Tufts CubeSat

Critical Design Review

SpacePort America Payload

Outline

- CubeSAT Overview
- Structures
- Power
- Flight Software
- Thermal
- Integration and Testing
- Weather and Altitude Sensing
- ADCS and SRAD Reaction Wheels

CubeSAT Team

Design Overview

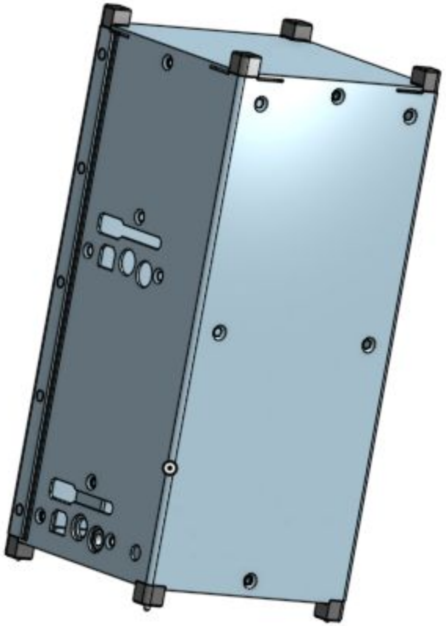
Section Requirements:

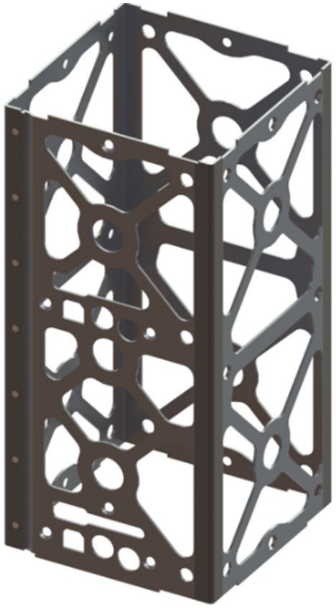
- Carry a 2U (10cmx10cmx20cm) CubeSat to a LEO orbit
- Deploy CubeSat in LEO detecting and classifying space debris using CV

The rocket keeps the satellite insulated during take-off and the interface includes the deployer, adapter, dispenser, and launcher. The purpose of this hardware is to eject the spacecraft safely into orbit.

