SABAHınız XEYIR!
GOOD MORNING!

Design and Assembly of a COTS CubeSat for Space Weather Applications

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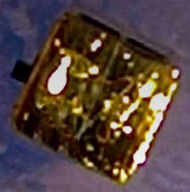
of the City University of New York (CUNY)



United Nations/Azerbaijan Workshop on the
International Space Weather Initiative:
The Sun, Space Weather and Geosphere
31 October – 4 November 2022
Baku, Azerbaijan

OUTLINE

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III. Challenges & Lessons Learned
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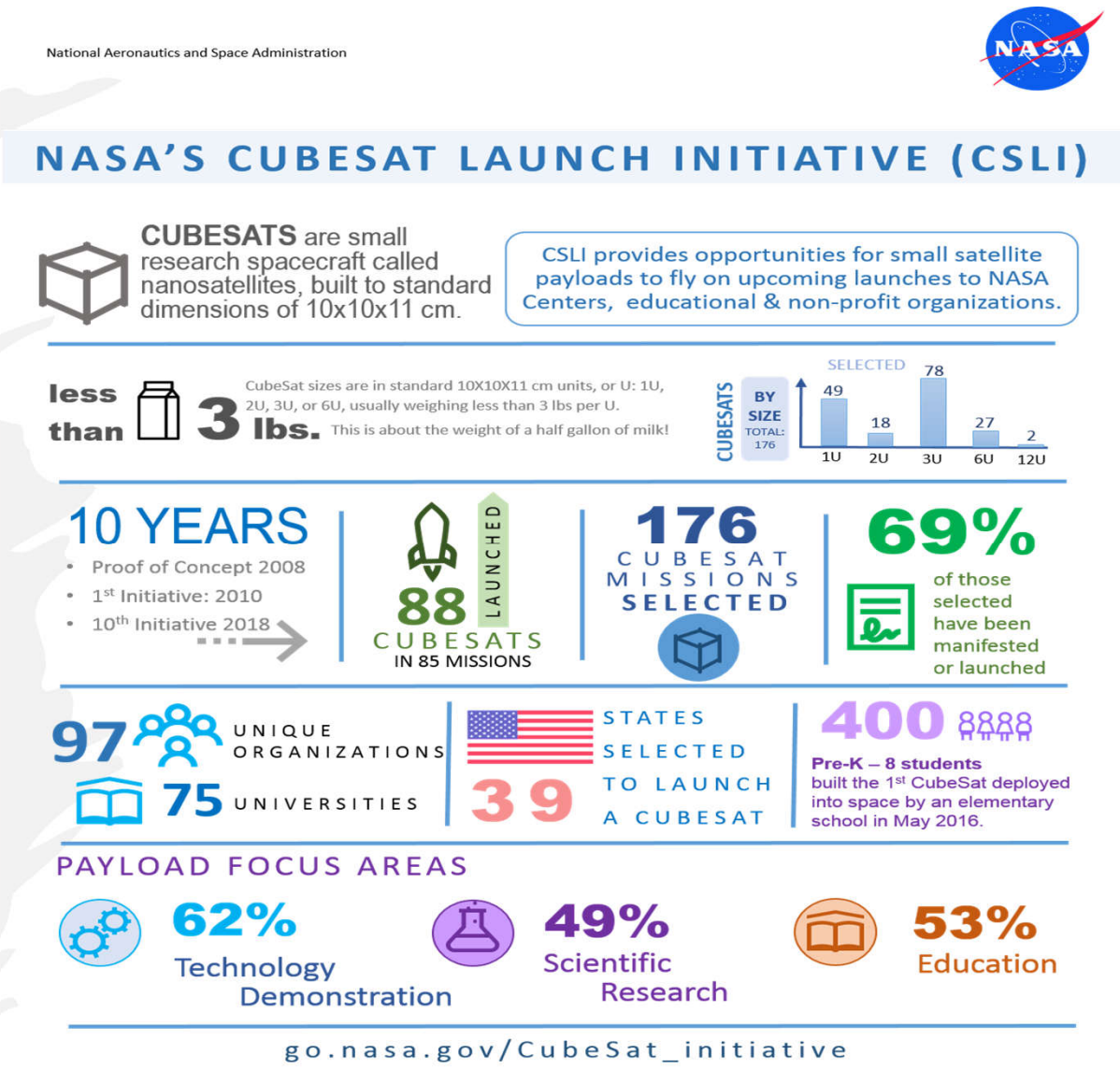
INTRODUCTION

Why CubeSats?

- During the past two decades, due to their relatively **low cost and short production time**, CubeSats have been developed for both educational and commercial use.
- Only a few universities have had the opportunity to engage students on actual CubeSat missions that were launched into space.
- **Great opportunity to teach students about scientific missions and NASA.**



Student-Led CubeSat Mission Project

The project aims at inspiring, as well as developing a community of students to pursue STEM careers through a challenging, engaging, exciting, and constructive project **that encourage problem solving, critical thinking, persistence and team work.**

Due to its low cost (~ <$500) and replicability, this project serves as a model for other colleges interested in engaging undergraduate and high school students in CubeSat design and hardware, based solely on inexpensive commercially off-the-shelf (COTS) components

The City University of New York (CUNY)

CUNY is USA's largest urban university and one of its most diverse.

CUNY, located in New York City, is USA's largest urban public university. It provides high-quality, accessible education for more than **269,000 degree-credit students** and **274,000 adult, continuing and professional education students** at 25 campuses across New York City.

- 11 Senior Colleges
- **7 Community Colleges**
- The Graduate School and University Center
- Macaulay Honors College
- CUNY Graduate School of Journalism
- CUNY School of Law at Queens College
- CUNY School of Professional Studies
- CUNY School of Public Health
- CUNY Medical School

QCC Students are…

- Diverse
- First-generation college students
- Immigrants
- Speak over 150 languages
- Part/Full-time workers
- Parents
- Academically diverse (some well-prepared; others math and science-challenged)

Space Science & Technology Curriculum

Table 1. Space Science & Engineering Design Systems Curriculum[1]		
Item	**Purpose/Contribution**	**Semester**
Train Peer-Project Team Leaders (PPTLs)/Teaching Assistants (TAs)	Contribute to course Lab Manual development & testing of equipment; tutorials; workshops; peer-mentoring	Fall
Course[2]	-Course activities foster a realistic environment for learning with hands-on applications enabling students to continue and enhance NASA CubeSat missions. course uses inexpensive commercially off-the-shelf components (COTS) electronics. -Introduction to CubeSat design practices -Software simulation packages -Assemble & test a Flatsat and CubeSat -Operation/data collection & analysis	Spring
Summer research internship[3] (Optional)	10-week research internship onsite at NASA GSFC to expand academic year experience	Summer
Synergistic Activities	Recruitment, Mentoring, workshops & training; virtual community, etc.	Year-long

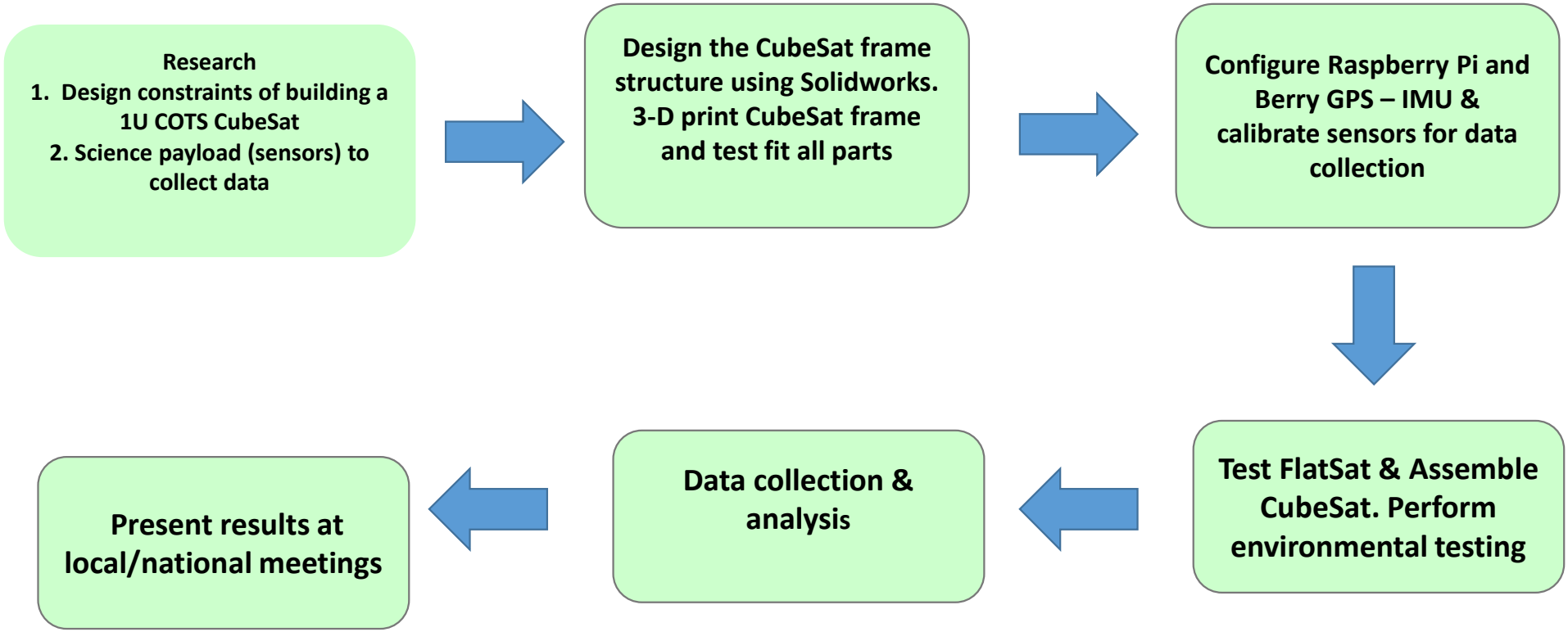
[1]Adapted from Damas, et al. (2020). A model of an integrated research and education program in space weather at a community college. Space Weather, 18, e2019SW002307. https://doi.org/10.1029/2019SW002307

