that pass through the bulkhead as shown.

The weight and the tension forces will be a shear load to the columns and accordingly, the cross-section is chosen as rectangular. The rotation of the columns in the clockwise direction will release the contact between the slots on the extrusion of the upper half and the columns of the bottom half. As a result, the tension force due to the drogue parachute will pull the upper half of the CanSat up.

Meanwhile, the gravitational force will pull down the lower portion, in turn separating the CanSat into two halves. Once the separation is done, the main parachute will have room to come out and inflate leading to main chute deployment. The servo motor is driven by the onboard computer which triggers the working when an altitude of 500m is achieved during descent.

Thus, with the help of the tension force of drogue parachute, shear loads of the columns and motion of the servo motor the deployment of main parachute is achieved in a novel and controlled manner. No part of the Rocket Air-frame is used during the CanSat operation.

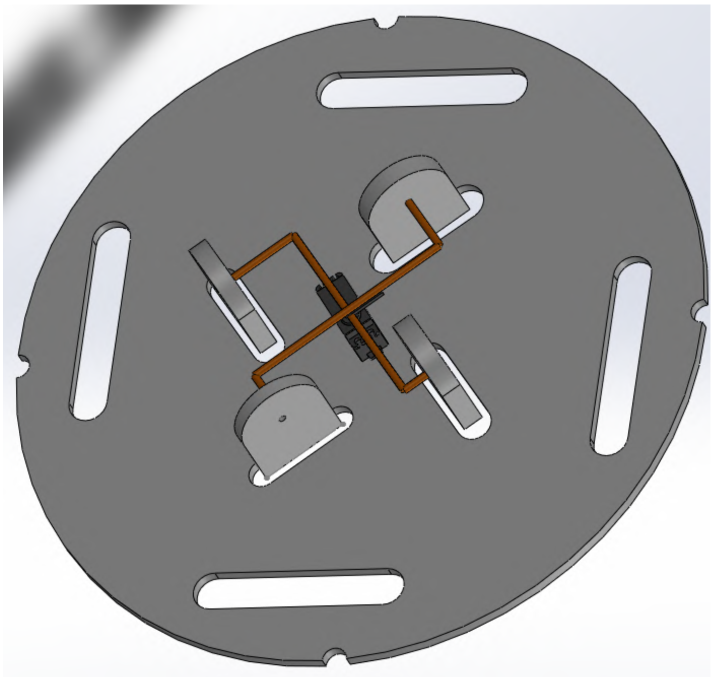


Figure 23: Release mechanism

5.2 Mechanical Subsystem

Mechanical subsystem mainly consists of structural components which includes Chassis/ body of the CanSat , Mount , load bars , electronic components(PCBs , sensors , antenna , batteries).

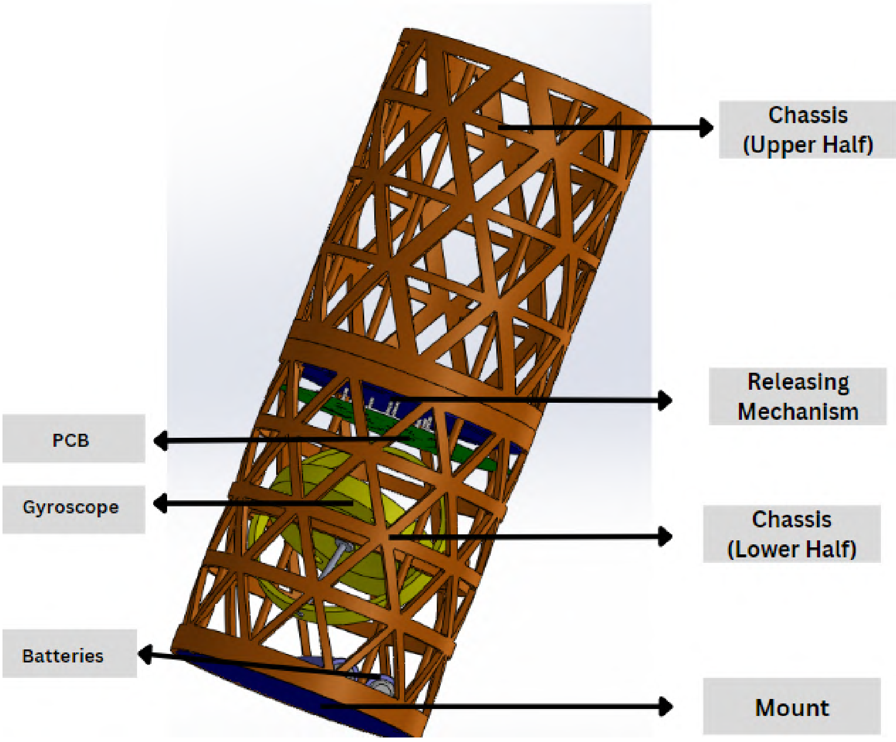


Figure 24: Assembly of all the components in CanSat body

Chassis

The chassis consists of a series of triangular holes which can be considered as trusses. These trusses can take vertical loads to the maximum extent. The structure is being divided into 2 parts of equal length so as to maintain the structural integrity and also solving the issue of the manufacturing constraint. Triangular pattern in the cylinder distributes loads more evenly, reducing the risk of concentrated loads and increasing the overall stability of the structure. As it is divided into 2 parts the upper part is where the parachute is being stored and the lower part consists of a series of components viz. Gyroscope , PCB , Battery , Antenna , Recording camera ,release Mechanism.The Chassis will be covered with Neon Orange coloured polymer casing to aid in recovery.

Dimensions for the chassis

- Outer Diameter : 120mm
- Inner Diameter : 114mm
- Thickness : 3 mm
- Depth : 300 mm (150 mm of upper half and 150 mm of the lower half)

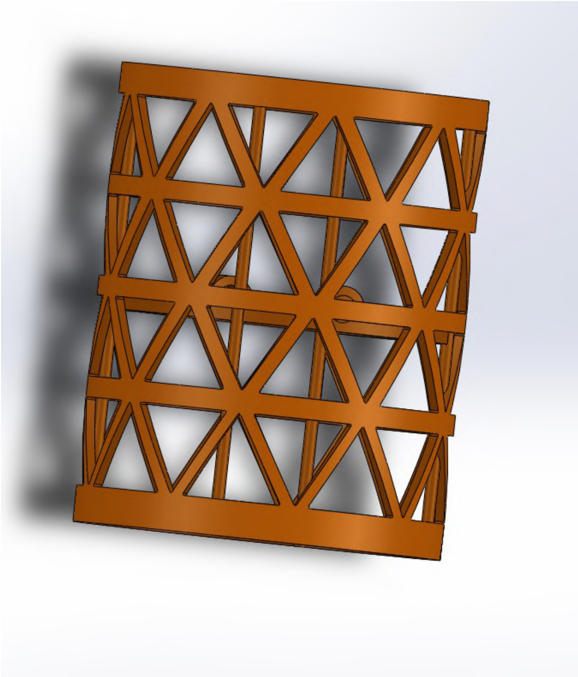


Figure 25: Chassis Lower Half

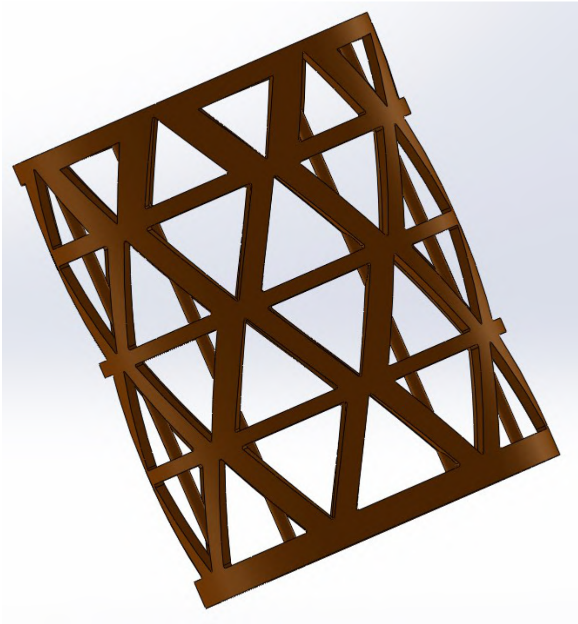


Figure 26: Chassis Upper Half

Mounts

These are used to place the electronic components which include antenna, sensors, gyroscope, parachutes and battery for powering the sensors. These components will be hard mounted to the bulkhead.

