CanSat 2024
Preliminary Design Review

2044

PWr Aerospace

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Team Organization

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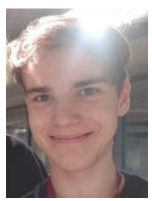

Maciej Sikorski
Electronic
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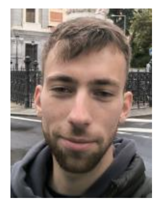

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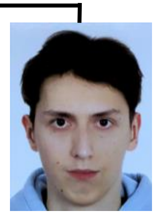

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Acronyms

A	– Analysis
ABS	– Acrylonitrile butadiene styrene
API	– Application Programming Interface
CAD	– Computer Aided Design
CDH	– Communication and Data Handling
CDR	– Critical Design Review
CONOP	– Concept of Operations
CG	– Center of Gravity
CP	– Center of Pressure
CSV	– Comma Separated Value
D	– Demonstration
DCS	– Descent Control System
DPS	– Differential Pressure Sensor
EPS	– Electrical Power Subsystem
FR–4	– Glass–reinforced epoxy laminate
FRR	– Flight Readiness Review
FSW	– Flight Software
GCS	– Ground Control System
GPS	– Global Positioning System
GS	– Ground Station
HW	– Hardware
I	– Inspection
I2C, IIC	– Inter–Integrated Circuit
IMU	– Inertial Measurement Unit
LCO	– Launch Control Officer
MCU	– Microcontroller Unit
uC	– Microcontroller
ADC	– Analog to Digital Converter
RTC	– Real Time Clock
SDIO	– Secure digital input/output interface
NMEA	– National Marine Electronics Association protocol
PDR	– Preliminary Design Review
PCB	– Printed Circuit Board
PETG	– Polyethylene terephthalate
PFB	– Pre–Flight Briefing
PFR	– Post Flight Review
PWM	– Pulse Width Modulation
RPM	– Rotations Per Minute
RSO	– Range Safety Officer
SOE	– Sequence of Events
SPI	– Serial Peripheral Interface
T	– Test
TBD	– To Be Determined
TBR	– To Be Resolved
TBT	– To Be Tested
UART	– Universal Asynchronous Receiver–Transmitter
USB	– Universal Serial Bus
VM	– Verification method

Systems Overview

Paweł Rak

Mission Summary

Main objectives
The CanSat shall be launched to a maximum altitude of 725 meters.
The CanSat shall operate as a nose cone during ascent and include a pitot tube.
The descent rate using an aero-braking heatshield shall be between 10 to 30 meters/sec.
At 100 meters, CanSat shall release the aero-braking heat shield and deploy a parachute to reduce the descent rate to less than 5 meters/sec.
The CanSat shall land with the egg intact.
A video recording camera shall be included capturing the horizontal view during ascent and landing. During descent, the camera shall point in one direction and maintain that direction.
CanSat shall collect the required telemetry at a 1 Hz sample rate and transmit the telemetry data to the ground station.
Bonus objective
A video camera shall be integrated into the CanSat and point aft. The camera shall capture the CanSat being deployed from the rocket and the release of the parachute. The video shall be in color with a minimum resolution of 640x480 pixels and a minimum of 30 frames per second. We made a decision to go for the bonus objective.
External objective
Create as a well-coordinated team. Make a video in a better resolution than last year.

System Requirement Summary (1/2)

Rn	Requirement	Verification			
		A	I	T	D
1	The CanSat shall be deployed from the rocket when the rocket motor ejection charge fires.	X		X	X
2	After deployment from the rocket, the CanSat shall deploy its heat shield/aerobraking mechanism.		X	X	X
3	At 100 meters, the CanSat shall deploy a parachute and release the heat shield.	X		X	X
4	During descent with the heat shield deployed, the descent rate shall be between 10 to 30 m/s.	X		X	
5	All telemetry shall be displayed in real time during descent on the ground station.	X			X
7	The heat shield shall be used as an aerobrake and limit the descent rate to 10 to 30 m/s.	X			X
8	At 100 meters, the CanSat shall release a parachute to reduce the descent rate to less than 5 m/s.	X		X	

System Requirement Summary (2/2)

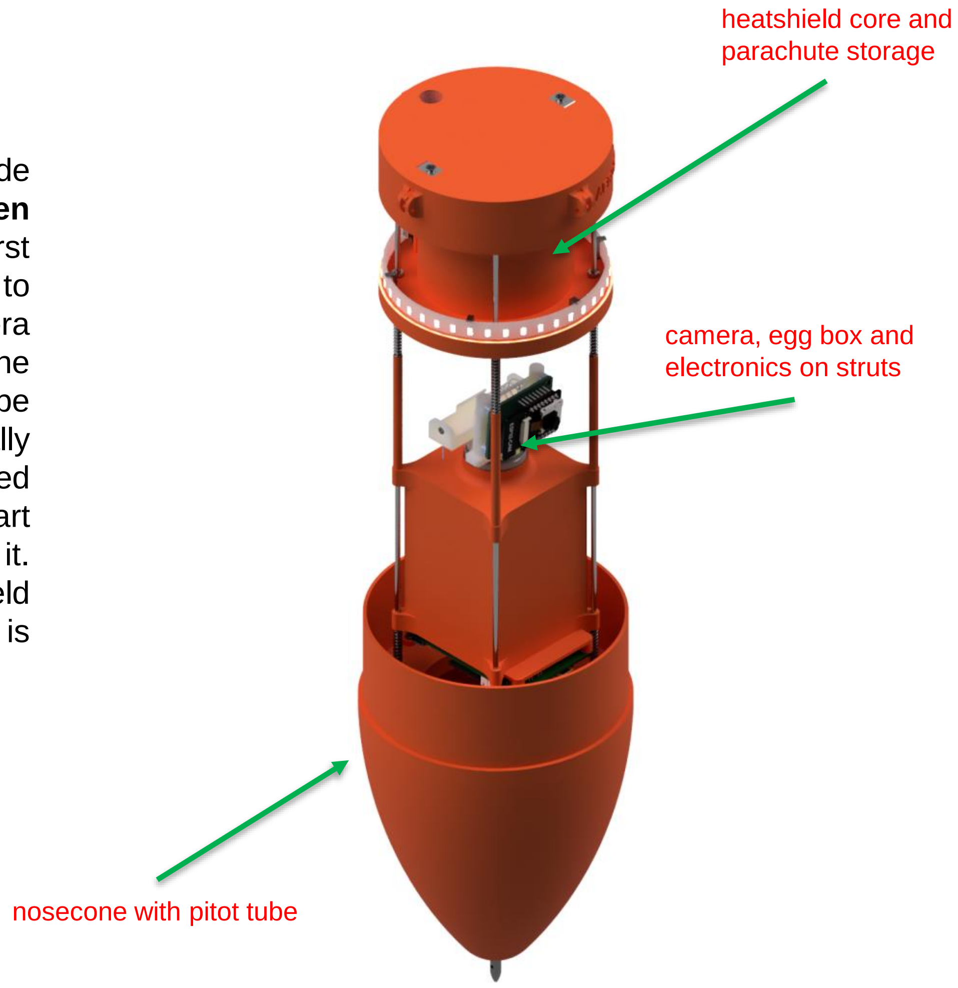
Rn	Requirement	Verification			
		A	I	T	D
9	A silver or gold mylar streamer of 50 mm width and 1.5 meters length shall be connected to the CanSat and released at deployment. This will be used to locate and identify the CanSat.			X	X
10	Upon landing, the CanSat shall stop transmitting data.	X			X
11	Upon landing, the CanSat shall activate an audio beacon.	X			X
12	After the CanSat has separated from the rocket and if the nose cone portion of the CanSat is to be separated from the rest of the CanSat, the nose cone portion shall descend at less than 10 meters/second using any type of descent control device.	X			

System Level CanSat Configuration Trade & Selection (1/5)

Design 1

Overall system configuration

Aerobraking structure is on the opposite side from nose cone and **opens passively when CanSat is deployed from the rocket.** The first design uses two pulling electromagnets to release heatshield at 100 meters. Main camera will be placed on gimbal motor to maintain the same direction. Egg, secured by foam, will be in the box mounted on struts and additionally depreciated by springs. PCB board is attached under egg box. Nose cone is a structural part of the CanSat with pitot tube mounted to it. The parachute will be stored under a heatshield core and released at the moment this part is detached at 100 m.

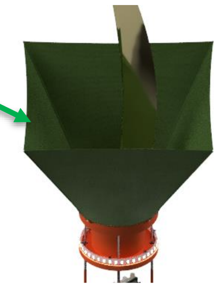


(Heatshield and fairings not visible)

System Level CanSat Configuration Trade & Selection (2/5)

Design 1

Main features
Electromagnets are used to detach the heatshield at 100 m.
Square-shaped heatshield.
A motor is used to maintain the same camera direction.
Parachute is stored under the heatshield core. Release of heatshield will cause parachute deployment.
Egg box filled with foam, mounted on struts and springs.
Reinforced nose cone.
Retractable pitot tube.
Electronics covered from the environment.



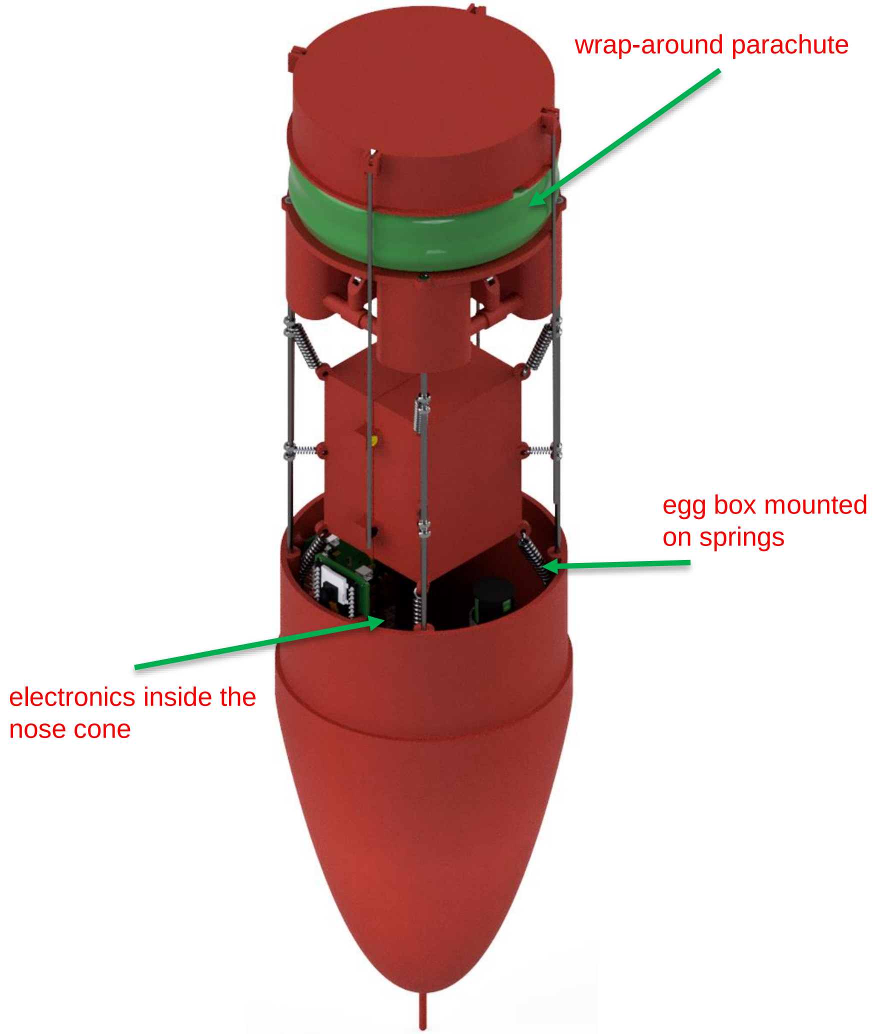
Main events of CONOPS
Rocket powered ascent and CanSat release at apogee.
Descent with the heatshield opened.
Heatshield release at 100m and immediate opening of parachute.
Landing

System Level CanSat Configuration Trade & Selection (3/5)

Design 2

Overall system configuration

The aerobraking structure located on the opposite side of the nose cone, **opens automatically when the CanSat is deployed from the rocket.** At an altitude of 100 meters, the second design employs two DC motors to deploy the heatshield. The main camera is permanently mounted to the nose cone shoulder. The egg box, filled with foam, is mounted to struts using springs. PCB is mounted like a camera, to the wall of the shoulder. The nose cone and pitot tube as a whole are structural parts of the CanSat. The parachute, stored in a wrap-around position, is released at the moment the heatshield is detached at 100 m.

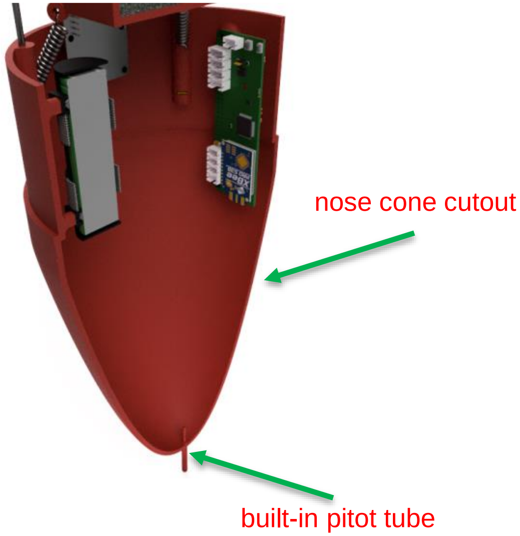


(Heatshield and fairings not visible)

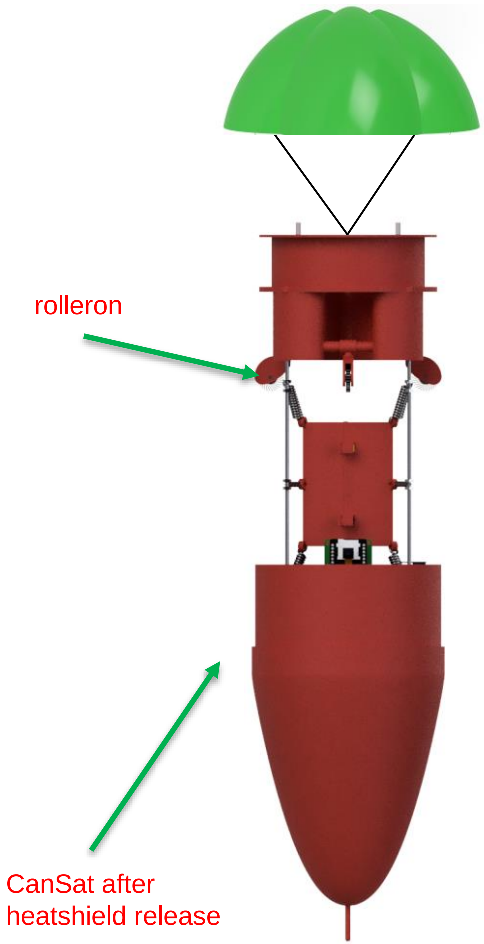
System Level CanSat Configuration Trade & Selection (4/5)

Design 2

Main features
DC motors used to detach heatshield at 100 m.
Square-shaped heatshield.
Rollerons for better stability during descent.
Main camera mounted stiffly.
Wrap-around parachute design to allow for more space for the mechanisms.
Egg box filled with foam.
Pitot tube integrated in the nose cone
Egg box mounted with springs.



Main events of CONOPS
Rocket powered ascent and CanSat release at apogee.
Descent with the heatshield opened.
Heatshield release at 100m and immediate opening of parachute.
Landing



System Level CanSat Configuration Trade & Selection (5/5)

Criteria	Design 1	Design 2
Parachute storage	Pros: Familiar design, less prone to malfunction Cons: Larger weight	Pros: Reduced weight Cons: Possibility of tangling
Heat shield shape	Pros: Easier to create Cons: Harder to store	Pros: Easier to store Cons: It's difficult to make a cone out of material
Heat shield release mechanism	Pros: More reliable solution Cons: New mechanism	Pros: Familiar design Cons: Bigger risk of malfunction
PCB placement	Pros: Held by springs, more resitant to shocks Cons: Additional moving part inside of CanSat	Pros: Stiff mounted Cons: Relies on nose cone strength
Pitot tube	Pros: Safer landing Cons: Additional mechanism	Pros: Easer to create Cons: May get destroyed during landing
Egg box	Pros: Easier access, better vertical cushioning Cons: Malfunction may damage PCB or camera	Pros: More versatile cushioning Cons: Problematic opening

Conclusion:
We have chosen Design 1 as we believe it has more reliable solutions and bigger chance of safe landing. We really like the idea of moving pitot tube and egg box with camera and PCB. The second design has its pros, like rollerons, but they are problematic due to weight requirements. Overall the first design suits better this year's mission.

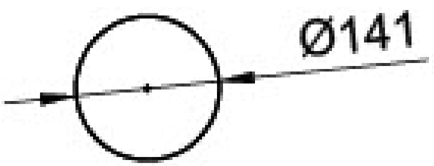
System Level Configuration Selection

Configuration	Selection options	Selection and reasoning
Detach mechanism	Electromagnets DC engines	**Electromagnets** Electromagnets are more reliable and make the detach mechanism lighter.
Descent stability control	Evenly distributed weight Rollerons	**Evenly distributed weight** The rejected option is hard to make (weight requirements).
Main camera	Mounted on gimbal motor Mounted to the nose cone shoulder	**Mounted on gimbal motor** Selected choice allows maintaining the same direction of the camera
Heatshield release	Pulling electromagnets DC motors	**Pulling electromagnets** More reliable solution.
Egg box assembly	On struts On springs	**On struts** With good stability control, this choice should work better.
CanSat parachute	Flat-circular parachute Parafoil	**Flat-circular parachute** This option will guarantee that we achieve both reliability and efficiency.
Pitot tube	Total and static pressure from outside of the CanSat Static pressure from inside of the CanSat	**Total and static pressure from outside of the CanSat** More popular and easier to make. The measured speed is more accurate with this configuration.

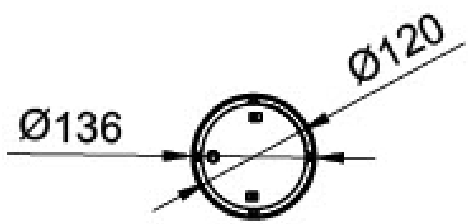
Physical Layout (1/3)

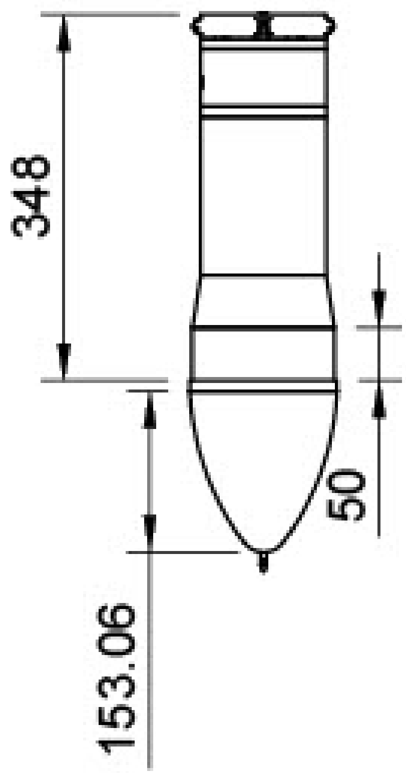
The most important dimensions of the CanSat are described in the pictures below:

Nose cone diameter:



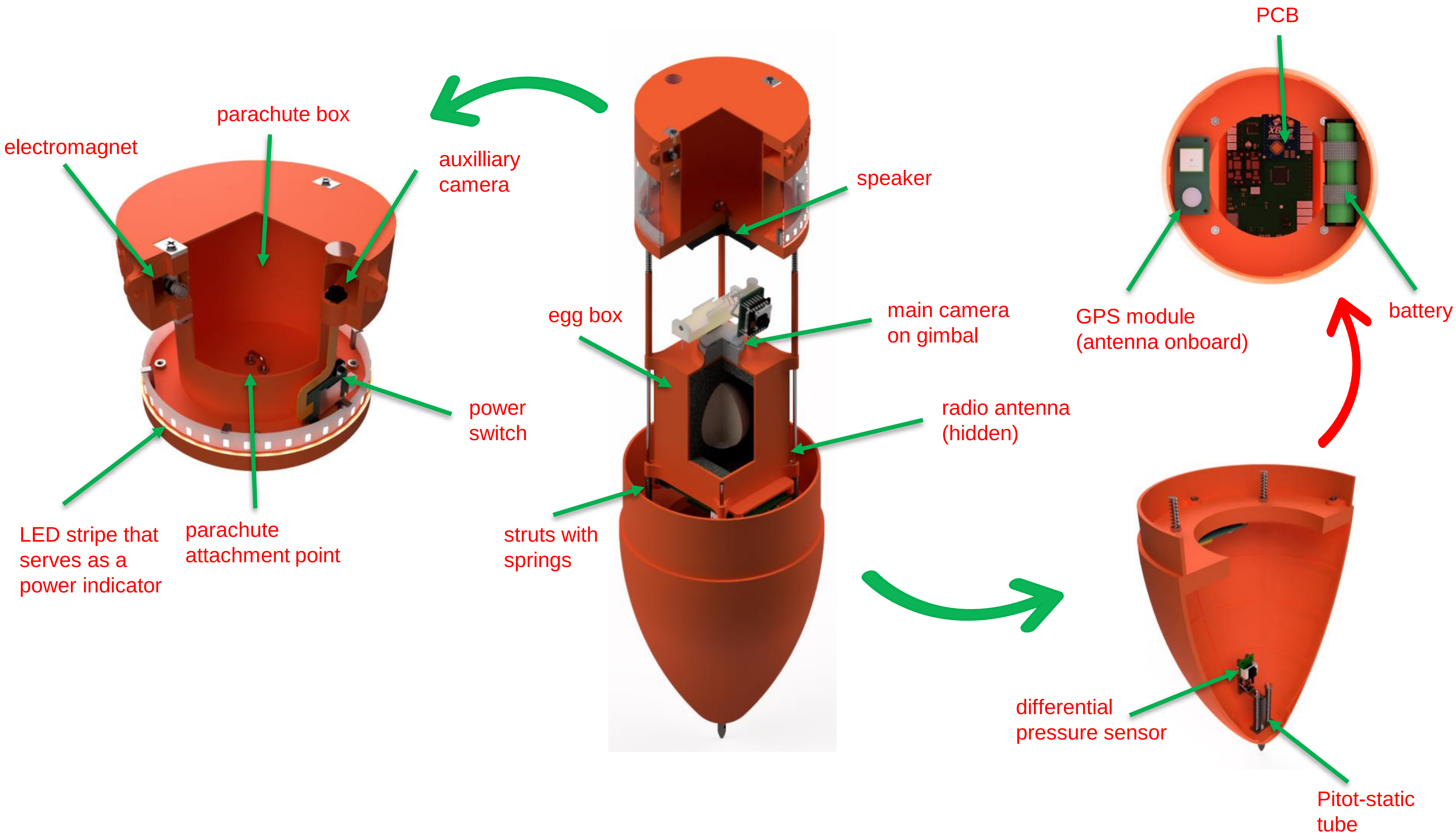
Shoulder diameter:





Note: All dimensions are in mm

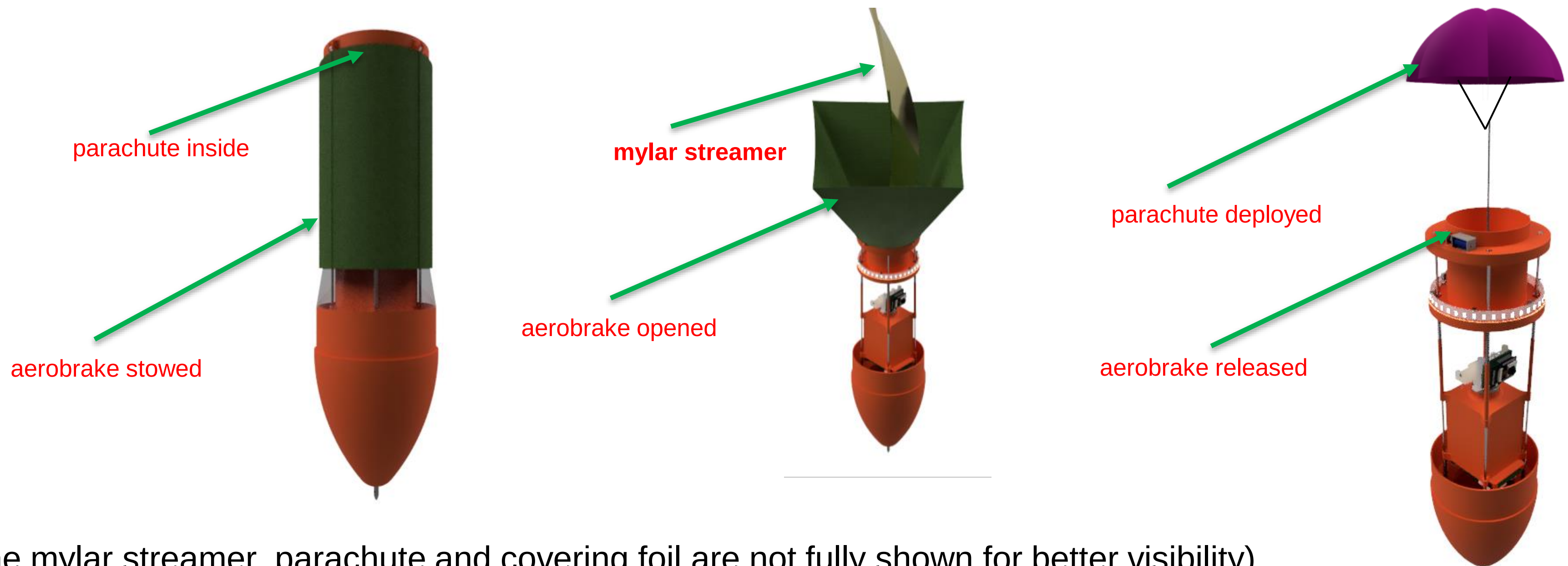
Physical Layout (2/3)