[2] Course was moved online due to the COVID-19 pandemic and ran remotely during Spring 2020 (hybrid) and 2021.

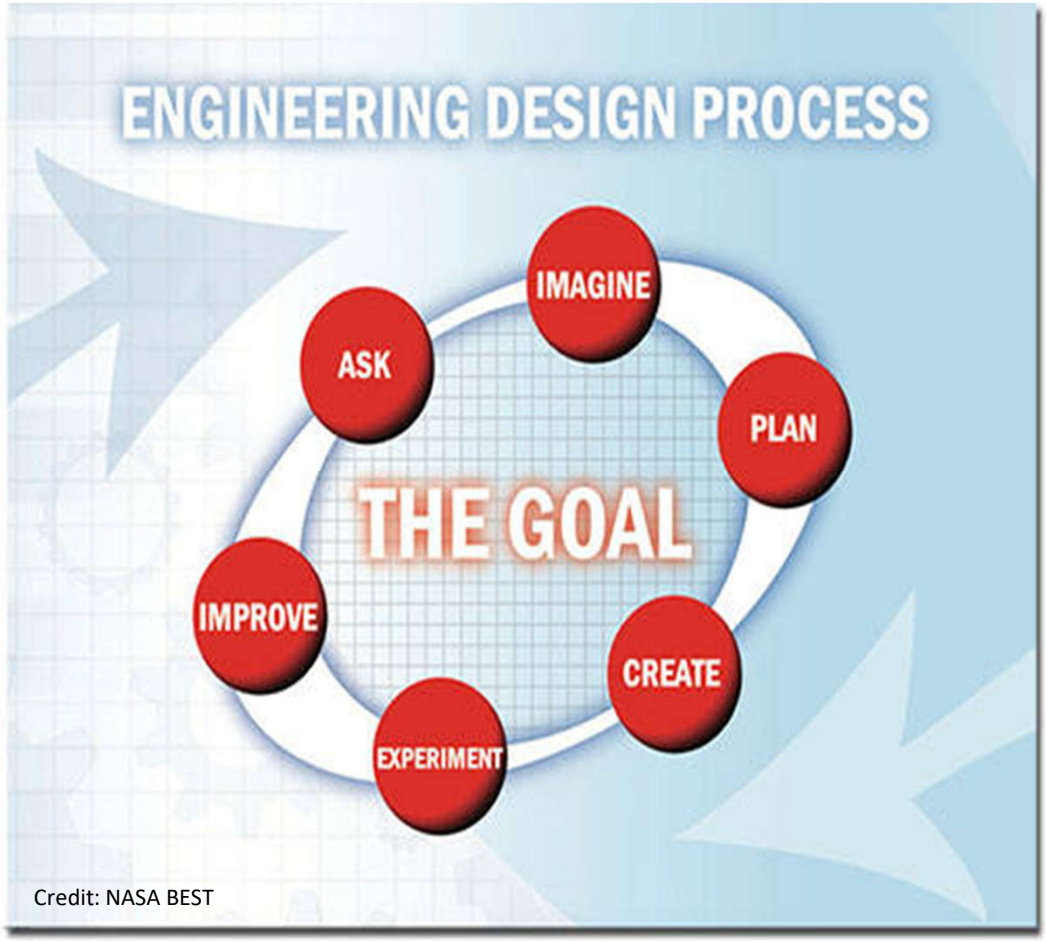
[3] NASA campuses were closed during the pandemic and internships were remote.

Project Pathway

Students are given a challenge and worked in teams to :



Engineering Design Process: NASA **B**eginning **E**ngineering, **S**cience & **T**echnology (BEST)



- ✓ **Ask a question, what is the challenge ?**
  Is it possible to build and design a low budget 1U CubeSat for scientific research & technology demonstration?

- ✓ **Imagine a possible solution to the challenge.**
  Use of COTS components and everyday *household items are readily available and reduce budget.*

- ✓ **Plan out a design and draw your ideas.**
  Develop science research question; research instruments payload (sensors); plan out design of CubeSat.

- ✓ **Create and construct a working model.**
  Construct FlatSat and CubeSat

- ✓ **Experiment and test model.**
  Test FlatSat and CubeSat

- ✓ **Improve and try to revise model.**
  Learn from failures and successes

Link:
https://www.nasa.gov/audience/foreducators/best/index.html

CubeSat Mission Project

To design experiments to test the scientific and technological capabilities of four COTS (Commercially-Off-the-Shelf) **CubeSats prototypes on Earth CSCOTS TeMP Mission** has the following:

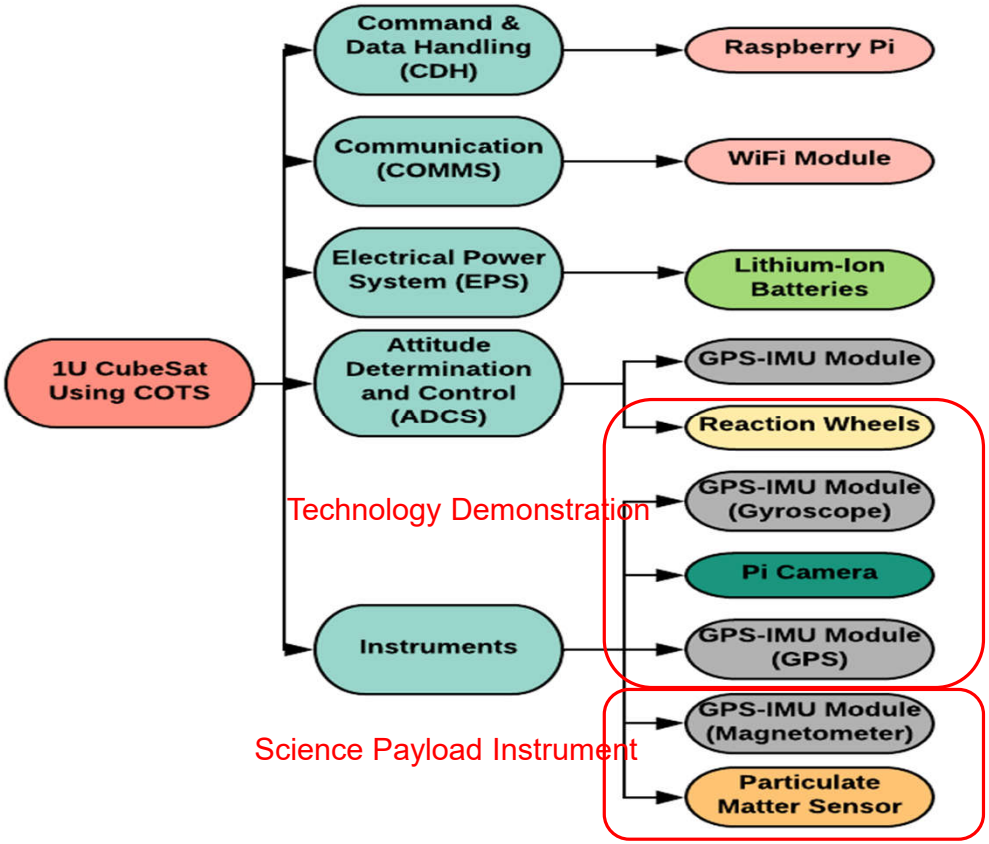
1. Two Science payloads (Particulate Matter & onboard magnetometer sensors)
2. Technology demonstration of both navigation and communication systems

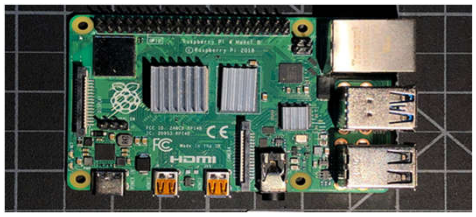
CubeSat Mission Project

- Project development has three main phases:
  - ✓ Phase 1: FlatSat development
  - ✓ Phase 2: FlightSat development
  - ✓ Phase 3: Data Collection

- Price tag < $500.