The dimensions of the mounts are as follows

- Diameter : 114mm
- Thickness : 4mm

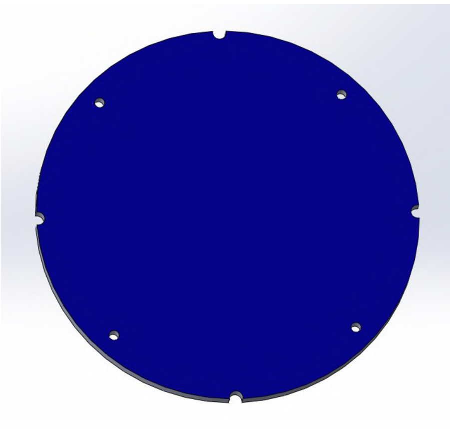


Figure 27: Mount

5.2.1 Analysis

The structural analysis of the whole body was done as there were changes from the previous model. This includes Static Structural Analysis and Modal Analysis.

Static Structural Analysis

As per the report the body was needed to handle 30g of shock and 15g of launch acceleration. The analysis of the body was performed considering PLA as the material of the body.

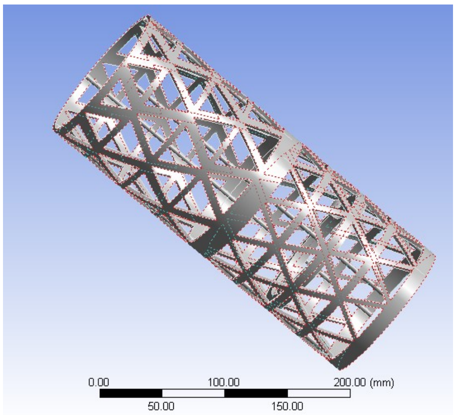


Figure 28: CanSat Body

Boundary Conditions

In the analysis, acceleration of 30g is applied on the CanSat body , fixed support is kept at the end face and force of 300 N is applied all over the body.This ensures that even at the extreme conditions our CanSat body remains intact.

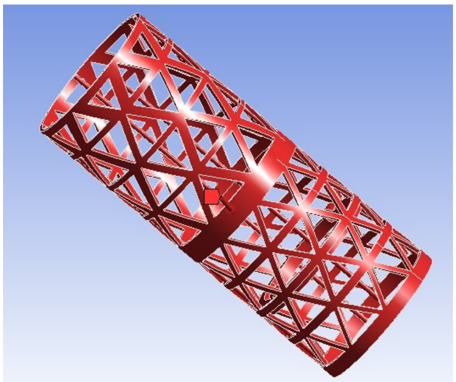


Figure 29: Boundary Conditions

Results

The results generated are given in Table 7, 8

Time(s)	Minimum(mm)	Maximum(mm)
1	0	3.095

Table 7: Deformation result

Time(s)	Minimum(MPa)	Maximum(MPa)
1	2.0532e-3	32.419

Table 8: Stress

Modal Analysis

Modal Analysis is the frequency analysis done on any body to obtain its natural frequencies and corresponding mode shapes. Modal analysis on the CanSat chassis setup was performed by using Lightweight PLA (Polylactic Acid) for the Cylinder body in ANSYS software.

Boundary Conditions

Here the number of mode shapes defined were 10 and frequency range were set to automatic. The fixed support for the cylindrical body was defined and the results were generated.

Results

A total of ten modal shapes were generated and the natural frequencies of the CanSat body and are indicated in Figure 30

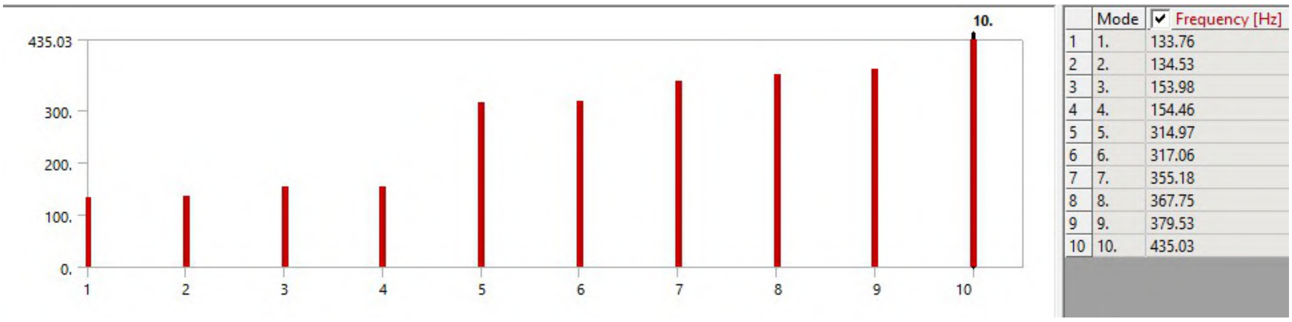


Figure 30: Modal Frequency

5.2.2 Mass Budget

Sl No	Component Name	No of Units	Weight of 1 unit (g)	Total Weight (g)
1	Sensors+Antenna	1	50	50
2	Battery+Casing	1	115	115
3	Gyroscope	1	94.77	94.77
4	Servo Motors	2	15	30
5	DC Motors	1	75	75
6	Primary and Secondary Recovery Systems	1	170	170
7	Mounts	1	40.1	40.1
8	Chassis(upper half)	1	79.37	79.37
9	Chassis(lower half)	1	95.48	95.48

Table 9: Mass Budget

The total mass of the whole CanSat body including the electronics and structural components came to be **749.72 g**

5.2.3 Changes from PDR :

- The outer body/chassis hole pattern was changed from Hexagonal pattern to triangular pattern
  The reasons being :
  1. Triangular holes can use less material compared to honeycomb while still providing the same level of strength and stiffness.
  2. They are easier to manufacture than honeycomb as they do not require a specific alignment or geometry to be maintained.
  3. They provide a more uniform distribution of material , leading to increased stiffness and strength compared to honeycomb structures.
- The outer diameter of the cylindrical body was changed from 125mm to 120 mm , as the initial dimensions led to very low clearance values which may cause disturbance to the smooth detaching mechanism from the rocket.
- The load bars are being embedded to the chassis during manufacturing rather than the external load bars as it increases the structural rigidity and helps the vertical loads to be distributed more equally.
- The gyro mount was embedded directly into the lower half of the chassis to reduce the weight and lower the usage of external components to attach the mount to the chassis.

5.3 Electrical and power subsystem

The subsystem is an important component in the proper and adequate delivery of power to each and every electrical component on the CanSat and therefore is a critical aspect of the working of the CanSat. This is ensured by splitting the power into different buses so that each bus can be allocated to a particular component/s.An external power switch with an indicator light is used to avoid de-assembling of CanSat on the launch pad. This division of power is highlighted effectively in the flowchart as given in Figure 31

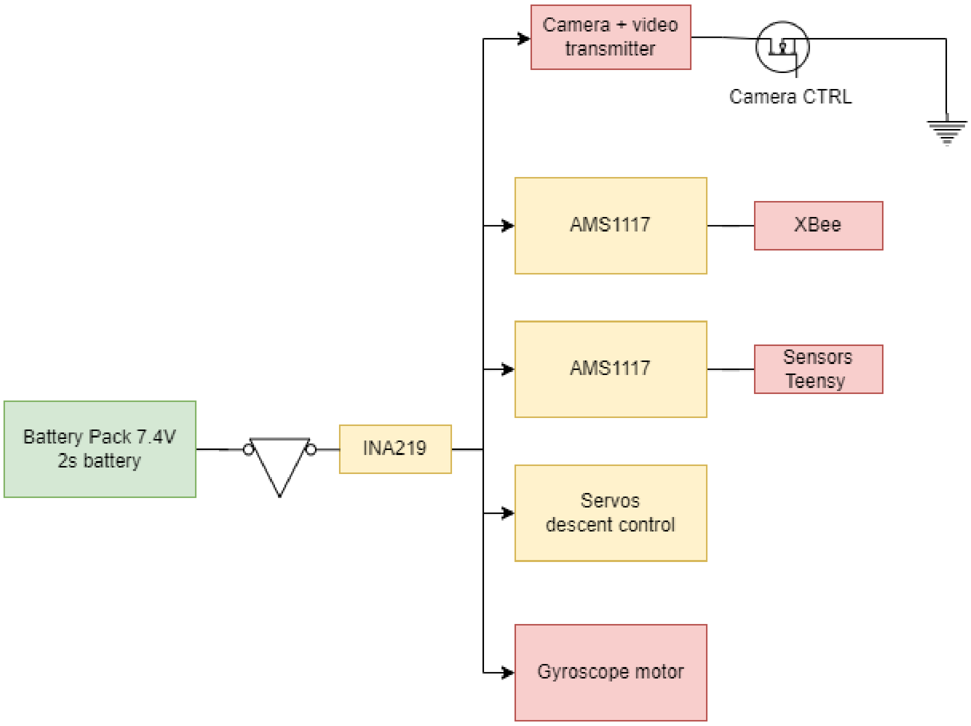


Figure 31: Block diagram of power circuitry

Changes since PDR

The procurablility of the Li-Mn batteries previously chosen was an issue in phase 1 procurement and therefore the choice was made to switch to an equally good 18500 Li-ion battery. Two such cells shall be used to make a battery pack that will be used to power the CanSat.