STRUCTURES

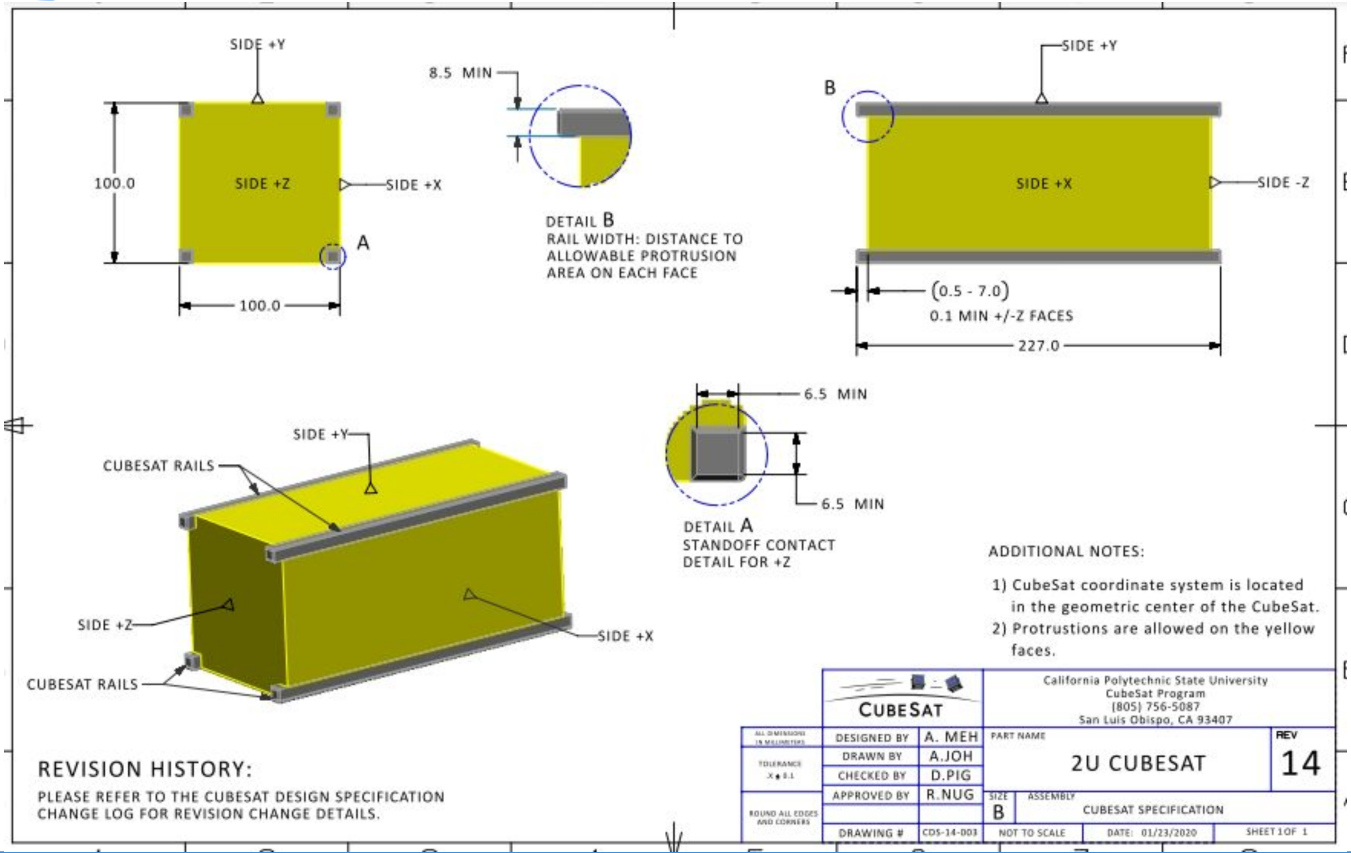
CAD/Schematics





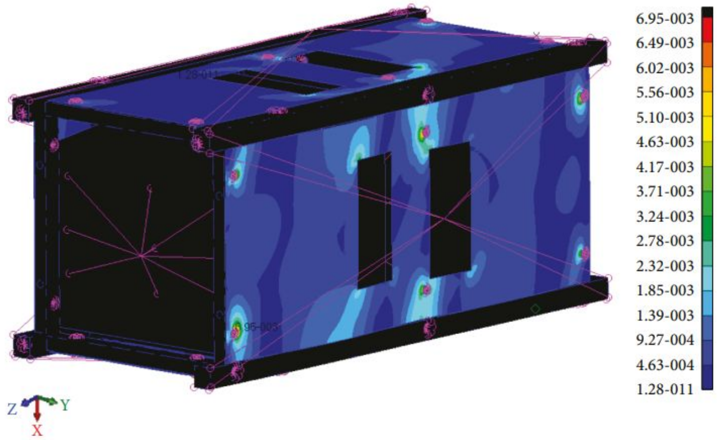
Most of the chassis is machined from aluminum alloy 6061 and is designed with several mounting locations for components to allow flexibility in spacecraft configuration.

Design Specifications



Analysis

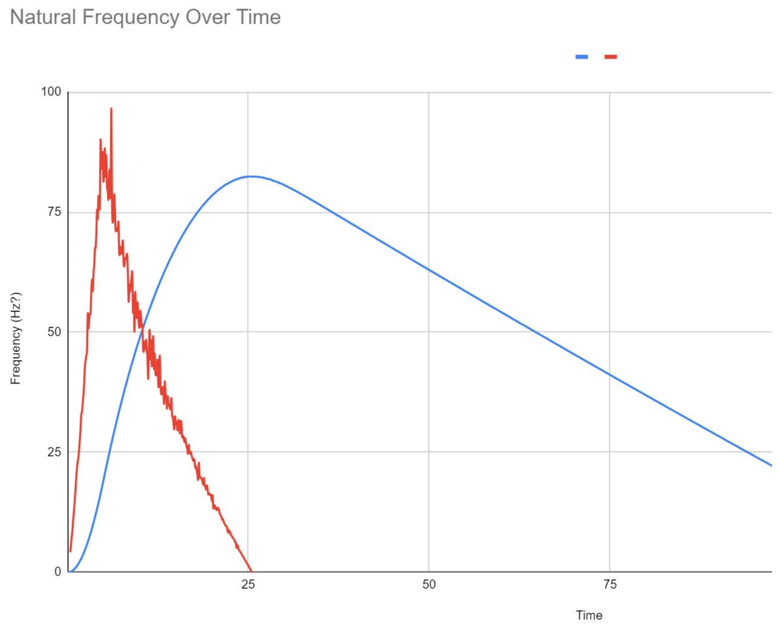
Simplified version of the satellite architecture is analyzed.



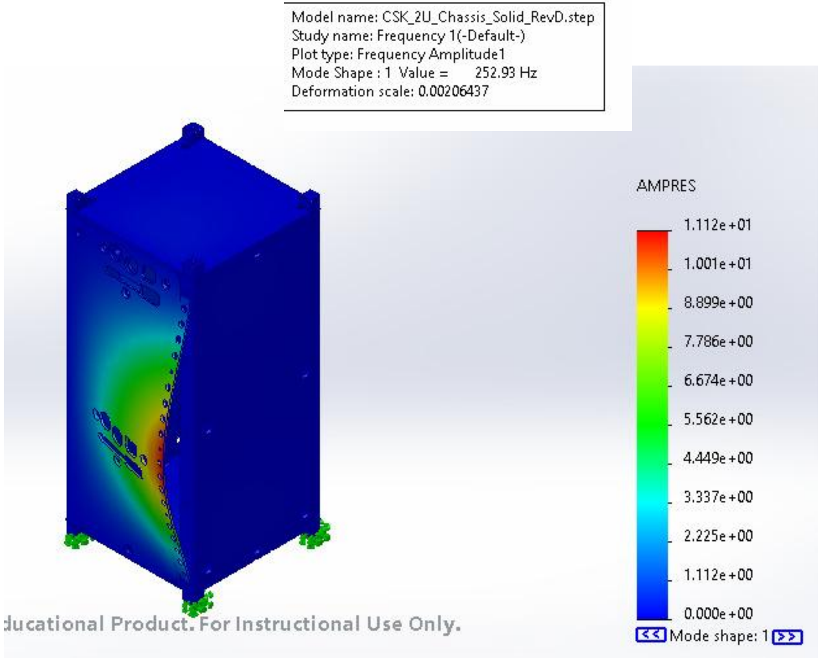
FEA, frequencies and modes analysis to avoid violent structural resonance, stress and displacement distributions analysis, radiation flux, and random vibration testing are proposed to be completed by launch on actual design.

Modal Analysis

Rocket Frequencies over time



First resonance frequency of CubeSat



Manufacturing Plan

- Currently manufacturing first prototype using water jet and mill. Testing other simple metal working techniques for first prototype.
- Chassis panels will be made using waterjet on Al 6061 sheet, rails and plates will be done using mill.
- Anodization of outer architecture is required.
- Rocket Integration structure will be 3D printed

- Reaction wheels will be constructed using mill and lathe.

