CanSat 2019
Critical Design Review (CDR)
Outline
Version 1.1

4440

White Noise

Presentation Outline

Presenters:


Dimitris Bralios


Miltiadis Stouras


Marios Papachristou


George Rapakoulias


Ioannis Christodoulou

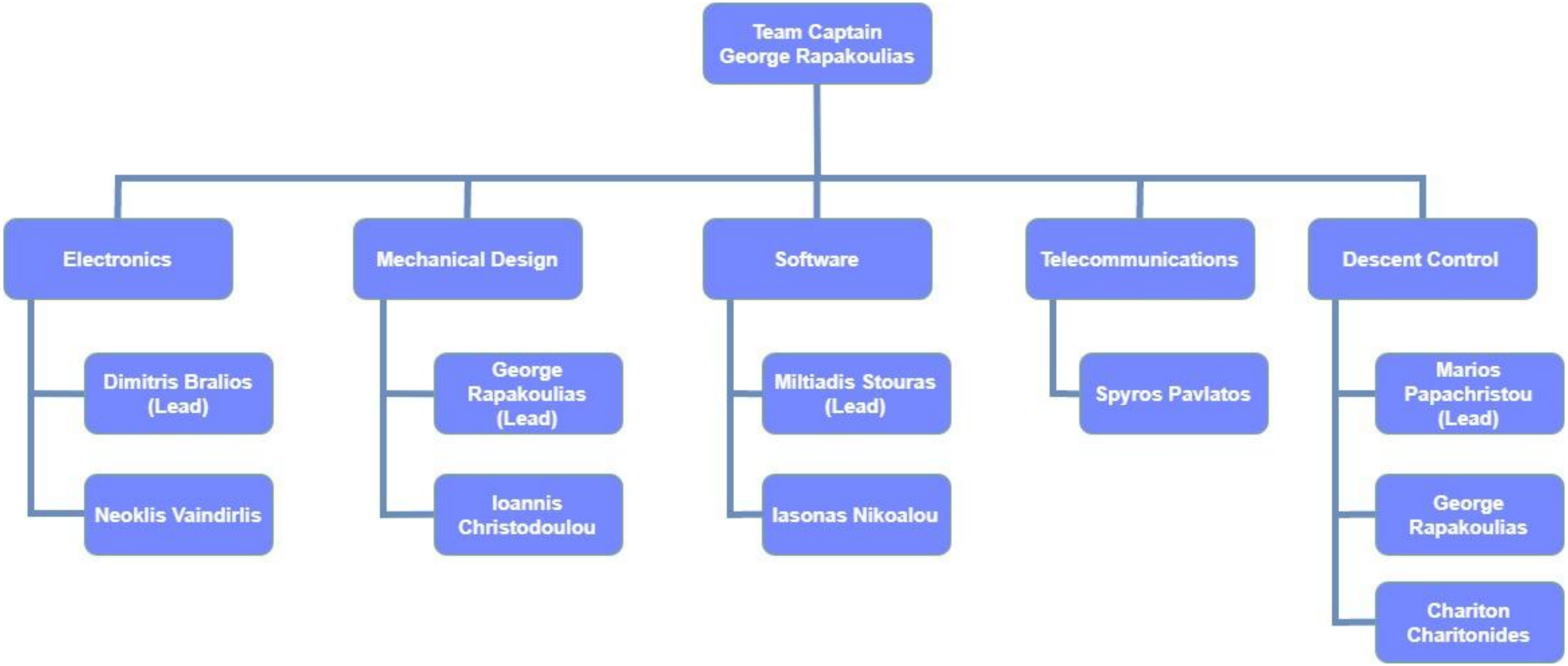

Spyros Pavlatos

Team Organization

NAME	YEAR	Subject of study
Dimitrios Bralios	3	Electrical & Computer Engineering
Chariton Charitonidis	3	Electrical & Computer Engineering
Ioannis Christodoulou	3	Mechanical Engineering
Iasonas Nikolaou	3	Electrical & Computer Engineering
Marios Papachristou	4	Electrical & Computer Engineering
Spyros Pavlatos	3	Electrical & Computer Engineering
George Rapakoulias	3	Mechanical Engineering
Miltiadis Stouras	3	Electrical & Computer Engineering
Neoklis Vaindirlis	3	Electrical & Computer Engineering

Faculty Advisor	Evangelos Papadopoulos	Department of Mechanical Engineering, NTUA

Organizational chart



Acronyms

ABS: Acrylonitrile Butadiene Styrene
AC: Alternating Current
ASCII: American Standard Code for Information Interchange
AT: Application Transparent
BEM: Blade Element Momentum
BIBO: Bounded Input Bounded Output
CAD: Computer Aided Design
CDH: Communication Data Handle
CDR: Critical Design Review
CG: Center of Gravity
CONOPS: Concepts of Operations
CP: Center of Pressure
CSV: Comma Separated Values
DOF: Degrees Of Freedom
EEPROM: Electrically Erasable Programmable Read-Only Memory
EPS: Electrical Power Subsystem
FPS: Frames Per Second
FSW: Flight Software
GCS: Ground Control System
GPS: Global Positioning System
I2C: Inter-Integrated Circuit
IDE: Integrated Development Environment
IEEE: Institute of Electrical and Electronics Engineers
IMU: Inertial Measurement System
LED: Light Emitting Diode
LQR: Linear Quadratic Regulator
LSB: Least Significant Bit
LTS: Long-Term Support
MOSFET: Metal-Oxide-Semiconductor Field-Effect Transistor
NACA: National Advisory Committee for Aeronautics
NETID: Network ID
NTUA: National Technical University of Athens
PCB: Printed Circuit Board
PDR : Preliminary Design Review
PFR: Post Flight Review
PLA: PolyLactic Acid
PPM: Parts Per Million
RAM: Random Access Memory
RC: Radio Controlled
RPM: Rotations Per Minute
RTC: Real Time Clock
S.Steel: Stainless Steel
SCCB: Serial Camera Control Bus
SD: Security Digital
SMA: Sub Micro type A connector
SPI: Serial Peripheral Interface
TC: Transition Counter
USB: Universal Serial Bus
VSWR: Voltage Standing Wave Ratio

VM:Verification Method
A: Analysis
I: Inspection
T: Testing
D: Demonstration

System Overview

George Rapakoulias

Mission Summary

- **This year's mission is to build an autogyro based descent control system**
  Specifically the mission will be as follows:
  - CanSat will be launched via a rocket at ~700 m
  - When apogee is reached, it will exit the rocket and parachute will deploy
  - It will descent to 450 m. At this altitude the payload will separate from the container and deploy its descent mechanisms. Container will continue its descent
  - Paload will use a passive autogyro rotor for slowing down its descent rate to ~11 m/s
  - After payload lands, an audio beacon will facilitate recovery
- **Out team has selected the bonus objective because**
  - Implementing just the autogyro mechanism will leave plenty of free space
  - Integration of a camera stabilization mechanism does not pose any significant problems to the design

WHITENOISE

Summary of Changes Since PDR

After completing the prototyping stage of the project, our team has made the following improvements in our design:

- The descent control strategy has changed from a completely active to a combination of active and passive design.
- We have changed the material of some parts, like the blades, in order to simplify the construction process
- We have changed the position and shape of the electronics board
- We have made minor changes in dimensions reinforcing our design where needed

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams	HIGH	X		X	X
2	CanSat shall fit in a cylindrical envelope of 125 mm diameter x 310 mm length	HIGH	X			X
3	The container shall not have any sharp edges to cause it to get stuck in the rocket payload section which is made of cardboard	MEDIUM				X
4	The container shall be a fluorescent color; pink, red or orange	LOW				X
5	The rocket airframe shall not be used to restrain any deployable parts of the CanSat.	MEDIUM				X
6	The rocket airframe shall not be used as part of the CanSat operations.	MEDIUM				X
7	The CanSat shall deploy from the rocket payload section and immediately deploy the container parachute.	MEDIUM				X
8	The descent rate of the CanSat (container and science payload) shall be 20 meters/second +/- 5m/s	HIGH/ MEDIUM	X		X	
9	The container shall release the payload at 450 meters +/- 10 meters.	MEDIUM	X			X

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
10	The science payload shall descend using an auto-gyro descent control system.	HIGH	X			X
11	The descent rate of the science payload after being released from the container shall be 10 to 15 meters/second	HIGH	X		X	
12	All descent control device attachment components shall survive 30 Gs of shock.	HIGH	X		X	X
13	All electronic components shall be enclosed and shielded from the environment with the exception of sensors.	MEDIUM		X		X
14	All structures shall be built to survive 15 Gs of launch acceleration.	HIGH	X		X	
15	All structures shall be built to survive 30 Gs of shock.	HIGH	X		X	
16	All electronics shall be hard mounted using proper mounts such as standoffs, screws, or high performance adhesives.	MEDIUM		X		X
17	All mechanisms shall be capable of maintaining their configuration or states under all forces.	MEDIUM			X	X
18	Mechanisms shall not use pyrotechnics or chemicals.	MEDIUM				X

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
19	Mechanisms that use heat (e.g., nichrome wire) shall not be exposed to the outside environment to reduce potential risk of setting vegetation on fire.	HIGH	X			X
20	The science payload shall measure altitude using an air pressure sensor.	HIGH		X		X
21	The science payload shall provide position using GPS.	HIGH		X		X
22	The science payload shall measure its battery voltage.	HIGH		X		X
23	The science payload shall measure outside temperature.	HIGH		X		X
24	The science payload shall measure the spin rate of the auto-gyro blades relative to the science vehicle.	HIGH	X			X
25	The science payload shall measure pitch and roll	HIGH		X		X
26	The probe shall transmit all sensor data in the telemetry	HIGH			X	X
27	The Parachute shall be fluorescent Pink or Orange	LOW				X

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
28	The ground station shall be able to command the science vehicle to calibrate barometric altitude, and roll and pitch angles to zero as the payload sits on the launch pad.	HIGH			X	X
29	The ground station shall generate a csv file of all sensor data as specified in the telemetry section	MEDIUM			X	
30	Telemetry shall include mission time with one second or better resolution. Mission time shall be maintained in the event of a processor reset during the launch and mission.	MEDIUM	X		X	
31	XBEE radios shall be used for telemetry. 2.4 GHz Series radios are allowed. 900 MHz XBEE Pro radios are also allowed.	HIGH		X		
32	XBEE radios shall have their NETID/PANID set to their team number.	MEDIUM			X	X
33	XBEE radios shall not use broadcast mode.	HIGH			X	X
34	Cost of the CanSat shall be under $1000. Ground support and analysis tools are not included in the cost	HIGH	X			
35	Each team shall develop their own ground station.	HIGH				X

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
36	All telemetry shall be displayed in real time during descent.	MEDIUM	X		X	X
37	All telemetry shall be displayed in engineering units (meters, meters/sec, Celsius, etc.)	MEDIUM				X
38	Teams shall plot each telemetry data field in real time during flight.	MEDIUM				X
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.	HIGH		X		X
40	The ground station must be portable so the team can be positioned at the ground station operation site along the flight line. AC power will not be available at the ground station operation site.	LOW		X		X
41	Both the container and probe shall be labeled with team contact information including email address.	MEDIUM				X
42	The flight software shall maintain a count of packets transmitted, which shall increment with each packet transmission throughout the mission. The value shall be maintained through processor resets.	HIGH	X		X	
44	No lasers allowed.	LOW				X

System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
45	The probe must include an easily accessible power switch that can be accessed without disassembling the cansat and in the stowed configuration.	MEDIUM		X		X
46	The probe must include a power indicator such as an LED or sound generating device that can be easily seen without disassembling the cansat and in the stowed state.	MEDIUM		X		X
47	An audio beacon is required for the probe. It may be powered after landing or operate continuously	HIGH				X
48	The audio beacon must have a minimum sound pressure level of 92 dB, unobstructed.	MEDIUM		X	X	
49	Battery source may be alkaline, Ni-Cad, Ni-MH or Lithium. Lithium polymer batteries are not allowed. Lithium cells must be manufactured with a metal package similar to 18650 cells.	MEDIUM		X		X
50	An easily accessible battery compartment must be included allowing batteries to be installed or removed in less than a minute and not require a total disassembly of the CanSat.	MEDIUM				X
51	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects.	HIGH				X

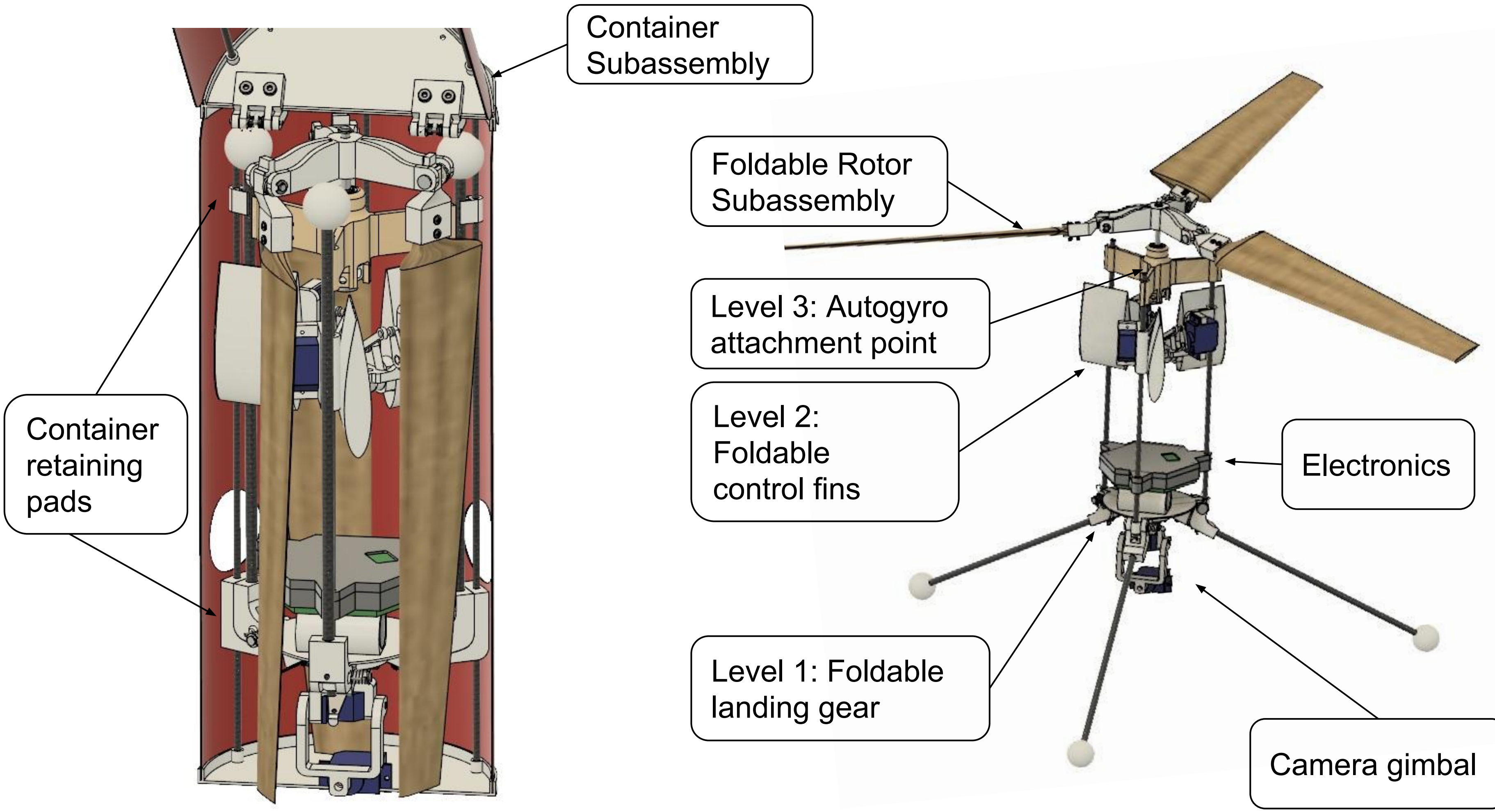
System Requirement Summary

No	Requirement	Priority	VM			
			A	I	T	D
52	The auto-gyro descent control shall not be motorized. It must passively rotate during descent.	HIGH	X			X
53	The GPS receiver must use the NMEA 0183 GGA message format.	MEDIUM	X			X
54	The CANSAT must operate during the environmental tests.	HIGH	X		X	
55	Payload/Container shall operate for a minimum of two hours when integrated into rocket.	HIGH	X		X	X

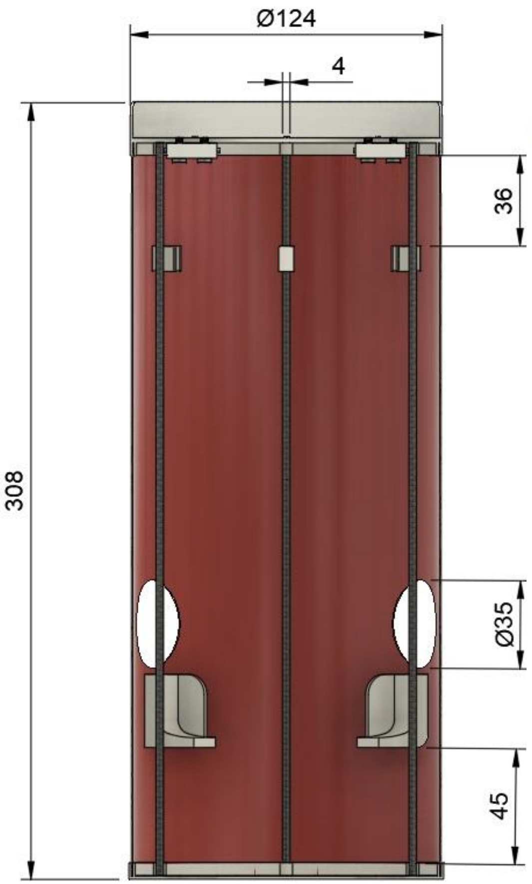
System Requirement Summary

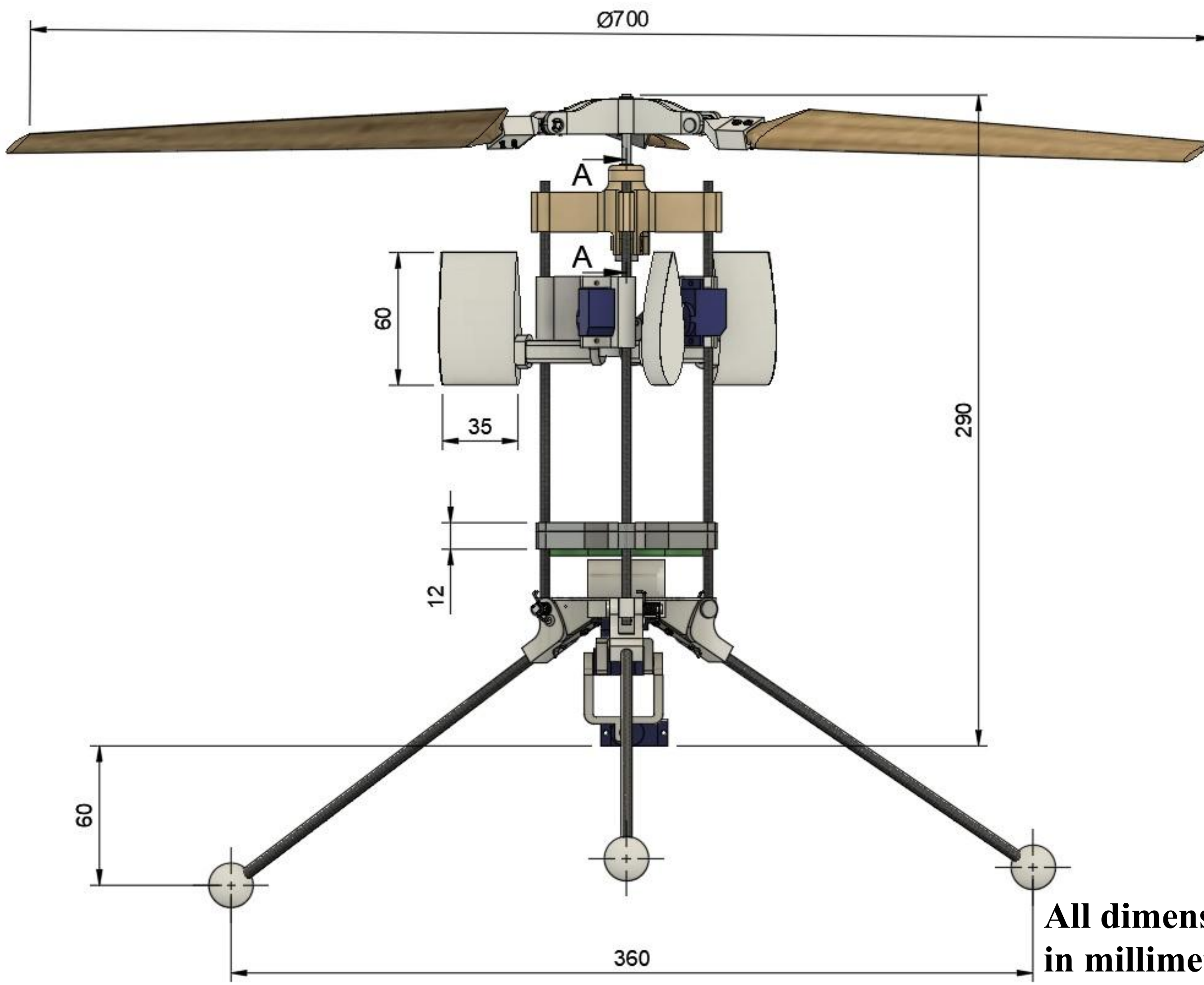
No	Requirement	Priority	VM			
			A	I	T	D
Bonus 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	MEDIUM		X		
Bonus 2	The camera shall point downward 45 degrees from nadir.	MEDIUM	X			X
Bonus 3	It shall be spin stabilized and point in one direction relative to the earth's magnetic field with a stability of +/- 10 degrees. Direction does not matter as long as it is in one direction.	MEDIUM	X			X
Bonus 4	Video shall be in color with a minimum resolution of 640x480 pixels and 30 frames per second	LOW/ MEDIUM	X			X
Bonus 5	The direction the camera is pointed relative to earth's magnetic north shall be included in the telemetry.	MEDIUM	X			

Payload Physical Layout



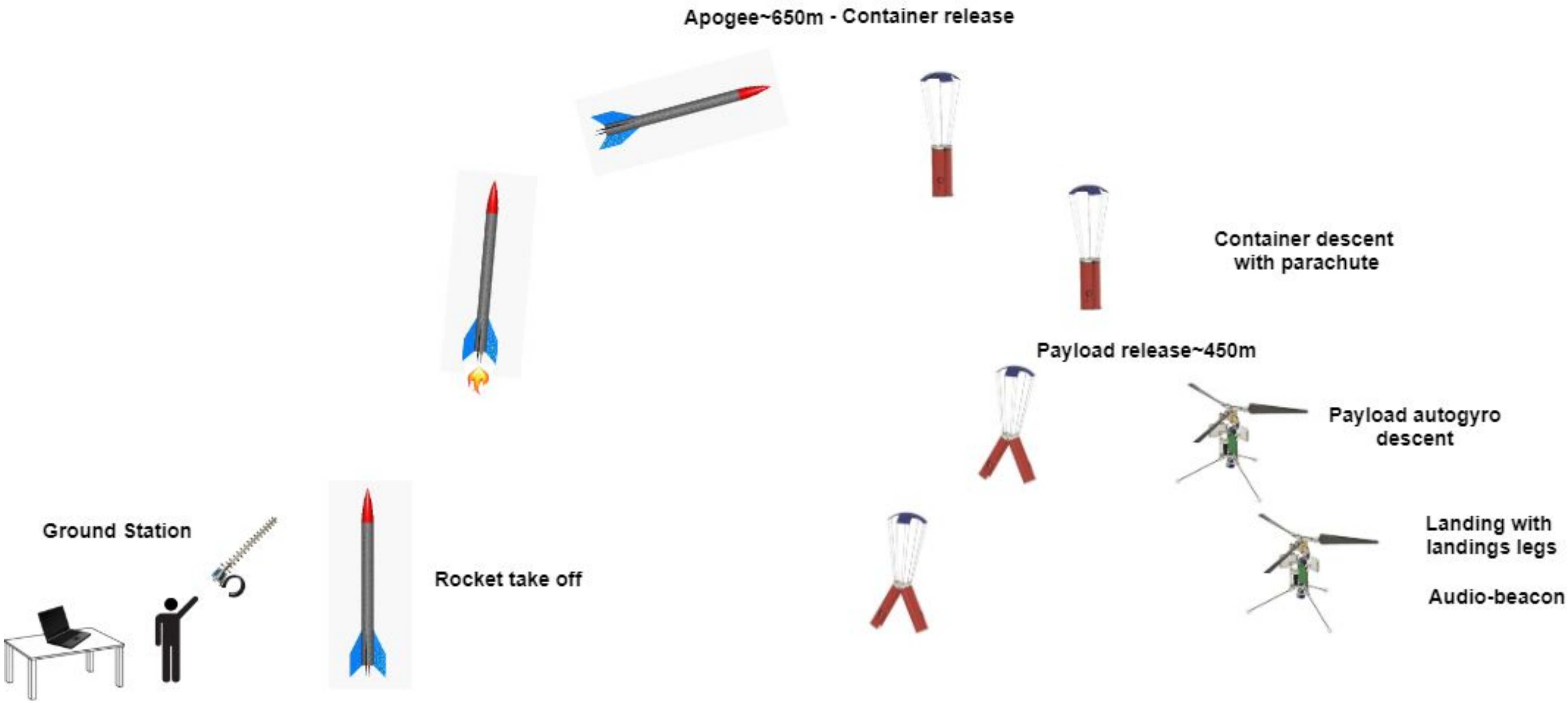
Payload Physical Layout





All dimensions in millimeters

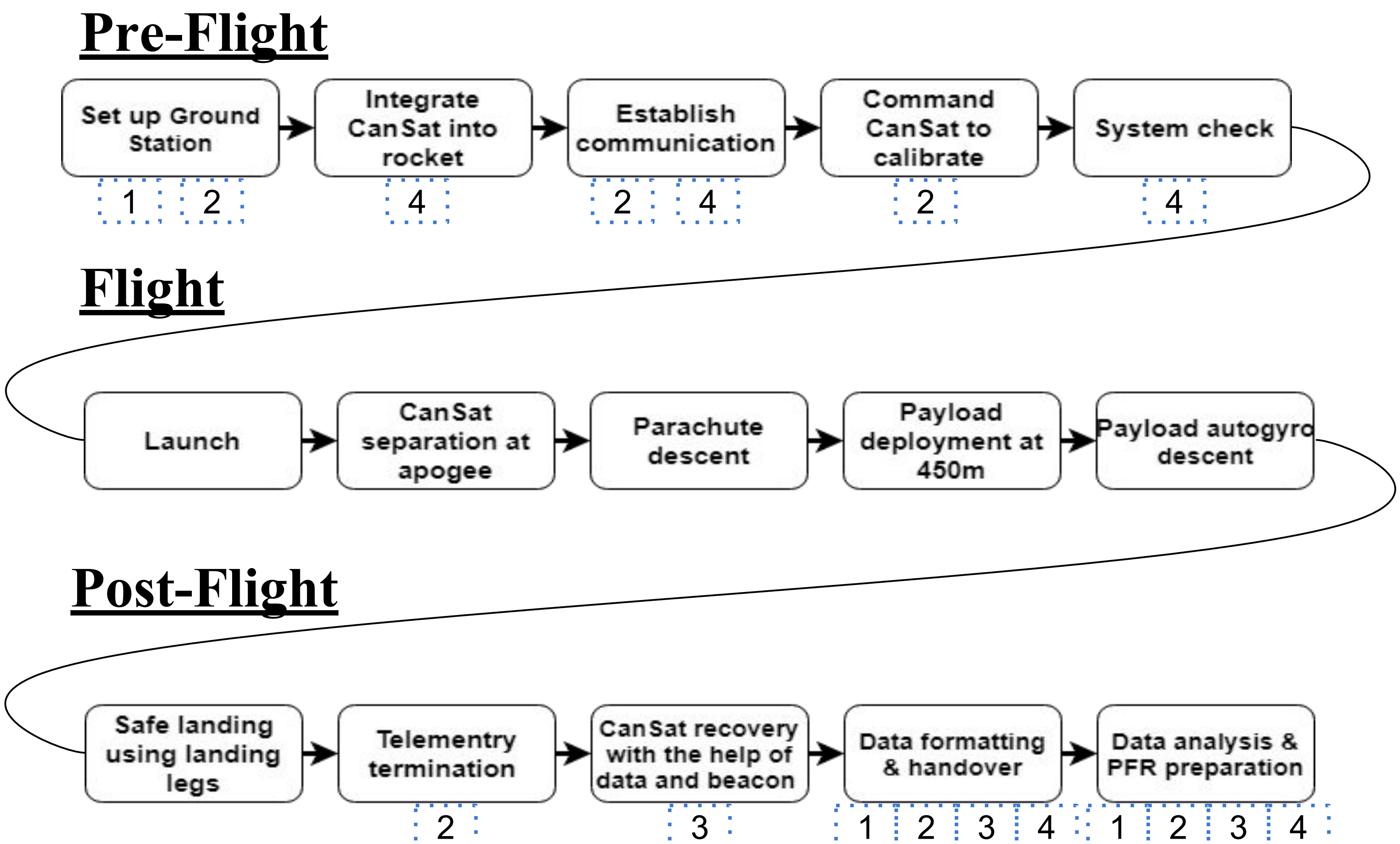
System Concept of Operations



System Concept of Operations

Roles & Responsibilities	
1. Mission Control Officer	Iasonas Nikolaou
2.GCS crew	Miltiadis Stouras, Spyridon Pavlatos, Marios Papachristou
3.Recovery crew	Chariton Charitonidis, George Rapakoulias, Dimitrios Bralios, Neoklis Vaindirlis
4.CanSat crew	George Rapakoulias, Dimitrios Bralios, Neoklis Vaindirlis, Ioannis Christodoulou