(Heatshield and covering foil are not shown for a better visibility)

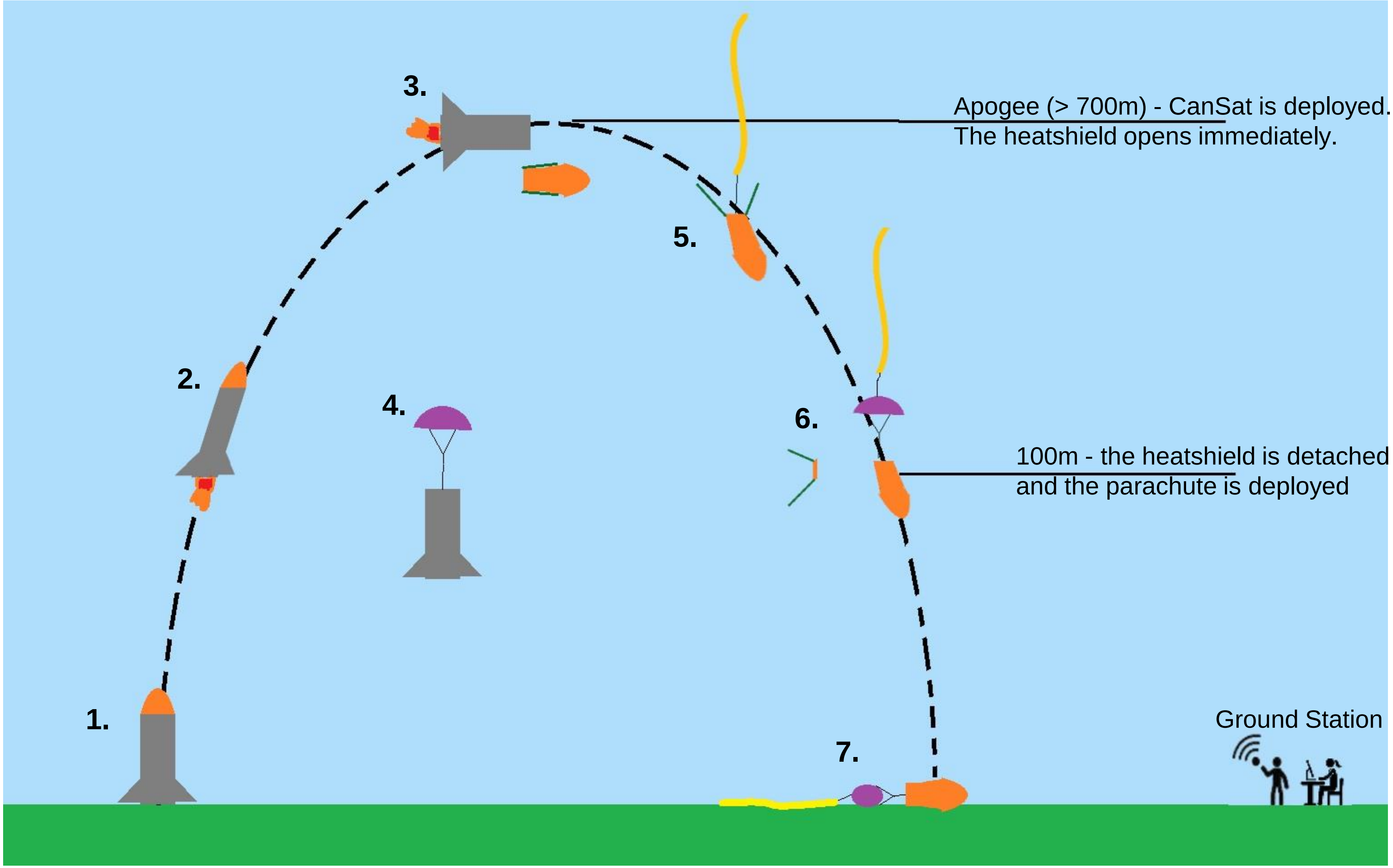
Physical Layout (3/3)

Configurations in flight stages		
Stage 1 (pre-deployment CanSat configuration)	Stage 2 (heatshield descent configuration)	Stage 3 (parachute descent configuration)
While inside the rocket **the CanSat functions as a nosecone for the rocket.** It is stored in a state shown below. Parachute is in the storage. The heatshield structure is in a closed position.	**Heatshield opens immediately after deployment.** The mylar streamer is unfolded and stabilizes the flight. In this configuration, the CanSat reaches a velocity between **10 to 30 m/s.**	**At the height of 100m**, the heatshield is detached from the CanSat by electromagnets**. It also triggers the parachute opening.** The CanSat slows down to the landing speed.



(The mylar streamer, parachute and covering foil are not fully shown for better visibility)

System Concept of Operations (1/2)



System Concept of Operations (2/2)

Mission phase:

1. Pre-launch preparation.
2. Launch and ascend to apogee.
3. Probe separation from the rocket at around 700m.
4. Rocket descends on it's parachute, then lands.
5. Deployment of probe's aerobraking mechanism. **Descent at 10-30m/s.**
6. At 100m the probe detaches the heat shield and it's mechanism, opens the parachute and slows below 5m/s.
7. CanSat lands with the egg intact, end of telemetry and cameras recording. **Audio and light beacon activation.**

Recovery and data reduction:

1. Probe recovery using the latest known GPS position, audio and light beacon, fluorescent probe body color **and observation of mylar streamer during descent.**
2. Video data recovery from camera internal storage.
3. Sampled data analysis, formatting and data reduction.
4. PFR preparation.
5. PFR presentation.

Launch Vehicle Compatibility

Protrusions

Edges will be rounded up to minimize the risk of failure during deployment. No additional protrusions are present. The parachute is located in the parachute compartment. **This ensures deployment when the rocket motor ejection charge fires**.

	Payload	Shoulder	Nose cone
Diameter	129 mm	136 mm	141 mm
Length	348 mm	50 mm	183.5 mm

CanSat dimensions:

Accurate dimensions

Shoulder and nose cone dimensions are **exactly as provided by the Mission Guide**. It allows CanSat to fit properly in the Payload section of the rocket. The length of the payload, from the top of the airframe is 350 mm. For the Rocket to fly straight the **nose cone is symmetrical around the vertical axis.** The heatshield has a diameter of 129 mm when closed, this leaves some margin for easy deployment.

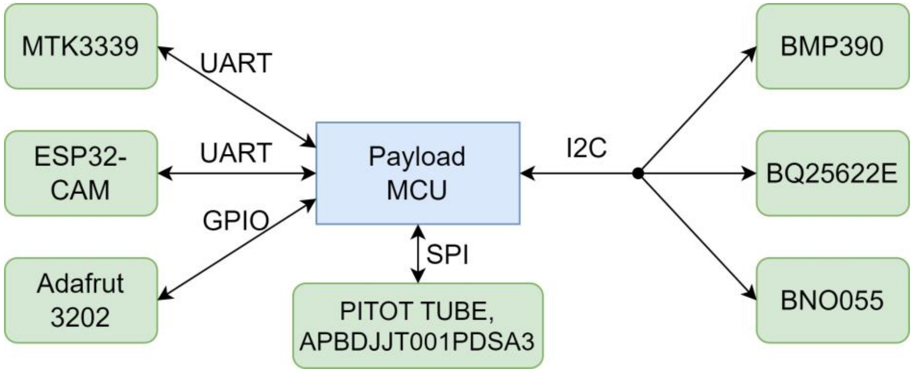
Note: All dimensions are in mm

Sensor Subsystem Design

Jakub Kaszowski

Sensor Subsystem Overview

TYPE	MODEL	FUNCTIONS	INTERFACE
AIR PRESSURE AIR TEMPERATURE	BMP390	Air temperature and **pressure (altitude) measurement**	I2C
GPS	MTK3339	Tracking the payload position	UART
VOLTAGE	BQ25622E	Monitoring the battery condition	I2C
GYROSCOPE	BNO055	Tracking the payload tilt and rotation	I2C
SPEED	PITOT TUBE, ABPDJJT001PDSA3	Tracking the payload speed	SPI
CAMERA	ESP32-CAM	Capturing the video during flight	UART
BONUS CAMERA	Adafruit 3202	Capturing the view behind the CanSat	GPIO



Payload Air Pressure Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Range [hPa]	Resolution [Pa]	Accuracy [hPa]	Interface	Price [$]
BMP390	2 2 0.75	0.9	1.8 ÷ 3.6	0.730	300 ÷ 1250	0.016	±0.03	I2C SPI	4
BMP280	2 2.5 1	1.2	1.8 ÷ 3.6	1.3	300 ÷ 1100	0.16	±0.12	I2C SPI	3
MPL3115A2	5 3 1.1	1.6	1.95 ÷ 3.6	1.2	500 ÷ 1100	1.5	±0.1	I2C	10

Selected sensor	Reasons
BMP390	• Proper voltage and low operating current • Best relative accuracy • Best resolution • Can also be used to measure temperature • Well known to the team

Payload Air Temperature Sensor Trade & Selection

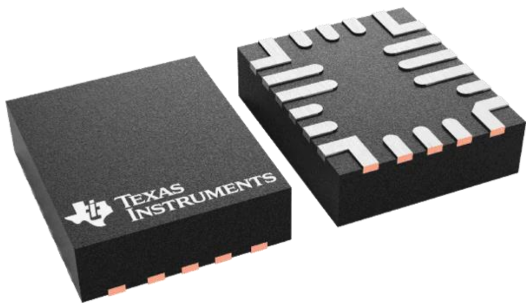
Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Range [°C]	Resolution [°C]	Accuracy [°C]	Interface	Price [$]
BMP390	2 2 0.75	0.9	1.8 ÷ 3.6	0.320	-40 ÷ 85	0.005	±0.5	I2C SPI	4
BMP280	2 2.5 1	1.2	1.8 ÷ 3.6	0.540	-40 ÷ 85	0.01	±0.5	I2C SPI	3
MS5611	19 13 2	1.5	1.8 ÷ 3.6	0.150	-40 ÷ 85	0.1	±0.8	I2C	10

Selected sensor	Reasons
BMP390	• Can also be used to measure pressure • Good range • Best resolution • Built-in filters • Well known to the team

Payload Battery Voltage Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating current [mA]	Range [V]	Resolution [V]	Interface	Price [$]
BQ25622E	2.5 3	2	0.260	0 ÷ 18	0.004	I2C	2
INA219	1.5 3	1	1	0 ÷ 26	0.004	I2C	5
INA220-Q1	3 3	1.2	1	0 ÷ 26	0.006	I2C	3

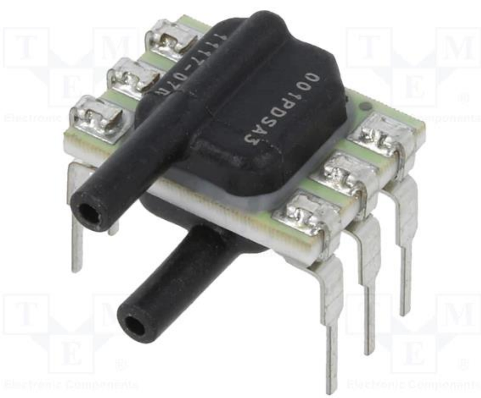
Selected sensor	Reasons
BQ25622E	• Very low operating current • Low price • Can also be used to charge batteries • Overcurrent protection • Integrated switch



Payload Speed Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Range [m/s]	Resolution [m/s]	Interfaces	Price [$]
ABPDJJT001PDSA3	8 11 7	0.8	3 ÷ 3.6	3.1	-107 ÷ 107	0.013	SPI	16
SDP810-500PA	29 18 23.5	5.4	3 ÷ 5.5	2.8	-29 ÷ 29	0.001	I2C	30
ABP2DDAN001PD2A3XX	9 11 14.5	0.7	1.8 ÷ 3.6	2.2	-107 ÷ 107	0.013	I2C SPI	43

Selected sensor	Reasons
ABPDJJT001PDSA3	• Low mass • Easiest control • Low price • Additional challenge

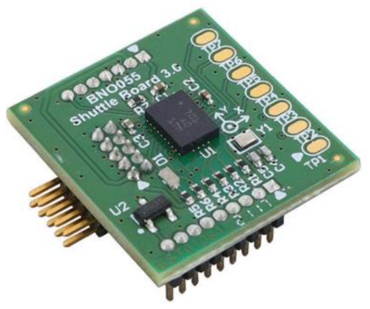


We will try to construct our own pitot tube, so we need only the sensor. Range and resolution are calculated.

Payload Tilt Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Range [°]	Resolution [°]	Interfaces	Price [$]
BNO055	3.8 5.2 1	0.15	2.4 ÷ 3.6	11	180*	0.005*	I2C UART	13
LSM6DSOX TR	2.5 3 0.8	13	1.7 ÷ 3.6	0.55	180	0.005	I2C SPI	8
MPU9250	3 3 1	0.11	2.4 ÷ 3.6	3.7	180	0.005	I2C SPI	11

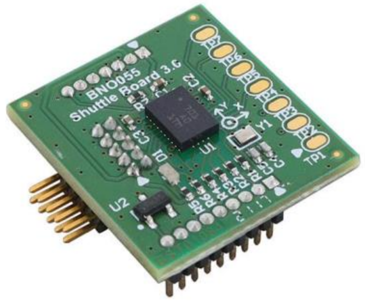
Selected sensor	Reasons
BNO055	• Small dimensions • Low mass • High range • Low operating current • Built-in sensor fusion algorithm – calculates tilt internally*



Rotation Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Range [°/s]	Resolution [°/s]	Interfaces	Price [$]
BNO055	3.8 5.2 1	0.15	2.4 ÷ 3.6	11	125, 250,500, 1000,2000	0.001	I2C UART	13
LSM6DSOX TR	2.5 3 0.8	13	1.7 ÷ 3.6	0.55	125, 250,500, 1000,2000	0.001	I2C SPI	8
MPU9250	3 3 1	0.11	2.4 ÷ 3.6	3.7	250,500, 1000,2000	0.004	I2C SPI	11

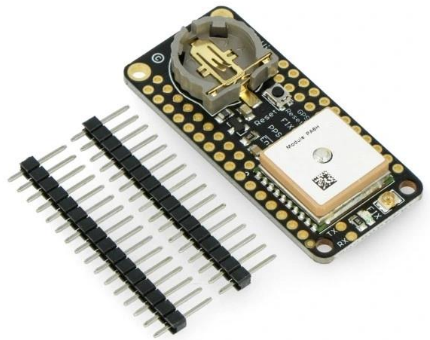
Selected sensor	Reasons
BNO055	• Small dimensions • Low mass • High range • Low operating current • Built-in sensor fusion algorithm



Payload GPS Sensor Trade & Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	Sensitivity [dBm]	Resolution [m]	Update rate [Hz]	Interfaces	Price [$]
MTK3339	23 51 7	8.8	3 ÷ 5.5	20	-165	<2.5	1÷10	UART	38
NEO-6M	31 12 2	1.2	3 ÷ 5	45	-161	2.5	1÷5	UART SPI	47
PA1616D	26 35 6.5	8.5	3.3 ÷ 5	30	-165	3	1÷10	UART	47

Selected sensor	Reasons
MTK3339	• NMEA 0183 • Onboard antenna • Onboard RTC • Lowest operating current • Good sensitivity • Good price



Payload Camera Trade & Selection

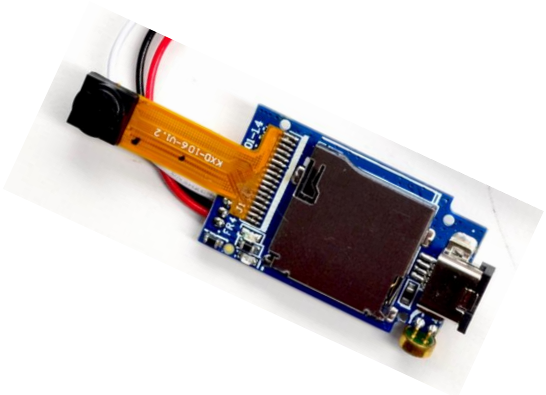
Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	microSD card	Resolution [pixels]	Field of view [°]	Frames per second	Interfaces	Price [$]
ESP32-CAM	40.5 27 4.5	20	3.3÷5.0	140	Yes	800x600	65	30	UART SPI I2C	8
Adafruit 3202	29 17 5	2.8	3.7÷5.0	110	Yes	640x480	120	30	GPIO	18
OV5640	8 8 13	6	3.8÷5.0	200	Yes	1920x1080 1280x720	120	30 60	Analog	30

Selected camera	Reasons
ESP32-CAM	• Small dimensions and mass • Video resolution and fps considering requirements • Low price

Bonus Camera Trade and Selection

Name	Size [mm]	Mass [g]	Operating voltage [V]	Operating current [mA]	microSD card	Resolution [pixels]	Field of view [°]	Frames per second	Interfaces	Price [$]
Adafruit 3202	29 17 5	2.8	3.7÷5.0	110	Yes	640x480	120	30	GPIO	18
ESP32-CAM	40.5 27 4.5	20	3.3÷5.0	140	Yes	800x600	65	30	UART SPI I2C	8
OV5640	8 8 13	6	3.8÷5.0	200	Yes	1920x1080 1280x720	120	30 60	Analog	30

Selected camera	Reasons
Adafruit 3202	• Dimensions compliant with the model • Video resolution and fps according to requirements • Easier control



Descent Control Design

Paweł Rak

Descent Control Overview

The payload descent is divided into 2 sections:

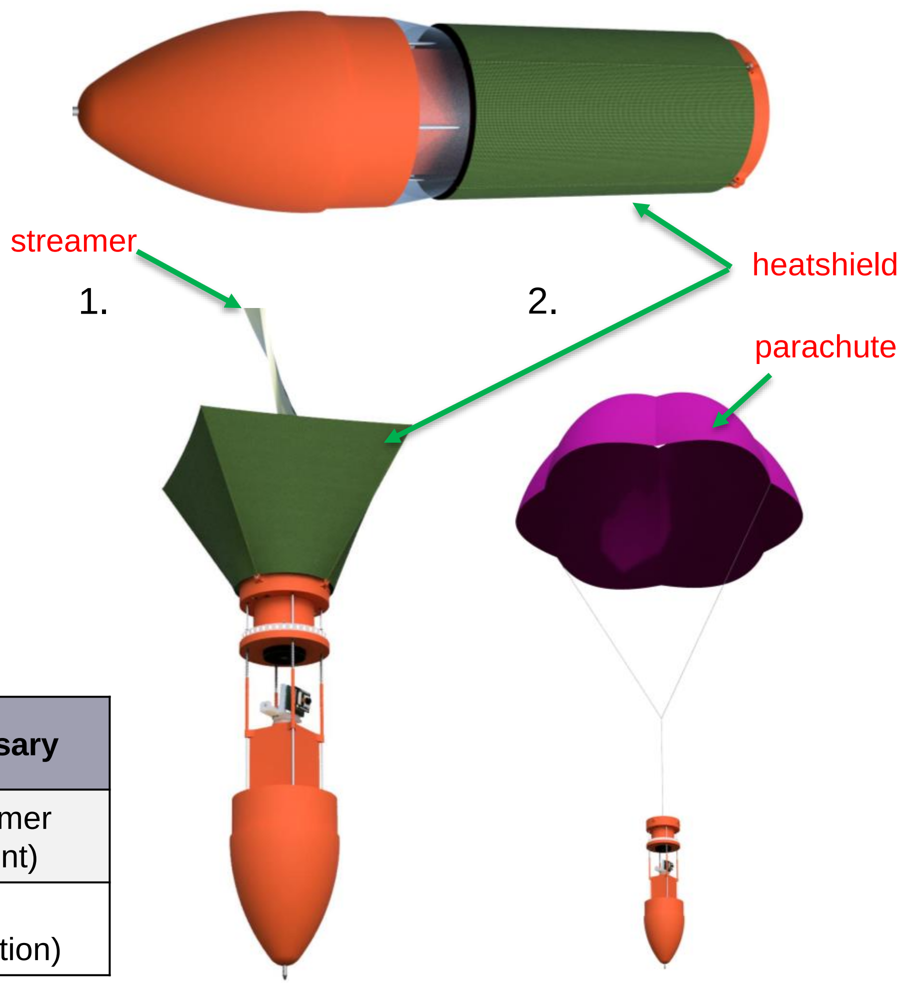
1. The first stage starts at an altitude of under 725m, just after the separation. The payload shall develop the **heatshield** and the **streamer** immediately afterward.

Payload velocity is in the range **of 10 to 30 m/s**.

2. At an altitude of **100 m** payload shall release the heatshield and develop the parachute.

Payload velocity is less than **5 m/s**.

0. The payload in the stowed configuration



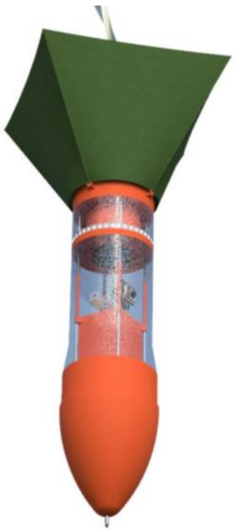
Flight Configuration	Altitude	Components necessary
After Separation	>700m – 100m	Heatshield and streamer (passive development)
Parachute descent	100m – 0m	Parachute (electromagnet activation)

Payload Aerobraking Descent Control Strategy Selection and Trade (1/2)

Design 1 (passive)

The heat shield is made of a durable material and is stretched over four spokes. It will be unfolded when the payload is ejected from the rocket by the air drag. The final spokes positions are restricted to create the desired angle (**55 deg**) and maintain the desired terminal velocity.

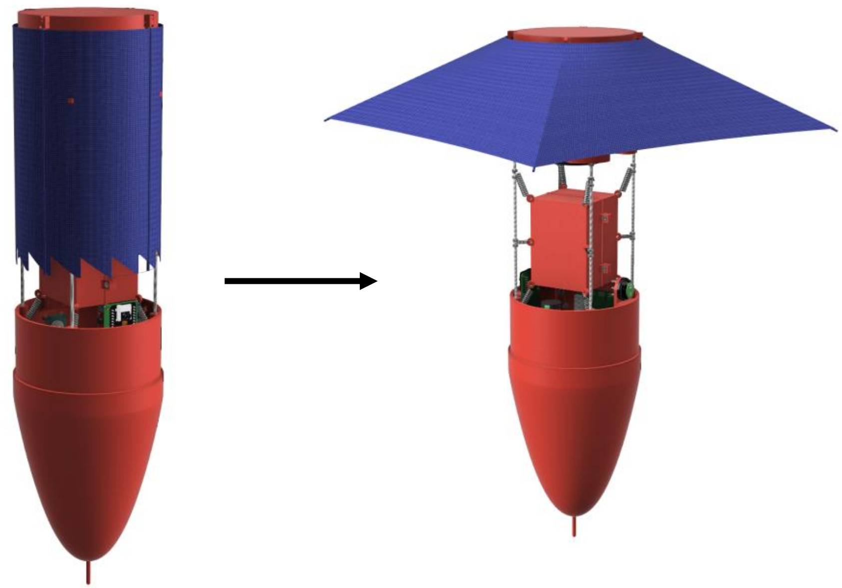
As the range of proper velocity is wide, no active correction is needed.



Design 2 (active)

The heat shield is mounted in the middle of the probe and is connected to spokes that are coupled to a DC motor.

DC motor can change the active heatshield surface to stabilize the velocity in an active way.



Payload Aerobraking Descent Control Strategy Selection and Trade (2/2)

Aerobraking descent control comparison:

Section	Solution	Rationale	Selection
Aerobraking Descent Control	Design 1 passive	+ simple and reliable mechanism + invulnerable to gusts of wind + easy to calculate + lighter - cannot be finetuned during flight	**Design 1** Reliability was the crucial factor. Small velocity changes are compliant with the Mission Guide
	Design 2 active	+ can maintain the velocity more precisely - more complex - greater mass - slower developement speed	

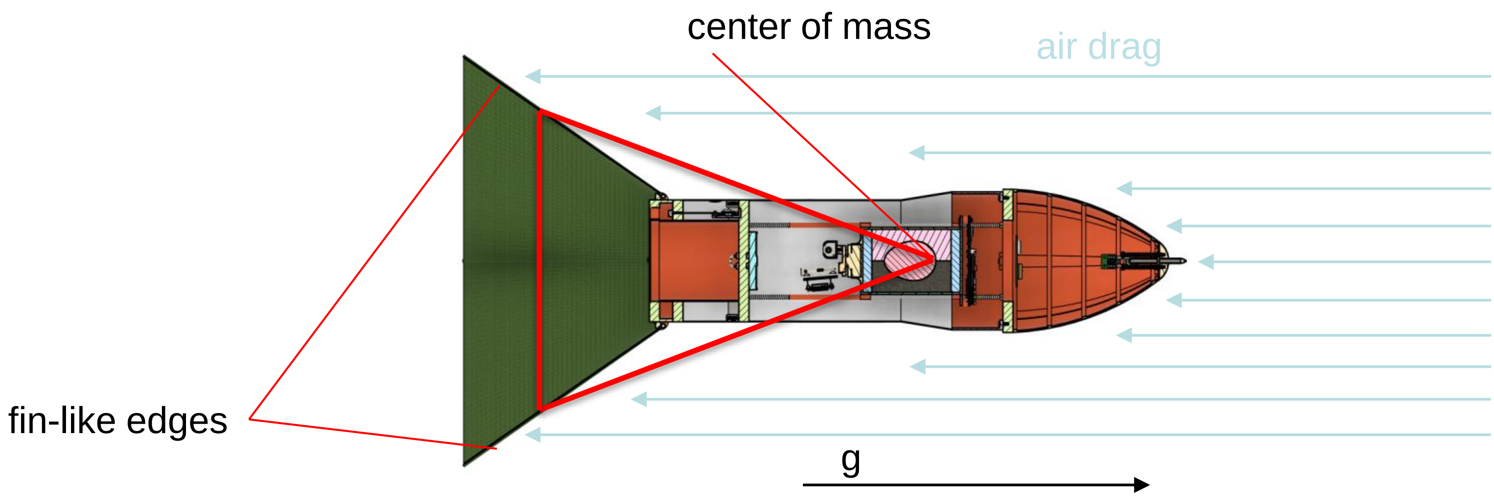
Payload Aerobraking Descent Stability Control Strategy Selection and Trade (1/2)

Design 1 (passive)

The stabilization of the Payload is based on the distribution of the center of mass in relation to the resultant point of the drag forces of the heatshield (red triangle) air drag is the smallest when the triangle is symmetrical, hence any other configuration generates force that counteracts the sway in a **passive way.**

Design 2 (passive)

The developed heatshield shape resembles a pyramid with metal rods at the edges. Those edges behave like fins, which **passively** leads to flight stabilization.



