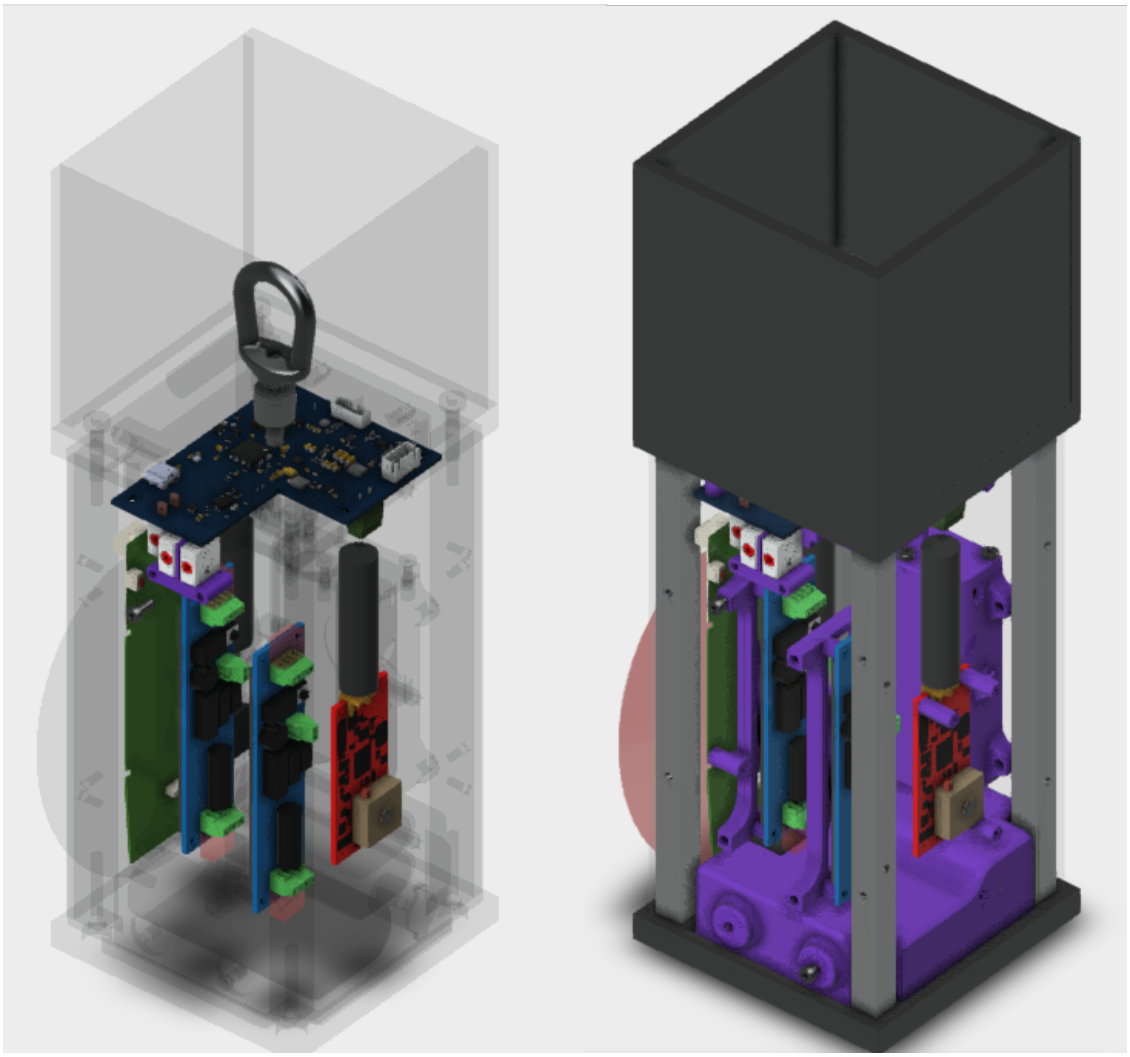
Payload Data Analysis

June 23, 2024

1 Preface

Heres a bunch of data recovered from the Grim Reefer, the payload cameras, and the payload RRC3s. All this data is sourced from the RIT Launch Initiative flight-data github repository

If you wanna skip all the boring stuff, go to Flight Analysis



I would like to formally apologive to Yev for not doing sig figs.

Contents

2 Data Sources

2.1 Grim

- Boost Detect 6 Axis IMU Buffer
- Boost Detect Altimeter Buffer
- Flight Fast Data (6 Axis IMU, Pressure)
- Flight Slow Data (Temperature, Humidity, Voltages, and Currents)
- Flight ADC Data

2.2 RRC3s

- Altitude
- Pressure
- Velocity
- Temperature
- Voltage

2.3 Cameras

- 6 Axis IMU

3 Data Cleanup

Here we cleanup data and merge it where applicable. Unless otherwise specified, linear interpolation is used to fill in gaps when joining.

3.1 Grim

3.1.1 Index by timestamp

3.1.2 Combine same data from different sensor files

Concatenate pre imu and flight imu, pre altitude and flight altitude

3.1.3 All the grim data

outer join on all grim data, linearly interpolating to fill holes

3.2 RRC3

Convert timestamps to milliseconds to match grim.

3.3 Camera

Drop raw columns so we can use unitted columns.

4 Flight Events

These numbers are found from looking at the data and finding the point that looks right. They are optimized for showing the data not pure mathematical rigor. Additionally, these timestamps

are ***not*** time aligned so while all grim data references a common timestamp, the RRC3s do not at this point.

```
<pandas.io.formats.style.Styler at 0x7fc87caf6a20>
```

RRC3 1 Events (RRC3 1 Time)

timestamp	Events
25700.0	Drogue
227810.0	Main

RRC3 2 Events (RRC3 2 Time)

timestamp	Events
25600.0	Drogue
227410.0	Main

5 Calculated & Filtered Data

5.1 Magnitude of Acceleration

5.1.1 Grim

Calculate magnitude of acceleration for all grim accelerometer entries. $||a|| = \sqrt{x^2 + y^2 + z^2}$

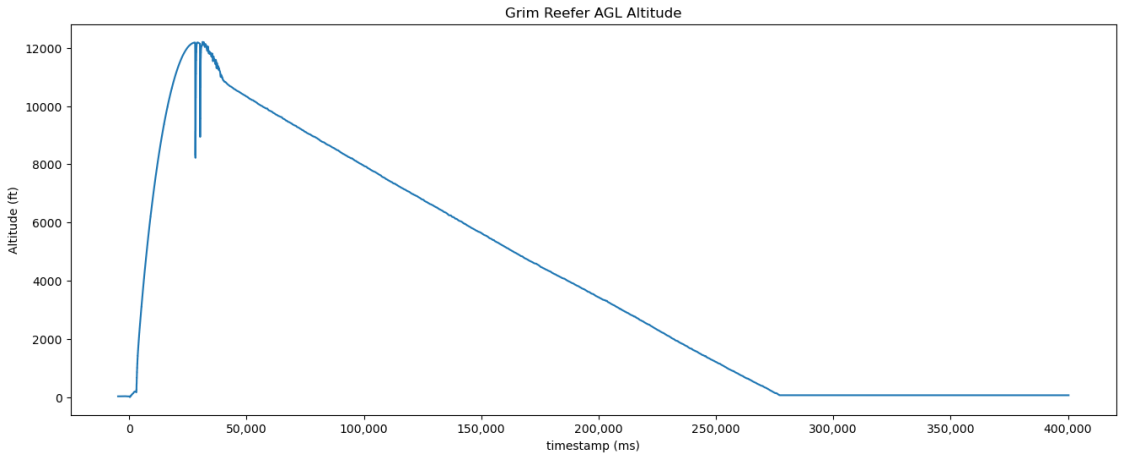
5.1.2 Cameras

Calculate magnitude of acceleration for all camera accelerometer entries. $||a|| = \sqrt{x^2 + y^2 + z^2}$

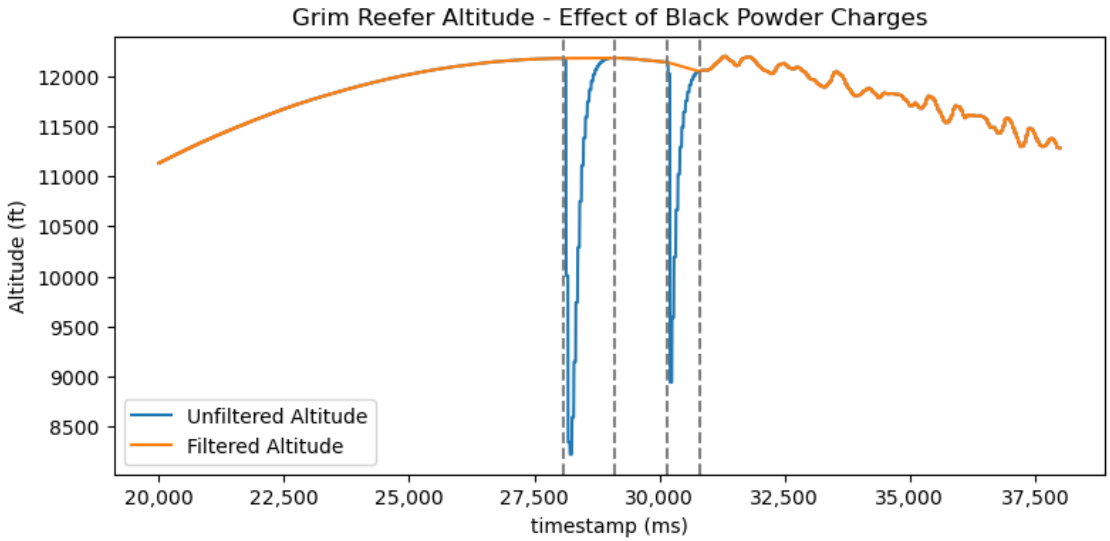
5.2 Altitude

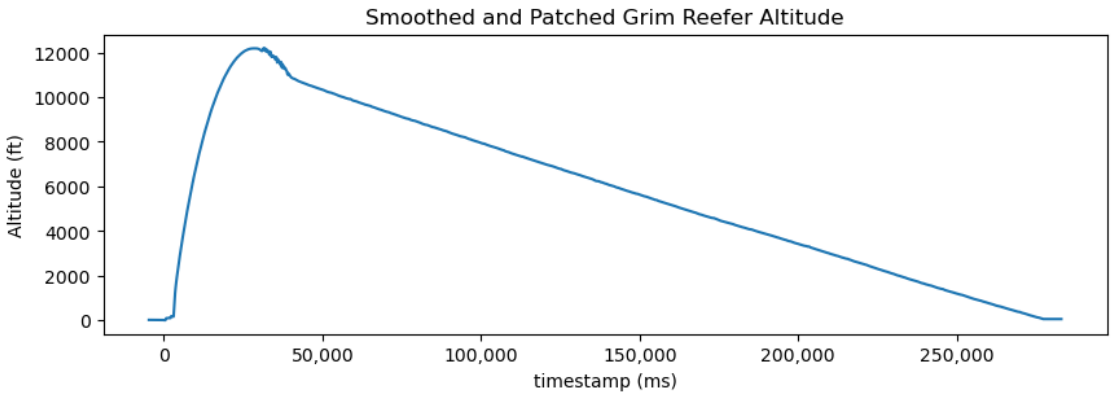
Get the altitude from pressure using the RRC3 Conversion function found here

$$h_{alt} = \left(1 - \left(\frac{P_{sta}}{1,013.25}^{0.190284}\right)\right) \times 134,366.34$$



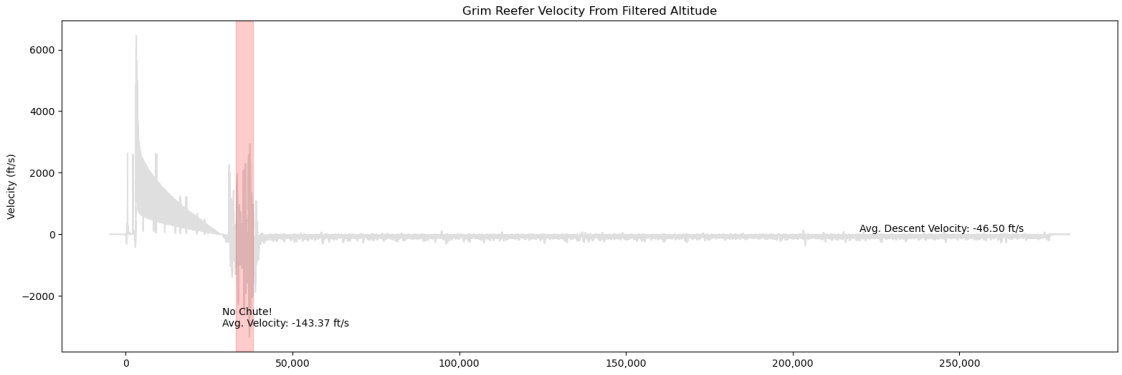
5.2.1 Fill Holes Caused by Black Powder Charges





5.2.2 Try to get Velocity from Altitude

with limited success



6 Aligning Times

grim is the timestamp to follow. Align to that

NOTE: The Camera timescale is out of wack with RRC3s and Grim. It is some factor of the others rather than just an offset. Here it is aligned at snatch force and gets worse as you move away from that point

