IU Capstone Design Team 4: IUB Sat

Will Brenneke, Annabel Brinker, Gourav Pullela, Lucas Snyder, and Caleb Vrydaghs

Team Introductions

Will Brenneke

- BS in ISE (CE)
- Expertise: C, Python, Verilog
- Experience: Undergraduate Researcher for Systems Assurance and Integrity Lab of Indiana, NSWC Crane Intern

Annabel Brinker

- BS in ISE (CE)
- Expertise: C, C++, Python, Verilog, ML
- Experience: NSWC Crane modeling and simulating intern, Internship at Navient, Various Research work

Joseph Patus

- BS in ISE (CE)
- Expertise: Python, C, EE designing and prototyping
- Experience: Intern at Tech. Serv. Firm, class/personal projects

Team Introductions Continued

Gourav Pullela

- BS in ISE (CE)
- Expertise: C, C++, HPC, Python, ML
- Experience: Research Work, Personal Projects, Teaching

Lucas Snyder

- BS in ISE (Bio)
- Expertise: HPC, Python, C
- Experience: HPC Intern at NASA, Purdue

Caleb Vrydaghs

- BS in ISE (CE), Minor in Mathematics
- Expertise: C, C++, Python, PHP, Fusion 360
- Experience: Embedded Firmware Development Intern at Alpha Technologies

Mission Statement

This project is aimed at advancing the IUBSAT suborbital payload structure, utilizing COTS electronics, and involving rigorous testing to perform an imaging mission during a total solar eclipse at high altitudes.

Overview

- Team Planning
- Gantt Chart
- Project Overview
- Objectives
- Constraints
- Payload Design
- Results

Weekly Project Meeting Plan

Semester 1: Sunday 11a-2p
@ Luddy

Semester 2: Saturday 2-5p
Friday 12:15p-2p
@ Luddy

The additional Friday meeting was added midway through the second semester closer to launch date.

Available Resource Estimate

- Individual Estimates
  - Lucas: 5 hours
  - Annabel: 5 hours
  - Caleb: 5 hours
  - Gourav: 5 hours
  - Will: 5 hours
- Work hours: 25 hours per week
- Available resources: FDM, SLA, and SLS Additive Manufacturing machines, Laser Cutters, Electronic Testing equipment.
- Other equipment included from prior CubeSat launches

Decision Making

- Majority voting
  - Each member gets one vote and time to explain their standpoint
  - If there is a tie, the professors will decide

Roles

- Project Coordinator (PC): Lucas Snyder
- System Manager (SM): Will Brenneke
- Presentation Manager (PM): Annabel Brinker
- Report Manager (RM): Caleb Vrydaghs
- Prototype Integrator (PI): Gourav Pullela

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Gantt Chart

TASK TITLE	START DATE	DUE DATE	% OF TASK COMPLETE
Payload Planning			
Detailed Block Diagram	9/1/23	10/30/23	100%
Parts Summary	9/1/23	10/30/23	100%
Parts comparison	10/1/23	10/15/23	100%
Part Review	11/1/23	11/23/23	100%
Order Parts	11/1/23	11/30/24	100%
Hardware Testing			
Sensors (temp/ pressure)	12/1/23	2/30/24	100%
Camera/s	12/1/23	2/30/24	100%
Communication system	2/1/24	3/15/24	100%
Batteries	2/1/24	3/15/24	100%
Flight Computer	2/1/24	3/15/24	100%
Non-CubeSat Hardware Parts			
Balloon	1/1/24	1/30/24	100%
Cable	1/1/24	1/30/24	100%
Parachute	1/1/24	1/30/24	100%
Tracking	1/1/24	1/30/24	100%
Order Parts	2/1/24	2/15/24	100%
CubeSat Prototype - PDR			
Documentation	9/1/23	4/30/24	100%
CAD Design of Sub-frame	9/1/23	12/30/23	100%
Prototype of Internal Hardware	1/1/24	3/30/24	100%
Fabrication of the Subframe	1/1/24	1/30/24	100%
Assembly of Prototype	2/1/24	3/30/24	100%

September October November December January February March April

Week Number Week Number

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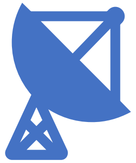
Design Details

Project Functions

Captures images

Process and encode images for transmission



Transmit packets via amateur radio

Sense the environment

CubeSat

The CubeSat is mainly used for educational purposes

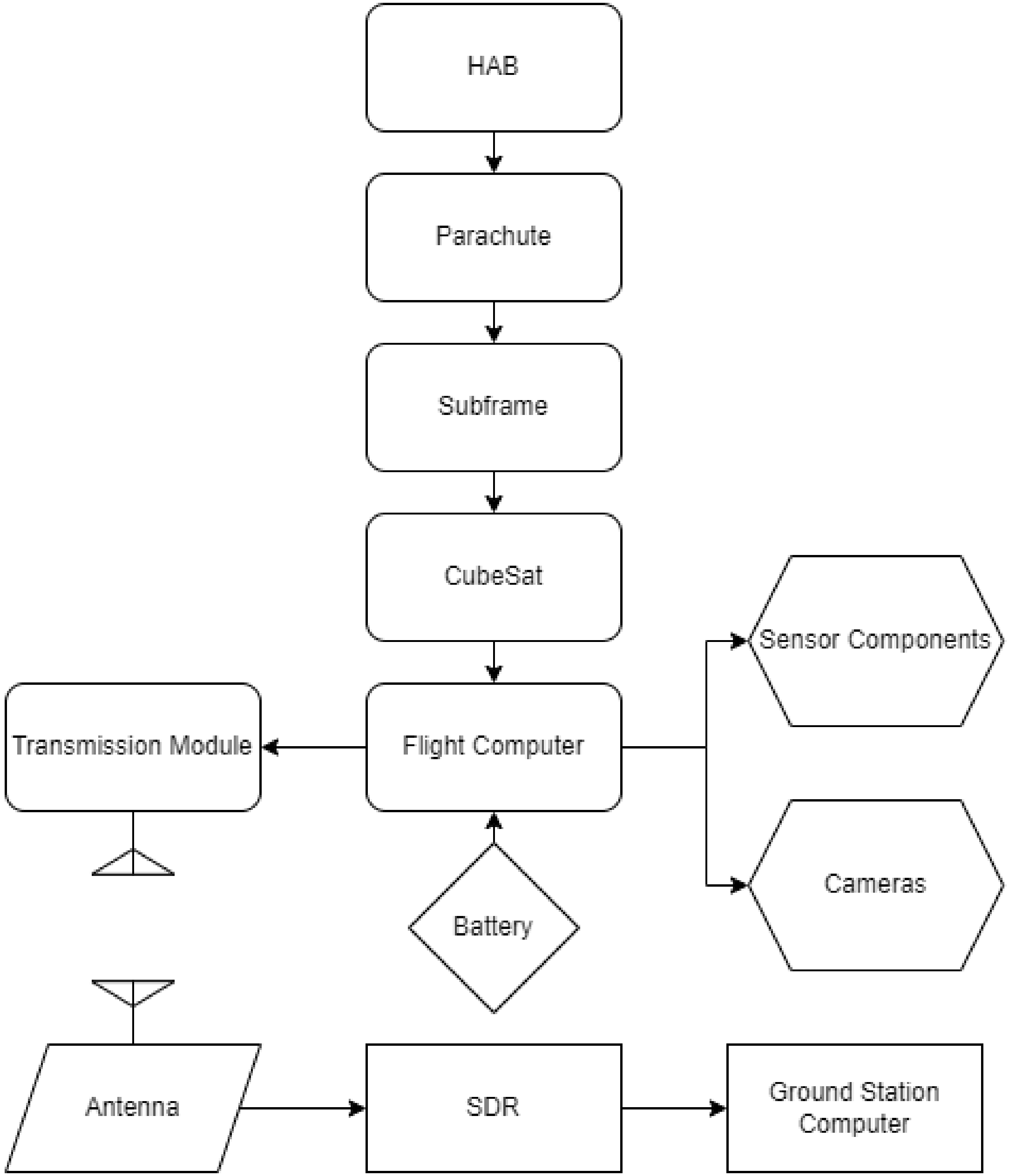
- There are few, if any, commercial products on the market
- Most projects are for research

This section describes several research papers and projects which deployed payloads similar to the IUBSAT. These were used to as reference in the design phase to determine which parts we would include in our CubeSat payload.

Major Industry Family: Aerospace research

General Block Diagram

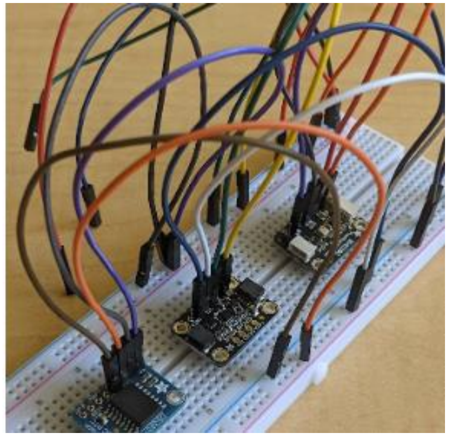
- High-Altitude balloon CubeSat to collect data and images in the high-altitude environment during the eclipse
- Stages: Takeoff, Ascent, Descent, Landing
- This is primarily a research project and not intended for public use



Similar Designs

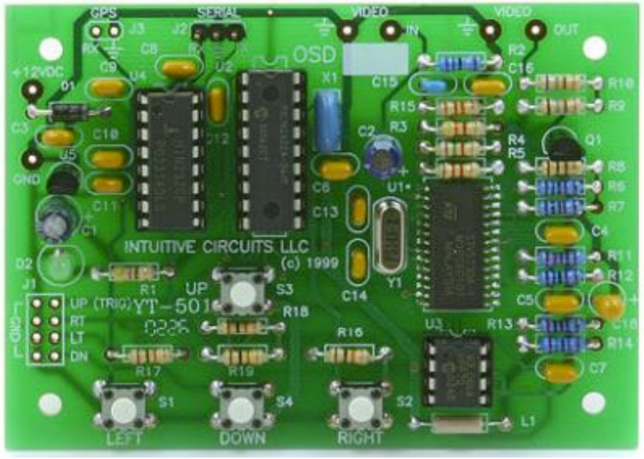
UTChattSat – John Barney, Lucas Nichols

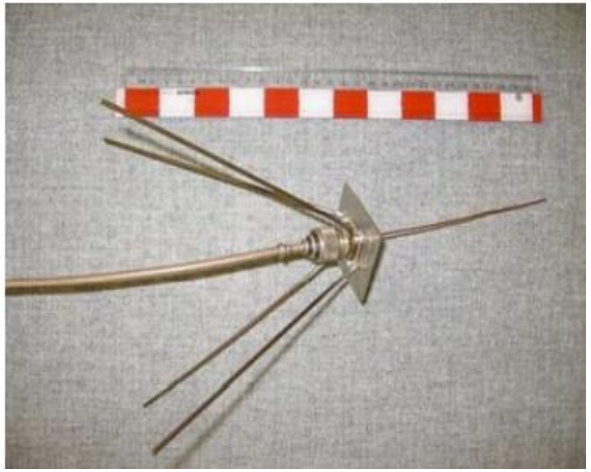
- Attempted to detect Muons at high altitudes using a CubeSat
- We will be using many of the same parts and some designs as well as expanding on what this other project attempted
- The overall operation of the previous project was successful but, unfortunately, the Muon detector failed during flight.



Real-Time Video Transmission from High Altitude Balloon- Wright State University

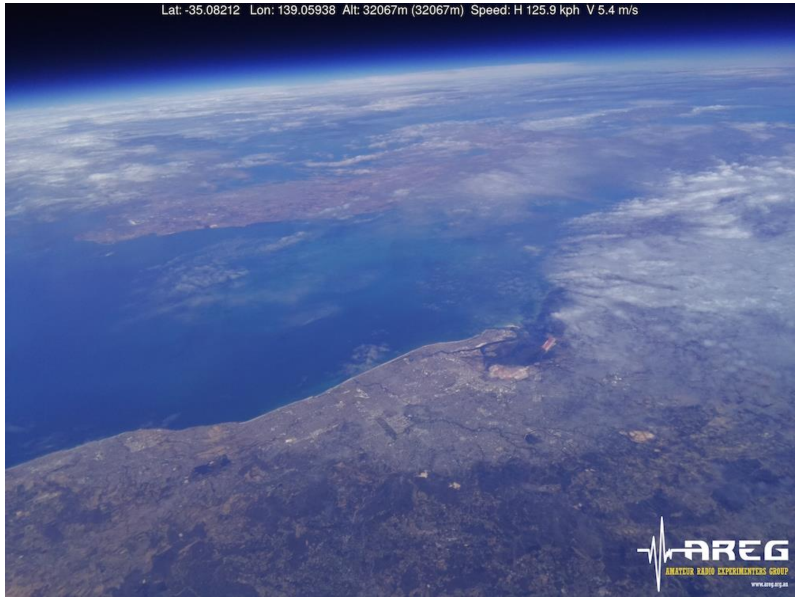
- Attempted to receive live video using off-the-shelf ATV transmitter
- Featured VM-70X in the 70cm band transmitting at 5 Watts
- Unable to receive live video after one minute of flight





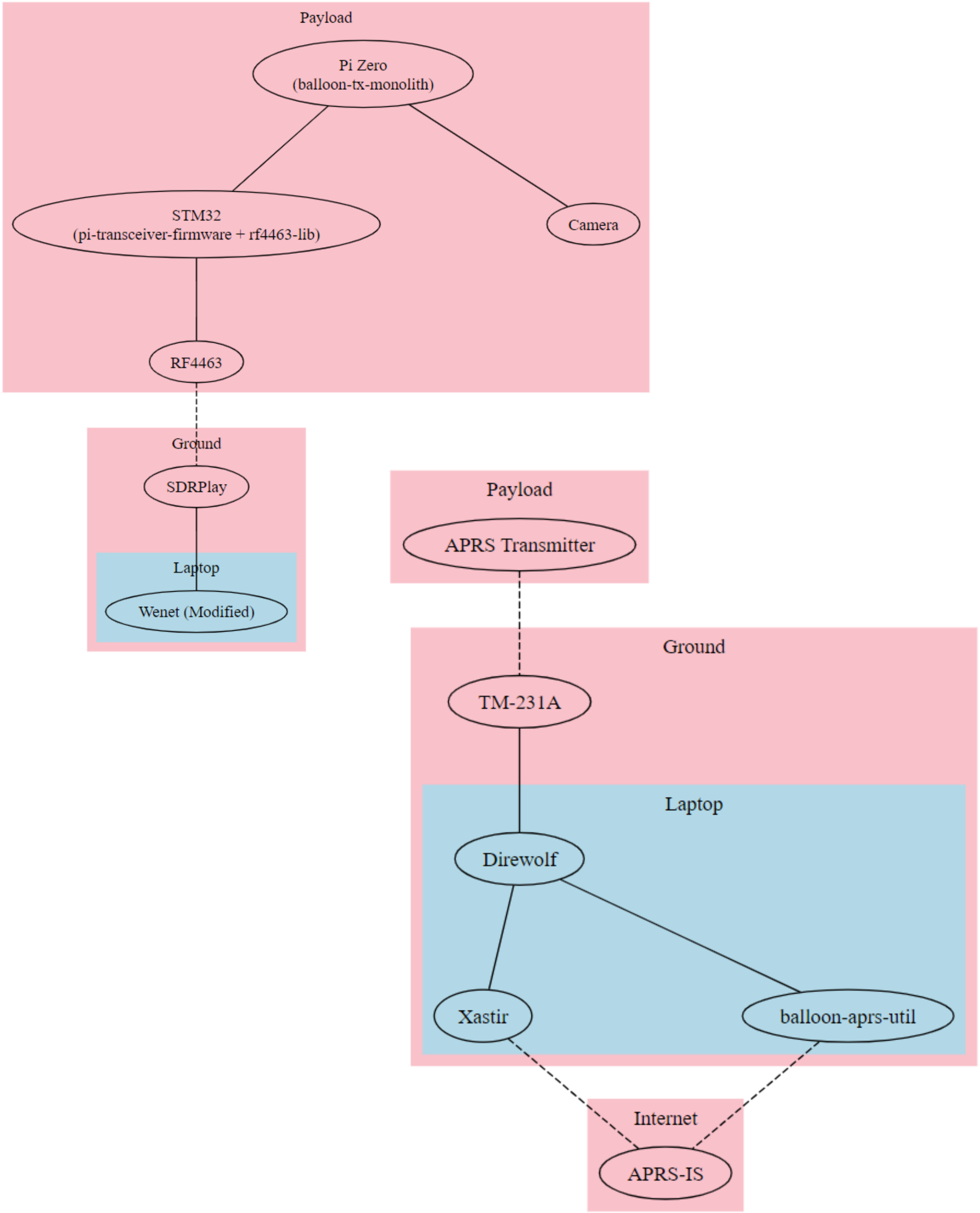
Wenet – Project Horus

- Utilized frequency-shift keying modulation and LDPC forward error correction to achieve a 115 kbit/s data rate in the 70cm band.
- Low-cost and proven downlink system with a developed software repository
- Low data rates do not allow for live video transmission, but work well for SSDV