Payload Aerobraking Descent Stability Control Strategy Selection and Trade (2/2)

Aerobraking descent stability comparison:

Section	Solution	Rationale	Selection
Aerobraking Descent Stability	Design 1 passive	+ requires no special parts + requires no energy - control is proportional to sway, can lead to oscillations	**Both!** The soultions can be applied at once.
	Design 2 passive	+ easy to integrate into the payload + requires no energy - edges must be enforced	

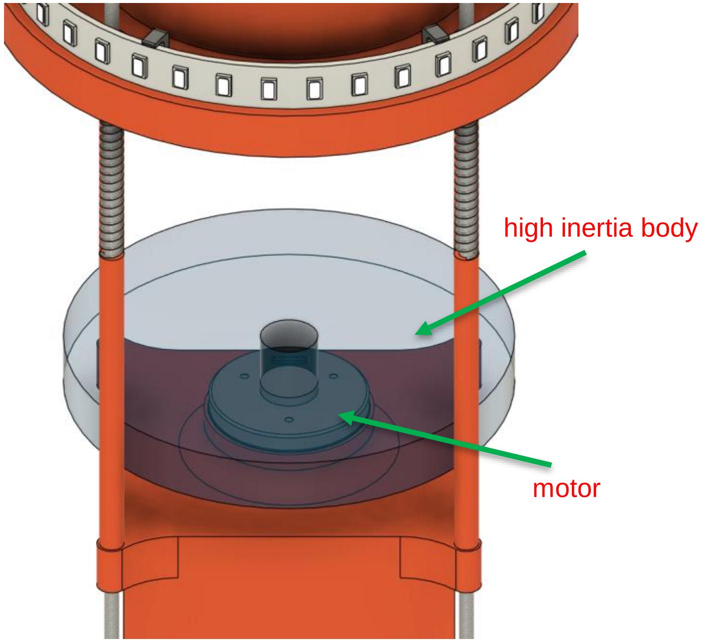
Payload Rotation Control Strategy Selection and Trade (1/2)

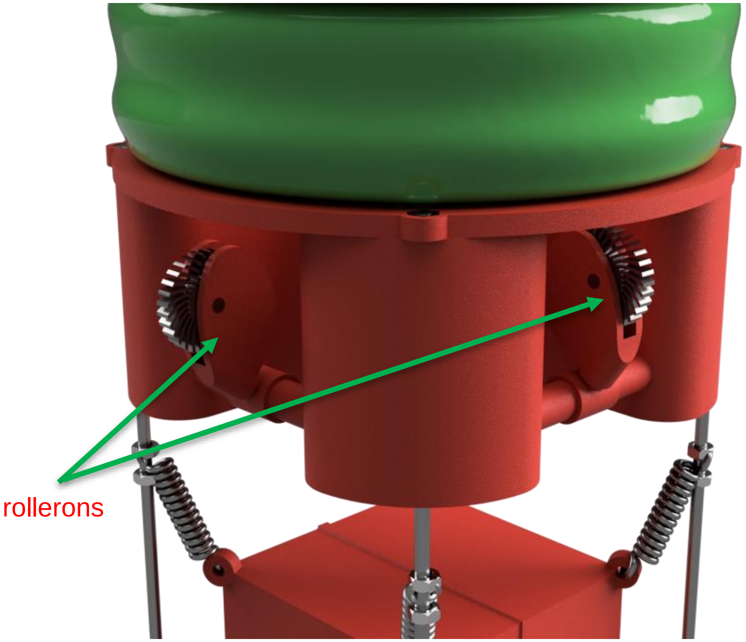
Design 1 (active)

In this idea, the stabilization of the payload rotation is based on angular momentum conservation law.
A motor is located inside the payload, that spins a high inertia body. When IMU shows that the payload is rotating, the motor changes its velocity.

Design 2 (passive)

Rolleron is a passive mechanism consisting of a rotating body that uses the gyroscopic effect to prevent rotations from occurring. The rollerons shaped as turbines are passively driven by the air drag.





Payload Rotation Control Strategy Selection and Trade (2/2)

Rotation control strategy comparison:

Section	Solution	Rationale	Selection
Rotation Control Strategy	Design 1 active	++ can reduce any rotation + all needed sensors are onboard -- complex - requires Energy - heavy	**Design 2** Due to its small mass, and compatibility. The team is still working on integrating this subsystem.
	Design 2 passive	+ easy to add + requires no energy + hard to broke - requires air flow -- unable to reduce all rotation -- hard to get optimal geometry	

Payload Parachute Descent Control Strategy Selection and Trade

Payload descent overview
The parachute awaits in a container opened by 2 redundant electromagnets. It will be tied to a metal ring to ensure a strong connection. The parachute will be made of nylon. We consider the parachute types:

Section	Solution	Rationale	Selection
Comparison of parachute designs	Design 1 **Hexagonal Parachute**	+ stable flight + reliability + simplicity of sewing + low price - problems with strong gusts of wind 	**HEXAGONAL PARACHUTE** Is our **current** choice as it is easier to make.
	Design 2 **Cruciform Parachute**	++ softer landing + reliability + stable flight - not available -- hard to make 	

Only the camera is being stabilized during parachute descent to point at nadir direction.

Descent Rate Estimates (1/2)

Assumptions (all situations):

ρ - air density at standard temperature: 1.12 (kg/m^3)
C_d - drag coefficient for parachute: 0.75
C_D - drag coefficient for heat shield 0.5

g - gravitational acceleration 9.81 m/s^2

Aerobraking descent:

Extra assumption: streamer is ommited

$$\frac{1}{2}\frac{\rho}{B}v^2 = g + \frac{dv}{dt}$$

$$B = \frac{m}{C_D\ S}$$

Parameters:

m - payload mass 0.955 kg (+/- 0.01)

S - aerobraking area 0.24 m^2

$\frac{dv}{dt}$ - tends to zero

B - balistic coefficient

Estimated payload aerobraking descent rate = 11.2 m/s

Parachute descent:

$$S_p = \frac{2mg}{v^2 \rho C_d}$$

$$d = \sqrt{\frac{2S_p}{\sqrt{3}}}$$

Parameters:

d - parachute diameter (diameter of inscribed circle) 1 m

m - payload mass 0.860 kg (+/-0.01)

Estimated payload aerobraking descent rate = 4.28 m/s

Descent Rate Estimates (2/2)

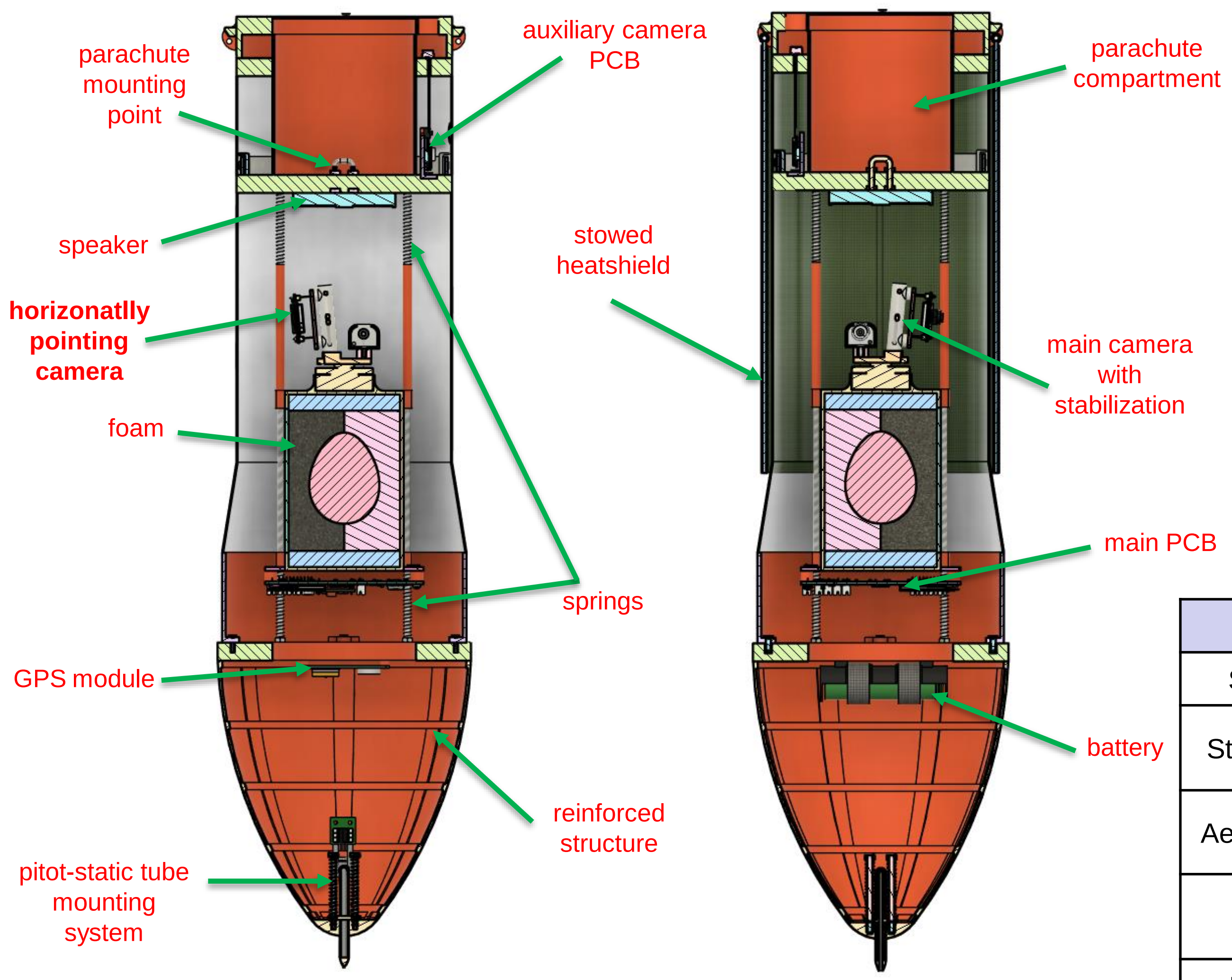
Flight phase	Speed of descent [m/s]
Payload descent with heatshield	**11.2**
Payload descent with parachute	**4.28**

Calculated values are within the scope of the competition!

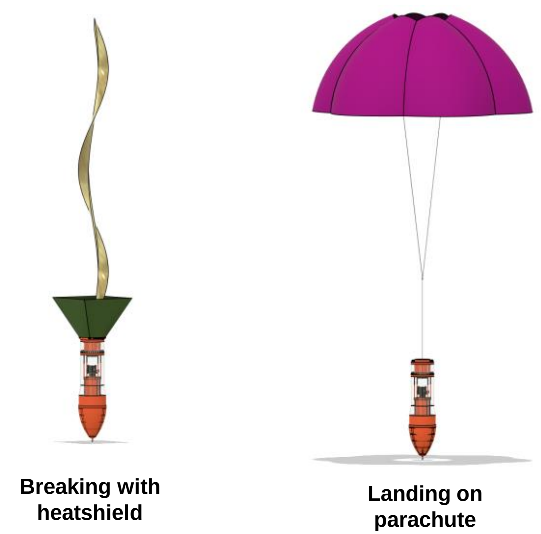
Mechanical Subsystem Design

Paweł Rak

Mechanical Subsystem Overview



Mechanical Configurations:



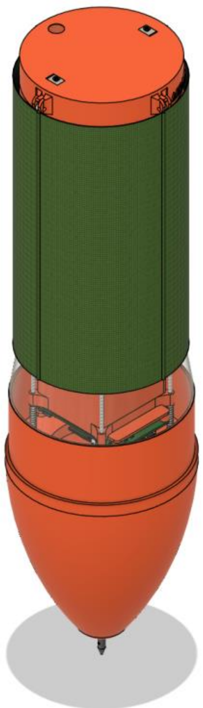
Part	Material
Structural Struts	Aluminium
Structural Elements	3D printed ABS, PET-G, Nylon
Aerodynamic Fairing	Laminating foil
Heatshield and parachute	Nylon, paracord
Egg suspension	Poliurethane foam

Payload Mechanical Layout of Components Trade & Selection (1/4)

Overall design trade and selection

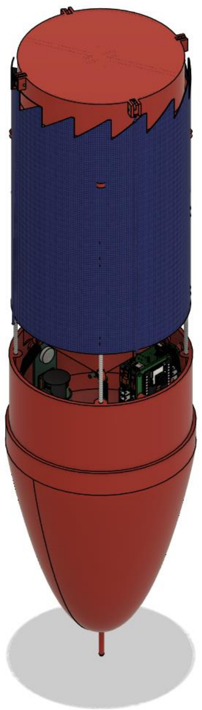
Design 1

- 3D printed structure with vertical aluminium struts
- Bottom heavy design for increased stability
- Custom electronics board
- Heatshield opened by aerodynamic pressure
- Parachute pulled from its compartment by detaching upper assembly with the heathsield.
- Egg suspended on struts with springs, enclosed in foam.
- Main camera single axis stabilization
- Auxilliary camera pointing upwards
- Self retracting pitot-static tube
- **No chemical actuators or pyrotechnics are used**
- **No heat mechanisms are used**



Design 2

- 3D printed structure with vertical aluminium struts
- Bottom heavy design for increased stability
- Custom electronics board
- Heatshield opened and closed by DC motor
- Rollerons used for stabilization
- Parachute deployed from wrap around position by aerodynamic pressure
- Egg suspended in a two piece box, held in place by 12 springs, enclosed in foam.
- No main camera stabilization
- No Auxiliary Camera
- Rigid pitot tube
- **No chemical actuators or pyrotechnics are used**
- **Enclosed burnwire mechanism is used**

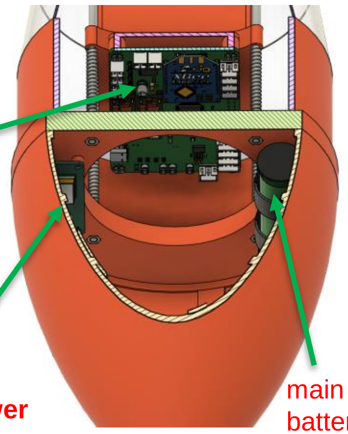


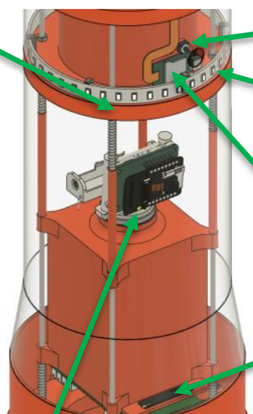
Payload Mechanical Layout of Components Trade & Selection (2/4)

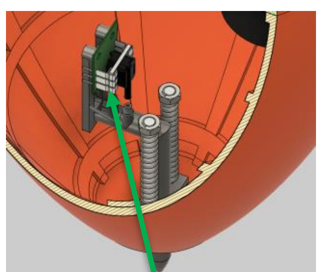
Location of electronics

Design 1

Main PCB is attached to the bottom of egg container, auxilliary electronics are scattered around the coresponding sections. Main camera, with its own power supply, and stabilization is located on the top of egg container.

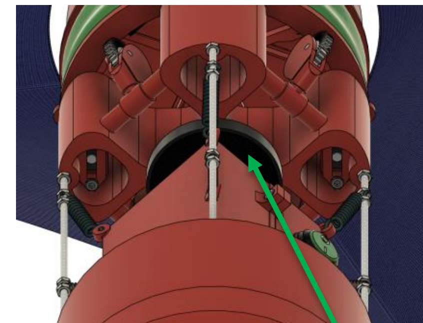


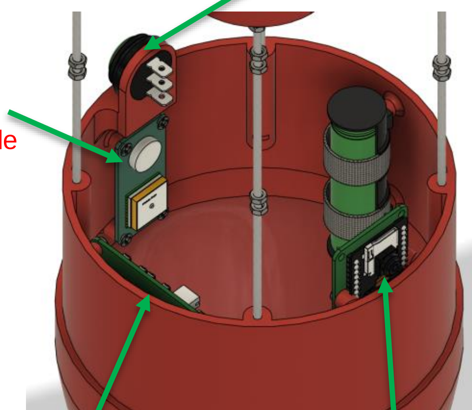


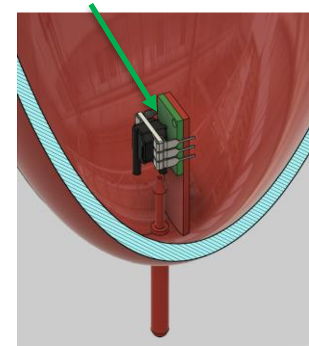


Design 2

Most of the electronics are concentrated in the nose cone fairing, for a nose-heavy mass distribution. Mounting points are aditionally strengthened with more material for increased durability, aditional stabilization of main camera will not be nescessary with rollerons deployed





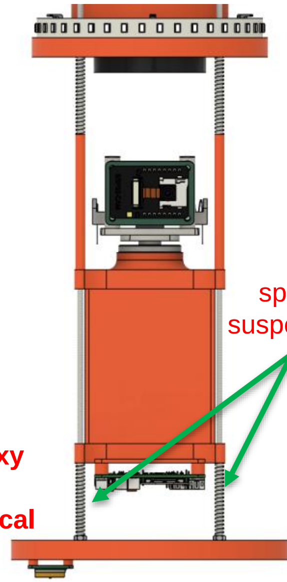


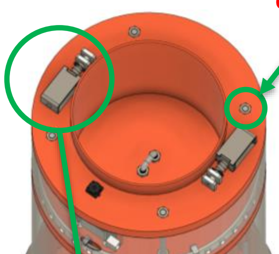
Payload Mechanical Layout of Components Trade & Selection (3/4)

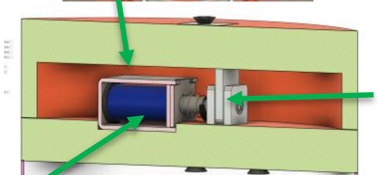
Mechanisms description

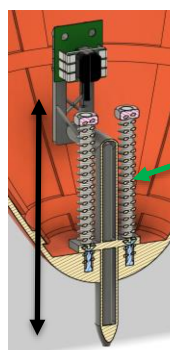
Design 1

Egg containment unit is placed on main struts, with spring suspension. Upper part with heatshield is held in place with locking brackets and pins. Pins can be released by solenoids, to detach heathsield and reveal the parachute. Pitot-static tube, is suspended on springs, so it can self retract, to avoid damage during touchdown. **All mechanisms were computer analized to ensure they can handle all the forces they may encounter.**



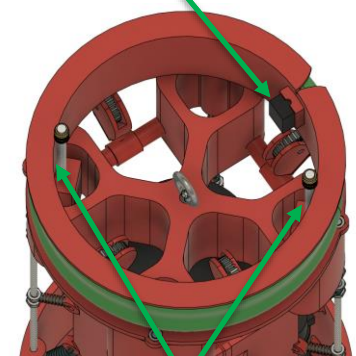


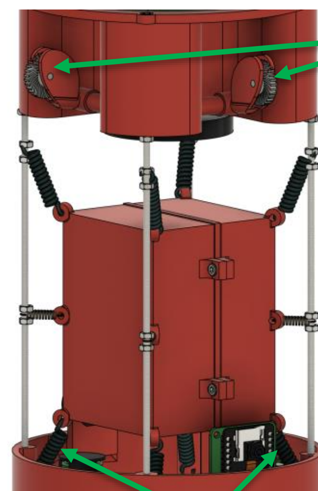


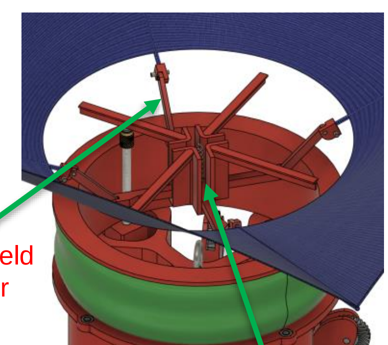


Design 2

Egg containment unit is suspended on the self centering 12 spring mechanism. heatshield opening angle is mechanically limited. DC motors detach the heatshield by unscrewing the top cover. Rollerons are used for rotation controll. **All mechanisms were oversized to ensure they withstand all encountered forces.**







Payload Mechanical Layout of Components Trade & Selection (4/4)

Payload design comparison

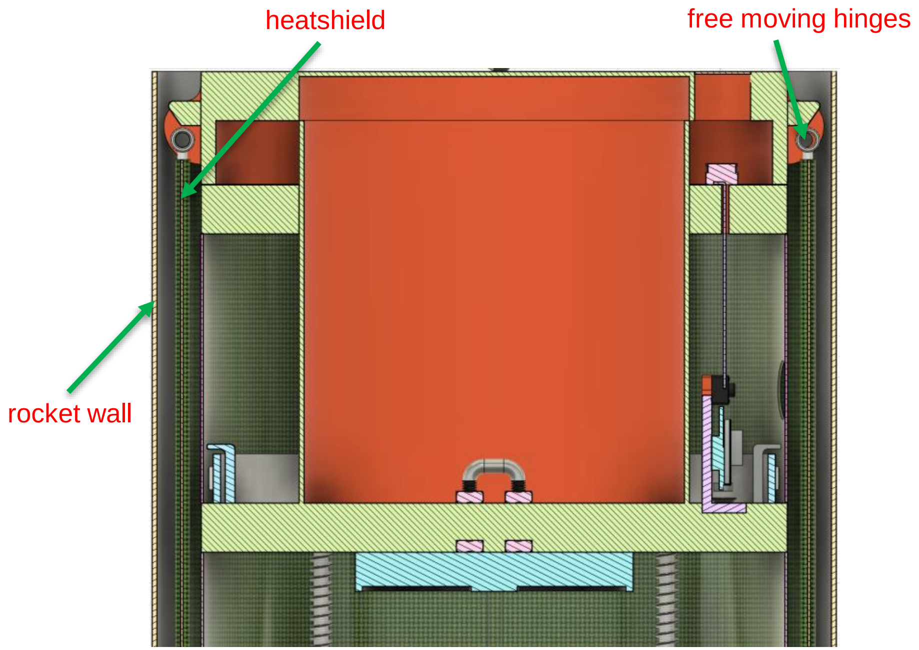
Section	Solution	Rationale	Selection
Payload Design	Design 1	+ Less complex + More reliable detaching mechanism + Reusable with no significant maintenance + Better structural integrity - Worse rotational stability - Heavier main camera with gimbal	**Design 1** A lot simpler, more reliable, cheaper and reusable with minimal preparation
	Design 2	+ Better weight distribution + Better stability control - Includes some fragile elements - Rollerons are hard to manufacture - Detaching mechanism prone to jam - Burn wire mechanism needs to be replaced after every single flight	

Payload Aerobraking Pre Deployment Configuration Trade & Selection (1/2)

Aerobraking pre deployment

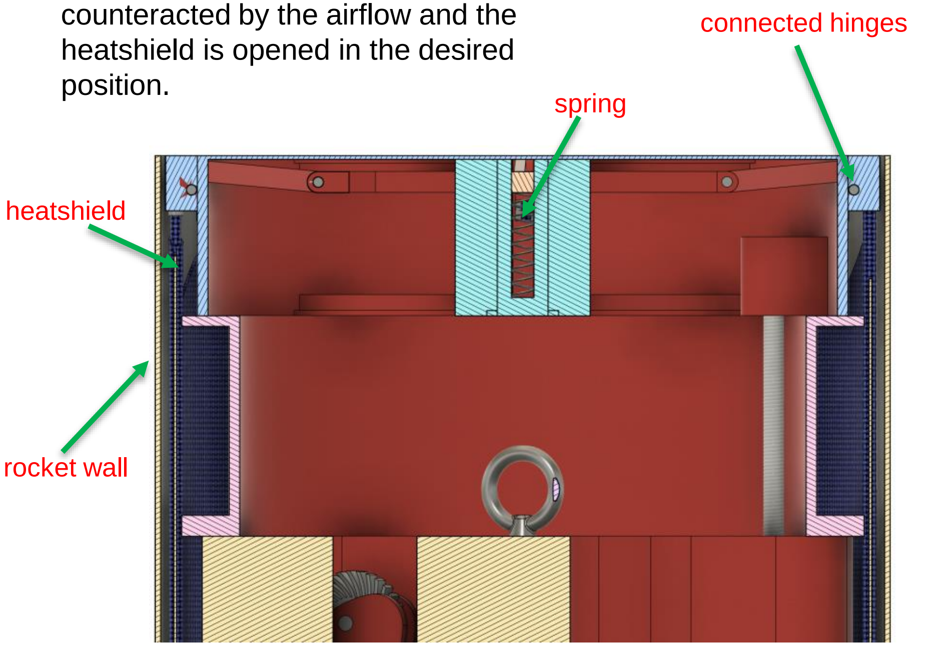
Design 1

The heatshield **is locked by the rocket walls.** When the pay load is deployed,
the heatshield is opened by the increasing air drag.