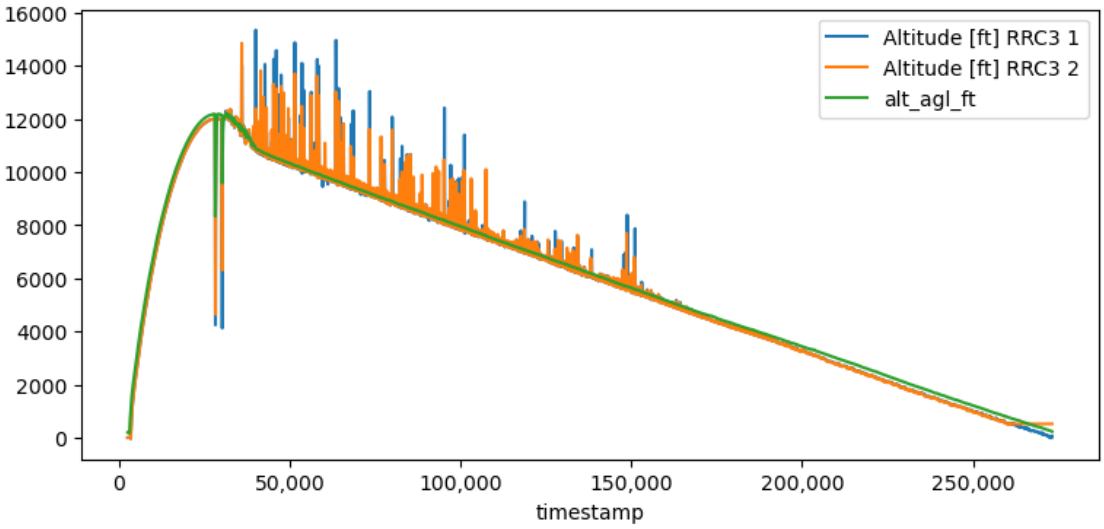
6.1 Cameras

line up the ground hit (highest acceleration (easy to find)) and add manual adjustment from there

```
Grim hit the ground 276836.0 ms grim time
Cam1 hit the ground 272584 ms cam1 time
We need to shit by 4252.0 ms
Manual Adjustement by -1055 ms
```

6.2 RRC3s

Aligned by charge spikes. Based on the Grim's IMU and barometer, barometer responds faster to the charges than it does a change in ambient pressure



7 Data by Type

7.1 Acceleration

Create a table of Grim Acceleration data and Camera Acceleration data

timestamp (ms)	grim acc	grim accx	grim accy	grim accz	cam acc	\
0.0	10.423808	-0.34400	0.94700	10.37500	NaN	
2.0	10.460771	-0.33700	0.94000	10.41300	NaN	
4.0	10.497752	-0.33000	0.93300	10.45100	NaN	
6.0	10.450612	-0.33900	0.93700	10.40300	NaN	
8.0	10.481617	-0.30100	0.91800	10.43700	NaN	
…	…	…	…	…	…	
282999.2	9.968669	-0.52245	9.92595	0.75955	9.827633	
282999.4	9.969657	-0.52390	9.92690	0.75910	9.826836	
282999.6	9.970645	-0.52535	9.92785	0.75865	9.826039	
282999.8	9.971633	-0.52680	9.92880	0.75820	9.825243	
283000.0	9.972621	-0.52825	9.92975	0.75775	9.824446	

timestamp (ms)	cam accx	cam accy	cam accz
0.0	NaN	NaN	NaN
2.0	NaN	NaN	NaN
4.0	NaN	NaN	NaN
6.0	NaN	NaN	NaN
8.0	NaN	NaN	NaN
…	…	…	…
282999.2	9.799462	-0.571931	-0.475172

```
282999.4        9.798504 -0.573847 -0.476130
282999.6        9.797546 -0.575763 -0.477088
282999.8        9.796588 -0.577679 -0.478046
283000.0        9.795630 -0.579595 -0.479004

[1303919 rows x 8 columns]
```

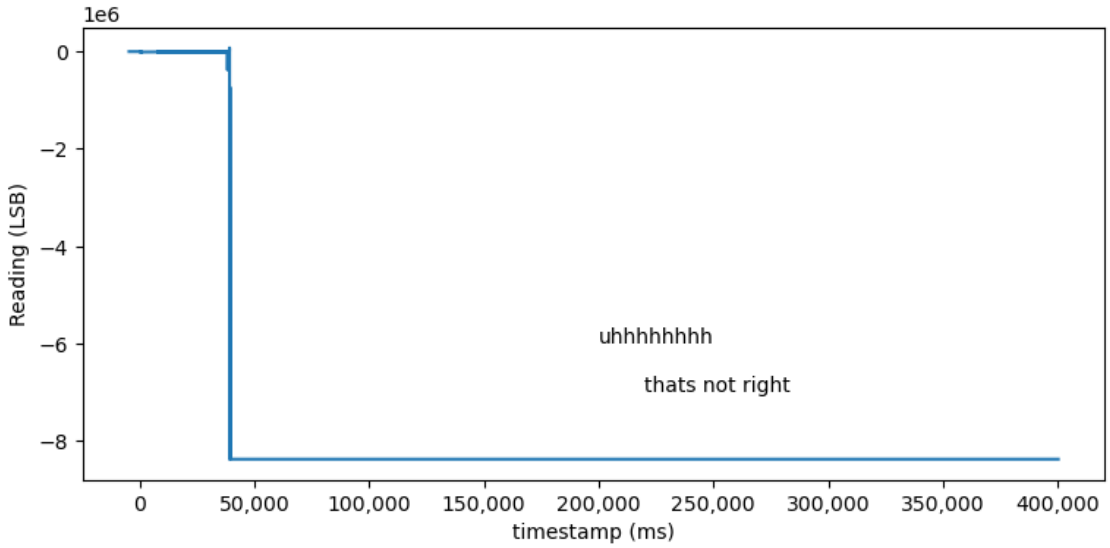
7.2 Gyroscope

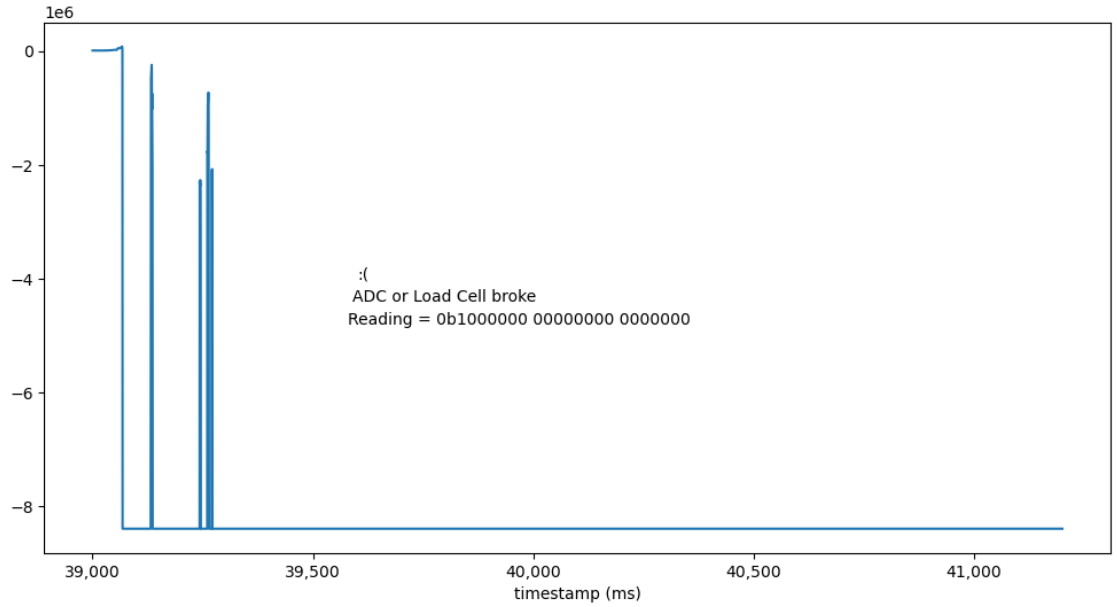
Create a table of Grim Gyroscope data and Camera Gyroscope data

```
           grim x   grim y   grim z    cam1 x    cam1 y   cam1 z
0.0       0.00700 -0.02300  0.02100       NaN       NaN      NaN
2.0       0.00700 -0.02400  0.02500       NaN       NaN      NaN
4.0       0.00700 -0.02500  0.02900       NaN       NaN      NaN
6.0       0.01300 -0.02300  0.02900       NaN       NaN      NaN
8.0       0.01700 -0.03400  0.02900       NaN       NaN      NaN
…           …       …       …           …         …
282999.2  0.00715 -0.02495  0.00815  0.007457  0.018642  8.53117
282999.4  0.00730 -0.02490  0.00930  0.007457  0.018642  8.53117
282999.6  0.00745 -0.02485  0.01045  0.007457  0.018642  8.53117
282999.8  0.00760 -0.02480  0.01160  0.007457  0.018642  8.53117
283000.0  0.00775 -0.02475  0.01275  0.007457  0.018642  8.53117

[1326584 rows x 6 columns]
```

7.3 Load Cell

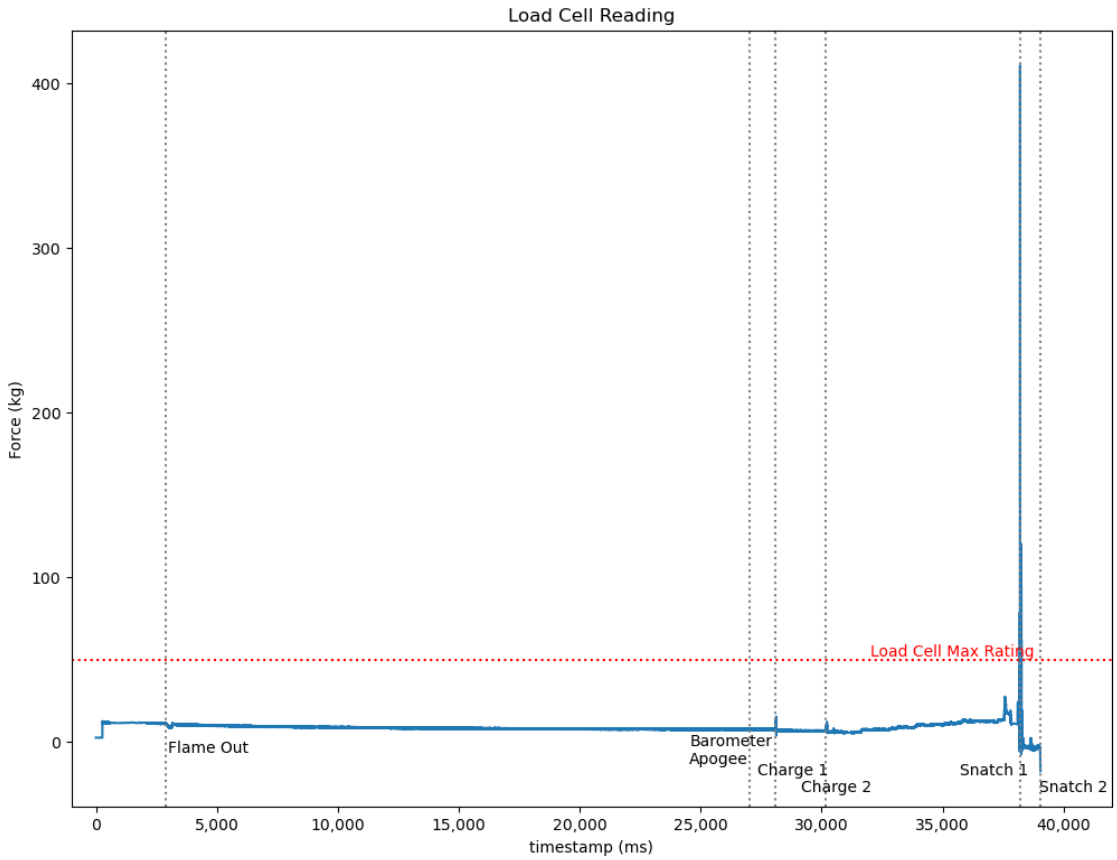
Convert ADC reading into a usable force value. Conversions from here. Calibrated by adding a bunch of lathe tools and reading out the voltage.