Cubesat subsystem layout

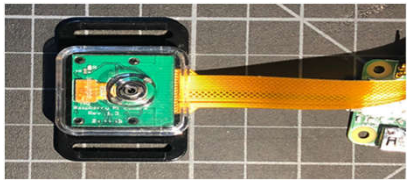




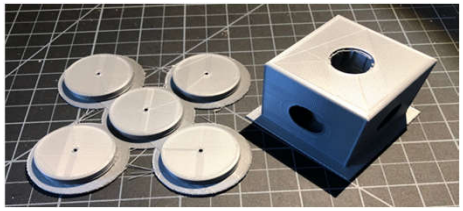
Raspberry Pi 4

SDS011 Particulate Matter Sensor

Berry GPS-IMU V3



Raspberry Pi Camera Module V2

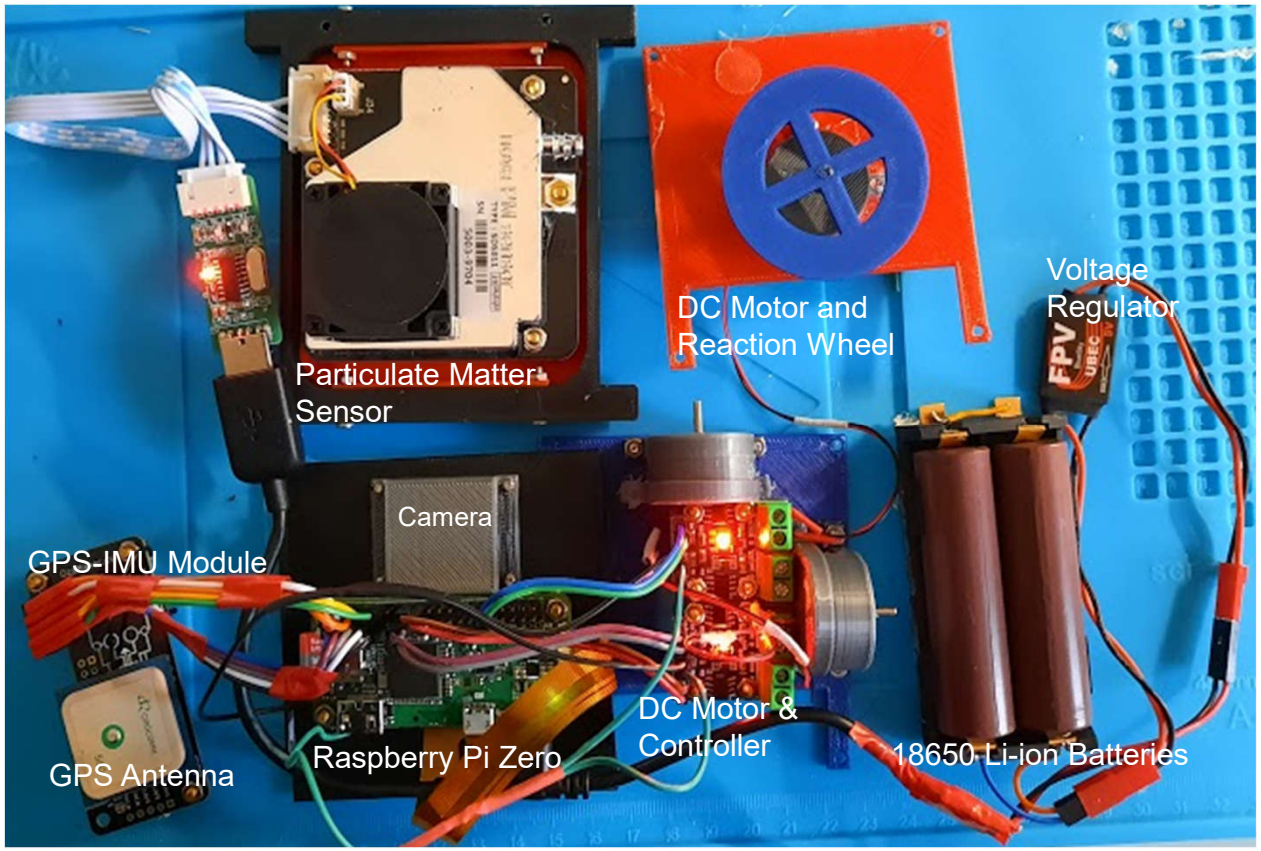


Reaction Wheels - 3D Printed

18650 Batteries

. Figure 1. Subsystem Chart

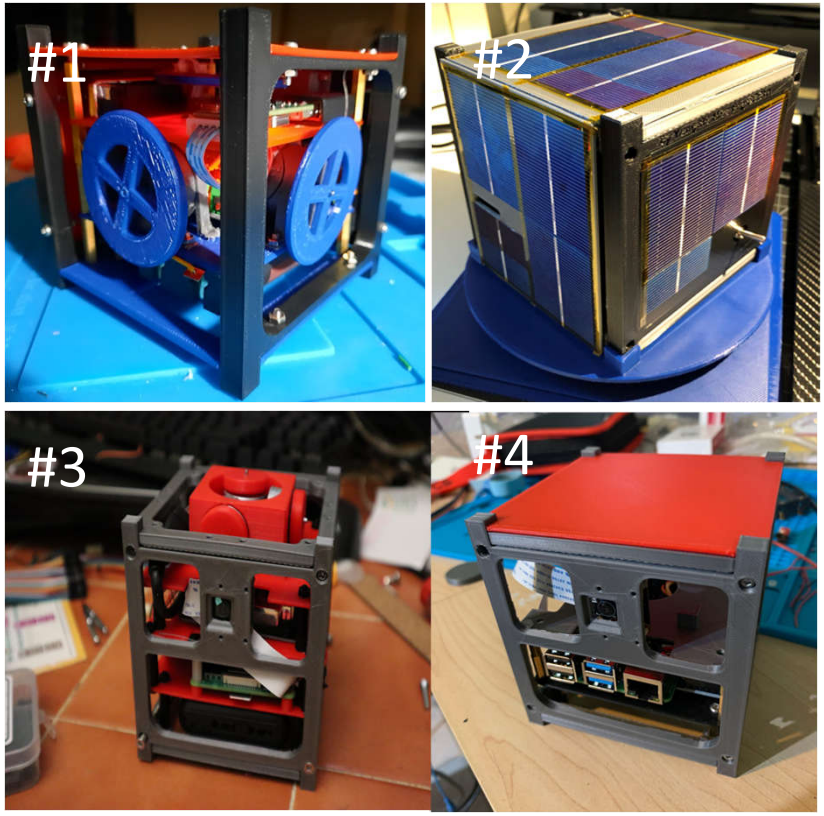
Project Development: Phase 1– FlatSat



Flatsat system

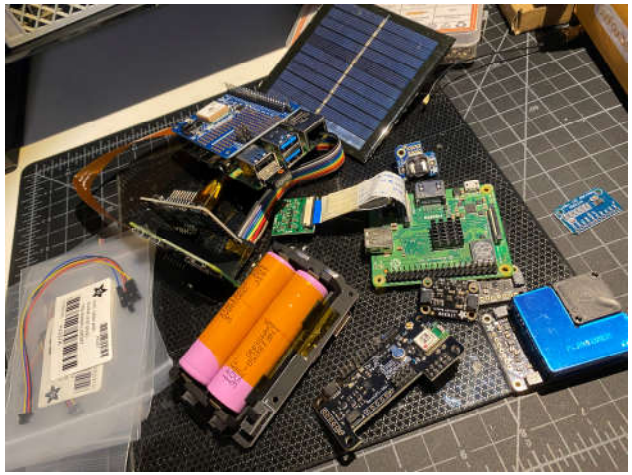
- ✓ Test components on a flat surface before CubetSat assembly
- ✓ Components are laid flat, then interconnected for power, commanding, and telemetry. Flatsat is used to test and troubleshoot systems without integrating everything onto the structure.
- ✓ Easy to test, diagnose, debug and change components