Design 2

The heatshield is coupled to sliders that are operated by a spring. **When the payload is stowed, the heatshield has no contact with the rocket walls**, the heatshield spokes, are pulled inside by the spirng. After deployment the spring fiorce is counteracted by the airflow and the heatshield is opened in the desired position.



Payload Aerobraking Pre Deployment Configuration Trade & Selection (2/2)

Aerobraking pre deployment comparison:

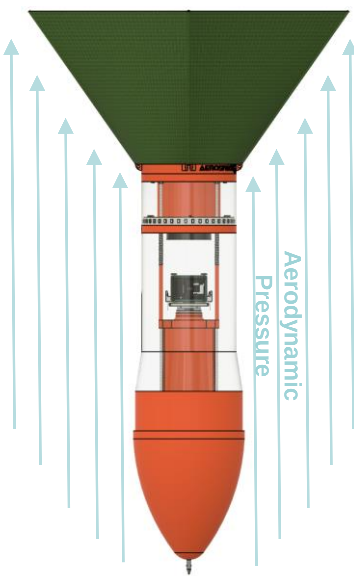
Section	Solution	Rationale	Selection
Aerobraking Pre Deployment	Design 1 passive	+ simple and reliable mechanism + lighter - heatshield touches the rocket walls	**Design 1** It is simple and compatible with the rocket design
	Design 2 passive	+ does not relay on the rocket compartement - more complex - heavy	

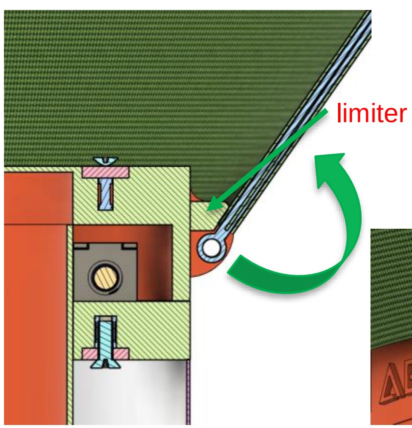
Payload Aerobraking Deployment Configuration Trade & Selection (1/2)

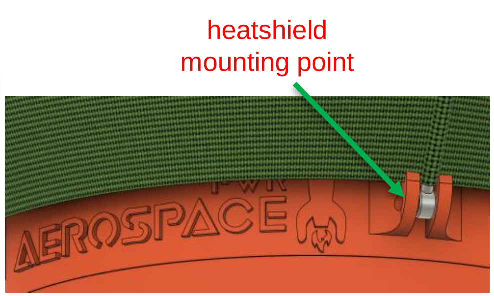
Aerobraking Deployment

Design 1

Aerobrake is opened by aerodynamic pressure after separation from starting container. The angle is individually limited for each supporting rod by a mechanical limiters. Design allows aerobrake rods to be longer, so smaller rod angle is needed, for the same breaking area, which puts less strain on a rods mounting points.

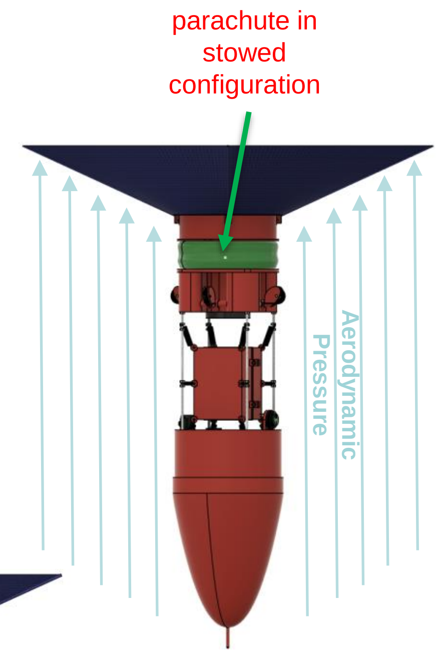


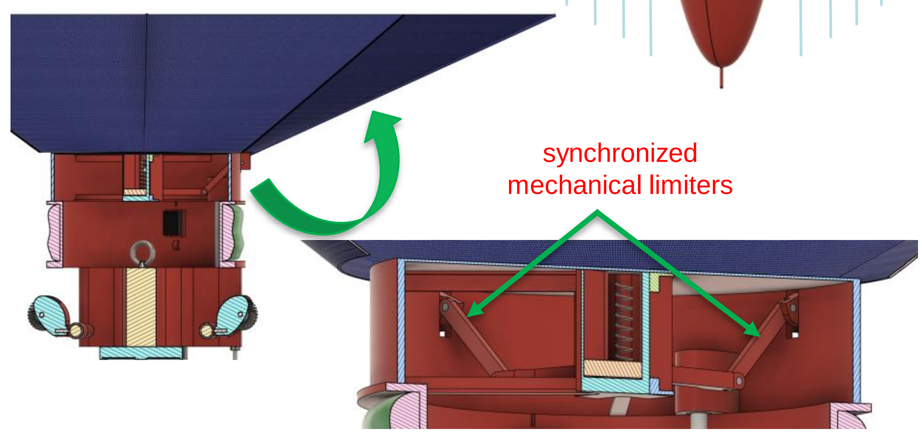




Design 2

Similiarly to design 1, aerobrake is opened by aerodynamic pressure, but all supporting rods are synchronized by a mechanical limiter, which ensures that aerobrake will be opened evenly. Design of the mechanism, and mid section fo the model forces shorter aerbrake rods greatly increrasing their angle.





Payload Aerobraking Deployment Configuration Trade & Selection (2/2)

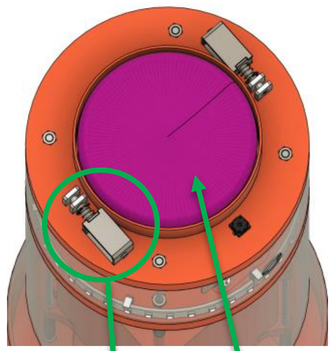
Aerobraking deployment comparison

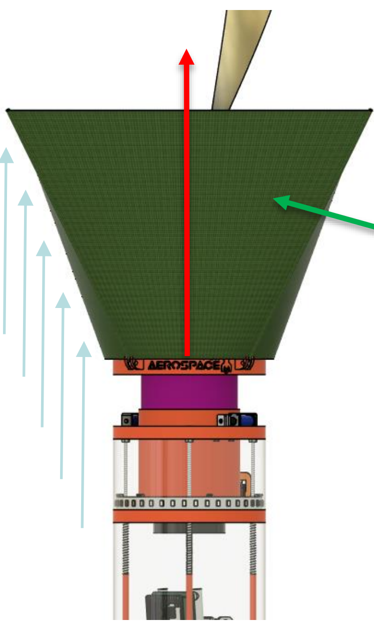
Section	Solution	Rationale	Selection
Aerobrake Design	Design 1	+ Less complex + Much more space may be used for storing of bigger parachute + Lighter - Uneven opening may induce some oscillations	**Design 1** Space and weight saved by the first design may be used for a bigger parachute, which will increase the safety of landing
	Design 2	+ Even opening of all the rods may reduce after-opening oscillation - More complex - Need significantly more space - Heavier	

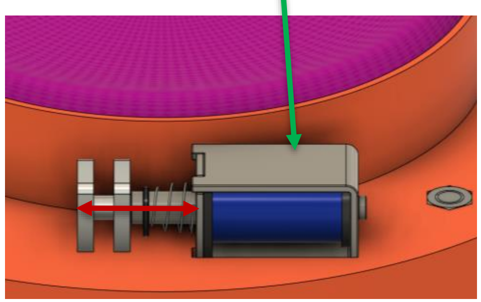
Aerobraking Release

Design 1

Aerobrake release mechanism uses metal pins and solenoid for locking areobrake assembly in place, and aerodynamic drag for detachment and separation. Solenoids are fast, easy to control and very reliable.

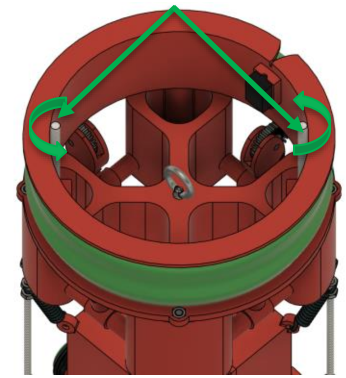


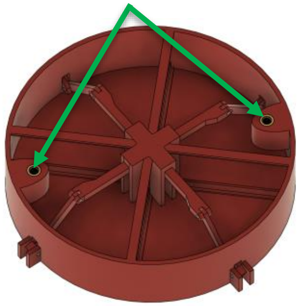


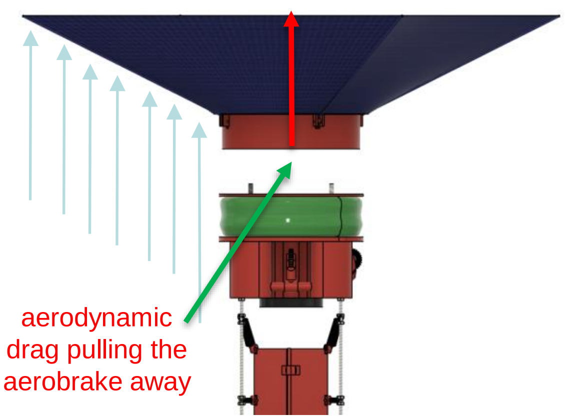


Design 2

Aerobrake mechanism, unscrews the top cover with heatshield mounted forcing a separation of aerobrake assembly and the rest of the model. Aerodynamic drag pulls the heatshield away. Mechanism needs a couple of seconds for separation to happen.







Payload Aerobraking Release Trade & Selection (2/2)

Aerobraking release comparison

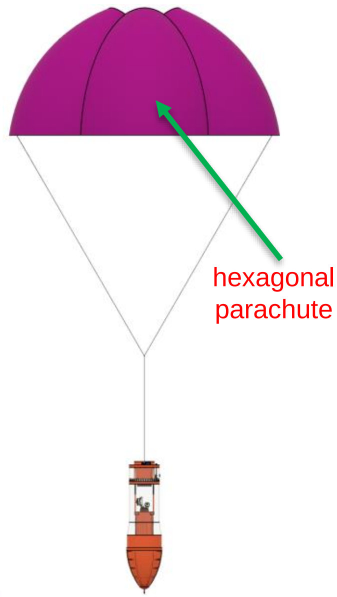
Section	Solution	Rationale	Selection
Aerobraking Release Design	Design 1	+ Solenoids are very reliable + Instant separation + Lower power required for activation + Lower weight, and less space - There is a risk of jam in case of uneven drag or rocking of the design	**Design 1** Lower chance of failure, and lower weight are deciding factor for the design one.
	Design 2	+ Team has experience with DC motors - Imperfections in engine manufacturing may cause uneven torque or rpm causing a jam. - More power hungry - Heavier, and more space	

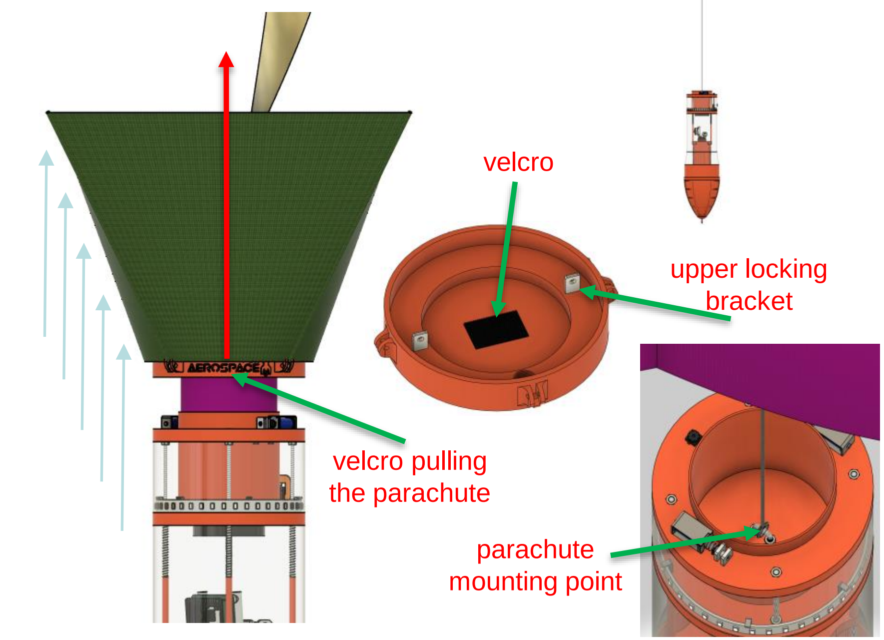
Payload Parachute Deployment Configuration Trade & Selection (1/2)

Parachute Deployment

Design 1

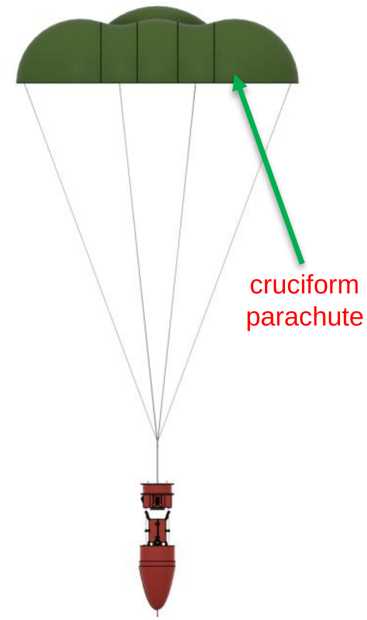
Parachute is pulled out from the parachute container by released aerobrake. Top of the parachute is attached to upper cover by a light velcro, which will ensure proper separation of parachute and cover after deployment.

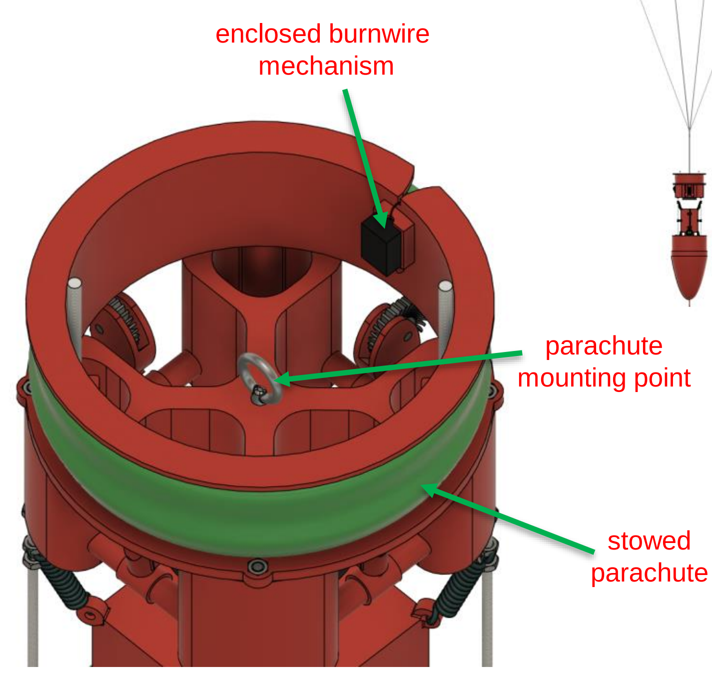




Design 2

After the aerobrake is detached, a burn wire mechanism is activated so parachute is deployed from it's round stowed position by an aerodynamic pressure.





Payload Parachute Deployment Configuration Trade & Selection (2/2)

Parachute deployment comparison

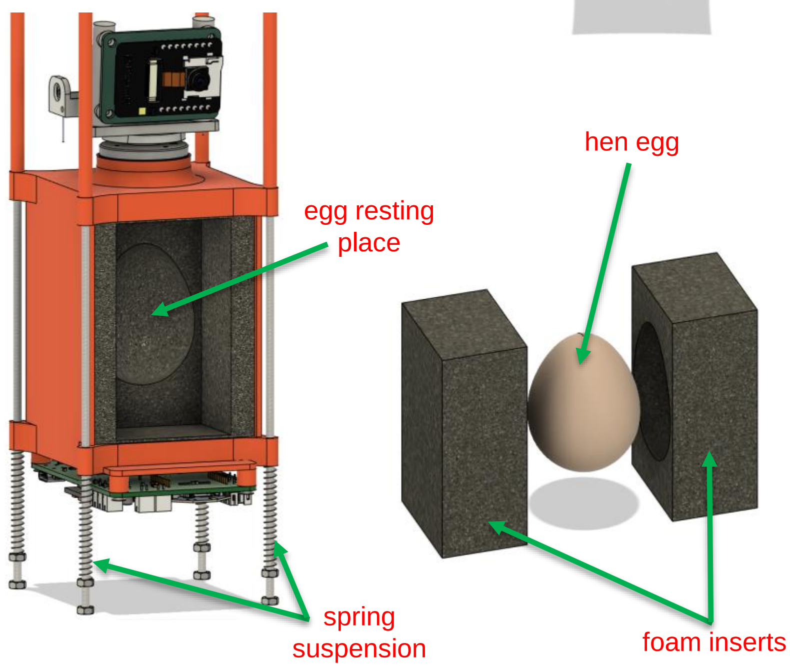
Section	Solution	Rationale	Selection
Parachute Design	Design 1	+ Ensures proper parachute deployment + Simple and elegant + A lot of space for a big parachute ++ Minimal chance for a deployment failure - Velcro may be to light or too strong for a proper separation	**Design 1** Lower chance of parachute deployment failure, and more space for parachute, are essential for mission success, and safety.
	Design 2	+ Leaves additional space for better stability control mechanism like rollerons, and synchronization of aerobrake rods. + Cruciform parachute creates more drag - Parachute is harder to construct - Held by a burn wire - Not a lot of space for storing parachute -- Potentially high chance for deployment failure	

Payload Egg Containment Configuration Trade & Selection (1/2)

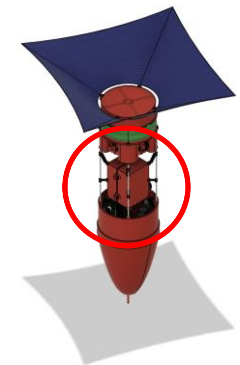
Egg Containment

Design 1

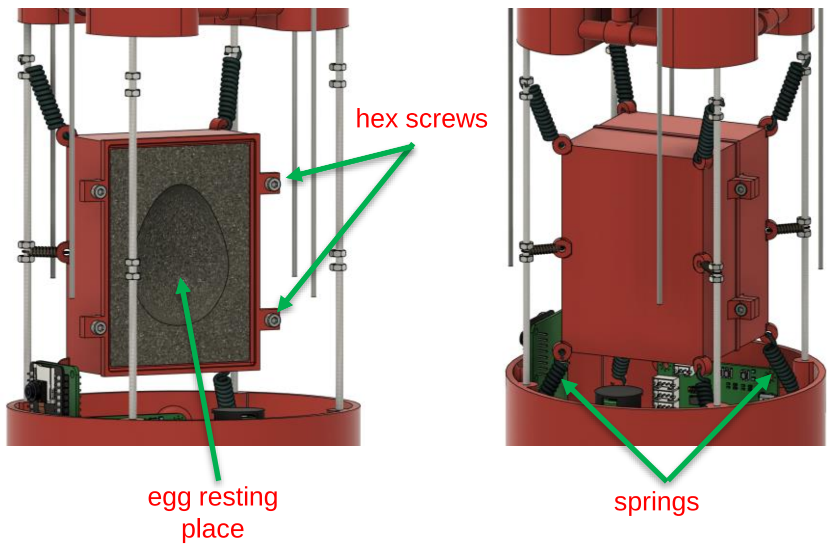
Hen's egg is contained in multilayer foam, which is inserted into plastic box. Box is suspended on the aluminium struts, with a spring suspension, to provide aditional shock protection.



Design 2



Egg containment unit is constructed from two distinctive parts, held together by hex screws. **Egg is supported by polyethylene foam.** Box is mounted on the main struts, and held in position by resultant force of 12 springs.



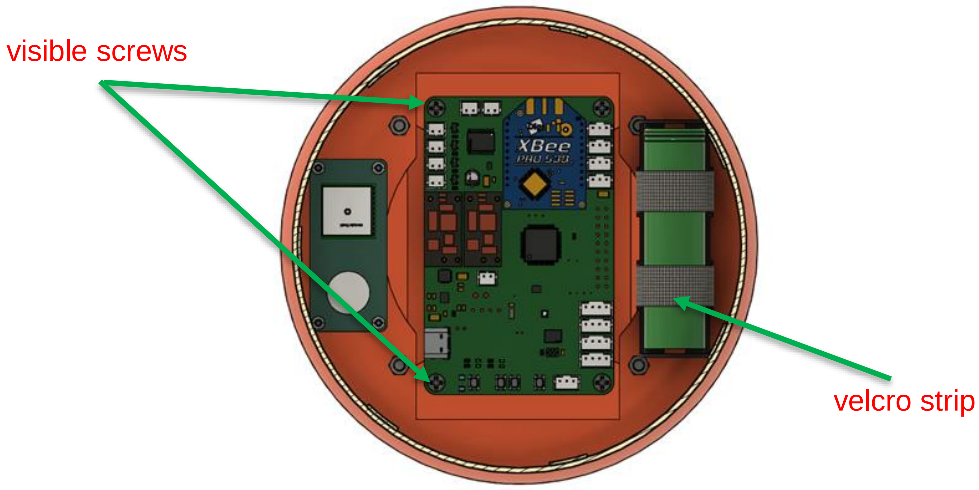
Payload Egg Containment Configuration Trade & Selection (2/2)

Egg containment comparison

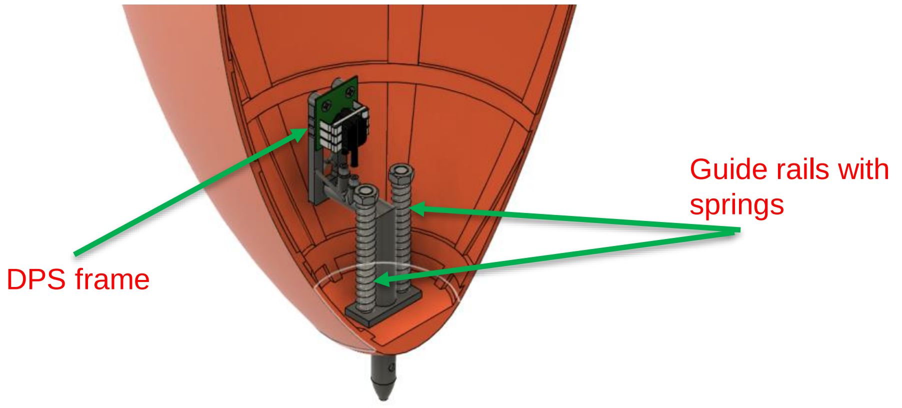
Section	Solution	Rationale	Selection
Egg Containement	Design 1	+ Quicker egg insertion + Significantly more vertical travel + Reusable with no significant maintenance + Easier to assemble + Stable platform for additional equipment - Harder to manufacture - No horizontal stabilization	**Design 1** Generally, more practical, provides stable mounting place for additional equipment
	Design 2	+ Spring stabilized in every direction + Better stability control - Harder to assemble - More time need to insert the egg - Less travel in the most probable shock direction - Risk of damaging electrical equipment in a situation of very strong shock	

Electronic Components Mounting Method

The main electronic board will be mounted to the bottom of the egg box (additional cutout to show this on the render below). A bit lower, in the nose cone, there will be a GPS and battery holder. All 3 of these elements will be **screwed down**. **The battery will be additionally secured by a velcro strip**. The pitot tube will be mounted with spring bolts. The differential pressure sensor **will be screwed** to the frame integrated with the pitot. The main camera board will be screwed to 3D printed chassis glued to the gimbal motor. This motor **will be glued** to the egg box, in the destined slot. Also, the camera battery **will be mounted with screws** to this chassis. The LED strip will be stuck between the upper fairing and L-shaped fixture. Just behind it, there will be a bonus camera board **screwed** to a 3D-printed wall. The power **switch will be glued** to the same element.