Negative max occurs when input signal moves out of range of what the ADC can read with those gain settings. unsure about the others

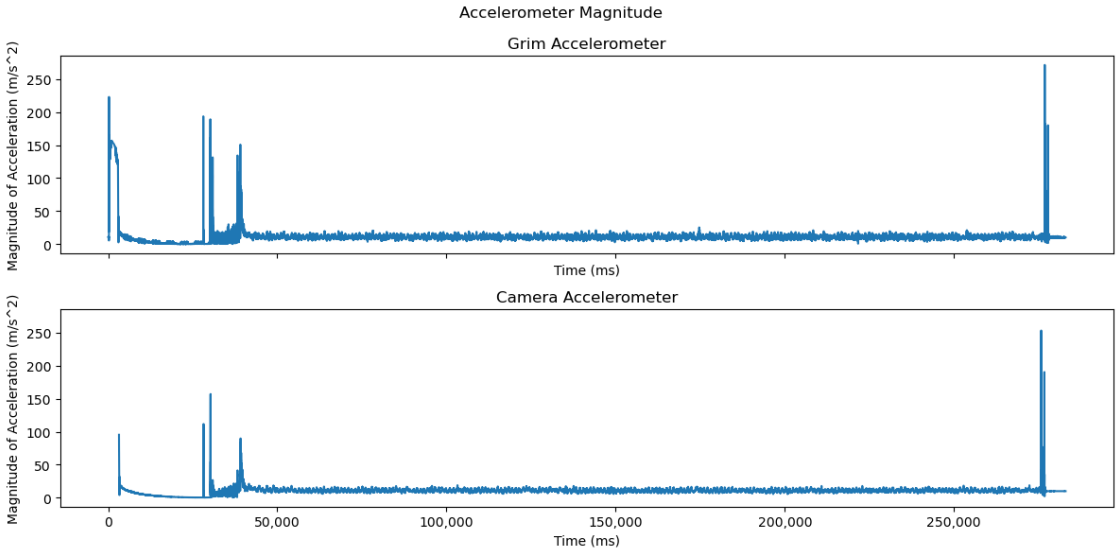
We can still look at the ADC before it exploded

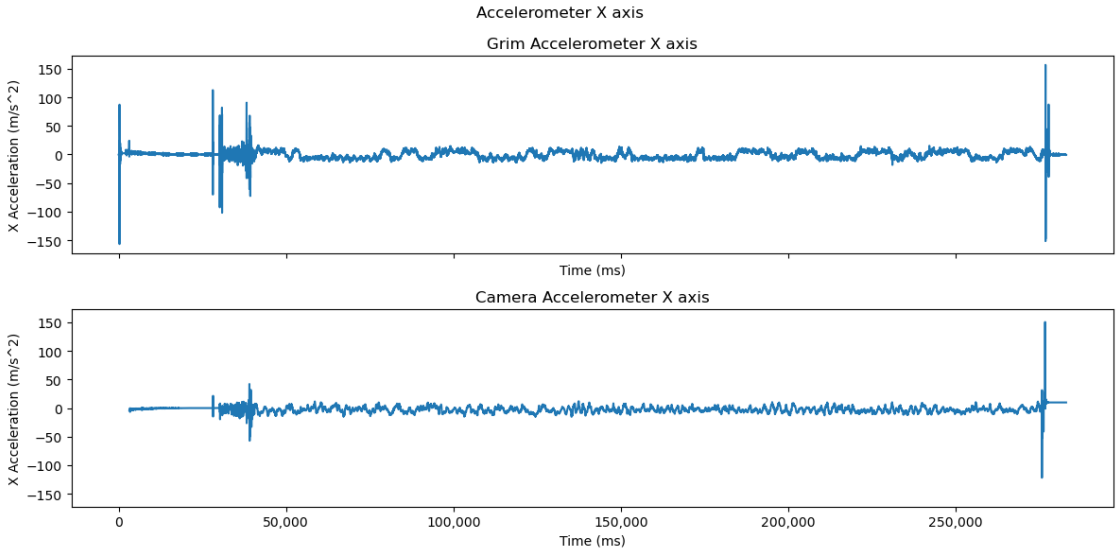


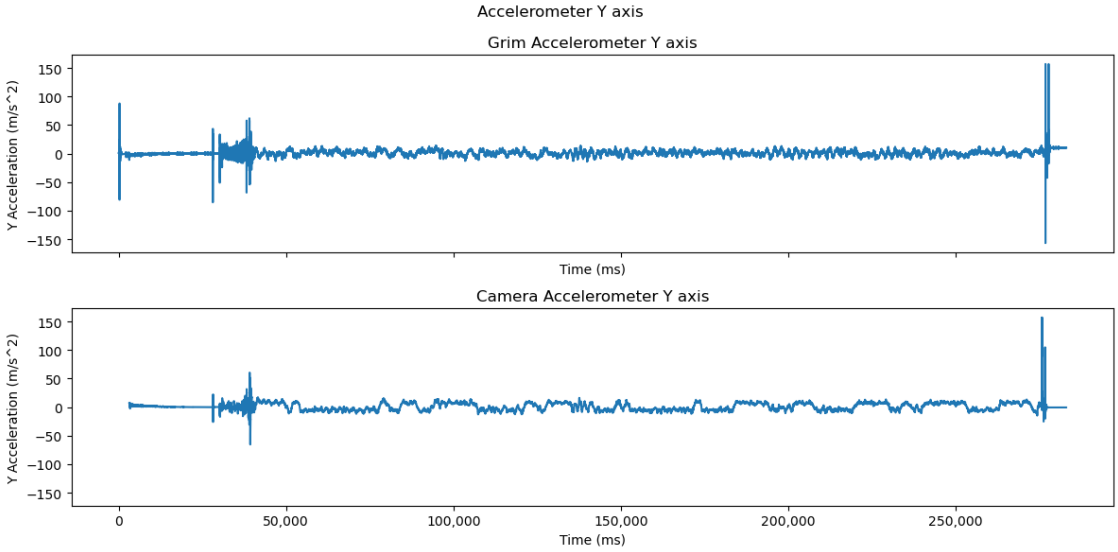
<Figure size 512x384 with 0 Axes>

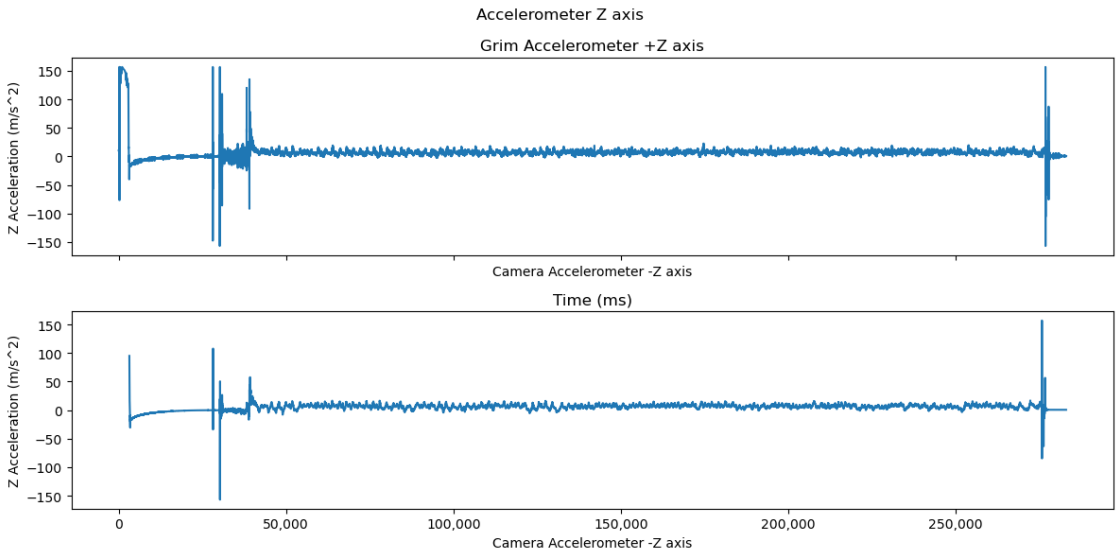
8 Comparisons

8.1 Camera vs Grim Accelerometer

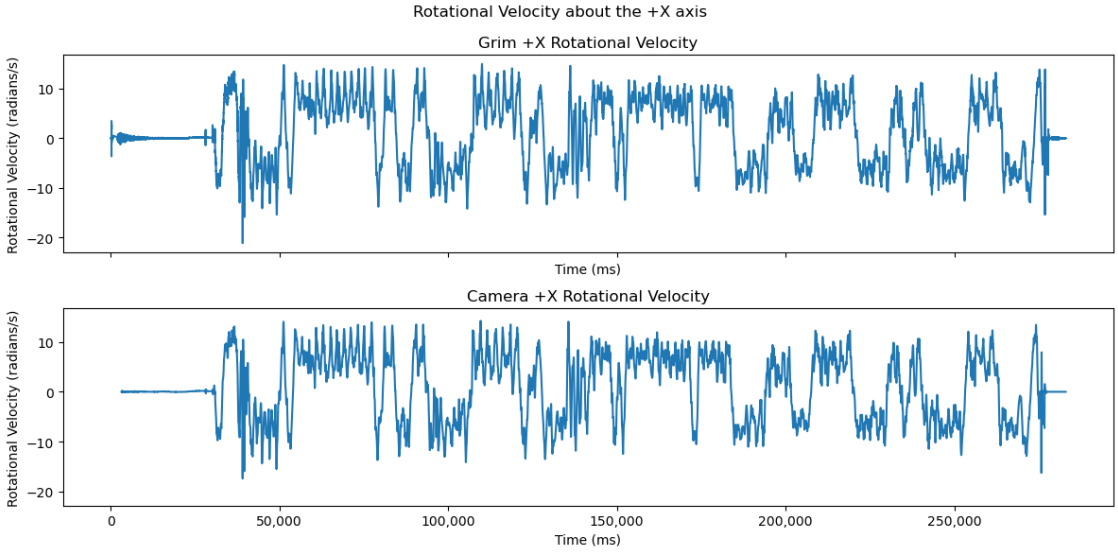


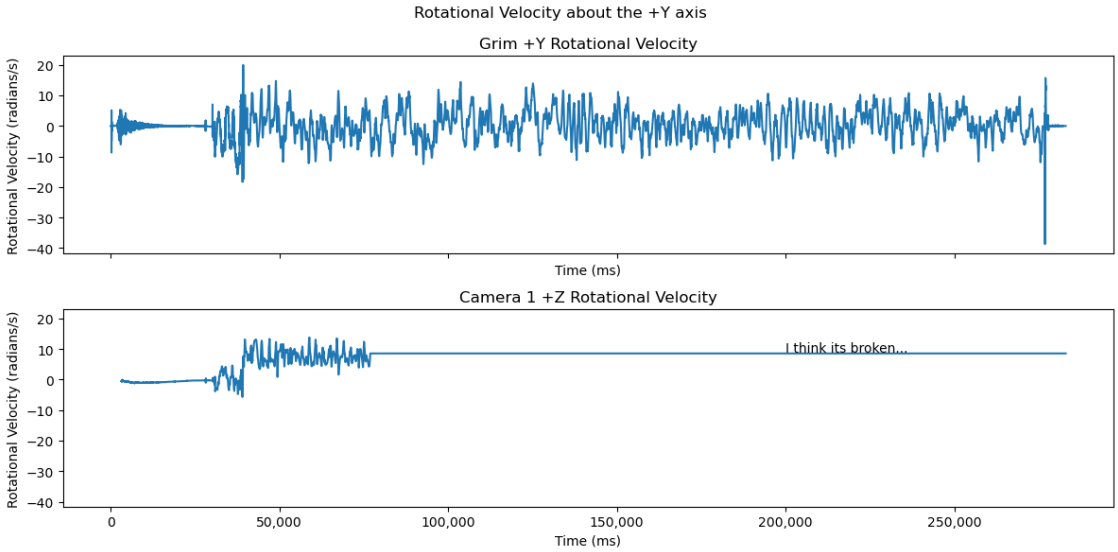


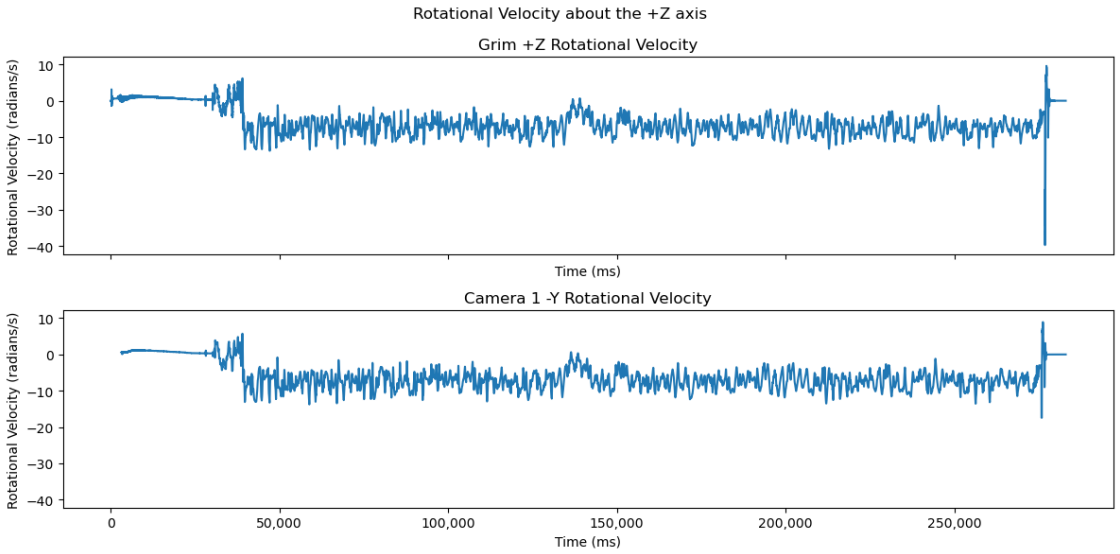

Accelerometer Y axis
Grim Accelerometer Y axis
Y Acceleration (m/s^2)
Time (ms)
Camera Accelerometer Y axis
Y Acceleration (m/s^2)
Time (ms)


Accelerometer Z axis
Grim Accelerometer +Z axis
Z Acceleration (m/s^2)
Camera Accelerometer -Z axis
Time (ms)
Z Acceleration (m/s^2)
Camera Accelerometer -Z axis

8.2 Camera vs Grim Gyroscope






Rotational Velocity about the +Z axis
Grim +Z Rotational Velocity
Rotational Velocity (radians/s)
10
0
−10
−20
−30
−40
Time (ms)
Camera 1 -Y Rotational Velocity
Rotational Velocity (radians/s)
10
0
−10
−20
−30
−40
0
50,000
100,000
150,000
200,000
250,000
Time (ms)


GETTING
SILLY
THE ADC
CAMERA 1'S
Z AXIS GYROSCOPE
imgflip.com

9 Flight Analysis

9.1 Overall

9.1.1 Pad Time

The system was on for 3 hours, 44 minutes, and 13 seconds before detecting boost.