Testing plan (CubeSat Integrity)

Vibration: whitstand General Environmental Verification Standard (GEVS) vibration environment of approximately 10 Grms over a 2-minute period.

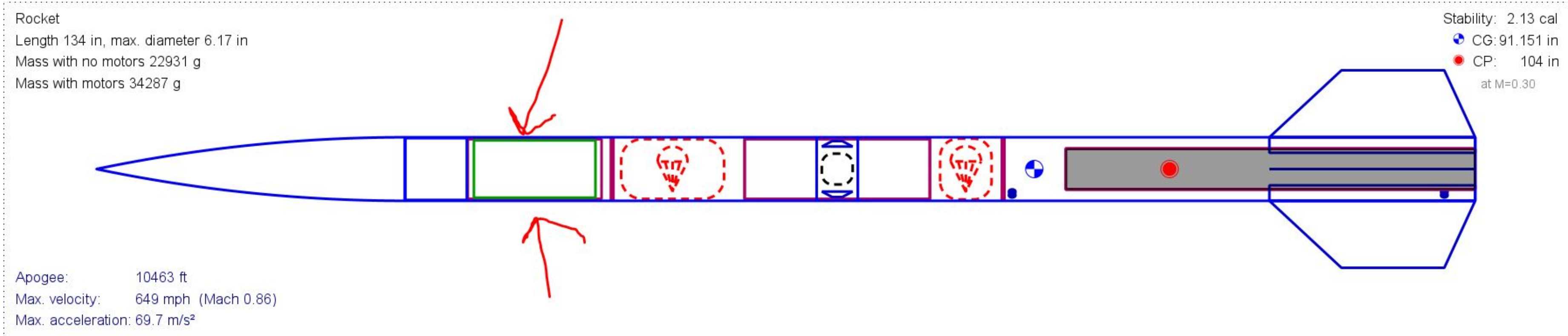
Radiation: shielding involves two basic methods: shielding with the spacecraft’s pre-existing mass, and spot/sector shielding. The classic method employed here is to increase the spacecraft’s structural skin thickness to account for the additional shielding required.

Thermal: In addition to passive thermal control technology, structural and electrical design methods also contribute to managing the thermal environment, passively.

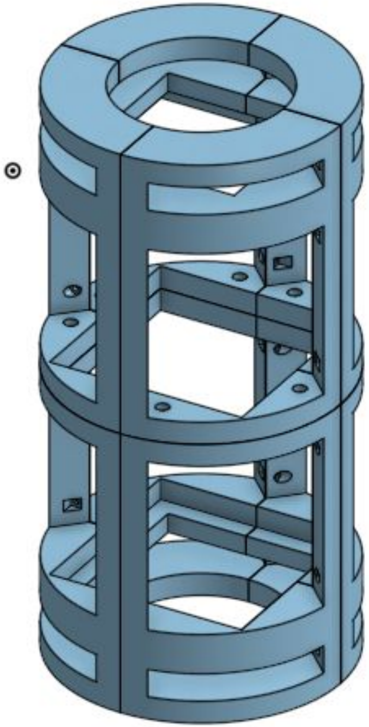
INTEGRATION and TESTING

Integration/Assembly Order

We will most likely be one of the last sections assembled into the rocket because of the control required on the CubeSAT.