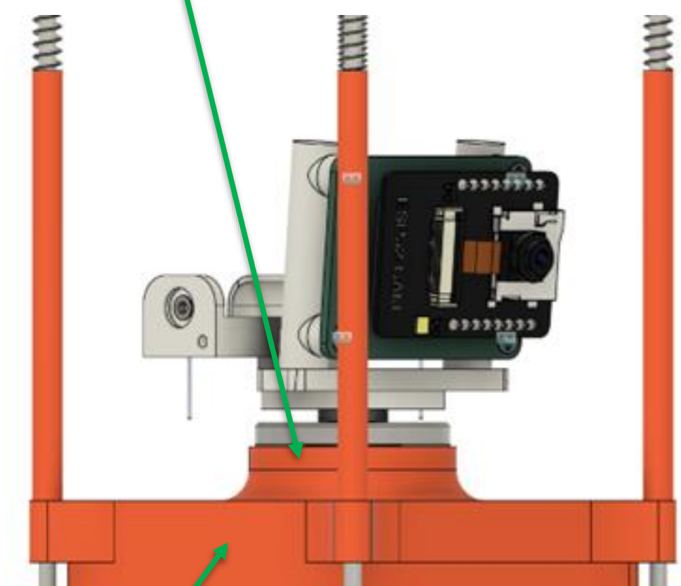
Electronics seen from the nose cone tip



Pitot tube

Electronics Structural Integrity (2/2)

gimbal motor **glued** in destined slot

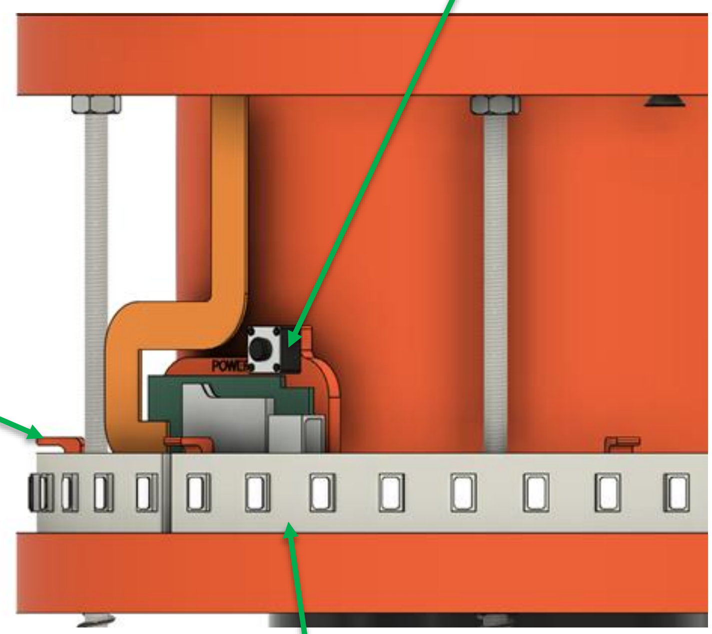


3D printed chassis

Main camera on top of the egg box

auxilliary camera PCB with main power switch

L-shaped fixture



LED strip

Upper assembly

Mass Budget (1/7)

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Nose cone Structure	Structural ring	PET-G	1	48.1±2	48.1±2	Calculated
	Aerodynamic fairings	PET	1	26.4±2	26.4±2	Estimated
	Nose cone shoulder	ASA	1	50.2±2	50.2±2	Calculated
	Nose cone fairing	Nylon	1	95.6±3	95.6±3	Calculated
	Pitot tube	PET-G	1	1.41±0.1	1.41±0.1	Calculated
	Pitot mounting struts	Steel	2	2.26±0.1	4.52±0.2	Estimated
	Pitot dampening springs	Steel	2	0.88±0.05	1.76±0.1	Estimated
	M3 x 5,5 mm brass inserts	Brass	8	0.27±0.0125	2.16±0.1	Estimated
	M3 | 5.5 | 2.4 | ISO nuts	Steel	4	0.37±0.02	1.48±0.08	Estimated
	M3 x 8 mm screw	Steel	8	0.46±0.025	3.68±0.2	Estimated

Summary mass = 235.33 ± 9.78 g

Mass Budget (2/7)

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Upper Structure (heatshield and parachute mechanism)	Upper cover	ASA	1	47.0±2	47±2	Calculated
	Camera glass	Glass	1	0.14±0.01	0.14±0.01	Estimated
	Detach mechanism structure	ASA	1	28.85±2	28.85±2	Calculated
	Parachute comprtment structure	ASA	1	66.0±3	66±3	Calculated
	Auxiliary camera mount	PET-G	1	2.69±0.1	2.69±0.1	Calculated
	Long brackets	Steel	2	7.44±0.25	14.88±0.5	Estimated
	Short brackets	Steel	4	3.41±0.1	13.65±0.4	Estimated
	Parachute mounting U-Bolt	Steel	1	1.95±0.05	1.95±0.05	Estimated
	M3 x 5,5 mm brass inserts	Brass	8	0.27±0.0125	2.16±0.1	Estimated
	M3 | 5.5 | 2.4 | ISO nuts	Steel	4	0.37±0.02	1.48±0.08	Estimated
	M3 x 8 mm screw	Steel	8	0.46±0.025	3.7±0.2	Estimated
	LED holders	Aluminium	6	0.22±0.01	1.3±0.06	Estimated

Summary mass = 183.82 ± 8.50 g

Mass Budget (3/7)

Subsystem	Component	Material / Part numer	Quantity	Mass piece [g]	Mass summary [g]	Source
Egg box structure	Egg box	ASA	1	62.2±2	62.2±2	Calculated
	Foam insert	Foam	1	10.0±1	10±1	Estimated
	Egg box door	ASA	1	10.5±0.2	10.5±0.2	Calculated
	M3 x 8 mm screw	Steel	8	0.46±0.025	3.68±0.2	Estimated
	PCB holder	ASA	2	1.71±0.1	3.42±0.2	Calculated
	Camera gimball	PET-G	1	10.7±0.2	10.7±0.2	Calculated

Summary mass = 100.5 ± 3.8 g

Mass Budget (4/7)

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Struts, springs and shock absorbers	Main struts	Aluminium	4	6.1±0.1	24.4±0.4	Estimated
	Spring distances	PET	4	1.12±0.02	4.48±0.08	Estimated
	Dampening spring	Steel	8	0.85±0.02	6.8±0.16	Estimated
	M3 | 5.5 | 2.4 | ISO nuts	Steel	24	0.37±0.02	8.88±0.48	Estimated

Summary mass = 44.56 ± 1.12 g

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Descent control system	50mm x 2m mylar streamer	PP	2	1.85±0.025	3.7±0.05	Calculated
	Heatshield material	silicone coated ripstop	1	32±2	32±2	Calculated
	Parachute material	silicone coated ripstop	1	48±3	48±3	Calculated
	Nylon thread	Nylon	4m	0.4±0.01	1.6±0.04	Estimated

Summary mass = 85.3 ± 5.09 g

Mass Budget (5/7)

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Main electronics board	Board	-	1	12±0.2	12±0.2	Measured
	Intergrated circuits	-	1	7.2±0.1	7.2±0.1	Estimated
	Passive components	-	-	18±0.2	18±0.2	Measured
	Connectors	-	4	1±0.2	4±0.8	Estimated
	XBee 900MHz	XBP9B-XCST-001	1	10±0.2	10±0.2	Datasheet

Summary mass = 51.2 ± 1.5 g

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Cameras and stabilisation mechanism	BLDC	PM3505	1	38±1	38±1	Estimated
	Camera	OV2640	1	3±0.3	3±0.3	Datasheet
	Controller	AI-Thinker	1	7±0.3	7±0.3	Measured
	Battery	Li-Ion 14500	1	21±0.1	21±0.1	Datasheet
	Camera	Adafrut 3202	1	10±0.6	10±0.6	Datasheet

Summary mass = 79 ± 2.3 g

Mass Budget (6/7)

Subsystem	Component	Material / Part number	Quantity	Mass piece [g]	Mass summary [g]	Source
Other elements	GPS	MTK3339	1	10±0.1	10±0.1	Datasheet
	Battery	Li-Ion 18650	1	59±0.1	59±0.1	Datasheet
	Pitot's tube sensor	ABPDJJT001PDSA3	1	5±0.3	5±0.3	Datasheet
	Speaker	57CS50G-75ND	1	12±0.1	12±0.1	Datasheet
	Electromagnets	JF-0530B	2	18±1	36±2	Estimated
	LED stripe	-	0.4m	12±1	4.8±0.4	Estimated
	Battery holder	-	1	2.4±0.2	2.4±0.2	Estimated

Summary mass = 129.2 ± 3.2 g

Mass Budget (7/7)

Component	Subsystem	Mass summary [g]
Payload	Nose cone structure	235.33 ± 9.78
	Upper Structure (heatshield and parachute mechanism)	183.82 ± 8.50
	Egg box structure	100.5 ± 3.8
	Struts, springs and shock absorbers	44.56 ± 1.12
	Descent control system	85.3 ± 5.09
	Main electronics board	51.2 ± 1.5
	Cameras and main camera stabilization mechanism	79 ± 2.3
	Other elements	129.2 ± 3.2

Summary mass: 908.91 ± 35.29 g

Margin: 908.91- 900 = **8.91 g**

The CanSat mass is within the given tolerance of ±10g, however, its uncertainty is quite large due to the fact that the mass of most components was given by the CAD program or estimated from the 3D model.

Correction methods if the mass falls out of spec (900 ± 10g)

- In case the mass will be greater than 910g:
    - the filling of 3D printed components will be reduced
    - PET-G will be substituted with ASA.

- In case the mass will be less than 890g:
    - aluminum parts will be repleaced with steel ones.

Communication and Data Handling (CDH) Subsystem Design

Jakub Kaszowski

Payload Command Data Handler (CDH) Overview

Component	Type	Functions
STM32F412RET6	Processor	Executing received commands. Reading and processing data from sensors. Progressing through FSM, enabling actuators.
Internal STM backup registers	Memory	Storage of software state in case of reset.
XBee: XBP9B-XCST-001	Radio	Transmitting data and commands. XBee 900 MHz.
ANTX150P118B09153	Antenna	Amplifying signal range.
STM32 internal RTC	RTC	Measurement of mission time.

Payload Processor & Memory Trade & Selection (1/2)

Name	Boot time	Processor speed [MHz]	Data interfaces	Flash memory[kB]	RAM[kB]
STM32F412RET6	~3ms	100	4x I2C, 4x UART, 5x SPI/I2S, 1x SDIO, 1x USB 2.0	1024	256
ESP32-H2	~300ms	96	2x I2C, 2x UART, 3x SPI, 1x USB 2.0, 1x TWAI	1024 or 2048	320
iMXRT1062	~5ms	600	2x I2C, 8x UART, 3x SPI, 1x SDIO, 2x USB 2.0	8092	1024

Selected processor	Reasons
STM32F412RET6	• Sufficient for required tasks • Has internal RTC with backup registers • Team already knows the architecture • High debugging support • Abundant in DMA and interrupts • Allows lowest level control

Payload Processor & Memory Trade & Selection (2/2)

Name	Capacity	Interfaces	Package
Internal STM backup registers	80B	APB1	-
Goodram M1A0 microCard 32GB	32GB	SPI SDIO	microSD
EEPROM 24LC01B	1KB	I2C	DIP-8

Selected memory unit	Reasons
Internal STM backup registers	• Is the most reliable among considered options • Does not take up extra space • Its capacity is sufficient for FSW state • Ultra fast access (~100us)
Goodram M1A0 microCard 32GB	• Provides large storage for telemetry backup • MCU has SDIO inteface • Not critical in terms of mission success

Payload Real-Time Clock

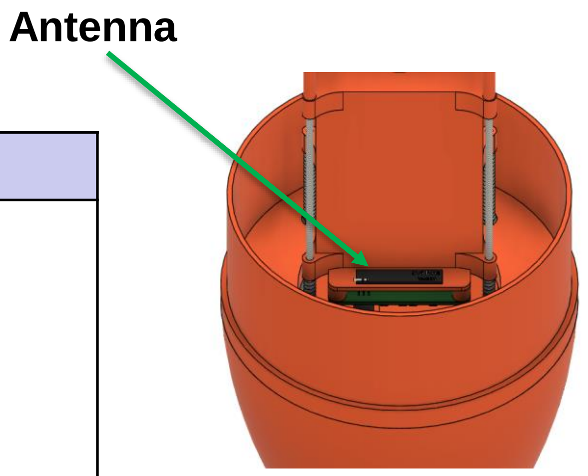
Name	Interface	Reset tolerance	Size	Weight
STM32 internal RTC	APB1	Resilient due to coin battery power backup	Integrated into STM32	-
Adafruit PCF8523 RTC	I2C	Resilient due to coin battery power backup	25.5mm x 21.7mm x 4.8mm	1.2g
DS1307 RTC	I2C	Resilient due to coin battery power backup	26mm x 22mm x 5mm	2.3g

Selected RTC	Reasons
Internal STM32 RTC clock	• STM32 is already selected • Can be calibrated down to 30µs • High customization options • Requires only external crystal

Payload Antenna Trade & Selection (1/2)

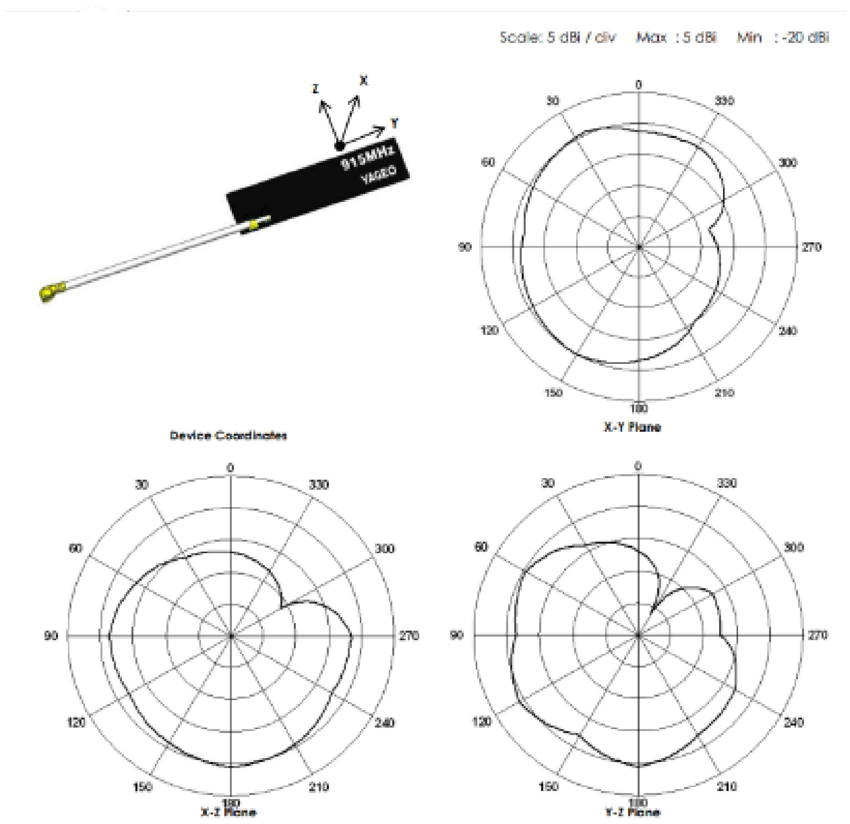
Name	Connector type	Antenna type	Frequency range(s) [MHz]	Weight [g]	Peak gain [dBi]	Efficiency [%]	Range [km]
ANTX150P118B09153	I-PEX (U.fl compatible)	PCB strip	890-925	0.675	1.9	>55	~0.6 (worst case) ~9 (best case)
MOLEX 2111400100	U.fl	PCB strip	868-870, 902-928	0.48	1	>60	~0.4 (worst case) ~7 (best case)

Selected antenna	Reasons
ANTX150P118B09153	• It has been already tested • Has better frequency range • Has higher gain

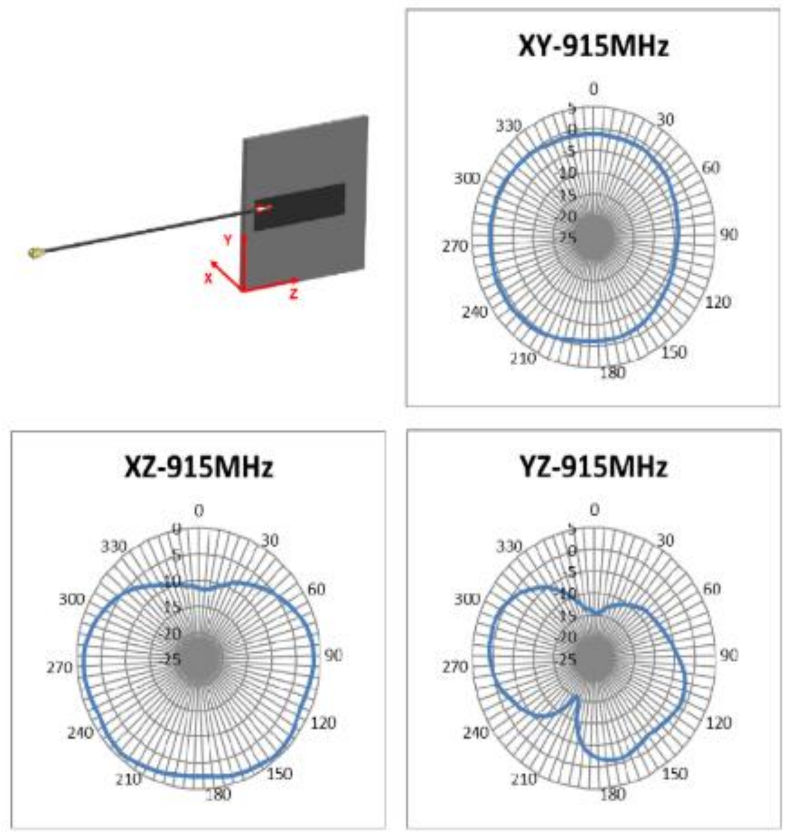


Payload Antenna Trade & Selection (2/2)

ANTX150P118B09153 (selected)



MOLEX 2111400100



Payload Radio Configuration

XBee Radio selection:

XBee XBP9B-XCST-001 has been selected to be used in both payload and Ground Station.

XBee Configuration

XBees will operate in the same network in AT (transparent) mode.

The radio will operate in **unicast mode**, and it will communicate with the MCU using UART interface.

PANID/NETID is set to 2044 in accordance with requirement **X2**.

Transmission Control

Before the start, the radio will be waiting for configuration (CAL, CX).

After receiving the CX command, a data frame will be transmitted every second (**1Hz** frequency).

When landing is detected, the packet transmission is stopped.

Payload Telemetry Format (1/3)

Data field	Description	Resolution
TEAM_ID	Four digit team identification number.	-
MISSION_TIME	UTC time in format hh:mm:ss.	1s
PACKET_COUNT	Total count of transmitted packets maintained through processor reset.	1
MODE	‘F’ for flight mode, ‘S’ for simulation mode.	-
STATE	The operating state of the software (BOOT, IDLE, READY, FLIGHTUP, MAIN, PARACHUTE, TOUCHDOWN).	-
ALTITUDE	Altitude relative to ground level in meters.	0.1m
AIR_SPEED	Air speed measured with the pitot tube during ascent and descent in meters per second.	1m/s
HS_DEPLOYED	‘P’ if heat shield is deployed, ‘N’ otherwise.	-
PC_DEPLOYED	‘C’ if parachute is deployed, ‘N’ otherwise.	-
TEMPERATURE	Temperature in degrees Celcius.	0.1°C
PRESSURE	Measured air pressure in kPa.	0.1kPa
VOLTAGE	Voltage of the CanSat power bus in volts.	0.1V
GPS_TIME	UTC time from the GPS receiver in format hh:mm:ss.	1s

Payload Telemetry Format (2/3)

Data field	Description	Resolution
GPS_ALTITUDE	Altitude above sea level from the GPS receiver in meters.	0.1m
GPS_LATITUDE	Latitude from the GPS receiver in decimal degrees.	0.0001°
GPS_LONGTITUDE	Longitude from the GPS receiver in decimal degrees.	0.0001°
GPS_SATS	Number of GPS satellites being tracked by the GPS receiver.	1
TILT_X	X angle of CanSat. Perpendicular to Y axis and gravitation force vector.	0.01°
TILT_Y	Y angle of CanSat. Perpendicular to X axis and gravitation force vector.	0.01°
ROT_Z	Rotation rate of CanSat in degrees per second.	0.1°/s
CMD_ECHO	Last command received and processed by CanSat.	-
CAMERA1_STATE	State of first camera. States are: ‘S’ - sleeping, ‘W’ - waiting, ‘R’ - recording, ‘E’ - error	-
CAMERA2_STATE	State of second camera. States are: ‘S’ - sleeping, ‘W’ - waiting, ‘R’ - recording, ‘E’ - error	-

The data will be transmitted at **1Hz** frequency with each field delimited by a comma. Every packet is terminated by a single carriage return character. Additional telemetry fields are **CAMERA1_STATE** and **CAMERA2_STATE**.

Payload Telemetry Format (3/3)

Telemetry packet format

TEAM_ID, MISSION_TIME, PACKET_COUNT, MODE, STATE, ALTITUDE, AIR_SPEED, HS_DEPLOYED, PC_DEPLOYED, TEMPERATURE, VOLTAGE, PRESSURE, GPS_TIME, GPS_ALTITUDE, GPS_LATITUDE, GPS_LONGITUDE, GPS_SATS, TILT_X, TILT_Y, ROT_Z, CMD_ECHO, CAMERA1_STATE, CAMERA2_STATE

Telemetry packet example

2044,13:37:37,42,S,READY,0.0,0.0,N,N,11.1,4.15,101.6,
13:37:37,153.3,51.1090,17.0327,7,0.21,0.83,0.0,CX,R,R

The telemetry data shall be named **Flight_2044.csv**.

Competition requirements are met!

Payload Command Formats (1/2)

Command name	Format	Description	Example
CX - Payload Telemetry On/Off Command	CMD,<TEAM_ID>, CX,<ON_OFF>	1. CMD and CX are static text. 2. <TEAM ID> is the assigned team identification. 3. <ON_OFF> is the string 'ON' to activate the payload telemetry transmissions and 'OFF' to turn off the transmissions.	CMD,2044,CX,ON Activate payload telemetry transmission.
ST – Set Time	CMD,<TEAM_ID>, ST, <UTC_TIME>|GPS	1. CMD and ST are static text. 2. <TEAM ID> is the assigned team identification. 3. <UTC_TIME>|GPS is UTC time in the format hh:mm:ss or 'GPS' string which sets the flight software time to the current time read from the GPS module.	CMD,2044,ST,GPS Set flight software time to the current GPS time.
SIM - Simulation Mode Control Command	CMD,<TEAM_ID>, SIM,<MODE>	1. CMD and SIM are static text. 2. <TEAM_ID> is the assigned team identification. 3. <MODE> is the string 'ENABLE' to enable the simulation mode, 'ACTIVATE' to activate the simulation mode, or 'DISABLE' which both disables and deactivates the simulation mode.	CMD,2044,SIM,ENABLE Enable simulation mode.
SIMP - Simulated Pressure Data	CMD, <TEAM ID>, SIMP, <PRESSURE>	1. CMD and SIMP are static text. 2. <TEAM ID> is the assigned team identification. 3. <PRESSURE> is the simulated atmospheric pressure data in units of pascals with a resolution of one Pascal. Only used in simulation mode.	CMD,2044,SIMP,101325 Set simulated pressure reading to 101325Pa.

Payload Command Formats (2/2)

Command name	Format	Description	Example
CAL - Calibrate Altitude to Zero	CMD,<TEAM ID>,CAL	1. CMD and CAL are static text. 2. <TEAM ID> is the assigned team identification.	CMD,2044,CAL Sets altitude of relative altitude of CanSat to 0 meters.
BCN - Control Audio Beacon	CMD,<TEAM ID>,BCN,ON|OFF	1. CMD and BCN are static text. 2. <TEAM ID> is the assigned team identification. 3. <ON|OFF> are static strings “ON” or “OFF” that control the audio beacon.	CMD,2044,BCN,ON Turn on audio beacon.
RST* – System Reset	CMD,<TEAM ID>,RST, <TYPE>	1. CMD and RST are static text. 2. <TEAM ID> is the assigned team identification. 3. <TYPE> is the string ‘HARD’ to simulate power loss of MCU or ‘SOFT’ to reset RTC, packet count and relative altitude to default values.	CMD,2044,RST,HARD Simulate hard reset of MCU.

* - optional command

Competition requirements are met!

Electrical Power Subsystem (EPS) Design

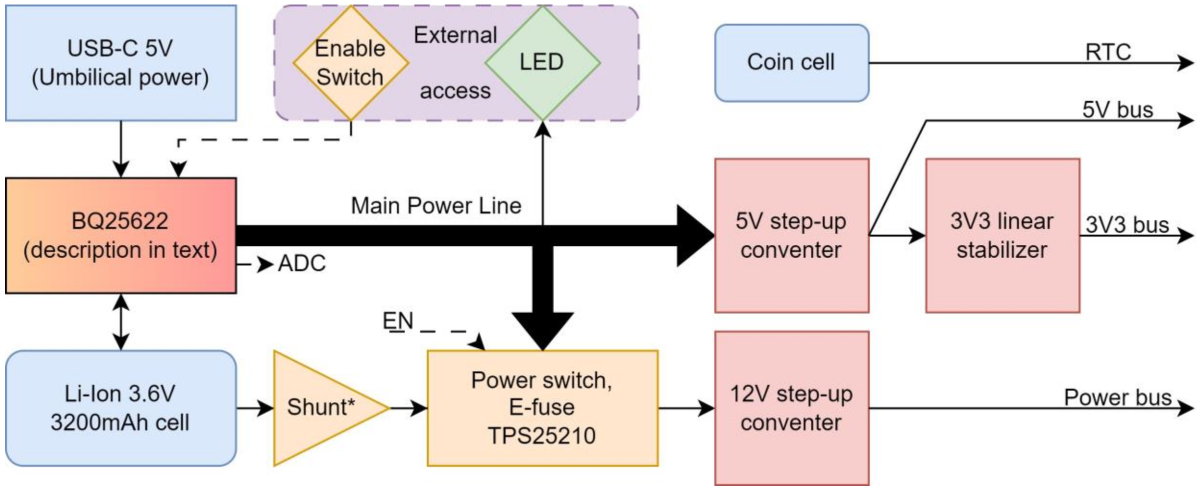
Jakub Kaszowski

EPS Overview

The power section is based on BQ25622 IC. It is a highly integrated single-cell manager, capable of:
- switching up to 7A
- charging the cell from USB
- communicating over IIC
- measuring cell voltage
- fuel estimation (Columb counter)
- measuring load and temperature

Required voltages are created by smps circuits, and RTC has its own cell to count time during unwanted restart.
There is an external switch to enable CanSat, and a well visible LED to show it is enabled.