The power budget is computed for the spad standby mode where it must last 2 hours. This is not the full power mode of the CanSat. The assumptions in this calculation include

- The servos are consuming standby current.
- The motor is consuming zero current and the motor driver is consuming standby current.
- The camera system and the video transmitter is turned off and consuming zero current.

Component	Operating mode	Voltage(V)	Current(mA)	Time	Energy(Wh)
Motor		-	-	-	-
Servo		-	-	-	-
L298N		7.2	36	7200	0.5184
Teensy 4.1		3.3	50	7200	0.33
XBee S2C pro	Continuous transmit	-	-	-	-
	Standby receive	3.3	31	7200	0.2046
Servo		-	-	-	-
Live video Transmitter		-	-	-	-
Camera		-	-	-	-
BM388		3.3	0.8	300	0.00022
MPU6500	Normal mode	-	-	-	-
	Standby	3.3	1.6	7200	0.01056
Quectel L89		3.3	99	300	0.027225
				Total	1.091005

Table 10: Power budget in launch pad standby

1.091Wh is less than 4.07Wh therefore the required energy is less than or equal to the available energy and on standby strictly.

The given energy consumption of 1.091 Wh when compared against the 8.14Wh can last up till $8.14/1.091 = 7.46hrs$.

Design of the schematics and PCB

The shape of the PCB is a section of the circle and the other unused edges are cut off so that the battery and camera components can be accommodated. Also on this lower PCB lies the XBee and this way it can be closer to the power source and the antenna can be placed close to the bottom as well enhancing the performance of the XBee and ensuring a stable telemetry link. An LED shall be incorporated onto the power PCB to indicate power. The battery pack will be made by tap welding zinc strips onto the battery terminals and soldering wires to it. The Terminals of the wire shall incorporate XT60 connectors so that the connection does not use spring contacts. This shall mean a solid connection by using the XT60 which is tolerant to vibrations. Screw in switches shall be used to turn the CanSat on and off. The Power PCB also has pins to connect the main power bus to the INA219 for power monitoring.[3]

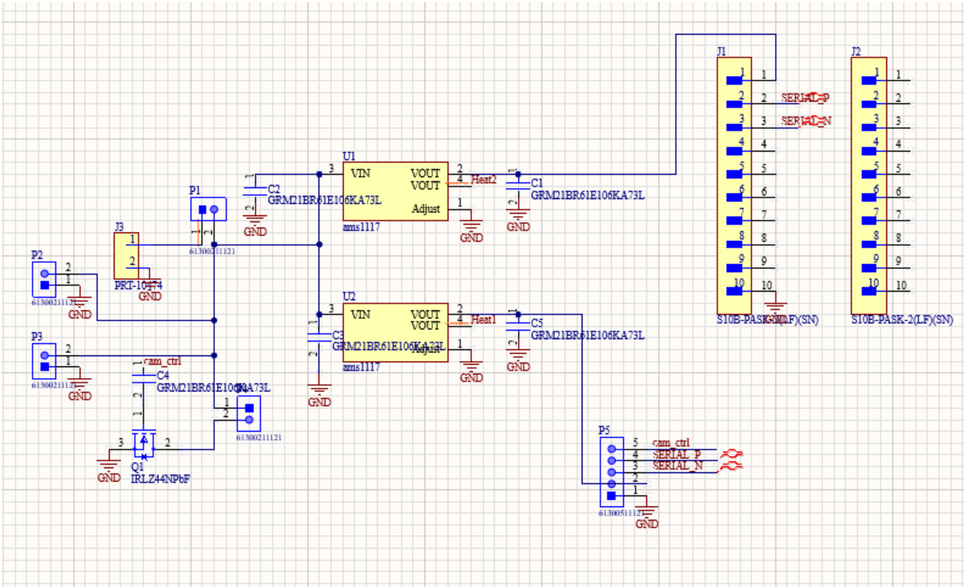


Figure 32: Schematics of the bottom mounted PCB

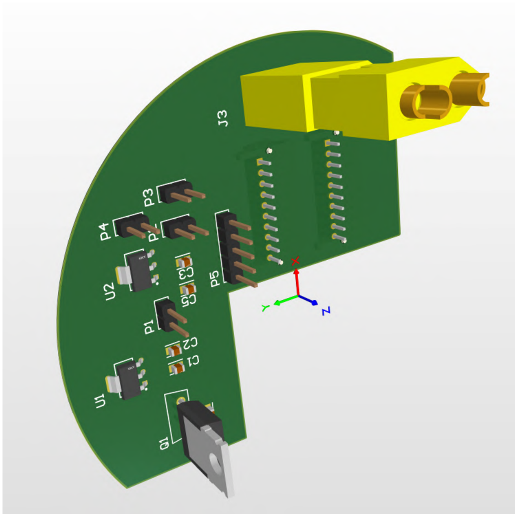


Figure 33: Model of the bottom mounted PCB

5.4 Sensors subsystem

The sensors and most of the electronics will be mounted on a PCB prototype board which is to be soldered further. The breadboard level testing for all the subsystem level tests has been successfully completed.
This PCB will collectively be referred to as the Flight Computer (FC). This flight computer consists of the following:

- Onboard sensors
- The connections in the form of soldered wires
- The power buses
- Downconverters and further circuits such as filtering circuits and connec-

tors for any other components off the board.

The detailed changes in the sensors subsystem include

- The FC is decided to be rigged and soldered on a PCB prototype board due to the ease in executing last minute changes.
- Another aspect that resulted in this decision was the fact that most of the sensors are commercially available for procurement with their evaluation module. This creates hassles in soldering the sensors and other components as they have to be de-soldered from their evaluation modules and re-soldered onto the PCB.
- The choice of PCB prototype boards enables direct soldering of the evaluation modules onto the board and thus serves as an optimal tradeoff between a breadboard and a PCB.

5.4.1 IMU unit

The mission objectives clearly state the importance of the calculation of orientation of the CanSat and acceleration in order to achieve stabilisation and also to determine the descent rate respectively. An Inertial Measurement Unit (IMU) is an electronic device that works by detecting linear acceleration using one or more accelerometers and rotational rate using one or more gyroscopes.

The chosen IMU should be able to measure accelerations precisely upto atleast ± 3g during the initial phases of the launch. The IMU should also determine the orientation of the CanSat in all three axes in order to validate the stabilisation mechanism.
The choice of IMU is due to the following reasons

- 6-axis Motion Tracking device that combines a 3-axis gyroscope, 3-axis accelerometer and a Digital Motion Processor (DMP)
- The triple-axis MEMS gyroscope outputs X-, Y-, and Z-axis angular rate to give the pitch, roll and yaw of the CanSat.
- Resolution of 16 bits which is high compared to other models in its same lineup.
- Light weight of about 2.1g
- Popular SPI protocol to interface with the micro controller.

The IMU will be calibrated to zero once the CanSat is accommodated in the launch vehicle on the launch pad.
No changes have been incorporated with respect to the IMU since the completion of PDR stage.

Subsystem tests

The MPU6500[5] was wired on the breadboard to Teensy 4.1 and was validated for acceleration and gyroscopic measurements. The IMU accelerometer was calibrated to (0,0,0) in all axes.

Test Case: The IMU was kept on a stationary table.

Parameter		Expected Results	Test Results
Accelerometer	X axis	0	-0.1
	Y axis	0	-0.1
	Z axis	0.98	1
Gyroscope	Pitch	0	38.74
	Roll	0	62.55
	Yaw	0	-64.00

Table 11: Test results for the IMU

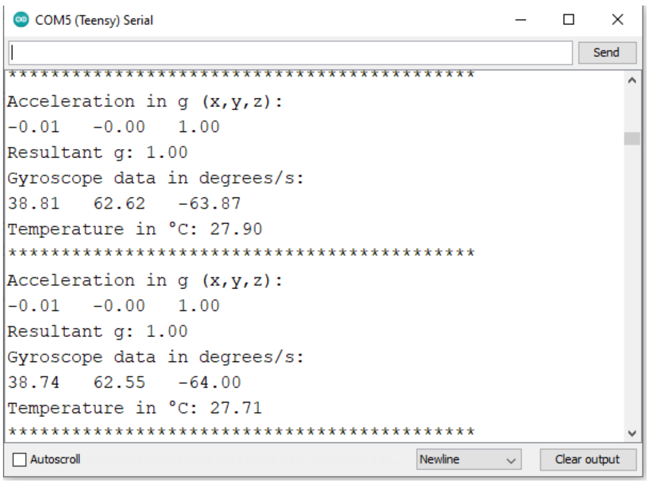


Figure 34: Screen capture of the data

Conclusions drawn from the above test

- The IMU was also tested for change in acceleration by manually peaking the sensor is various directions.
- Thus, the IMU readings are successfully validated with marginal errors.

5.4.2 Altimeter, temperature and pressure sensor

Altitude determination is a key factor in the recovery phase to initiate the deployment of primary and secondary descent control mechanisms. Pressure and Temperature measurements are also equally necessary to ensure the safe operation of the electronics, especially the battery.