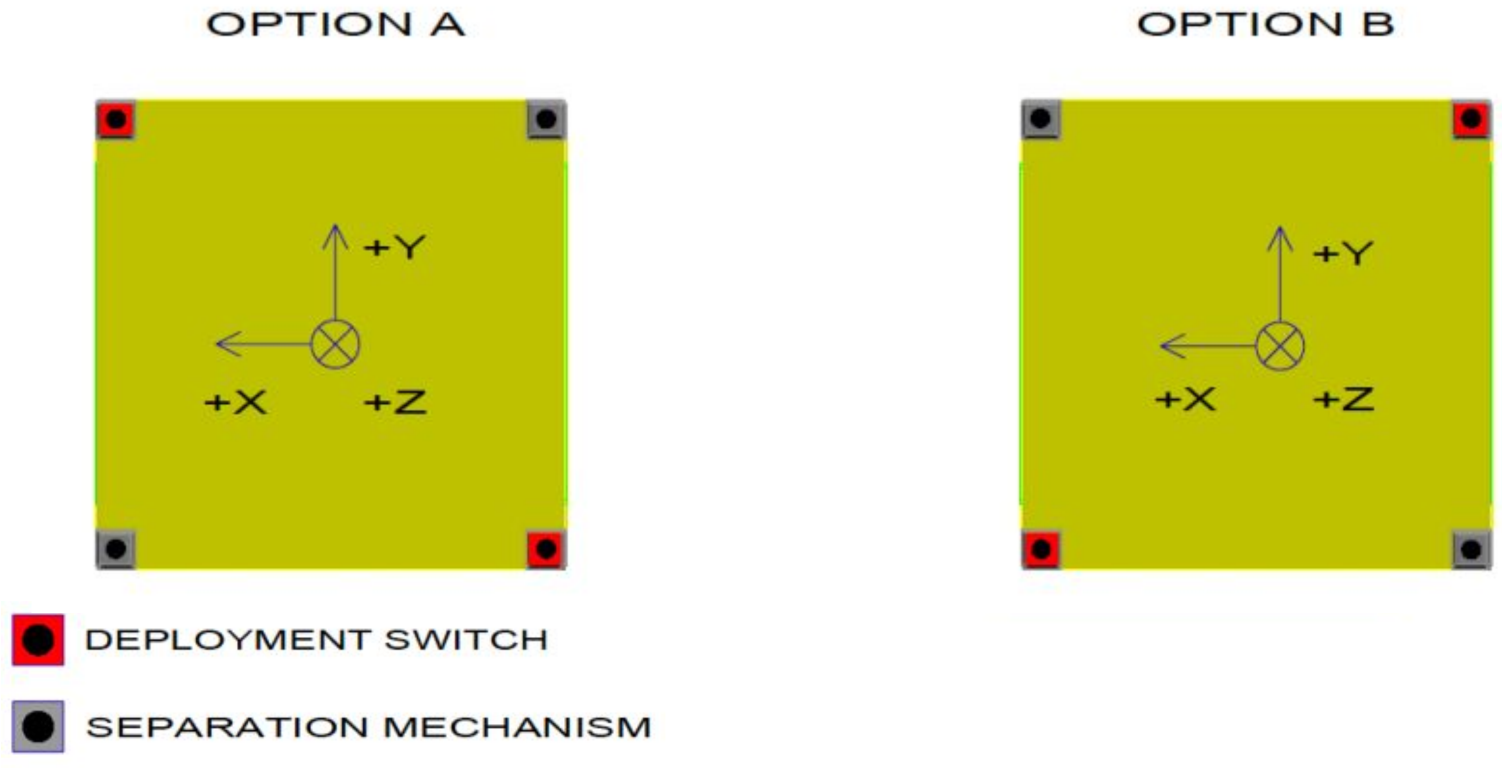
Rocket Integration



Assembly of 8 modular pieces.

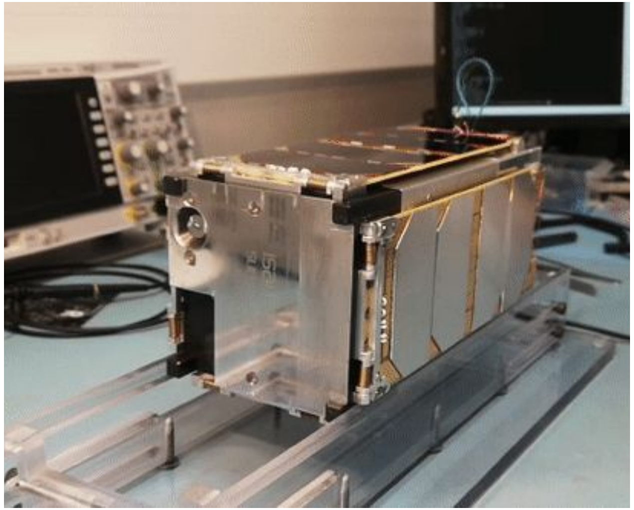
- 4-40 bolts and square nuts epoxied to square cavities for secure fastening.
- Compacted in the rocket body (minimal mission impact if loose bolts)

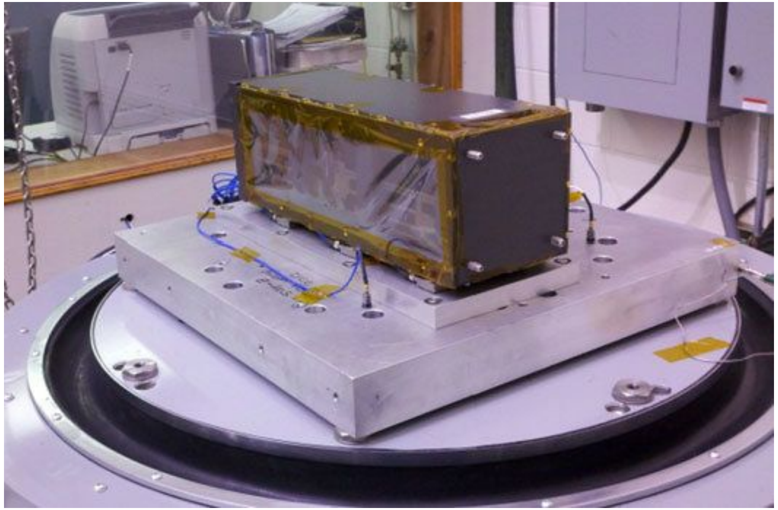
Deployment and separation mechan.



Testing (Systems Integration)

Impact test, battery life, deploy test, power systems and communications testing.





POWER

The PI has a maxim total USB peripheral current draw of 1.2 A. This means 6 W needed at 5V.

Product	Recommended PSU current capacity	Maximum total USB peripheral current draw
Raspberry Pi 1 Model A	700mA	500mA
Raspberry Pi 1 Model B	1.2A	500mA
Raspberry Pi 1 Model A+	700mA	500mA
Raspberry Pi 1 Model B+	1.8A	1.2A
Raspberry Pi 2 Model B	1.8A	1.2A
Raspberry Pi 3 Model B	2.5A	1.2A
Raspberry Pi 3 Model A+	2.5A	Limited by PSU, board, and connector ratings only.
Raspberry Pi 3 Model B+	2.5A	1.2A
Raspberry Pi 4 Model B	3.0A	1.2A
Raspberry Pi 400	3.0A	1.2A
Raspberry Pi Zero	1.2A	Limited by PSU, board, and connector ratings only
Raspberry Pi Zero W	1.2A	Limited by PSU, board, and connector ratings only.
Raspberry Pi Zero 2 W	2A	Limited by PSU, board, and connector ratings only.

https://www.raspberrypi.com/documentation/computers/raspberry-pi.html

The Inertial Measurement Unit (IMU)

Since it is running in Normal mode that will draw 4.3 mA.
At 3.3 V.
So 14.19 mW of power needed.