Real Time Video from High Altitude Balloon- Stephen Downward

- Developed a video streaming system using SDR over the 70cm (430MHz) band
- Used an SDRplay RSP1A and an Arrow II Yagi antenna for receiving, and a RF4463F30 with a Raspberry Pi 4 for transmitting
- Encoded video via H264 into packets, which could be streamed to the ground station and decoded
- Video fidelity was 640x480 at 12FPS throughout the flight over an estimated distance of 50km



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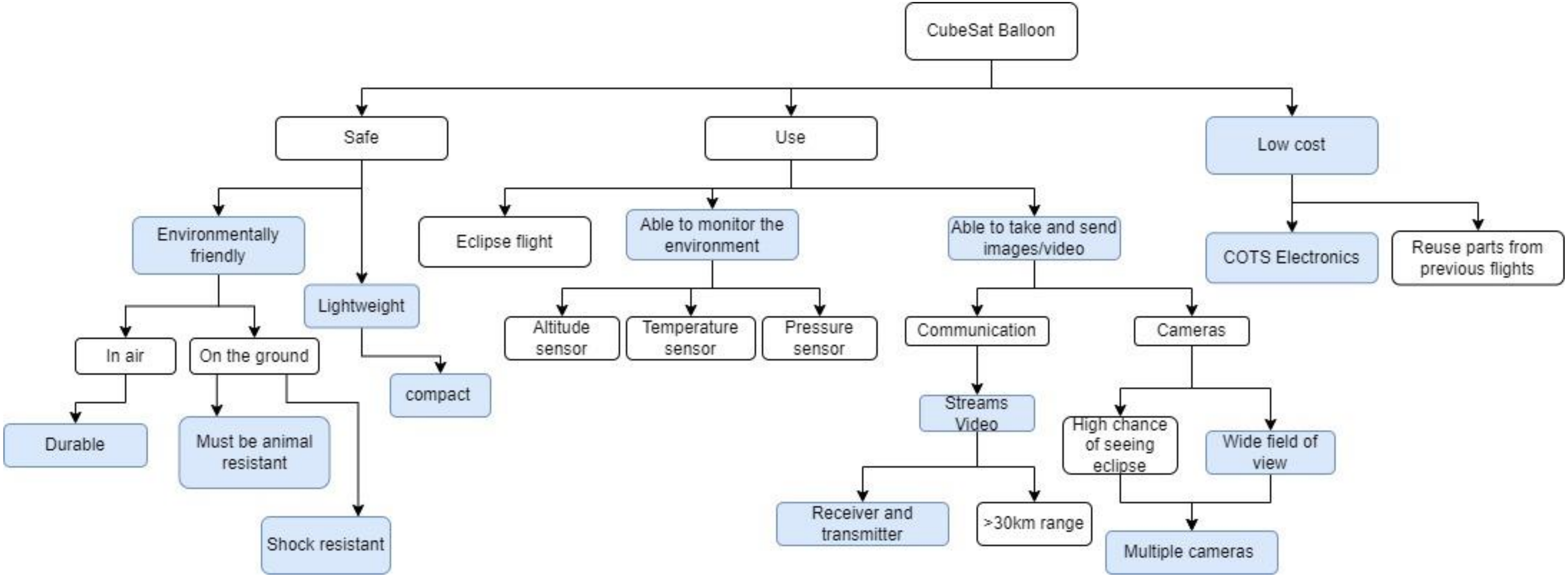
Objectives



CubeSat Balloon
Safe
Use
Low cost
Environmentally friendly
Lightweight
Eclipse flight
Able to monitor the environment
Able to take and send images/video
COTS Electronics
Reuse parts from previous flights
In air
On the ground
compact
Altitude sensor
Temperature sensor
Pressure sensor
Communication
Cameras
Durable
Must be animal resistant
Shock resistant
Streams Video
High chance of seeing eclipse
Wide field of view
Receiver and transmitter
>30km range
Multiple cameras

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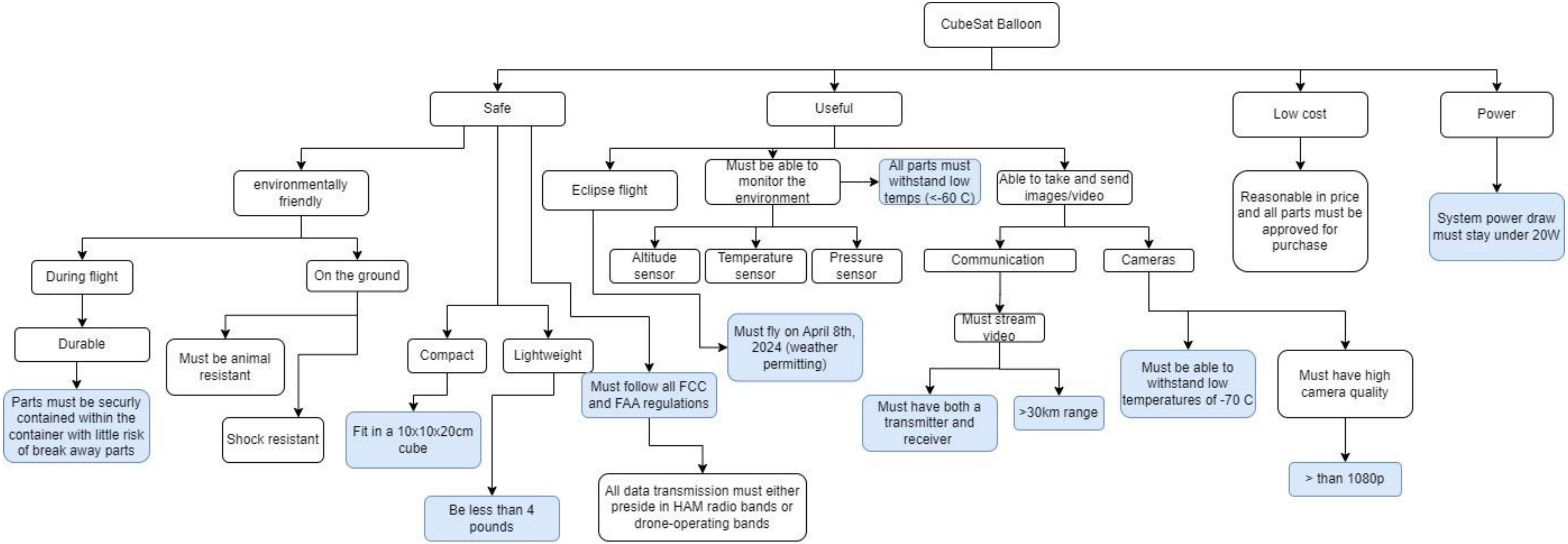
Constraints



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  - Alternative Designs
  - Testing
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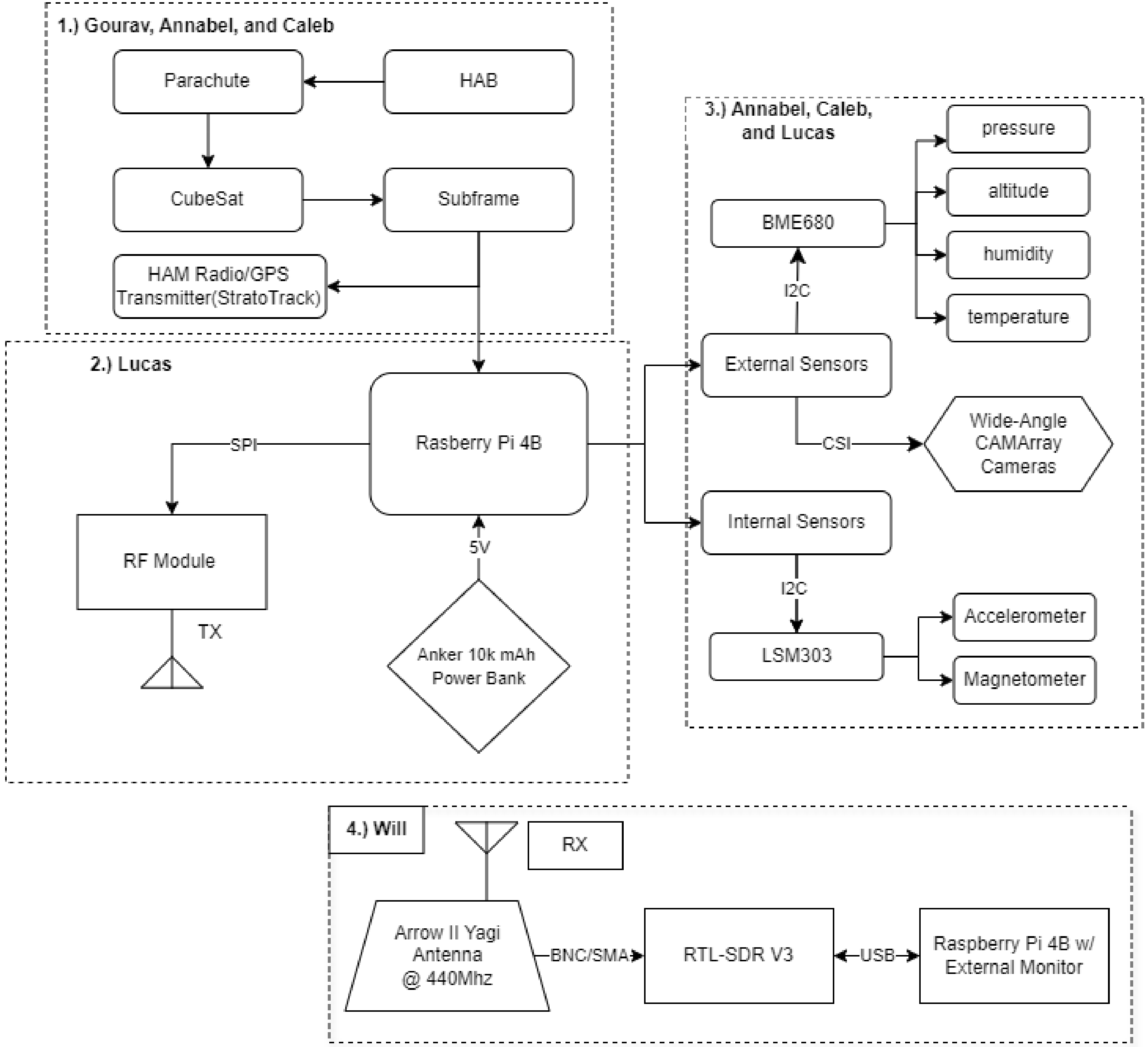
Block Diagram



Component Overview

- CubeSat:
  - Pi4B for running flight code and SSDV encoding
  - ArduCam CAMarray for 360-degree imaging
  - RFM98W transceiver mounted on LoRa expansion board sends SSDV packets down to the ground station
  - System power will be handled by one primary battery pack at 5V and the Pi will be able to distribute system power off of its power rail.
  - The CubeSat also contains a small sensor array consisting of a BME680 and LSM303AGR that we will use to sample flight and atmospheric data throughout the duration of the flight.
- Ground Station:
  - RTL-SDR hooked into an Arrow II Yagi Antenna will be the reception hardware that will run into another Pi4B to receive and decode packets.

Block Diagram Description Table

Block #	Block Name	Owner	Brief Description of Block Function	Power Interfaces	Digital Interface	Analog Interfaces	Weight
1	Structure/ Basic Tracking	Gourav, Annabel, and Caleb	3D Printed Subframe housing for payload + Stratotrack	Tracking (self-contained)- AA Battery (1.5V DC)	N/A	N/A	Subframe/ enclosure: TBD Strato-track: 30g
2	Flight Control/ Packeting	Lucas	Main Processing Unit(s)	Pi: 5V @ 3A (main power bus for sensors) STM32: 5V 100mA	SPI + I2C	N/A	Pi: 46g STM32: 4.5g Battery: TBD Other est.: 2g
3	Flight RF Transmitter	Lucas	Packet Transmitter	3.3V @ 13.5mA	SPI	N/A	Si RF 4463: 1.3g
4	Sensors/ Cameras	Caleb and Annabel	Sensor data collection and Camera Array	CAMArray: 5V pin from power supply Sensors: 3.3V provided by Pi	CSI + I2C	N/A	BME800: ~1.7g Camera Array: 30g LSM303: ~1.7g
5	Ground Station	Will	Collect signals and decode images from balloon	12V power from a car battery	SMA + USB	RX to Arrow II Yagi Antenna	N/A

Payload Bill Of Materials

Team #4	IUB-SAT										
Date											
#	Component Function (Resistor, Capacitor, Regulator, etc)	Distributor (Digikey, Mouser, Jameco etc.)	Part Description	Manufacturer Name	Package	Package Type (TH or SMT)	Price Each	Qty	Price Total	In Stock? (Yes/No)	Part Link
1	Camera Array	UCTRONICS	B0396	Arducam	N/A	N/A	$139.99	2	$279.98	Yes	https://www.uctronics.com/camera-modules/camera-for-nvidia/arducam-1mp-4-quadrascopic-camera-bundle-kit-imx219-raspberry%20pi-nvidia-jetson-nano-xavier-nx,.html
2	Camera Lenses	UCTRONICS	B0180	Arducam	N/A	N/A	$9.99	8	$79.92	Yes	https://www.uctronics.com/arducam-8-mp-sony-imx219-camera-module-with-m12-lens-wide-angle-for-raspberry-pi-invidia-jetson-nano.html
3	SDR Receiver	Amazon	R860 RTL2832U	RTL-SDR Blog	N/A	N/A	$33.95	1	$33.95	Yes	https://www.amazon.com/RTL-SDR-Blog-RTL2832U-Software-Defined/dp/B0BMKZCKTF?th=1
4	Transceiver Module	Uputronics	Raspberry PI+ LoRa Expansion Board(RF98W)	Uputronics HopeRF	PCB	N/A	$44.11	1	$44.11	Yes	https://store.uputronics.com/index.phproute=product/product&product_id=68
5	Yagi Antenna	Arrow Antenna	Model 440-7	Arrow Antenna	N/A	N/A	$128.00	2	$256.00	Yes	https://www.arrowantennas.com/arrowii/440-7ii.html
6	Temp, Pressure, and Altitude Sensor	Adafruit	BME680	Adafruit	Carrier Board	TH	$18.95	2	$37.90	Yes	https://www.adafruit.com/product/3660
7	Accelerometer and Magnetometer Sensor	Mouser	LSM303	Adafruit	Carrier Board	TH	$12.50	2	$25.00	Yes	https://www.adafruit.com/product/4413
8	Flight and Ground Station Computers	Amazon	Raspberry Pi 4 Model B 4GB	Raspberry Pi	N/A	N/A	$55.00	2	$110.00	Yes	https://www.adafruit.com/product/4296
											https://www.anker.com/products/a1229?variant=37438231806102&collections_power-