The constraints of the choice of such components are mainly

- The chosen sensor has to be employed as a barometric altimeter. Thus, the resolution of the sensor has to be at least 8-10 bits in order to get precise pressure readings.
- It is advantageous as the altimeter has an integrated temperature sensor that avoids the usage of an external sensor for the same.

BMP280 is a high resolution absolute barometric pressure sensor, chosen because of the following specifications

- Provides extremely precise data output.
- Comes with an integrated temperature sensor which eliminates the need for an external temperature sensor, thus saving power consumption.
- The need for an exclusive altimeter is also redundant as the BMP280 can be used as an altimeter based on the barometric readings. The altitude is calculated using Equation 2
- The data interface is commonly used I^2C interface.

The equation governing the altitude and pressure is as given by the datasheet.[6]

$$Altitude(m) = 44330 \times (1 - \frac{P}{P_0})^{\frac{1}{5.255}} \tag{2}$$

Changes since PDR

The finalised selection of the barometric pressure sensor is the BMP280. This choice deviates from the PDR stage that states the use of BMP388. The team arrived at this decision due to

- Current unavailability of BMP388 in the market .
- Factory Lead Time of BMP388 would disrupt the timeline greatly, if opted to wait.
- BMP280 was an ideal replacement for BMP388 as the former is the predecessor of the latter and doesn't compromise on any of the primary selection parameters set by the team.

Subsystem level test results

The BMP was wired on the breadboard to Teensy 4.1 and was validated for pressure and temperature measurements. The raw data output by the sensor was converted to read the pressure in hector Pascal (hPa) and temperature in degree Celsius (℃).

Test Case: The sensor was subjected to indoor ambient conditions at room temperature (Location: Bengaluru)

Parameter	Expected Results	Test Results
Pressure	1015 hPa	987 hPa
Temperature	27℃	28.23℃

Table 12: Pressure and temperature readings of BMP280

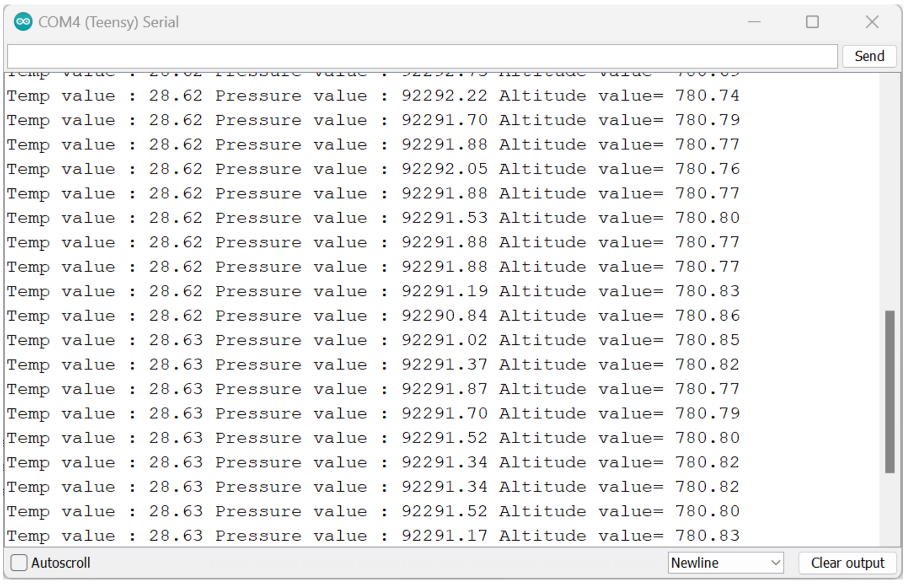


Figure 35: Screen capture of the data

Remarks of the above test results

- The temperature readings were validated by manually subjecting the sensor in the vicinity of heating elements.
- The tests were successful with marginal errors in the measurements.

5.4.3 Power monitor

All the electronic components housed in the CanSat are voltage sensitive. Over voltage and under voltage conditions might lead to the failure of these components. Malfunction of one of the sensors/ components might lead to the compromise of the entire mission. Hence it is an important aspect to measure the bus voltage to ensure the optimum functionality of every component on-board CanSat.

- The various sensors and components onboard the CanSat have their operating points varying from 3.3V to 5.5V. Hence it is extremely important for the chosen sensor to cover these voltages for measurement.

The INA239 is the chosen power monitor that reports current, bus voltage, temperature, and power, all while performing the needed calculations in the

Parameter	Expected Results	Test Results
Voltage 1	3.3V	3.30V
Voltage 2	5.0V	5.01V

Table 13: Test results of the INA

background. The sensor is chosen primarily because of its favourable specifications and no change has been implemented post PDR

- Accuracy: 0.7% full scale, providing the most accurate measurements of the power bus
- Common mode Voltage: -0.3V to 85V, which covers a wide span of voltages
- Resolution: 16 bit
- Data Interface: SPI/ I^2C

The INA219 was wired on the breadboard to Teensy 4.1 and was validated for current, voltage and power measurements. The raw data output by the sensor was converted to read the voltage in volts (V), Current in amperes (A) and power in Watts (W).

Test case: The Teensy power rails of 5V and 3.3V were measured with an LED load drawing current

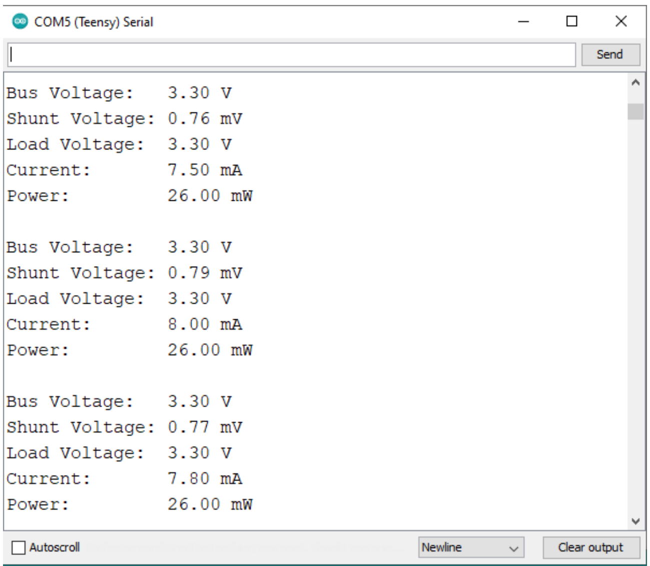


Figure 36: Screen capture of the data

5.4.4 Audio beacon

The CanSat has to be identified after the recovery phase. An audio beacon along with the characteristic colour and Team Logo is to be used as an aid of assistance to the ground crew of the team.

Design constraints are mainly that the chosen beacon should have a pressure level of 95 dBm.

The chosen beacon is CMI-1210-5 by CUI devices, a magnetic buzzer indicator that is 5V rated and has a continuous tone with a maximum sound pressure level of 95 dBm.

No changes have been incorporated with respect to the Audio Beacon since the completion of PDR stage.

The beacon (buzzer) was tested by initiating with a start command. The buzz was continuous and thus the test was successful.

5.4.5 On board computer

A controller unit is the brain of the CanSat that coordinates with the sensor subsystem, payload subsystem, and communication and Data Handling subsystem. The sensors will be interfaced to the controller, the data would be logged into the storage systems as well as sent to the CDH subsystem for telemetry at 1Hz.

5.4.6 GNSS

The geolocation of CanSat is one of the important telemetry data that needs to be acquired .A GNSS module is a device that provides geolocation data by receiving signals from multiple satellites of a GNSS constellation. The geolocation has to be calculated precisely and hence Quectel L89 Compact GNSS Module is used. L89 is a high performance GNSS module supporting multi-constellation GNSS and dual GNSS bands. It can acquire and track both GPS and Indian Regional Navigation System (NavIC).

5.4.7 Motor RPM sensor

The RPM of the motor is sensed by using an IR system as depicted in the schematic.

The system uses a black patch on top of the rotating disc that will cause a change in the reflective properties of the disc beneath and the black patch on top. The frequency of dip in the reflectivity indicates one full rotation of the disc. By measuring the time it takes for this to happen we can measure the time per rotation and therefore the RPM

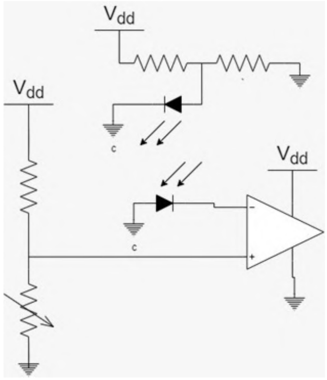


Figure 37: RPM sensor circuit diagram

5.4.8 Servo motor angle measurement

The angle of rotation of the servo motor during the descent control phase is measured by accessing a parallel connection to the servo output and connecting the same to the internal Analog to Digital Converter (ADC) pins (Analog pins) of the microcontroller and measuring the voltage, thereby calculating the angle.