9.1.2 Flight Time

```
Flight Time: 4 minutes 43 seconds
```

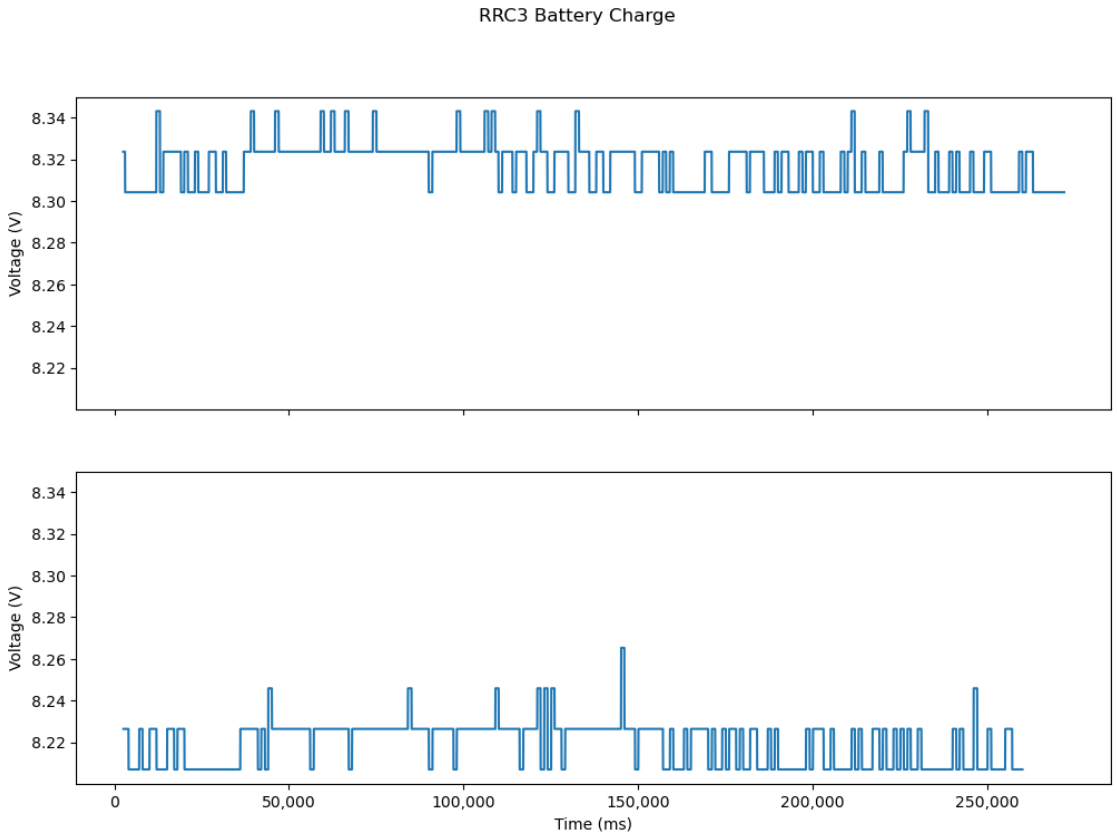
9.1.3 How fast did the sensors actually collect

i2c lockup issue, flash speeds, and more all contribute to not being able to collect as fast as we want. What did we actually get

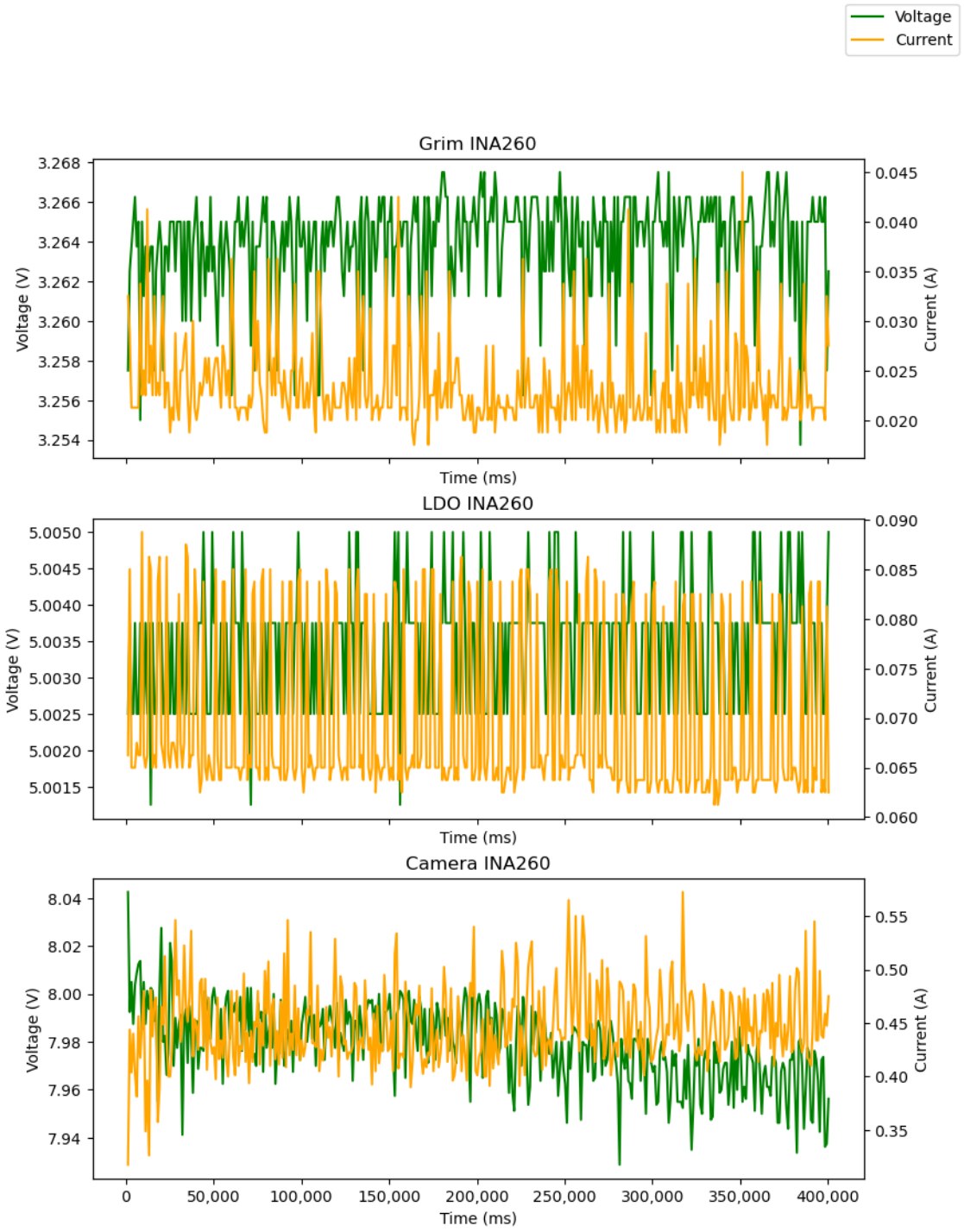
```
IMU, pressure period:                       3.55 ms
Battery, temperature, humidity  period:     997.50 ms
ADC period:                                 0.22 ms

IMU boost Detect period:                    2.77 ms
Altitude boost Detect period:               9.98 ms
```

9.1.4 Batteries

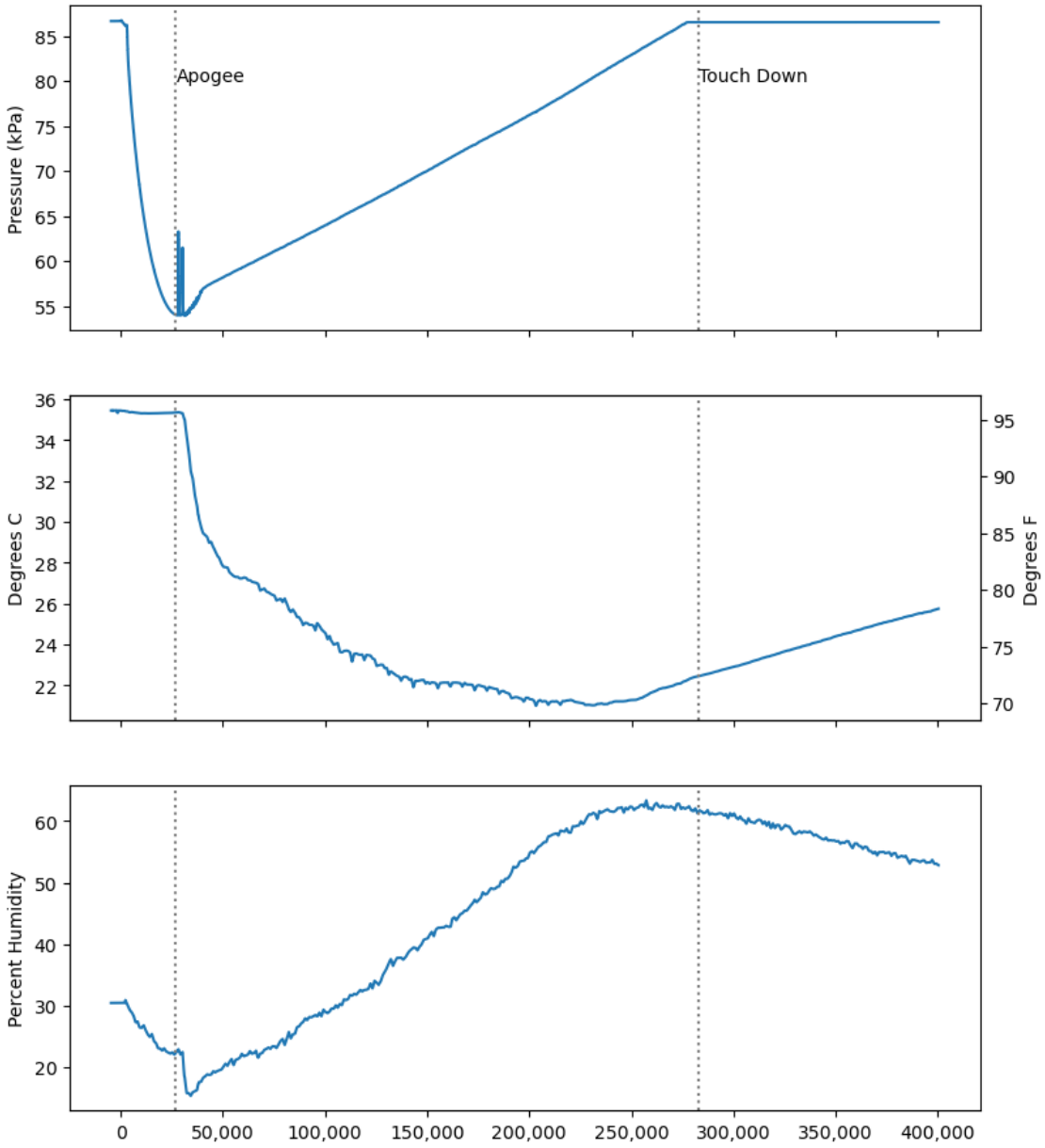
RRC3s


RRC3 Battery Charge
Voltage (V)
8.34
8.32
8.30
8.28
8.26
8.24
8.22
Voltage (V)
8.34
8.32
8.30
8.28
8.26
8.24
8.22
0
50,000
100,000
150,000
200,000
250,000
Time (ms)

Grim


Voltage
Current
Grim INA260
Voltage (V)
Current (A)
Time (ms)
LDO INA260
Voltage (V)
Current (A)
Time (ms)
Camera INA260
Voltage (V)
Current (A)
Time (ms)

9.1.5 Atmospheric Conditions



9.2 Boost

9.2.1 Detection

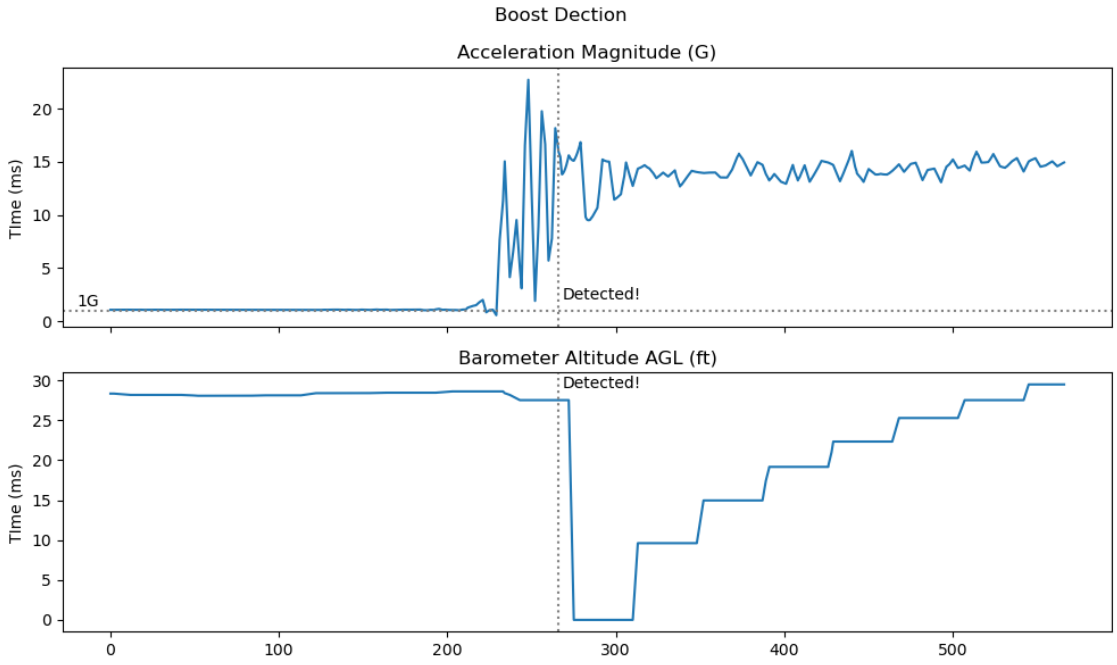
Boost was detected by the IMU, the Altimeter did not see any change until after the flight started.