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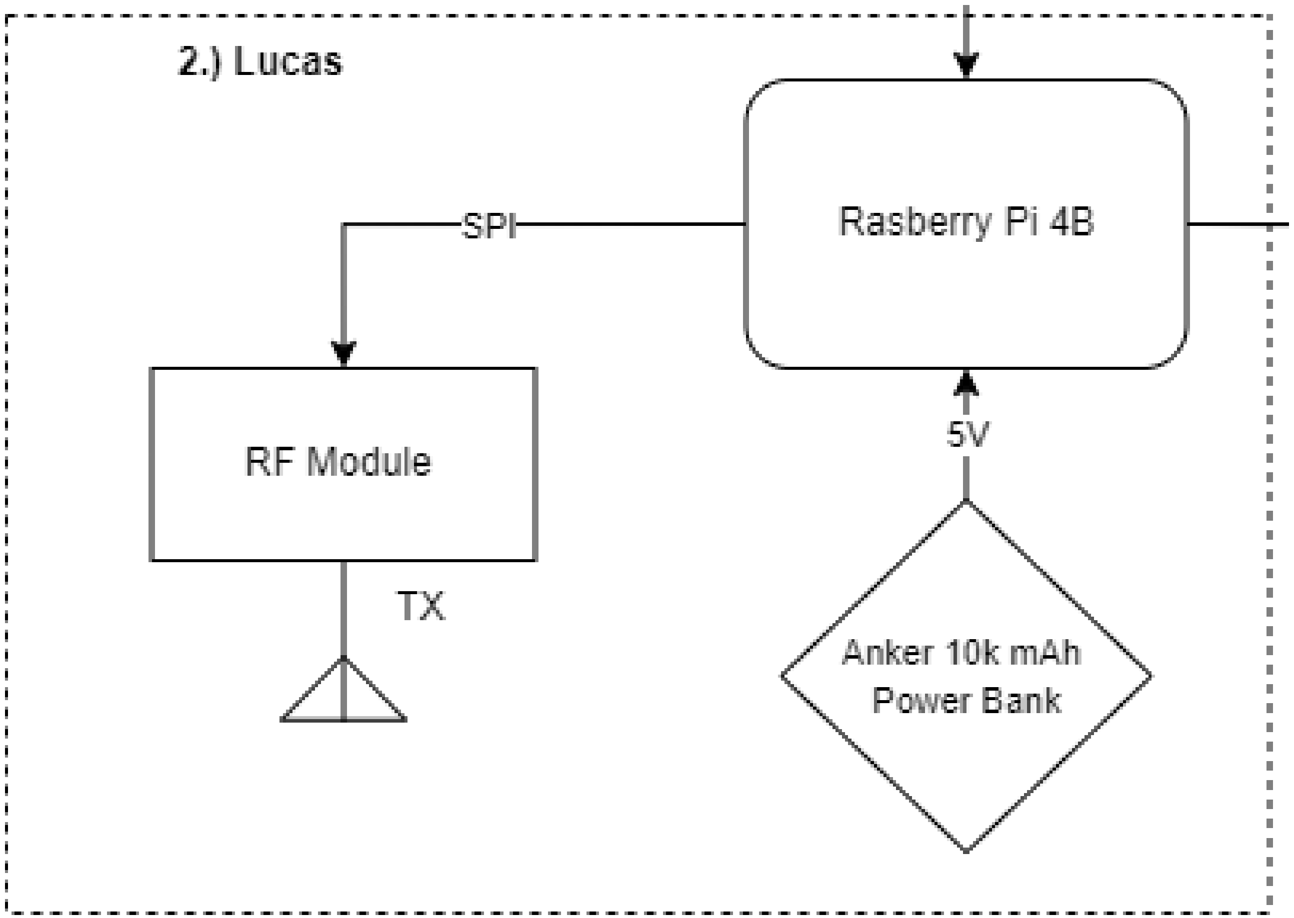
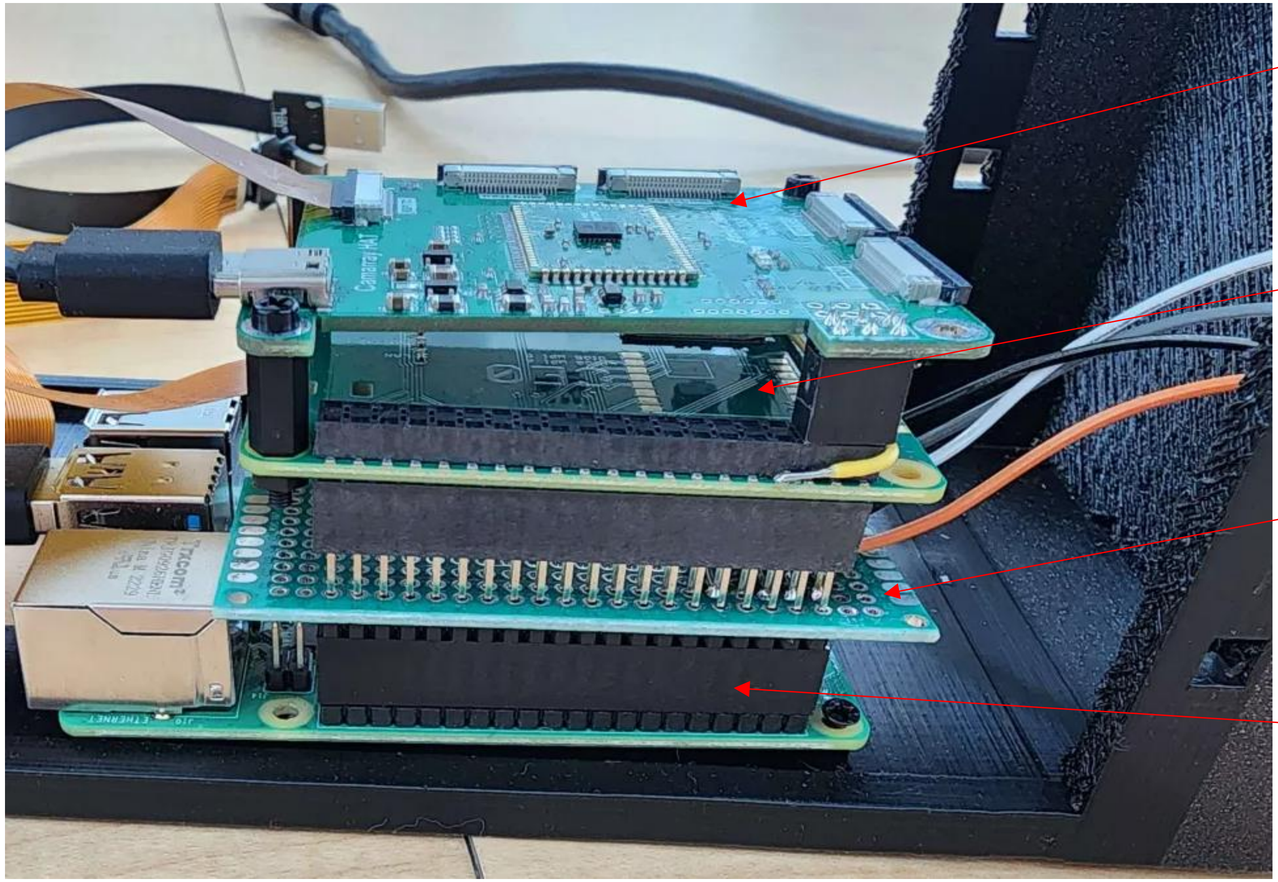
Flight Computer Diagram



Flight Computer



ArduCAM CamArray

LoRa RF Module

Pinout Board for SenseHAT

Raspberry Pi 4B+

Flight Code

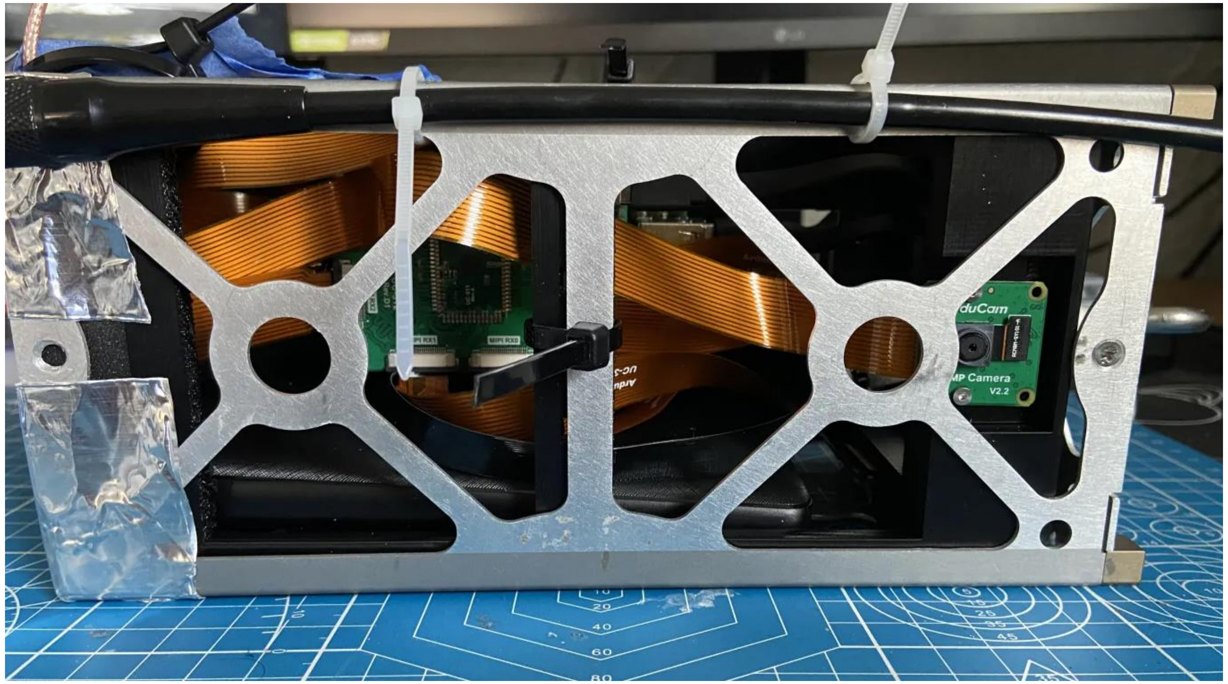
Spawns multiple processes for:

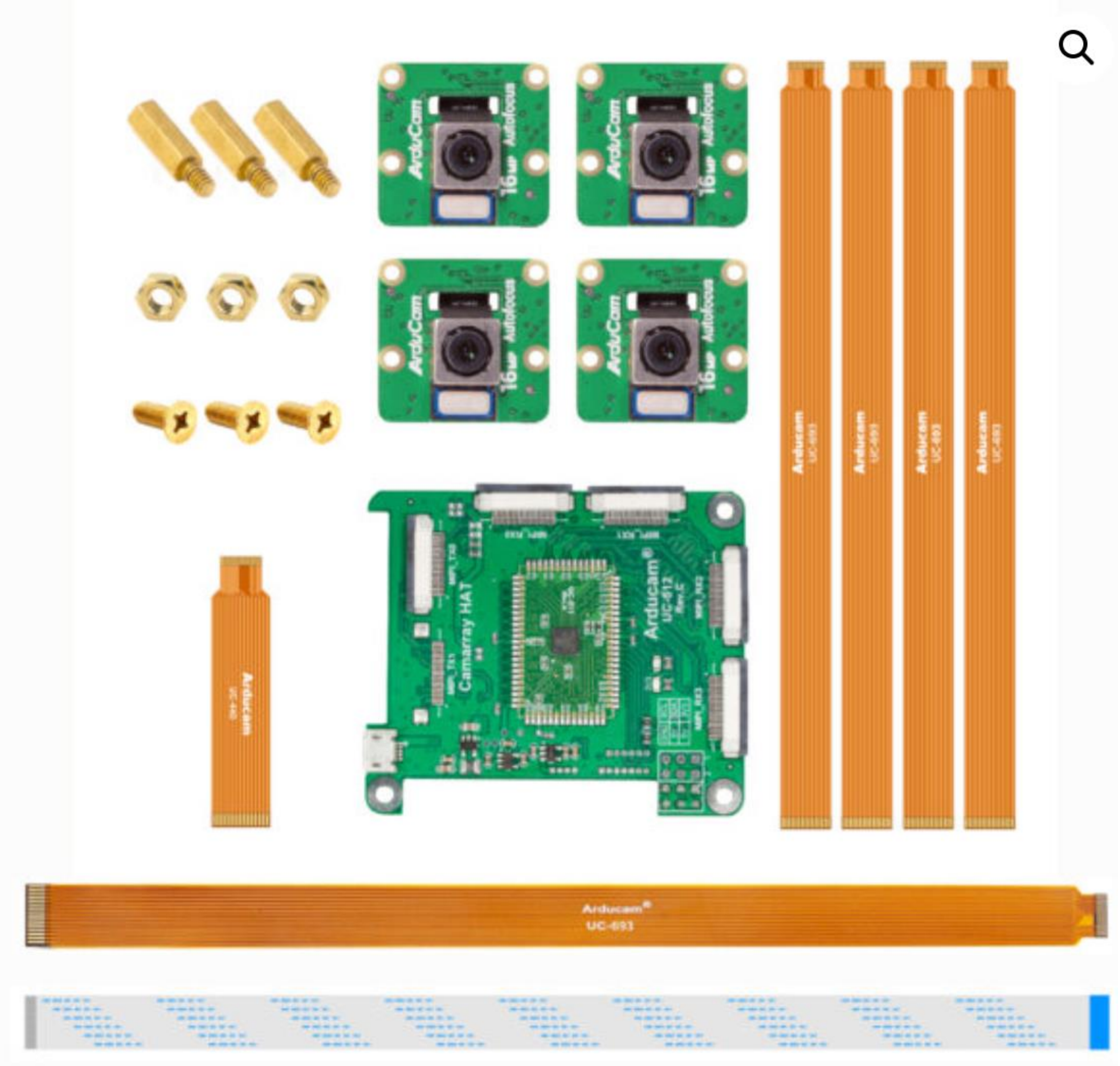
- Image Capture
    - Captures images every second using `libcamera-still`.
    - Adds image index to shared buffer which can be referenced by encoder process
- Encoding
    - Encodes newest captured image with telemetry data (altitude, temperature, etc.) using an overlay and resizing.
- Transmission
    - Transmits encoded image file using functions from Wenet.
- Sensor Data Logging
    - Logs sensor data occasionally (max interval of 10s) to a CSV file.

Key Points:

- Processes communicate using a shared memory Manager for lists and sets to synchronize images.
- A shared event (tx_done_event) coordinates encoding and transmission so that only sent images are encoded.
- The main process uses a “try…except…finally” block to ensure proper process termination and cleanup.