5.4.9 Data Interface

Sl. No.	Component	Part No.	Interface
1	IMU	MPU6500	SPI
2	Altimeter	BMP388	SPI
3	Power Monitor	INA239	SPI
4	GNSS	Quectel L89	UART
5	XBee	XBee Pro S2C	UART
6	RTC	Teensy 4.1 RTC	I2C

Table 14: Data interfaces of sensors on board

5.4.10 Controller Unit

Design constraints

- The controller must have hardware resources and software support packages to support multiple data interfaces.
- It is advantageous to have an internal RTC.
- It is extremely advantageous to have the controller programmable using Arduino IDE as it significantly reduces the software development time.

Teensy 4.1 is the microcontroller, which houses an ARM Cortex M7 processor, chosen due to its low power consumption and sufficient processing capabilities. The specifications of Teensy 4.1 are

Sensor	Test status
IMU – MPU6500	Success
Altimeter, Pressure and Temperature sensor – BMP280	Success
INA219	Success
Motor RPM sensor	TBT
Audio Beacon	Success

Table 15: Subsystem level test results

- Arduino IDE compatible (teensyduino extension to be used), which reduces the embedded code development time
- 7936K Flash, 1024K RAM (512K tightly coupled), 4K EEPROM (emulated)
- Data Interface:8 serial, 3 SPI, 3 I2C ports providing protocol flexibility
- 1 SDIO (4 bit) native SD Card port, cancelling the need for external memory interface
- Internal Real-Time Clock (RTC) for date/time
- The Boot Time is 0.3ms which makes the hardware response quicker.

Changes from PDR stage

- Teensy 3.6 was chosen as the controller during the PDR stage.
- Due to the unavailability of the same, the team decided to upgrade to Teensy 4.1.
- Teensy 4.1 is indeed computationally more powerful than Teensy 3.6 and hence does not compromise on the primary selection features that the team had listed out.

Subsystem level tests

Embedded codes were written using the Arduino IDE to interface different sensors to Teensy 4.1. The same were dumped to the controller using the teensyduino extension package. The interfacing schematic of all the sensors to Teensy 4.1 is shown in Figure. Physical breadboard testing for all the sensors has successfully been carried out, and the test results are satisfactory.

5.4.11 Realtime Clock (RTC)

RTCs play an important role during telemetry of the sensors' data of the CanSat. Hence reliable and precise RTCs have to be used.

Design

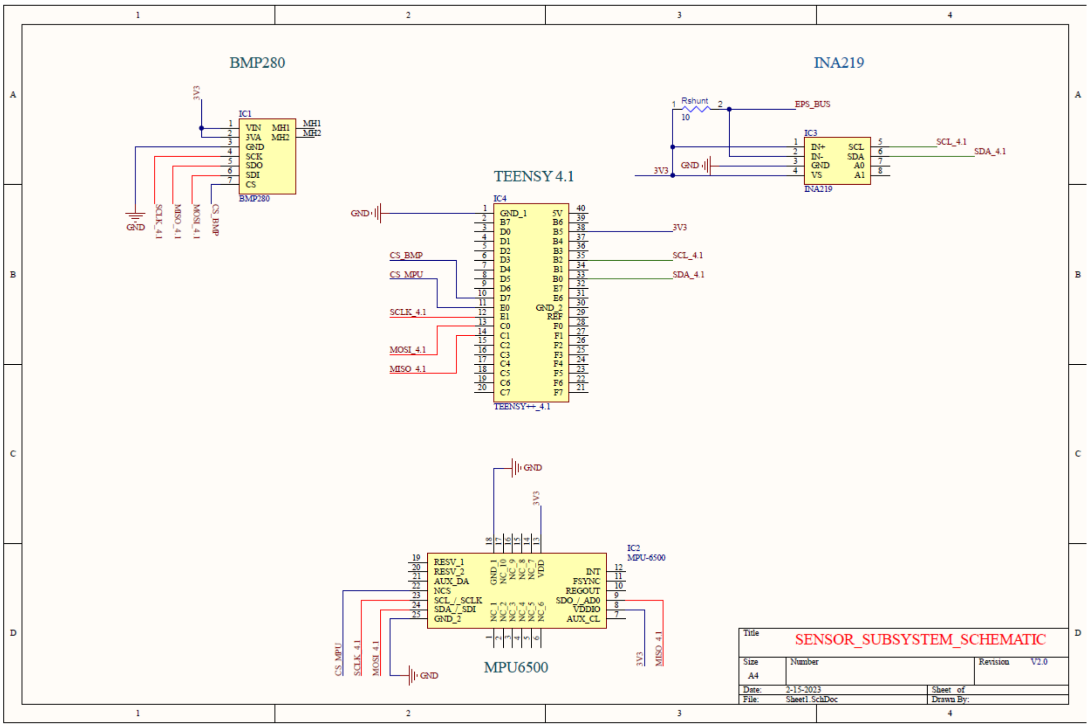


Figure 38: Schematic of the sensors and the controller

The microcontroller unit, Teensy 4.1, provides an Internal Real-Time Clock. As it is internal to the microcontroller, the procurement of an external RTC and interfacing it with control unit is avoided. The precision of the clock is more and the error is less as it is an internal hardware.

Changes from PDR stage

As the Controller unit was upgraded to Teensy 4.1 from Teensy 3.6, the RTC of Teensy 4.1 would be accessed for timestamping.

Subsystem level tests

The internal RTC of Teensy 4.1 is read using I^2C protocol. The output is indicated in Table 15

5.4.12 Memory interface

The sensor data has to be logged onto a memory device. SD cards and EEPROMs are two widely used memory devices to store data.

Design

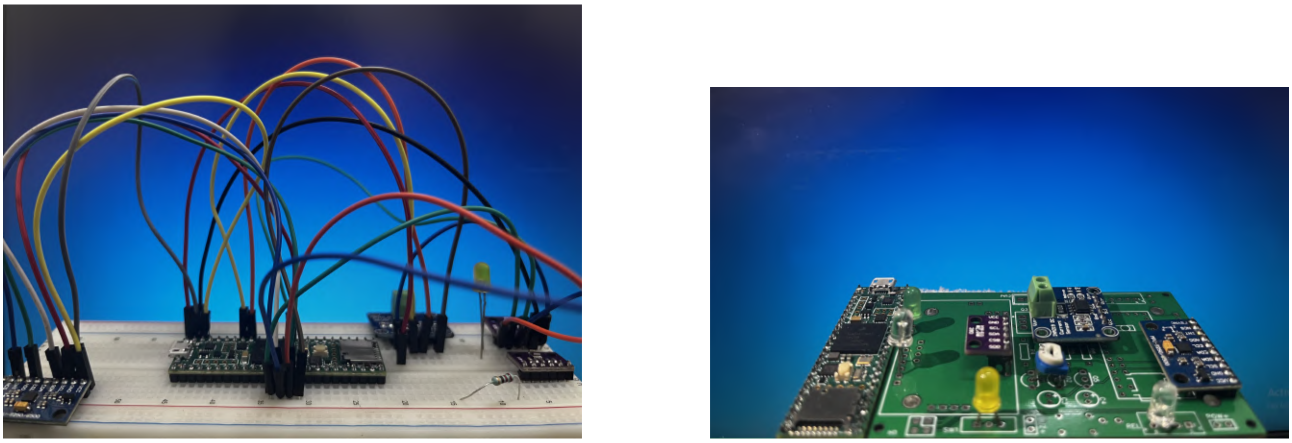
The microcontroller, Teensy 4.1, has an internal MicroSD card interface which makes it easier to use. SD card is chosen over EEPROMs due to the ease in interfacing and writing data. SanDisk Ultra 16GB MicroSD card is the selected SD card as the memory storage capacity is sufficient to log all the sensor outputs from launch to recovery.

Changes from PDR stage

No changes have been incorporated with respect to the Memory interface since the completion of PDR stage.

Subsystem level tests

The sensors' test measurements are datalogged onto the SD card by making use of the SD.h library in the Arduino IDE. The figure _ depicts the .csv file of the logged sensor data.



(a) Breadboard model of PCB

(b) Actual PCB

Figure 39: Flight computer iterations

5.5 Communication and Data Handling Subsystem

5.5.1 XBee

The XBee is the main telemetry link from the CanSat to the ground station and is key to ensure the successful transmission of data happens back and forth allowing the team to control and monitor the CanSat's functionalities. The chosen XBee modules are the XBee Pro S2C and are chosen for the following reasons.

- Comes in the familiar XBee form factor with an SMA connector for the antenna.
- The XBee operates on 2.4GHz ISM bands and therefore requires no ham licenses.