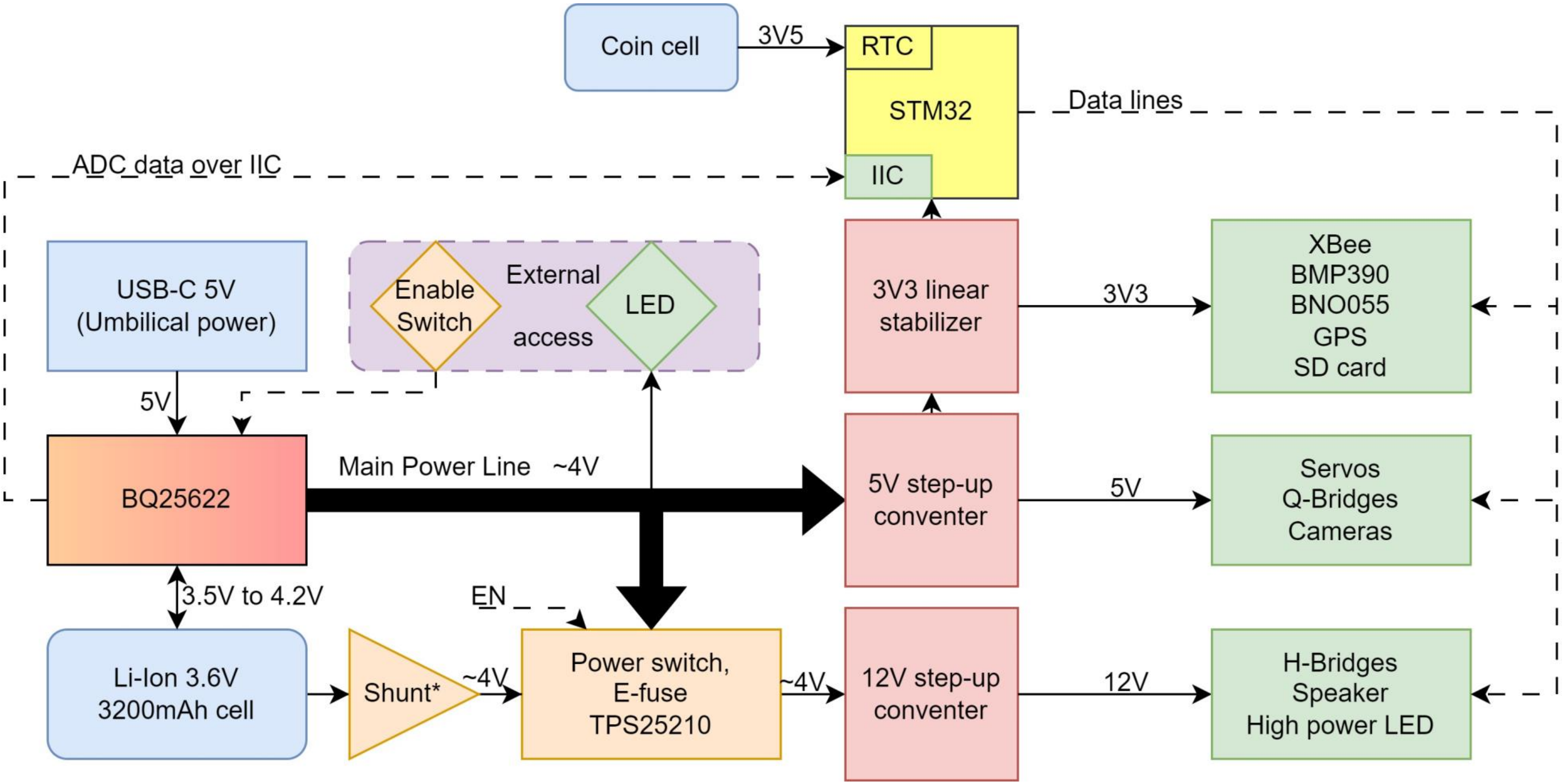
Component	Description	Type
USB-C connector	Umbilical power source	Source
3.7V Li-Ion cell	Main power source	Source
Coin cell	**Prevents RTC from resetting**	**Source**
5V step-up smps	Power supply for sensors and servos	Conventer
3V3 linear stabilizer	Power supply for sensors and MCU	Conventer
12V step-up smps	Power supply for power elements	Conventer
External switch	Turns on/off main power line	Management
BQ25622	Highly integrated power manager IC	Management
TPS25210	Power switch with protection	Management



*if more power is needed

Payload Electrical Block Diagram

The external switch will allow us to switch on the circuit. LED provides feedback on the power state independent of the MCU. The main bus voltage is measured by BQ25622.



Payload Power Trade & Selection

Part	Dimensions [mm]	Weight [g]	Voltage [V]	Capacity [mAh]	Current max [mA]	Type	Charge cycles	Integrated fuses	Cost [$]
Panasonic NCR18650B	⌀18.5 x 65.3	48.5	3.6	3200	6400	**Li-Ion**	500	No	7.39
Energizer L522	46.50 x 26.50 x 17.50	33.9	9	~750	1000	Lithium	0	No	8.8

Selected battery:	Reasons:
Panasonic NCR18650B	• High capacity • Small dimensions • High energy density • Low internal resistance • Easy to replace • Rechargeable

The battery will be placed in a custom holder that is a part of the CanSat cone.
No spring contacts are used, **the cell will be spot-welded to wires.**

A single cell **does not have a configuration.**

Li-Poly cells are not used!

Payload Power Budget (1/2)

Component	Model	Voltage [V]	Current [mA]	Power [mW]	Duty cycle [s]	Duty Cycle [%]	Required Energy [Wh]	Source
uC+memory	STM32F412	3.3	30	99	7200	100%	0.198	Datasheet
Radio (TX)	XBP9B-XCST-001	3.3	215	709.50	1080	15%	0.213	Datasheet
Radio (RX)		3.3	26	85.80	6120	85%	0.146	Datasheet
GPS	MTK3339	3.3	20	66.00	7200	100%	0.132	Datasheet
Pressure Temperature	BMP390	3.3	1	3.30	7200	100%	0.007	Datasheet
IMU 9axis	BNO055	3.3	11	36.30	7200	100%	0.073	Datasheet
Pitot DPS	ABPDJJT001PDSA3	3.3	3.1	10.23	1080	15%	0.003	Datasheet
LED Strip	30/m	12	100	1200	1080	15%	0.360	Calculated
LED indicators	Multiple LEDs	3.3	30	99	7200	100%	0.198	Datasheet
SD card	GoodRam 32GB	3.3	(30) 100	(99) 330	(5760) 1440	(80%) 20%	0.290	Datasheet
3V3 stabilizer	AZ1117-3V3	5	0.06	0.30	7200	100%	0.001	Datasheet
5V SMPS /w main power IC	JENOR20200908 BQ25622E	3.7	3	11.10	7200	100%	0.022	Datasheet
12V SMPS	JENOR20200908	3.3	2	6.60	300	4.2%	0.001	Datasheet
Speaker	57CS50G-75ND	12	500	6000	360	5%	0.600	Datasheet
Electromagnets	JF-0530B	12	1000	12000	30	0.5%	0.100	Datasheet
Gimbal	PM3505	5	600	3000	240	3.3%	0.200	Calculated
Camera	ESP32-CAM	5	140	700	240	3.3%	0.047	Datasheet
Bonus Camera	Adafruit 3202	5	110	550	240	3.3%	0.037	Datasheet

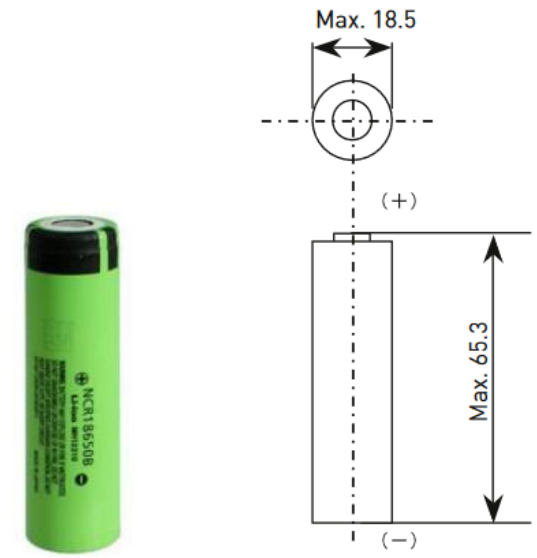
Note: The value inside brackets () is standby or idle value.

Payload Power Budget (2/2)

Summary:

Energy required:	2.626 Wh
Energy required assuming efficiency 50%	~ 5.3 Wh
Power source:	One Li-ion cell
Total power available:	3.6 V * 3200 mAh = 11520 mWh = 11.52 Wh
Margin:	11.52 Wh – 5.3Wh = 6.22 Wh
Percent margin:	5.3 Wh / 11.52Wh * 100% = 46%

DIMENSIONS (MM)



SPECIFICATIONS

Model number	NCR-18650B
Nominal voltage (V)	3.6
Nominal capacity*1 - Minimum (mAh)	3,250
Nominal capacity*1 - Typical (mAh)	3,350
Dimensions - Diameter (mm)	18.5
Dimensions - Height (mm)	65.3
Approx. w^eight (g)	47.5

With the selected battery, **the payload can operate for approximately 4 hours** when integrated into the rocket.

For safety we assumed that combined efficiency is 50%.

Flight Software (FSW) Design

Jakub Kaszowski

FSW Overview (1/3)

Overview

Flight software operates on the state machine concept. Using collected data, the FSW evaluates different states and manages events, such as reaching the proper altitude. Additionally, it is responsible for transmitting data to the Ground Station (GS) via XBee and restoring the correct state and time in the event of an unwanted restart.

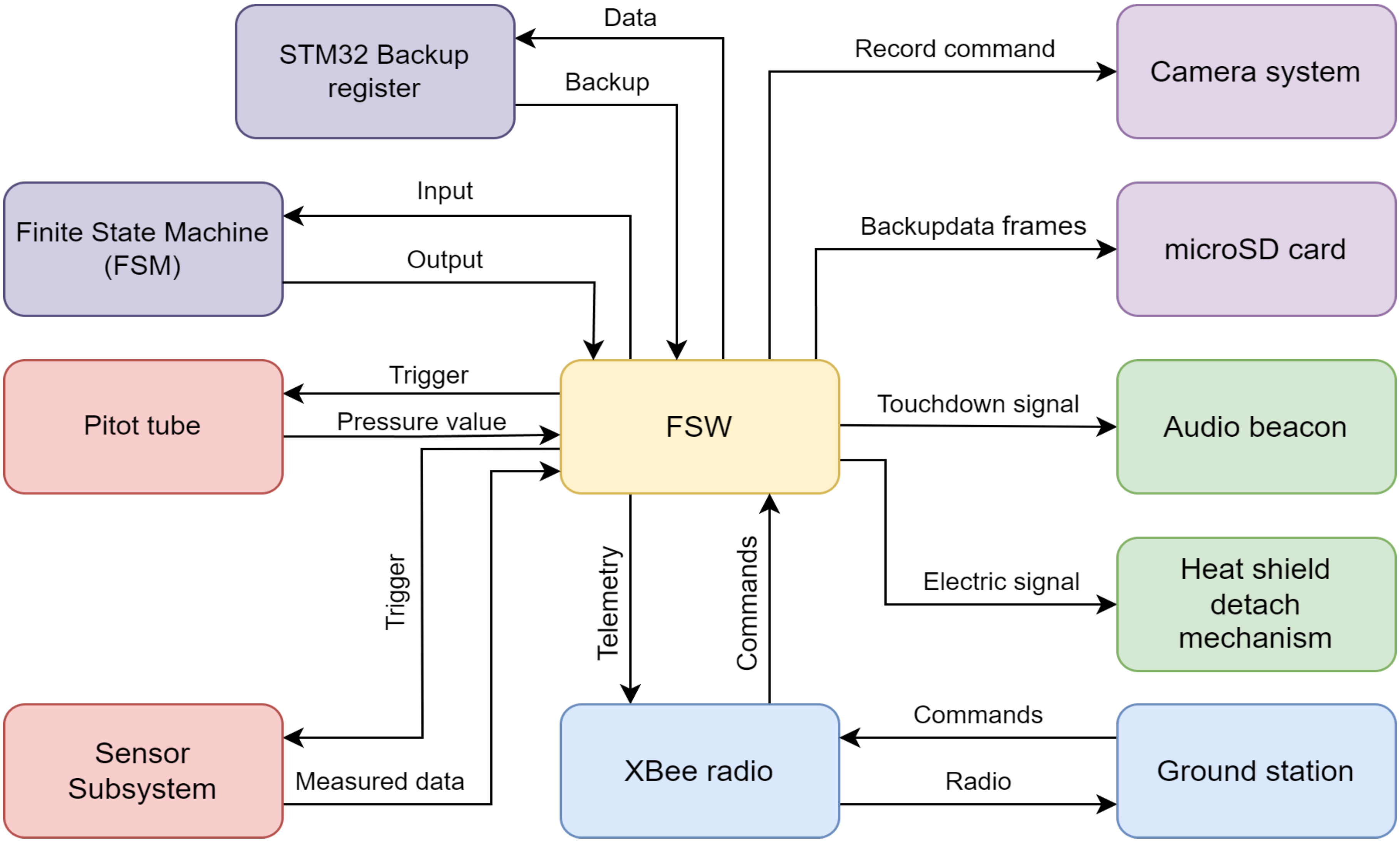
Programming language

Our software is based on C/C++ language.

Developing environment

CubeIDE, arm-none-eabi (compiler and debugger)

FSW Overview (2/3)

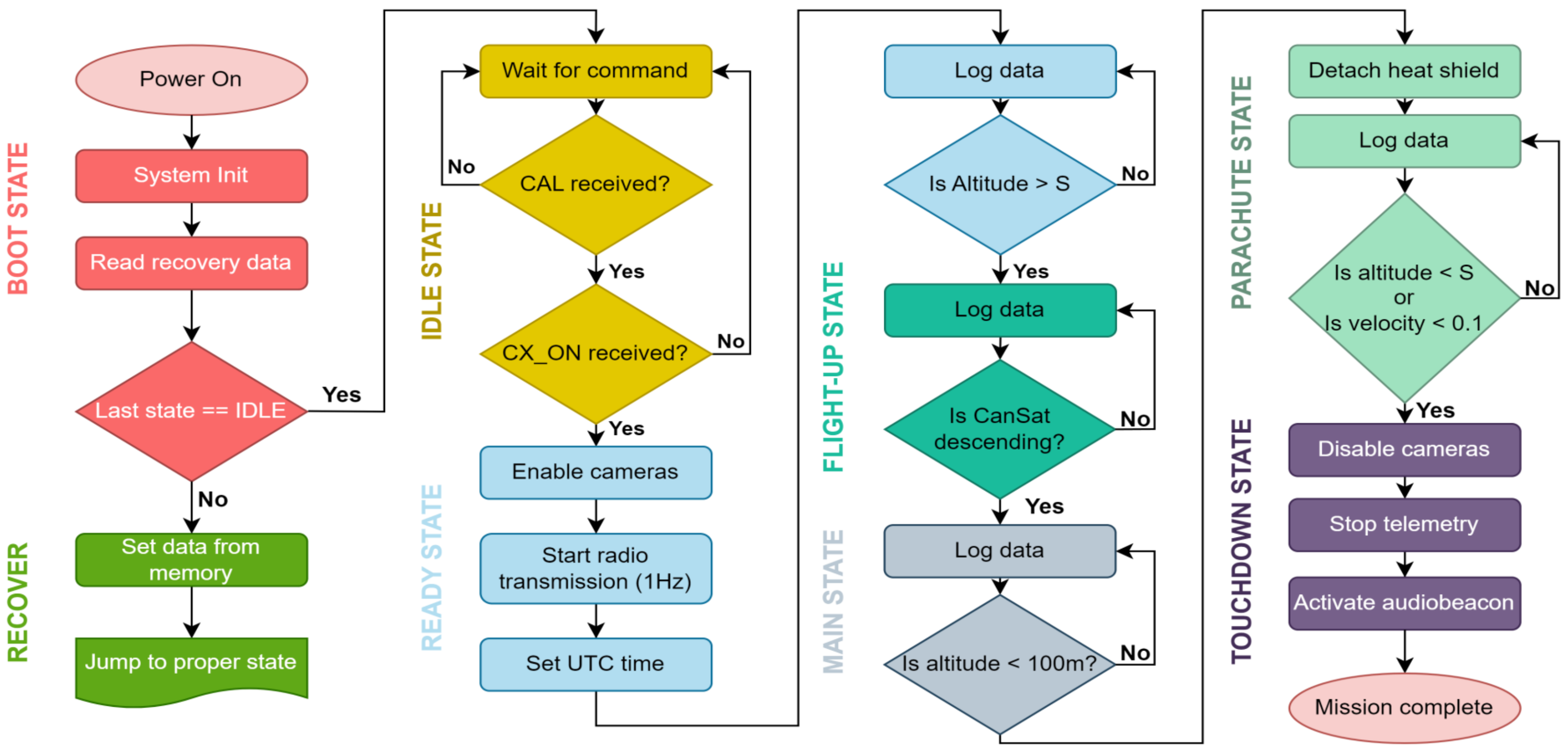


FSW Overview (3/3)

FSW Summary Tasks

- Recording raw sensor values and translating them into standardized engineering units
- Sensor calibration
- Collect and analyze commands from the Ground Station (e.g. to start transmission or perform reset)
- Formatting data packets in the necessary format for transmission
- Swapping pressure readings for received values in simulation mode
- Backing-up telemetry data on SD cards
- Activating the audio beacon
- Advancing through Flight Software (FSW) States
- Detaching the heat shield at the appropriate moment
- Controlling video recording
- Transmitting telemetry packets to Ground Station via XBee
- Saving recovery information on MCU battery backed-up registers

Payload FSW State Diagram (1/2)



Sampling of Sensors	Communications	Extra data storage
The sensors are sampled with a frequency of 1 Hz.	XBee transmit data at a rate of 1 Hz.	Telemetry data is also saved on an SD card.

S - safe altitude over the launchpad that cannot be reached before flight

Payload FSW State Diagram (2/2)

Unwanted restart mechanism

- In the event of an unwanted restart, correct values are retrieved from non-volatile memory (STM32 backup registers). The values are saved every time they change. These values are:
  - **internal packet counter**
  - **software state number**
  - **altitude of the launchpad**

- Reasons for reset are:
  - RST command
  - watchdog timer error
  - momentary power loss

To restore the state after a restart, the MCU will examine the backup registers. If data is available, it will be loaded into variables, and the state selector will transition to the appropriate state. Otherwise, the state selector will transition to the Idle state.

Simulation Mode Software

Simulation mode serves testing and demonstration needs. **To activate simulation mode, the Ground Station must transmit two commands (SIM ENABLE and SIM ACTIVATE) to the Payload.** Requiring two commands minimizes the risk of unintentional activation.

Once initiated, the Ground Station will periodically dispatch air pressure values as barometric pressure sensor commands (SIMP) at one-second intervals. FSW will use received values instead of real data from pressure sensor. It will let FSW to compute a simulated altitude for use in software logic.

SIM - Simulation Mode Control Command

- CMD,2044,SIM,ENABLE - enable the simulation mode
- CMD,2044,SIM,ACTIVATE - activate the simulation mode
- CMD,2044,SIM,DISABLE - both disables and deactivates the simulation mode

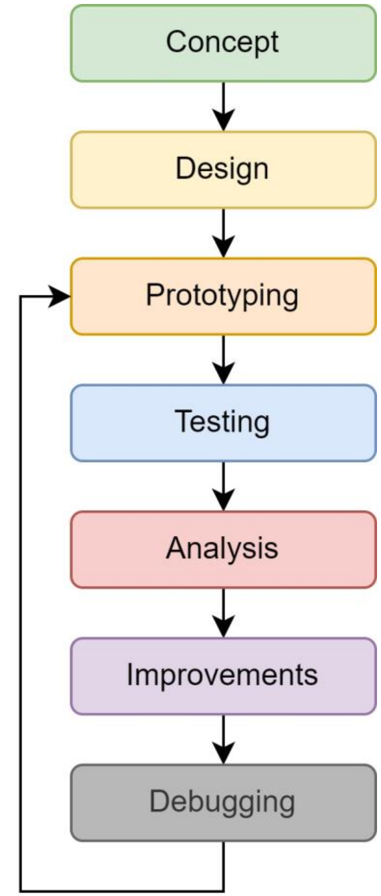
SIMP - Simulated Pressure Data

- CMD,2044,SIMP,<PRESSURE> - simulated atmospheric pressure data in Pascals (1Pa resolution)

Software Development Plan

Prototyping and prototyping environments

For prototyping, breakout modules and breadboards are employed. Each sensor undergoes individual testing. Upon successful completion of the tests and meeting the specified requirements, all components are integrated into a custom printed circuit board (PCB). This approach facilitates the development of the entire system in a cohesive manner.



Software developing

We use Git to store and manage our codebase. This tool enables collaborative work within the team, issue tracking, and facilitates code reviews. To maintain the continuity of development, we plan to conduct weekly meetings to address and discuss any problems or challenges. We recreated XBee which used a USB connector instead of an antenna to transmit data.

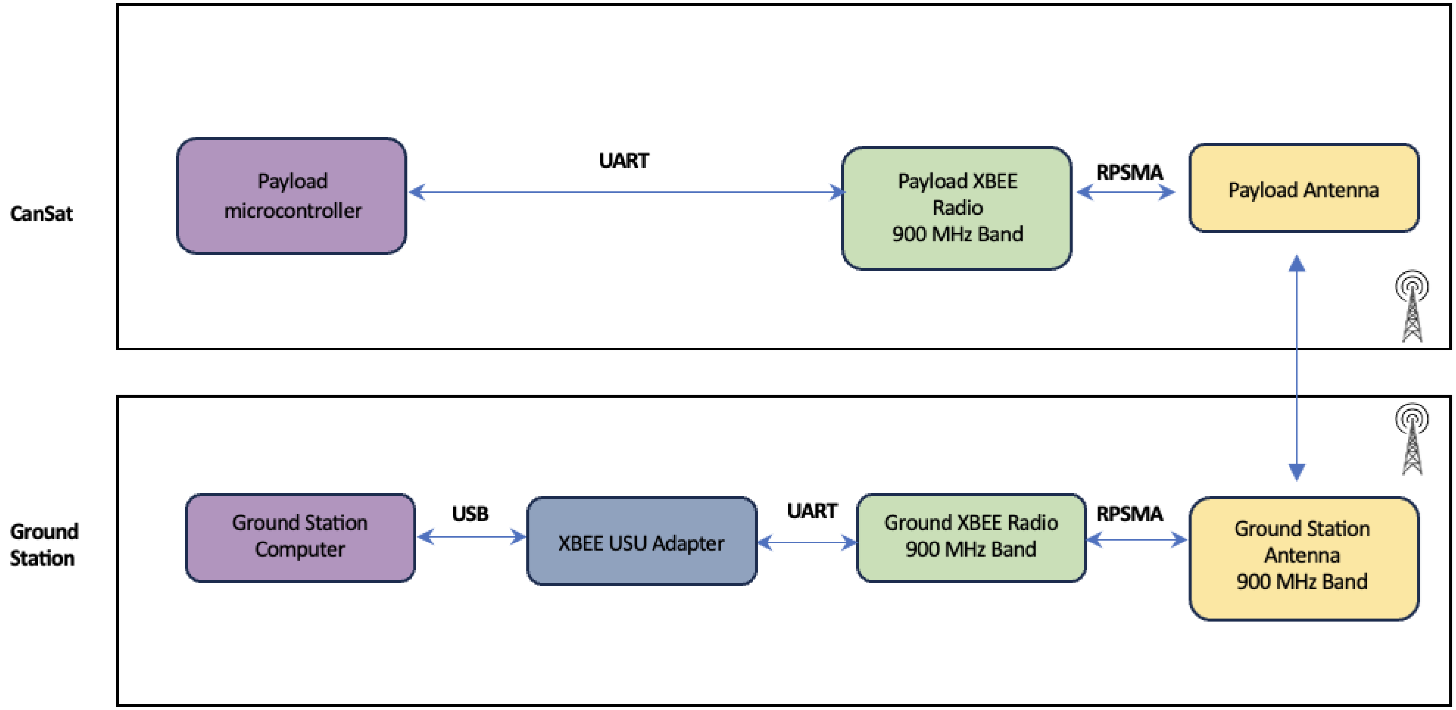
Development team: Hubert Kulik, Jakub Kaszowski, Filip Zioło, Maksymilian Tara.

Ground Control System (GCS) Design

Jakub Kaszowski

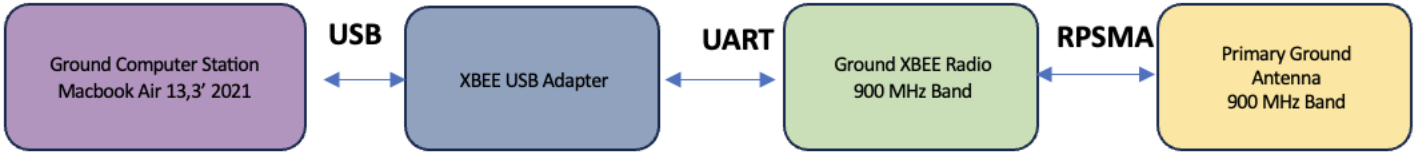
GCS Overview

We will configure our own Ground Station setup, comprising the following components:



GCS Design

Specifications	
Operation time	GCS will be able to operate for at least **3 hours** with no external power supply.
Overheating mitigation	We will protect the computer from sunlight with an umbrella.
Screen reflection mitigation	The umbrella will be covered with a blanket. The computer will operate in light mode (black text on white background). The plots will be made using bold colors on light background
Autoupdate mitigation	A Macbook Air is going to be used with auto updates turned off, and macOS does not enforce auto updates when they are disabled.



GCS Antenna Trade & Selection (1/4)

Model	Type	Frequency range [MHz]	Gain [dBi]	Size [mm]	Direction	Range [km]
Interline HORIZON 900 8V	Dipole	900-950	8	8600x260	Omnidirectional	-5
Hyperlink Wireless 900Mhz	Patch Antenna	908-928	8	220 x 220	Omnidirectional	-5

Reasons
• The build of the antenna is preferable for field • The best gain • Better radiation characteristic • Acceptable signal range

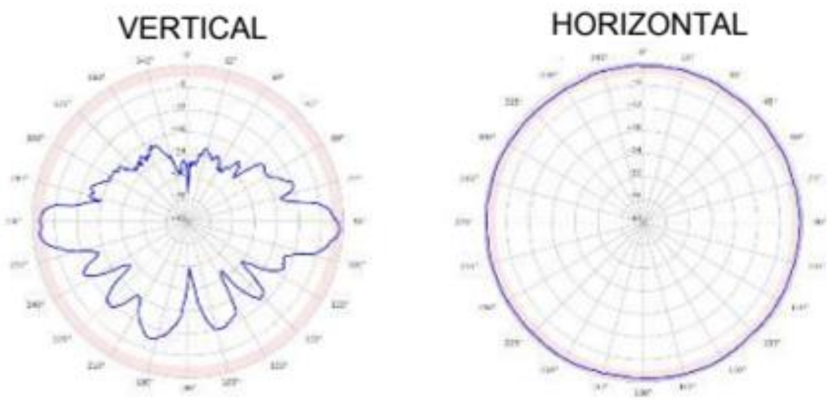
Interline HORIZON 900 8V

The dipole antenna offers excellent signal reception coverage. Furthermore, this particular design underwent testing in real-world scenarios during past CanSat competitions.