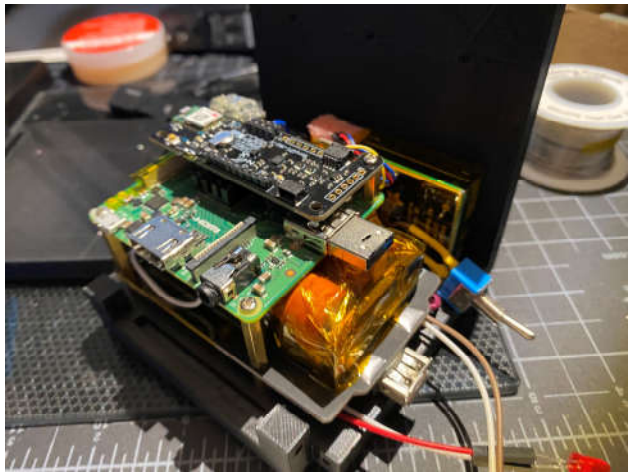
Project Development: Phase 2– FlightSat

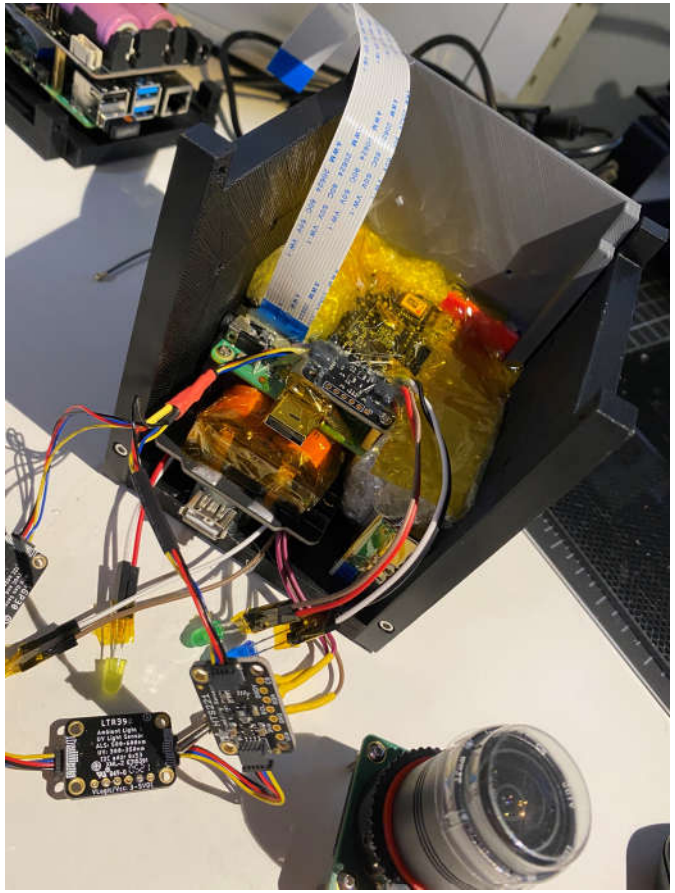


Type	Team	Engineering Technology Demonstrations, Primary Science Instructurments
#1	Hoon	Camera, Particulate Matter(PM) sensor
#2	Yang He	Reaction Wheel Dynamics, Magnetometer, GPS
#3	Brianna	Gyroscope, PM Sensor
#4	Tricia	Magnetometer, GPS

FlatSat & CubeSat Assembly

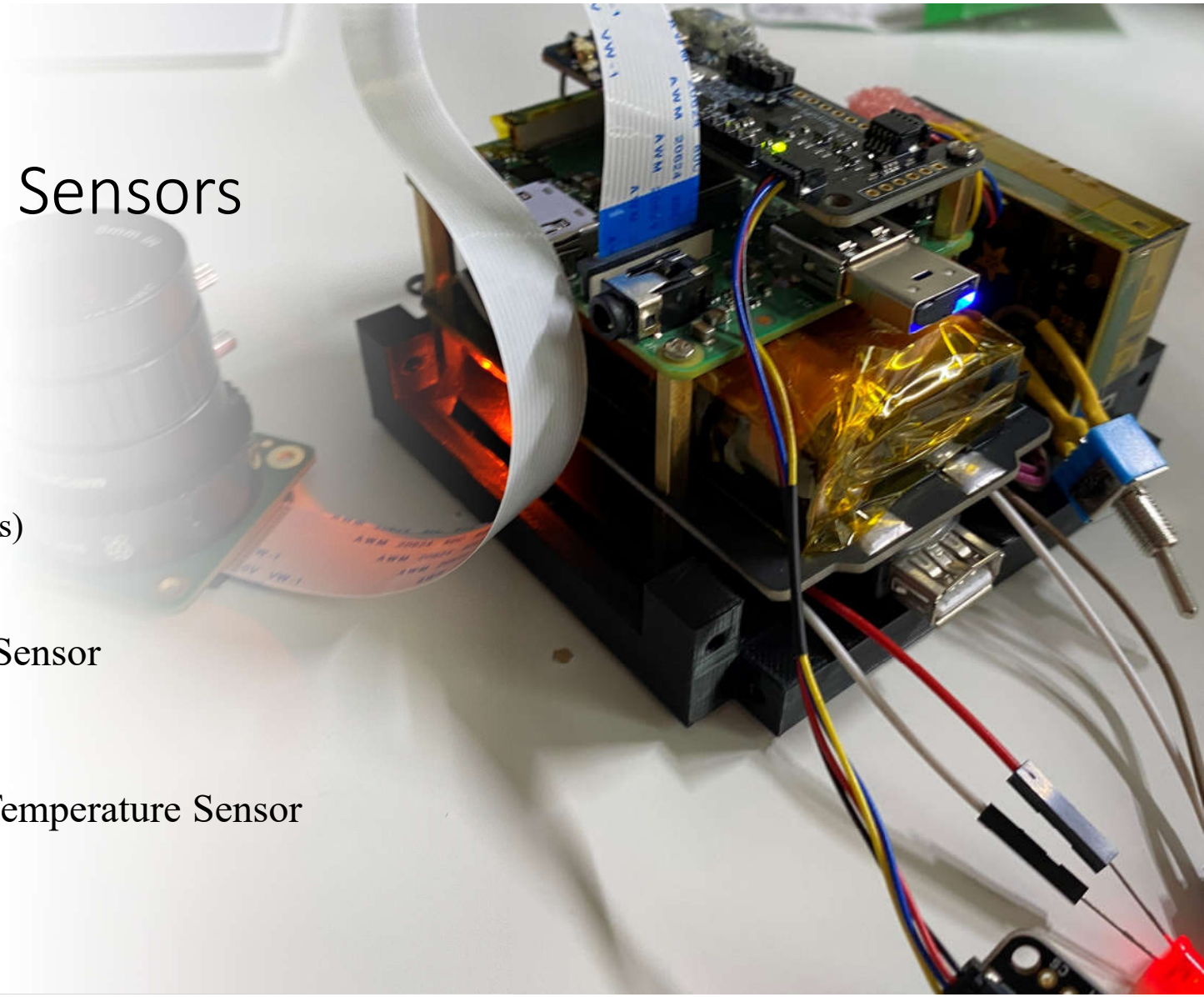






Controller and Sensors

- Raspberry Pi 3 A+
- Raspberry Pi HQ Camera
- BerryGPS-IMU V4
  - GPS
  - Accelerometer
  - Gyroscope
  - Magnetometer (Compass)
  - Barometric/Altitude
  - Temperature (inside)
- Particulate Matter (PM) Sensor
- UV Sensor
- CO_2 Sensor
- Ambient Humidity and Temperature Sensor