Table 10. Operating mode current consumption

ODR [Hz]	Power mode	Current consumption(1) [mA]
14.9	Low-power	1.9
59.5	Low-power	2.4
119	Low-power	3.1
238	Normal mode	4.3
476	Normal mode	4.3
952	Normal mode	4.3

1. Typical values of gyroscope and accelerometer current consumption are based on characterization data.

https://cdn-learn.adafruit.com/assets/assets/000/038/883/original/LSM9DS1.pdf?148599936

Battery for PI and sensors

PI SugarPlus

5V. 5000 mAh.

https://cdn.sparkfun.com/assets/1/1/f/3/b/Sensirion_Humidity_Sensors_SHTC3_Datasheet.pdf

Weather sensors

[4258 | Digi-Key Electronics]

Symbol	Parameter	Test condition	Min.	Typ. b	Max.	Unit
VDD	Supply voltage		1.7		3.6	V
Vdd_IO	IO supply voltage		1.7		Vdd+0.1	V
Idd	Supply current	@ODR 1 Hz LC_EN bit =0		15		µA
		@ODR 1 Hz LC_EN bit =1		3		µA

Will use 3.3 V, from pi. So it will take 0.0000495 W.

SparkFun Humidity Sensor Breakout - SHTC3 (Qwiic)

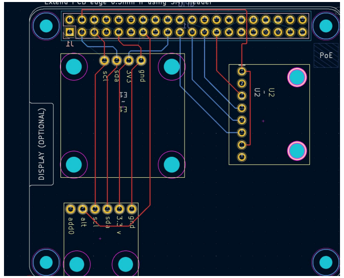
Parameter	Symbol	Conditions		Min	Typ.	Max	Units	Comments
Supply voltage	V_{DD}			1.62	3.3	3.6	V	-
Power-up/down level	V_{POR}	Static power supply		1.28	1.4	1.55	V	-
Supply current	I_{DD}	Idle state		-	45	70	µA	After power-up the sensor remains in the idle state unless a sleep command is issued or other data transmission is active
		Sleep Mode		-	0.3	0.6	µA	When in sleep mode, the sensor requires a dedicated wake-up command to enable further I²C communication
		Measurement	Normal Mode	-	430	900	µA	Average current consumption while the sensor is measuring
			Low Power M.	-	270	570	µA	
		Average	Normal Mode	-	4.9	-	µA	Average current consumption (continuous operation with one measurement per second)
			Low Power M.	-	0.5	-	µA	Average current consumption (continuous operation with one measurement per second)
Low level input voltage	V_{IL}	-		-	-	0.42 V_{DD}	V	-
High level input voltage	V_{IH}	-		0.7 V_{DD}	-	-	V	-
Low level output voltage	V_{OL}	3 mA sink current		-	-	0.2 V_{DD}	V	-

While measuring Will take a max of 900 uA. And runs at 3.3 V So 0.00297 W consumed

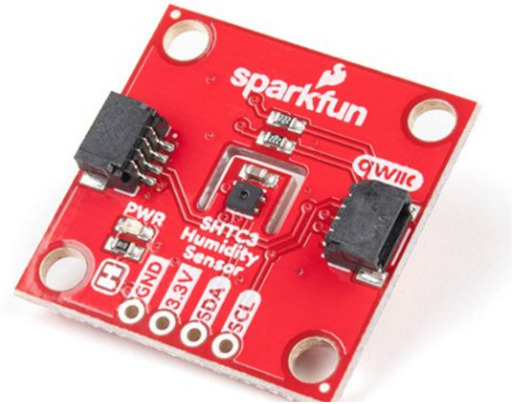
NImH batteries for the motors:
12 V-2000 mAh

WEATHER and ALTITUDE SENSING

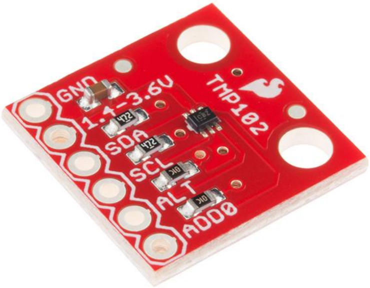
Array of Sensors



Atmospheric pressure for Pi



Humidity sensor



Temp Sensor

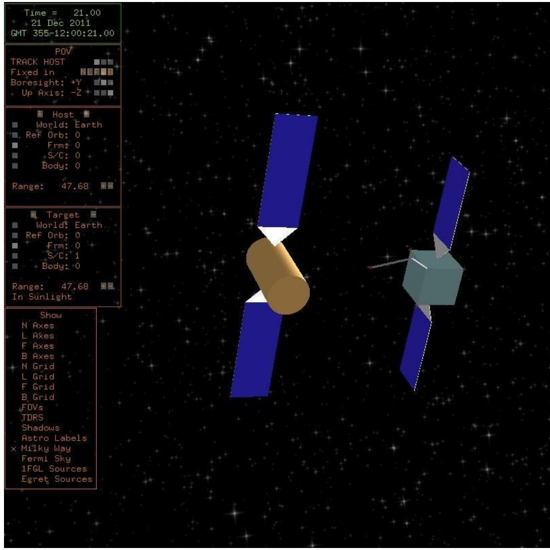
FLIGHT SOFTWARE

General Flight Software

- OBC is used to monitor overall health of satellite
  - EPS
  - ADCS
  - Telecommunications
  - Payload
- Software reusability is paramount
- "Development of a flight software framework for student CubeSat missions"
  - Compares NASA Core Flight System (cFS), KubOS, and CubedOS
- (1) Design and Implementation of Generic Flight Software for a CubeSat (psu.edu)