System Concept of Operations



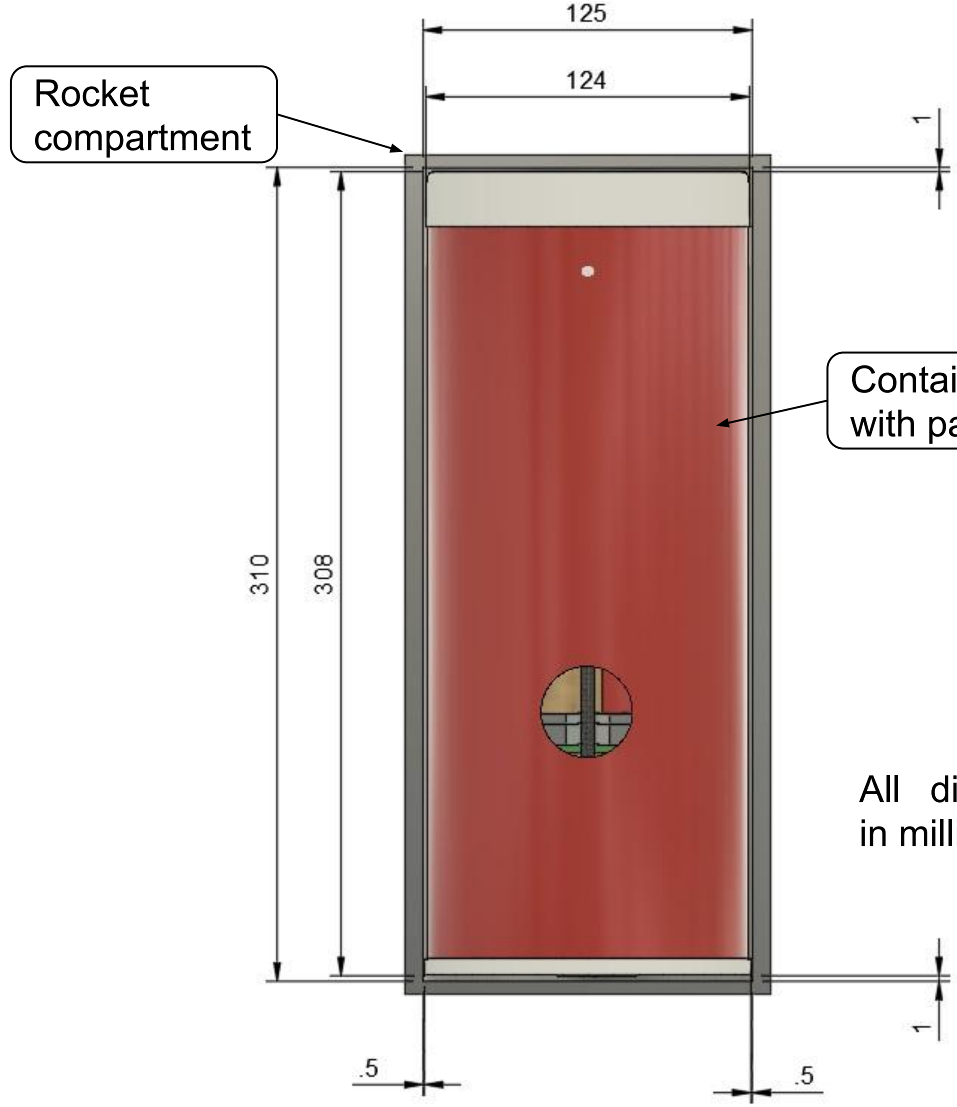
Note: 1,2,3,4 indicate the teams mentioned in the previous slide

Launch Vehicle Compatibility

- **Include a dimensioned drawing that shows *clearances* with the payload section**
  - Focus on launch configuration (Container + Payload)
  - Include all descent control apparatus (no sharp protrusions)
  - What is the clearance? (Leave margin to allow *easy* deployment!)
- **Notes:**
  - In past years there were a large number of CanSats that did not deploy from the payload sections of the rocket because of protrusions or because the CanSat was too wide to fit in the rocket
  - Lack of sharp protrusions and fit within the Launch Vehicle will also be scored at the Flight Readiness Review

Launch Vehicle Compatibility

- In order to guarantee that the cansat will exit the rocket flawlessly, we have left a 0,5 mm radial and 1 mm axial margin from the rocket compartment.
- As indicated on the left drawing, there are no sharp protrusions from the container. As seen from top, it is fully circular

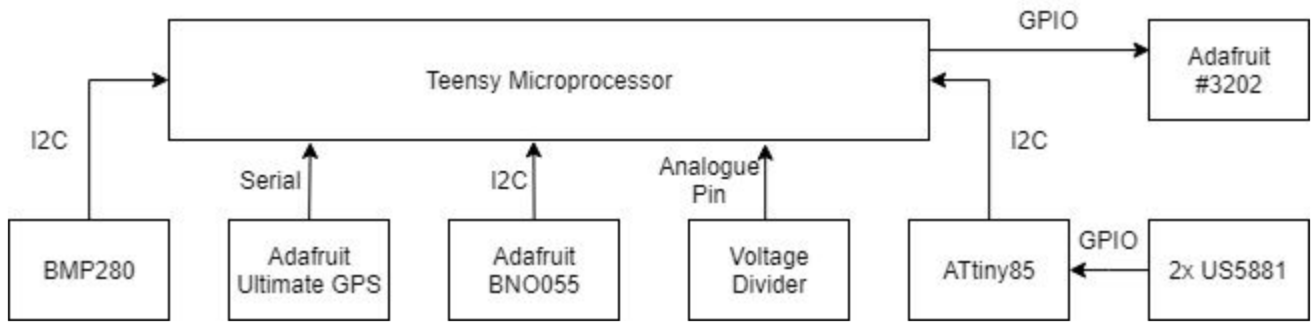


All dimensions are in millimeters.

Sensor Subsystem Design

Dimitrios Bralios

Sensor Subsystem Overview



Sensors	Component Type	Component Model
Air Pressure	Air Pressure sensor	BMP280
Air Temperature	Temperature sensor	BMP280
GPS	GPS	Adafruit Ultimate GPS
Voltage	Voltage Divider	Resistors
Pitch and Roll	IMU 9 DOF	Adafruit BNO055
Blade Spin Rate	Hall Effect Sensor and Microcontroller	US5881 and ATtiny85
Camera	Camera	Adafruit #3202

Sensor Changes Since PDR

Sensors	PDR	CDR	Rationale
Air Pressure	BMP388	BMP280	Wider availability Lower power consumption Both have comparable accuracy
Air Temperature	BMP388	BMP280	

Details of changes are discussed in subsequent slides.

Sensor Subsystem Requirements

No	Requirement	Priority	VM			
			A	I	T	D
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams.	HIGH	X			X
13	All electronic components shall be enclosed and shielded from the environment with the exception of sensors.	MEDIUM		X		X
20	The science payload shall measure altitude using an air pressure sensor.	HIGH		X		X
21	The science payload shall provide position using GPS.	HIGH		X		X
22	The science payload shall measure its battery voltage.	HIGH		X		X
23	The science payload shall measure outside temperature.	HIGH		X		X
24	The science payload shall measure the spin rate of the auto-gyro blades relative to the science vehicle.	HIGH	X			X
25	The science payload shall measure pitch and roll.	HIGH		X		X

Sensor Subsystem Requirements

No	Requirement	Priority	VM			
			A	I	T	D
34	Cost of the CanSat shall be under $1000. Ground support and analysis tools are not included in the cost.	HIGH	X			
53	The GPS receiver must use the NMEA 0183 GGA message format.	MEDIUM	X			X
55	Payload/Container shall operate for a minimum of two hours when integrated into rocket.	HIGH	X		X	X
Bonus 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	MEDIUM				X
Bonus 4	Video shall be in color with a minimum resolution of 640x480 pixels and 30 frames per second.	MEDIUM	X			X

Payload Air Pressure Sensor Summary

Component	Power	Interface	Accuracy	Resolution	Operating Range	Dimensions	Mass	Cost
BMP280	2.8uA x 3.3V	I2C	12Pa 1m	0.66Pa 0.055 m	300 - 1100hPa -600 - 9000m	19.2mm x 17.9mm x 2.9mm	1.3g	12.20 €

Sample Data Format: Altitude: 123.4m Pressure: 99851 Pa

The data from the sensor will be collected via I2C and then processed by the Adafruit BMP280 library.

The equation used, to convert the pressure measurement to the corresponding altitude, is the following which is derived from the barometric formula.

$$altitude = 44330 \cdot \left(1 - \left(\frac{p}{p_0}\right)^{0.1903}\right)$$

where p is the measured pressure in hPa, p_0 is the pressure at sea level in hPa and the result is given in meters.

Calibration is done by setting the correct p_0 parameter.

Payload Air Temperature Sensor Summary

Component	Power	Interface	Accuracy	Resolution	Operating Range	Dimensions	Mass	Cost
BMP280	2.8uA x 3.3V	I2C	1.0°C	0.01°C	-40 - 85 °C 0 - 65 °C (full accuracy)	19.2mm x 17.9mm x 2.9mm	1.3g	12.20 €

Sample Data Format: 12.34 °C

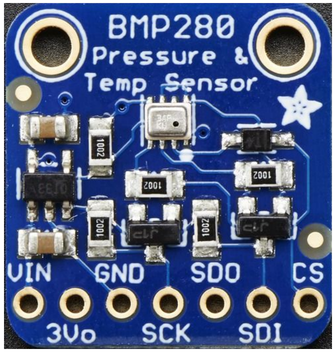
The data from the sensor will be collected via I2C and then processed by the Adafruit BMP280 library.

Calibration can be performed using the API provided by Bosch Sensortec.

BMP388 was replaced by BMP280

Rationale

- Wider availability of the BMP280, as it is an more established model.
- Both have comparable accuracy in their measurements, well within competition's requirements.
- Slightly lower power consumption



GPS Sensor Summary

Component	Power	Interface	Accuracy	Resolution	Operating Range	Dimensions	Mass	Cost
MTK3339 (Adafuit Ultimate GPS)	20mA x 3.3V	Serial	<3m, 0.1m/s	0.0001° 0.1m	up to 32 km	25.5mm x 35mm x 6.5mm	8.5g	34.41 €

Sample Data Format: UTC Time: 06:49:51.000 Latitude: 2307.1256 N Longitude: 12016.4438 E Altitude: 39.9 meters Satellites: 4

The data from the sensor will be collected via serial interface and then processed by the Adafruit GPS library. The library extracts the latitude, longitude, altitude, UTC time and the number of satellites from the NMEA packets.

The message format used is the NMEA 0183 GGA. The warm/cold start time is 34 seconds and the update rate goes up to 10Hz.

The altitude measurement can be used as a backup to the measurement of the BMP280.

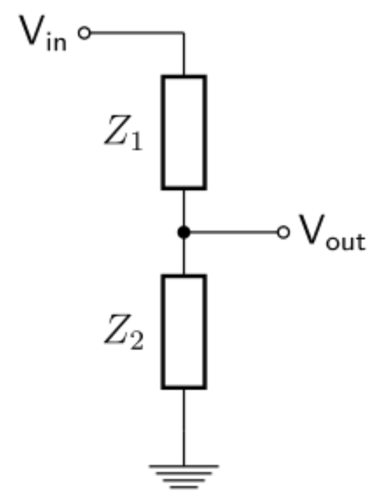
Payload Voltage Sensor Summary

Component	Power	Interface	Accuracy	Resolution	Operating Range	Dimensions	Mass	Cost
Voltage Divider (SMD 1% resistors)	0.1mA x 3.6V	1 Analog Pin	1.7%	12 bits (1.2 mV/LSB)	0 - 5 V	2.0 mm × 1.25 mm (x2)	~10mg	1 €

Sample Data Format: 1.234 V

Two SMD resistors with accuracy of 1% will be used. The first having a value of 33kΩ and the second 17kΩ. The teensy ADC reads a 12 bit value, which can be translated to the corresponding voltage value (in Volts) using the following formula.

$$V_{in} = \frac{analogue\_input}{2^{12}-1} \cdot 3.3 \cdot \frac{R_1 + R_2}{R_2}$$



Based on this formula, the relative accuracy of the voltage value is 1.7%.

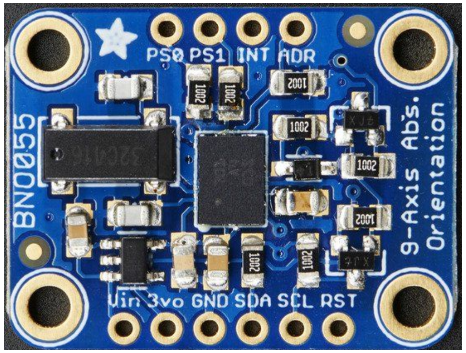
Pitch/Roll Sensor Summary

Component	Power	Interface	Accuracy	Resolution	Operating Range	Dimensions	Mass	Cost
Adafruit BNO055	12.3mA x 3.3V	I2C	0.1°	0.0625° (1 deg / 16 LSB)	up to ±16g ±1300µT ±2000°/s	27.0mm x 20.5mm x 4.0mm	3g	30.70 €

Sample Data Format: Pitch: 12.3° Roll: 12.3°

The sensor internally calculates the pitch and roll angles from the accelerometer, gyroscope and magnetometer data. Then the data is collected, via I2C interface, by the Adafruit BNO055 library, which also allows easy calibration.

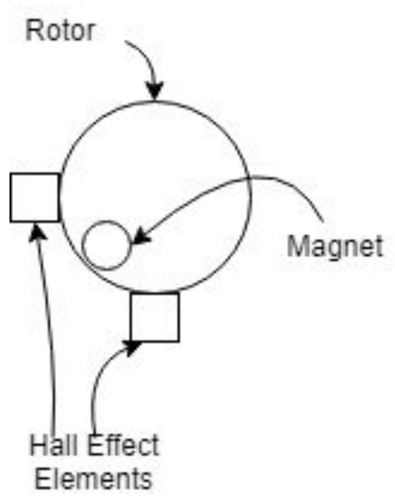
Data collection rate can be configured up to 100Hz.



Auto-Gyro Blade Spin Rate Sensor Summary

Hall Effect Sensor	Type	Power	Interface	Mass	Cost
US5881	Non-Latching	2mA x 3.6V	1 Digital Pin	0.12g	3.00 €
Microcontroller	**Clock Speed**	**Power**	**Interface**	**Mass**	**Cost**
ATtiny85	1MHz	5mA x 3.3V	I2C	0.5g	1.02 €

Accuracy	Resolution	Operating Range
4 RPM at 2000 RPM	1 RPM	1 - 5000 RPM



Sample Data Format: 1234 RPM

A magnet is attached to the rotor and two hall effect elements are spaced 120 degrees apart, mounted on the CanSat body. The calculation method of the spin rate is the pulse timing method. Each time a magnet passes in front of a hall effect sensor a pulse is produced and an interrupt is triggered on the ATtiny85. The microcontroller counts the period of the rotation, (in number of ticks). The tick length selected is 64μs.

Finally, the spin rate measurement is transmitted to the teensy microprocessor via I2C.

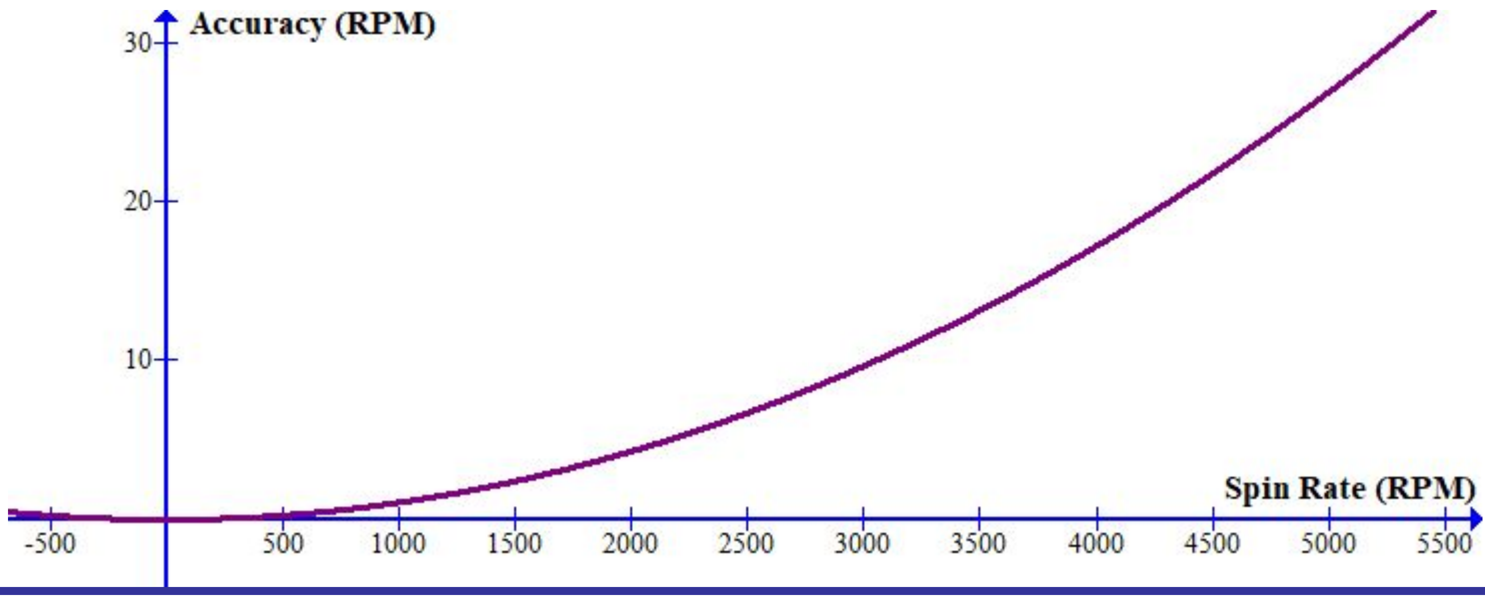
Auto-Gyro Blade Spin Rate Sensor Summary

The equation used to derive the spin rate in RPM from the ticks counted is the following.

$$n = \frac{60}{T} = \frac{60}{\#ticks \cdot tick\_length}$$

Where n is the spin rate in RPM of the rotor and T is the period of the rotation in seconds.

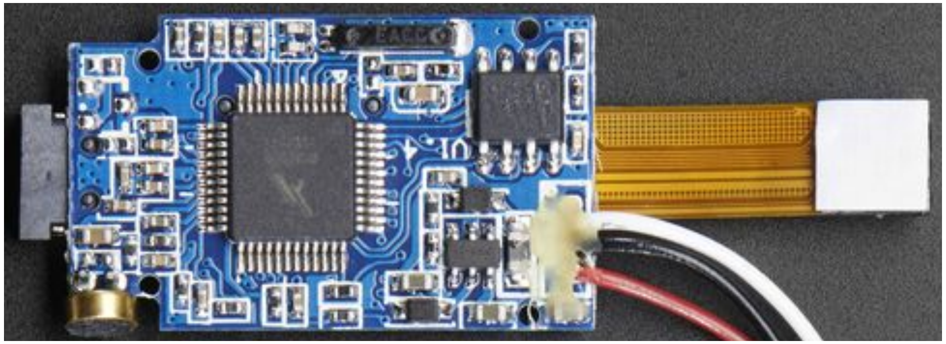
The accuracy of the measurement is depends on the current spin rate, as seen in the following graph. At the desired spin rate the accuracy is around 4 RPM.



Bonus Objective Camera Summary

Component	Power	Interface	Video Resolution	Dimensions	Mass	Cost	Other
Adafruit #3202	80mA x 3.6V 110mA x 3.6V (recording)	1 Digital Pin	640x480 (30fps)	28.5mm x 17mm x 4.2mm	2.8g	11.00 €	Built in SD

The camera is activated by one trigger pin. When activated, it records 640x480 video and stores it on the MicroSD mounted on the onboard MicroSD slot.



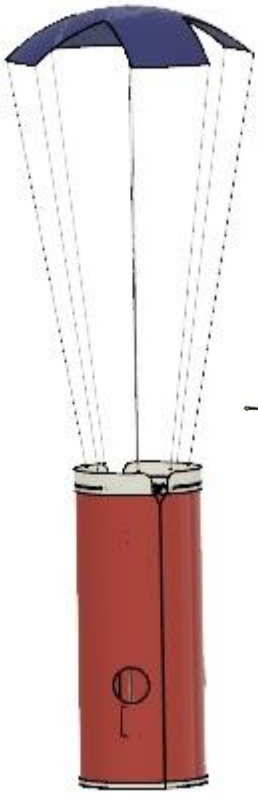
Container Air Pressure Sensor Summary

The container will not have any electronics.

Descent Control Design

George Rapakoulias
Marios Papachristou
Miltiadis Stouras

Descent Control Overview



- **1st stage 650-450 m:** When apogee is reached the container with the science payload exits the missle. A circular parachute opens immediately and the target terminal velocity is reached within about 2 seconds. Payload is in stowed configuration inside the container during this stage. Container has specially designed pads for retaining the payload in place safely.

- **2nd stage 450m-landing:** Container opens and payload is released. The container continues its descent with a lower speed. Science payload deploys blades and fins. Air flow spins the rotor and lift is produced. Stability against tumbling is achieved with a combination of active and passive systems.

Descent Control Changes Since PDR

Changes since PDR

- Blade shape was changed to simplify manufacturing process and save weight
- Minor changes to stability control strategy. We will rely on a combination of active/passive control in order to maintain stability during descent. The rotor will be designed in such a way that pitch and roll will be inherently stable. Therefore the active control surfaces will fine tune pitch and roll, and mainly maintain yaw.
- The changes result in an overall simpler and more robust design while still guaranteeing compliance with mission requirements.

Prototyping

- Because the final payloads design is too complex to build during the prototyping phase, we designed a simplified version of it, with the aim to test the descent control mechanisms separately.
- This test platform featured all the components from the final design, without any stowing mechanism(folding joints etc) and a data logging device for recording all critical parameters for the mission, like RPM, heading altitude, etc.