Grim waited until it felt an average acceleration of 5G over 250ms. It then considered the start of that 250ms window the start of the flight. Since the acceleration was substantially higher than 5G, the average was higher and as such the first couple hundred ms are considered part of the flight

despite not actually being under power. This can be accounted after the fact, however, I didnt do that.

In reality, the software can not always keep up to match the 250ms window and its buffer is actually slightly longer.

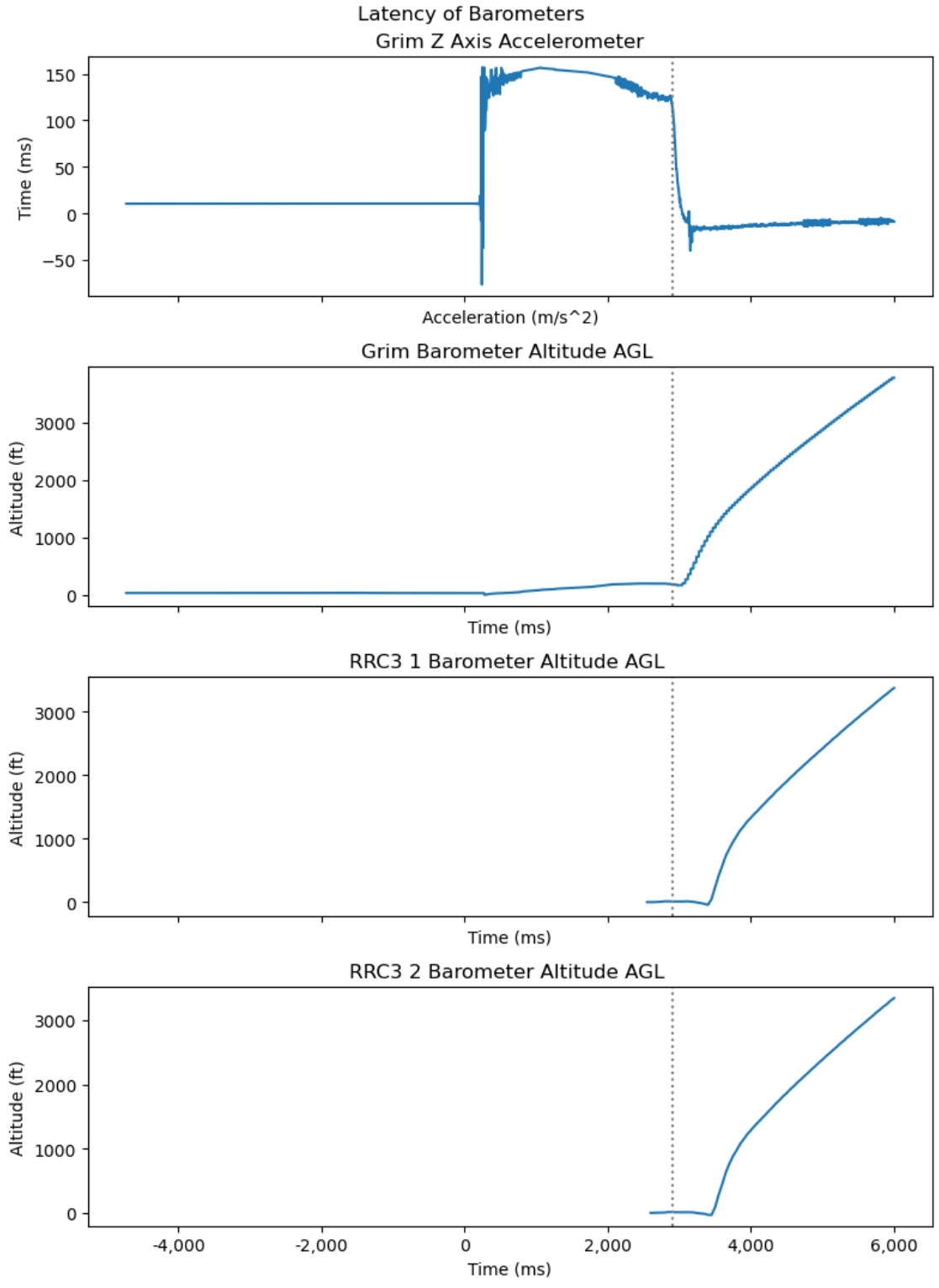
```
Actual IMU boost detect window length: 266 ms
```

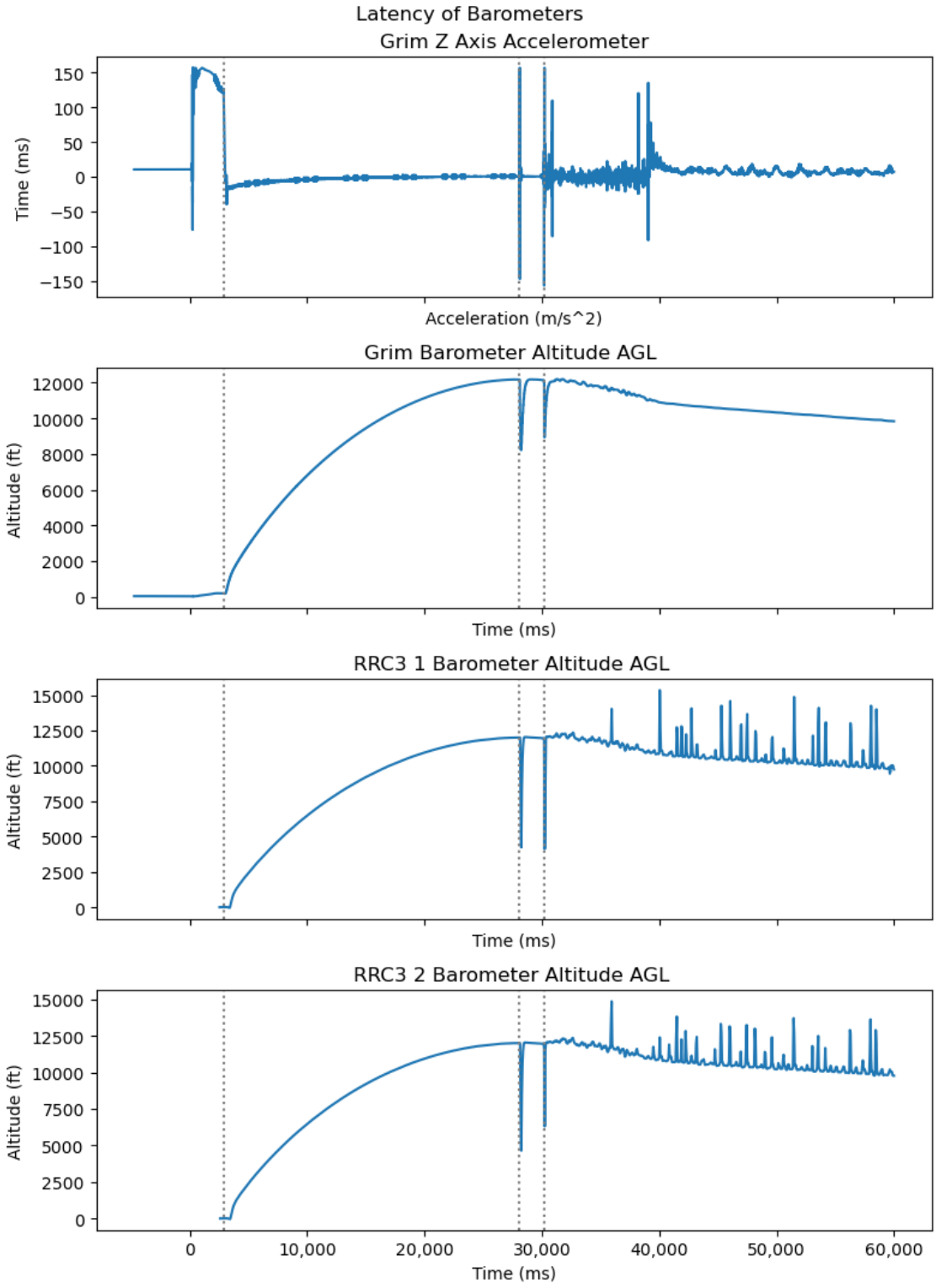


Interestingly, the barometer altitude drops when the motor first fires. Additionally, the altimeter lags substantially behind, not really responding until the entire boost is done.

The lag also occurs in the RRC3s. When aligned by the time of first charge detonation, they lag behind similarly to the Grim Barometer.

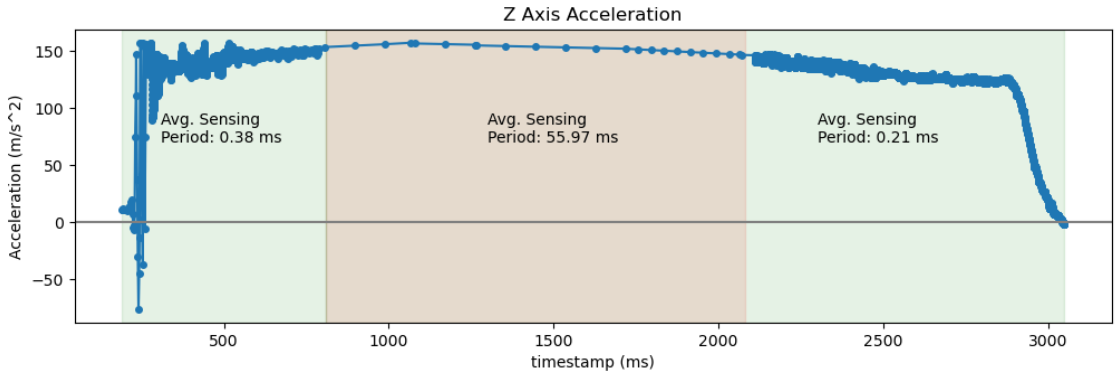
9.2.2 Barometer Latency




Latency of Barometers
Grim Z Axis Accelerometer
Time (ms)
Acceleration (m/s^2)
Grim Barometer Altitude AGL
Altitude (ft)
Time (ms)
RRC3 1 Barometer Altitude AGL
Altitude (ft)
Time (ms)
RRC3 2 Barometer Altitude AGL
Altitude (ft)
Time (ms)

9.2.3 Computer Performance

The Grim Reefer failed miserably to hit its targets between T+850 ms and T+2080 ms. The most likely reason for this is that this is when pre boost data is being flushed to flash such that in the case of any failure during flight, we still retrieve some data. Unfortunately, the cameras have not started recording at this point so we do not have that data to fill in the gaps. Nonetheless, we still have data albeit at a slower rate