Arducam CamArray





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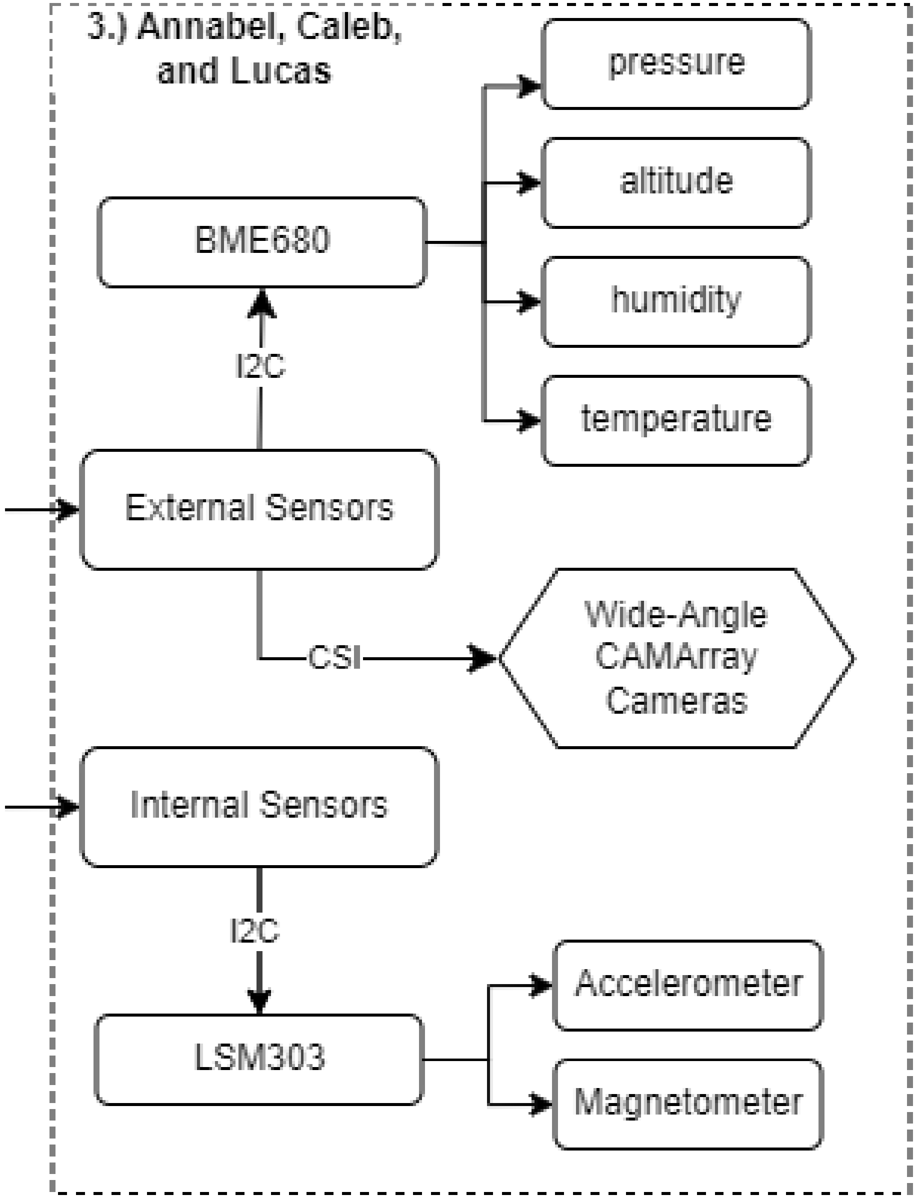
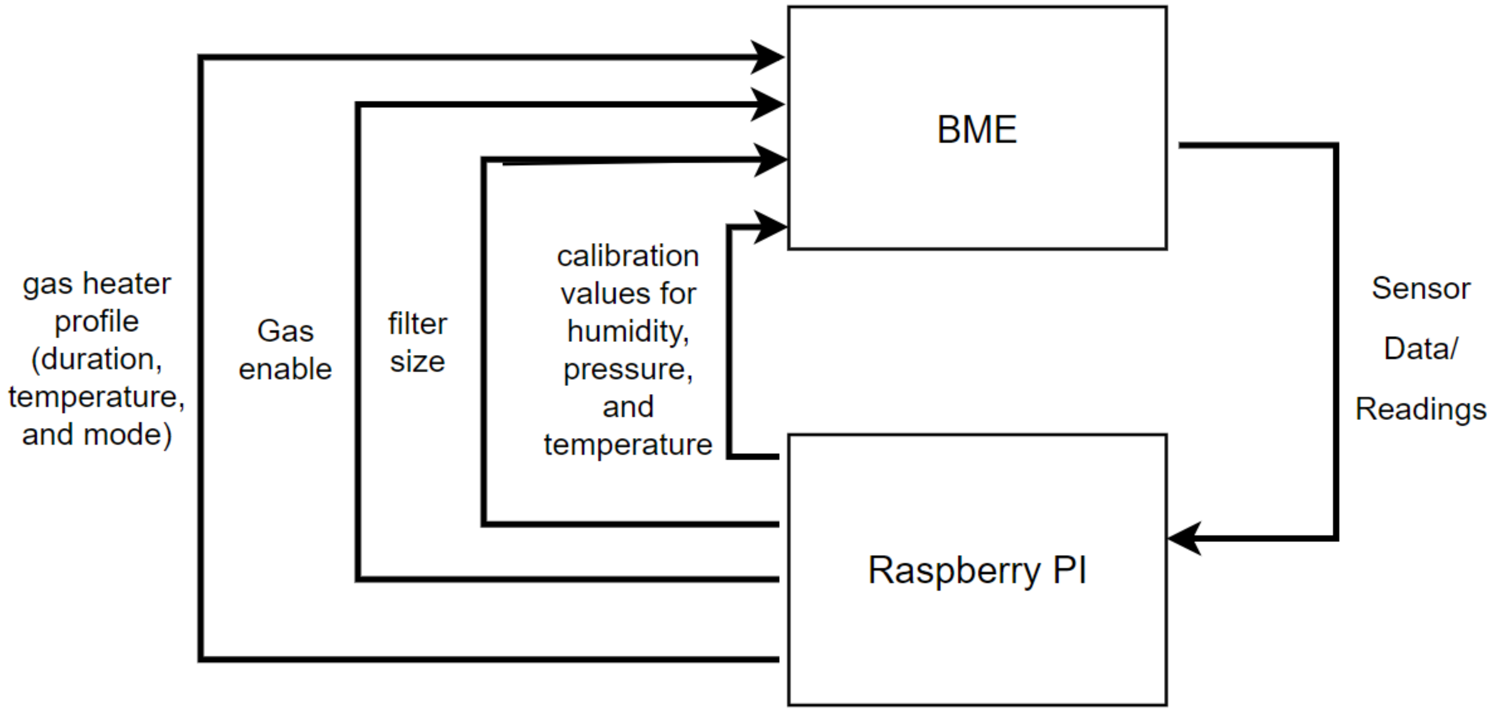
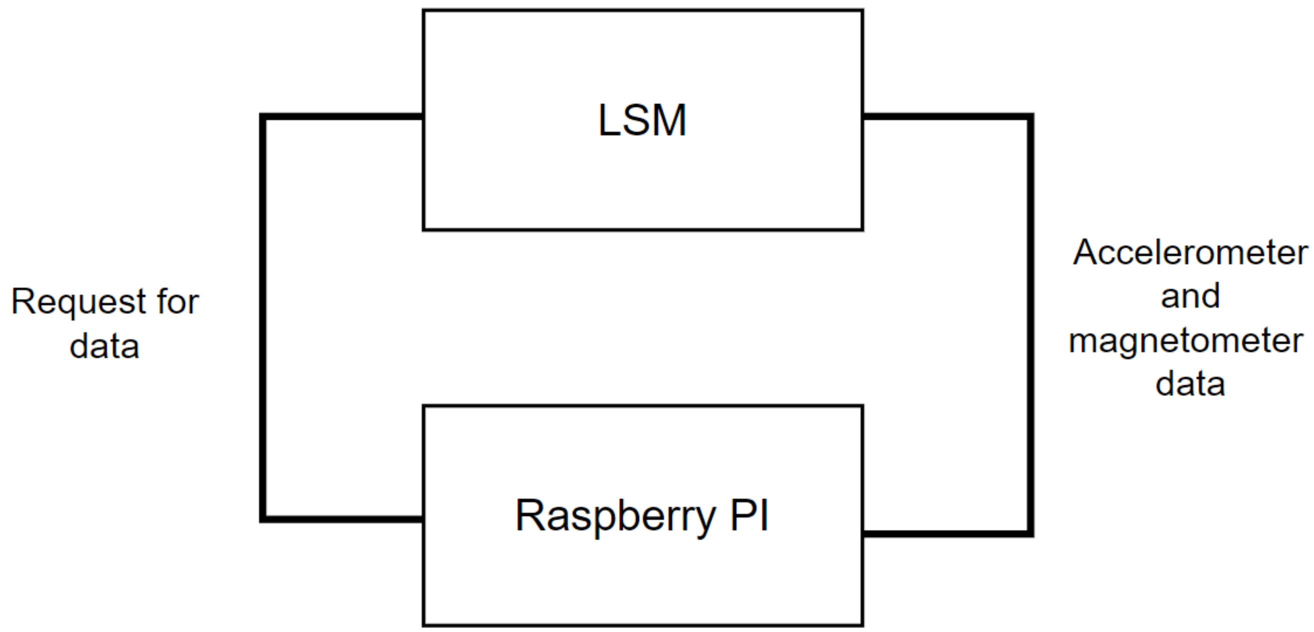
Sensor Unit Diagram





The BME680 sensor tracks temperature, pressure, and humidity using a function call and calibration data. Using this data we then can do some post processing to track the altitude as well. To measure the gas resistance, used in tracking air quality, is a bit more difficult. The BME sensor is a heated type metal oxide-based sensor. This allows for a longer sensor life and increased accuracy; however, humidity can impact results. For these reasons you must select the gas heater profile which includes the duration, temperature, and mode of the gas sensor.

BME680 Sensor



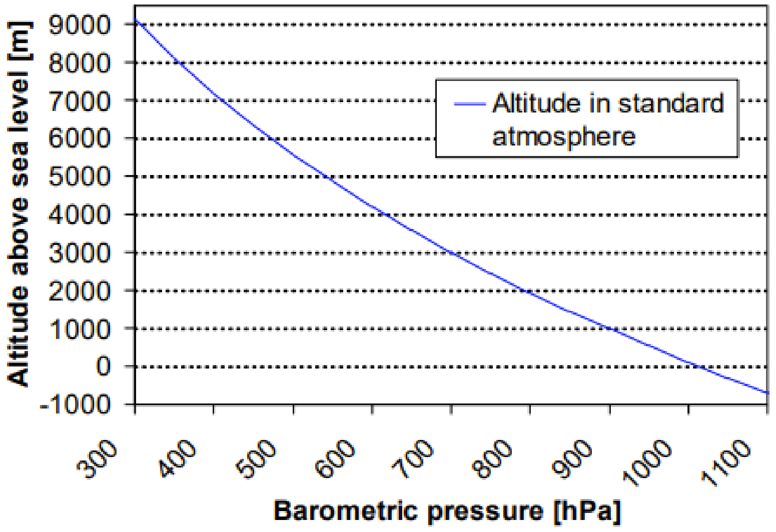
The LSM data retrieval is much simpler and is just a call to the sensor asking for information. All the data is collected and saved to a file on the pi.

LSM303 Sensor

Altitude Calculation

International Barometric Formula, pressure change of Δp = 1hPa corresponds to 8.42m at sea level

$$\text{altitude} = 44330 * \left(1 - \left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right)$$

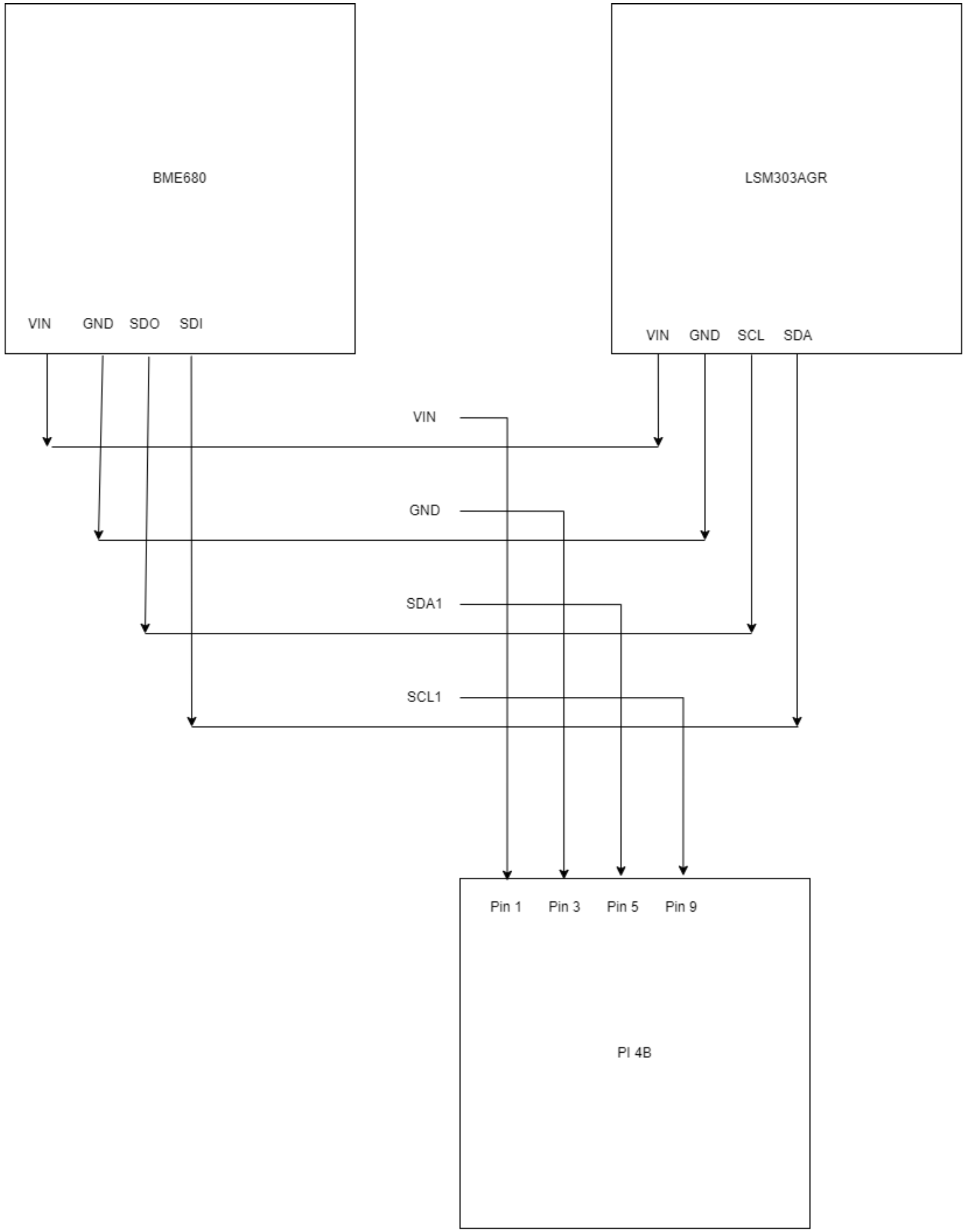


To use this formula, we first need to know the pressure at sea level when we are not at sea level

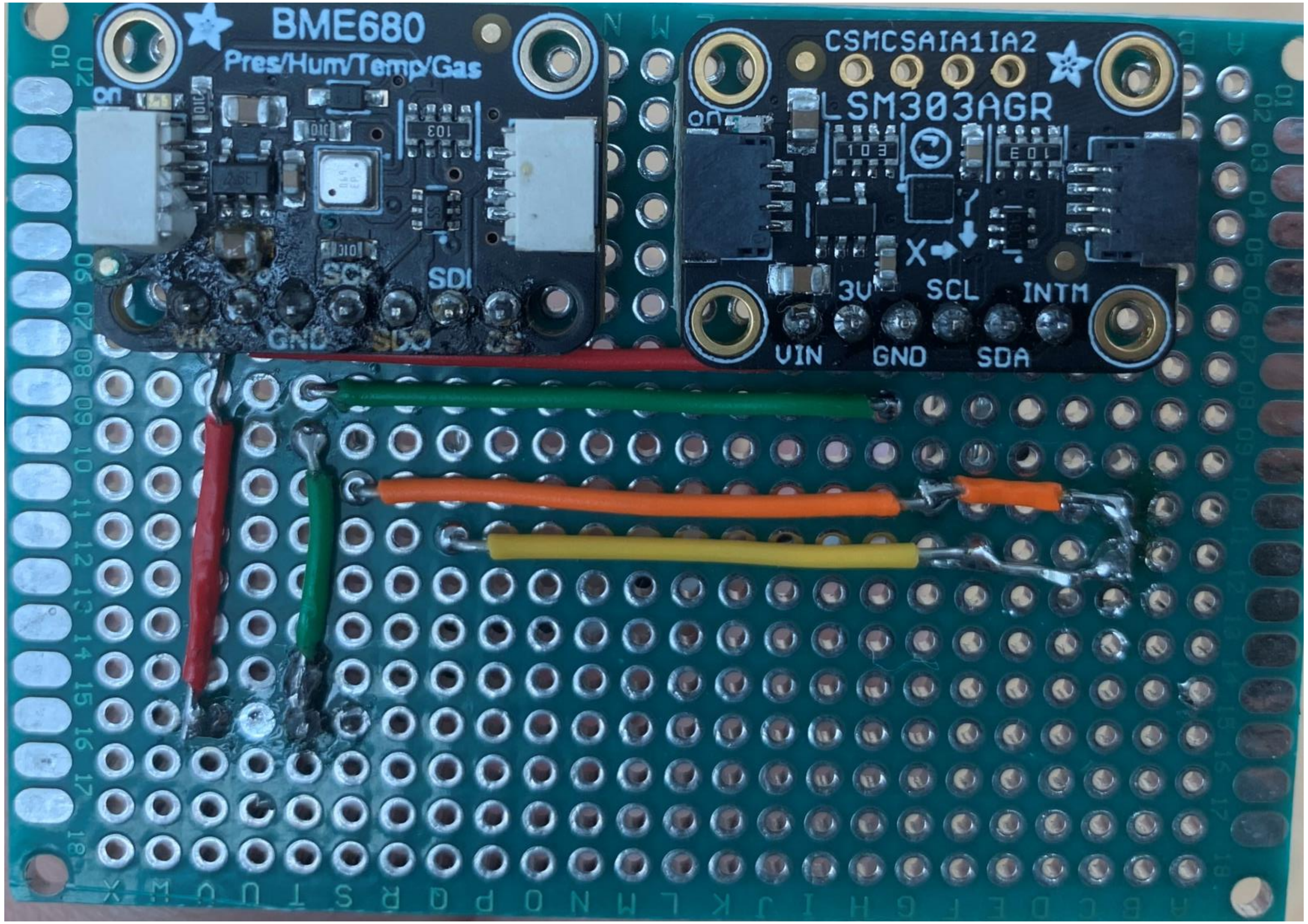
$$p_0 = \frac{p}{\left(1 - \frac{\text{altitude}}{44330}\right)^{5.255}}$$