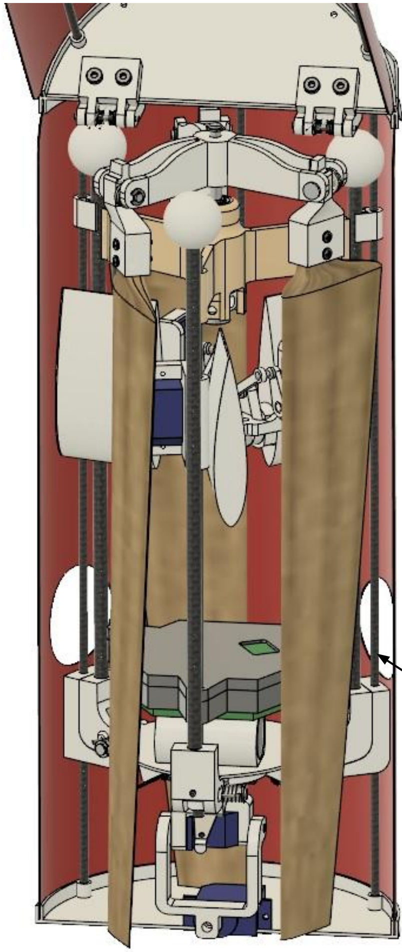
Descent Control Requirements

No	Requirement	Priority	VM			
			A	I	T	D
1	The descent rate of the CanSat (container and science payload) shall be 20 meters/second +/- 5m/s.	MEDIUM - HIGH	X		X	
2	The science payload shall descend using an autogyro descent control system.	HIGH				X
3	The descent rate of the science payload after being released from the container shall be 10 to 15 meters/second.	HIGH	X		X	
4	All descent control device attachment components shall survive 30 Gs of shock.	HIGH	X		X	X
5	The Parachute shall be fluorescent Pink or Orange	MEDIUM				X
6	The auto-gyro descent control shall not be motorized. It must passively rotate during descent.	HIGH				X

Descent Control Requirements

No	Requirement	Priority	VM			
			A	I	T	D
Bonus 2	The camera shall point downward 45 degrees from nadir.	MEDIUM	X			X
Bonus 3	It shall be spin stabilized and point in one direction relative to the earth's magnetic field with a stability of +/- 10 degrees. Direction does not matter as long as it is in one direction.	MEDIUM	X			X

Payload Descent Control Hardware Summary



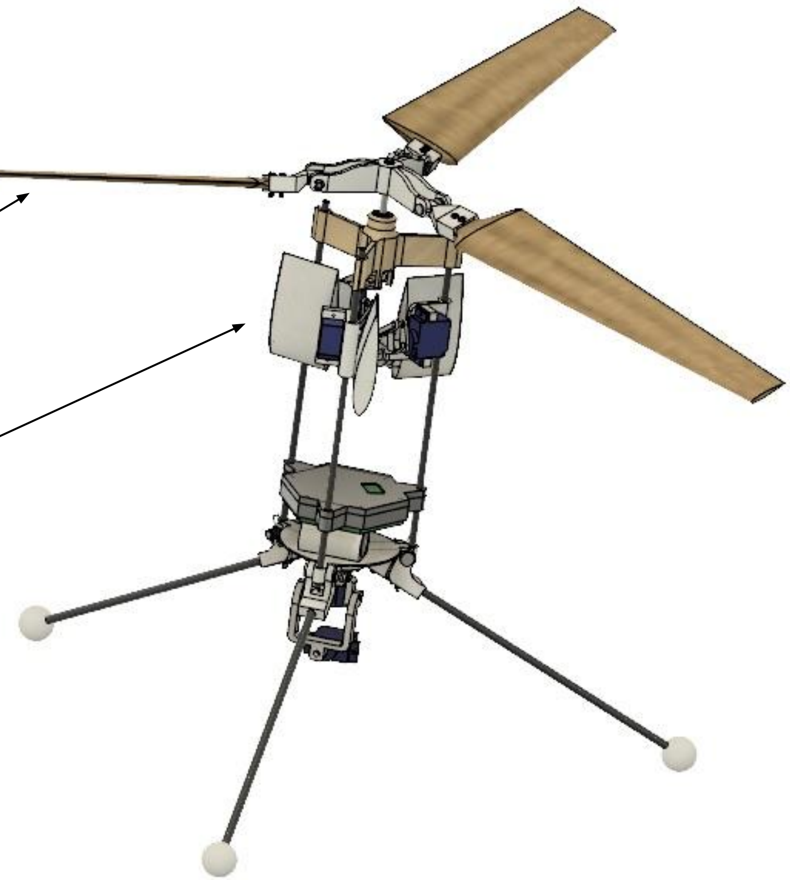
Payload in **stowed configuration**

Container splits with hinges, releasing the payload

Autogyro Rotor

Active control surfaces for orientation adjustments

Release will be triggered with the burn of a retaining rope tied around the carbon rods



Payload in **deployed configuration**

Payload Descent Control Hardware Summary

Key parameters of our design

- Blade shape and color:
  - We optimized this parameter and designed a blade that has minimum angular momentum in the equilibrium point, minimizing gyroscopic effects. The process we used is discussed on the next slide.
  - Torsion spring are featured for deploying the blades when they are not spinning.
  - They will be painted in a fluorescent color for easy spotting.
- Placement of CG: This is a very critical parameter for the stability of our system, so we tried to keep it as far apart from the aerodynamic CP as possible, maximizing the stabilizing effect of the lift - weight force couple.
- Active control:
  - For controlling yaw and fine tuning pitch and roll, a closed loop control system is implemented. Measurements are taken from the IMU sensor and fed to the controller. After the signal is processed, commands are sent to the servos for making adjustments.
  - Control fins equipped with springs for transitioning from stowed to deployed state
- Sensor/Actuator accuracy:

Sensor/Actuator	Absolute(?) precision
IMU	0.1 deg
Rotor RPM	4 RPM
Sevo	1 deg

Payload Descent Control Hardware Summary

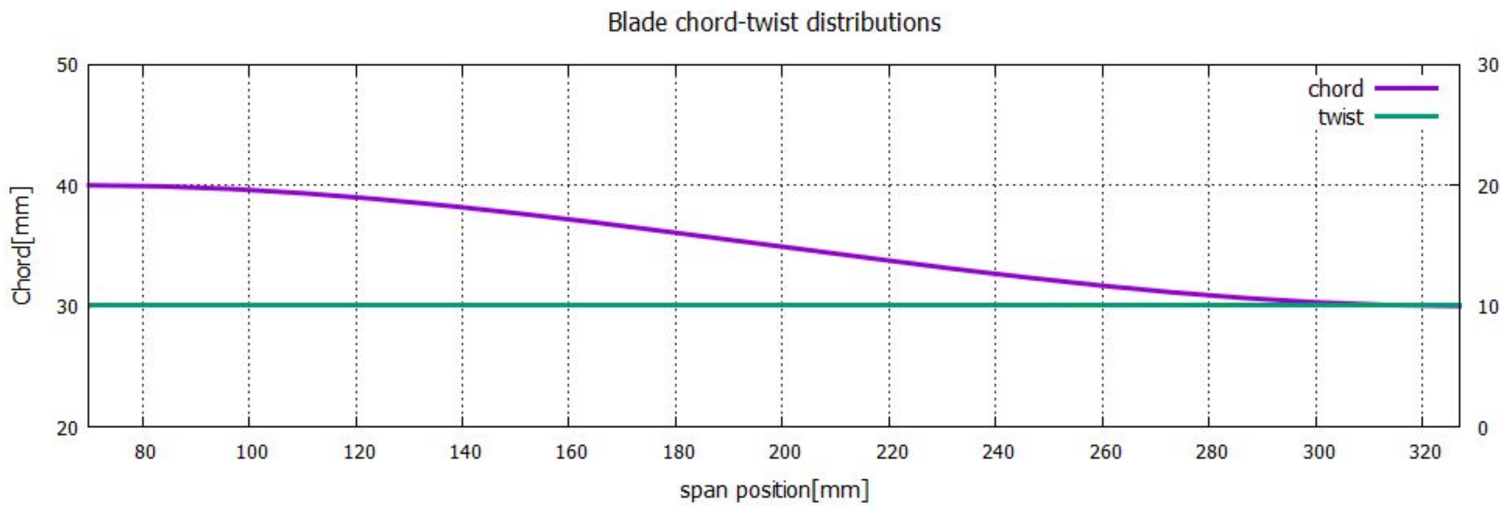
Optimizing Blades' shape: As we discussed earlier, we developed an optimization algorithm to find a blade shape that **minimizes the angular momentum** in equilibria and also satisfies the terminal velocity and manufacturing constraints. To begin with, we modeled the **chord-radius** and **twist-radius** functions as **Bezier curves** with 4 and 3 control points respectively, therefore being able to **uniquely describe a blade using only 7 variables.** $\overrightarrow{x} = [c_1, c_2, c_3, c_4, t_1, t_2, t_3]$

The aerodynamic simulation accepts as input a blade described by the state vector and outputs the angular velocity at the equilibrium and the terminal descent rate. We determined a **cost function** that we want to **minimize** :

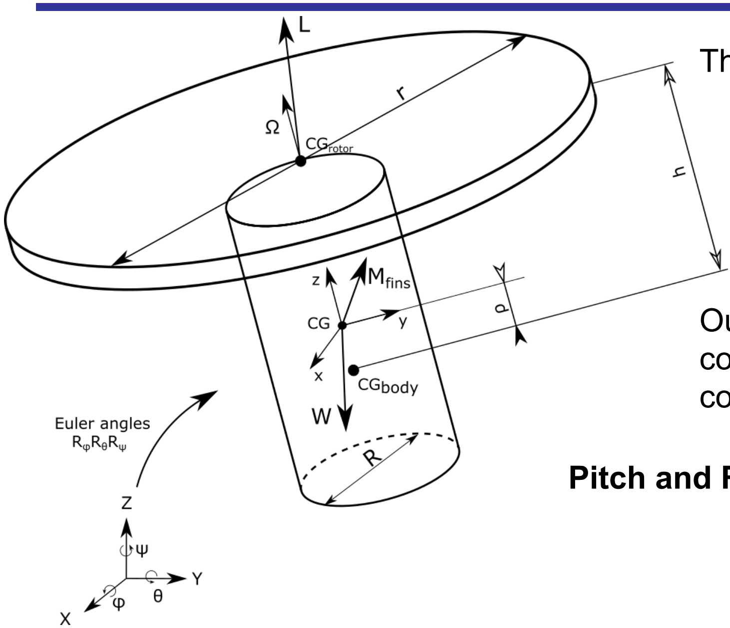
$$L(\overrightarrow{x}) = I(\overrightarrow{x}) \cdot \omega(\overrightarrow{x}) + f(v(\overrightarrow{x}))$$

Where f is a function of the terminal velocity that has 0 cost in the region [10,14] and very large cost values outside that region. The manufacturing constraints imposed to the problem were some limitations on the chord and twist values along the blade. To minimize the cost we used the Projected Gradient Descent algorithm, which improves the blade cost iteratively:

$$\overrightarrow{x}_{i+1} = proj(\overrightarrow{x}_i - \eta \cdot \nabla L(\overrightarrow{x}_i))$$



Descent Stability Control Design



The **simplified dynamic model** using the Euler-Lagrange equations is:

$$\ddot{\phi} + a\dot{\theta} = \mu_x$$
$$\ddot{\theta} - a\dot{\theta} = \mu_y$$
$$\ddot{\psi} = M_z / I_{bz}$$

$$a = (I_z - I_y)/I_x, \; \mu_i = M_i / I_i$$

$$\dot{\varphi} = \omega_x \quad \dot{\theta} = \omega_y$$

Our goal will be the fine tuning of pitch and roll during descent via active control so that the payload remains **nadir oriented**. We also need to the control yaw so that the payload **does not spin**.

Pitch and Roll Control: The system is **controllable** so a **state feedback law** of the form

$$\begin{pmatrix} \mu_x \\ \mu_y \end{pmatrix} = -K_p \begin{pmatrix} \phi \\ \theta \end{pmatrix} - K_d \begin{pmatrix} \dot{\phi} \\ \dot{\theta} \end{pmatrix}$$

In order to send the pitch and roll to zero. The value of the gain matrix K can be chosen arbitrarily such that the closed loop system is stable. The gain choice can be determined via solving an the Linear Quadratic Regulator Optimal Control Problem

Yaw Control: For the yaw axis since no moments can be transferred through the joint in this direction, a moment acting upon the body will not affect the rotor. Therefore the dynamical system equation for the yaw axis is

For the yaw control we can use a PD-PV controller of the form

$$M_z = -K_{pz}\psi - K_{dz}\dot{\psi}$$

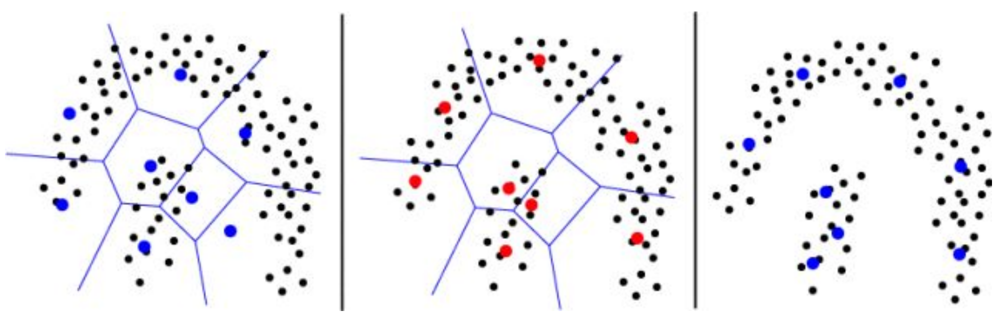
So the closed-loop system becomes: , which is stable for any positive values of the gains.

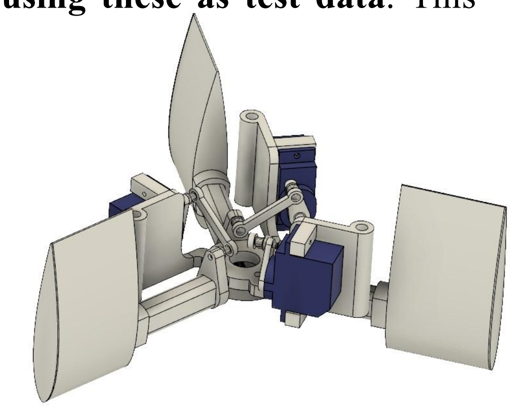
$$I_{bz}\ddot{\psi} + K_{dz}\dot{\psi} + K_{pz}\psi = 0$$

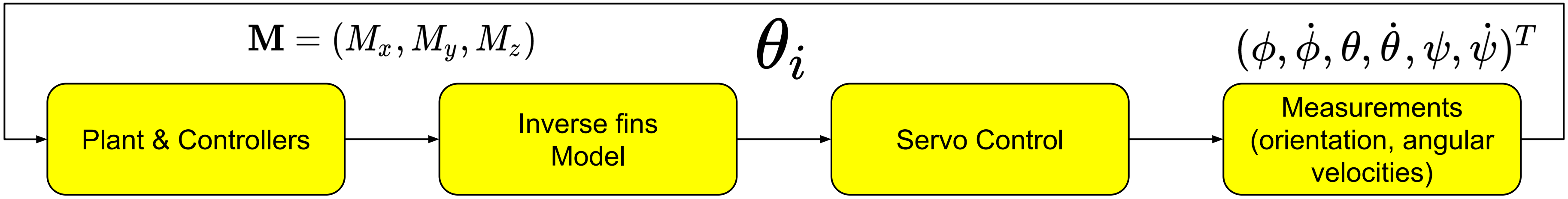
Descent Stability Control Design

Active control mechanisms:

For exerting the required moments, 3 independently moving fins are used, as described in the PDR. In order to add them in the control loop, we first modeled their interaction with the flow in a matlab code, 2D lift, drag and moment coefficients. Then, values were sampled across the functional range of motion of each fin. The resulting moments have a non-linear relation wrt to the input angles, hence the inversion seemed very challenging since classical numerical methods failed to find solutions. We needed a solution that generalized easily whenever an arbitrary moment vector was provided by the controllers. The idea was initially to keep some representatives of the various data points that we had acquired through sampling via using **K-Means clustering** and then keeping the angles that their respective moment vectors were the closest to the cluster centers. Then we used these representative data points for the inversion procedure for **fitting a hyperplane using these as test data**. This model generalizes very well giving a very small error without overfitting.



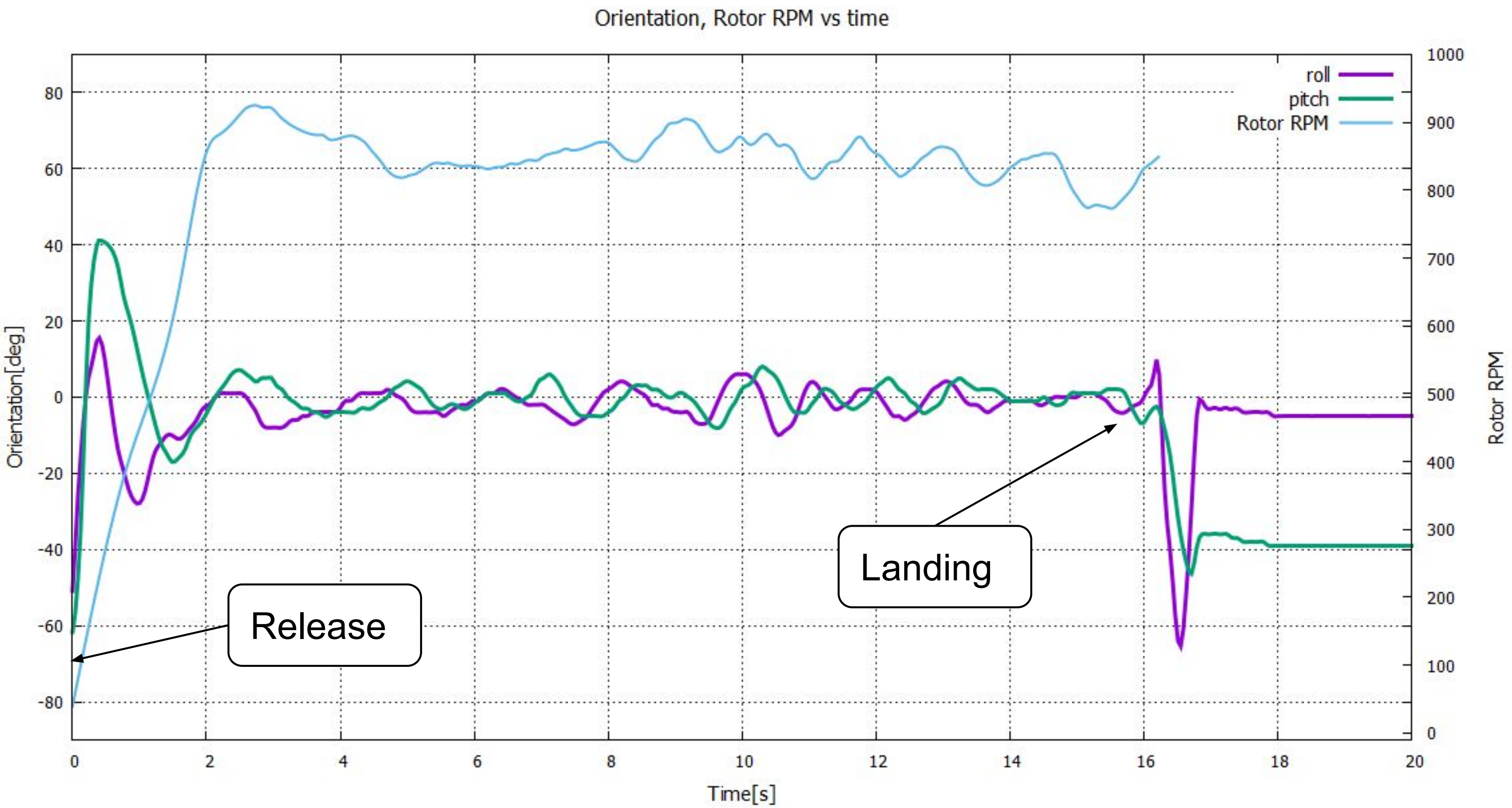




Descent Stability Control Design

Drop test results without control

In order to verify that our model is not over idealized, we performed a drop test with our simplified test platform via a drone. The results agreed with our predictions, since the payload has a small orientation oscillation but is otherwise stable. The fins will fins tune this fluctuation and will primarily correct yaw, which in this experiment had a constant speed of about 30 RPM.

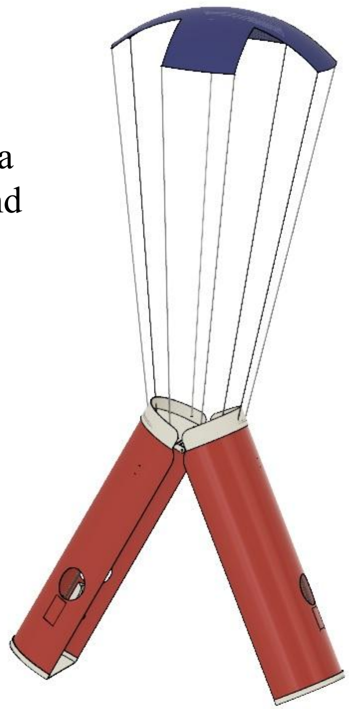


Container Descent Control Hardware Summary

Container in **stowed configuration**

Key design variables

- <u>Parachute area and shape:</u> The parachute's shape will be flat circular with a spill hole for increased stability. Its area was approximated theoretically using the drag equation and fine tuned experimentally.
- <u>Stability against tumbling:</u> The container - parachute system is similar to a pendulum. It is stable in orientation disturbances and won't capsize. Adjusting the paracord length in the final tests will maximize its stability.
- <u>Color:</u> Parachute's color will be fluorescent orange and container's color will be **red** for easy spotting after landing.



Container in **deployed configuration**

Descent Rate Estimates

Container's descent rate estimates:

- We use the drag equation for calculating terminal velocities
- In equilibrium drag force and weight are equal. Solving for A with V as a parameter gives the parachute area.
- Drag coefficients for each scenario are estimated empirically from tables

$$F_D = C_D A \frac{\rho V^2}{2}$$

where
F_D is the drag force
C_D is the drag coefficient
A is the reference area
ρ is the density of the fluid
V is the flow velocity relative to the object

	Parachute	Container
Cd	0.7	1
Area[m^2]	0,018	0,012
Drag force[N]	2.75	2.14

Descent rate estimates[m/s]	
Container + Payload	Container
20	10.9

Descent Rate Estimates

Autogyro Study

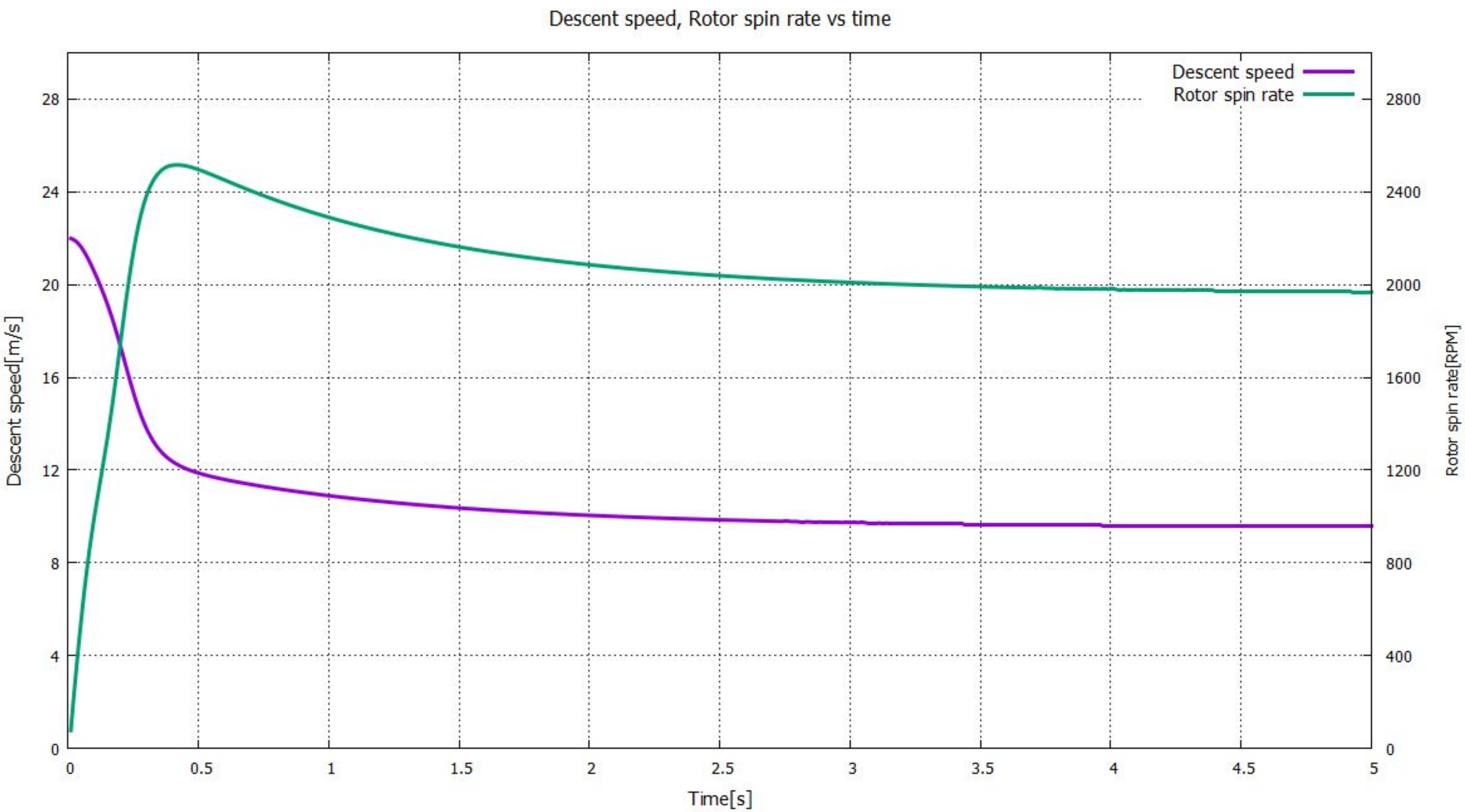
- In order to capture the complex aerodynamic phenomena that occur in a spinning rotor we use blade element momentum theory(BEM). Software written in FORTRAN was provided to us from the university’s fluid dynamics department
- Airfoil analysis was performed using Xfoil
- As a first approach, for the calculation of the terminal velocity we assumed that the payload only moves vertically with constant orientation and free of external disturbances. With a second order linear system we couple rotor aerodynamic thrust and torque with the dynamic equations for the degrees of freedom of the vertical displacement z and rotor rotation φ. We used blade element momentum theory to calculate rotor thrust and torque and Neumark numerical integration scheme for solving the system of dynamic equations. Initial conditions considered are 1 RPM and parachute terminal velocity (20-25 m/s).

m : total mass **L : lift**
I : rotor inertia **M : Rotor Moment**
z : descent distance **g : gravity constant**
φ : rotor angle

$$\begin{bmatrix} m & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} \ddot{z} \\ \varphi \end{bmatrix} = \begin{bmatrix} M \\ -L + mg \end{bmatrix}$$

Descent Rate Estimates

Simulation Results with optimized blades



Descent Rate Estimates

Descent Rate Estimates Summary

Container:

Container + Payload (1st stage)	Container (2nd stage)
20 m/s	10.9 m/s

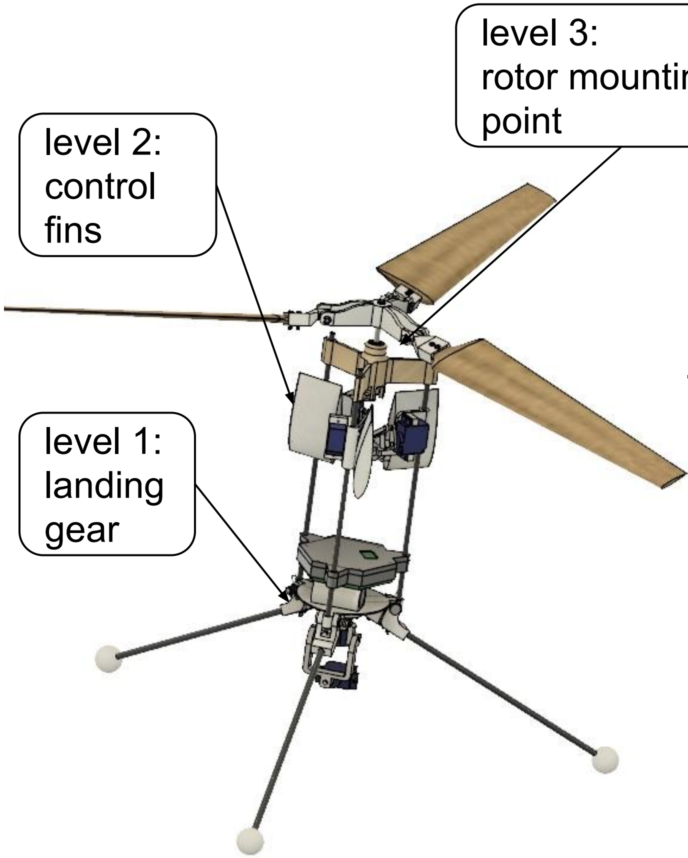
Payload:

Descent velocity	Rotor spin rate
10.5 m/s	1950 RPM

Mechanical Subsystem Design

George Rapakoulias
Ioannis Christodoulou

Mechanical Subsystem Overview

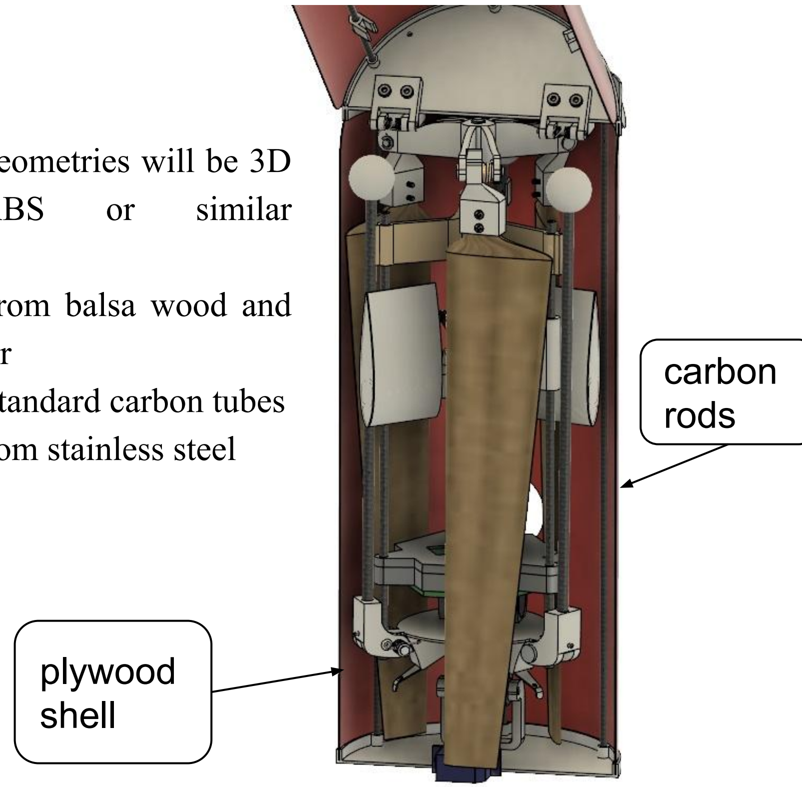


Container Main Structural Elements

- Consists of a a frame made of carbon rods and 3D printed ABS parts
- It has a 0.5 mm plywood shell painted in a fluorescent color

Material Selection

- Parts with complex geometries will be 3D printed with ABS or similar thermoplastics
- Final blades cutted from balsa wood and shaped with sandpaper
- Connecting rods are standard carbon tubes
- Pivot shafts will be from stainless steel



Payload Main Structural Elements

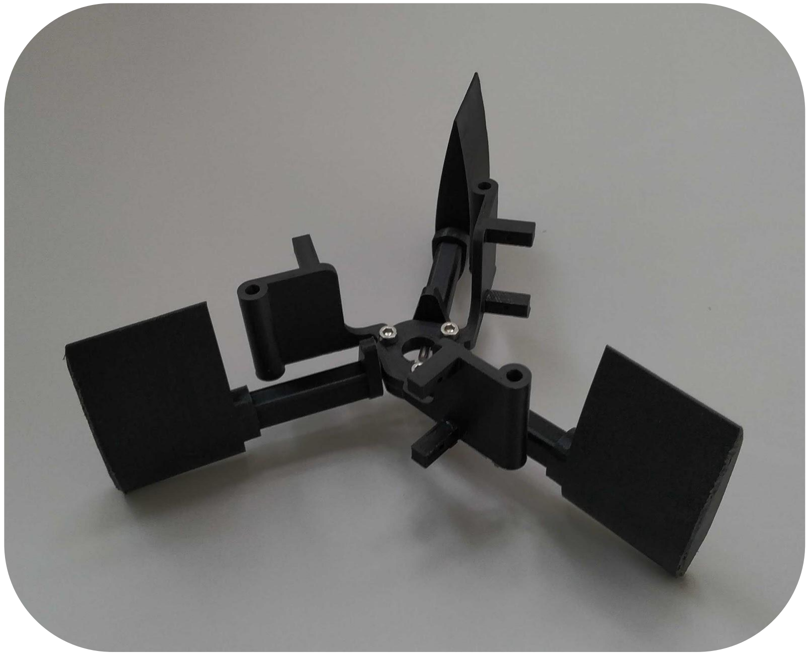
- Design consists of 3 levels connected via carbon rods
- When in stowed configuration, it has a total height of 286mm and fits in a 120mm tube

Changes since PDR

- Changed the position of the electronics resulting in greater robustness and protection to PCBs while lowering the assembly's CG.
- Changed blade's material from carbon fiber to plywood.
- Reinforcement of critical parts mainly in the landing gear.
- Refinement of critical points in the design like tolerances in joints

Prototyping

- We have 3D printed prototypes of all critical subsystems, like the fins, the rotor, the landing gear and the camera gimbal, and tested them individually.
- We have conducted tests in a integrated systems level to ensure that the design meets our structural and functionality criteria.



Mechanical Sub-System Requirements

No	Requirement	Priority	VM			
			A	I	T	D
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams	HIGH	X			X
2	CanSat shall fit in a cylindrical envelope of 125 mm diameter x 310 mm length	HIGH	X			X
3	The container shall not have any sharp edges to cause it to get stuck in the rocket payload section which is made of cardboard	MEDIUM				X
4	The container shall be a fluorescent color; pink, red or orange	LOW				X
5,6,7	The rocket airframe shall not be used to restrain any deployable parts of the CanSat. The rocket airframe shall not be used as part of the CanSat operations. The CanSat shall deploy from the rocket payload section and immediately deploy the container parachute.	MEDIUM				X
12	All descent control device attachment components shall survive 30 Gs of shock	HIGH	X			
13	All electronic components shall be enclosed and shielded from the environment with the exception of sensors	LOW-MEDIUM	X	X		

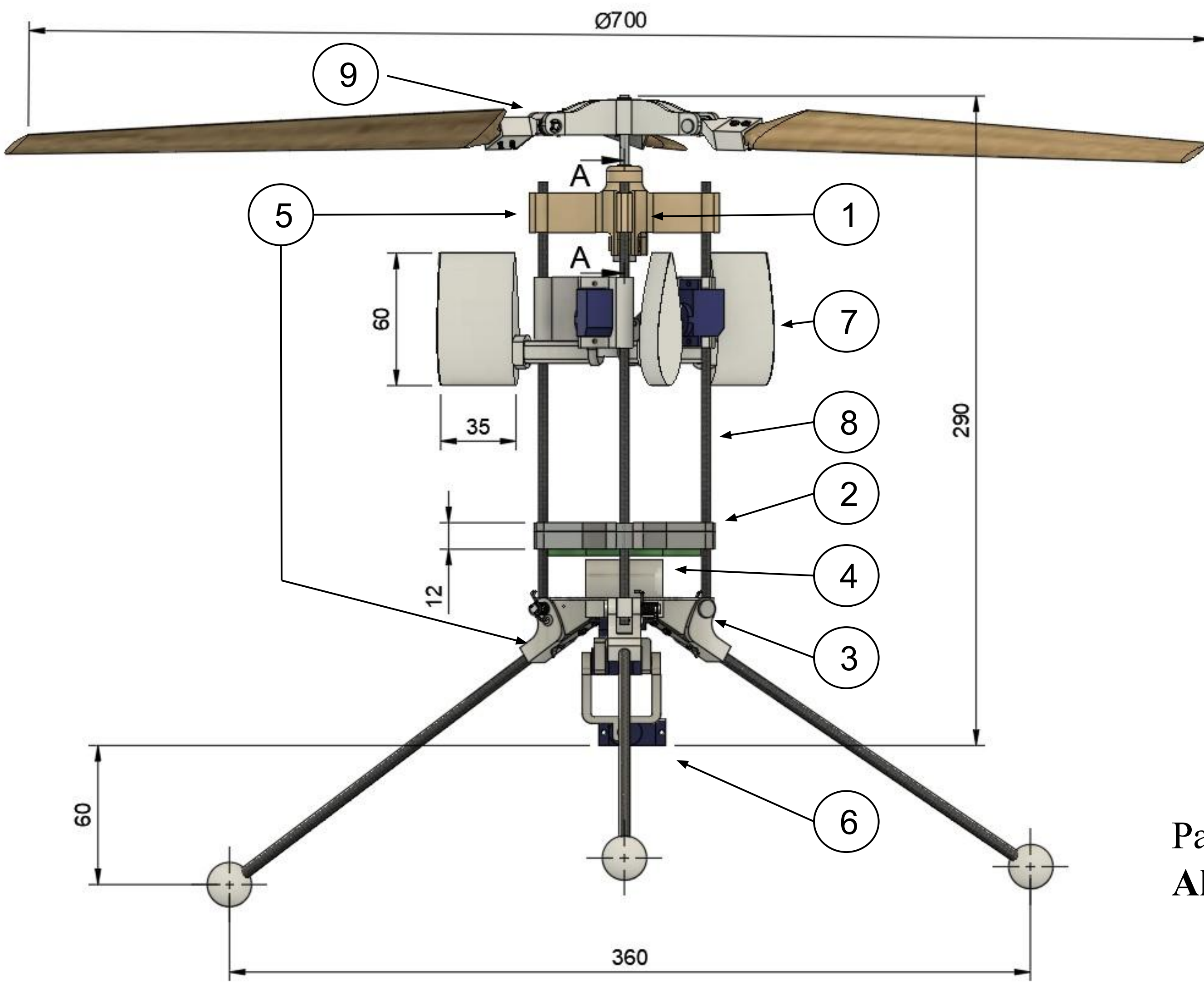
Mechanical Sub-System Requirements

No	Requirement	Priority	VM			
			A	I	T	D
14	All structures shall be built to survive 15 Gs of launch acceleration	HIGH	X			
15	All structures shall be built to survive 30 Gs of shock	HIGH	X			
16	All electronics shall be hard mounted using proper mounts such as standoffs, screws, or high performance adhesives	HIGH	X		X	
17	All mechanisms shall be capable of maintaining their configuration or states 8 under all forces	HIGH	X			
18	Mechanisms shall not use pyrotechnics or chemicals	LOW				X
19	Mechanisms that use heat (e.g., nichrome wire) shall not be exposed to the outside environment to reduce potential risk of setting vegetation on fire	HIGH	X			X
34	Cost of the CanSat shall be under $1000. Ground support and analysis tools are not included in the cost.	HIGH	X			
44	No lasers allowed	LOW				X

Mechanical Sub-System Requirements

No	Requirement	Priority	VM A	VM I	VM T	VM D
45	The probe must include an easily accessible power switch that can be accessed without disassembling the cansat and in the stowed configuration.	LOW-MEDIUM		X		X
51	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects	HIGH	X			
52	The auto-gyro descent control shall not be motorized. It must passively rotate during descent	HIGH	X			X
54	The CANSAT must operate during the environmental tests laid out in Section 3.5	HIGH	X			
Bonus 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	MEDIUM		X		
Bonus 2	The camera shall point downward 45 degrees from nadir.	MEDIUM	X			X
Bonus 3	It shall be spin stabilized and point in one direction relative to the earth's magnetic field with a stability of +/- 10 degrees. Direction does not matter as long as it is in one direction.	MEDIUM	X			X

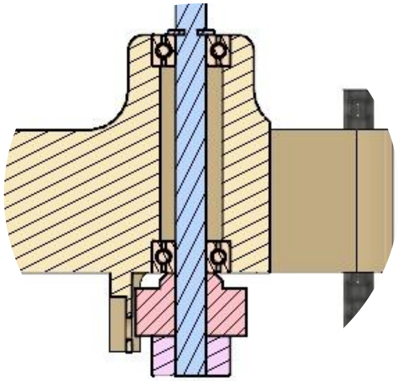
Payload Mechanical Layout of Components



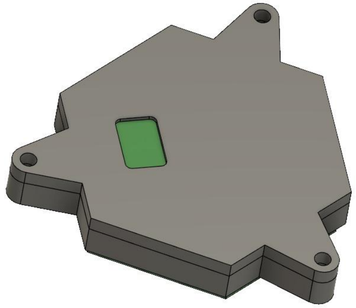
No	Component
1	Rotor attachment point
2	Electronics
3	Lockslice mechanism
4	Battery
5	Container attachment points
6	Camera gimbal
7	Control fins
8	Carbon rods
9	Blade's pivot point

Payload technical drawing
All dimensions in millimeters

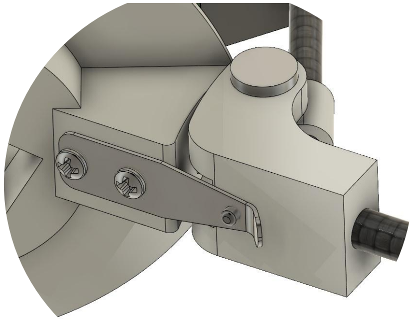
Payload Mechanical Layout of Components



Detail 1: Rotor attachment point

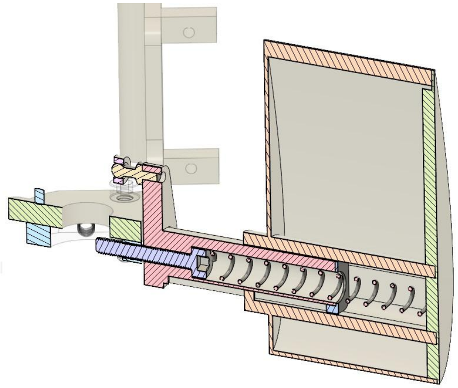


Detail 2: Electronics enclosure

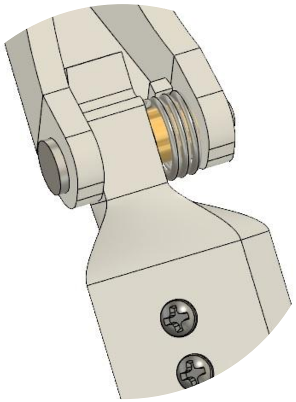


Detail 3: Lockslice mechanism

Detail 6: Camera gimbal



Detail 7: Control fins

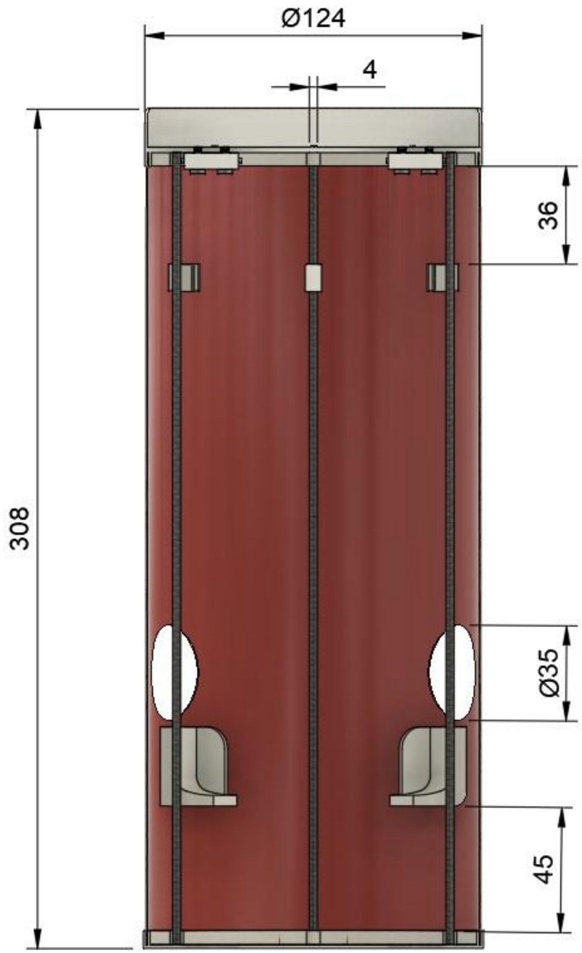


Detail 9: Blade's pivot point

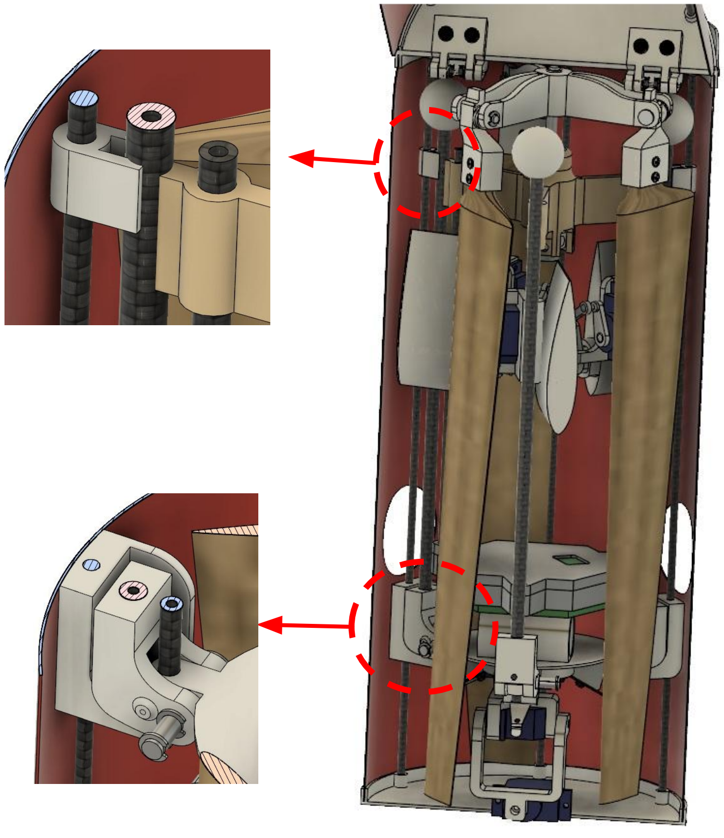
Payload Mechanical Layout of Components

Structural Material Selection					
Part	Material	Density (kg/m3)	Manufacturing	Advantages	Disadvantages
Rotor Hub	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures
Spacer	Brass	8500	Lathe	Very strong, low friction makes in ideal for spacer	Expensive, heavy
Blade shaft	Carbon fibre	1480		Very strong, stiff, lightweight	Expensive, time consuming
Fins	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures
PCB mounting	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures

Container Mechanical Layout of Components



Container technical drawing
All dimensions in millimeters

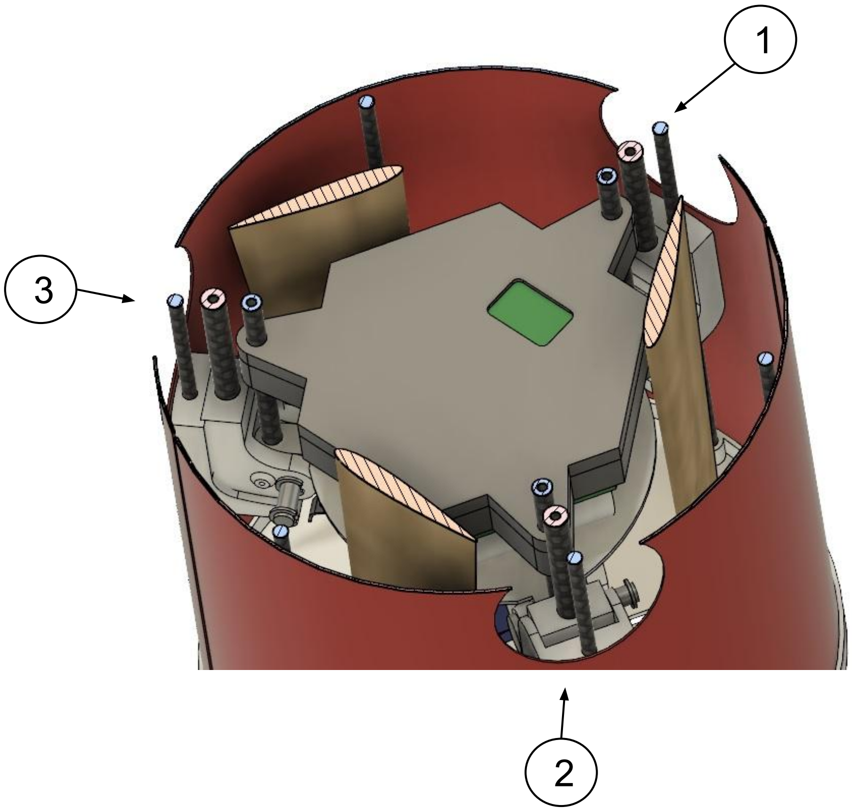


Container has specially shaped pads for retaining the payload in place without stressing any fragile parts

Payload Mechanical Layout of Components

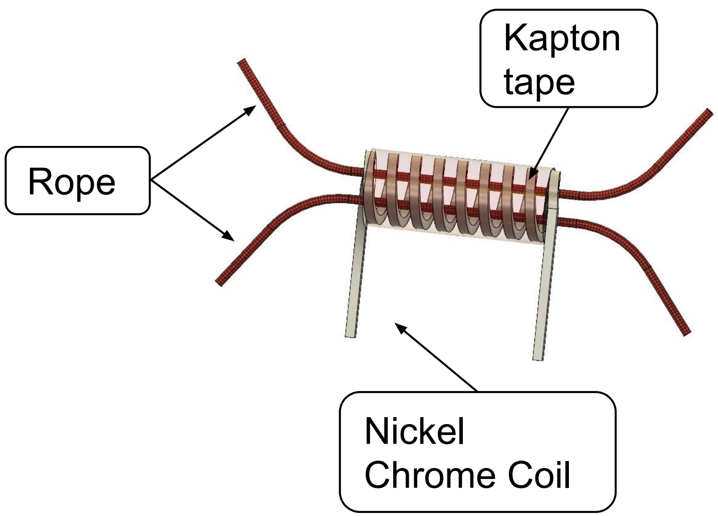
Structural Material Selection					
Part	**Material**	**Density (kg/m3)**	**Manufacturing**	**Advantages**	**Disadvantages**
Top frame	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures
Rods	Carbon fibre	1480		Very strong, stiff, lightweight	Expensive, Hard to shape
Bottom frame	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures
Landing legs	ABS	1070	3D Printed	Very strong, easy to make complex shapes	Heavy, loses structural properties in mid-high temperatures
Leg rod	Carbon fibre	1480		Very strong, stiff, lightweight	Expensive, Hard to shape
Pivot shaft	S. Steel	7500	Milling	Very strong, elastic	Heavy

Payload Release Mechanism

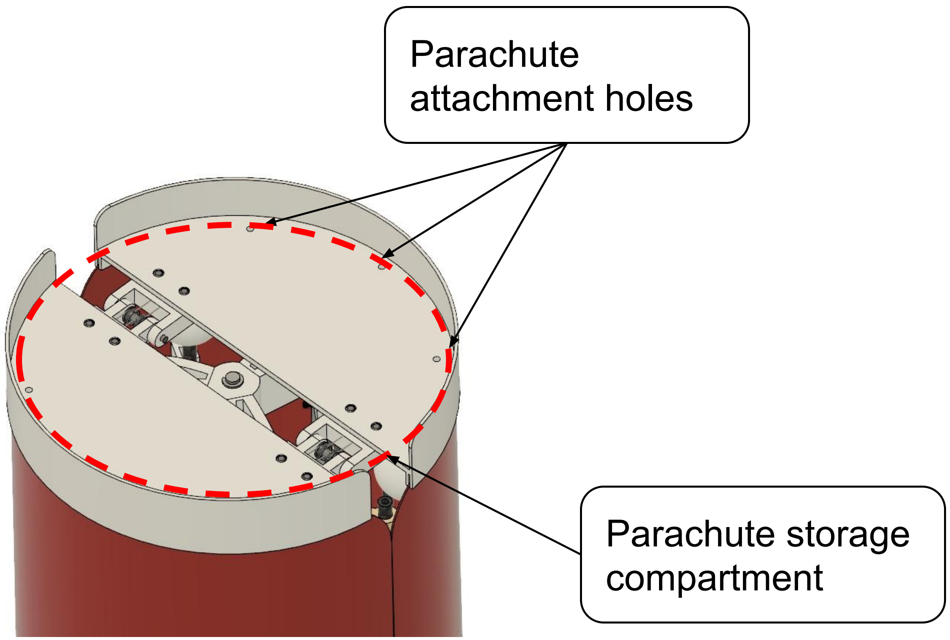


Burning Rope Retaining Mechanism

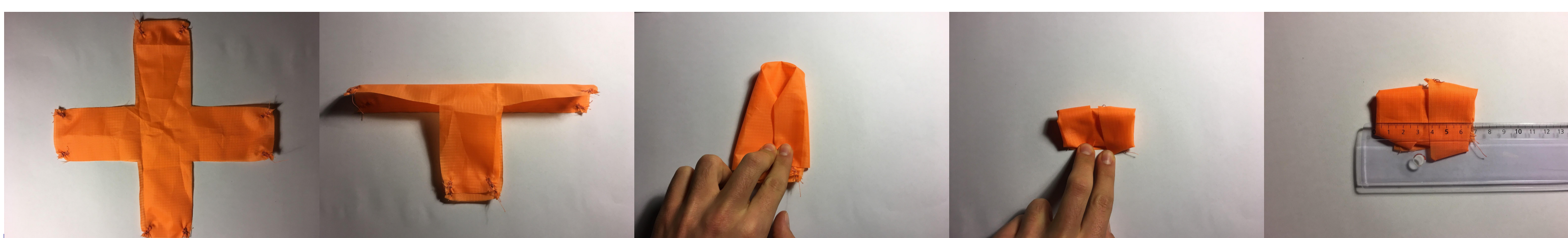
- A plastic rope tied to the container carbon rods in the points indicated on the left will hold the 2 halves together.
- A nickel chrome coil will burn the rope and the 2 container parts will split, releasing the payload
- The coil will be wrapped with heat resistant kapton tape for safety
- A switch will be accesible from one of the holes 1-3.



Container Parachute Release Mechanism



Parachute will be folded on top of the container in a specially shaped space. When the container exits the rocket it will unfold due to the airflow around it and obtain its designed shape.