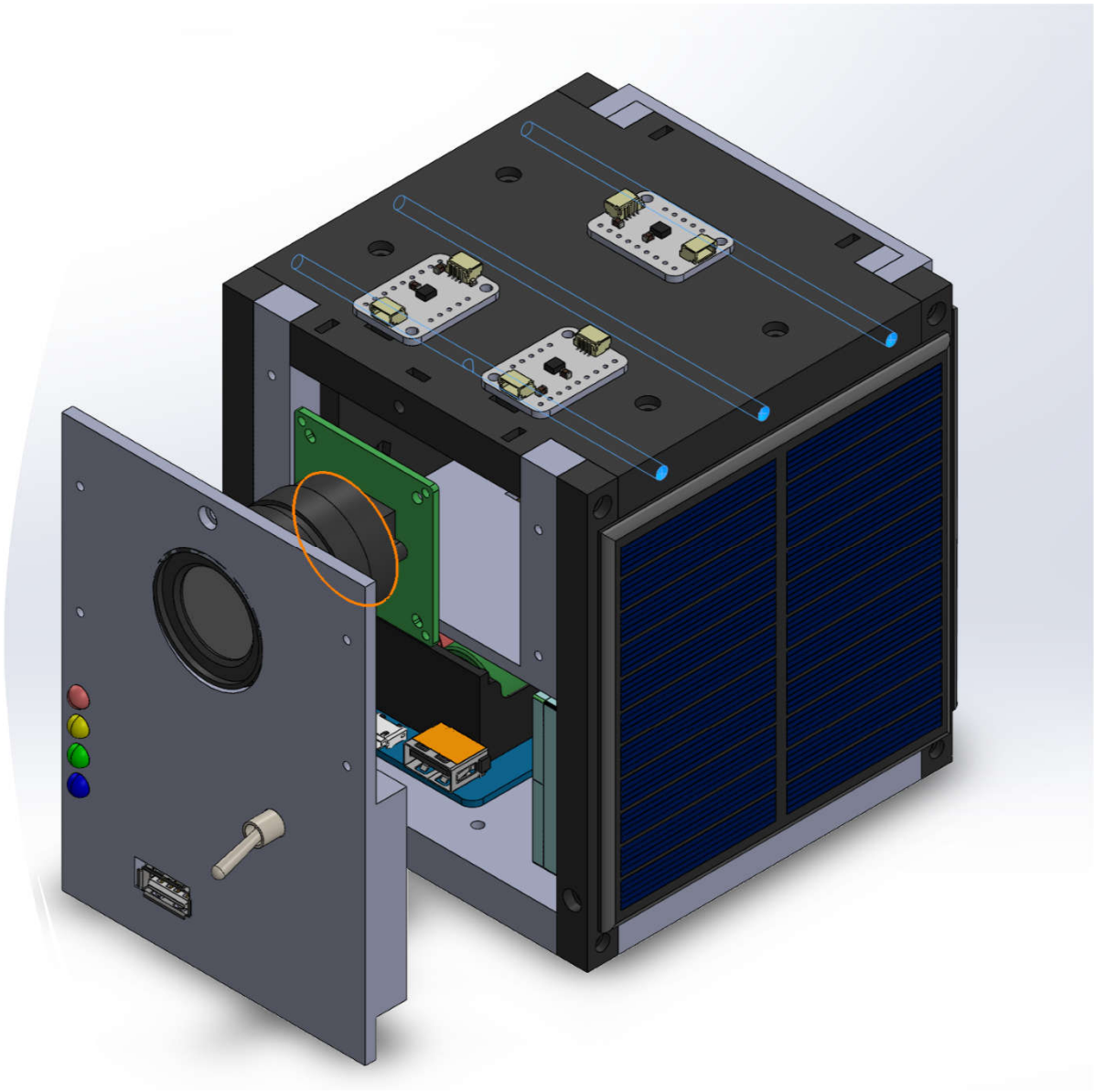
Environmental Stress Tests

CubeSats are subjected to “environmental’ testing listed below:

Test type	Results		
	Passed	**Failed**	**Comments**
Shock Test(Drop from 3 ft)	✓		All modules working correctly, minor signs of dent on structure frames
Thermal Test (Cold, freezer)	✓		All modules working correctly after the test
Thermal Test (Hot, outdoors in car)	✓		Frame distorted but all modules fully functional
Vibration (Shake)	✓		All modules are in position and working properly

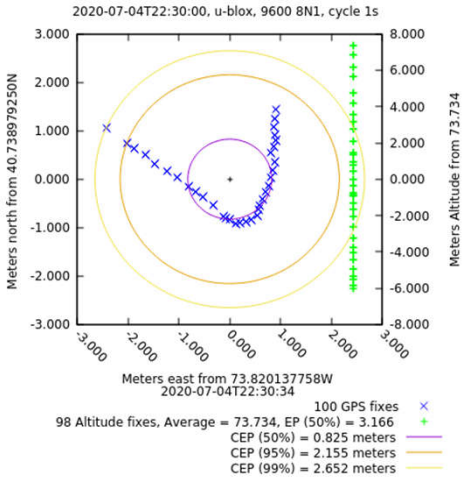
3D Modeling and Design Constraints

- 1U CubeSat (10*10*11.35cm)
- Extreme Environment
  - Ambient Temperature ~ 98 F
  - Strong UV & Sun light
- Battery life > 3 hours
- Impact Forces
  - Hitting ground
  - Severe shaking
- COTS Material
  - 3D Printed plastic parts
  - Standardized Screws & Nuts

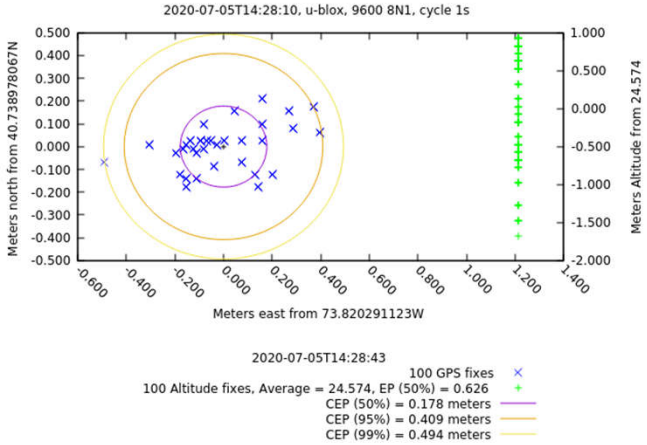


Project Development: Phase 3– Data Collection (& Results)

Science instrument: Onboard magnetometer



GPS GNUPLOT scatter graph 1



GPS GNUPLOT scatter graph 2

Camera Ground Test

GPStime u	System Tir	latitude	longitude	speed m/s	sats in viev	altitude m	In_pressur	In_temper	UV_raw	Uv_index	lux_cal	Ambient li	Particles >	Particles >	Particles >	Particles >	Particles >	Particles >	Relative H	Ambient T	Gx	Gy	Gz	magX nT	magY nT	magZ nT
	20210717-	40.72565	-73.8016	nan	7	0	1016.2	30.68	0	0	51.2	64	2967	937	178	20	6	6	77.41	29.96	0.03	-0.02	1.03	-69.6872	0.496931	-36.6121
2021-07-1	20210717-	40.72564	-73.8016	0.694	22	60.2	1016.19	30.69	0	0	53.6	66	2889	914	176	20	6	6	77.5	29.96	0.04	-0.01	1.03	-68.9126	0.526162	-41.9176
2021-07-1	20210717-	40.72563	-73.8016	0.573	22	62.724	1016.2	30.71	0	0	48.8	61	2781	874	163	20	6	6	77.39	29.96	0.04	-0.02	1.03	-68.708	0	-40.8799
2021-07-1	20210717-	40.72563	-73.8016	0.42	22	62.647	1016.24	30.74	0	0	92	136	2793	863	146	24	8	8	77.37	29.98	0.03	-0.02	1.03	-69.4534	0.190003	-36.3929
2021-07-1	20210717-	40.72563	-73.8016	0.247	22	62.484	1016.18	30.76	0	0	73.6	89	2793	863	146	24	8	8	77.38	29.96	0.19	0	1.03	-62.8179	1.227711	-37.5475
2021-07-1	20210717-	40.72563	-73.8016	0.412	22	62.17	1016.18	30.75	0	0	57.6	53	2610	806	125	16	4	2	77.38	29.96	0.08	0.11	1.1	-67.2464	12.39404	-41.406
2021-07-1	20210717-	40.72564	-73.8016	0.288	22	60.774	1016.17	30.77	0	0	24.8	27	2529	783	131	16	4	2	77.28	29.96	-0.08	0.33	1.06	-68.8395	41.50833	-32.3736
2021-07-1	20210717-	40.72563	-73.8016	0.873	22	60.506	1016.14	30.8	0	0	17.6	24	2382	735	119	14	4	2	77.13	30	-0.52	0.64	0.77	-78.3104	55.78778	-22.245
2021-07-1	20210717-	40.72564	-73.8016	0.514	22	59.655	1016.2	30.8	0	0	48	62	2325	716	98	10	6	4	77.18	29.96	0.61	0.33	0.77	-66.4426	44.57761	-48.6846
2021-07-1	20210717-	40.72564																					0.76	-65.3318	22.14265	-68.0064
2021-07-1	20210717-	40.72565																					0.83	-64.1771	45.03069	-57.8194
2021-07-1	20210717-	40.72565																					0.83	-87.299	43.0722	-44.5484
2021-07-1	20210717-	40.72565																					0.88	-73.8381	49.67846	-48.6115
2021-07-1	20210717-	40.72565																					0.68	-55.2178	45.74686	-56.1824
2021-07-1	20210717-	40.72565																					0.79	-79.1143	19.33645	-62.5548
2021-07-1	20210717-	40.72566																					0.68	-82.3443	8.798597	-46.9892
2021-07-1	20210717-	40.72566																					0.79	-84.639	-4.94008	-56.0362
2021-07-1	20210717-	40.72567																					0.72	-81.4236	11.95557	-56.9716
2021-07-1	20210717-	40.72567																					0.91	-84.2151	12.89097	-56.9716
2021-07-1	20210717-	40.72567																					1.07	-88.4683	19.59953	-48.9184
2021-07-1	20210717-	40.72568																					0.71	-85.3844	15.90178	-53.4054
2021-07-1	20210717-	40.72567																					0.88	-87.7083	8.798597	-49.7515
2021-07-1	20210717-	40.72568																					0.88	-80.2397	-5.78778	-60.0994
2021-07-1	20210717-	40.72568																					0.78	-82.6367	8.827828	-62.131
2021-07-1	20210717-	40.72568																					1.05	-89.6814	19.02952	-46.6238
2021-07-1	20210717-	40.72567																					0.96	-85.6767	14.76177	-33.2505
2021-07-1	20210717-	40.72567																					1.03	-70.3011	12.33557	-41.5376
2021-07-1	20210717-	40.72567																					0.77	-72.5519	-13.8702	-35.0482
2021-07-1	20210717-	40.72568																					1	-70.6957	8.769366	-42.1222
2021-07-1	20210717-	40.72568																					1.01	-69.9503	8.38936	-47.033
2021-07-1	20210717-	40.72567																					1.01	-70.3888	7.936276	-42.7653
2021-07-1	20210717-	40.72568																					1.01	-70.2426	7.848582	-46.4484
2021-07-1	20210717-	40.72568																					1.02	-68.9857	8.287051	-41.8299
2021-07-1	20210717-	40.72568																					1.01	-68.6495	7.775504	-46.3315
2021-07-1	20210717-	40.72568																					1.01	-69.468	7.337036	-42.546
2021-07-1	20210717-	40.72567																					1.01	-68.1526	8.213973	-46.0538
2021-07-1	20210717-	40.72566																					1.01	-68.1672	7.658579	-46.5361