Bloomington is 804ft (~245m) above sea level

Sensor Block Diagram



SenseHAT


BME680
Pres/Hum/Temp/Gas
LSM303AGR
CSMCSAIA1IA2
VIN
GND
SCL
SDA
SDI
3V
INTM

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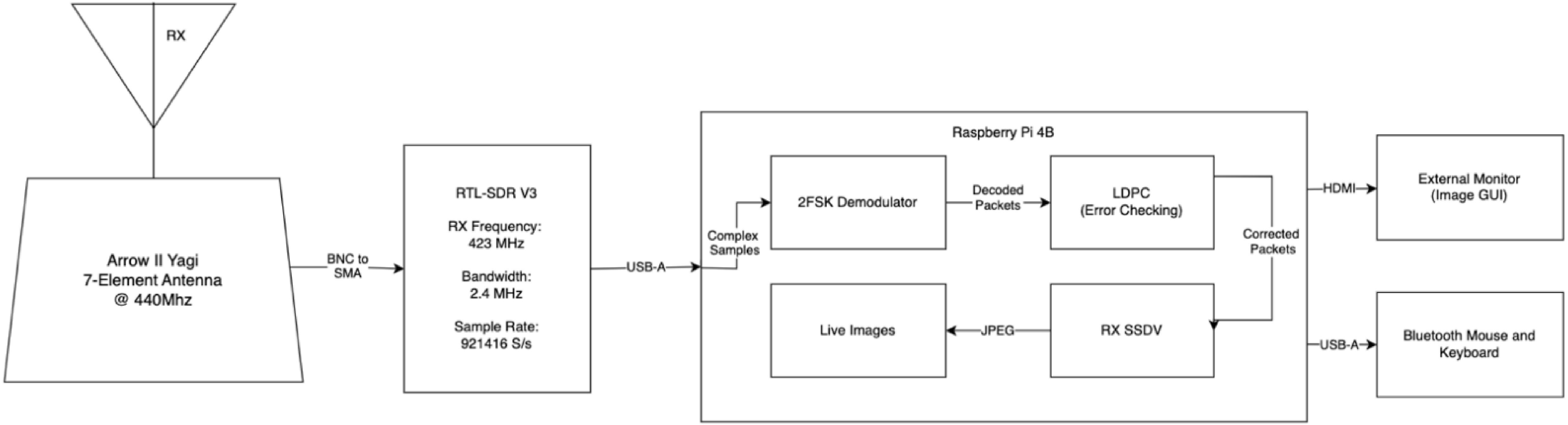
Ground Station Block Diagram



Ground Station

Purpose: Receive live image packets transmitted by the RF module and perform demodulation to display images on the ground station computer.

Three Main Components:

- Arrow II Yagi 7-Element Antenna: Satellite antenna centered at 440 MHz.
- RTL-SDR V3: Software Defined Radio used to sample RF module signal.
- Raspberry Pi 4B: Perform demodulation, error correction, and Slow Scan Digital Video (SSDV) decoding.

Ground Station on Launch Day

Theoretical Distance Calculation from Free Space Path Loss Equation

```python
import math

pi = math.pi

c = 2.99792458e8

f = float(input("Frequency in Mhz: "))
gtx = float(input("Enter transmitter gain (db): "))
grx = float(input("Enter reciever gain (db): "))


d = 10**((90+gtx+grx-(20*math.log10(f*1000000))-(20*math.log10((4*pi)/c)))/20)
print(d/1000,"km")
```

```
Frequency in Mhz: 423
Enter transmitter gain (db): 17
Enter reciever gain (db): 12
50.265553774584255 km
```

$$FSPL = 20log_{10}(d) + 20log_{10}(f) + 20log_{10}\left(\frac{4\pi}{c}\right) - GTx - GRx$$

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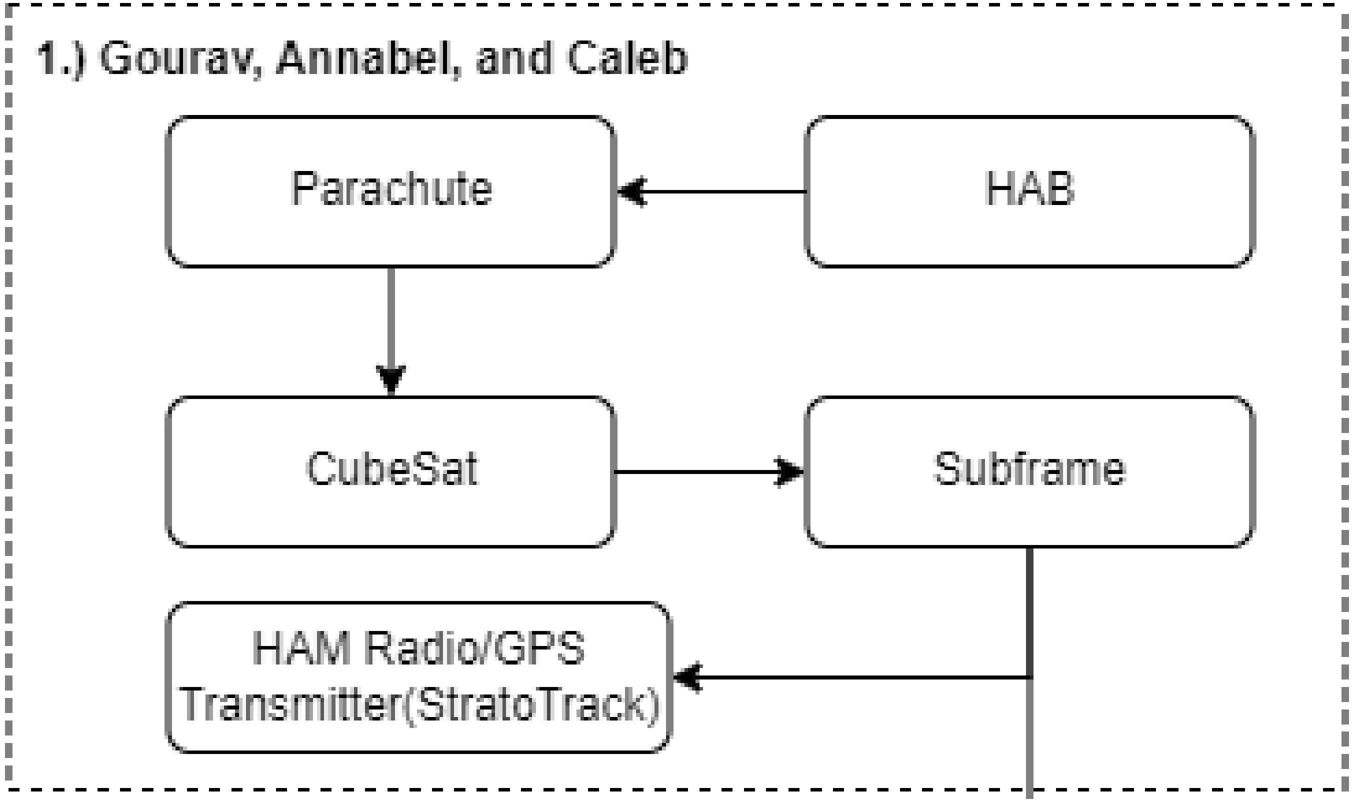
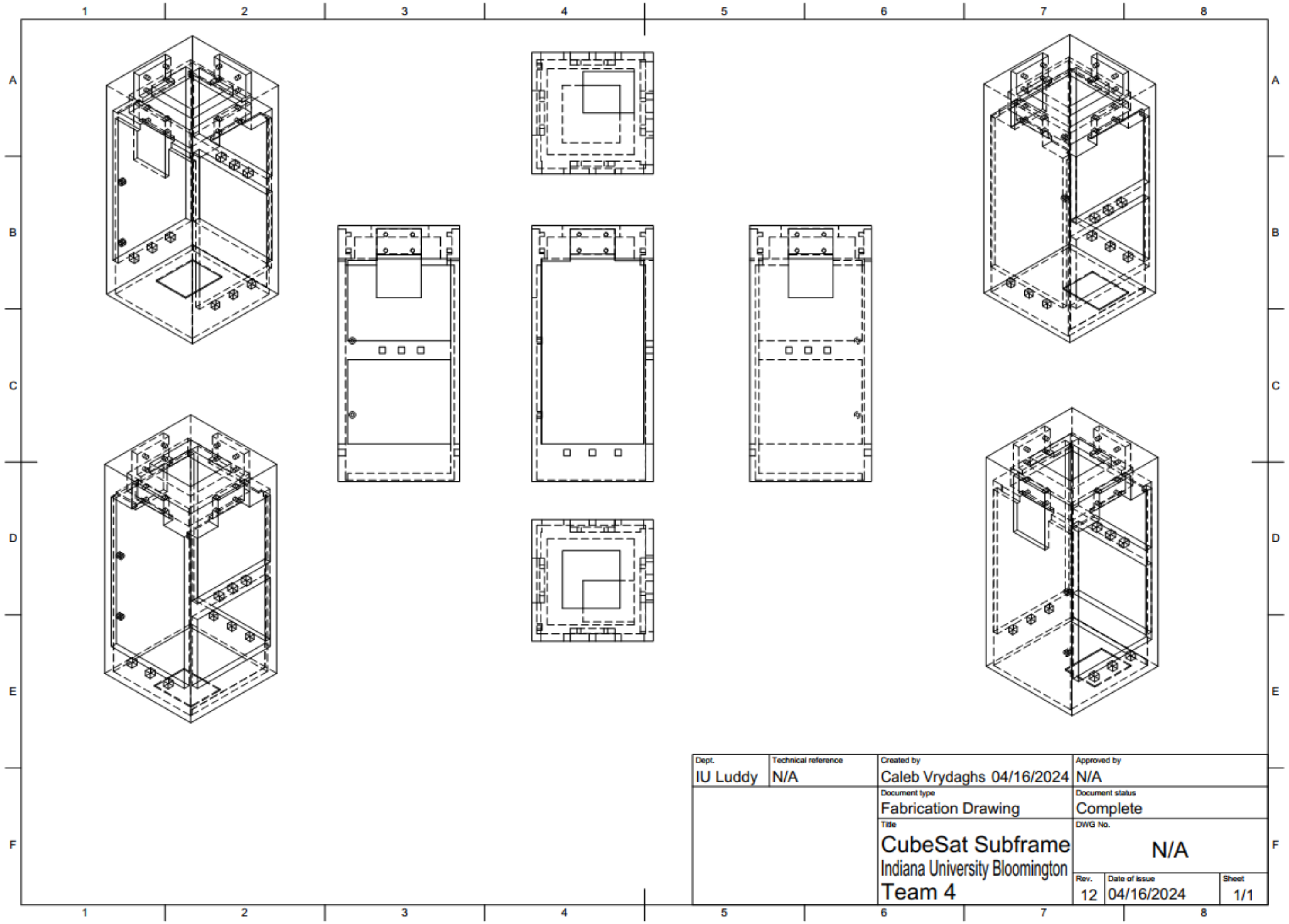
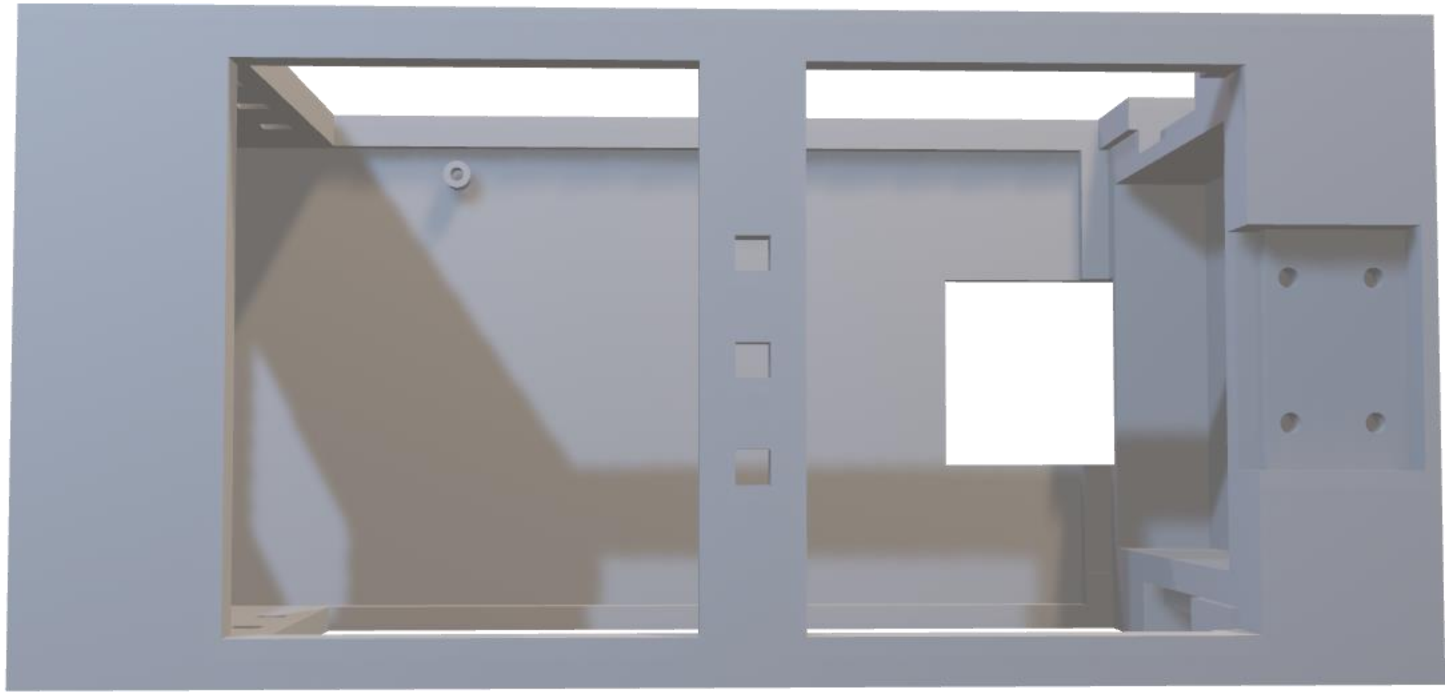
Enclosure Rigging, and Tracking Diagram



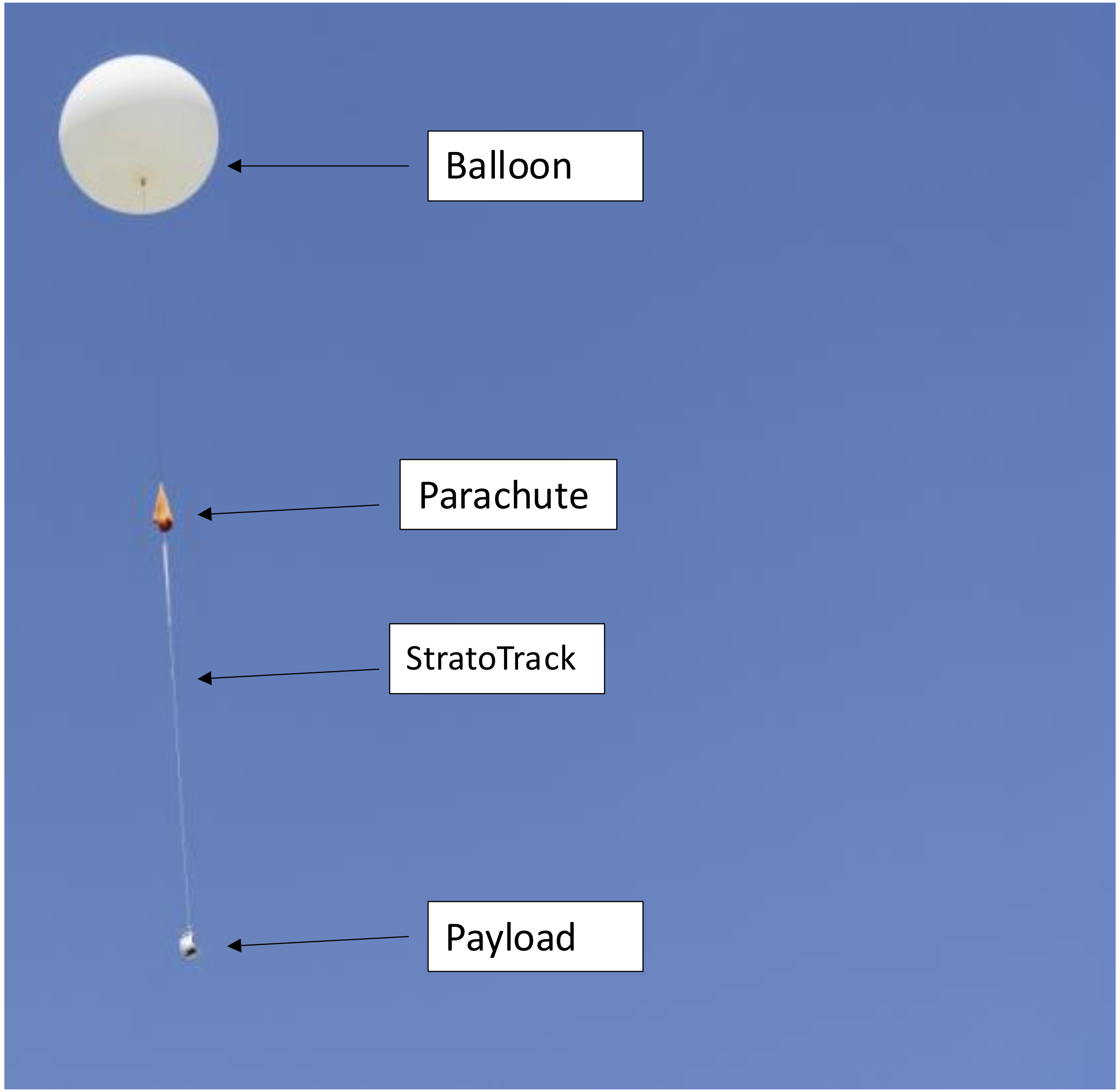
Subframe Engineering Drawing



Subframe Model



Rigging



StratoTrack

APRS Transmitter

- Designed for tracking high-altitude balloons.
- Uses amateur radio network on the 2-meter band
- Transmits GPS, barometric pressure, altitude, and speed.
- Allows users to view their telemetry data in real-time on a web interface.
- Requires line-of-sight to nearby digipeaters which means packets are usually only received at altitudes >1000 meters.