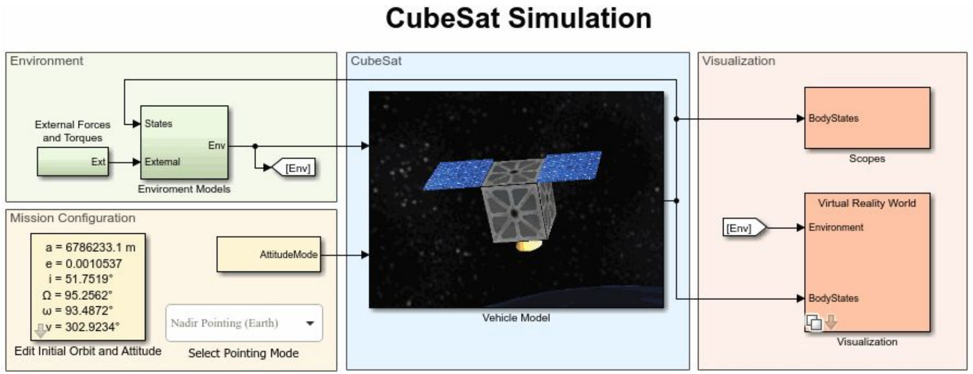
42 - Comprehensive General-Purpose Simulation of Attitude and Trajectory Dynamics and Control of Multiple Spacecraft Composed of Multiple Rigid or Flexible Bodies

- OSS recommended by NASA Goddard ADCS Engineer and developed by Eric Stone King
- Multi-body dynamics (tree topology, rotational and/or translational joints)
- Rigid and/or flexible bodies
- Fast setup for concept studies
- Rigorous and full-featured to support full spacecraft life cycle



Model and Simulate CubeSats - Matlab + Simulink

- Model and Simulate CubeSats - MATLAB & Simulink (mathworks.com)
- Support for:
  - Mission analysis
  - Satellite scenarios
  - Coordinate transforms
    - Position + velocity vectors
  - Modeling
  - Visualizations
  - Templates + blocks



Arduino Environment for Sensor Code (EPS)

- pre-written code that simplifies complex tasks and functionalities
- Popular and OSS
- Abundance of resources for onboarding members new to embedded programming

THERMAL

Thermal Control System Challenges

SmallSat Property	Challenge
Low thermal mass	The spacecraft is more reactive to changing thermal environments.
Limited external surface area	There is less real estate to be allocated to solar cells, designated radiator area, and/or viewports required for science instruments.
Limited volume	There is less space for electronic components, science instruments, and thermal control hardware. Components can be more thermally coupled and it can be harder to isolate different thermal zones.
Limited power	There is less power available for powered thermal control technology.
Power Density	There is a big challenge to dissipate power as electronics are stacked close to each other, sometimes with no direct path to radiator.
MLI Edge Effects	MLI can “short” along the edges resulting in degraded performance, not specific to SmallSats; more of a general spacecraft issue.

Thermal Multilayer Insulation

For SpacePort America Cup, the CubeSat won't be subject to high radiations or extreme temperature oscillations. Therefore, we are employing PTC through multilayer insulation.

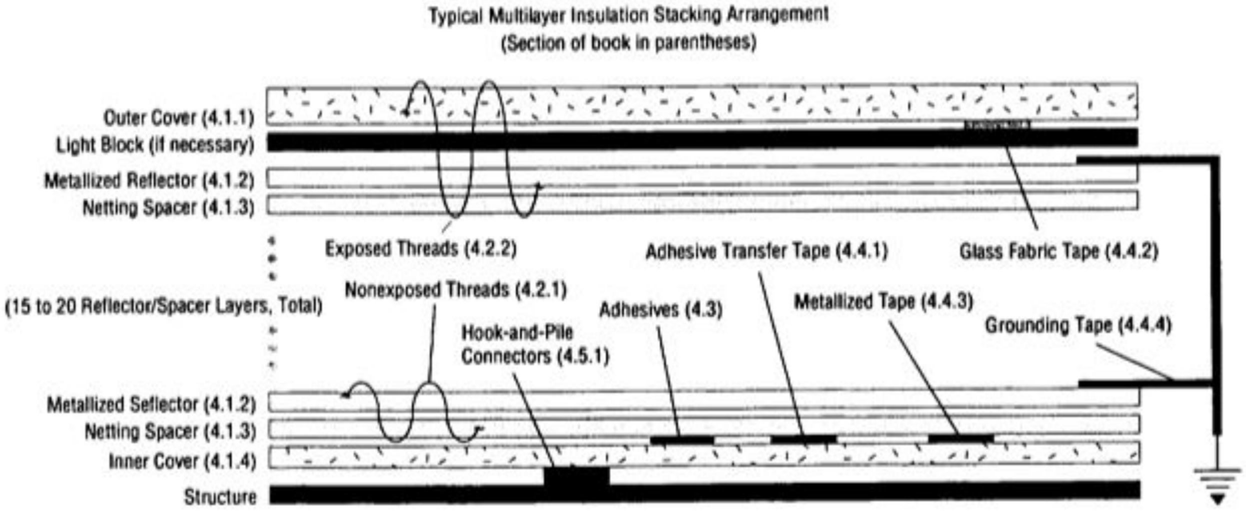


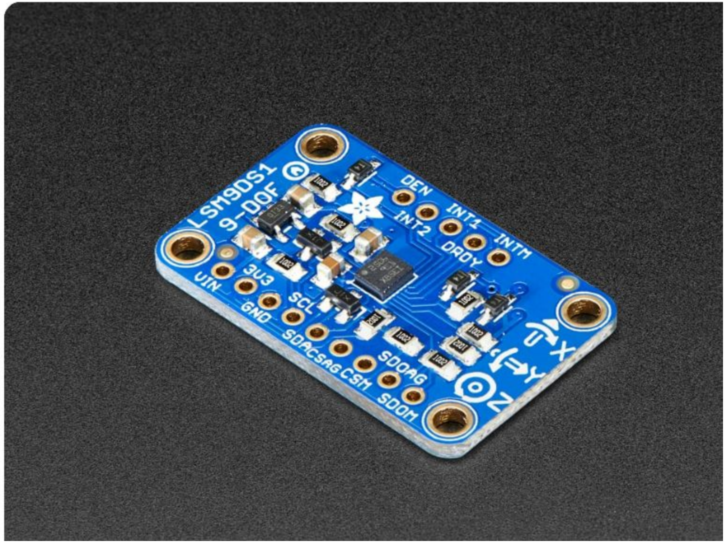
Image Credit: [NASA/tp-1999-209263]