CHALLENGES AND LESSONS LEARNED

Challenges

- ✓3D design a challenge (learning new design software, high demand on computer resources)
- ✓3D printer errors causing pieces to either not align correctly or in some cases not fit at all.
- ✓Use of COTS materials that may not be reliable (product heritage).
- ✓Performing stress tests (not under well-controlled conditions)
- ✓Funding!!!!

Challenges: COVID-19

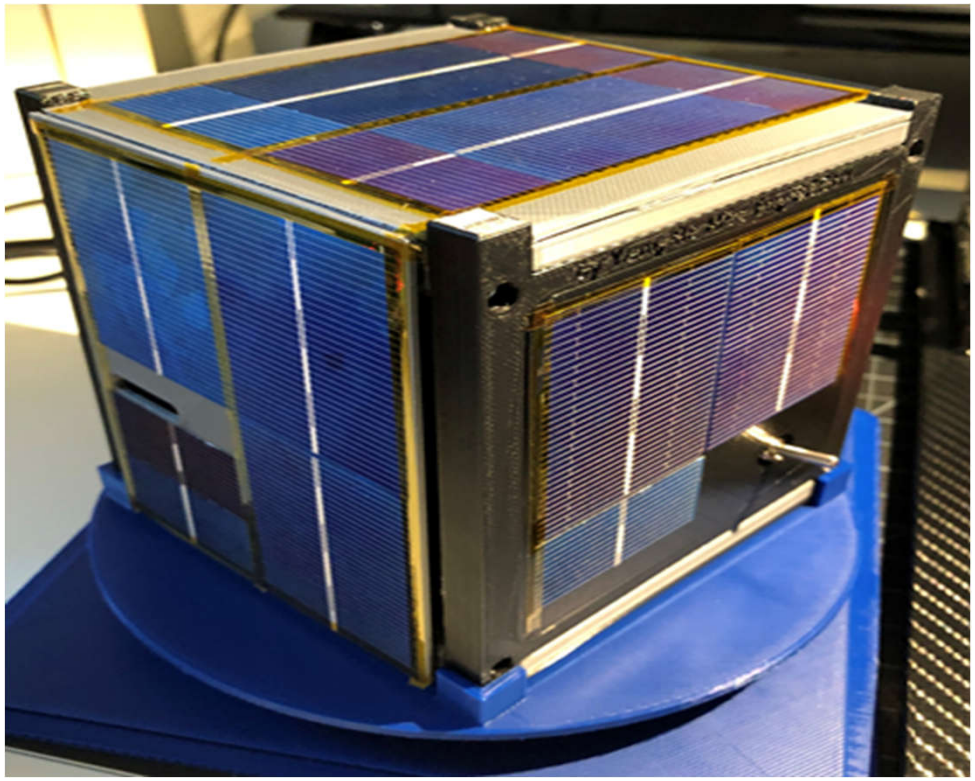
- ✓Everything moved online
- ✓Students' home became labs
- ✓Coordinating student time and availability to meet and work with instructor, TAs and teams.
- ✓Shipped CubeSat kit to each student (costly)
- ✓Working remotely as a team
- ✓No access to NASA facilities
- ✓Obtaining materials during the pandemic

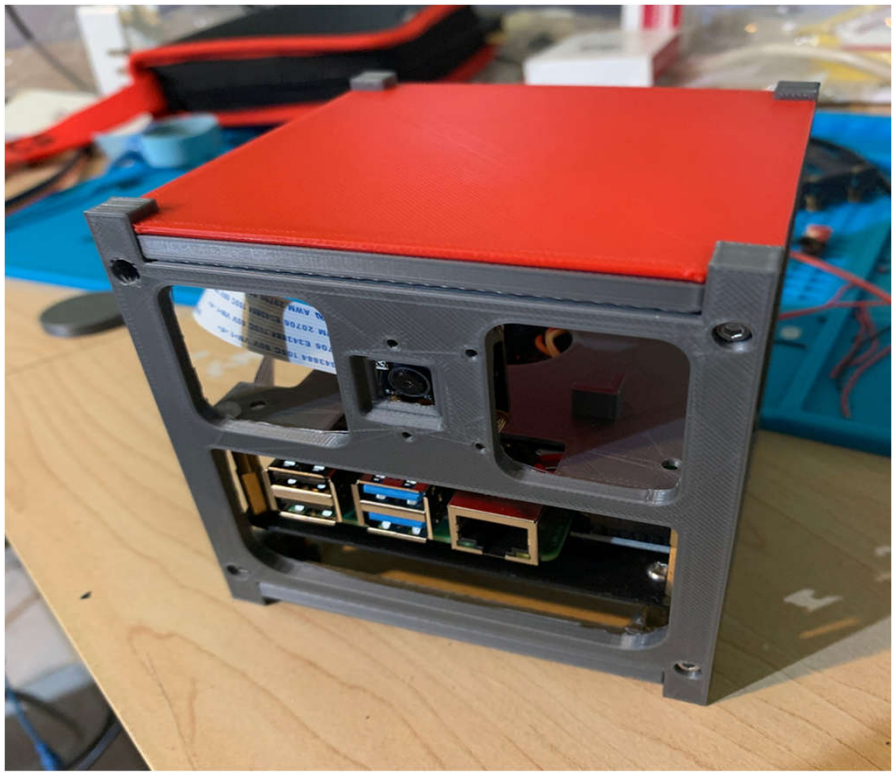
Lessons Learned

- ✓Seek out subject matter experts (scientists & engineers). For this project, we worked with NASA engineers.
- ✓Train & make use of trained TAs
- ✓Give students autonomy to decide how to organize and work on project with some guidance.
- ✓DO NOT underestimate students' resourcefulness and willingness to work under pressure and as a team to undertake project they find interesting and worthwhile. True during COVID!!
- ✓Students learned to work both independently and in teams. Increased confidence & self-efficacy