SPOT Trace

Satellite GPS Device

- Used of tracking the payload at low altitudes.
- Uploads GPS location to website/app every 5 minutes.
- Reported to work at altitudes below 20,000 ft.
- Intended to locate the payload after landing when APRS transmissions are no longer being received.

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Morphological Chart

Function	1	2	3	4
Imaging	ArduCAM Array	IMX519 Pi Cam	IMX219 Pi Cam	Go Pro
Video Transmission (VTX)	RF4463F30 1W Transceiver	HopeRF RFM98W Lora Expansion Board	434MHz Radiometrix NTX2	RM-70X ATV Transmitter
Video Reception (VRX)	SDRplay RSP1A	RTL-SDR	1.3 GHz RMRC FPV Reciever	
Measure Temperature and Pressure	BME680	BME280	MPL3115A2	MS8607
Measure Magnetic Field and acceleration	LSM303AGR	MMC5983MA	HMC5883L	BMM150
Power	Phone Power Bank	LiPo drone cell	AA/AAA batteries	DC-DC voltage steppers on a 12V pack

First-Person View (FPV) Drone Technology

- FPV equipment can operate in digital and analog environments and can operate in multiple frequencies such as 5.8GHz, 2.4GHz, 1.3GHz, and 900MHz
- High cost and limited transmission range
- Digital transmission has low hardware selection with a select few companies with little crossover
- Analog systems have a longer range with decreased fidelity however, power requirements for different components represented a major hurdle

Real-Time Video

- Differences from final design:
  - Completely custom flight code written in Rust
  - STM32 Blackpill for video packeting to be transmitted
  - RF4463 transceiver to send video packets
- Ground Station:
  - SDRplay SDR hooked into an Arrow II Yagi Antenna connected to a laptop for reception

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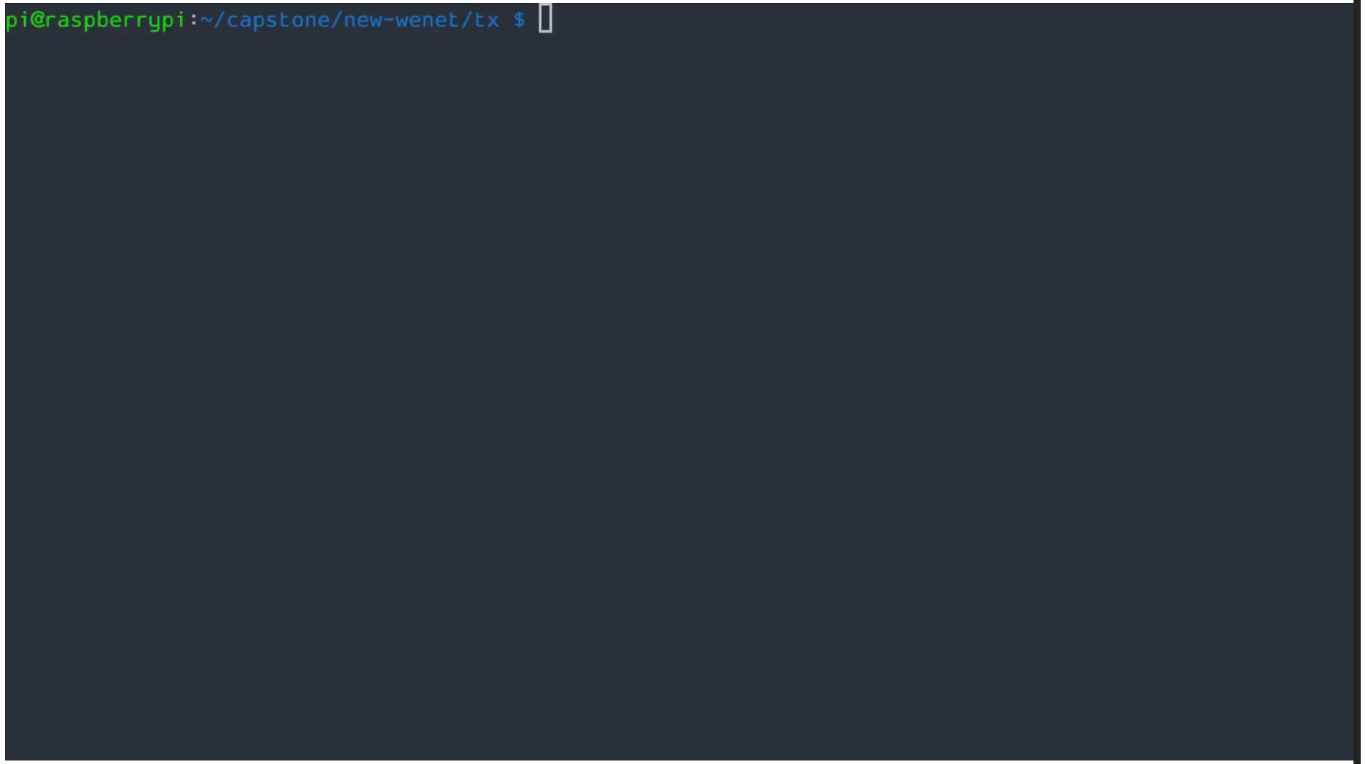
  - Considerations

Demo Video


pi@raspberrypi:~/capstone/new-wenet/tx $


Wenet Dashboard
Project Horus
www.projecthorus.org

Tether Test

- For prep, we performed a tether test to:
  - Understand and practice rigging of the balloon and payload.
  - Test the electronics of the payload
- The test was successful, with the transmission working after a quick reboot inside Luddy
- Prior to the test permission had to be granted by the IU office of Insurance, Loss Control and Claims.

Tether Test Helium Calculations

Balloon Stats

1500g balloon

950g payload weight

Neutrally Buoyant

(weight of balloon and payload) / (28g/ cubic ft) = (1500+950)/28 = 87.5 cubic feet of helium

1 cubic foot of helium = 0.0114 pounds

Helium Requirements

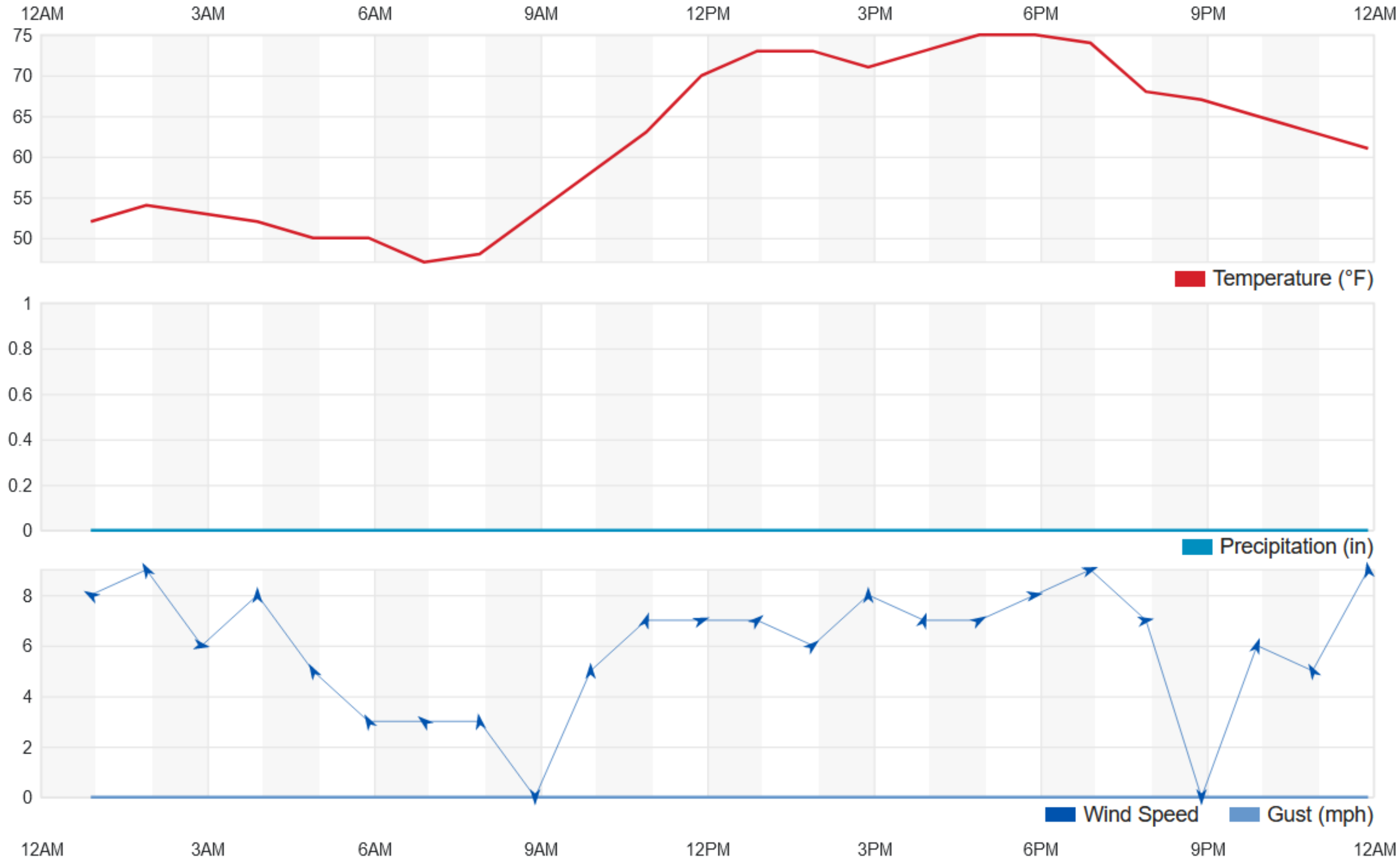
For slight upward lift 90 cubic feet is roughly 1.026 pounds of helium.

Overview

- Payload Design
  - Block Diagram
  - Flight Computer
  - Sensor Unit
  - Ground Station
  - Enclosure, Rigging, and Tracking
  - Alternative Designs
  - Testing
  - Flight Path and Planning
  - Considerations

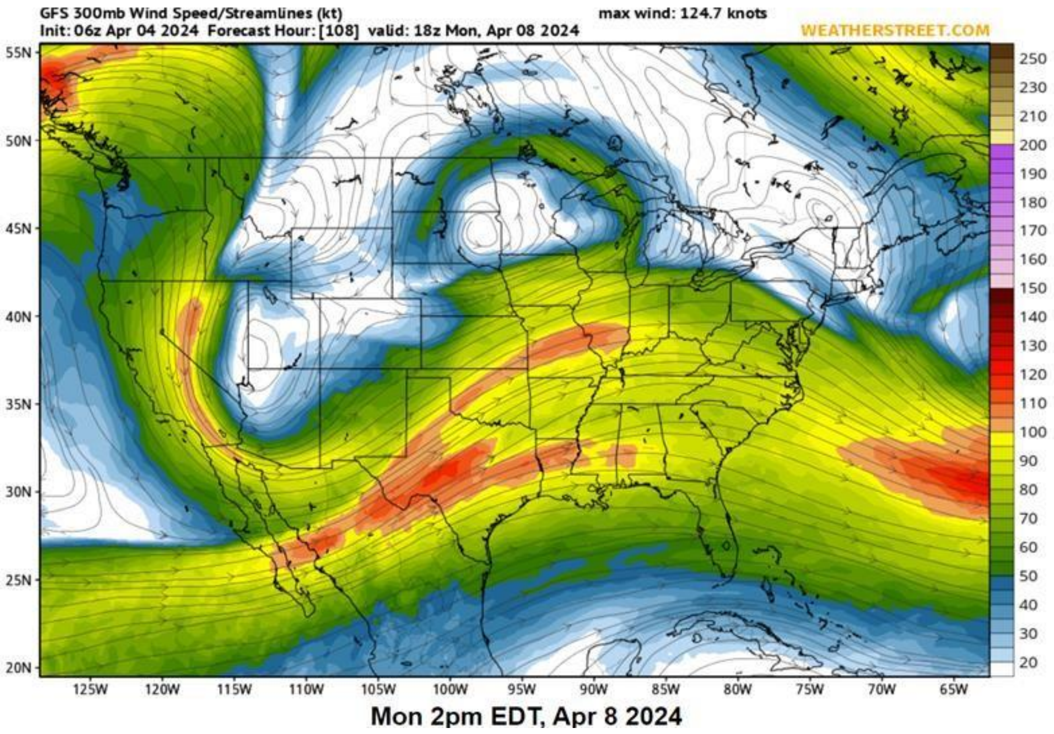
Weather

- Launch weather greatly influenced our flight planning
  - FAA requires <50% cloud coverage
  - Need little/no wind
  - Need acceptable jet stream speeds
- Weather variability required agile planning
  - Decisions made on the morning of launch day

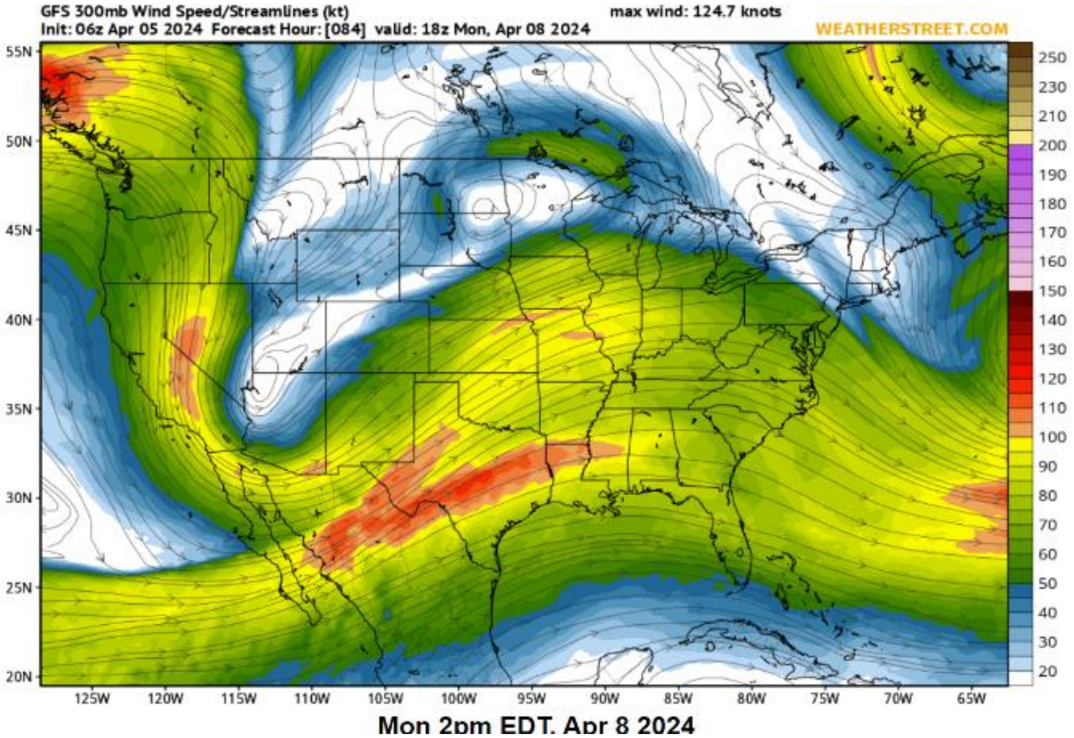


https://www.wunderground.com

Jet Stream Patterns



Day Before Launch



Day of Launch

Balloon Performance

Balloon Performance Calculator

Input

Balloon Size (grams)