9.2.4 Motor Performance

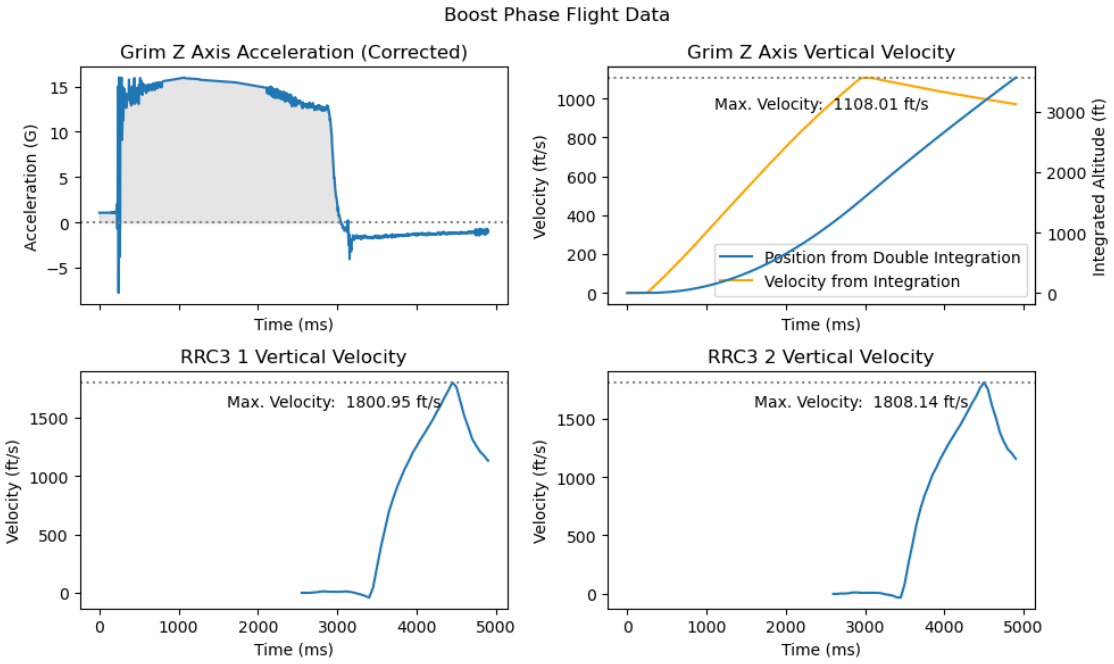
The motor fired for 3045ms causing an average of 12.40 G of measured vertical acceleration
By integrating vertical acceleration wrt. time, we calculate a vertical velocity of 1178.67 ft/s when the motor flames out
This is however to be taken with a grain of salt as the accelerometer is not perfectly calibrated and has some bias (sitting still is not 9.81 m/s but rather 10.44 m/s)
By simply scaling by (Expected 1G) / (Observed 1G) we get an average acceleration of 11.65 G and velocity of 1108.01 m/s

RRC3 1 Measured a max velocity 1800.952
RRC3 2 Measured a max velocity 1808.143

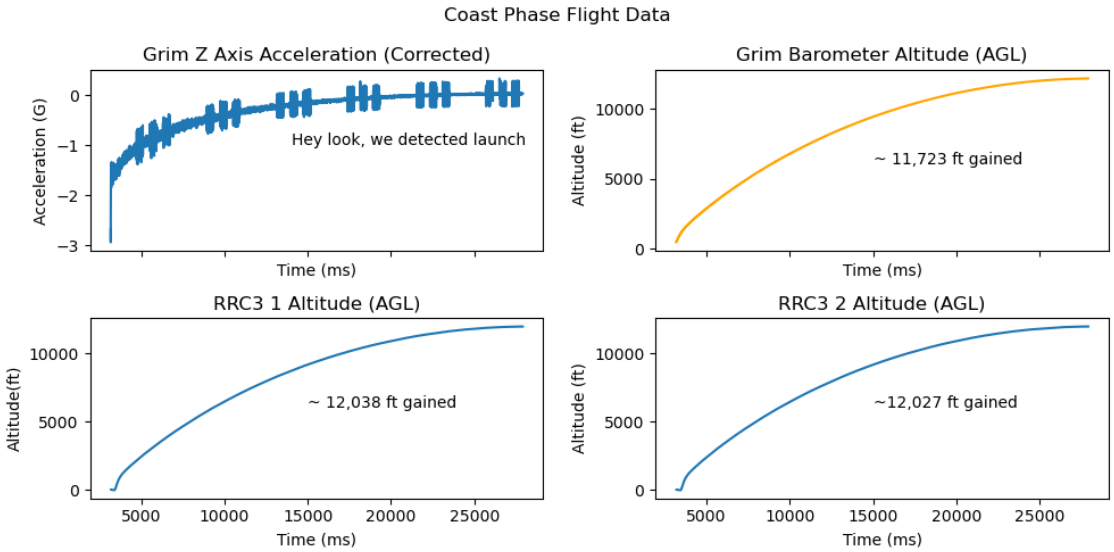
OpenRocket Simulations predicted ~1050 ft/s

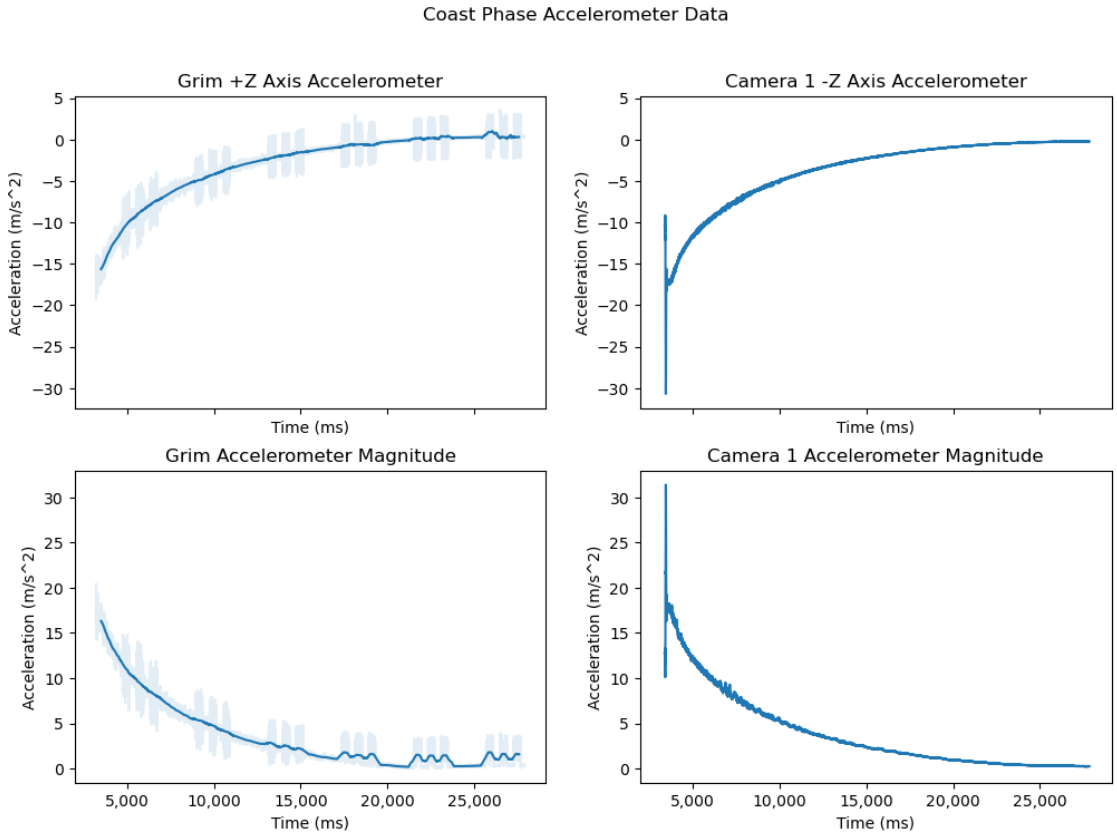
The height change during boost is highly contested. See Barometer Latency section for why.

Method	Altitude Gain (ft)
grim integrate	3792.314999
grim barometer	448.457232
RRC3 1	12.456400
RRC3 2	12.458710


Boost Phase Flight Data
Grim Z Axis Acceleration (Corrected)
Acceleration (G)
Time (ms)
Grim Z Axis Vertical Velocity
Max. Velocity: 1108.01 ft/s
Position from Double Integration
Velocity from Integration
Velocity (ft/s)
Integrated Altitude (ft)
Time (ms)
RRC3 1 Vertical Velocity
Max. Velocity: 1800.95 ft/s
Velocity (ft/s)
Time (ms)
RRC3 2 Vertical Velocity
Max. Velocity: 1808.14 ft/s
Velocity (ft/s)
Time (ms)

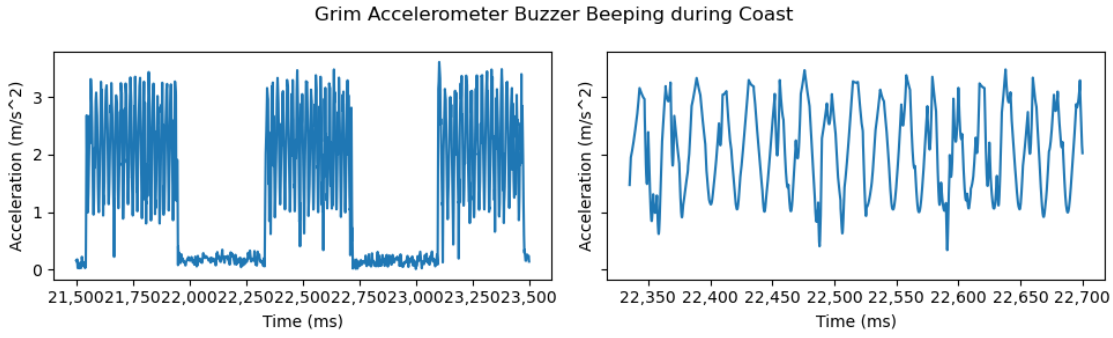
9.3 Coast


Coast Phase Flight Data
Grim Z Axis Acceleration (Corrected)
Hey look, we detected launch
Acceleration (G)
Time (ms)
Grim Barometer Altitude (AGL)
~ 11,723 ft gained
Altitude (ft)
Time (ms)
RRC3 1 Altitude (AGL)
~ 12,038 ft gained
Altitude(ft)
Time (ms)
RRC3 2 Altitude (AGL)
~12,027 ft gained
Altitude (ft)
Time (ms)



9.3.1 Sooooo yea we measured the buzzer

The accelerometer is precise enough and the buzzer strong enough that you can identify the beep-code from the IMU

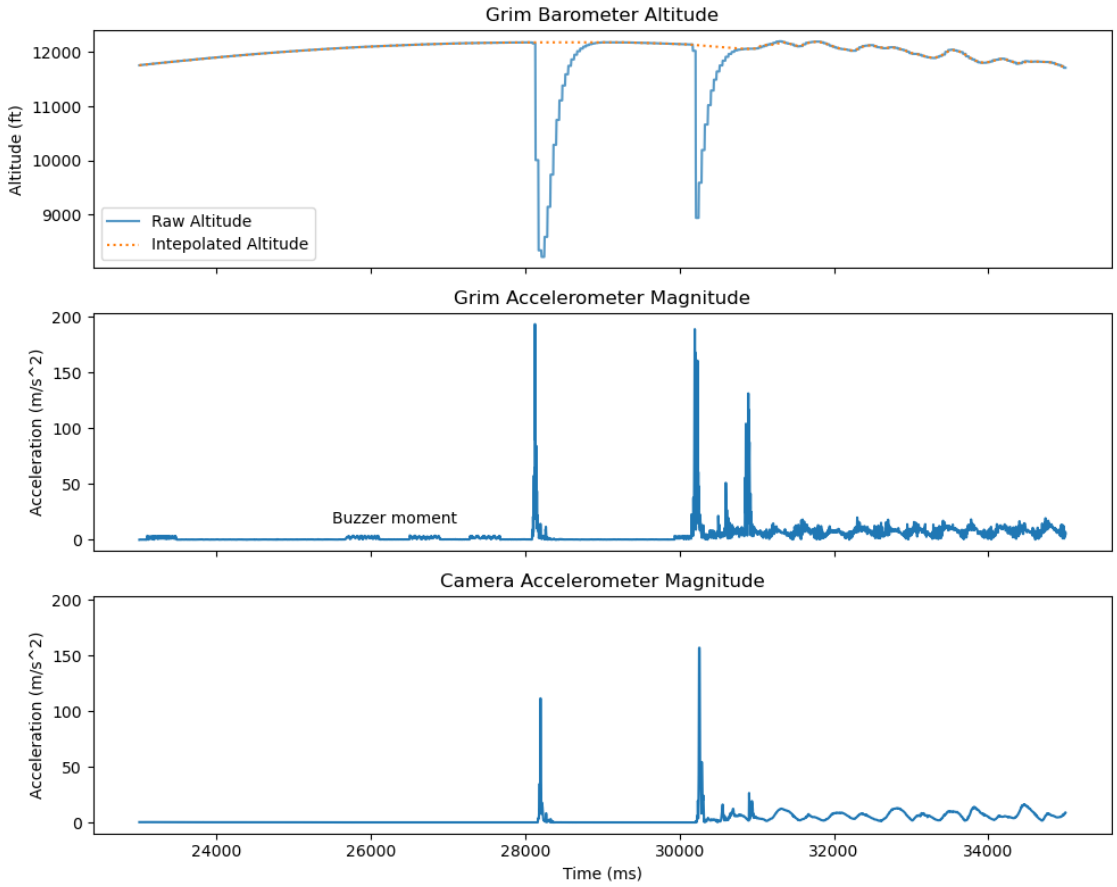


Figuring out the note the buzzer plays is left as an excercise to the reader

9.4 Apogee

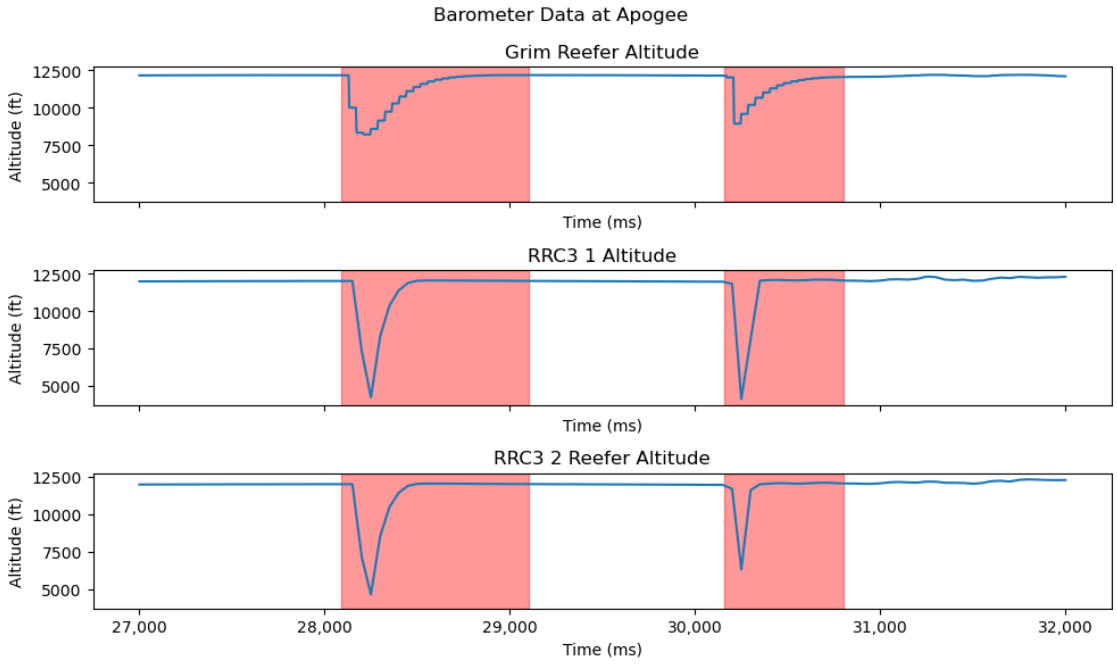
Apogee is cool and also when things got a little silly

