USLI

WORCESTER POLYTECHNIC INSTITUTE

G.O.A.T.S. Flight Readiness Review

March 20th

Team Members

Officers:

Team Captain: Caroline Kuhnle
Director of System Integration: Krystina Waters
Rocket Lead: Krystina Waters
Safety Officer: Christian Max Shrader
Payload Lead: Peter Dentch
Logistics Officer: Jacob Koslow
Funding Officer: Christopher Renfro
Outreach Officer: Ian Scott

General Members:

Kirsten Bowers
Drake Tierney
Troy Otter
James Kajon
Samantha Crepeau
Sophie Balkind
Gracie Lodge-McIntire
Sophiya Litovchick
Benjamin Waid
Daniel Weber
Adrianne Curtis
Veronika Karshina
Minh-Chau Doan
Thierry de Crespigny
Trevor Shrady
Lannan Jiang
Jeremiah Valero

Acronyms

cal - caliber
CG - Center of Gravity
CP - Center of Pressure
CTI - Cesaroni Technology Inc.
dB - Decibels
DC - Direct Current
ft -Feet
g - Grams
GPS - Global Positioning System
in - inches
kg - Kilogram
lb - Pounds
lbf - Pound-Force
N - Newtons
NASA - National Aeronautics and Space Administration
PPE - Personal Protective Equipment
RF - Radio Frequency
s - Seconds
SGA - Student Government Association
UAV - Unmanned Aerial Vehicle
V - Volts
WPI - Worcester Polytechnic Institute

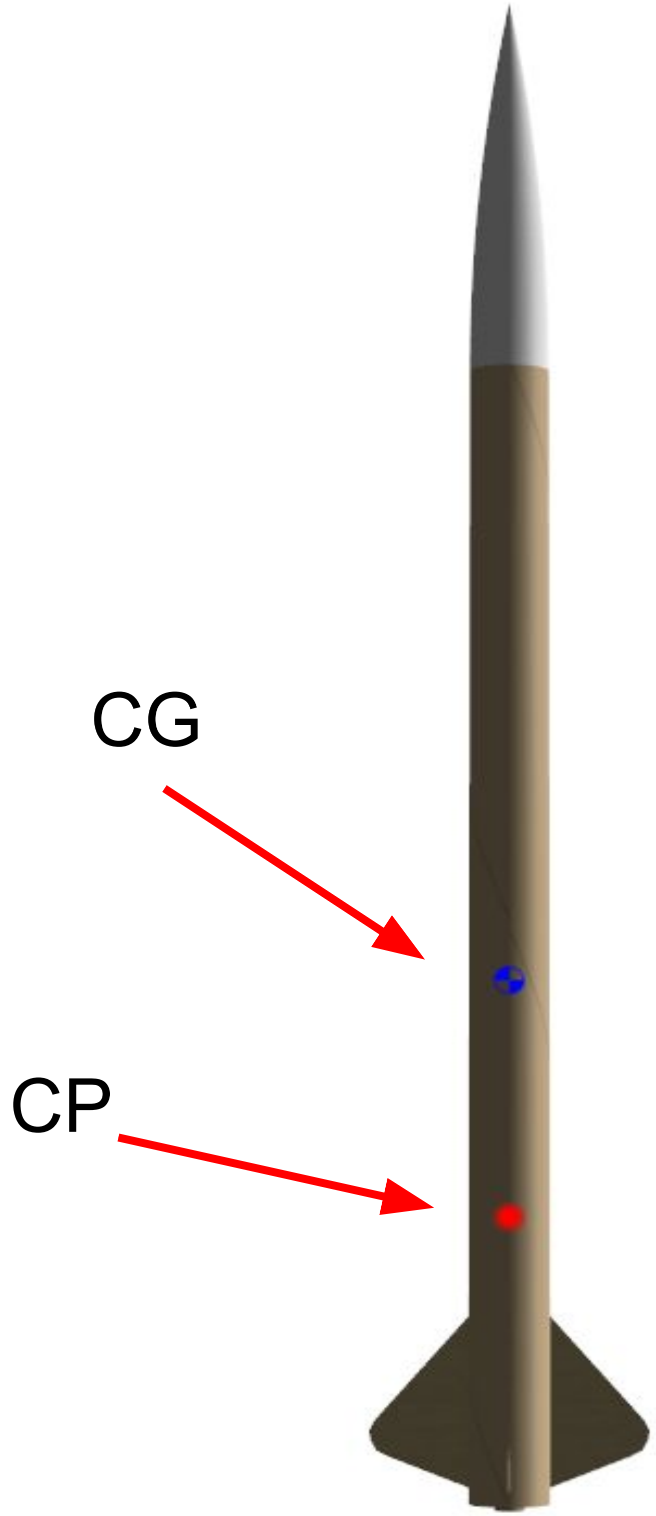
Mission Statement

Through using The National Aeronautics and Space Administration's (NASA) design lifecycle, we aim to gain real world experience about working in the field of engineering and encourage our members and team to excel through Worcester Polytechnic Institute's (WPI) philosophy of collaborative learning.