- It has a maximum transmission power of 63mW which ensures that the signal is pushed effectively into the antenna.
- Claims an outdoor LoS range of about 3200m which is far greater than the mission requirements.
- Common UART protocol for the communication with the

The XBees are operating in (Application Peripheral Interface) API mode mainly as it provides much better communication interface with the XBees with frames that consist an amount of overhead in order to ensure the data sanity and error free data. Secondly, all libraries need the XBee to be set up to use API mode. This also has the following frame structure.

5.5.2 Antenna onboard the CanSat

Theoretical analysis

Antenna on board the CanSat should be in a position to transmit power uniformly in all directions i.e., omnidirectional, as the line-of-sight between the CanSat and the ground station is indeterminate. The antennas are placed inside the CanSat body walls. Hence, the antenna gain and polarization has to be carefully chosen such that the link margin is satisfactorily maintained.

Design constraints

- The antenna gain has to be at least 3dB to maintain the link margin.
- The form factor has to less than at least half of the CanSat height (15cm) to easily accommodate it inside the CanSat body.
- It should possess omnidirectional radiation pattern.

Dipole antennas would be the first instinctive choice, as they exhibit near isotropic radiation pattern. The band selected for telemetry is the 2.4GHz - 2.5GHz ISM band due to the requirement of high bit-rates and to limit the form factor of the antenna due to dimensional constraints of the CanSat. The antenna selected is the LWC-2400-RD-RA-SMA-PLUG-03 3dBi omnidirectional antenna which is compatible with the XBee S2C Pro module having RP-SMA connectors

- Weight 10 g
- Length 11 cm
- Gain 3dB

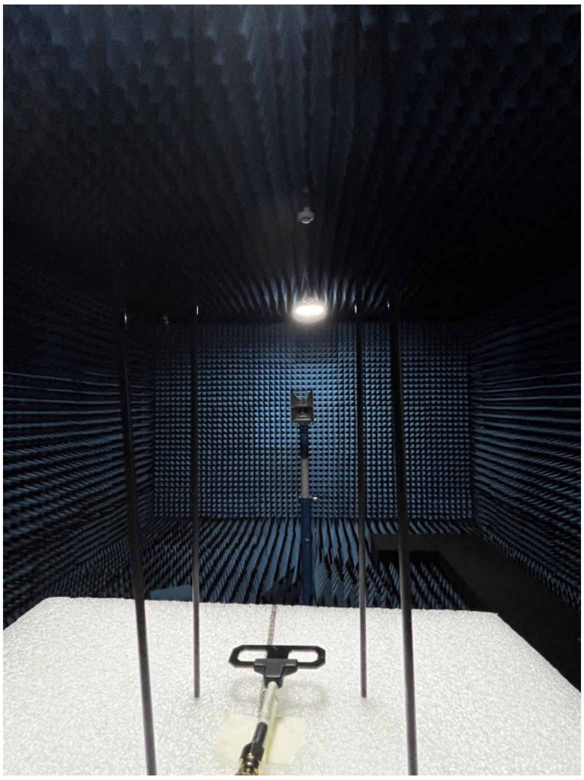
Changes since PDR stage

The onboard antenna was proposed to be VERT2450 during the PDR stage.

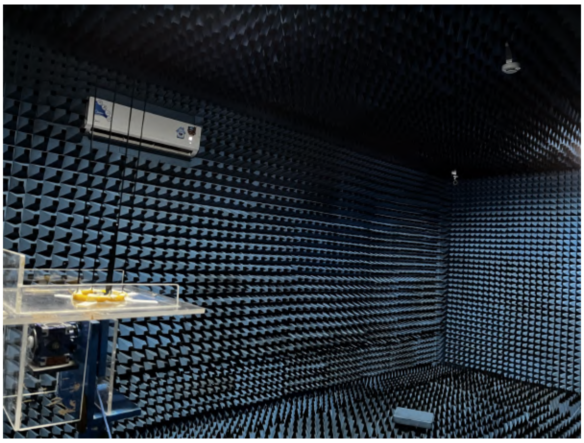
The team decided to use LWC-2400-RD-RA-SMA-PLUG-03 as a replacement for VERT2450 due to the following reasons

- VERT2450 was unavailable for procurement in India.
- The team had to bear additional shipment charges and custom duties, if VERT2450 had to be internationally procured.
- LWC-2400-RD-RA-SMA-PLUG-03 serves as an ideal replacement for VERT2450 as both operate in the same frequency band, possess similar radiation pattern and more importantly, the former is readily available for commercial procurement in India.

The team is also experimenting with a Moxon antenna design that is COTS and the comparison between the monopole and the moxon antenna.



(a) Test setup for radiation pattern characterization of moxon antenna with carbon fibre rods

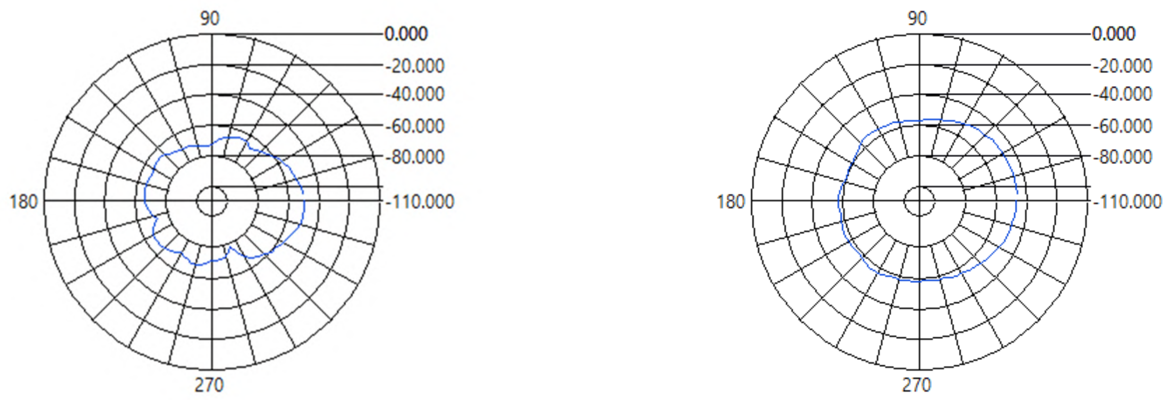


(b) Test setup for radiation pattern characterization of monopole antenna without carbon fibre rods

Figure 40: Testing of monopole and moxon antennas

Test case 1

The antennas are tested and validated for isotropic radiation in the Centre of Excellence: Smart Antennas Systems and Measurement (CoE-SASM) Anechoic chamber facility at RV College of Engineering. The radiation pattern of the antenna is shown in Figure 41(a)

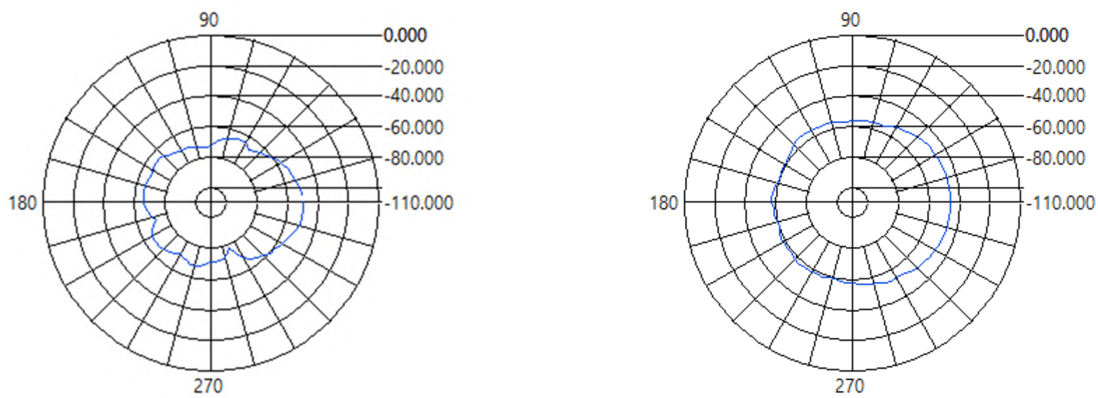


(a) Dipole radiation pattern (b) Moxon radiation pattern

Figure 41: Radiation patterns without the carbon fibre rods

Test case 2

The antenna is tested and validated for its radiation when kept inside the CanSat body. The body wall of the CanSat is 3D printed out of PLA which is non-shielding for the radiations. The radiations are expected to digress from their ideal characteristics due to the carbon fibre load bars that support the cylindrical wall of the CanSat. Therefore, the dipole is mounted inside a transparent enclosure supported by the four carbon fibre load bars and validated for radiation in the Centre of Excellence: Smart Antennas Systems and Measurement (CoE-SASM) Anechoic chamber facility at RV College of Engineering. The radiation pattern of the antenna is shown and the comparison is done below.



(a) Dipole radiation pattern (b) Moxon radiation pattern

Figure 42: Comparison of radiation patterns with the carbon fibre rods

- The radiation patterns obtained for the chosen dipole with/ without the interference of carbon fibre load bars, closely overlap on each other.