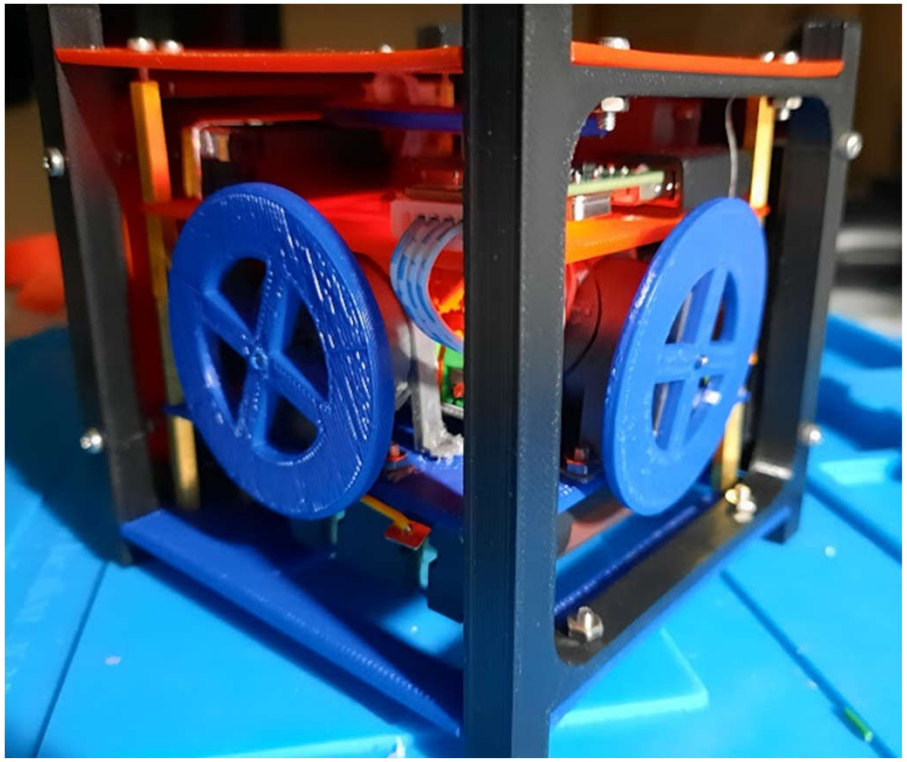
CONCLUSIONS

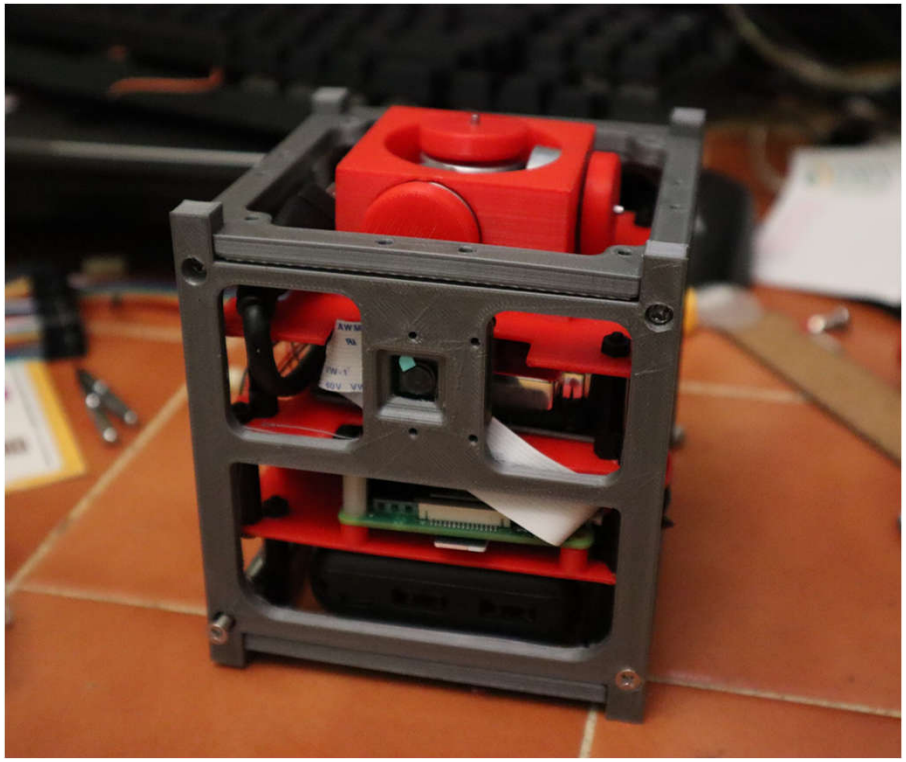
Student-built CubeSats – 1st Iteration



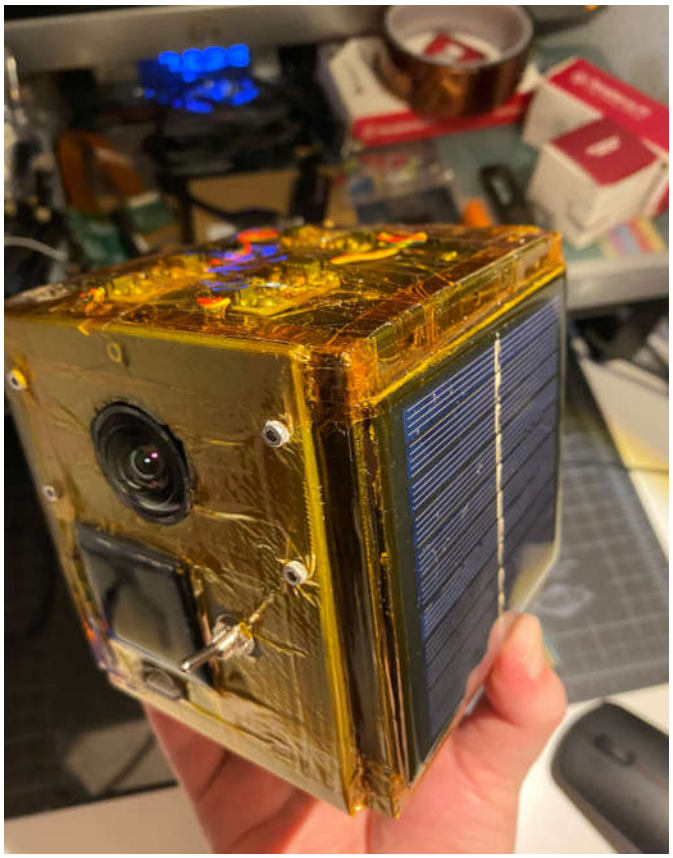


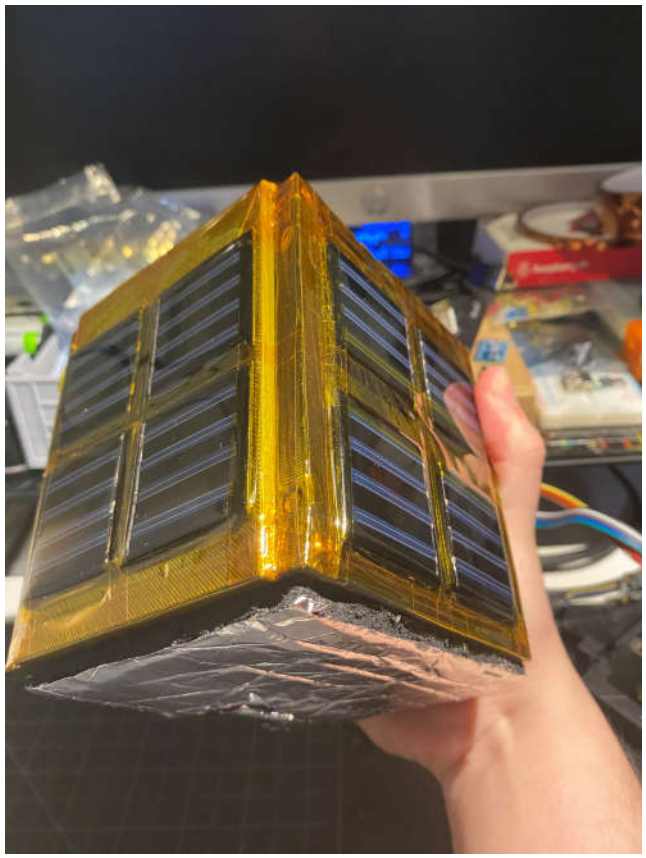
Student-built CubeSats – 1st Iteration



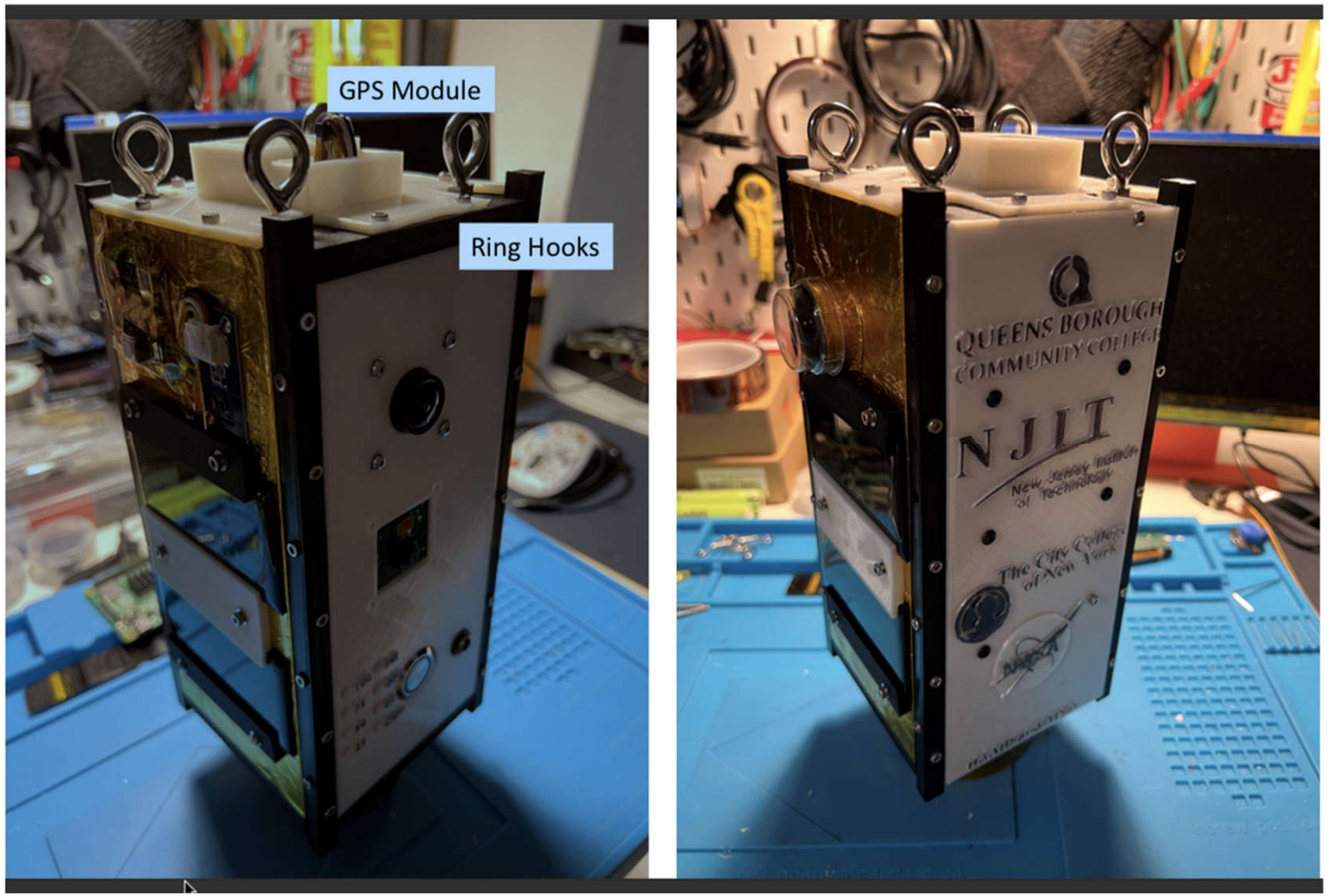


Successful CubeSat– 2nd Iteration (Launched via Balloon)

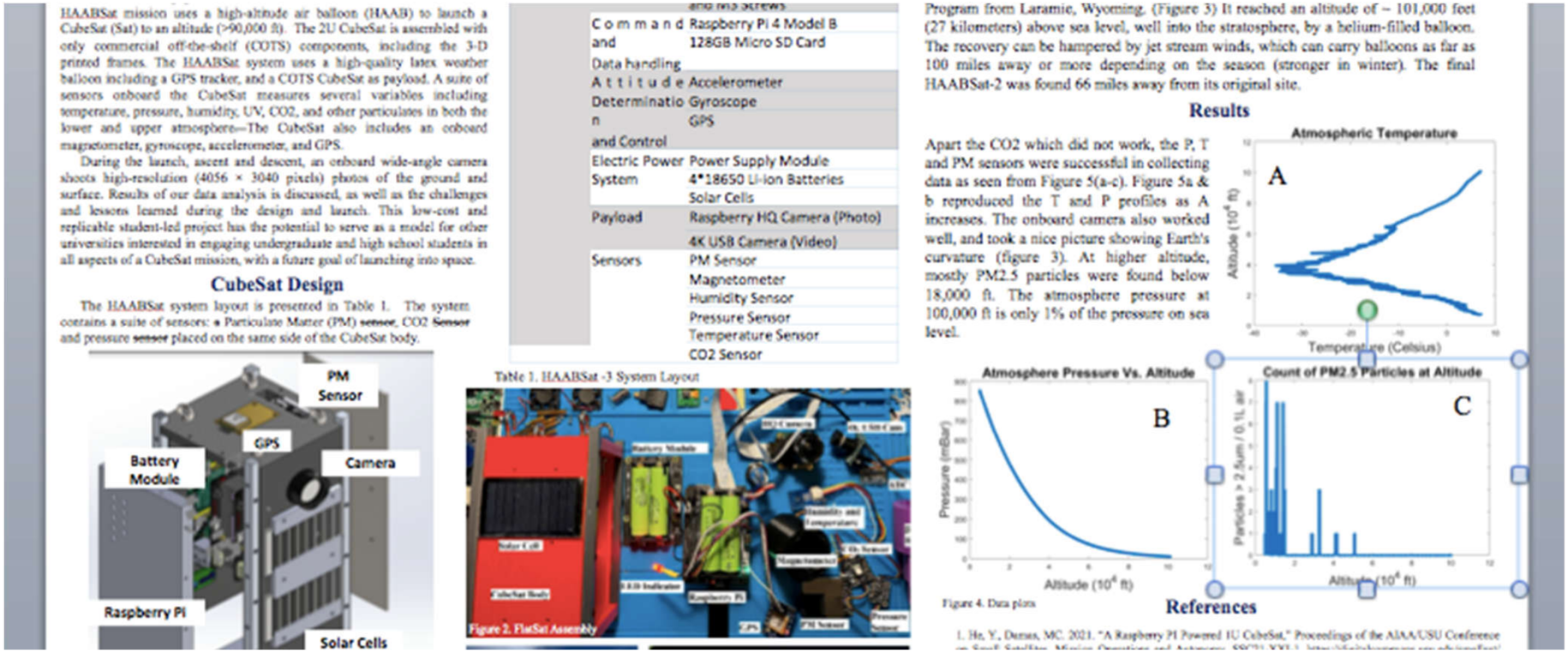




Successful CubeSat– 3rd Iteration (Launched via Balloon)



Poster presented at 2022 Small Satellite Conference Logan, Utah (virtual)



HAABSat mission uses a high-altitude air balloon (HAAB) to launch a CubeSat (Sat) to an altitude (>90,000 ft). The 2U CubeSat is assembled with only commercial off-the-shelf (COTS) components, including the 3-D printed frames. The HAABSat system uses a high-quality latex weather balloon including a GPS tracker, and a COTS CubeSat as payload. A suite of sensors onboard the CubeSat measures several variables including temperature, pressure, humidity, UV, CO2, and other particulates in both the lower and upper atmosphere—The CubeSat also includes an onboard magnetometer, gyroscope, accelerometer, and GPS.

During the launch, ascent and descent, an onboard wide-angle camera shoots high-resolution (4056 × 3040 pixels) photos of the ground and surface. Results of our data analysis is discussed, as well as the challenges and lessons learned during the design and launch. This low-cost and replicable student-led project has the potential to serve as a model for other universities interested in engaging undergraduate and high school students in all aspects of a CubeSat mission, with a future goal of launching into space.

CubeSat Design

The HAABSat system layout is presented in Table 1. The system contains a suite of sensors: a Particulate Matter (PM) sensor, CO2 Sensor and pressure sensor placed on the same side of the CubeSat body.

	and M3 screws