ADCS and SRAD REACTION WHEELS

IMU - Adafruit 9-DOF Accel/Mag/Gyro+Temp Breakout Board - LSM9DS1

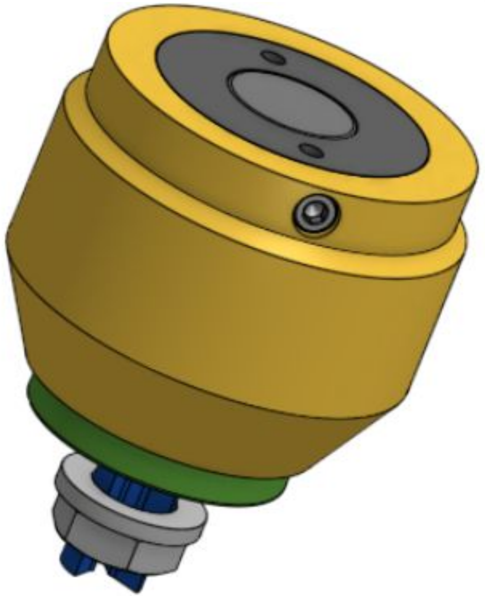
Three sensors

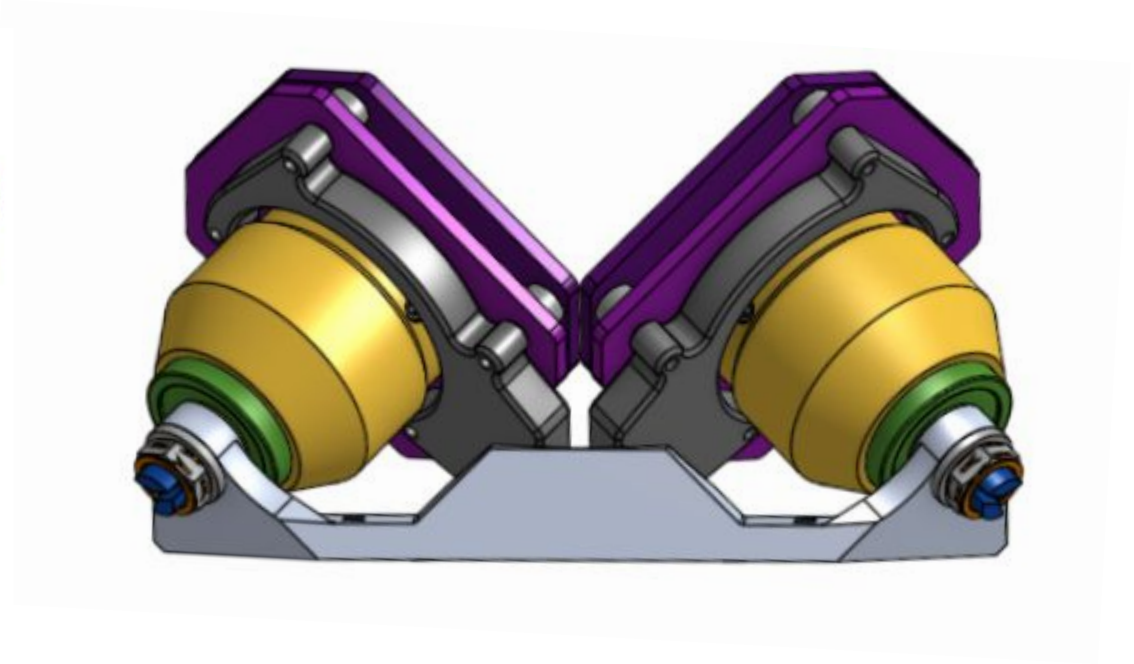
- 3-axis accelerometer: tells which direction is down towards the Earth or how fast the board is accelerating
- 3-axis magnetometer senses where the strongest magnetic force is coming from, generally used to detect magnetic north.
- 3-axis gyroscope that can measure spin and twist



PAYLOAD: ORESAT REACTION WHEEL

[oresat-structure | TEMP RW v4 Mockup (onshape.com)](https://onshape.com)





Motors:

GM5208-120T Gimbal Motor *3

Used with encoder/motor driver

Model: GM5208

Motor Out Diameter: Φ63±0.05mm

Motor Height: 22.7±0.2mm

Hollow Shaft(OD): Φ15-0.008/-0.012 mm

Hollow Shaft(ID): Φ12+0.05/0 mm

Wire Length: 610±3mm

Cable AWG: #24

Motor Weight: 195±0.5g

Wire plug: 2.5mm dupont connector

No-load current: 0.09±0.1 A

No-load volts: 20V

No-load Rpm: 456~504 RPM

Load current: 1A

Load volts: 20V

Load torque(g·cm): 1800-2500

Motor internal resistance: 15.2Ω±5% (Resistance varies with temperature)

High voltage test: DC500V 10mA @1sec

Rotor housing runout: ≤0.1mm

Steering (axle extension): clockwise

High-low temperature test:

High temperature: Keep at 60℃ for 100 hours, and the motor can work normally after 24 hours at room temperature

Low temperature: Keep at -20℃ for 100 hours, and the motor can work normally after 24 hours at room temperature