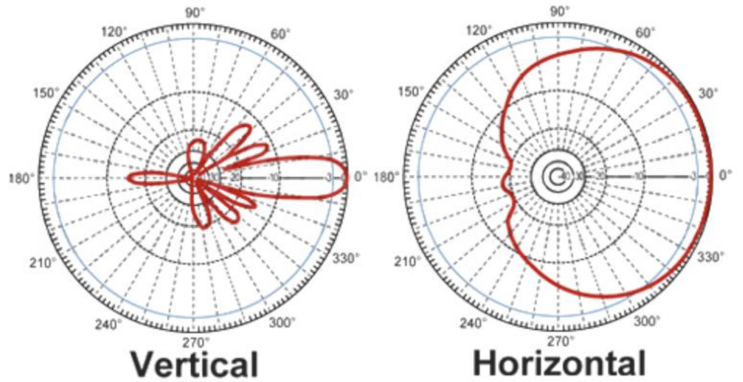
GCS Antenna Trade & Selection (2/4)

Radiation patterns comparison

Interline HORIZON 900 8V (selected)



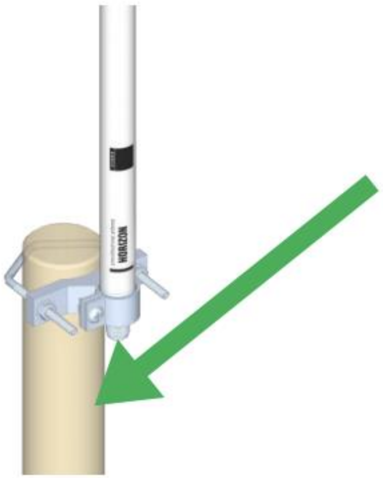
Hyperlink Wireless 900 MHz



GCS Antenna Trade & Selection (3/4)

Antenna mounting design

Our primary transmitter is the Interline HORIZON 900 8V antenna. We'll mount it onto a handle and manually adjust its direction to align with the signal sent from the CanSat. Attaching the Interline HORIZON 900 8V dipole antenna to a PVC pipe via its mounting holes allows for convenient handling and manipulation by the operator. This configuration facilitates easy maneuvering of the antenna during operation. **This is a handheld antenna.**



Interline HORIZON 900 8V

GCS Antenna Trade & Selection (4/4)

Path loss

Predicted distance: $d = 3500m = 3.5\ km$
Center frequency: $f = 915\ MHz$
Center frequency wavelength: $d = 0.327\ = 32.7\ cm$

$$L_{FS}[dB] = 20\log_{10}\left(\frac{4\Pi d}{\lambda}\right) = 20\log_{10}\left(\frac{4\Pi\ \cdot 3500}{0.327\lambda}\right) = 102.7\ [dB]$$

Link Budget

$P_{rx} = ?$
$P_{tx} = 20\ dBm(XBEE)$
$G_{tx} \approx 2\ \mathrm{dBi}$
$P_{rx} = P_{tx} + G_{tx} - L_{fs} - L_{ADD} + G_{rx}$
$G_{rx} = 8\ dBi$
$L_{fx} = 102.8\ dBi$
$P_{rx} = 20 + 2 - 102.7 - 5 + 8 = -77.7\ dBm$
$L_{ADD} = 5\ DBi$

Link Budget (Z)

Receiver sensitivity (min) = -106 dBm @ (10kbps)
$-77.7\ dBm > -106\ dBm$

Receiver satisfies requirements

P_{rx} - Power @ receiver input
P_{tx} - *Transmitter power*
G_{tx} - Gain of transmit antenna
G_{rx} - Gain of receiver antenna
L_{fs} - Free space loses
L_{ADD} - Additional loses (cable etc.)

GCS Software (1/2)

- **Software packages**

The GCS software will be built based on the QT framework and the C++ standard library. QT will be used for the frontend in order to achieve **real-time plotting**. The QT backend will process data received on the serial port from the XBee radio.

- **Telemetry**

Telemetry will be live plotted during flight. **All data will be displayed using engineering units.** The units will be indicated on the displays. After the flight, **telemetry data from all sensors will be saved to a Flight_2044.csv.** In the end, CSV files are going to be handed over to judges on USB stick. All plots will be made using **bold colors on white background, text will be black with with size at least 14 points. The program will count received packets** independently from packet counter value of the received packets.

- **Simulation mode description**

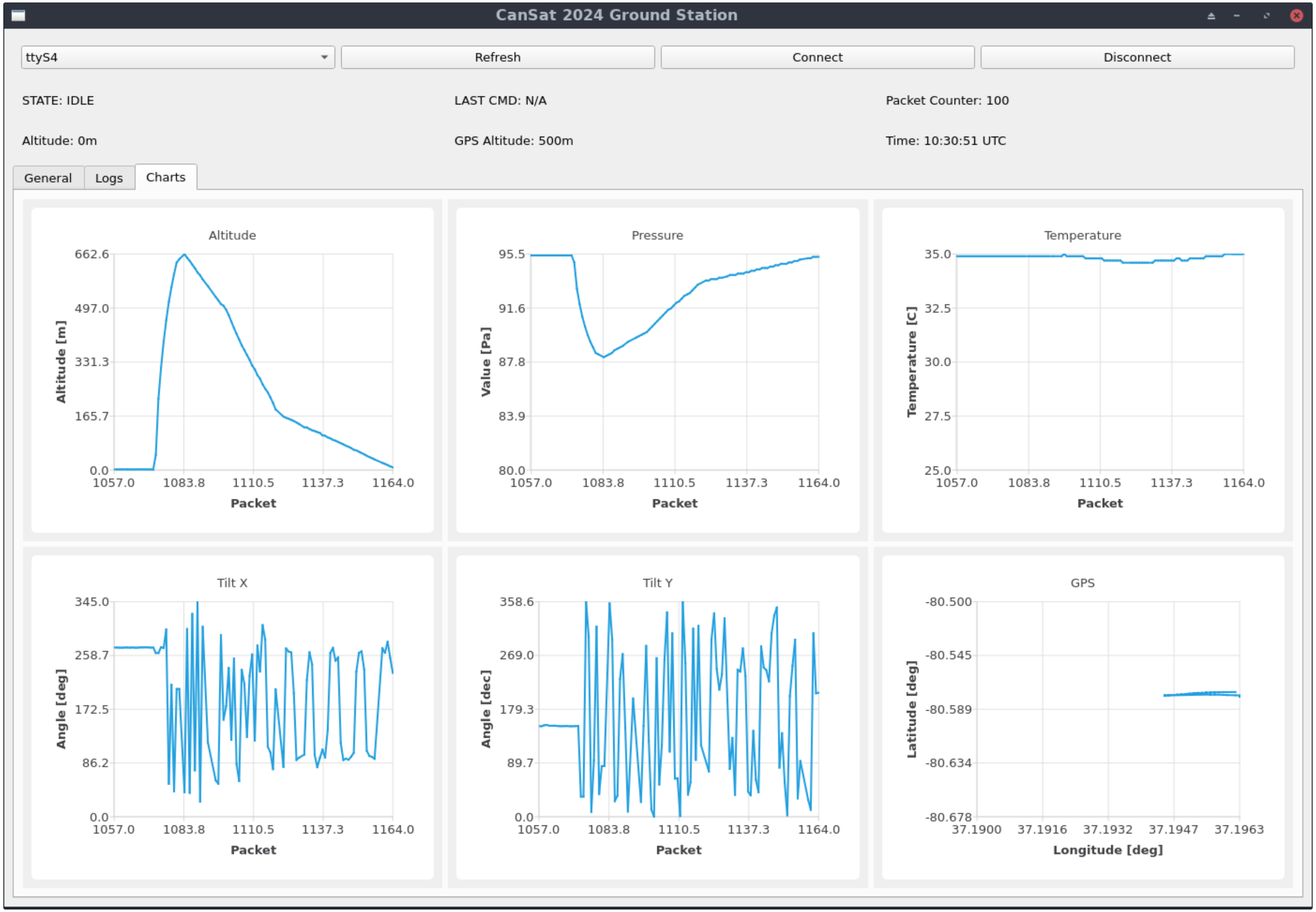
The Ground Station operator can enable the simulation mode by sending two commands: **SIMULATION ENABLE and SIMULATION ACTIVATE.** A file with simulation data will be loaded. After broadcasting a packet that enables simulation mode, the operator will send an activation command, after which the Ground **Station will start sending successive values from the CSV file at a frequency of 1 Hz as SIMP command.**

- **Commands**

The Ground Station operator **can send a calibration command** for the launchpad altitude calibration and the tilt sensor. Calibration command will be transmitted by using XBEE radio link.

The results of calibration can be verified it in the GCS interface in the field “last command received”. Verification before launch: altitude shown as 0, tilt shown as 0 and should be steady.

GCS Software (2/2)



CanSat Integration and Test

Jakub Kaszowski

CanSat Integration and Test Overview

Our CanSat will be tested by four level testing		
Subsystem level	All the subsystems will be tested separately	Sensors, CDH, EPS, Radio Communications, FSW, Mechanical, Descent Control
Integrated level	Subsystems will be integrated and tested together	Descent Testing, Communications, Mechanisms, Deployment
Simulation level	Integrated subsystems will be tested in simulation mode to test flight level software logic	Flight Software Logic
Environment level	Whole device will be subjected to extreme conditions and final mechanical checks will be performed.	Drop test, Thermal test, Vibration test, Fit Check, Vacuum test

Subsystem level → Integrated level → Simulation level → Environmental level

1. Firstly, the payload, container body and mechanism will be built and initially tested. Independently, the electronics circuits will be soldered, programmed and debugged.
2. When all of the components are working properly, they will be put together and tested as a whole device to ensure that all mechanism and electronics work together properly.
3. Once the integration test are complete, we will use simulation mode to ensure that all algorithms are implemented properly.
4. Finally, the environmental tests will be conducted to make sure that our CanSat can work within specified environment.

Subsystem Level Testing Plan (1/4)

Subsystem	Test case	Acceptance criteria	Test result
FSW	Microcontroller is correctly initialized	Debugger is connecting	To be tested
	Debug logs can be sent via serial interface	Serial interface transmits data	TBT
	After initialization FSM jumps to state selector	Debug log indicates FSM entered state selector	TBT
	FSW can progress through mission states	Each state sends signed debug log	TBT
	FSW Can survive power cuts	FSM starts with last state, sensor calibration data is remembered, date and time is correct	TBT
Mechanical	Payload must maintain its structural integrity after experiencing shock and vibrations	No cracks or loose bolts must be detected after a shock test, vibration test and simulated landing	TBT
	The heatshield opens immediately after the payload is released	The heatshield spokes move freely	TBT
	The mechanism detaches the heatshield assembly	The heatshield assembly detaches easily after the mechanism is activated	TBT
	Stable descent on heatshield is maintained	The main camera faces in one direction for the whole descent	TBT
	The pitot tube is not destroyed upon landing	The pitot tube must be operational after a simulated landing	TBT
	The Egg Compartment can protect the hen's egg from impact	The egg isn't cracked after a simulated landing	TBT
	Payload parachute opens after heatshield assembly detachement	Heatshield is detached, parachute cords are not tangled	TBT
	Main electronics board is isolated from vibrations	Electronics does not reset, all communications interfaces are working	TBT

Subsystem Level Testing Plan (2/4)

Subsystem	Test case	Acceptance criteria	Test result
Sensors	Sensors and devices are initialized, communication is possible	Correct sensor/device data can be read via debug logs	To be tested
	Altitude can be properly calculated	Altitude calculated from test values corresponds to expected altitude	TBT
	Temperature measuring	Temperature is correctly measured	TBT
	Pressure measuring	Pressure is correctly measured	TBT
	Voltage measuring	Voltage is correctly measured	TBT
	GPS data is available	GPS data can be read by FSW	TBT
	GPS NMEA frame is correctly decoded	GPS time, latitude, longitude, altitude and sats are available	TBT
	Sensors can be calibrated and return zero values when stationary on ground	Values read from sensors are zeroed	TBT
CDH	File System is properly initialized on SD Card	File system initialization success, SD card can be read by a windows laptop	TBT
	SD Card is ready for writing data	File system returns success when saving files	TBT
	SD Card is accessible, data can be read	File system allows fore reading files, data in files are correct	TBT
	Data saved on SD Card survives resets and power downs	Files are consistently available	TBT
	Real-Time Clock measures time	Times of CanSat and GS are in-sync during the tests	TBT

Subsystem Level Testing Plan (3/4)

Subsystem	Test case	Acceptance criteria	Test result
EPS	Pressure sensor is powered	Proper voltage on necessary pins is measured	TBT
	Temperature sensor is powered	Proper voltage on necessary pins is measured	TBT
	GPS sensor is powered	Proper voltage on necessary pins is measured	TBT
	Voltage sensor is powered	Proper voltage on necessary pins is measured	TBT
	Camera is powered	Proper voltage on necessary pins is measured	TBT
	Processor is powered	Proper voltage on necessary pins is measured	TBT
	microSD card is powered	Proper voltage on necessary pins is measured	TBT
	PCB doesn't have shortcuts	PCB has no shorts to ground or power lines	TBT
	PCB is properly soldered	Joints are properly soldered, there are no cold joints	TBT
	Battery withstands high current	Battery works correctly under high current	TBT
	CanSat can operate for two hours	CanSat does not turn off when left in IDLE state for two hours	TBT
	Voltage regulators and DC converters work properly	Proper voltage on all power lines under load	TBT
	IMU is powered	Proper readings from the sensor given the positioning	TBT
	XBee is powered	Proper voltage on necessary pins is measured	TBT

Subsystem Level Testing Plan (4/4)

Subsystem	Test case	Acceptance criteria	Test result
Descent control	FSW can control deployment mechanisms	FSW can control parachute and heatshield	TBT
	State machine detects change in flight phases	State is changed when appropriate conditions are met	TBT
	Aerobraking surface maintain correct descent velocity	CanSat descents at rate between 10 to 30 m/s	TBT
	Parachute flight maintain correct descent velocity	CanSat descents at less than 5 m/s	TBT
Radio communication	XBee Radio can receive data	Data sent to XBee can be read via debug logs	TBT
	XBee Radio can transmit data	Data sent from FSW can be read on PC with XBee	TBT
	XBee radios NETID/PANID is set to their team number	NETID/PANID is set to 2044	TBT
	Open air radio range testing	Radio range is sufficient for double of the planned flight altitude	TBT
	Ground level radio range testing	Radio range is sufficient for the flight altitude	TBT
	GCS can connect with the CanSat	The connection is reached and stable	TBT
	GCS can transmit and receive data	Data is successfully transmitted and received	TBT
	GCS plotting data	Data is plotted in real time	TBT

Integrated Level Functional Test Plan

System	Test overview
Descent testing	The CanSat will be lifted using an airplane and then released. The stability of flight will be checked. Both cameras stability will be verified. Descent rate of the probe with heatshield open shall be between 10 to 30 m/s. The descent rate after releasing the parachute at 100m shall be less than 5 m/s.
Communications	We will conduct field tests to check the range of radio communication and bandwidth. The range will be checked on a football field by increasing distance between probe and ground station.
Mechanisms	Tests of Mechanical and Descent Control Subsystem, such as release mechanism of heat shield and parachute, and drop test will be performed with the CanSat at Integrated Level.
Deployment	To make sure that each deployment subsystem works according to our assumptions, the Payload drop test will be performed. Additionally, stationary tests of parachutes opening and heatshield release will be done.

Environmental Test Plan

Test	Test overview
Drop test	The CanSat parachute mounting will be mounted to a non-stretching cord and then dropped, letting the probe free fall from altitude of 61 cm to simulate 30 Gs shock. After the test, the mechanical and electronic systems will be checked. During the test the communications will be maintained. All of them shall survive and work properly, data packets should not be lost.
Thermal test	As a thermal chamber, an oven will be used. It will be heated to 60°C. Once hot, the CanSat will be placed inside for 2 hours. During the whole test telemetry shall be received constantly to verify if all systems work in required temperature range.
Vibration test	The CanSat will be attached to an orbit sander. Vibrations (up to 233 Hz) must not affect the operation of all systems and all mechanical components must avoid damage. The accelerometer data shall be collected throughout the test.
Fit Check	A shoulder of 136 mm diameter x 50 mm length will be built. The test will verify, if the CanSat fits inside and can be easily deployed during the flight (it must not get stuck).
Vacuum test	The CanSat will be placed in a hermetic chamber connected to a vacuum cleaner. The pressure value will decrease and the altitude value will increase. The test will show how the altitude value change when the pressure value changes.

Simulation Test Plan

Simulation mode is used mostly for testing the Flight Software. It helps testing general logic and corner cases.

In this mode, the probe swaps actual readings of **pressure sensor** for those received from ground station.

It doesn’t affect other sensors readings - the values, other than the pressure and altitude will be actual sensor readings.

Simulation sequence:

- Ground Station sends a sequence of two commands (SIM ENABLE and SIM ACTIVATE)
- FSW enters simulation mode
- GS sends air pressure values at a one second interval as barometric pressure sensor commands, using a provided CSV file
- FSW uses received values instead of real data from pressure sensor
- To disable simulation mode, GS sends SIM DISABLE
- FSW goes back to normal mode

Mission Operations & Analysis

Jakub Kaszowski

Overview of Mission Sequence of Events (1/3)

Our team acquired experience thanks to participation in the previous competition editions. For this reason, we expanded our team with new members to share our knowledge and make the design better.

Role	Person
Mission Control Officer (MCO)	Jakub Kaszowski
Ground Station Crew (G)	Julia Szymańska, Tymoteusz Puślecki, Filip Zioło
Recovery Crew (R)	Maciek Sikorski, Ula Wiśniewska
CanSat Crew (C)	Paweł Rak, Szymon Jutrzenka, Maksymilian Tara, Hubert Kulik

Each role's responsibilities will be attached in the remaining two slides of this section.

Antenna construction and ground system setup

We want to make our design as simple as possible, to mitigate the risk of running out of time to prepare the setup during launch day. The laptop will be properly connected to XBee Radio via dedicated USB adapter and connected to the dipole antenna. CanSat will communicate with ground station via its onboard antenna, connected before probe check-in.

CanSat assembly and test:

MicroSD card will be inserted, electronics will be mounted, parachute will be attached, and heatshield stowed. The final communication tests will be performed right before check-in.

Overview of Mission Sequence of Events (2/3)

Arrival

- Arriving at launch site (whole team)
- Check for any damages that could appear during the travel (C)

Setting up Ground Station

- Ground control station assembly (G)
- Antenna assembly (G)

Preparations

- Battery charge control (C)
- CanSat assembly and test (C)
- CanSat communication and sensors test (C/G)
- Mounting heatshield (C)
- Weight and size final check (MCO/C)
- Turning in the CanSat for inspection (MCO/C)

Pre-launch

- Moving GCS to dedicated position (G)
- Mounting CanSat in the rocket (MCO/G)
- Communication check (G)
- Sensors calibration (G)
- Safety check (whole team)

Overview of Mission Sequence of Events (3/3)

Launch → **Recovery** → **Post-launch**

Launch

- Executing launch procedures (MCO/C/G)
- Performing flight operations (G)
- CanSat landing (whole team)
- Delivering USB stick with data to the judge (G)

Recovery

- Heading out to recover the probe (R)
- MicroSD card recovery (R)
- Backing up flight data after probe recovery (G)

Post-launch

- Return to the check-in for final judging (R)
- Clearing Ground Station area (G)
- Data analysis (whole team)

Mission Operations Manual Development Plan (1/1)

Development
The Mission Operations Manual will be developed using our experience from previous years and based on tests that are yet to be carried. The final version of the operations manual will be ready after completion of Critical Design Review. The Mission Operation Manual will be assembled into a three-ring binder and include not only Mission Sequence but team members' roles and safety instructions as well.
Content
Knowing the overview of the Mission Sequence of Events, some of the crucial points of the Mission Operation Manual can be indicated already. The diagram depicting them is presented on the next slide.

Mission Operations Manual Development Plan (2/2)

Configure GS → Prepare probe → Integrate probe into the rocket → Probe recovery

Configuring the Ground Station
Ground Station & antenna assembly, system initialization
Preparing the CanSat
Communication test, sensors test, separation mechanism test, battery check, probe assembly
Integrating the CanSat into the rocket
Stowing the heatshield, folding and securing probe parachute, mounting CanSat inside the rocket, communication check, sensors calibration
CanSat recovery
Backing up data from GS, finding the CanSat, damage check, securing microSD card

CanSat Location and Recovery

Probe Recovery
• Probe's color will be fluorescent orange so that it can be easily detected. • An attached parachute will be in fluorescent orange color. • Landing zone will be determined by observing the descent and GPS location data. • Buzzer (92dB loud) will be activated after touchdown.
Labeling
Payload and container will be labeled with the team email address, contact informations and phone number.

Requirements Compliance

Jakub Kaszowski

Requirements Compliance Overview

Current state of design meets all requirements although some changes may appear before construction in order to improve already working systems.

Tests are planned out and scheduled however the CanSat parts are still being produced. Only electronics elements were tested.

Further test are prepared in order to check if there is anything to improve before final design, even though constructing the probe as it is, should suffice to all the tasks mentioned in Mission Guide.

Following slides provide information about design compliance to requirements based on Mission Guide.

Requirements Compliance (1/13)

Operational Requirements (1/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
C1	The CanSat shall function as a nose cone during the rocket ascent portion of the flight.	Comply	10,17	-
C2	The CanSat shall be deployed from the rocket when the rocket motor ejection charge fires.	Comply	20	-
C3	After deployment from the rocket, the CanSat shall deploy its heat shield/aerobraking mechanism.	Comply	9, 17, 18	-
C4	A silver or gold mylar streamer of 50 mm width and 1.5 meters length shall be connected to the CanSat and released at deployment. This will be used to locate and identify the CanSat.	Comply	17, 19	-
C5	At 100 meters, the CanSat shall deploy a parachute and release the heat shield.	Comply	10, 17	-
C6	Upon landing, the CanSat shall stop transmitting data.	Comply	91	-
C7	Upon landing, the CanSat shall activate an audio beacon.	Comply	91, 19	-
C8	The CanSat shall carry a provided large hen's egg with a mass range of 51 to 65 grams.	Comply	16, 57	-

Requirements Compliance (2/13)

Operational Requirements (2/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
C9	0 altitude reference shall be at the launch pad.	Comply	91, 102	-
C10	During descent with the heat shield deployed, the descent rate shall be between 10 to 30 m/s.	Comply	17, 19, 33, 42	-
C11	At 100 meters, the CanSat shall have a descent rate of less than 5 m/s.	Comply	17, 19, 33, 42	-
C12	Cost of the CanSat shall be under $1000. Ground support and analysis tools are not included in the cost of the CanSat. Equipment from previous years shall be included in this cost, based on current market value.	Comply	139	-

Structural Requirements (1/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
S1	The CanSat mass shall be 900 grams +/- 10 grams without the egg being installed.	Comply	67	-
S2	Nose cone shall be symmetrical along the thrust axis.	Comply	20	-
S3	Nose cone radius shall be exactly 71 mm.	Comply	15, 20	According to appendix F from mission guide, the nosecone diameter shall be 141 mm.
S4	Nose cone shoulder radius shall be exactly 68 mm.	Comply	15, 20	-
S5	Nose cone shoulder length shall be a minimum of 50 mm.	Comply	15, 20	-
S6	CanSat structure must survive 15 Gs vibration.	Comply	45, 47, 111	-

Requirements Compliance (4/13)

Structural Requirements (2/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
S7	CanSat shall survive 30 G shock.	Comply	45, 47, 111	-
S8	The CanSat shall perform the function of the nose cone during rocket ascent.	Comply	10, 17	-
S9	The rocket airframe can be used to restrain any deployable parts of the CanSat but shall allow the CanSat to slide out of the payload section freely.	Comply	49	-
S10	The rocket airframe can be used as part of the CanSat operations.	Comply	49	-
S11	Nose cone shoulder length shall be a minimum of 50 mm.	Comply	20, 15	-
S12	All electronics and mechanical components shall be hard mounted using proper mounts such as standoffs, screws, or high performance adhesives.	Comply	47, 59, 60	-

Requirements Compliance (5/13)

Mechanical Requirements (1/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
M1	No pyrotechnical or chemical actuators are allowed.	Comply	45	-
M2	Mechanisms that use heat (e.g., nichrome wire) shall not be exposed to the outside environment to reduce potential risk of setting the vegetation on fire	Comply	45, 55	-
M3	All mechanisms shall be capable of maintaining their configuration or states under all forces.	Comply	47	-
M4	Spring contacts shall not be used for making electrical connections to batteries. Shock forces can cause momentary disconnects.	Comply	84	-
M5	The CanSat shall deploy a heat shield after deploying from the rocket.	Comply	9, 11 ,17 ,49	-
M6	The heat shield shall be used as an aerobrake and limit the descent rate to 10 to 30 m/s.	Comply	17, 19, 33, 42	-