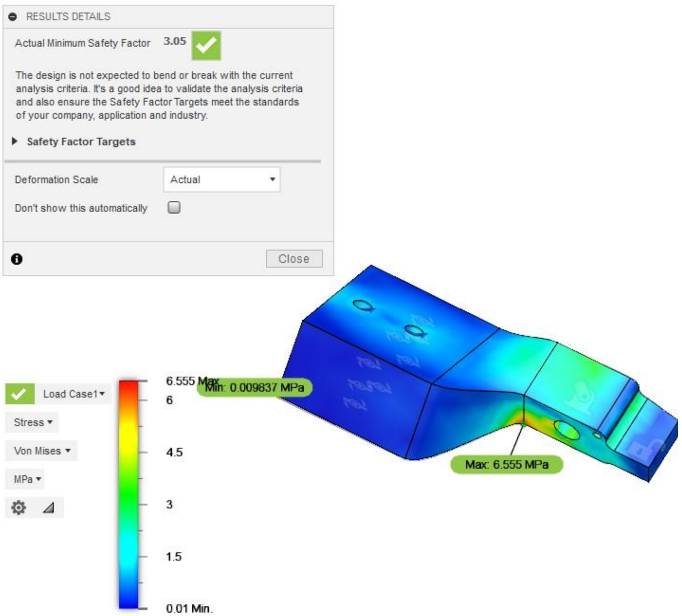


Structure Survivability

Electronics mounting, exploded view

- Regarding the electronics mounting method, we have splitted the circuit into 2 separate PCBs. This enables us to mount them in the lower part of the frame, lowering our CG and protecting them in case of a failure in the frame.
- Both PCBs are mounted with bolts in a bracket that sits in between them. On top of the first board sits an enclosure.
- The rear part of the lower board is exposed to the environment because it will host the pressure sensor
- The enclosure has a hole for the cables from servos to enter.
- For securing electrical connections, special plugs will be used
- An easily accesible battery compartment will be hosted under the PCB boards

Shock and acceleration testing



In a first level, test were conducted using **finite element** analysis tools provided by the CAD software. This is a simulation from the part that connects the blades with the rotor. Stress conditions are under maximum calculated RPM and maximum lift.

In a prototyping level, as described in the descent control chapter, we conducted a **drop Test** with a prototype cansat using a **drone**. **The design survived** with minor damages during landing, but all descent control subsystems were intact. Similar tests will be conducted with our final design.
We have also conducted **stress tests individually in each subsystem**, like in the fins and rotor assembly.

Mass Budget

Payload Mass Budget						
Subassembly	Components			Material	Mass per part(g)	Justification
Frame	Connecting rods			Carbon fiber	12.00	Estimated
	Level 3 Subassembly	Level 3		ABS	8.10	Estimated
		Bearings (x2)		S. Steel	1.95	Datasheet
		Rotor shaft		S. Steel	11.20	Estimated
	Level 1 Subassembly	Level 1		ABS	18.00	Estimated
		Leg assembly(x3)	Retaining ring	S. Steel	0.08	Datasheet
			Leg shaft	S. Steel	3.00	Estimated
			Leg end cap	TPU rubber	5.00	Estimated
			Rod	Carbon fiber	2.70	Estimated
			Leg joint	ABS	3.30	Estimated
			Lock pin	Steel	0.15	Estimated
			Torsion spring	Music wire	0.55	Estimated
			Lock slice	S. Steel	3.50	Estimated

Mass Budget

Payload Mass Budget						
Subassembly	Components			Material	Mass per part(g)	Justification
Rotor	Blade hub			ABS	10.0	Estimated
	Blade subassembly (x3)	Blade connector		ABS	2.5	Estimated
		Rotor blade pin		S. Steel	1.4	Estimated
		Spacer		Brass	0.9	Estimated
		Torsion spring		Music wire	0.6	Estimated
		Blade		Balsa Wood	12	Estimated
Gimbal	Servo Motor (x3)				5	Datasheet
	Bracket_1			ABS	2.3	Estimated
	Bracket_2			ABS	2.5	Estimated
	Pin			S. Steel	0.46	Estimated

Mass Budget

Payload Mass Budget						
Subassembly	**Components**			**Material**	**Mass per part(g)**	**Justification**
Control fins	Fin hub			ABS	2.8	Estimated
	Fins Frame			ABS	12.9	Estimated
	Fins assembly (x3)	Ball link (x2)		S. Steel	0.4	Estimated
		Fin		ABS	6.8	Estimated
		Fin shaft		ABS	2.9	Estimated
		Ball link rod		ABS	0.16	Estimated
		Servo Motor			5	Datasheet
		Servo arm		ABS	0.18	Estimated
		Spring		Music Wire	0.6	Estimated
Others	All bolts				15	Estimated
	Electronics cover				3.7	Estimated

Mass Budget

Container Mass Budget						
Subassembly	Components			Material	Mass per part(g)	Justification
Container	Upper cap (x2)			ABS	15	Estimated
	Bottom cap (x2)			ABS	12	Estimated
	Connecting rods (x6)			Carbon fiber	3	Estimated
	Walls (x2)			Plywood	15	Estimated
	Lower pads (x3)			ABS	5.5	Estimated
	Top Pads (x3)			ABS	0.6	Estimated
	Hinges assembly (x2)	Body 1 (x2)		ABS	2.2	Estimated
		Axle		S. Steel	0.5	Estimated
		Torsion springs (x2)		Music wire	0.2	Estimated

Mass Budget

Payload Electronics Mass Budget		
Component	**Mass (g)**	**Justification**
Teensy 3.2	3	Datasheet
Adafruit Ultimate GPS	8.5	Datasheet
Adafruit BNO055	3	Datasheet
Adafruit BMP280	1.3	Datasheet
Adafruit Camera	2.8	Datasheet
Hall Effect Sensor - US5881 x2	0.12 x2	Datasheet
ATtiny85	0.5	Datasheet
XBee S2C Pro	4	Datasheet
Payload Antenna	1.2	Datasheet
Real Time Clock - DS1337C	0.7	Datasheet
Coin Cell Battery - BR1225	0.8	Datasheet

Mass Budget

Payload Electronics Mass Budget		
Component	**Mass (g)**	**Justification**
Coin Cell Battery Holder	0.58	Datasheet
Buzzer - 95dB 12mm 2.048kHz	1.4	Datasheet
5V Step Up Regulator	0.5	Estimate
Power Switch	0.5	Estimate
LED Light	0.01	Estimate (SMD Package)
Nichrome Wire	0.005	Datasheet/Estimate
Voltage Divider	0.01	Estimate (SMD Package)
3.6V Lithium Battery	18.8	Datasheet
PCBs	19.9	Estimate
Other (Connectors, Pins, etc)	10	Estimate
Total	77.75	

Mass Budget

Subassembly total weight	Weight (g)
Frame	108.04
Rotor	62.2
Gimbal	20.26
Fins	65.02
Container	129.10
Bolts and nuts	15.00
Electronics	77.75
Total	**477.37**
Margin	**32.63**

Sources of errors:

- Density of 3D printer filament may vary slightly from CAD material library value
- Glue has not been added to the total weight

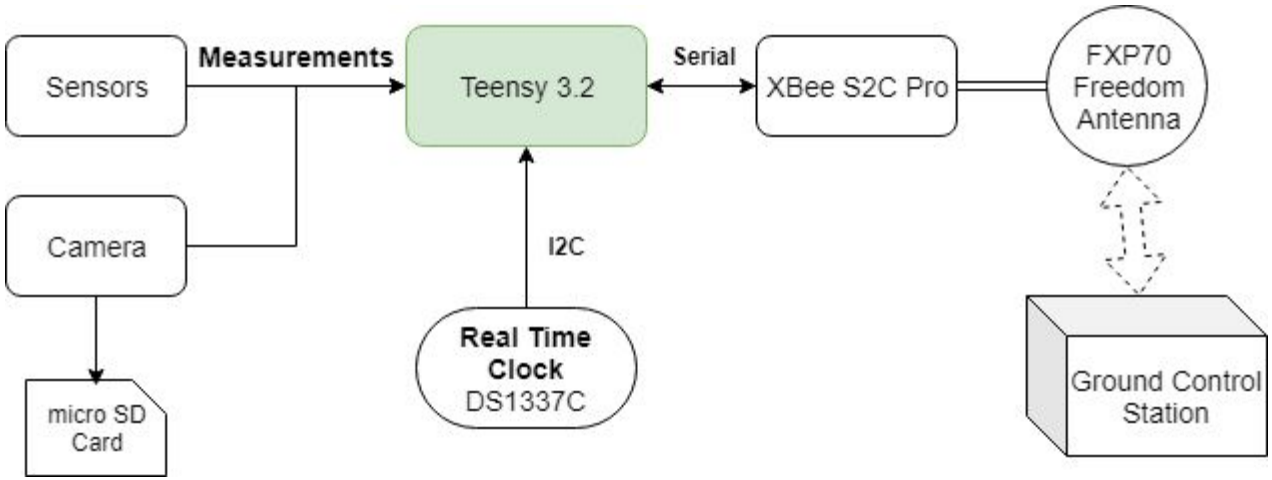
We have reduced the total weight of our design from 501 to 477.37 g . **In order to reduce weight even more we can:**

- Decrease infill density in 3D printed parts. All masses calculated with 100% density in CAD. Lowering the infill density up to 50% while using honeycomb patterns has very small effect on rigidity.
- Consider using different materials and manufacturing methods for some key parts

Communication and Data Handling (CDH) Subsystem Design

Dimitrios Bralios
Spyridon Pavlatos

CDH Overview



Payload Processor	Teensy 3.2
Real Time Clock	DS1337C
Payload Antenna	FXP70 Freedom 2.4Ghz
Payload Radio	XBee S2C Pro

CDH Changes Since PDR

Component	PDR	CDR	Rationale
Real Time Clock	DS1337	DS1337C	Contains an integrated oscillator, eliminating the need for an external.

Details of changes are discussed in subsequent slides.

CDH Requirements

No	Requirement	Priority	VM			
			A	I	T	D
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams.	HIGH	X			X
26	The probe shall transmit all sensor data in the telemetry	HIGH			X	X
28	The ground station shall be able to command the science vehicle to calibrate barometric altitude, and roll and pitch angles to zero as the payload sits on the launch pad.	HIGH			X	X
30	Telemetry shall include mission time with one second or better resolution. Mission time shall be maintained in the event of a processor reset during the launch and mission.	HIGH	X		X	
31	XBEE radios shall be used for telemetry. 2.4 GHz Series radios are allowed. 900 MHz XBEE Pro radios are also allowed.	HIGH		X		
32	XBEE radios shall have their NETID/PANID set to their team number.	MEDIUM/HIGH			X	X
33	XBEE radios shall not use broadcast mode.	HIGH			X	X

CDH Requirements

No	Requirement	Priority	VM			
			A	I	T	D
42	The flight software shall maintain a count of packets transmitted, which shall increment with each packet transmission throughout the mission. The value shall be maintained through processor resets.	HIGH			X	X
47	An audio beacon is required for the probe. It may be powered after landing or operate continuously.	HIGH				X
48	The audio beacon must have a minimum sound pressure level of 92 dB, unobstructed.	MEDIUM		X	X	
Bonus 5	The direction the camera is pointed relative to earth's magnetic north shall be included in the telemetry.	MEDIUM				X

Payload Processor & Memory Selection

Component	Power	Boot Time	Clock Speed	Data Interfaces		Memory	Mass	Cost
Teensy 3.2	34mA x 3.6V	5ms	72MHz	Digital I/O: 34 PWM: 12 Analog In: 21	Serial: 3 SPI: 1 I2C: 2	EEPROM: 2KB Flash: 256KB RAM: 64KB	3g	17.40 €

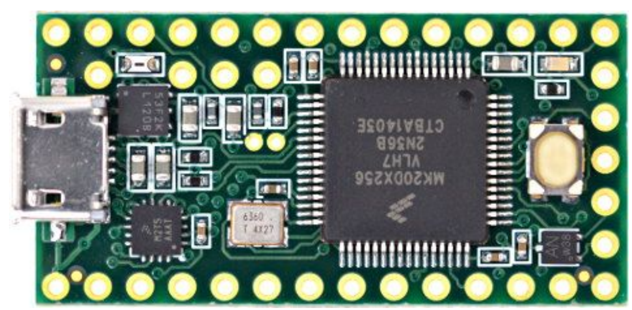
Memory and storage

- The software state as well as the packet counter will be saved on the non-volatile EEPROM memory. Enabling recovery from processor resets.
- Video recorded by the camera will be saved on the onboard micro SD card.
- Telemetry packets sent will not be saved by the flight processor, because of the weight, power and size cost of having another onboard SD card.

Notes

Programming is done using the Arduino IDE.

Uses a 32 bit ARM processor.



Payload Real-Time Clock

Component	Power	Crystal Frequency	Accuracy	Interface	Weight	Cost
DS1337C	150 μA x 3V	32768 Hz	10 ppm	I2C	<3g (including battery)	2.41€

Sample Data Format: 3:45:40 29 3 2019 (Hours, Minutes, Seconds, Day, Month, and Year)

Hardware real-time clock

A dedicated 3V coin cell battery will power the real-time clock, making it **reset tolerant.** The Teensy microprocessor can read the time using the I2C interface, with the help of the Teensy time library.

Note: An error of 10 ppm is equivalent to approximately 1 minute per 2 months. Calibration can be performed with the help of the Teensy library.

DS1337 was replaced by DS1337C

Rationale

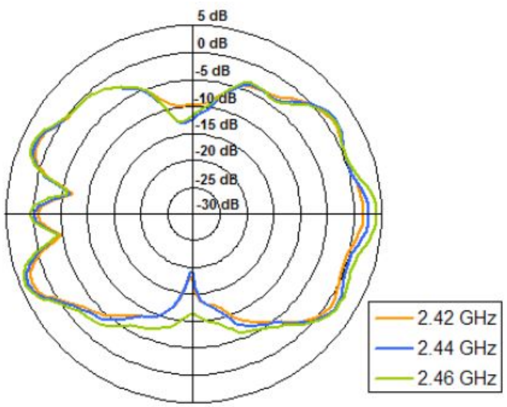
- The DS1337C contains an integrated oscillator with good accuracy, eliminating the need for an external.
- No other difference than slightly larger size, because of the integrated oscillator.

Payload Antenna Selection

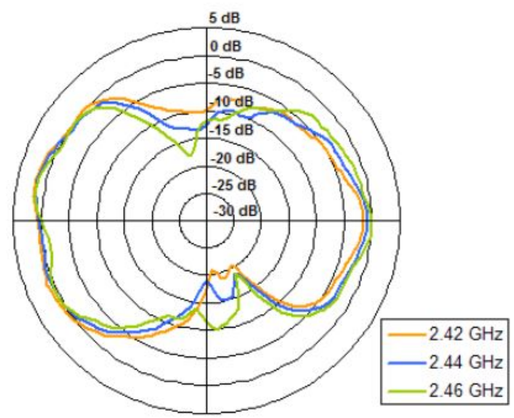
Antenna	Type	Gain	Polarization	VSWR	Dimensions & Weight	Connector	Cost
FXP70 Freedom 2.4GHz	Flex	5dBi	Vertical,horizontal	≤1.5:1	27x 25 mm 1.2g	U.FL	2,93 €

Rationale :

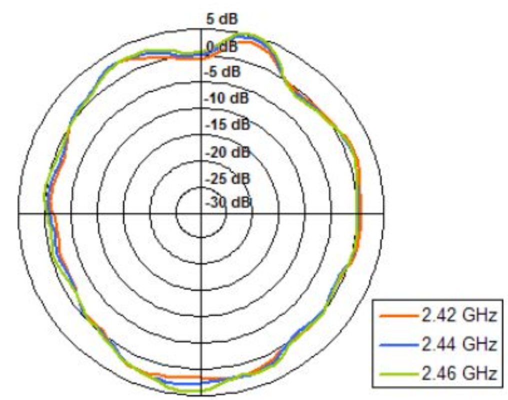
- High gain
- Low weight & small size
- Low VSWR



YZ Plane



XY Plane



XZ Plane

Payload Radio Configuration

Radio	Operating Frequency	Transmit Current	Receive Current	Transmit Power	Sensitivity	RF Data Rate	Cost
XBee S2C Pro	2.4GHz	120 mA @ 3.3 VDC	31 mA @ 3.3 VDC	63 mW (+18 dBm)	-101 dBm	250 Kbps	25.21 €

Rationale:

- Lower transmit current
- Sufficient transmit power
- Lower cost
- 900 MHz is allocated to mobile networks and we cannot conduct tests on this frequency

Connector: U.FL.

Payload Radio Configuration

- XBee configuration will be accomplished with XCTU Software.
- NETID will be set through the configuration to the team number (#4440).
- XBees will operate at AT (Transparent) mode.
- Broadcast will not be used. We will use unicast between the payload radio and the ground station.
- XBee communication protocol : ZigBee specification of IEEE 802.15.4..
- Ground station radio will be set as the coordinator and payload radio as router
- Transmission control will be managed by FSW during the flight and by Ground Station for the calibration of the sensors when the payload sits on the launch pad. At around 5m above the ground the audio beacon will be activated via FSW and when we land we will stop telemetry transmission.

DIGI XCTU

Configuration & Test
Utility Software

Payload Telemetry Format

- Upon powering up, the CanSat probe shall collect the required telemetry at a **1 Hz** sample rate (bursts). The telemetry data shall be transmitted with **ASCII comma separated fields** followed by a carriage return in the following format (matching the Competition Guide requirements) :

<TEAM ID>,<MISSION TIME>,<PACKET COUNT>,<ALTITUDE>,<PRESSURE>,<TEMP>,<VOLTAGE>,<GPS TIME>,<GPS LATITUDE>,<GPS LONGITUDE>,<GPS ALTITUDE>,<GPS_SATS>,<PITCH>,<ROLL>,<BLADE SPIN RATE>,<SOFTWARE STATE>,<BONUS DIRECTION>

- Example frame:

4440,55,55,375.3,10112,27.5,3.71,14:34:12,37.9790,23.7843,640.5,12,11,13,2340,deployed,5

- The received probe telemetry for the entire mission will be saved on the ground station computer as a comma separated value (.csv) file named “Flight_4440.csv” (matching the Competition Guide requirements).

Payload Telemetry Format

<TEAM ID> is the assigned team identification.

<MISSION TIME> is the time since initial power up in seconds.

<PACKET COUNT> is the count of transmitted packets, which is to be maintained through processor reset.

<ALTITUDE> is the altitude in units of meters and must be relative to ground level. The resolution must be 0.1 meters.

<PRESSURE> is the measurement of atmospheric pressure in units of pascals. The resolution must be 1 pascals.

<TEMP> is the sensed temperature in degrees C with one tenth of a degree resolution.

<VOLTAGE> is the voltage of the CanSat power bus. The resolution must be 0.01 volts.

<GPS TIME> is the time generated by the GPS receiver. The time must be reported in 11 UTC and have a resolution of a second.

<GPS LATITUDE> is the latitude generated by the GPS receiver in decimal degrees with a resolution of 0.0001 degrees.

<GPS LONGITUDE> is the longitude generated by the GPS receiver in decimal degrees with a resolution of 0.0001 degrees.

<GPS ALTITUDE> is the altitude generated by the GPS receiver in meters above mean sea level with a resolution of 0.1 meters.

<GPS SATS> is the number of GPS satellites being tracked by the GPS receiver. This must be an integer number.

<PITCH> is the tilt angle in the pitch axis in degrees. The resolution must be 1 degree.

<ROLL> is the tilt angle of the roll axis in degrees. The resolution must be 1 degree.

<BLADE SPIN RATE> is the rate the auto-gyro blades spin relative to the science payload. The units must be in revolutions per minute (rpm). The resolution must be 1 rpm.

<SOFTWARE STATE> is the operating state of the software. (boot, idle, launch detect, deploy, etc.).

<BONUS DIRECTION> is the direction the camera is pointed relative to earth's magnetic north specified in degrees.

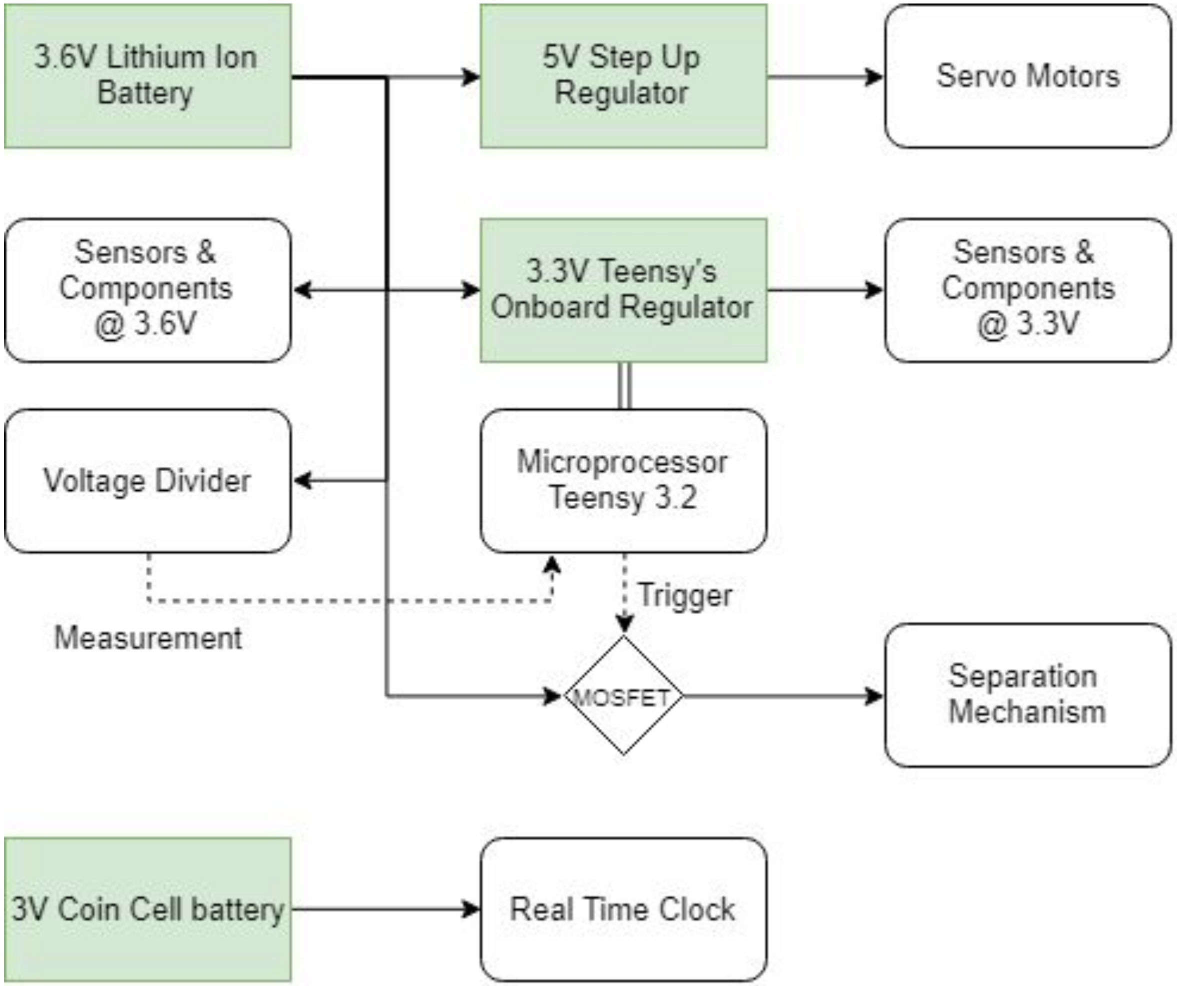
Container Processor & Memory Selection

The container will not have any electronics.

Electrical Power Subsystem Design

Dimitrios Bralios

EPS Overview



3.6V Lithium Ion Battery
3.6V FENIX ARB-L16-700UP 16340

5V Step Up Regulator
Pololu 5V Step-Up Regulator U1V11F5

3.3V Regulator
Teensy's onboard regulator

3V Coin Cell Battery
Panasonic BR1225

EPS Changes Since PDR

Component	PDR	CDR	Rationale
3.3V Regulator	LM3671	Teensy's onboard regulator	Saves weight and space Fits requirements
Coin Cell Battery	N/A	Panasonic BR1225	Small size and high capacity Fits requirements

Details of changes are discussed in subsequent slides.