9.4.1 Charges Go Off



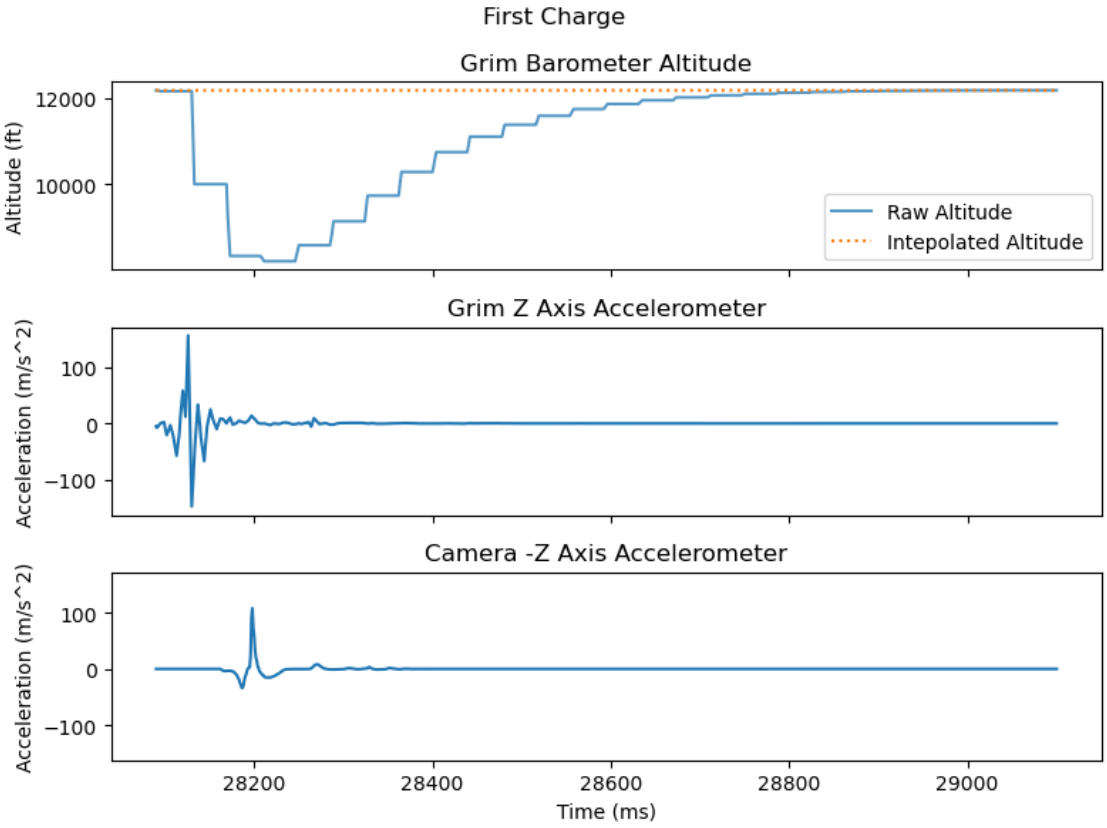
9.4.2 Barometers Have a Bad Time

Since the black powder charges cause a spike in pressure, they interfere with using the barometers to measure pressure and thus altitude.

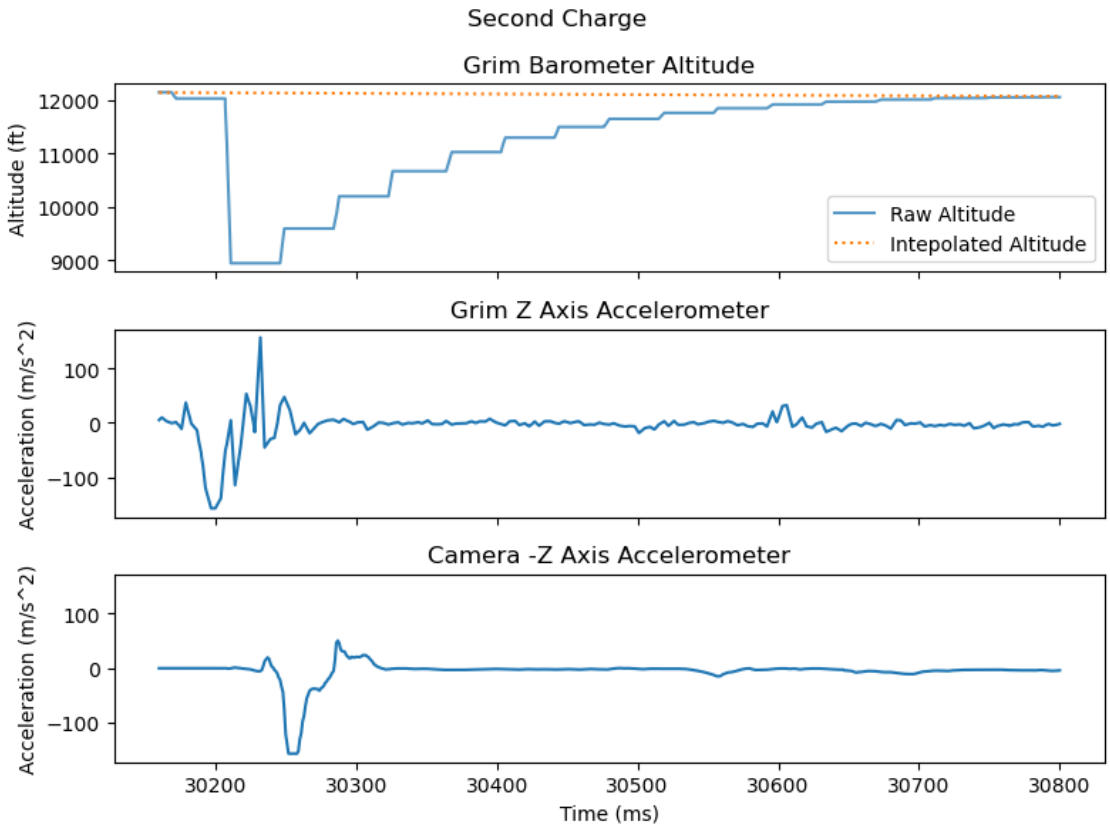


First spike began at T+ 28,090 ms and lasted 1010 ms
Second spike began at T+ 30,160 ms and lasted 640 ms

9.4.3 Charge 1


First Charge
Grim Barometer Altitude
Altitude (ft)
12000
10000
Raw Altitude
Intepolated Altitude
Grim Z Axis Accelerometer
Acceleration (m/s^2)
100
0
−100
Camera -Z Axis Accelerometer
Acceleration (m/s^2)
100
0
−100
28200
28400
28600
28800
29000
Time (ms)

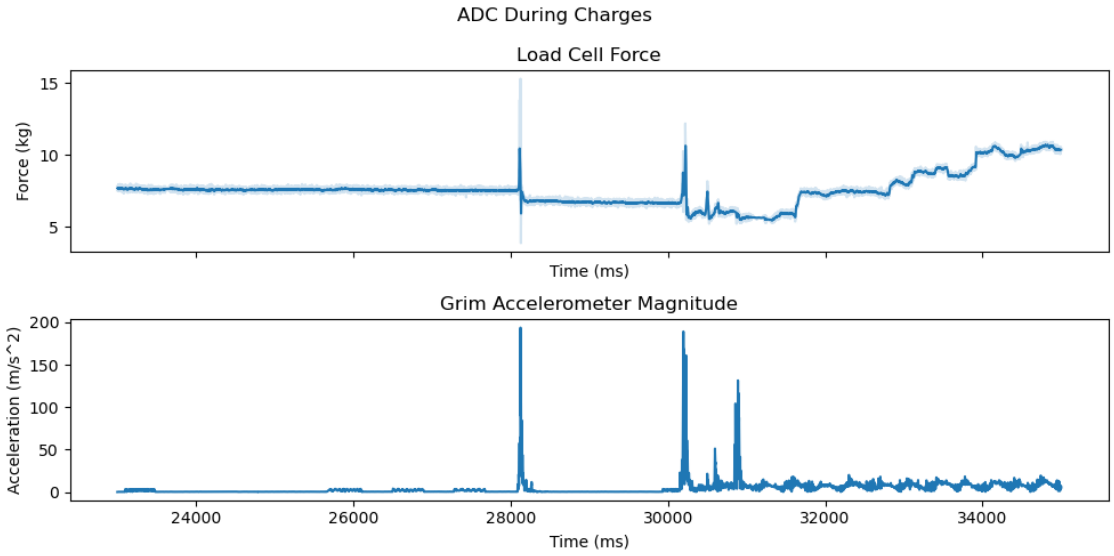
9.4.4 Charge 2



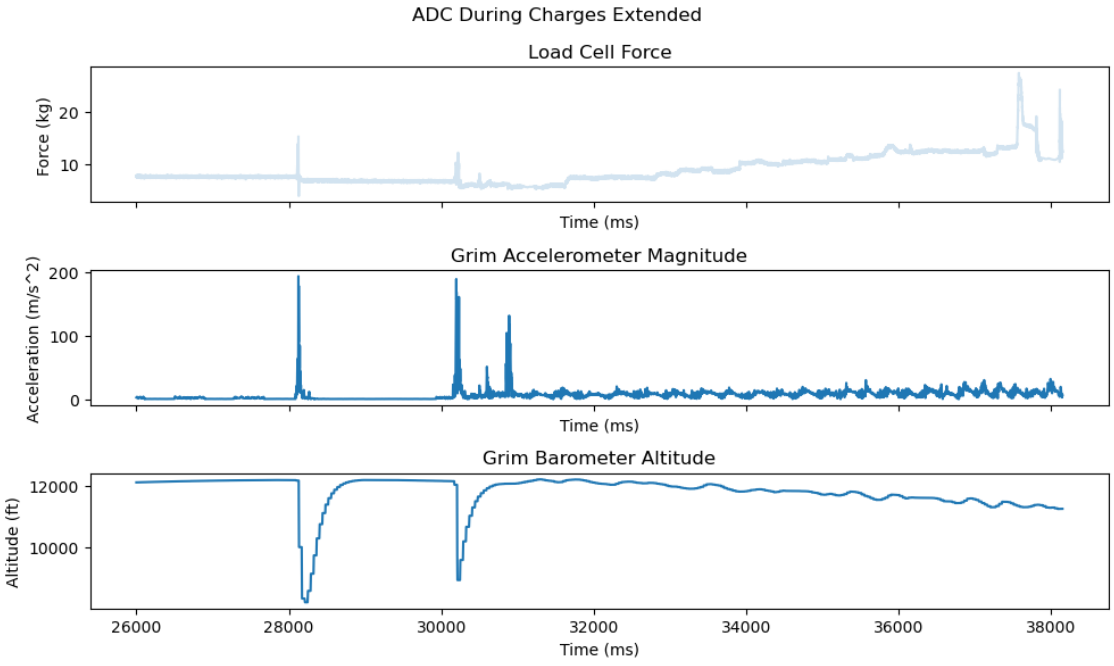
By some mechanism, the grim reefer was less affected in magnitude by these pressure spikes but took longer to recover.