1500

Payload Weight (grams, 1-20000)

950

Positive Lift (grams, 1-20000)

1260

Calculate

Output

Required Helium (in cubic feet)

133.37594643462538

Estimated Burst Altitude (in meters)

33180

Average Ascent Rate (in meters/second)

5.2461003899633525

Ascent Time (in minutes)

105.41163128673242

a High Altitude Science project

Launch Details

Launch site

[redacted]

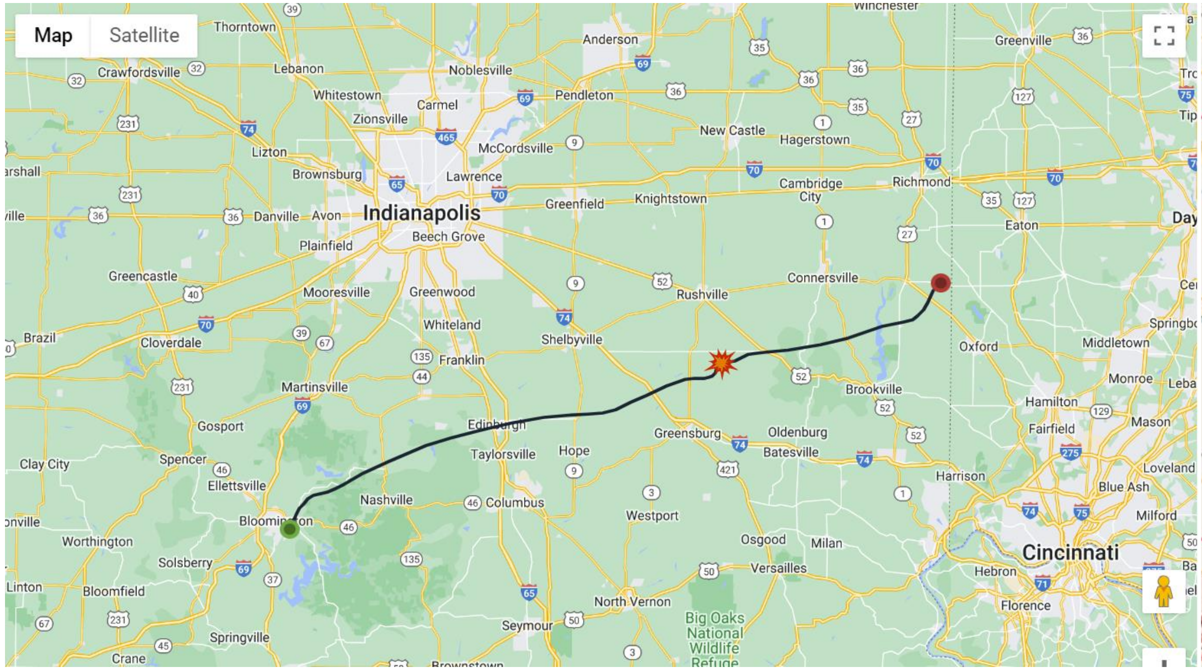
Date	Local launch time
08/04/2024	13 : 15

Launch altitude (m)	Burst altitude (m)
840	33180

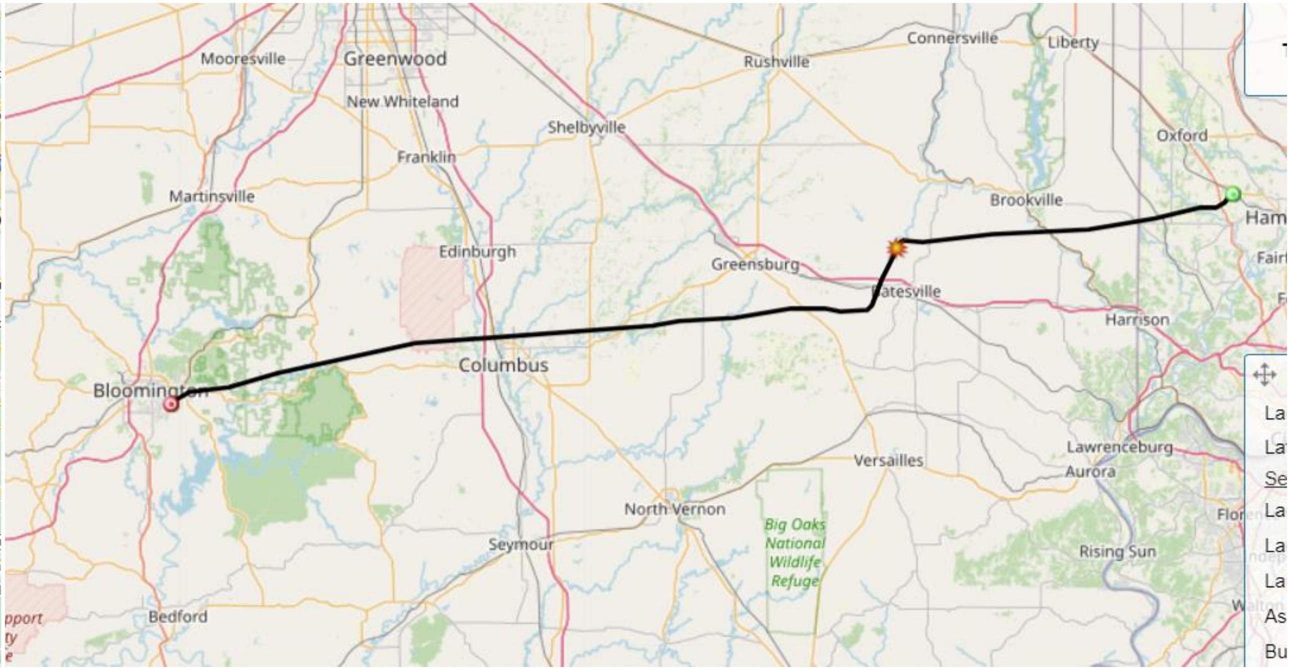
Ascent rate (m/s)	Descent rate (m/s)
5.25	5.35

This information is fed into several different flight path prediction tools. This information is gathered from the balloon performance tool.

Flight Path

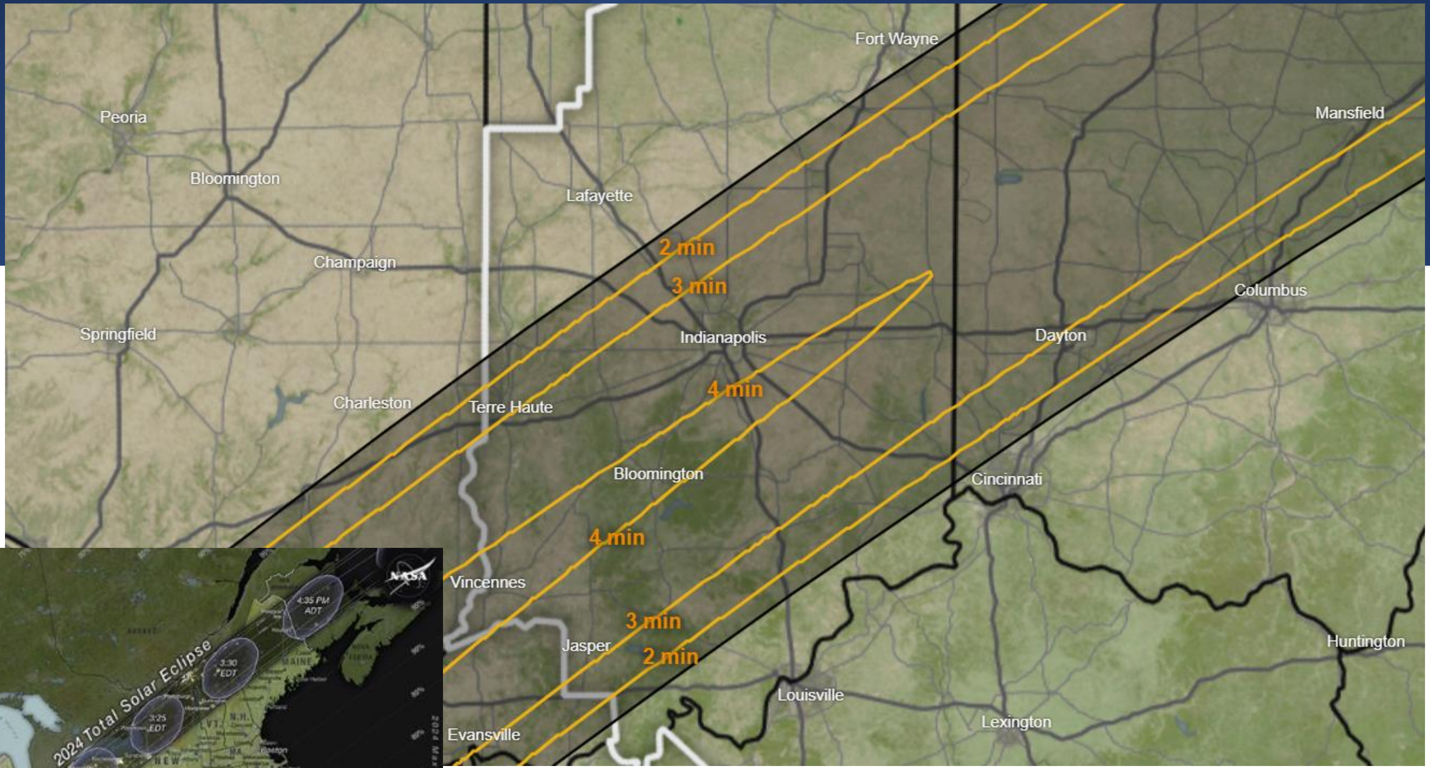


Map
Satellite
Indianapolis
Cincinnati
Bloomington
Columbus
Greensburg
Batesville
Rushville
Connersville
Richmond
Oxford
Brookville
Big Oaks National Wildlife Refuge



Mooresville
Greenwood
New Whiteland
Franklin
Shelbyville
Rushville
Connersville
Liberty
Oxford
Brookville
Martinsville
Edinburgh
Greensburg
Batesville
Harrison
Columbus
Bloomington
Versailles
Lawrenceburg
Aurora
North Vernon
Seymour
Big Oaks National Wildlife Refuge
Rising Sun
Bedford

Eclipse Path



Notice to Airmen (NOTAM)

To ensure safety the team had to submit a NOTAM. This was done by calling a number and giving information such as the state, radial and distance (nm) to the nearest VOR station (OOM), direction of flight, maximum altitude, and expected time to certain altitudes.

Ascent Time Calculations

```
ftlist = [1000,2000,5000,10000,20000,30000,40000,50000,60000,75000,100000] # Altitudes in ft (FAA/NOTAM requirements)
ascent_rate = 5.4/0.3048 # in m/s convert to ft/s

for i in ftlist:
    print(i,"ft = ",(i/(ascent_rate*60)), ' min, \n')
```

```
1000 ft =  0.9407407407407408  min,

2000 ft =  1.8814814814814815  min,

5000 ft =  4.703703703703703  min,

10000 ft =  9.407407407407407  min,

20000 ft =  18.814814814814813  min,

30000 ft =  28.22222222222222  min,

40000 ft =  37.629629629629626  min,

50000 ft =  47.03703703703704  min,

60000 ft =  56.44444444444444  min,

75000 ft =  70.55555555555556  min,

100000 ft =  94.07407407407408  min,
```

The duration taken to reach specific altitudes during the ascent stage is calculated based on our expected ascent rate.

This is relevant as the time to certain altitudes is relevant to the NOTAM request. We also used this calculation to determine optimal launch time for the eclipse.

Flight Plan

Day of flight:

- 10:15a Arrive at the Geology building and load equipment into cars
- 10:40a Arrive to Kroger and get donuts
- 11:00a Arrive at launch location
- 11:00a-11:30a Set up tables and tent
- 11:30a-12:15p Software and transmission testing
- 12:15p-12:50p Rigging
- 12:50p-1:20p Final preparations
- 1:36p Launch
- 1:45p-3:30p watch eclipse
- 3:35p Leave Bloomington to recover payload
- 8:30p Payload recovered
- 1:30a Arrive back in Bloomington with payload

Overview

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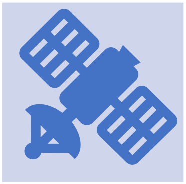
  - Flight Path and Planning
  - Considerations

Legal Considerations

Patents



1.) Satellite Imaging System (US9052571B1)

Capturing wide-area aerial images, specifies parameters relating to camera comp., frames, focal length, camera angle, and FOV

2.) CubeSat (US9248924B2)

Specifications relating to a CubeSat system, its methods, and apparatus relating specifically to pico-class satellites

3.) RF CubeSat System (US11005165B2)

System and method to use a transceiver antenna mounted on the outer panel of a CubeSat

Outlines a method of wrapping a CubeSat in a RF antenna to provide a higher degree of uplink sensitivity

FAA

1. Cannot uses cell phones to track at high altitudes
2. Payloads cannot exceed a package weight/size ratio of 3 oz per square inch measured on any side of the package
3. No payload can exceed 6 lbs. in weight
4. Entire weight of payload must be under 12 lbs
5. No rope or cable should be used, which requires more than 50lbs of force to separate
6. Cannot create a hazard to other people or property
7. Cannot drop objects
8. Less than 50% cloud coverage with visibility of 5+ miles
9. Prelaunch notice

FCC

The FCC regulations are mainly discussed in Title 47, telecommunications. In part 97 of title 47 of the FCC regulations, amateur radio services are discussed in depth. The teams' system is running in the 70 cm band in the amateur television, ATV, frequency. The ATV frequencies in the 70 cm band include 420-432 (423) MHz and 438- 444 MHz. These bands are both classified as ultra-high frequency, UHF. Transmissions are also given a three-symbol label describing the emission. Our transmission is classified as an image due to its F1F coding. This means that the transmission if frequency modulated (F) is a "single channel containing quantized or digital information without the use of a modulation sub-carrier, excluding time-division multiplex" (1)[10], is television- video (F). These classification codes are important as they define what transmission you have and what band you are allowed to transmit in.

In order to transmit in the 70 cm band, one must hold an amateur license as well as a station license. This allows for the legal transmitting within 50 km of the Earth's surface aboard any vessel or craft that is documented or registered in the US. The person with these licenses must be in physical control of all transmitting devices. When the station is automatically controlled, there must be other regulations involved depending on the band and power of the transmitter.

The FCC procedures and practices are updated every October first.

Ethical & Environmental Concerns

Ethical Considerations

It is important to follow good radio operator etiquette when using HAM radio.

Radio etiquette ensures that the rights of other HAM users are not infringed upon.

If the payload lands on private property, it is important that the team respects the rights of landowners.

Ask for explicit permission to retrieve the payload from the private property.