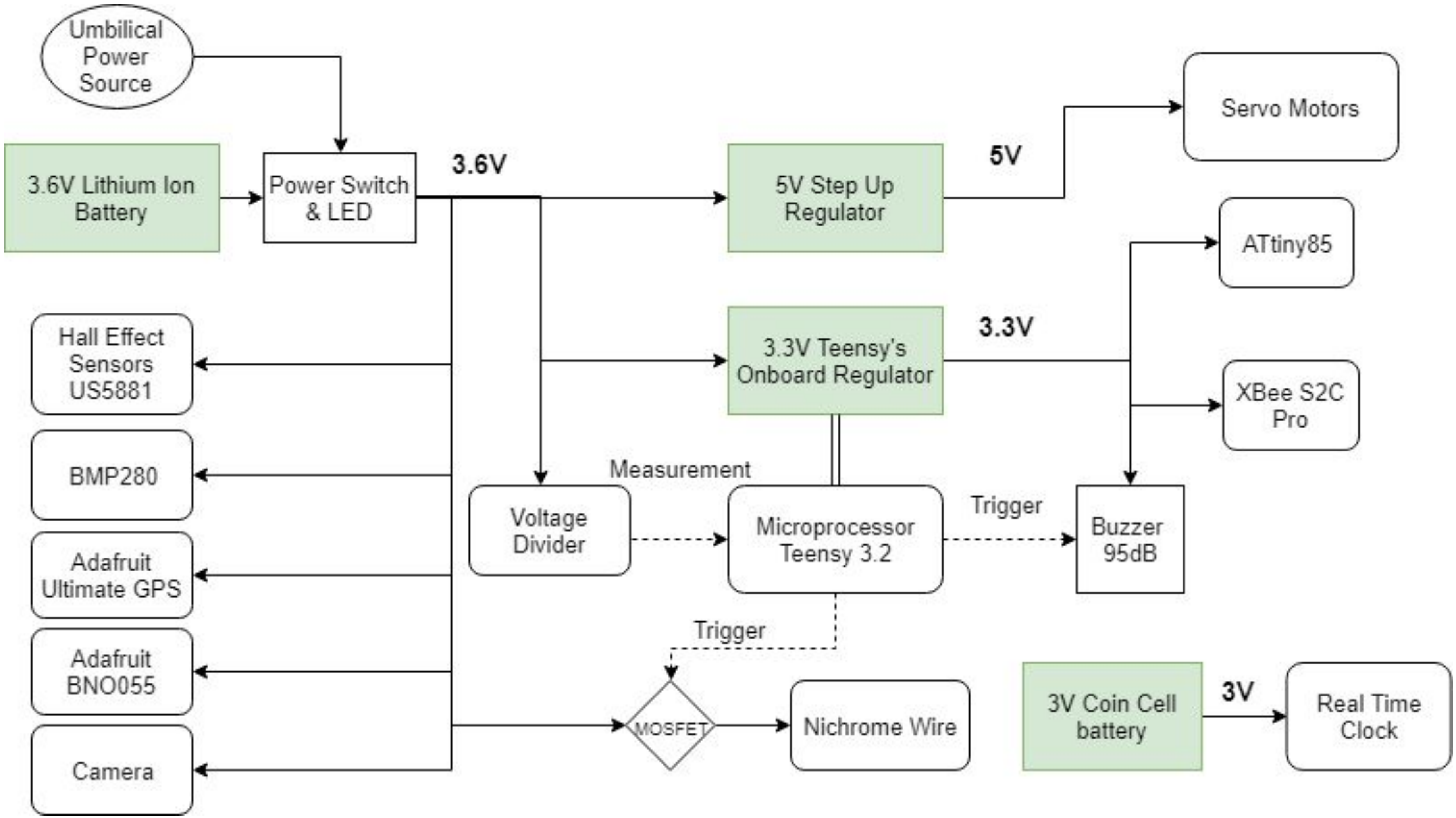
EPS Requirements

No	Requirement	Priority	VM			
			A	I	T	D
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams.	HIGH				X
13	All electronic components shall be enclosed and shielded from the environment with the exception of sensors.	HIGH		X		X
16	All electronics shall be hard mounted using proper mounts such as standoffs, screws, or high performance adhesives.	HIGH		X		X
45	The probe must include an easily accessible power switch that can be accessed without disassembling the cansat and in the stowed configuration.	HIGH		X		X
46	The probe must include a power indicator such as an LED or sound generating device that can be easily seen without disassembling the cansat and in the stowed state.	HIGH		X		X
47	An audio beacon is required for the probe. It may be powered after landing or operate continuously.	HIGH				X

EPS Requirements

No	Requirement	Priority	VM			
			A	I	T	D
48	The audio beacon must have a minimum sound pressure level of 92 dB, unobstructed.	MEDIUM		X	X	
49	Battery source may be alkaline, Ni-Cad, Ni-MH or Lithium. Lithium polymer batteries are not allowed. Lithium cells must be manufactured with a metal package similar to 18650 cells.	HIGH		X		X
50	An easily accessible battery compartment must be included allowing batteries to be installed or removed in less than a minute and not require a total disassembly of the CanSat.	HIGH		X		X
51	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects.	HIGH				X
55	Payload/Container shall operate for a minimum of two hours when integrated into rocket.	HIGH	X		X	X
Bonus 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	MEDIUM		X		

Payload Electrical Block Diagram



Payload Power Source

Battery	Voltage	Capacity	Max Discharge Current	Size	Weight	Cost
FENIX ARB-L16-700UP 16340	3.6V	2.52 Wh (700mAh)	3A 2.5A (stable)	∅16.0 x 35.0mm	18.8g	6.00 €
5V Step Up Regulator	**Voltage Range**	**Efficiency at 3.6V**	**Max Output Current**	**Size**	**Weight**	**Cost**
Pololu 5V Step-Up Regulator U1V11F5	0.5 - 5.5V	85%	1.2A	12mm x 15mm	0.6g	7.45 €

Power source description

The CanSat has one **3.6V Lithium Ion battery** (neither in series nor parallel configuration) which powers most of the components. The servo motors are powered by a **5V step up regulator**, which is powered by the Lithium Ion battery. The XBee, ATtiny85 and buzzer will be powered at 3.3V by **Teensy's onboard 3.3V regulator**, which can give up to 250 mA. Finally, the real-time clock will be powered by a dedicated **3V coin cell battery**.

Voltage Levels: 5V, 3.6V, 3.3V, 3V

3.3V Regulator	Voltage	Max Output Current
Teensy's onboard regulator	3.3V	250 mA

Coin Cell Battery	Voltage	Capacity
Panasonic BR1225	3V	48 mAh

Payload Power Source

Notes

As shown in the following slides the power sources have more than enough capacity to power all of the CanSat's components.

Finally, the maximum current draw by the components never exceeds the 3A limit of the lithium ion battery. While the components powered by the regulators never exceed the current draw limits (1.2A for the 5V step up and 250mA for the 3.3V regulator)

Changes since PDR

The LM3671 3.3V Regulator was replaced by Teensy's onboard regulator

Rationale:

- We save weight and space
- The components draw substantially less current than the 250 mA limit

The coin cell battery chosen is the Panasonic BR1225

Rationale:

- Fits the requirements perfectly.
- Has very high capacity, being able to power the real-time clock for up to 320 hours.

Payload Power Budget

Component	Current (mA)	Voltage (V)	Power (mW)	Duty Cycle (sec)	Power Consumption (mWh)	Source
Teensy 3.2	34	3.6	122.4	7200	244.8	Datasheet
Adafruit Ultimate GPS	20	3.6	72	7200	144	Datasheet
Adafruit BNO055	12.3	3.6	44.28	7200	88.56	Datasheet
Camera	110	3.6	396	100	11	Datasheet
BMP280	0.1	3.6	0.36	7200	0.72	Datasheet/Estimate
US5881 x2	2.5	3.6	18	7200	36	Datasheet
Voltage Divider	0.1	3.6	0.36	7200	0.72	Estimate
XBee S2C Pro (idle/transmitting)	31/ 120	3.3	111.6/ 432	7200/ 100	222.2/ 12	Datasheet
ATtiny85	5	3.3	18	7200	36	Datasheet
Buzzer	35	3.3	126	600	21	Datasheet
DS1337C	0.15	3	0.45	7200	0.9	Datasheet
Servo Motor x6	150	5	5294	50	73.5	Measurement
Nichrome Wire	700	3.6	2520	5	3.5	Measurement

Payload Power Budget

Power Source: Lithium Ion Battery

Total Power Consumed (Wh)	Total Capacity Required (mAh)	Available Capacity (Wh)	Margin (Wh)
0.89 (894 mWh)	249	2.52	1.63

Notes

Power of components powered by the 3.3V Regulator are calculated using the following equation, because of the heat losses.

$$P_{LOAD} + I_{LOAD} \times 0.3$$

Power of the components powered by the 5V Step Up Regulator are calculated as follows, because of the 85% efficiency.

$$\frac{P_{LOAD}}{0.85}$$

Power Source: Coin Cell Battery

Total Power Consumed (mWh)	Available Capacity (mWh)	Margin (mWh)
0.9	48	47.1

Conclusion

The power sources are capable of powering all the components for the required amount of time.

Container Electrical Block Diagram

The container will not have any electronics.

Container Power Source

The container will not have any electronics.

Container Power Budget

The container will not have any electronics.

Flight Software (FSW) Design

Miltiadis Stouras

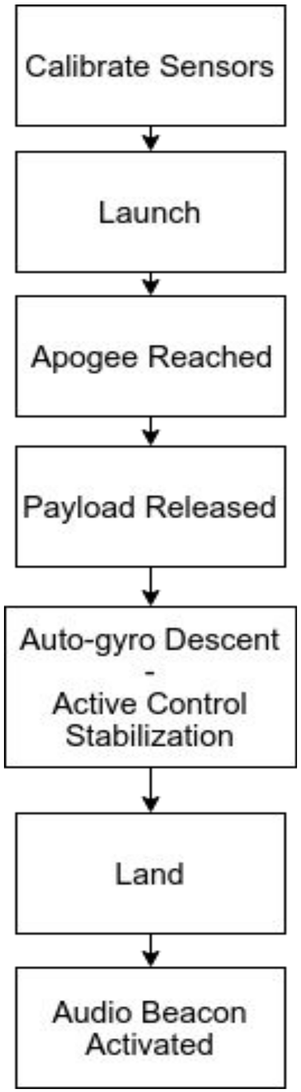
FSW Overview

Overview of FSW tasks:

- Correctly calibrate sensors
- Activate mechanisms in the correct time
- Ensure telemetry’s frequency is 1Hz
- Bypass minor sensor failures
- Design a software architecture such that the processor can **fully recover from a sudden power loss** that might occur **in any time** during the mission and **for arbitrary duration**

Programming languages: For the flight software development, our team will use the Arduino programming language as it offers a simple interface to program microcontrollers and also comes with a great variety of open source libraries for the sensors we selected.

Development Environments: The IDE used is Atom, because it is user-friendly, it has many packages for the Arduino programming language and can also be used with a Linter program that ensures code readability. We are also using Teensy Loader & Arduino IDE for uploading code to our microcontrollers



FSW Changes Since PDR

- **There have not been any major changes.**
- **Our team switched from C programming language to Arduino programming language, which is a subset of C/C++, since it offers a more easy-to-use interface in order to program the microcontroller we have selected.**

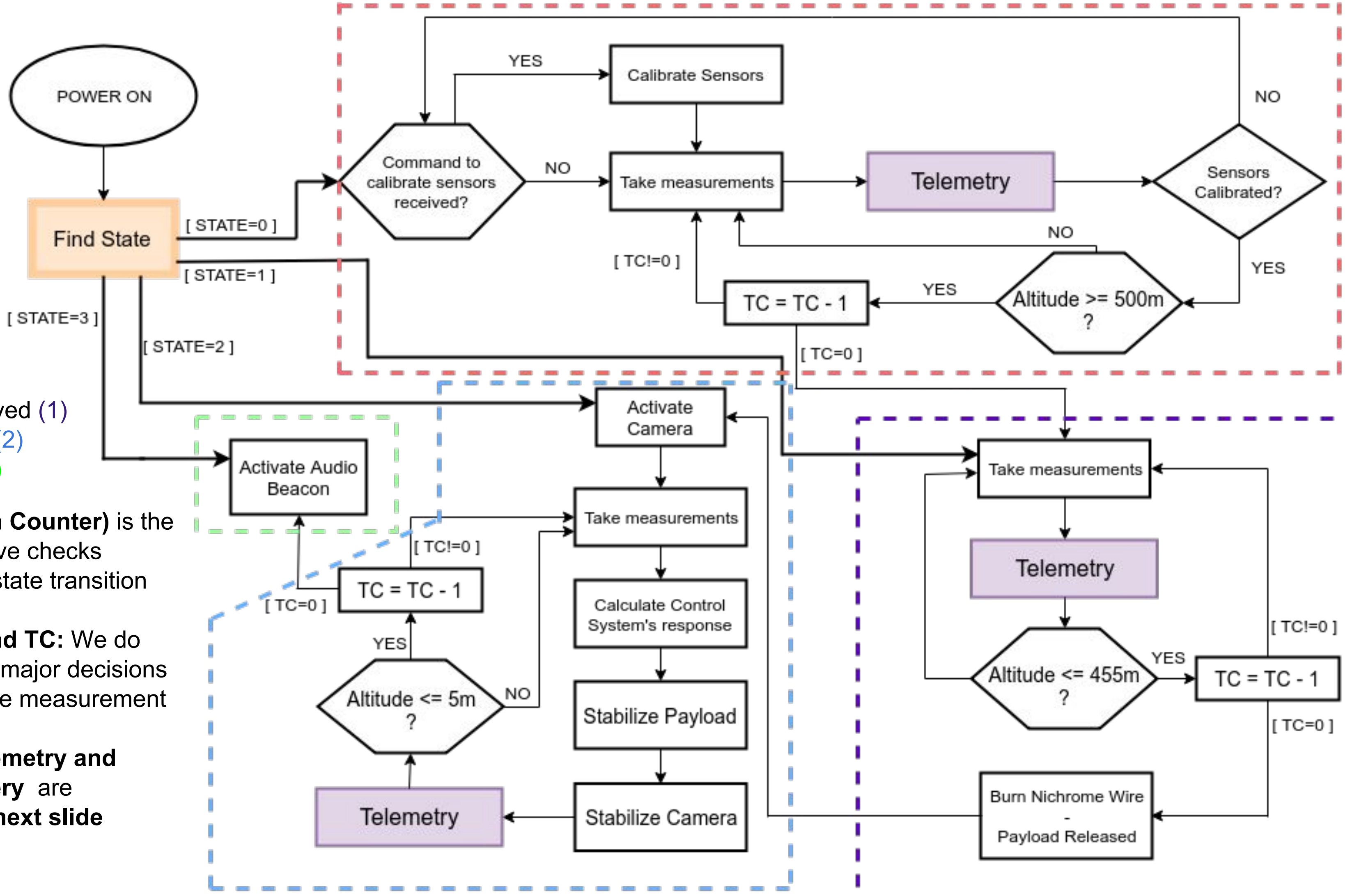
FSW Requirements

No	Requirement	Priority	VM			
			A	I	T	D
9	The container shall release the payload at 450 meters +/- 10 meters.	HIGH	X		X	X
28	The ground station shall be able to command the science vehicle to calibrate barometric altitude, and roll and pitch angles to zero as the payload sits on the launch pad.	HIGH	X	X	X	X
30	Telemetry shall include mission time with one second or better resolution. Mission time shall be maintained in the event of a processor reset during the launch and mission.	HIGH	X		X	X
42	The flight software shall maintain a count of packets transmitted, which shall increment with each packet transmission throughout the mission. The value shall be maintained through processor resets.	HIGH	X		X	X
47	An audio beacon is required for the probe. It may be powered after landing or operate continuously.	HIGH			X	X
53	The GPS receiver must use the NMEA 0183 GGA message format.	HIGH	X		X	X

FSW Requirements

No	Requirement	Priority	VM			
			A	I	T	D
Bonus 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	MEDIUM	X	X	X	X

Payload CanSat FSW State Diagram



Software States:

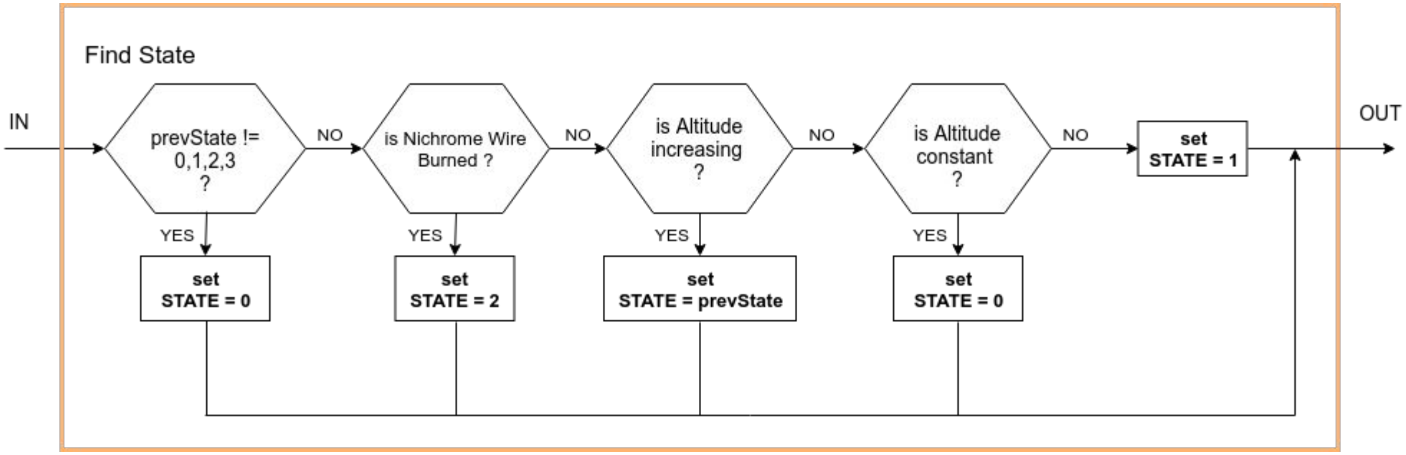
- Launch (0)
- Not Deployed (1)
- Deployed (2)
- Landed (3)

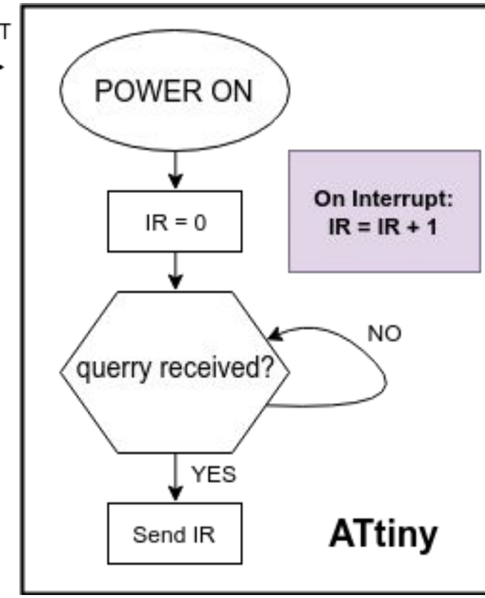
[TC] (Transition Counter) is the number of positive checks remaining for a state transition

Rationale behind TC: We do not want to take major decisions based on a single measurement

Find State, Telemetry and System Recovery are analyzed in the **next slide**

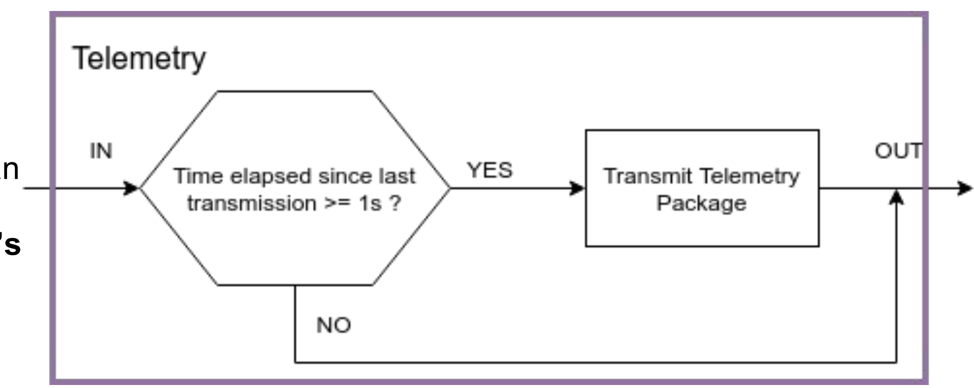
Payload CanSat FSW State Diagram





For **System Recovery**, we are saving the following data in Teensy's non-volatile memory (EEPROM) :

- **prevState:** The last known software state the processor has been in. It takes values 0,1,2 or 3 and before the mission it will be initialized to our team's ID.
- **isNichromeBurned:** A boolean variable that is true if and only if the payload has been deployed. It will be initialized to false.
- **packetCount:** The running count of the packets transmitted throughout the mission.



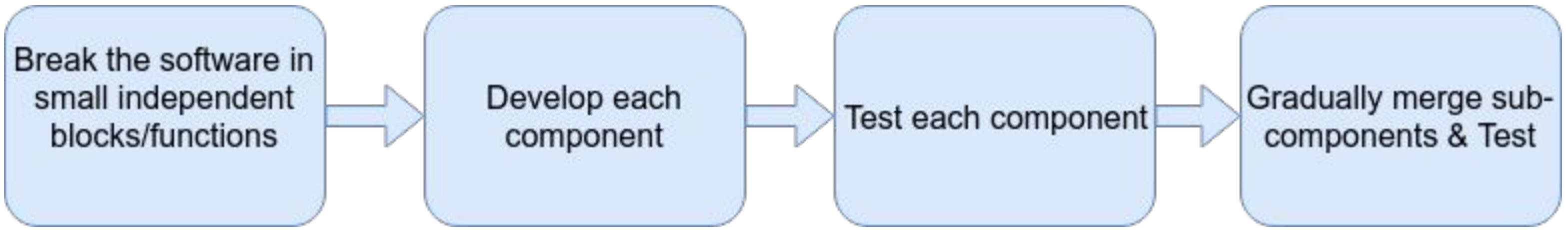
Find State, using EEPROM and on the spot measurements, can determine in which state the software should continue if we experience a processor reset. Notice that **just using EEPROM's prevState would not be enough** in a case where we should have transitioned to another state while being powered off.

Container CanSat FSW State Diagram

Container will not have any electronics.

Software Development Plan

For version control & team cooperation, we use **Git & GitHub.**



The flight software is tested on experiments (drop tests, measurements in extreme conditions, processor reset simulations etc.) to ensure it is properly working.

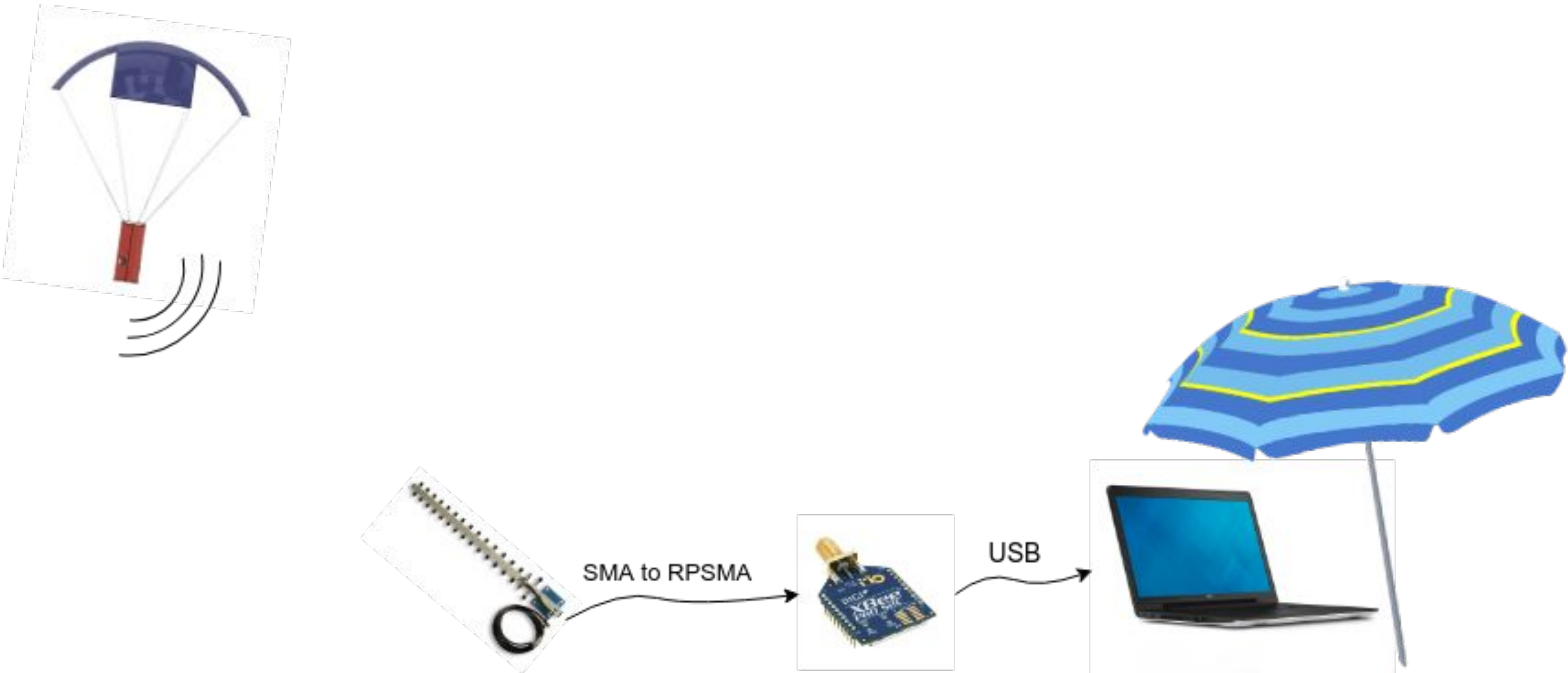
Progress:
- Completed the code for every subsystem.
- Tested every subsystem independently.
- Completed the code for blade optimization.
- Completed the code for the gimbal mechanism
- Performed basic tests for the gimbal mechanism.

To be done:
- Test all subsystems together.

Ground Control System (GCS) Design

Miltiadis Stouras

GCS Overview



GCS Changes Since PDR

There have not been any changes.

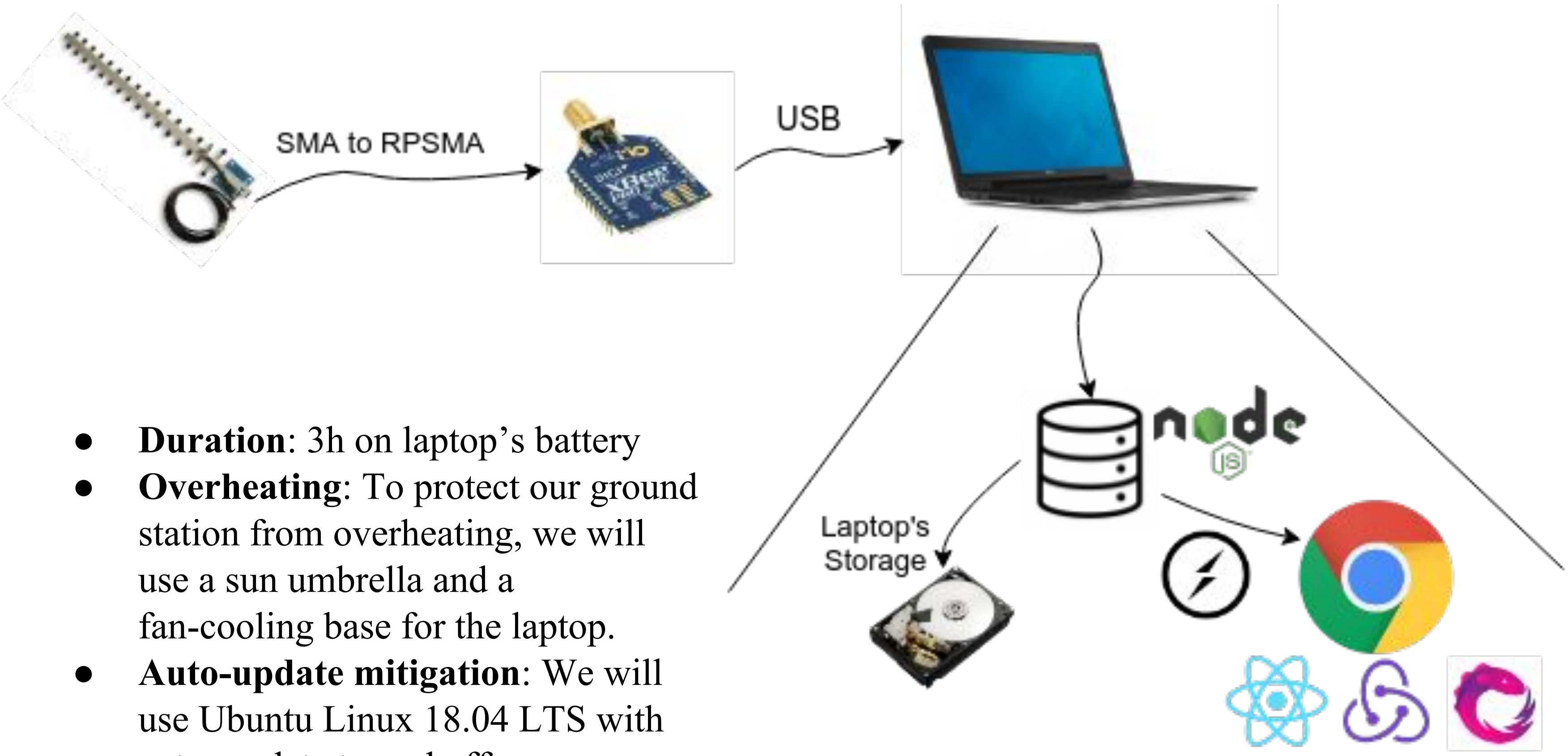
GCS Requirements

No	Requirement	Priority	VM			
			A	I	T	D
28	The ground station shall be able to command the science vehicle to calibrate barometric altitude, and roll and pitch angles to zero as the payload sits on the launch pad.	HIGH			X	X
29	The ground station shall generate a csv file of all sensor data as specified in the telemetry section.	HIGH			X	X
35	Each team shall develop their own ground station.	HIGH	X	X		X
36	All telemetry shall be displayed in real time during descent.	HIGH	X		X	X
37	All telemetry shall be displayed in engineering units (meters, meters/sec, Celsius, etc.)	HIGH			X	X
38	Teams shall plot each telemetry data field in real time during flight.	HIGH	X	X	X	X

GCS Requirements

No	Requirement	Priority	VM			
			A	I	T	D
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.	HIGH			X	X
40	The ground station must be portable so the team can be positioned at the ground station operation site along the flight line. AC power will not be available at the ground station operation site.	HIGH			X	X

GCS Design



- **Duration**: 3h on laptop's battery
- **Overheating**: To protect our ground station from overheating, we will use a sun umbrella and a fan-cooling base for the laptop.
- **Auto-update mitigation**: We will use Ubuntu Linux 18.04 LTS with auto- update turned off.