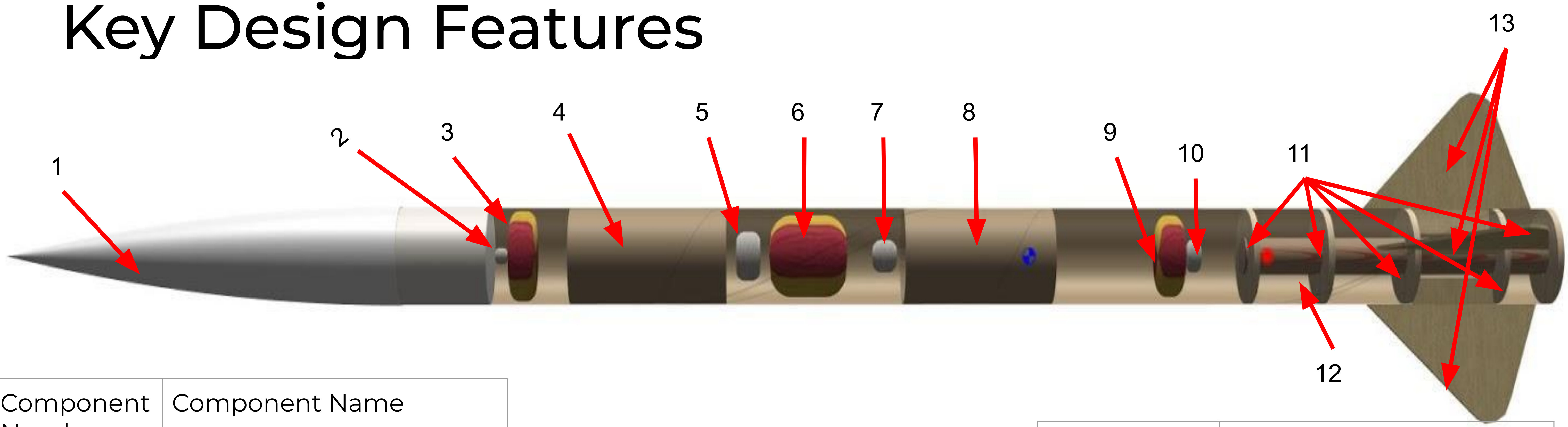
Vehicle Design

Overview of Rocket Dimensions

- Rocket Weight: **11.935 kg**
- Motor: Cesaroni Technology Inc. **L 730-0**
  - Alternate: Cesaroni Technology Inc. L1030-RL
- Airframe: **6 in x 92 in, .074 in** Blue Tube 2.0
- **4 Fins: 13.76 in** long x **~7.33in** radially
- Full Rocket Length: **125in'**
- Nose Cone:
  - Nose Length: **31.5 in**
  - Shoulder Length: **7.13 in**
- Distance between center of pressure (CP) and Center of Gravity (CG): **19.81 in**
- Stability: **3.36 cal**