Environmental Considerations

Wildlife

- Consuming parts of balloon, parachute, and CubeSat
- Damage to live-stock and crops

Natural Resources

- Water contamination
- Fire risk

Engineering Standards

Engineering Standards

Topic Area	Standard	Abbreviated Name	Originating Organization	Coverage Level
Safety	14 CFR 1.F.101.D	FAA Unmanned Free Balloons	US Federal Aviation Administration	Key Specifics
Regulatory	47 CFR 15 B	FCC Unintended Radiators	US Federal Communications Commision	Key Specifics
	ISO 17770:2017	Space systems - Cube satellites (CubeSats)	International Organization for Standards	Standards for CubeSats
Quality, Reliability	IEEE 1625-2004	Rechargeable Batteries for Portable Computing	Insitute of Electrical and Electronics Engineers	Awareness
	IEEE 211-1997	Definitions of Terms for Radio Wave Propagation	Insitute of Electrical and Electronic Engineers	Key Specifics

Overview

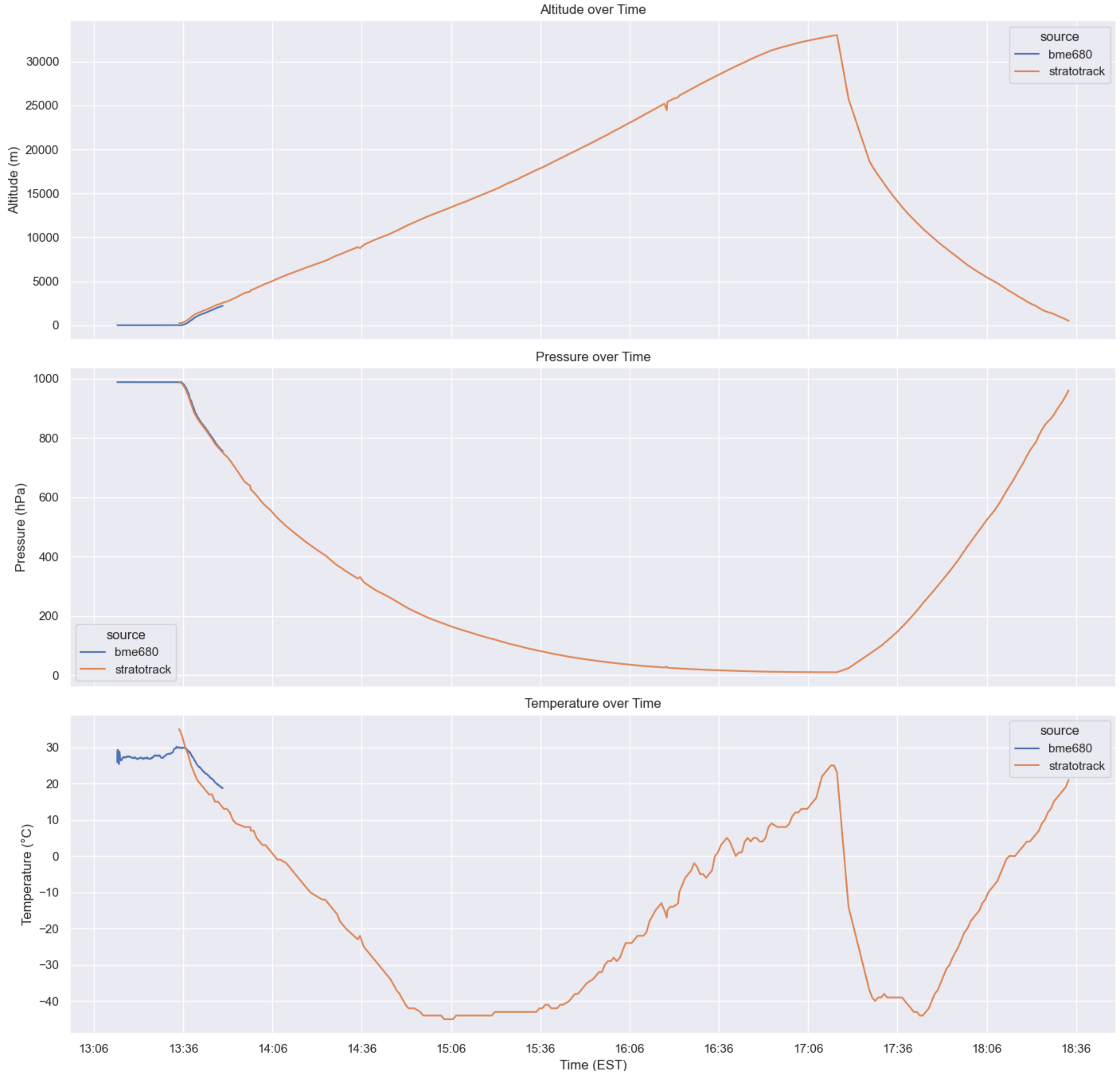
- Team Planning
- Gantt Chart
- Project Overview
- Objectives
- Constraints
- Payload Design
- **Results**

Results

RECOVERY!

The balloon was recovered at approx. 8:30p after a call by a homeowner in Hebron, OH.

Data Results



Flight Data from Stratotrack

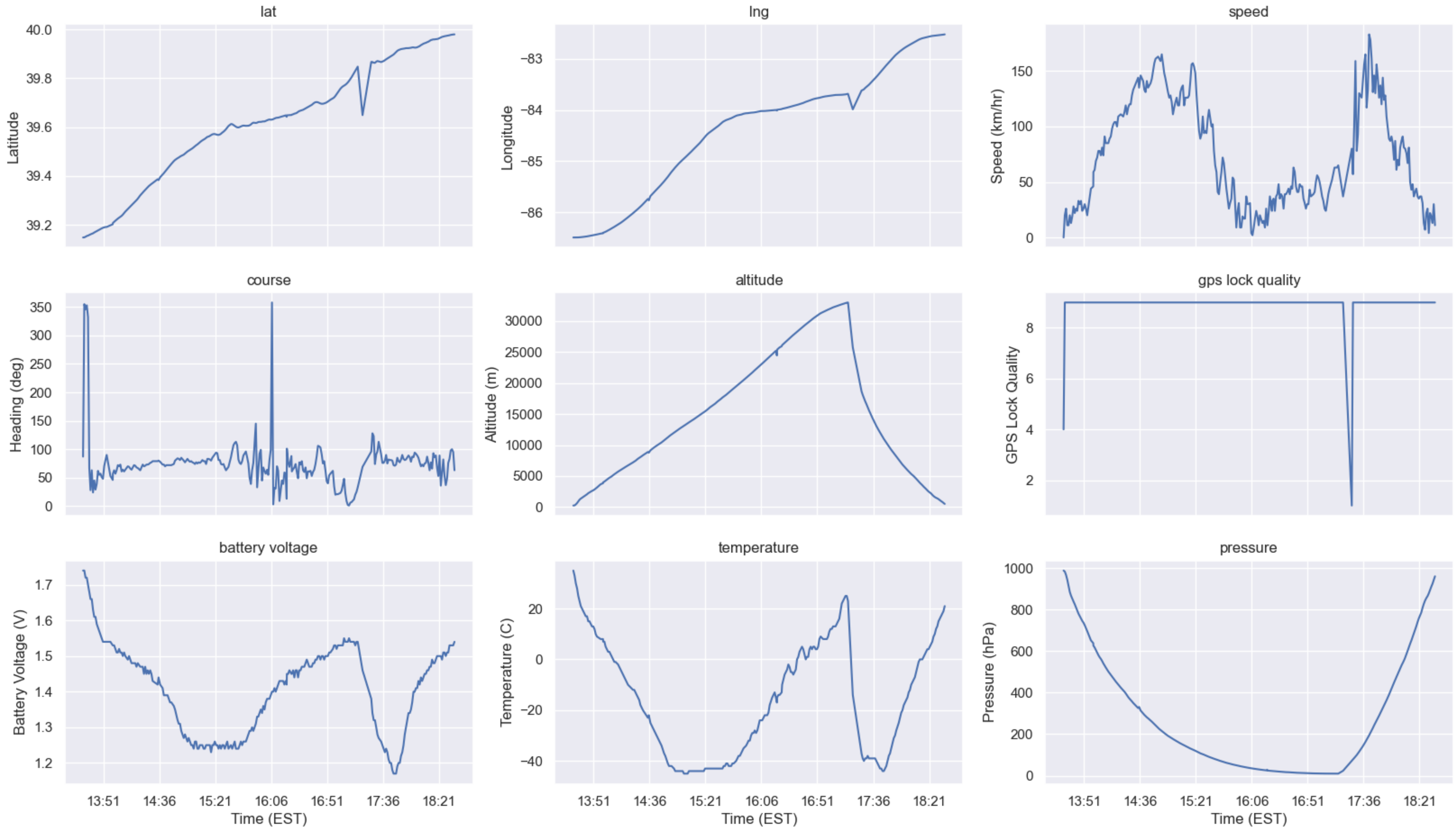
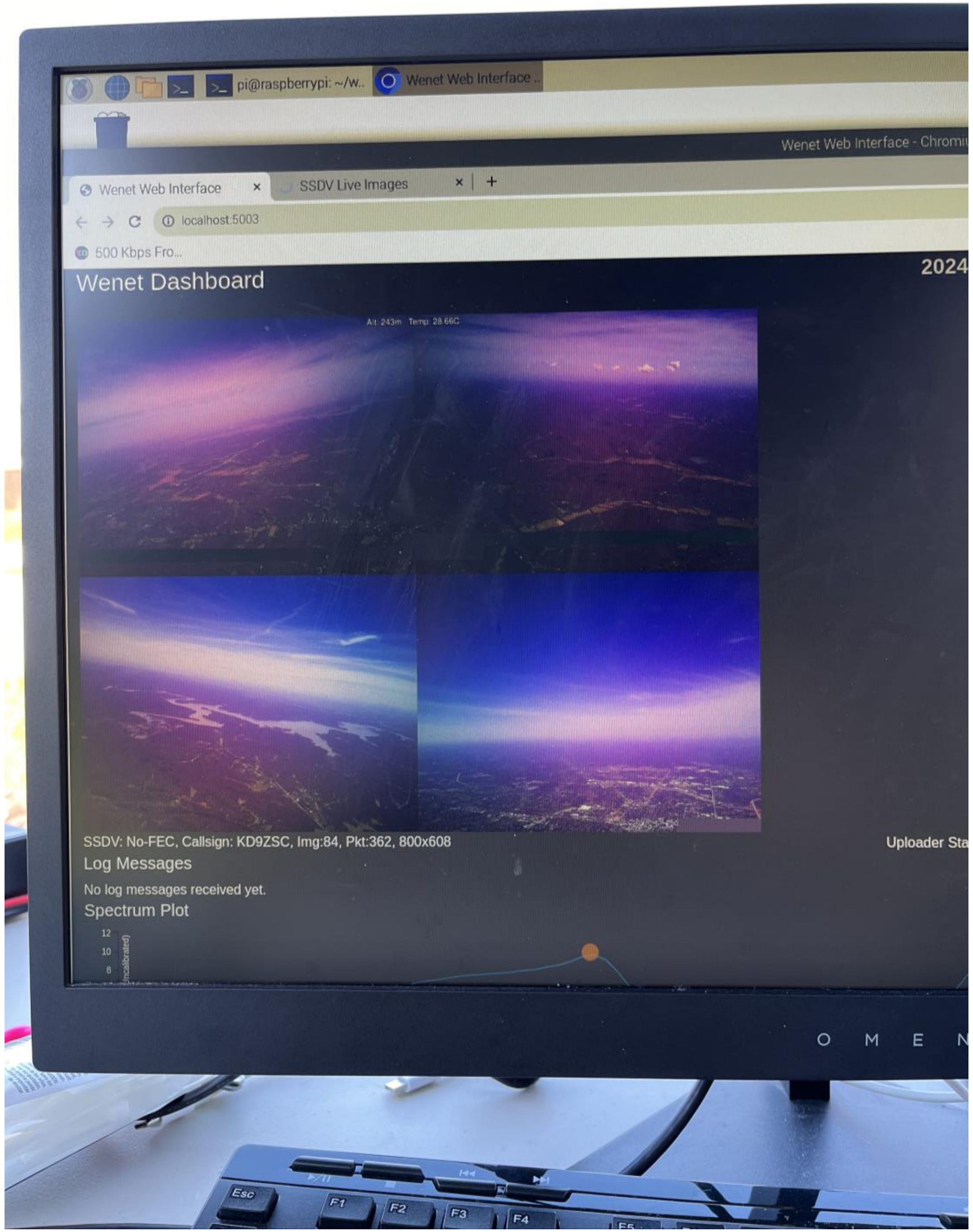


Image Results

Ground Station Image Results



Points of Failure

Opportunities for growth

Weight

Initial allotment for payload weight was 950g

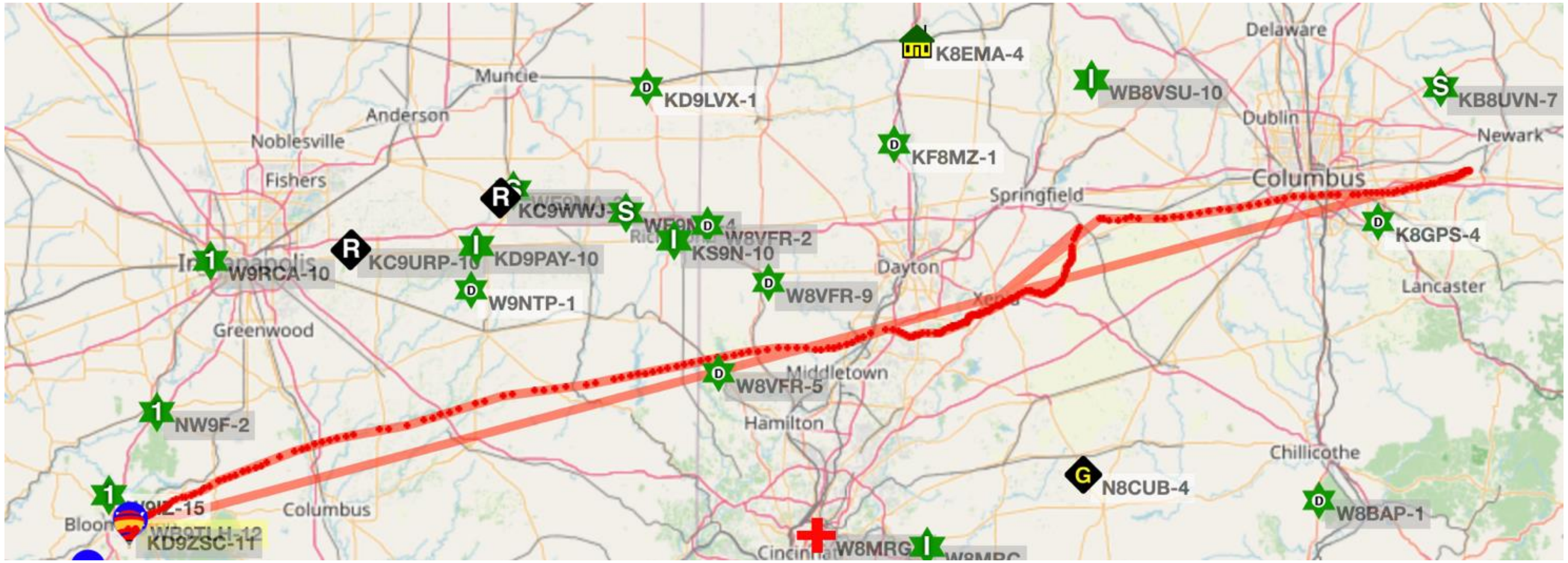
Actual payload weight was 1120g

Rigging and insulation needed a higher weight allotment than we had estimated surpassing the buffer built into the calculations

Helium

The balloon was underfilled due to errors in weight calculations and trouble taking an accurate force measurement

Underfilled balloons travel a further linear distance and have an increased maximum altitude



Oversights in payload weight led to underfilling the balloon the flight path turned out to be nearly twice the distance predicted.

The payload still landed in a rural area despite crossing through several large populated areas.

Helium + Weight = Flight Path Failure

Potential Failure Points

Battery Bank

- Anker smart shutoff feature

Software Issues

- Logging data from post-flight review wasn't indicative of issues

Potential ESD from Insulation

Lifelong Learning Objectives

- How to work on an extended engineering design project
- Working as part of a large team
    - Division of work
    - Team strengths
- Understand how to work on a project within the confines of legal restrictions
- Even if you have a good plan, something can go wrong

Acknowledgments

The team would like to thank Professor Daniel Loveless for his continued sponsorship throughout the project. The team is also grateful to Professor Bryce Himebaugh for his guidance and advice on all aspects of radio communication and to Mary Loveless for her continued support.

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[2] “Everything RF,” Link Budget Calculator - everything RF, https://www.everythingrf.com/rf-calculators/link-budget-calculator (accessed Nov. 6, 2023).

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[6] “500 kbps from a high altitude balloon,” Stephen’s Site, https://www.scd31.com/posts/high-speed-balloon-comms (accessed Nov. 6, 2023).

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[8] Projecthorus, “Projecthorus/wenet: Wenet (‘The swift one’) - transmit and receive code for the project Horus High-speed imagery payload.,” GitHub, https://github.com/projecthorus/wenet (accessed Nov. 6, 2023).

[9] “Indiana Repeater Council,” Indiana Repeater Council Serving Indiana Amateurs Since 1971, https://www.ircinc.org/?page_id=390 (accessed Nov. 6, 2023).

[10] “The Federal Register,” Federal Register :: Request Access, https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-101/subpart-D/section-101.35#p-101.35(a)(1) (accessed Nov. 6, 2023).

IU Capstone Design Team 4: IUB Sat

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