Maximum power: ≤40W

Working Voltage: 3-5S

Working temperature: -20~60℃;10~90%RH

Potential alt motor

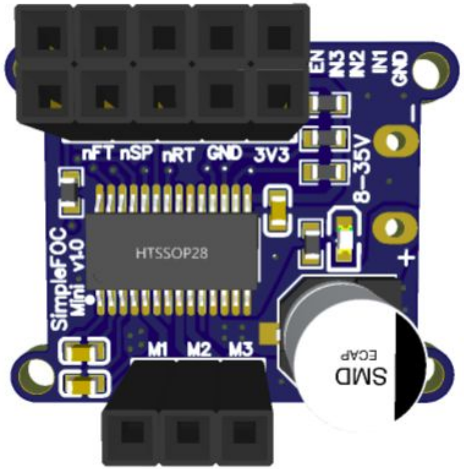
Requires an ESC

CMC_24H series motor

Output

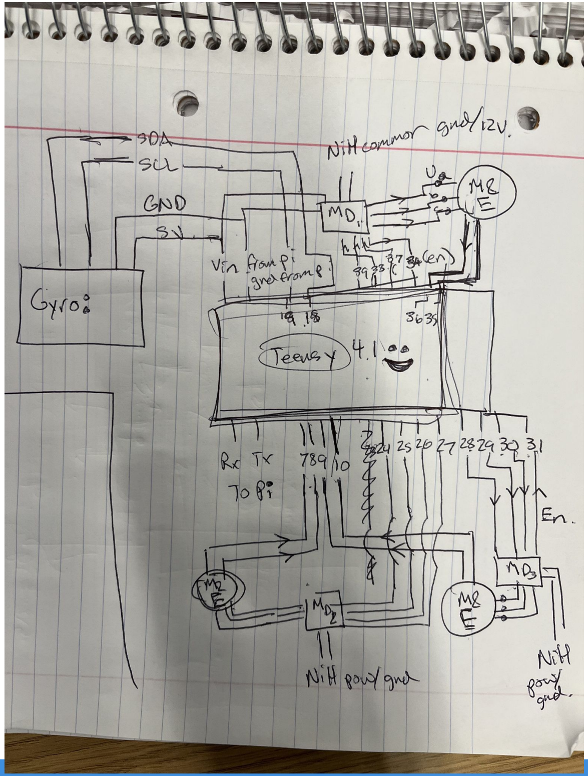
output		~11 W
torque		~25 mN・m
Stall torque		70~ mN・m
Rpm	4200 min-1	3800~4600 min-1
No-load rpm	5800 min-1	5200~6400 min-1
Momentary maximum torque		70~ mN・m

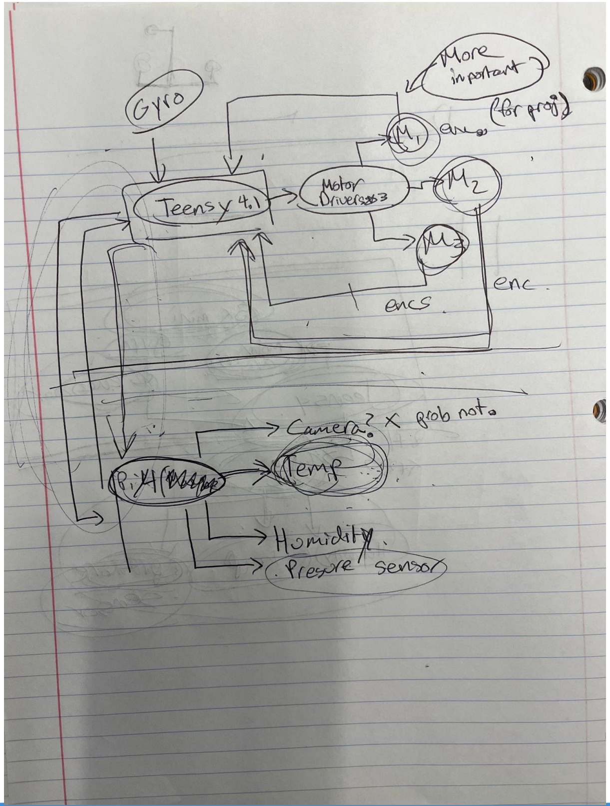
Motor Drivers



If using the gimbal motor *3

Wiring Schematic for gimbals





0.5 watts

Overall Design Conclusions

Risk Assessment

#	Risk	Risk Reduction Plan
1	SCH-1, Failure to deliver CubeSat	Develop a timely plan with repetitive checks with subsystems to ensure delivery in schedule
2	SP-1, Inadequate deployment	Run simulations to ensure deployment mechanism is working at a speed that won't affect the CubeSat. Ensure correct adionizing.
3	SP-2, Flight Termination Systems	Test communications, ADCS, and power subsystems repetitively.
4	SP-3, Loss of Structural Integrity	Test random vibrations in clean room, frequencies, modes, radiation and stress distributions. A lot of simulations too.
5	PAY-1, Reaction Wheel Malfunction	Run simulations to ensure reaction wheel is working, testing in several conditions

Risk Assessment

#	Risk	Risk Reduction Plan
6	COMS-1, Electromagnetic Interference	Develop a plan around interference so that it does not impact our communication
7	INT-1, Hardware interfaces integration	Hardware interfaces between Rocket and CubeSat not properly monitored causing inability to properly fit. Communication with Rocketry.
8	SP-4, Loss of Safe Return Capability	Won't impact mission itself. Develop a plan to ensure safe return
9	TEST-1, Testing facility required	Doubt exists about whether or not we can access testing facilities. Reach out in a timely manner to ensure access.

Open Issues

- Flight software integration with sensors and power
- Data handling upon sensor data retrieval
- Integration of subsystems to CubeSAT bus
- Simulation testing of subsystems prior to integration
- Facilities for testing of subsystems prior to integration
    - Collaborations are currently being planned and discussed
    - Includes clean room issue for
- Best practices around simulation vs physical testing

Questions?