- Thus the dipole is validated to be used for transmitting data when placed inside the CanSat body.

Based on the above tests, we can conclude that a moxon antenna is better than monopole and therefore we have chosen a moxon antenna to

5.5.3 Ground Station antenna

The Ground station hand held antenna has to be directional in order to maintain constant communication link with the omnidirectional transmitting monopole. The antenna also must provide higher gain in order to maintain decent link margin. **Design constraints**

- The gain of the antenna has to be atleast 10dBi in order to maintain sufficient link margin
- The antenna should be handheld and directional to maintain LOS with the transmitting monopole, hence array antennas are preferred.

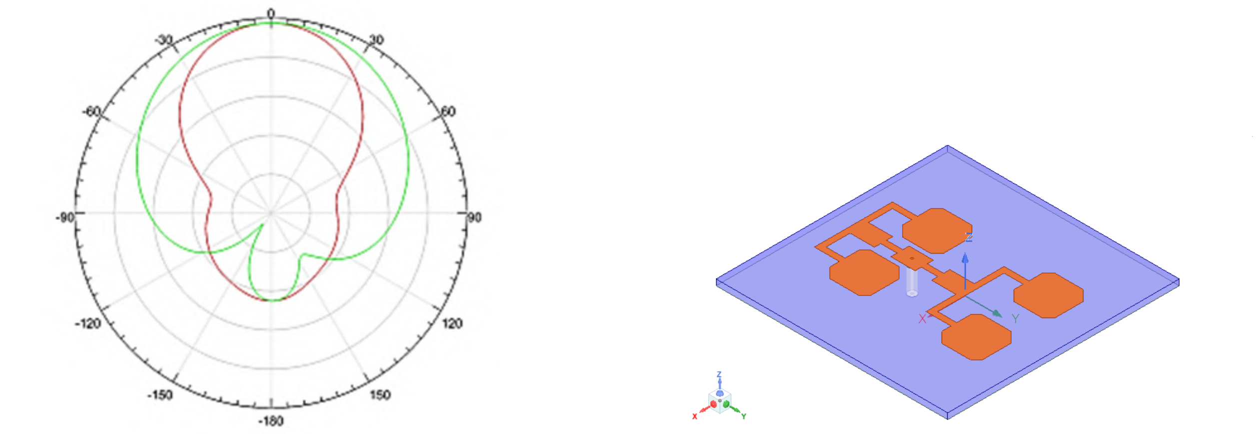
Design
A 2x2 array of corner truncated microstrip patch antenna is used as the Ground Station Receiver. The specifications of the receiver are as follows

- Dimensions: 8 cm x 8 cm
- Directivity (Individual patch): 7.24 dBi
- Array gain: 12 dBi

Changes from PDR stage
No changes have been incorporated with respect to the Ground Station antenna since the completion of PDR stage.

The 2x2 array version of the antenna is tested and validated in the Centre of Excellence: Smart Antennas Systems and Measurements (CoE-SASM) Anechoic chamber facility at RV College of Engineering. The radiation pattern of the antenna is shown in Figure 43(a)

- The intended gain was practically validated by calculating the receiver gain (array antenna) from the radiation pattern obtained, by considering the calibrated transmitter (horn antenna) gain and cable losses used while testing.
- The 2x2 version of the corner truncated array antenna has been simulated and optimised. The array antenna is under the fabrication process and would be tested once fabricated.



(a) Radiation pattern of a 2×2 antenna array

(b) A 2×2 antenna array

Figure 43: Two images side by side

5.5.4 Link Budget

A link budget is an accounting of all of the power gains and losses that a communication signal experiences in a communication system[1] from the transmitter, through a communication medium (free space with respect to CanSat – Ground Station link), to the receiver. The communication link is depicted in Figure 44.

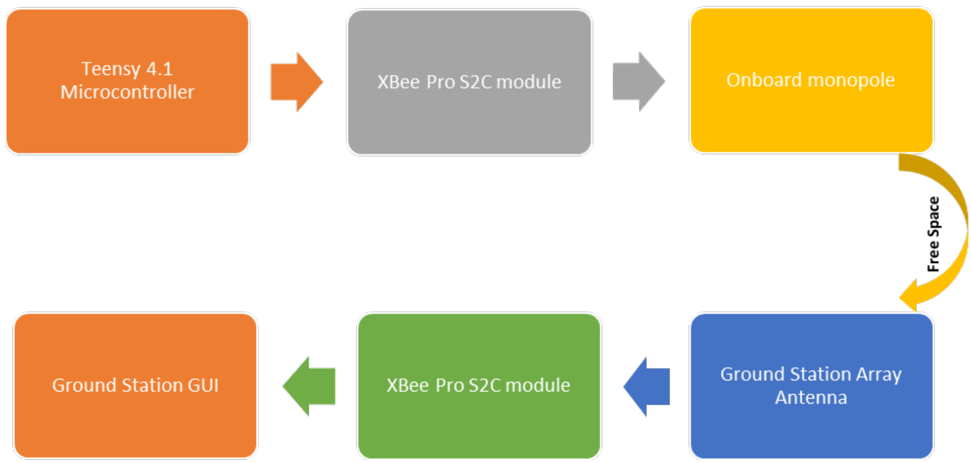


Figure 44: CanSat - Ground Station Communication

The communication between the CanSat and the ground station is considered to be direct Line-of-Sight (LoS) communication assuming the Ground Station would be in an open area. In this case, the probability of multipath propagation would be negligible. The Link Budget for the mission is calculated using the values given in Table 16.

Criterion	Value	Units
P_{rx} (Received power)	-52.63	dBm
P_{tx} (Transmitter power output)	18	dBm
G_{tx} (Transmitter gain)	3	dBi
L_{tx} (Transmission-end losses)	0.06	dB
L_{fs} (Free space path loss)	85.23	dB
G_{rx} (Receiver gain)	12	dBi
L_m (Miscellaneous losses)	0	dB
L_{rx} (Reception-end losses)	0.34	dB
XBEE Transmit power	18	dBm
XBEE Receiver sensitivity	-101	dBm

Table 16: Link Budget

- The values in bold are the calculated values using the required mission/ antenna parameters as input data
- The transmission-end (Ltx) losses typically is the connector losses, approximately 0.06 dB at 2.4GHz.
- Reception-end (Lrx) losses include connector and cables losses that account for 0.34 dB, inclusive of a 2 feet coaxial cable and connectors.
- Miscellaneous (Lm) losses are taken to be 0 dB, as in near ideal scenario.

From Free space path loss model, the free space path loss is calculated

$L_{fs}(db) = 32.45 + 20log_{10}(freq(MHz)) + 20log_{10}(dist(km)) - G_{rx} - G_{tx}$
$Frequency = 2400MHz$
Considering distance = 1000m = 1km, proving an error margin of 100m
$L_{fs} = 85.23dB$

From Friss Transmission rule , Received Power is calculated :

$P_{rx} = P_{tx} + G_{tx} - L_{tx} - L_{fs} - L_m + G_{rx} - L_{rx}$
$Therefore, P_{rx} = -52.63dBm$

5.5.5 Link Margin

In a wireless communication system, the link margin (LKM), measured in dB, is the difference between the minimum expected power received at the receiver's end, and the receiver's sensitivity.

$LKM(dB) = P_{rx}(dBm) - XBeeProS2CSensitivity(dBm)$
$LKM = -52.63dBm - (-101dBm)$
Therefore, $LKM = 48.37dBm > 20dBm$
This establishes a reliable communication between the CanSat and the ground station

Sl no.	Telemetry Parameter	Function	Resolution/ Format
1.	<TEAM ID>	Team Number	2022ASI-020
2.	<TIME STAMPING>	Time since the initial power	Seconds
3.	<PACKET COUNT>	Count of transmitted packets	
4.	<ALTITUDE>	Altitude in units of meters and must be relative to ground	0.1 meters
5.	<PRESSURE>	Measurement of atmospheric pressure	1 pascal
6.	<TEMP>	Temperature in Celsius	0.1 degree C
7.	<VOLTAGE>	Voltage of the CANSAT power bus	0.01 Volts
8.	<GNSS TIME>	Time generated by the GNSS receiver	Seconds
9.	<GNSS LATITUDE>	Latitude generated by the GNSS receiver	0.0001 degrees
10.	<GNSS LONGITUDE>	Longitude generated by the GNSS receiver	0.0001 degrees
11.	<GNSS ALTITUDE>	Altitude generated by the GNSS receiver	0.1 meters
12.	<GNSS SATS>	GNSS satellites connected	integer number
13.	<ACCELEROMETER DATA>	Data received from the gyroscopic sensor i.e acceleration and roll & pitch parameters	m/s2
14.	<GYRO SPIN RATE>	Spin rate of Mechanical Gyro With respect to CanSat	deg/s
15.	<FLIGHT SOFTWARE STATE>	Operating state of the software	(boot, idle, launch detect, deploy, etc.)