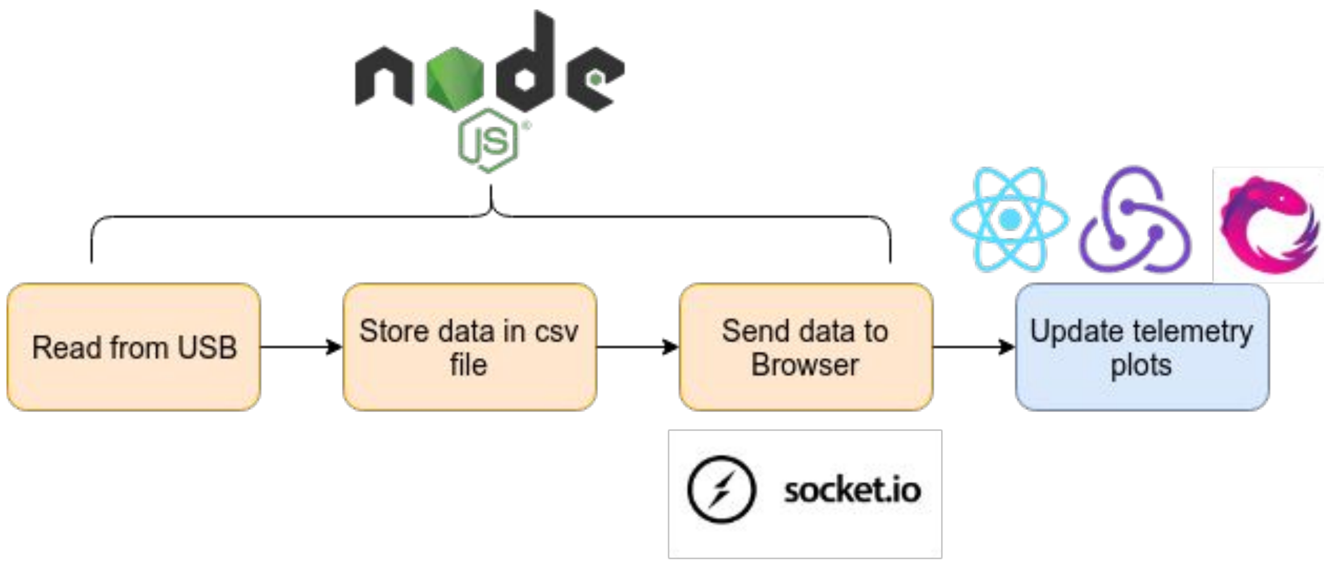
GCS Software

Software packages used:

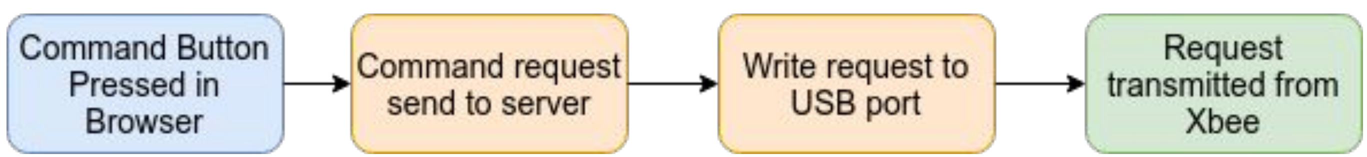
- **Server Side**:
  Node.js,
  Express.js,
  Socket.io
- **Front-end**:
  React
  Redux
  RxJS

Progress since PDR:
The Ground Station Software is completed, has been tested and is fully operational.

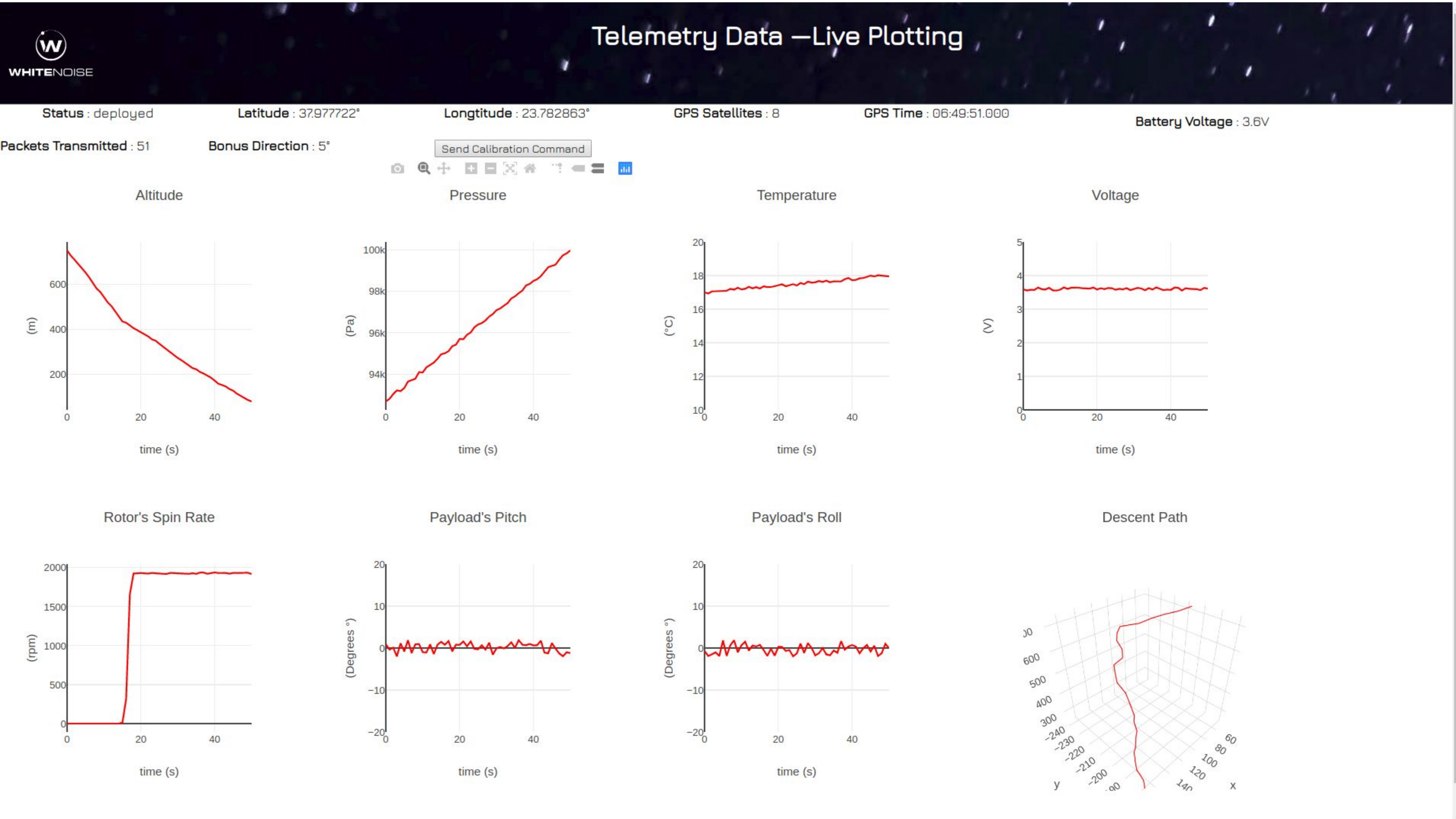
Incoming data flow:



Command flow:



GCS Software



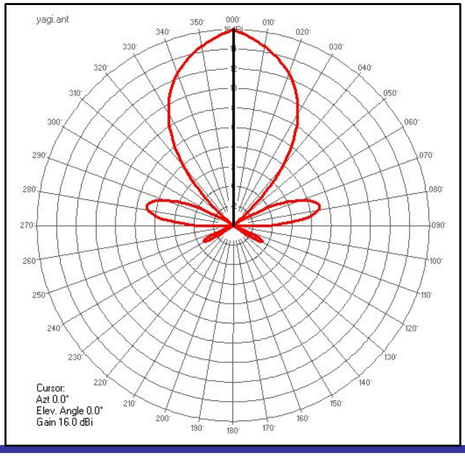
GCS Antenna

Antenna	Type	Gain	Polarization	VSWR	H-V Beamwidth	Mounting	Cost
ANT-2YAG16-SMA	Yagi-directional	16dBi	Vertical, horizontal	≤2.0:1	23°/23°	hand-held	53.67 €

Rationale:

- High gain
- Lower cost
- Low VSWR
- Hand-held → we can direct it easily

Radiation pattern:

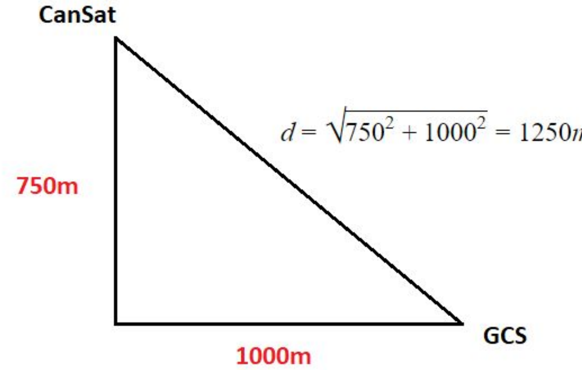


*we only consider the horizontal plane radiation pattern, because we will aim the antenna by hand

GCS Antenna

- **Link Budget:** $P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$

  where
  P_{RX} = received power(dBm)
  P_{TX} = transmitter output power 18dBm
  G_{TX} = transmitter antenna gain 5dBi
  L_{TX} = transmitter losses (dBm)
  L_{FS} = FSPL (Free Space Path Loss)
  L_M = miscellaneous losses (dBm)
  G_{RX} = receiver antenna gain 16dBi
  L_{RX} = receiver losses (dBm)



- We can assume that L_{RX}, L_M are approximately 10dBm together and L_{TX} is 0.
- Free Space Path Loss equation derived from Friis transmission equation :

$L_{FS} = FSPL(dB) = 20log_{10}(4\pi fd/c)$ where f=2.4GHz, d=1.25km and c speed of light.

- Therefore, $L_{FS} = 102dB$ and $P_{RX} \simeq -73.0dBm$
- XBee sensitivity -101dBm → Safe margin ~ 28dBm for d=1.25km

CanSat Integration and Test

Miltiadis Stouras

CanSat Integration and Test Overview

In order to make sure everything works as designed a series of tests will be/have been conducted:

- All subsystems have been tested individually with prototypes. More tests will be conducted when the final ones are constructed.
- After all subsystems are assembled together tests will be done in order to ensure that operation of each subsystem doesn’t affect others in any non predicted manner. Some of those tests have already been carried out in the test platform.
- The design during testing will be subjected to worse or similar conditions, than during the mission.
- Testing design early is key for having a high end result. Tests will point out weaknesses in the design and sufficient time must be available for design tweaks.

Subsystem Level Testing Plan

Sensors Subsystem Testing Plans	
Components	**Tests**
Air Pressure	• Verify the validity of the measurements by measuring altitude at locations where altitude is known.
Air Temperature	• Verify the validity of the measurements by measuring temperature and comparing to other thermometers.
GPS	• Verify the validity of the position measurements by comparison to other GPS devices with the help of Google Maps.
Pitch and Roll	• Verify the validity of the pitch and roll measurements by rotating to specific Euler angles.
Blade Spin Rate	• Verify the validity of the blade spin rate measurements by comparison to an optical tachometer. • Verify that the sensor module provides correct measurements with the expected accuracy.
Voltage Sensor	• Verify that the voltage level measured corresponds to the voltage level of the battery powering the CanSat.
Camera	• Verify that the module works as specified, outputting 640x480, 30fps color video.

Subsystem Level Testing Plan

EPS Subsystem
Tests
• Verify current draw stated on the datasheet of all the electronics at different stages of the mission.
• Verify that the CanSat can operate for at least two hours on internal power.
• Verify the stated efficiency of the 5V step up regulator by measuring the output as well as the input current, powering the servo motors.
• Verify that the battery can provide the peak current level (1.5A) without major consequences on the battery capacity. • Verify that the current draw of the components powered by the Teensy’s onboard regulator is under 250mA.
• Test the ability of the nichrome wire to cut the string that holds the container closed. While, verifying the current draw is the expected.
• Verify the voltage levels are as expected under all possible loads and all components are powered.
• Verify that the CanSat operates using the umbilical power source.

Subsystem Level Testing Plan

CDH Subsystem	
Components	**Tests**
Processor and Memory	• Ensure the processor is fast enough to collect all the measurements and perform the necessary calculations for the control system.
Real Time Clock	• Verify that we can correctly calibrate the real time clock and the time drift has the expected value
Camera SD card	• Ensure the SD card storage is enough to store the video recorded during the descent.

Radio Communication Subsystem	
Components	**Tests**
Antennas	• Range test to ensure that antenna amplifies the signal enough, so that the communication can be achieved in distances even bigger than the estimated distance for the launch day.
XBee radio	• Configuration test. Set the parameters to match the Mission Requirements : NETID, unicast mode. • Test communication between the 2 XBees.

Subsystem Level Testing Plan

FSW
Tests
• Processor Resets: Simulate all possible processor shut downs (in any state of the mission) and check that state recovery functions works properly.
• Ensure that it is not possible to be stuck in a state after reset.
• Ensure that all sensors' accuracy is being considered in condition checks.
• Verify state transitions are done correctly. • Verify software state is correct after giving any possible input.
• Test software using corrupted sensor data (produced randomly) to check its ability to handle failures.
• Check that sensors' refresh rates are sufficient for the active control system.
• Test the code that drives the servos of the gimbal mechanism.

Subsystem Level Testing Plan

Descent Control Subsystem	
Subsystem level	**Tests**
Rotor	• Measure lift and RPM with final blades in the wind tunnel and compare with model predicted values
Control system/Fins	• Before drop test check that fins turn in the correct direction (ie when cansat is tilted fins try to restore it in an intuitive way) • Plot the orientation's response over time and to see it's within specs
Camera gimbal	• Rotate cansat and monitor cameras orientation with second IMU. Check its within specs.

Subsystem Level Testing Plan

Mechanical Subsystem	
Subsystem level	**Tests**
Rotor	• Verify that rotor is balanced and doesn't vibrate when rotating in high speeds • Verify alignment in bearings and measure torque transmitted to the frame through friction • Verify joints can withstand forces in all scenarios ie. rapid change in orientation, vibrations
Fins	• Verify that all fins are aligned when in neutral position • Verify that servos have the required response when in full load conditions
Landing gear	• Make sure joints can withstand all scenarios
Camera Gimbal	• Make sure gimbal moves in the full servo range.
Container	• Ensure that springs on the container separate the 2 parts faster than Payload Deploys. This will prevent any malfunctions during deployment

Integrated Level Functional Test Plan

Test type	Tests
Sensors	• Verify that the sensors are calibrated providing the correct measurements. • Verify that the sensors provide measurements with the expected accuracy and resolution in the expected range. • Ensure the sampling rate is at least 1Hz
Mechanical	• Ensure that all mechanisms are working as designed when all parts are assembled • Ensure that glued parts are rigidly connected and can withstand acceleration requirements • Ensure frame won't deform in any scenario causing fragile parts to undergo stresses • Verify that it all scenarios landing legs deformation will not cause camera to touch the ground. • Free fall and parachute drop tests will be conducted extensively • Conduct vibration test
Descent Control	• Perform drop test from drone to check autogyro mechanism works as designed • Measure vibrations caused from poorly balanced rotor and gyroscopic effects during descent to see if they exceed safe limit

Environmental Test Plan

Drop Test procedure:

1. Attach parachute to a ceiling bolt using a non stretching cord.
2. Let the CanSat fall from ceiling height, and measure acceleration when the cord strains.
3. Quick Check for damage.
4. Repeat for various lengths acceleration values.
5. Release CanSat.
6. Check for: Power Loss, damage, detached parts, parachute fail etc.

Data must be transmitted through the procedure from the CanSat to the GCS.

Thermal Test procedure:

We are planning to construct a thermal chamber that can accomodate our CanSat, following the steps described in the mission guide. More specifically :

1. A temperature sensor will be placed in the chamber and for temperature control. Data will be sent to an arduino that will be out of the chamber.
2. We will start the heating with a hairdryer connected to the chamber.
3. When temp. reaches 60℃ we turn of the heat source via a relay.
4. If temperature falls below 55℃, we turn on the heat source.
5. Temperature will be maintained between 55℃ and 60℃ for two hours.
6. Get the CanSat out of the chamber.
7. Inspect for any kind of damage.

Data must be transmitted through the procedure from the CanSat to the GCS.

Environmental Test Plan

Vibration Test Procedure:

We plan to use an orbit sander for this test.

1. Secure the sander upside down, via a bench vise.
2. Secure CanSat on the moving pad of the sander.
3. Power on the CanSat.
4. Verify that telemetry works.
5. Power on the sander.
6. When sander reaches full speed, wait 5 or more seconds.
7. Turn of the sander.
8. Inspect for damage.
9. Repeat steps 5-7.

Data must be transmitted through the procedure from the CanSat to the GCS.

Fit check:

For checking that the cansat will fit inside the rocket's compartment we will do the following:

1. Measure the container's outside dimensions and check that they are equal or slightly smaller than designed.
2. 3D print a cylinder with dimensions equal to the rocket's payload compartment.
3. Check that cansat can easily slide in the 3D printed compartment

Test Procedures Descriptions

Test Proc	Test Description	Requirements	Pass Fail Criteria
1	Measure lift and RPM with final blades in the wind tunnel and compare with model predicted values	11	They should be within a 20% of calculated
2	Before drop test check that fins turn in the correct direction (ie when cansat is tilted fins try to restore it in an intuitive way)	Bonus 2, Bonus 5	Yes/no
3	Measure torque fins can exert on frame and compare them with model predicted ones	Bonus 2, Bonus 5	They should be within a 30% of calculated
4	Verify that all fins are aligned when in neutral position	Bonus 3, Bonus 5	Yes/no
5	Verify that servos have the required response when in full load conditions	Bonus 3, Bonus 5	response must not be sluggish
6	Make sure joints can withstand all scenarios	12,14,15	Joints won't break in all tests.
7	Ensure that springs on the container separate the 2 parts faster than Payload Deploys. This will prevent any malfunctions during deployment	9	Payload must deploy without errors
8	Verify that rotor is balanced and doesn't vibrate when rotating in high speeds	Bonus 2, Bonus 3	Check values from accelerometer are within +-30G during test

Test Procedures Descriptions

Test Proc	Test Description	Requirements	Pass Fail Criteria
9	Verify alignment in bearings and measure torque transmitted to the frame through friction	Bonus 2, Bonus 3	Spin rotor and see if the frame rotates while in the air
10	Make sure gimbal moves in the full servo range.	Bonus 2, Bonus 3	Yes/no
11	Weigh container, payload and see that masses are as calculated	1	Yes/no
12	Plot the orientation's response over time and to see it's within specs	Bonus 2, Bonus 3	It should be within +-40 deg range to prevent capsizing
13	Rotate cansat and monitor cameras orientation with second IMU. Check its within specs.	Bonus 2, Bonus 3	It should be within the +-5 deg range.

Test Procedures Descriptions

Test Proc	Test Description	Requirements	Pass Fail Criteria
18	Check that the radio configuration complies with the Mission Guide	31,32,33	XBee's operating frequency at 2.4 GHz, set in unicast mode and NETID set to our team number
19	Antennas (both payload's and GS's) range test.	26,28	Communication achieved for distances bigger than 1.25km.
20	Verify the CanSat can operate for at least 2 hours on internal power.	55	CanSat is still operational after 2 hours
21	Verify the buzzer reaches the required sound level.	48	Sound level is above 92dB
22	Verify the sensors operate in the expected range with the expected accuracy.	20,21,22,23,24,25	Receive measurement,s within the specified range, at a rate of at least 1Hz.

General Comments

- We have specified the tests only for the requirements that need testing. The ones that are evident through demonstration are not included here.

Mission Operations & Analysis

Dimitrios Bralios

Overview of Mission Sequence of Events

Roles & Responsibilities	
1. Mission Control Officer	Iasonas Nikolaou
2.GCS crew	Miltiadis Stouras, Spyridon Pavlatos, Marios Papachristou
3.Recovery crew	Chariton Charitonidis, George Rapakoulias, Dimitrios Bralios, Neoklis Vaindirlis
4.CanSat crew	George Rapakoulias, Dimitrios Bralios, Neoklis Vaindirlis, Ioannis Christodoulou

Overview of Mission Sequence of Events

Arrival:

- Arrival at the launch location **(1,2,3,4)**
- Ground station set up **(2)**

Pre-Launch:

- Antenna check **(2)**
- Communication check **(2,4)**
- Fit check & mass measurement **(4)**
- Container release mechanism check **(4)**
- Processor's EEPROM initialized **(4)**
- Inspection of electronics **(4)**
- Turn in CanSat at Check-in **(4)**

Launch:

- Lift-off
- Apogee reached - Container separated from the rocket
- Parachute released, container descenting with terminal velocity 20m/s
- Payload released at an altitude of 450m

Overview of Mission Sequence of Events

Mission:

- Payload descents with auto-gyro mechanism. Descent rate at 10.5m/s
- On-board camera activated
- Camera & Payload stabilization through active control
- The audio beacon will operate throughout the mission

CanSat Recovery:

- Trace CanSat during descent **(3)**
- Find payload **(3)**
- Detach SD card and back-up data **(3)**

Post-Mission, Data Analysis:

- Check video stabilization and quality **(2)**
- Check collected mission data for inconsistencies **(2)**
- Compare observed trajectory with collected mission data **(2)**

Field Safety Rules Compliance

All the Field Safety Rules mentioned in the mission guide will be strictly observed by all team members.

The Mission Operations Manual will be ready before the Flight Readiness Review. During the launch event it will be available in multiple copies in a three ring binder.

The Mission Operation Manual will include detailed instructions of the mission sequence of events discussed in the previous slide, indicating every subteam's activities at each point during the mission.

CanSat Location and Recovery

CanSat Recovery Strategy:

- The Recovery Crew will be tracing the CanSat during descent
- The audio beacon will be operating after landing
- We will also use payload's GPS location provided in telemetry, to get a better estimate of the landing zone

CanSat Color: Both the container and the payload will be **Orange** so they can easily be spotted in the sky or the field.

CanSat Label: The container will have a label with the following information:

National Technical University of Athens, White Noise
Zografou Campus
9, Iroon Polytechniou str
15780, Zografou, Attica, Greece
whitenoisegreece@gmail.com

Mission Rehearsal Activities

Part of the Mission Operation Manual has already been developed and our team is rehearsing the mission sequence of events, ensuring the mission will proceed as planned.

Specifically, we are focusing on the following procedures

- Check of the Ground Control Station
- Preparing the CanSat for launch
- Loading of the CanSat and final launch preparations
- Calibration of the CanSat on the launch platform
- Handling of telemetry and analysis of the data
- Recovery of the probe, using the audio beacon

Requirements Compliance

Dimitrios Bralios

Requirements Compliance Overview

Compliance Summary

- All contest requirements have been tested theoretically using simulation methods.
- Most of the tests, during the prototyping stage, have been performed providing valuable results.
- Tests on the final design will be conducted again to ensure compliance to the requirements.