9.4.5 Load Cell

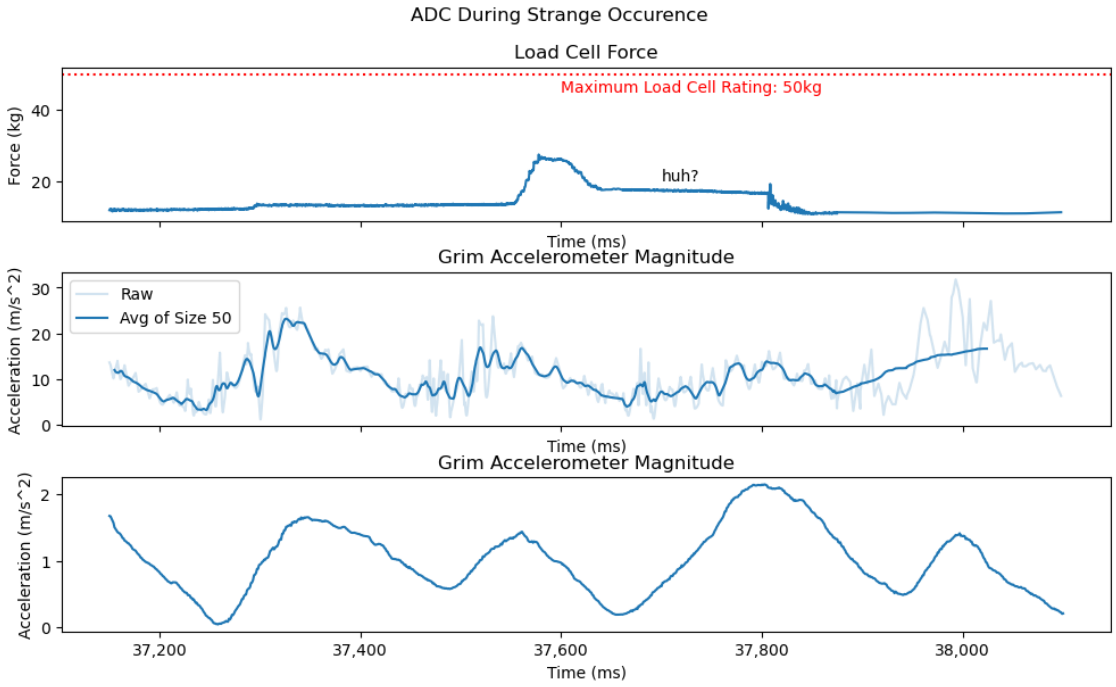
Load Cell During Charges



Load Cell During Charges and Later Window from before charges go off to a little before the parachute catches.

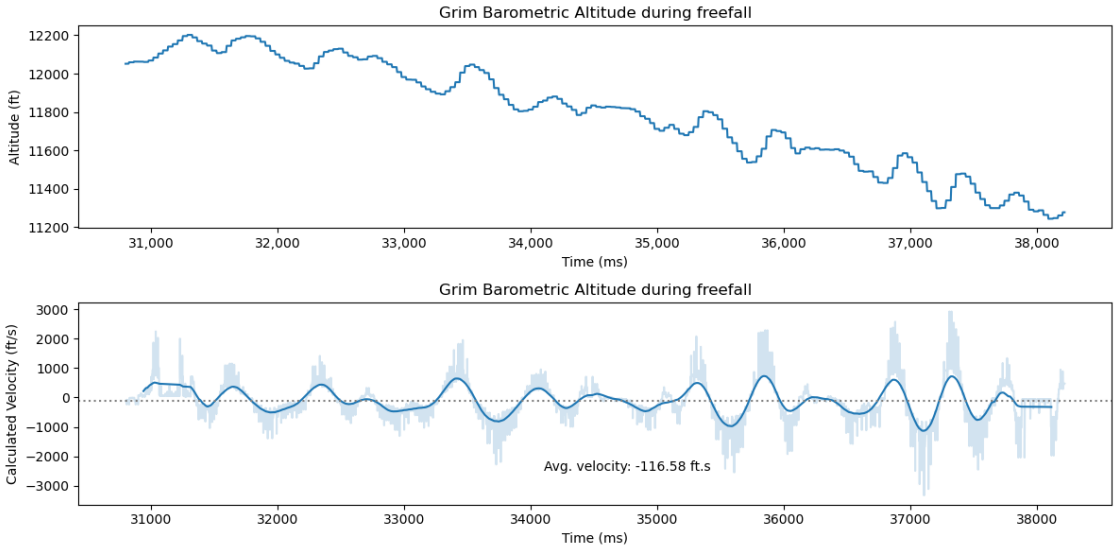


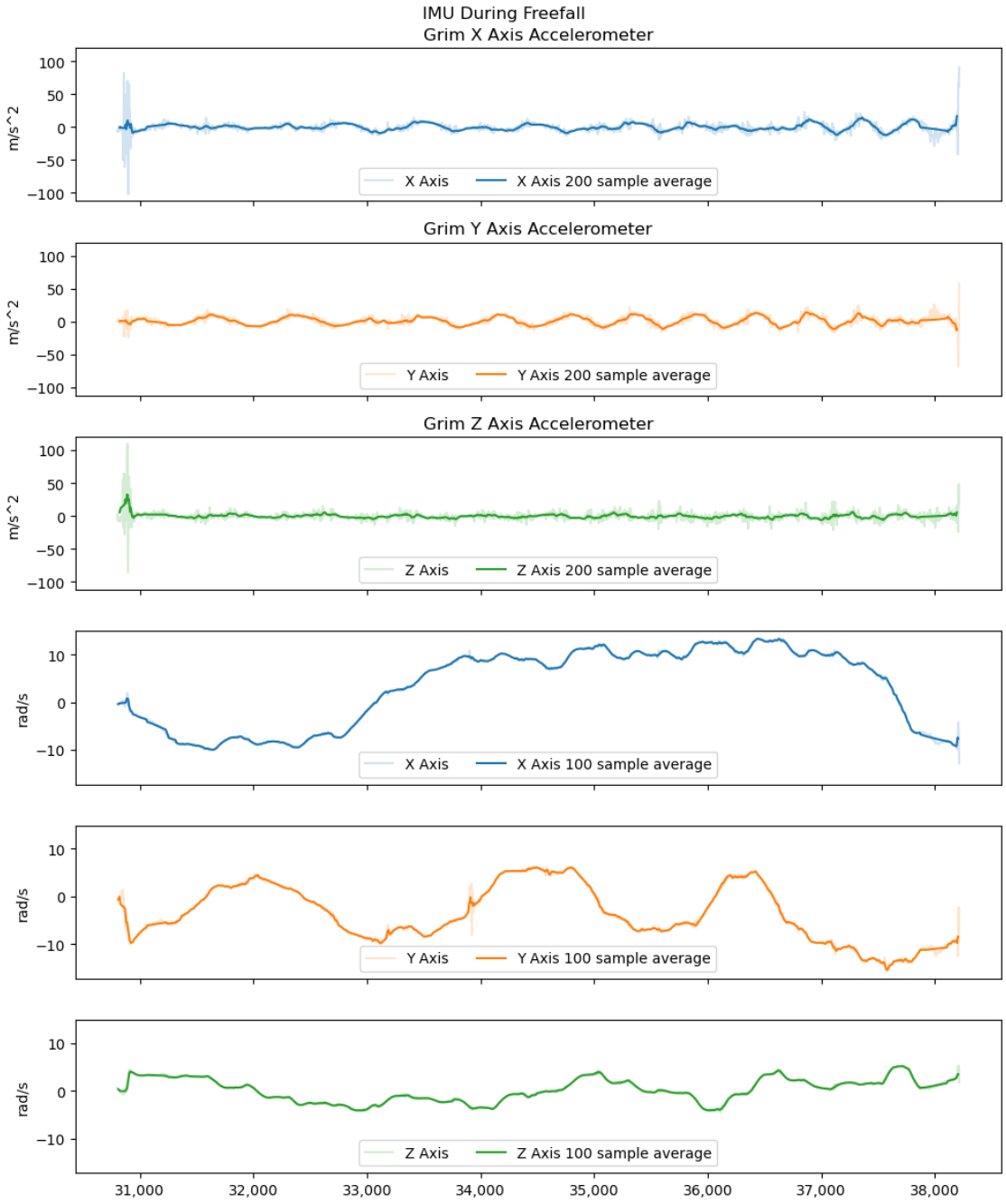
Strange ADC Bump not really sure what this is



9.5 Freefall

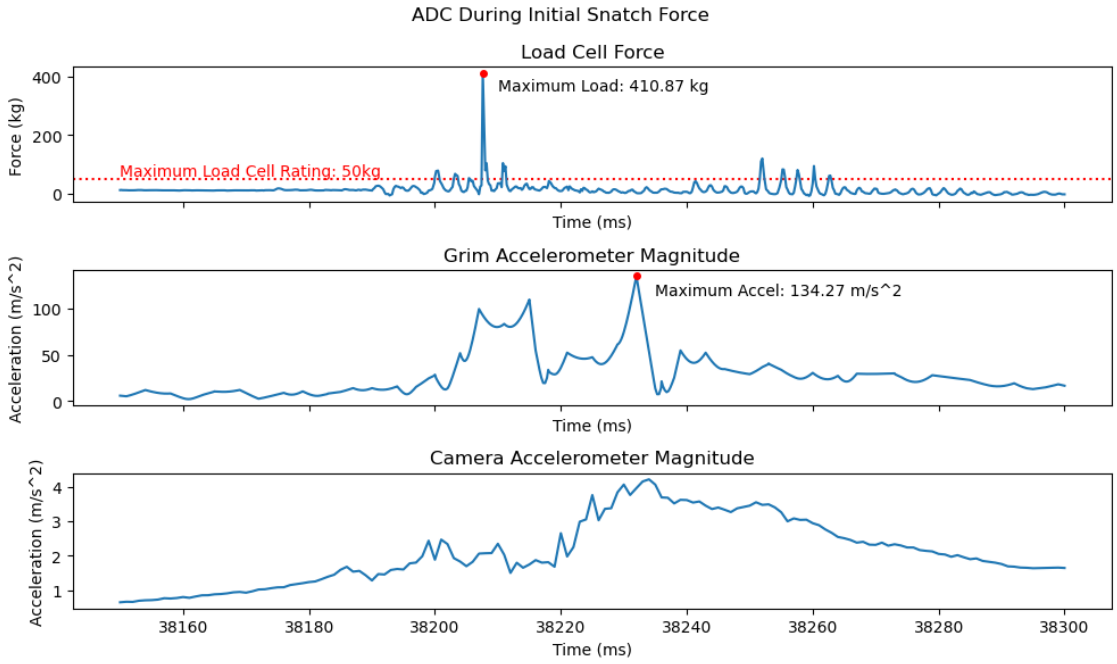
After the payload is ejected, there is a 7415 ms delay until the parachute catches where the payload is in freefall



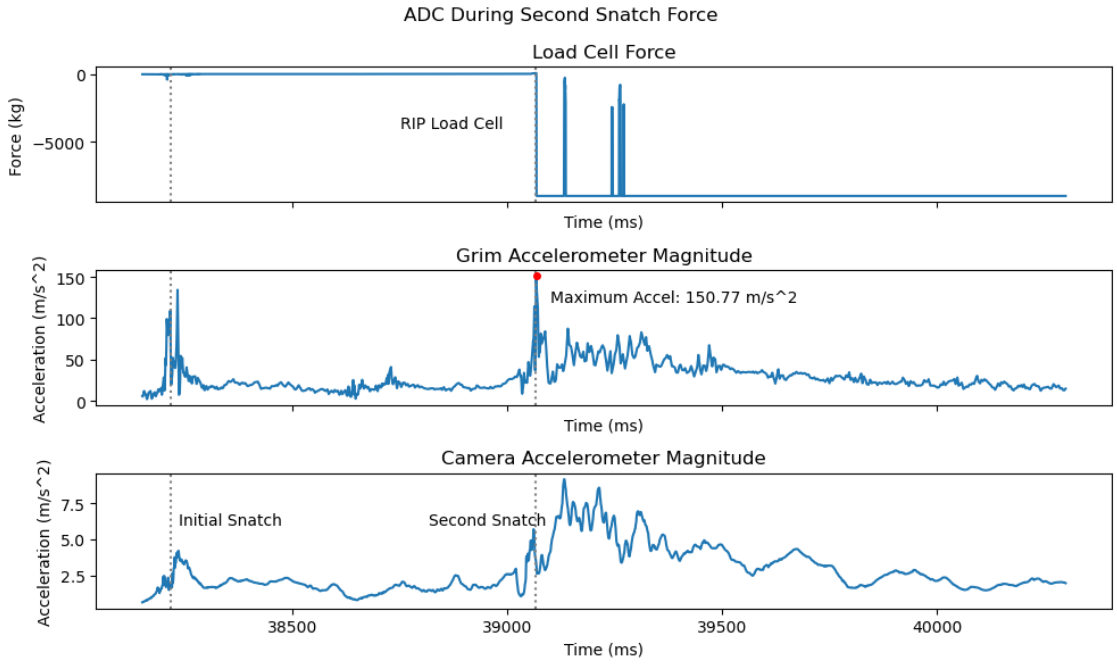


9.6 Parachute Deploy

Load Cell During Initial Snatch Force



Load Cell During Second Snatch Force



9.6.1 Flawed Comparisons

If we assume, that the max load felt by the load cell and the max acceleration of the payload measured by the IMU during a snatch event (Big If), we can make a guess at what the actual load that would have been felt had the load cell not died.

$$\frac{\text{load 1}}{\text{accel 1}} = \frac{\text{load 2}}{\text{accel 2}}$$

$$\text{load 1} \times \frac{\text{accel 2}}{\text{accel 1}} = \text{load 2}$$

Second Snatch Load Estimate = 461.37 kg

9.7 Descent

The RRC3 Pressure is very noticably weird here.