Table 17: Telemetry frame format

We, Team Titans have undertaken rigorous brainstorming sessions to ideate the innovative descent and gyro control mechanisms. The drogue and main chutes that will be used during respective descent phases have been designed with airfoil structures. The drop test has to be conducted to ensure the attainment of the desired terminal velocities. The stabilization of the CanSat would be through the two axis gyro wheel mechanism. The gyro-wheel and its holder ring have been 3D printed and tested for rigidity and functionality. All the onboard sensors except the in-house Motor RPM sensor and the GNSS module have been procured, calibrated and verified with measurements of known parameters. System level integration has to be done with the flight software to ensure the state machine retrieves the required readings from the sensors for telemetry. Telemetry module, XBee Pro S2C has been procured, configured and verified by transmitting and receiving test symbols. The same has been integrated with the ground station GUI such that all the required parameters are displayed in a user-friendly manner. The on-board Monox antenna is characterized in the Anechoic chamber of the Centre of Excellence: Smart Antenna Systems and Measurements. The ground station directional array antenna has been fabricated for 1x2 array structure and characterized in the same facility. The same has to be replicated to obtain the 2x2 array configuration to achieve increased receiver gain levels. The link budget and link margin have been estimated such that the transmission of data is never in fault. The same has been to be tested for LoS transmission to verify the obtained theoretical values.
The following section deals with the Compliances that are being followed.

6 Compliance

Sl. No.	Requirement	Satisifed	Section
1	Total mass of the CanSat shall be under 0.700 kg (+/- 0.050 kg).	YES	5.2.2
2	CanSat shall fit in a cylindrical body of 0.125 m diameter x 0.310 m height. Tolerances are to be included to facilitate container deployment from the rocket fairing.	YES	5.2
3	Any sharp edges on the container body shall be avoided as it can cause interfere during the CanSat ejection from the rocket.	YES	5.1.1
4	Color of the CanSat body shall be fluorescent i.e., pink, red or orange, and shall embody the Indian flag.	YES	5.2
5	Rocket Airframe will not be allowed to be used as a part of any CanSat operation.	YES	5.1.1
6	The CanSat shall consist of necessary sensors to provide the following mandatory Real-time datasets: Position data, altitude, pressure, temperature, orientation data, power data & system status.	YES	5.4
7	Each data field shall be displayed in real-time on the ground station user interface/software.	YES	3.4
8	CanSat shall also record the data and save it into an onboard SD card in case of telemetry connection loss	YES	5.4.12
9	All electronics shall be enclosed and shielded from the environment. No electronics can be exposed except for sensors. There must be a structural enclosure.	YES	5.2
10	CanSat structure shall be built to survive 15 Gs of launch acceleration & 30 Gs of shock.	YES	5.2.1
11	Electronic circuit boards must be hard mounted using proper mounts such as standoffs and screws. High-performance adhesives can also be used.	YES	5.2
12	Team number, email address and phone number must be placed on the structure in English, Hindi and the Regional language of the launch state to aid in recovery.	YES	

Sl. No.	Requirement	Satisifed	Section
13	An audio beacon shall be installed on CanSat as a recovery assist. It may be powered after landing or operate continuously. The audio beacon must have a minimum sound pressure level of 92 dB, unobstructed.	YES	5.4.4
14	The CanSat shall have an external power switch with an indicator light or sound for being turned on or off, in order to avoid the deassembling of CanSats on the launch pad.	YES	5.3
15	The CanSat shall have a battery capacity to support up to 2 hours of wait in on the launch pad with additional time for flight operations.	YES	5.3
16	The battery source may be alkaline, Ni-Cad, Ni-MH or Lithium ion. Lithium polymer batteries are not allowed. Lithium cells must be manufactured with a metal package similar to 18650 cells.	YES	5.3
17	An easily accessible battery compartment must be included allowing batteries to be installed or removed in less than a minute and not require total disassembly of the CanSat.	YES	5.3
18	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects.	YES	5.3
19	The CanSat shall contain a total of 2 descent control mechanisms, to be used at different stages while descent.	YES	5.1.1
20	CanSat shall immediately deploy the first parachute after ejection from the rocket.	YES	5.1
21	The first parachute shall be connected to the outer body of the CanSat and no ejection mechanism shall be attached to it.	YES	5.1
22	The descent rate of the 1st parachute shall be 20 m/s +/- 5m/s	YES	5.1
23	The second descent control mechanism shall open at an altitude of 500m (+/-10 m) to further decrease the descent rate of the CanSat to 1 to 3m/s	YES	5.1.1

Sl. No.	Requirement	Satisifed	Section
24	The descent control system shall not use any hazardous chemical-based explosive or pyrotechnic devices. However, green propulsion is allowed if being used under the same weight constraint.	YES	5.1.1
25	CanSat shall stabilize itself during the decent using the mechanical gyro mechanism.	YES	4.3
26	The CanSat communications radio shall be the XBee radio series 1/2/pro.	YES	5.1.1
27	The XBee radios shall have their NETID/PANID set to the team number.	YES	5.5.5
28	The XBee radio shall not use the broadcast mode.	YES	3.4
29	The XBEE radio can operate in any mode as long as it does not interfere with other XBEE radios.	YES	5.5.2
30	Each team shall develop and use their own ground station. All telemetry shall be displayed in real-time during launch and descent. All telemetry shall be displayed in engineering units (meters, meters per second, Celsius, etc.). Teams shall plot data in real-time during flight.	YES	3.4
31	The ground station shall command the CanSat to start transmitting telemetry prior to launch.	In progress	
32	The ground control station antenna shall be elevated from ground level to ensure adequate coverage and range.	YES	3.4
33	Stability of the ground station must be ensured.	YES	3.4
34	The CanSat shall not transmit telemetry until commanded by the team ground station. Command can be executed while the CanSat is in the rocket on the launch pad.	YES	3.3
35	The ground station shall be able to command the CanSat to calibrate gyros, barometric altitude, accelerometer to command the parameters to zero as the CanSat sits on the launch pad.	YES	3.3

Sl. No.	Requirement	Satisifed	Section
36	The ground station shall generate .csv files of all sensor data as specified in the Telemetry Requirements section.	YES	3.4
37	Telemetry shall include mission time with one second or better resolution.	YES	3.3
38	Mission time/timestamp and system status states shall not be affected in the event of a processor reset during the launch and mission.	YES	3.3
39	The ground station shall include one laptop computer with a minimum of two hours of battery operation, XBee radio and a hand-held antenna.	YES	3.3
40	The ground station must be portable so the team can be positioned at the ground station operation site along the flight line and if required the team can also move to a different location in case of distant landing location in order to locate the CanSat.	YES	3.3
41	The flight software shall maintain and telemeter an indicator of the CanSat flight software state. An example set of states is 0 (BOOT), 1 (TEST_MODE), 2 (LAUNCH_PAD), 3 (ASCENT), 4 (ROCKET_DEPLOY), 5 (DESCENT), 6 (AEROBREAK_RELEASE), and 7 (IMPACT).	YES	3.3
42	Upon powering up, the CanSat shall collect the required telemetry at a 1 Hz sample rate or more. The telemetry data shall be transmitted with ASCII comma-separated fields followed by a carriage return	YES	5.4.5

Table 18: Compliance of the design

7 Logistics and Transportation of the CanSat

Since the launch of CanSat is going to take place in Dholera Gujarat, and the team has to travel from Bangalore, Karnataka, the transportation of the CanSat is planned to be carried out by domestic airlines and is relatively simple for the following reasons.

- The total weight of the CanSat is a maximum of 750 gms which is not an issue considering the limit on domestic flights, which is 15 kgs per person.
- The dismantled CanSat will have its structural components protected by packing foam and safely stored in boxes that shall be along with the check in luggage of a single person.
- The electronics are critical and shall not be checked in, instead they will be carried in the cabin luggage along with batteries that are mandatory to be carried in cabin luggage.
- Most of the tools and requirements for the CanSat such as screw drivers, soldering equipment etc shall be along with the check in luggage as they are not allowed in the cabin luggage.
- The parachute and recovery mechanisms are to be placed along with the structural components but further discussions might change these situations depending on the safety and the reliability of the service.
- This method reduces the logistics involved in transport of the CanSat and efficiently solves all the underlying issues with shipping and logistics.

7.1 Special permit requirements

Due to previous experiences of the team members on other projects, a letter of permission indicating the names of the team, the participants and their association with the competition hosted by IN-SPACe is required to grant permission to the team members to transport the above mentioned components by air as per the above means.

8 CanSat ready to launch and final comments

The CanSat is currently an ideation in progress but as discussed, the funding and all the other non-technical tasks now being resolved along with an intensive technical analysis by such an amazing hard working team. This puts the mission within sight for not only a completion but also a successful launch and a successful recovery.

9 Conclusion

The CanSat design by Team Titans is a viable option as the extensive report indicates, and is on course for its launch date as given by the team at IN-SPACe.

References

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