The following table provides details for all contest requirements, their compliance, and their referencing slides Requirements have been marked as per compliance, as suggested in the template:

Comply

Partial

No comply

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
1	Total mass of the CanSat (science payload and container) shall be 500 grams +/- 10 grams	comply	70-74,75	
2	CanSat shall fit in a cylindrical envelope of 125 mm diameter x 310 mm length	comply	23, 63	
3	The container shall not have any sharp edges to cause it to get stuck in the rocket payload section which is made of cardboard	comply	23	
4	The container shall be a fluorescent color; pink, red or orange	comply	140	Colors will differ from CAD due to limitations
5	The rocket airframe shall not be used to restrain any deployable parts of the CanSat.	comply	23	
6	The rocket airframe shall not be used as part of the CanSat operations.	comply	23	
7	The CanSat shall deploy from the rocket payload section and immediately deploy the container parachute.	comply	66	
8	The descent rate of the CanSat (container and science payload) shall be 20 meters/second +/- 5m/s	comply	50,53	
9	The container shall release the payload at 450 meters +/- 10 meters.	comply	19	

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
10	The science payload shall descend using an auto-gyro descent control system.	comply	19	
11	The descent rate of the science payload after being released from the container shall be 10 to 15 meters/second	comply	51,52,53	
12	All descent control device attachment components shall survive 30 Gs of shock.	comply	67, 68	
13	All electronic components shall be enclosed and shielded from the environment with the exception of sensors.	comply	67	
14	All structures shall be built to survive 15 Gs of launch acceleration.	comply	67, 68	
15	All structures shall be built to survive 30 Gs of shock.	comply	67, 68	
16	All electronics shall be hard mounted using proper mounts such as standoffs, screws, or high performance adhesives.	comply	67	
17	All mechanisms shall be capable of maintaining their configuration or states under all forces.	comply	67, 68	
18	Mechanisms shall not use pyrotechnics or chemicals.	comply	54-75	Not used

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
19	Mechanisms that use heat (e.g., nichrome wire) shall not be exposed to the outside environment to reduce potential risk of setting vegetation on fire.	comply	65	
20	The science payload shall measure altitude using an air pressure sensor.	comply	29	
21	The science payload shall provide position using GPS.	comply	31	
22	The science payload shall measure its battery voltage.	comply	32	
23	The science payload shall measure outside temperature.	comply	30	
24	The science payload shall measure the spin rate of the auto-gyro blades relative to the science vehicle.	comply	34, 35	
25	The science payload shall measure pitch and roll	comply	33	
26	The probe shall transmit all sensor data in the telemetry	comply	77,86,87	
27	The Parachute shall be fluorescent Pink or Orange	comply	140	

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
28	The ground station shall be able to command the science vehicle to calibrate barometric altitude, and roll and pitch angles to zero as the payload sits on the launch pad.	comply	77, 85	
29	The ground station shall generate a csv file of all sensor data as specified in the telemetry section	comply	86	
30	Telemetry shall include mission time with one second or better resolution. Mission time shall be maintained in the event of a processor reset during the launch and mission.	comply	86, 87	
31	XBEE radios shall be used for telemetry. 2.4 GHz Series radios are allowed. 900 MHz XBEE Pro radios are also allowed.	comply	83, 84	
32	XBEE radios shall have their NETID/PANID set to their team number.	comply	85	
33	XBEE radios shall not use broadcast mode.	comply	85	
34	Cost of the CanSat shall be under $1000. Ground support and analysis tools are not included in the cost	comply	153-158, 159	
35	Each team shall develop their own ground station.	comply	111 - 120	

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
36	All telemetry shall be displayed in real time during descent.	comply	117, 118	
37	All telemetry shall be displayed in engineering units (meters, meters/sec, Celsius, etc.)	comply	117, 118	
38	Teams shall plot each telemetry data field in real time during flight.	comply	117, 118	
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.	comply	112, 116	
40	The ground station must be portable so the team can be positioned at the ground station operation site along the flight line. AC power will not be available at the ground station operation site.	comply	112, 116	
41	Both the container and probe shall be labeled with team contact information including email address.	comply	140	
42	The flight software shall maintain a count of packets transmitted, which shall increment with each packet transmission throughout the mission. The value shall be maintained through processor resets.	comply	108	
44	No lasers allowed.	comply	17, 18	Design doesn't feature lasers

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
45	The probe must include an easily accessible power switch that can be accessed without disassembling the cansat and in the stowed configuration.	comply	65, 94	
46	The probe must include a power indicator such as an LED or sound generating device that can be easily seen without disassembling the cansat and in the stowed state.	comply	94	
47	An audio beacon is required for the probe. It may be powered after landing or operate continuously	comply	94, 140	
48	The audio beacon must have a minimum sound pressure level of 92 dB, unobstructed.	comply	94	Sparkfun's PC Mount 12mm 2.048kHz 95dB
49	Battery source may be alkaline, Ni-Cad, Ni-MH or Lithium. Lithium polymer batteries are not allowed. Lithium cells must be manufactured with a metal package similar to 18650 cells.	comply	95	16340 metal package
50	An easily accessible battery compartment must be included allowing batteries to be installed or removed in less than a minute and not require a total disassembly of the CanSat.	comply	67	
51	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects.	comply	67	

Requirements Compliance

No	Requirement	Status	Ref. slides	Comments
52	The auto-gyro descent control shall not be motorized. It must passively rotate during descent.	comply	38 - 53	
53	The GPS receiver must use the NMEA 0183 GGA message format.	comply	31	
54	The CANSAT must operate during the environmental tests.	comply	130, 131	
55	Payload/Container shall operate for a minimum of two hours when integrated into rocket.	comply	95 - 97, 98	
B 1	A video camera shall be integrated into the science payload to record the descent after being released from the container.	comply	36	
B 2	The camera shall point downward 45 degrees from nadir.	comply	48, 61	
B 3	It shall be spin stabilized and point in one direction relative to the earth's magnetic field with a stability of +/- 10 degrees. Direction does not matter as long as it is in one direction.	comply	46, 47	
B 4	Video shall be in color with a minimum resolution of 640x480 pixels and 30 frames per second	comply	36	
B 5	The direction the camera is pointed relative to earth's magnetic north shall be included in the telemetry.	comply	86, 87	

Management

Dimitrios Bralios

Status of Procurements

Sensors and Components

The **majority** of the sensors and components, listed in the SS, MS, CDH and EPS, have been ordered and **have arrived**. The only significant components that have not arrived yet are the Lithium Ion Battery and the 5V Step Up Regulator which are not available in Greece and have been ordered from the US, expected to arrive in the next month.

Mechanical

Raw materials like ABS filament, s. steel shafts, etc have all been ordered.

Other

Printed circuit boards have been designed to host the sensors and most of the electrical components. They will be ordered from China within the next month.

CanSat Budget – Hardware

Mechanical Hardware Budget						
Subassembly	Components			Comments	Price per part(€)	Cost type
Frame	Connecting rods			Raw material(to be cut in pieces)	4.00	Actual
	Level 3 Subassembly	Level 3		3D printed	0.73	estimate
		Bearings (x2)			0.60	Actual
		Rotor shaft		Raw material	3.20	Actual
	Level 1 Subassembly	Level 1		3D Printed	1.00	Estimated
		Leg assembly(x3)	Retaining ring		1.50	Actual
			Leg shaft	Raw material	1.00	Actual
			Leg end cap	3D printed	0.50	Estimated
			Rod	Raw material	2.00	Actual
			Leg joint	3D printed	0.17	Estimated
			Lock pin	Raw material	0.50	Actual
			Torsion spring	Raw material	0.50	Actual
			Lock slice	Raw material	2.00	Actual

CanSat Budget – Hardware

Mechanical Hardware Budget						
Subassembly	Components			Comments	Price per part(€)	Cost type
Rotor	Blade hub			3D printed	0.64	Estimated
	Blade subassembly (x3)	Blade connector		3D printed	0.16	Estimated
		Rotor blade pin		Raw material	0.50	Actual
		Spacer		Raw material	1.00	Actual
		Torsion spring		Raw material	0.50	Actual
		Blade		Raw materials	5.00	Estimated
Gimbal	Servo Motor (x3)				5.00	Actual
	Bracket_1			3D printed	0.12	Estimated
	Bracket_2			3D printed	0.12	Estimated
	Pin			Raw materials	0.50	Actual

CanSat Budget – Hardware

Mechanical Hardware Budget

Subassembly	Components			Comments	Price per part(€)	Cost type
Control fins	Fin hub			3D printed	0.14	Estimated
	Fins Frame			3D printed	0.3	Estimated
	Fins assembly (x3)	Ball link (x2)			1.00	Actual
		Fin		3D printed	0.30	Estimated
		Fin shaft		3D printed	1.00	Estimated
		Ball link rod		3D printed	0.10	Estimated
		Servo Motor			4.00	Actual
		Servo arm			1.00	Actual
		Spring		Raw materials	0.50	Estimated
Others	All bolts			Bought	4.00	Actual
	Electronics cover			3D printed	0.50	Estimated

CanSat Budget – Hardware

<table>
<tr><th colspan="7">Mechanical Hardware Budget</th></tr>
<tr><th>Subassembly</th><th colspan="3">Components</th><th>Comments</th><th>Price per part(€)</th><th>Cost Type</th></tr>
<tr><td rowspan="9">Container</td><td>Upper cap (x2)</td><td></td><td></td><td>3D printed</td><td>0.75</td><td>Estimated</td></tr>
<tr><td>Bottom cap (x2)</td><td></td><td></td><td>3D printed</td><td>0.60</td><td>Estimated</td></tr>
<tr><td>Connecting rods (x6)</td><td></td><td></td><td>Raw material</td><td>2.00</td><td>Actual</td></tr>
<tr><td>Walls (x2)</td><td></td><td></td><td>Raw material</td><td>3.00</td><td>Actual</td></tr>
<tr><td>Lower pads (x3)</td><td></td><td></td><td>3D printed</td><td>0.25</td><td>Estimated</td></tr>
<tr><td>Top Pads (x3)</td><td></td><td></td><td>3D printed</td><td>0.60</td><td>Estimated</td></tr>
<tr><td rowspan="3">Hinges assembly (x2)</td><td>Body 1 (x2)</td><td></td><td>3D printed</td><td>0.15</td><td>Estimated</td></tr>
<tr><td>Axle</td><td></td><td>Raw materials</td><td>0.50</td><td>Estimated</td></tr>
<tr><td>Torsion springs (x2)</td><td></td><td>Raw materials</td><td>0.20</td><td>Estimated</td></tr>
</table>

CanSat Budget – Hardware

Payload Electronics Budget		
Component	**Cost (€)**	**Justification**
Teensy 3.2	17.40	Actual
Adafruit Ultimate GPS	34.41	Actual
Adafruit BNO055	30.70	Actual
Adafruit BMP280	12.20	Actual
Adafruit Camera	11.00	Actual
Hall Effect Sensor - US5881 x2	2.14	Actual
ATtiny85	1.07	Actual
XBee S2C Pro	25.21	Actual
Payload Antenna	2.93	Actual
Real Time Clock - DS1337C	4.81	Actual
Coin Cell Battery	1.6	Actual

CanSat Budget – Hardware

Payload Electronics Budget		
Component	**Cost (€)**	**Justification**
Coin Cell Battery Holder	1.14	Actual
Buzzer	1.73	Actual
5V Step Up Regulator	7.45	Actual
Power Switch	0.48	Actual
LED Light	0.1	Actual
Nichrome Wire	1.00	Actual
Voltage Divider	2.28	Actual
3.6V Lithium Battery	6.00	Actual
PCB x2	10.00	Actual
Other (Pins, Cables, etc)	15.00	Estimate
Total	188.55	

CanSat Budget – Hardware

CanSat Budget Summary	
Subsystem	**Cost (€)**
Mechanical	140.39
Electronics	188.55
Total	328.94

Total (€)	328.94
Total ($)	**371.70**
Exchange Rate	1€ = 1.13$

The cost of the CanSat is under 1000$ as required.

CanSat Budget – Other Costs

Budget Summary - Other Costs			
	Detail	Cost (€)	Justification
Ground Station	GS antenna + XBee	78.8	Actual
Prototyping		300	Estimate
Facilities & equipment	Provided by university	-	Actual
CanSat Shipping	5kg packet to Stephenville	250	Estimate
Travel	9 air tickets to Dallas	7200	Estimate
Visas	14$ per application	113	Estimate
Accomodation	4 Days	2000	Estimate
Rentals	2 Cars	1200	Estimate
Competition Fee		87.7	Actual
Total	1€ = 1.13$	11204.4€	9915.4$

Sources of Income

Our team is currently using internal funds for purchasing components, prototyping and testing.

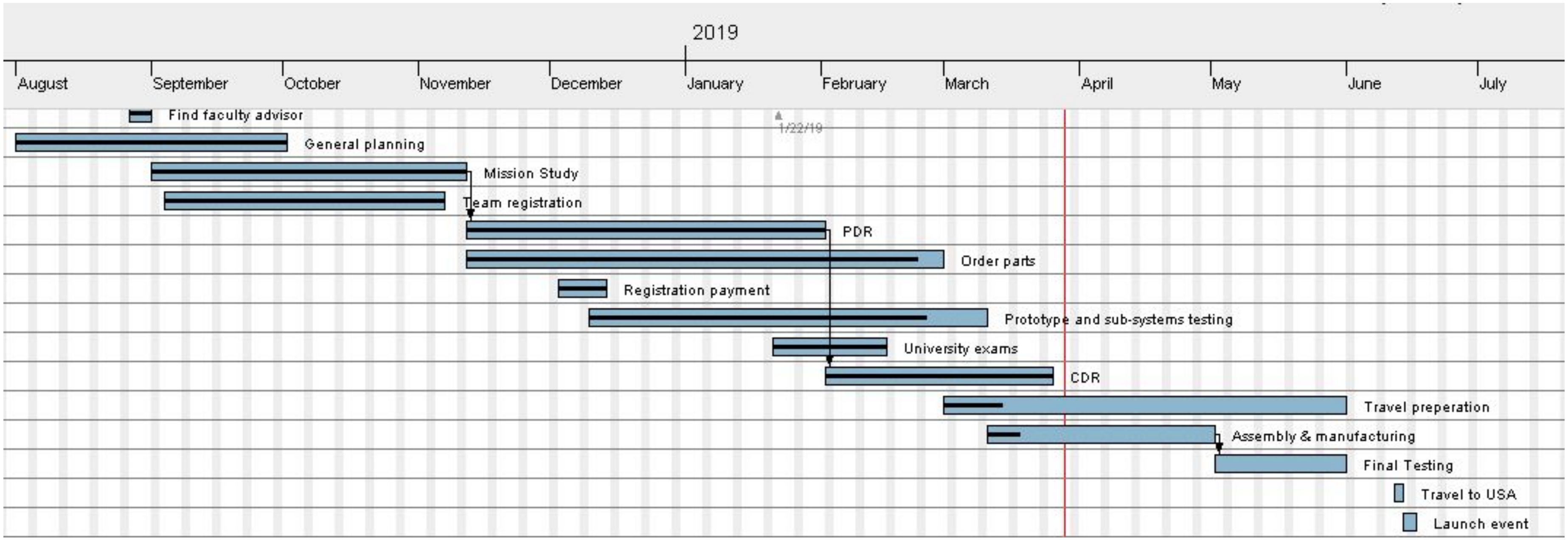
The school of Electrical and Computer Engineering will cover the cost of 3 air tickets. Also, the school of Mechanical Engineering has pledged to cover some of the air fares.

Furthermore, we are actively seeking for sponsors. Currently, we are in contact with a few potential sponsors, but nothing is final yet.

We are confident that we will manage to cover the majority of the expenses.

Program Schedule Overview

We use GanttProject software to manage tasks for our project.



Subteams

General Tasks

Mechanical

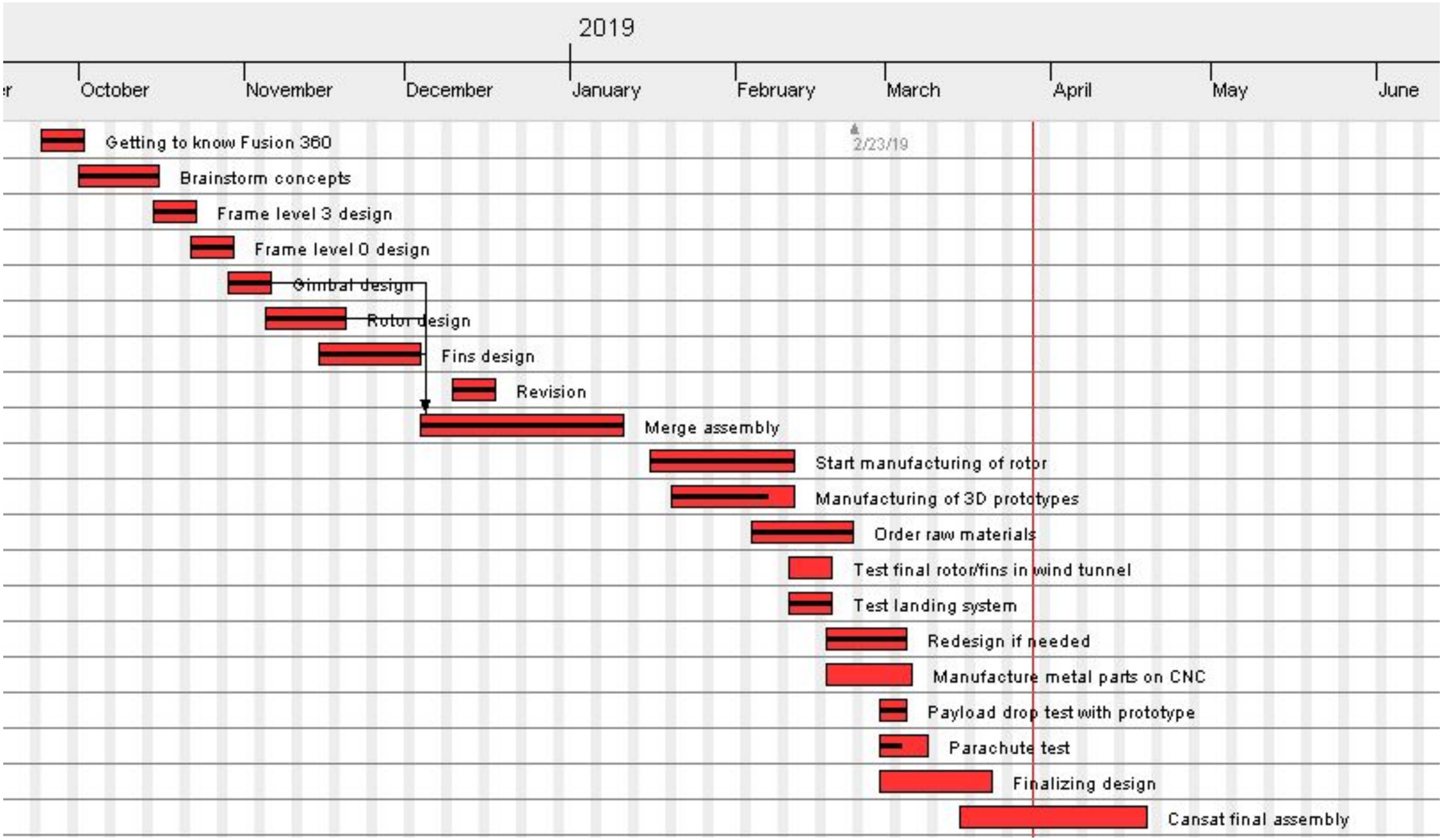
Control System

Electronics

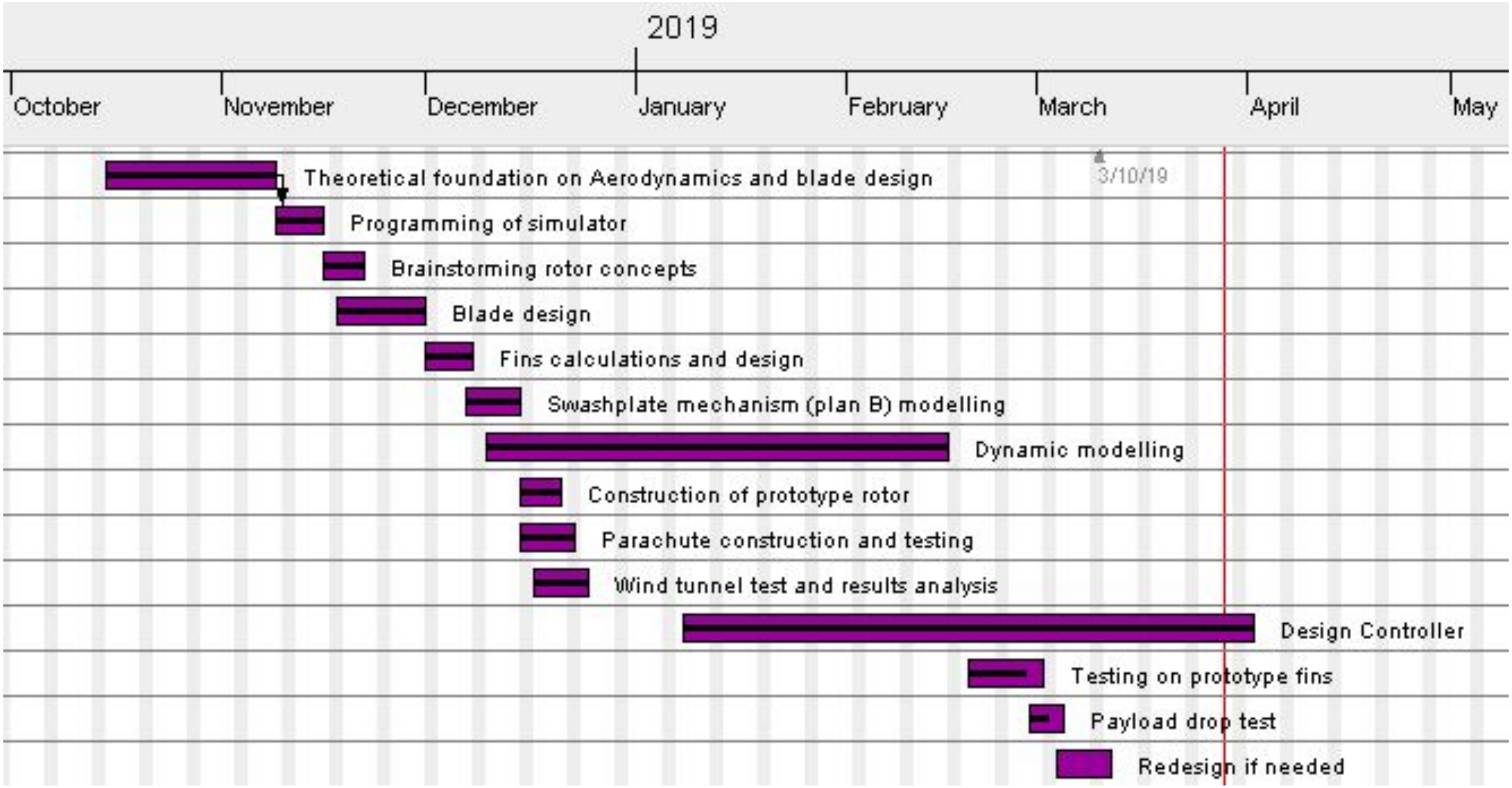
FSW & GCS

Marketing & FR

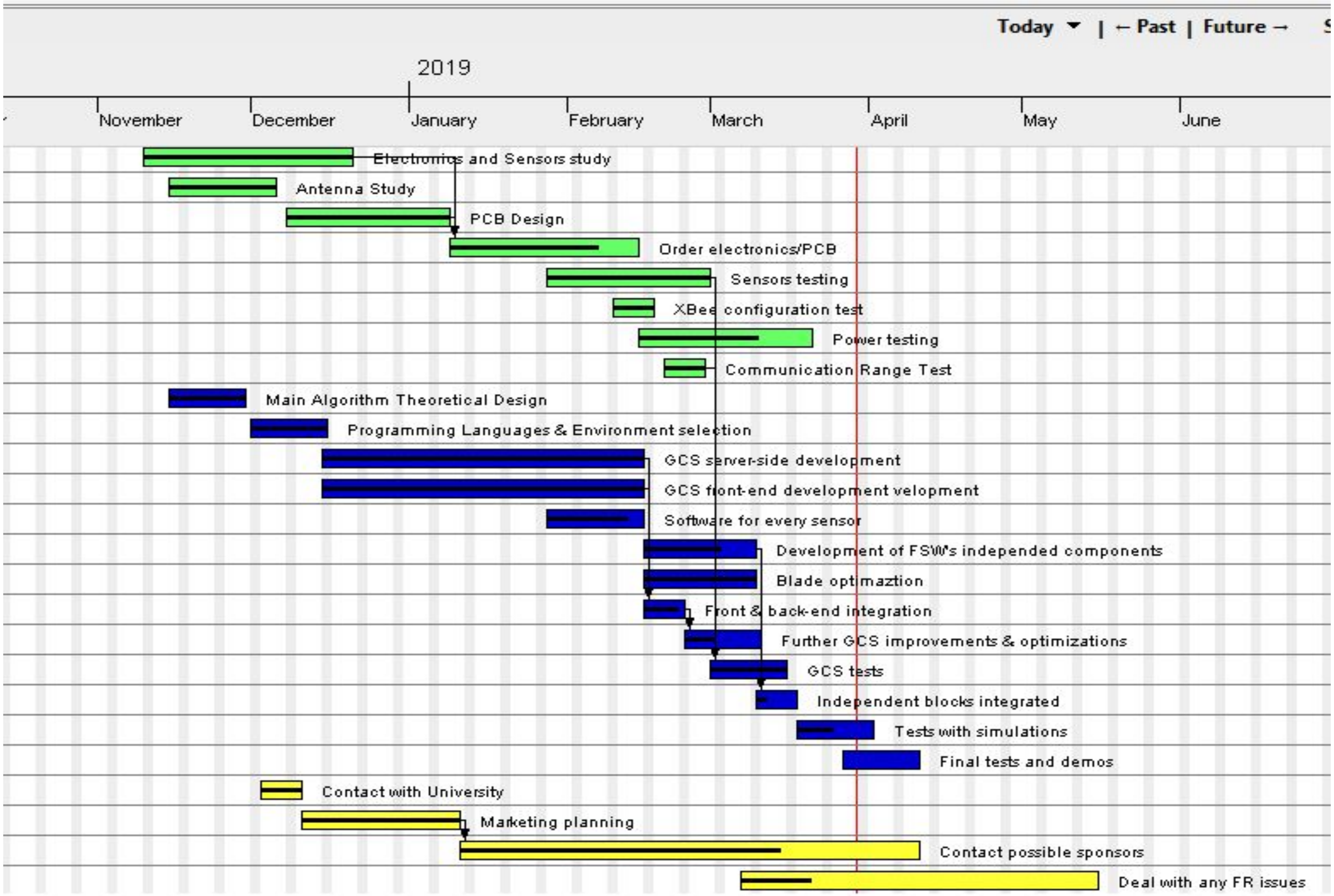
Detailed Program Schedule



Detailed Program Schedule



Detailed Program Schedule



Detailed Program Schedule

- The black line inside each task box represents the percentage completed.
- GanttProject has the option to calculate the total percentage of the project that has been completed and the results are shown below. We have to notice though that this can be a little misleading, because there are no weights assigned to each task.

CanSat competition 2019 Gant Chart

Mar 28, 2019

White Noise - NTUA

http://whitenoise.gr

Project manager	George Rapakoulias
Project dates	Aug 1, 2018 - Jun 17, 2019
Completion	78%
Tasks	76
Resources	9

Shipping and Transportation

Shipping/Transporting the CanSat hardware to the launch site

In order to make sure the CanSat hardware and any other needed component will make it to the launch event, in Stephenville TX, we will ship two CanSats and the ground control station hardware with an international courier company, such as TNT or DHL. Price quotes have been included in the budget.

We will contact the organizers, regarding the possibility of delivering the package to Tarleton State University, a few days prior to the competition. Apart from that we will explore other delivery options.

Shipping/Transportation of tools and equipment

Extra components, equipment and laptops will be transported on our carry-on and extra luggage, considering of course the safety restrictions. If any needed tools are not allowed on our luggage, they will be shipped with the CanSats.

Conclusions

After completing the second stage of the competition out team has acomplished the following:

- Finshed building prototypes of all critical subsysyems.
- Have conducted tests in an integrated systems level as described in the descent control chapter.
- We have made improvements based on the tests we conducted
- We are on track with our schedule
- We are ready to proceed to the next phase of the competition