Command and Data handling	Raspberry Pi 4 Model B
	128GB Micro SD Card
Attitude Determination and Control	Accelerometer
	Gyroscope
	GPS
Electric Power System	Power Supply Module
	4*18650 Li-ion Batteries
	Solar Cells
Payload	Raspberry HQ Camera (Photo)
	4K USB Camera (Video)
Sensors	PM Sensor
	Magnetometer
	Humidity Sensor
	Pressure Sensor
	Temperature Sensor
	CO2 Sensor

Table 1. HAABSat -3 System Layout

Program from Laramie, Wyoming. (Figure 3) It reached an altitude of ~ 101,000 feet (27 kilometers) above sea level, well into the stratosphere, by a helium-filled balloon. The recovery can be hampered by jet stream winds, which can carry balloons as far as 100 miles away or more depending on the season (stronger in winter). The final HAABSat-2 was found 66 miles away from its original site.

Results

Apart the CO2 which did not work, the P, T and PM sensors were successful in collecting data as seen from Figure 5(a-c). Figure 5a & b reproduced the T and P profiles as A increases. The onboard camera also worked well, and took a nice picture showing Earth's curvature (figure 3). At higher altitude, mostly PM2.5 particles were found below 18,000 ft. The atmosphere pressure at 100,000 ft is only 1% of the pressure on sea level.

Figure 4. Data plots

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Acknowledgement

This work was funded by a grant from the NASA MUREP Innovations in Space technology Curriculum Group 2 (MISCT-2) under NASA award number 80NSSC19M0221.

Dr. M. Chantale Damas gratefully acknowledges Dr. Sean Semper of the NASA Goddard Space Flight Center MESA

Her Teaching Assistants: **Yang He**, Seughoon (Hoon) Kim and Brianna Solano!

Her many wonderful and hard working students!

She also acknowledges travel funds from QCC's Office of Academic Affairs & Physics Department.

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THANK YOU!

QUESTIONS?