Mechanical Requirements (2/2)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
M7	At 100 meters, the CanSat shall release a parachute to reduce the descent rate to less than 5 m/s.	Comply	17, 19, 33, 42	-
M8	The CanSat shall protect a hens egg from damage during all portions of the flight.	Comply	16, 57, 58	-
M9	If the nose cone is to be considered as part of the heat shield, the documentation shall identify the configuration.	Not applicable	-	The nosecone is **NOT** a part of the heatshield
M10	After the CanSat has separated from the rocket and if the nose cone portion of the CanSat is to be separated from the rest of the CanSat, the nose cone portion shall descend at less than 10 meters/second using any type of descent control device.	Not applicable	-	The nosecone **DOES NOT** separate from the CanSat

Requirements Compliance (7/13)

Electrical Requirements

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
E1	Lithium polymer batteries are not allowed.	Comply	84	-
E2	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. Coin cells are allowed.	Comply	84	-
E3	Easily accessible power switch is required.	Comply	16, 46, 82	-
E4	Power indicator is required.	Comply	16, 46, 82	-
E5	The CanSat shall operate for a minimum of two hours when integrated into the rocket.	Comply	86	-

Requirements Compliance (8/13)

Communications Requirements

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
X1	XBEE radios shall be used for telemetry. 2.4 GHz Series radios are allowed. 900 MHz XBEE radios are also allowed.	Comply	69, 75	-
X2	XBEE radios shall have their NETID/PANID set to their team number.	Comply	75, 109	-
X3	XBEE radios shall not use broadcast mode.	Comply	75	-
X4	The CanSat shall transmit telemetry once per second.	Comply	77	-
X5	The CanSat telemetry shall include altitude, air pressure, temperature, battery voltage, CanSat tilt angles, air speed, command echo, and GPS coordinates that include latitude, longitude, altitude and number of satellites tracked.	Comply	78	-

Requirements Compliance (9/13)

Sensor Requirements

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
SN1	CanSat shall measure its speed with a pitot tube during ascent and descent.	Comply	26	The idea requires more tests
SN2	CanSat shall measure its altitude using air pressure.	Comply	22, 23	-
SN3	CanSat shall measure its internal temperature.	Comply	24	-
SN4	CanSat shall measure its angle stability with the aerobraking mechanism deployed.	Comply	27	-
SN5	CanSat shall measure its rotation rate during descent.	Comply	28	-
SN6	CanSat shall measure its battery voltage.	Comply	25	-
SN7	The CanSat shall include a video camera pointing horizontally.	Comply	44, 60	-
SN8	The video camera shall record the flight of the CanSat from launch to landing.	Comply	91	-
SN9	The video camera shall record video in color and with a minimum resolution of 640x480.	Comply	30	-

Requirements Compliance (10/13)

Ground Station Requirements (1/3)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
G1	The ground station shall command the CanSat to calibrate the altitude to zero when the CanSat is on the launch pad prior to launch.	Comply	102	-
G2	The ground station shall generate csv files of all sensor data as specified in the Telemetry Requirements section.	Comply	102	-
G3	Telemetry shall include mission time with 1 second or better resolution.	Comply	76	-
G4	Configuration states such as zero altitude calibration shall be maintained in the event of a processor reset during launch and mission.	Comply	92	-
G5	Each team shall develop their own ground station.	Comply	96	-
G6	All telemetry shall be displayed in real time during descent on the ground station.	Comply	102	-
G7	All telemetry shall be displayed in engineering units (meters, meters/sec, Celsius, etc.) and the units shall be indicated on the displays.	Comply	102	-
G8	Teams shall plot each telemetry data field in real time during flight.	Comply	102	-

Requirements Compliance (11/13)

Ground Station Requirements (2/3)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
G9	The ground station shall include one laptop computer with a minimum of two hours of battery operation, XBEE radio and an antenna.	Comply	97	-
G10	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	97	-
G11	The ground station software shall be able to command the payload to operate in simulation mode by sending two commands, SIMULATION ENABLE and SIMULATION ACTIVATE.	Comply	102	-
G12	When in simulation mode, the ground station shall transmit pressure data from a csv file provided by the competition at a 1 Hz interval to the CanSat.	Comply	102	-

Requirements Compliance (12/13)

Ground Station Requirements (3/3)

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
G13	The ground station shall use a table top or handheld antenna.	Comply	100	-
G14	Because the ground station must be viewed in bright sunlight, the displays shall be designed with that in mind, including using larger fonts (14 point minimum), bold plot traces and axes, and a dark text on light background theme.	Comply	102, 97	-
G15	The ground system shall count the number of received packets. Note that this number is not equivalent to the transmitted packet counter, but it is the count of packets successfully received at the ground station for the duration of the flight.	Comply	102	-

Requirements Compliance (13/13)

Flight Software Requirements

Rqmt Num	Requirement	Comply / No Comply / Partial	Slide	Notes
F1	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	76, 78, 92	-
F2	The CanSat shall maintain mission time throughout the whole mission even with processor resets or momentary power loss.	Comply	72, 82 ,91	-
F3	The CanSat shall have its time set to within one second UTC time prior to launch.	Comply	76 ,91	-
F4	The flight software shall support simulated flight mode where the ground station sends air pressure values at a one second interval using a provided flight profile csv file.	Comply	93	-
F5	In simulation mode, the flight software shall use the radio uplink pressure values in place of the pressure sensor for determining the payload altitude.	Comply	93	-
F6	The payload flight software shall only enter simulation mode after it receives the SIMULATION ENABLE and SIMULATION ACTIVATE commands.	Comply	93	-

Management

Jakub Kaszowski

CanSat Budget – Hardware (1/4)

Construction – components and electronics					
Component	**Model/Material**	**Quantity**	**Price per unit [USD]**	**Total [USD]**	**Status**
Structural Ring	PET-G	1	1.44	1.44	Estimated
Aerodynamic Fairings	PET	1	5	5	Estimated
Shoulder	ASA	1	1.51	1.51	Estimated
Nose cone Fairing	Nylon	1	4.78	4.78	Estimated
Pitot tube	PET-G	1	0.04	0.04	Estimated
Pitot mounting struts	steel	2	0.1	0.2	Estimated
Pitot dampening springs	steel	2	0.5	1	Estimated
Detachable Structural Ring	ASA	1	1.41	1.41	Estimated
Camera Glass	Glass	1	0.5	0.5	Estimated
Detach mechanism structure	ASA	1	0.87	0.87	Estimated
Parachute comprtment structure	ASA	1	1.98	1.98	Estimated
Auxiliary Camera Mount	PET-G	1	0.08	0.08	Estimated
Long Brackets	Steel	2	0.2	0.4	Actual
Short Brackets	Steel	4	0.2	0.8	Actual
Parachute mounting U-Bolt	Steel	1	1	1	Estimated

CanSat Budget – Hardware (2/4)

Construction – components and electronics					
Component	**Model/Material**	**Quantity**	**Price per unit [USD]**	**Total [USD]**	**Status**
LED holders	Aluminium	6	0.05	0.3	Estimated
Main Struts	Aluminium	4	2	8	Estimated
Spring Distancer	PET	4	0.05	0.2	Estimated
Dampening spring	Steel	8	0.5	4	Estimated
Egg Box	ASA	1	1.87	1.87	Estimated
Foam insert	Foam	1	1	1	Estimated
Egg Box dooor	ASA	1	0.32	0.32	Estimated
PCB Holder	ASA	2	0.12	0.24	Estimated
Camera Gimball	PET-G	1	0.32	0.32	Estimated
50mm x 2m mylar streamer	PP	2	1	2	Actual
Heatshield material	silicone coated ripstop	1	6	6	Actual
Parachute material	silicone coated ripstop	1	10	10	Actual
Nylon thread	Nylon	4m	0.3	1.2	Estimated
M3 x 5.5 mm Brass inserts	Brass	16	0.1	1.6	Estimated
M3 x 8 mm screw	Steel	24	0.1	2.4	Estimated

CanSat Budget – Hardware (3/4)

Construction – components and electronics					
Component	**Model/Material**	**Quantity**	**Price per unit [USD]**	**Total [USD]**	**Status**
M3 | 5.5 | 2.4 | ISO Nuts	Steel	32	0.05	1.6	Estimated
Board	-	1	2	2	Actual
Intergrated circuits	-	1	24	24	Actual
Passive components	-	-	4	4	Actual
Connectors	-	4	6	24	Estimated
XBee 900MHz	XBP9B-XCST-001	1	54	54	Actual
BLDC	PM3505	1	50	50	Estimated
Camera	OV2640	1	2	2	Estimated
Controller	AI-Thinker	1	3	3	Estimated
Battery	Li-ion 14500	1	7.5	7.5	Actual
Camera	OV2640	1	2	2	Estimated
Controller	AI-Thinker	1	3	3	Estimated
GPS	MTK3339	1	5	5	Actual
Battery	Li-ion 18650	1	7.5	7.5	Actual
Pitot’s tube sensor	ABPDJJT001PDSA3	1	12	12	Actual

CanSat Budget – Hardware (4/4)

Construction – components and electronics					
Component	**Model/Material**	**Quantity**	**Price per unit [USD]**	**Total [USD]**	**Status**
Speaker	57CS50G-75ND	1	3	3	Actual
Electromagnets	JF-0530B	2	5	10	Estimated
LED Stripe	-	0.4	1.5	0.6	Estimated
Battery holder	-	1	1	1	Actual

Total cost [USD]
274.89

The maximum cost of a CanSat is specified as $1000. The cost of our CanSat is well within this limit with plenty of room to spare.

We reuse a BLDC PM3505 motor as it is the best choice for our application and it is hard to get. Our motor, although used, is in an excellent condition The price given in the budget is a price we found for this motor on e-commerce sites.

Prices were converted from Polish złoty to US dollars using current exchange rate, which was USD/PLN = 3.97 at the time.

CanSat Budget – Other Costs

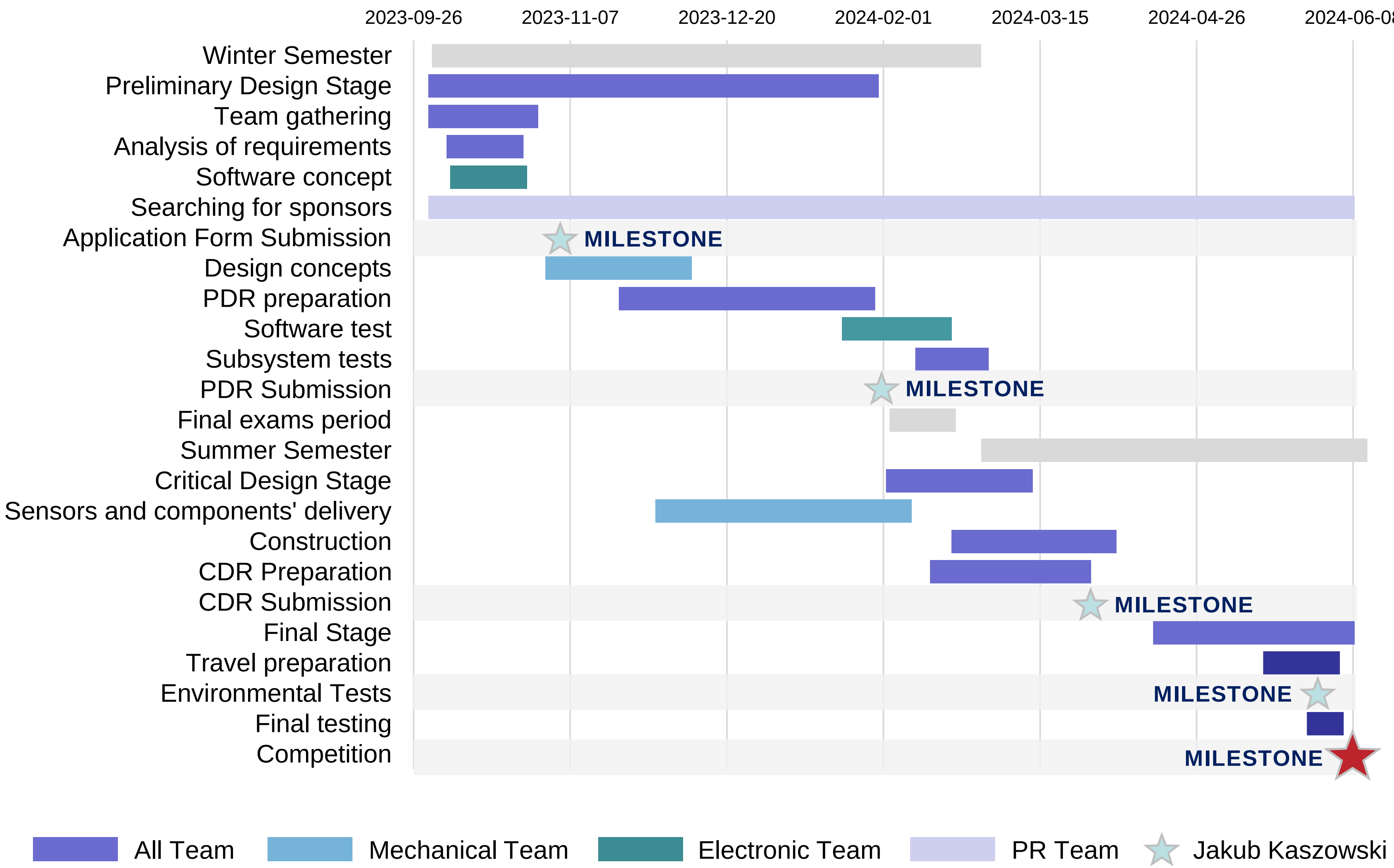
Attending cost	Quantity	Price [PLN/USD]	Total [PLN/USD]
Travel	10	3 970/1 000	39 700/10 000
Accomodation	10	4 049/1 020	40 490/10 200
T-shirts	10	59/15	590/150
Registration	1	794/200	794/200
Car rent + fuel	2	6 850/1 725	13 700/3 550
Total cost			95 274/24 100

Overall mission cost [USD]	24 100

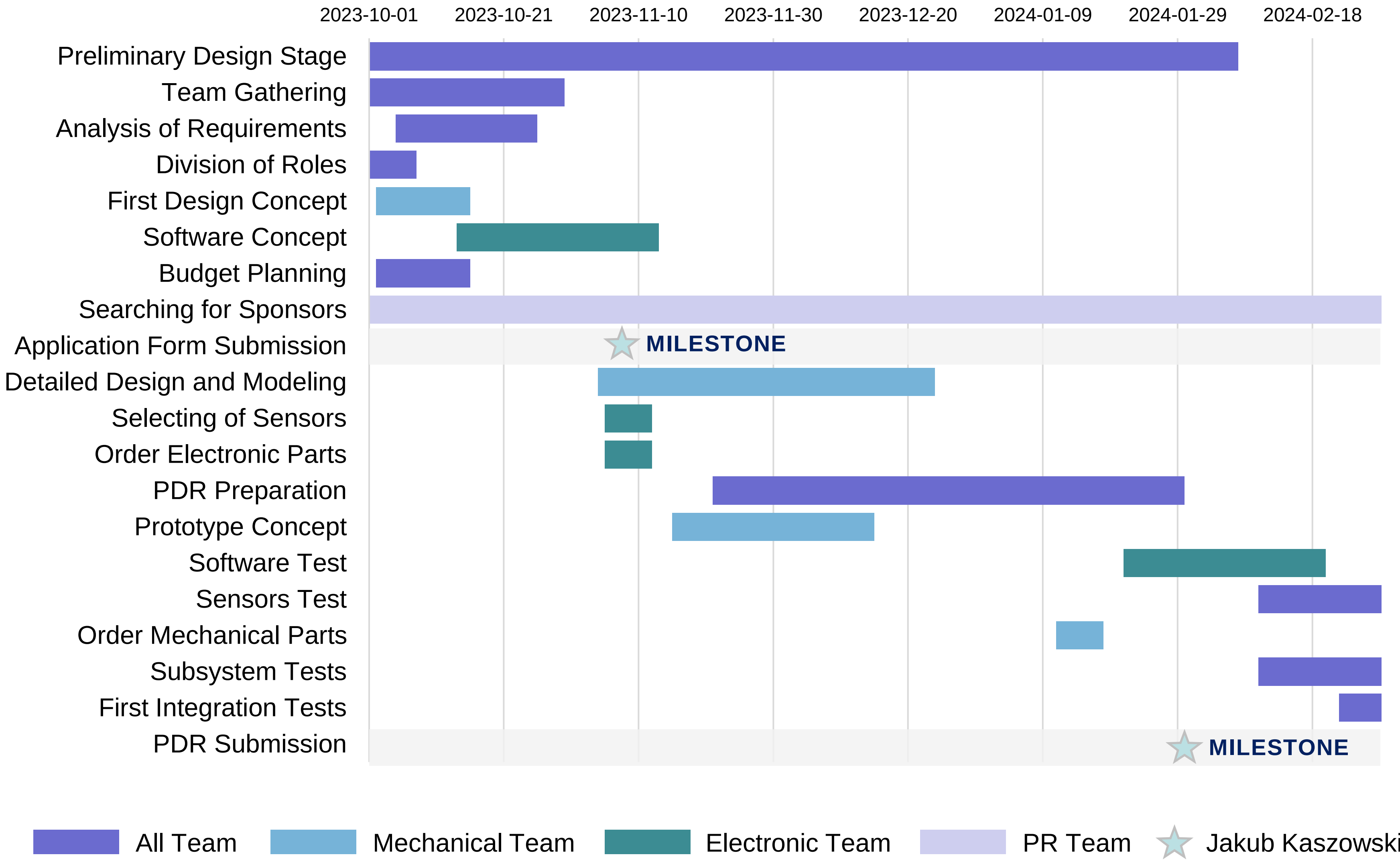
Sources of income [PLN/USD]	
University	100 000/25 189

However, all prices are estimates and are subject to change. We are still talking to sponsors.

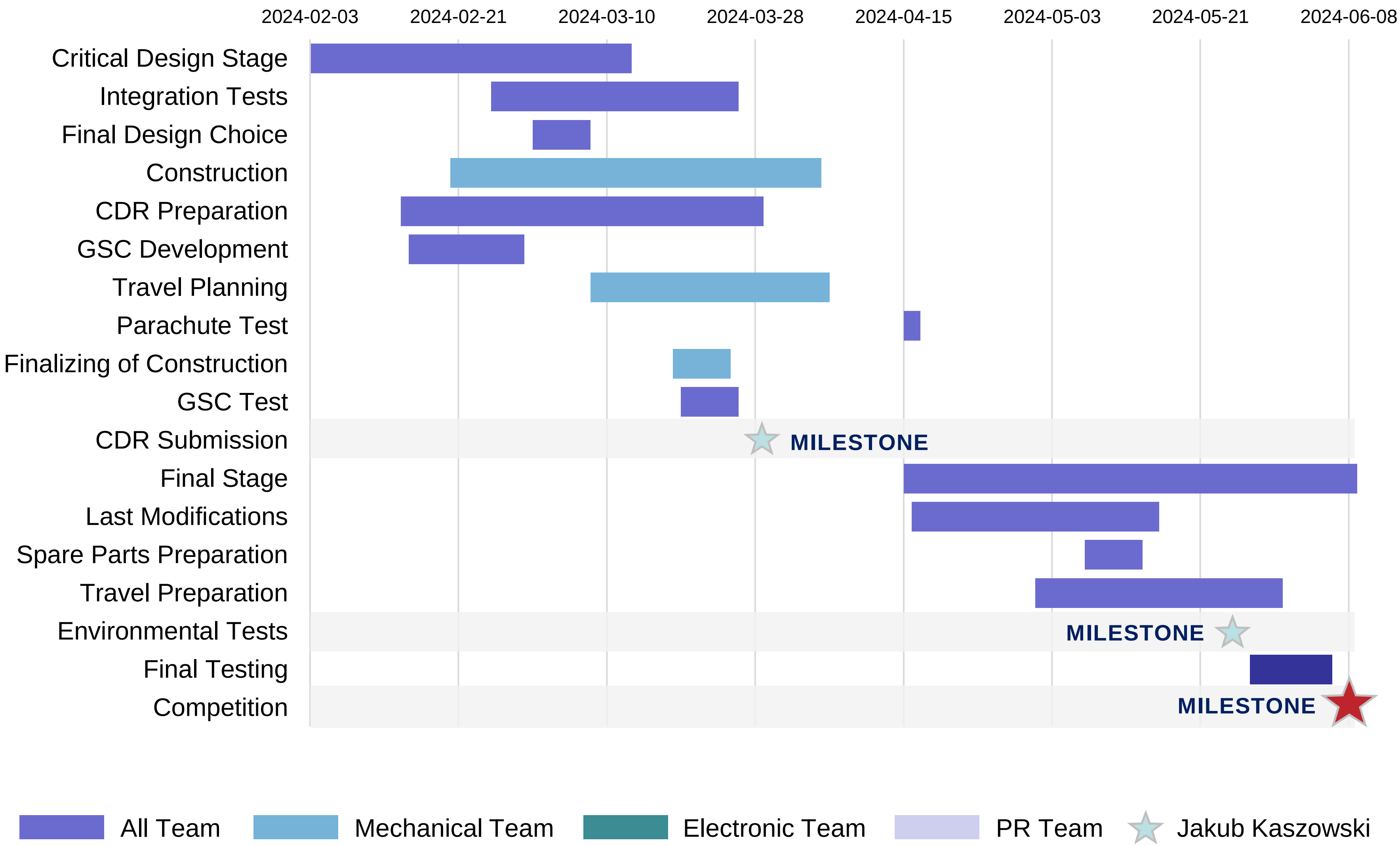
Program Schedule Overview



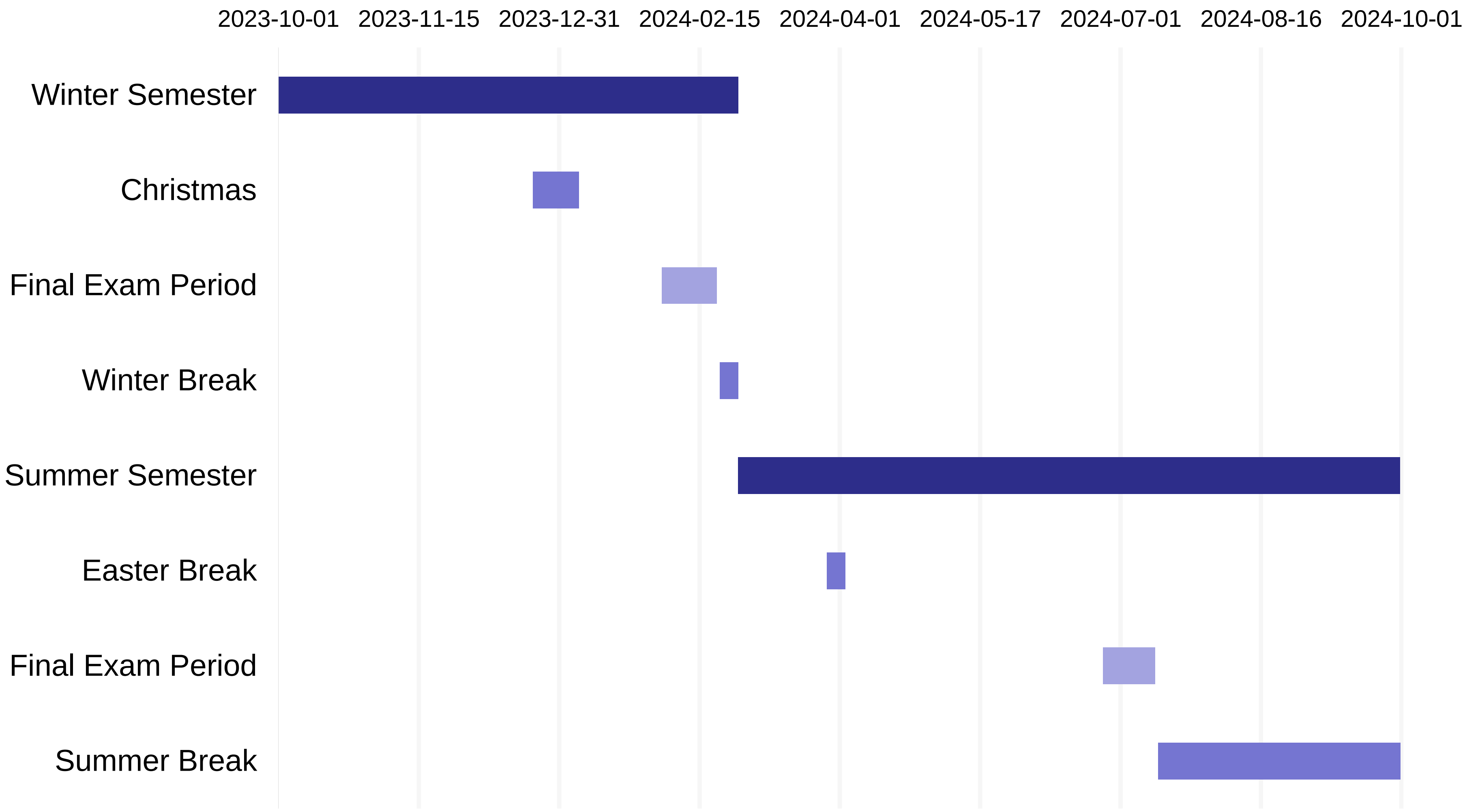
Detailed Program Schedule (1/3)



Detailed Program Schedule (2/3)



Detailed Program Schedule (3/3)



Conclusions

Accomplishments

- Mechanical and electronic systems have been designed.
- Teamwork has been organized and conducted following the principles of agile methodologies, including weekly online meetings.
- A team of competent people was formed. Tasks and responsibilities were assigned.
- Mechanical construction was designed, a prototype of flight computer is working.

Unfinished work

- All mechanical systems need to be assembled and tested, after then all changes which will come up, have to be implemented in the existing design.
- Funding is yet to be obtained.
- The development and testing stages will be carefully planned in detail.

Readiness for the Critical Design Stage

- Interviews with sponsors are underway. The application for funding from university is in progress.
- The software under development will be finalized and tested on a specially constructed electronic system.
- The majority of electronic and mechanical components that are yet to be obtained are either scheduled for delivery or the necessary funds for them have been secured.