Key Design Features



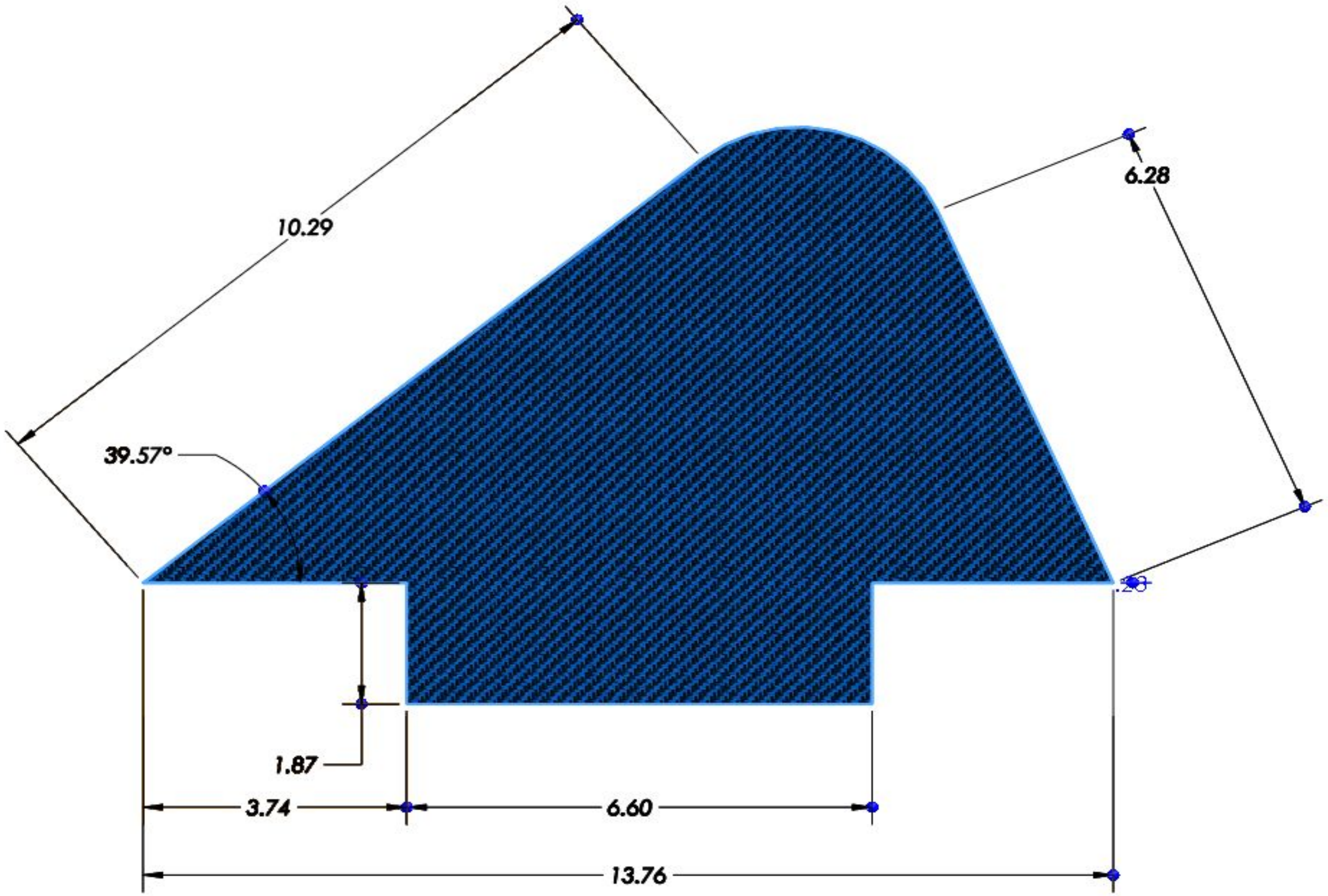
Component Number	Component Name
1	Nose Cone
2	Nose Cone Shock Cord
3	Nose Cone Parachute
4	Payload Retention System
5	Shock Cord

Component Number	Component Name
6	Main Parachute
7	Main Shock Cord
8	Electronics Bay
9	Drogue Parachute

Component Number	Component Name
10	Drogue Shock Cord
11	Centering Rings (Plywood)
12	Motor Tube
13	4 Fins

Fin Properties

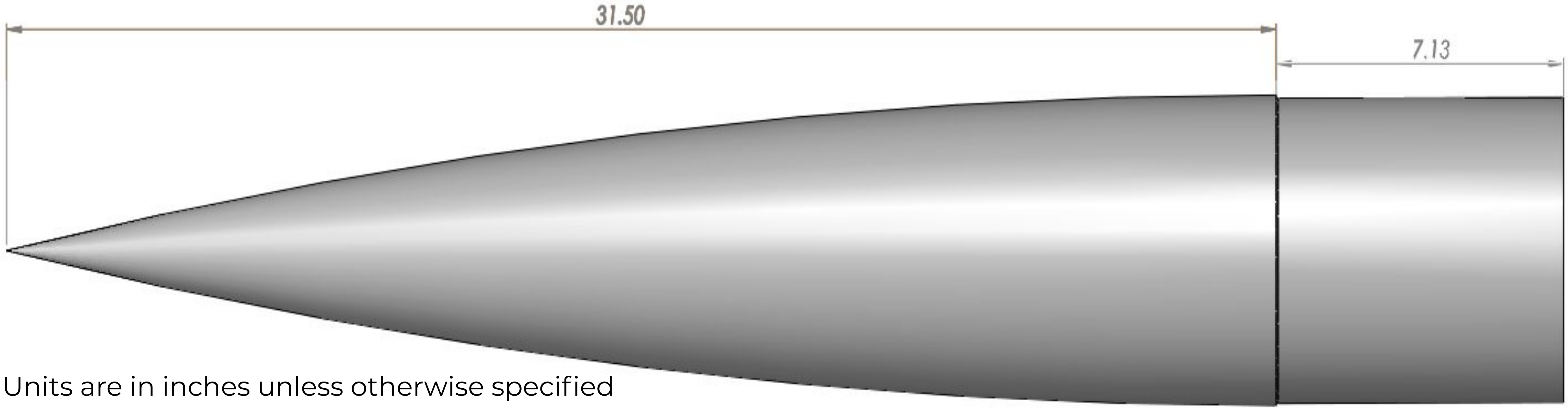
- Rounded shape, carbon fiber
- Aerodynamically better
- Fin Dimensions
- Through the wall



Units are in inches unless otherwise specified

Nose Cone Properties

- Fiberglass
- Metal Tip
- Lands separately with own parachute



Units are in inches unless otherwise specified

Final Secondary Motor Selection

Motor: L1030-RL

Manufacturer: CTI

Class: 9% L

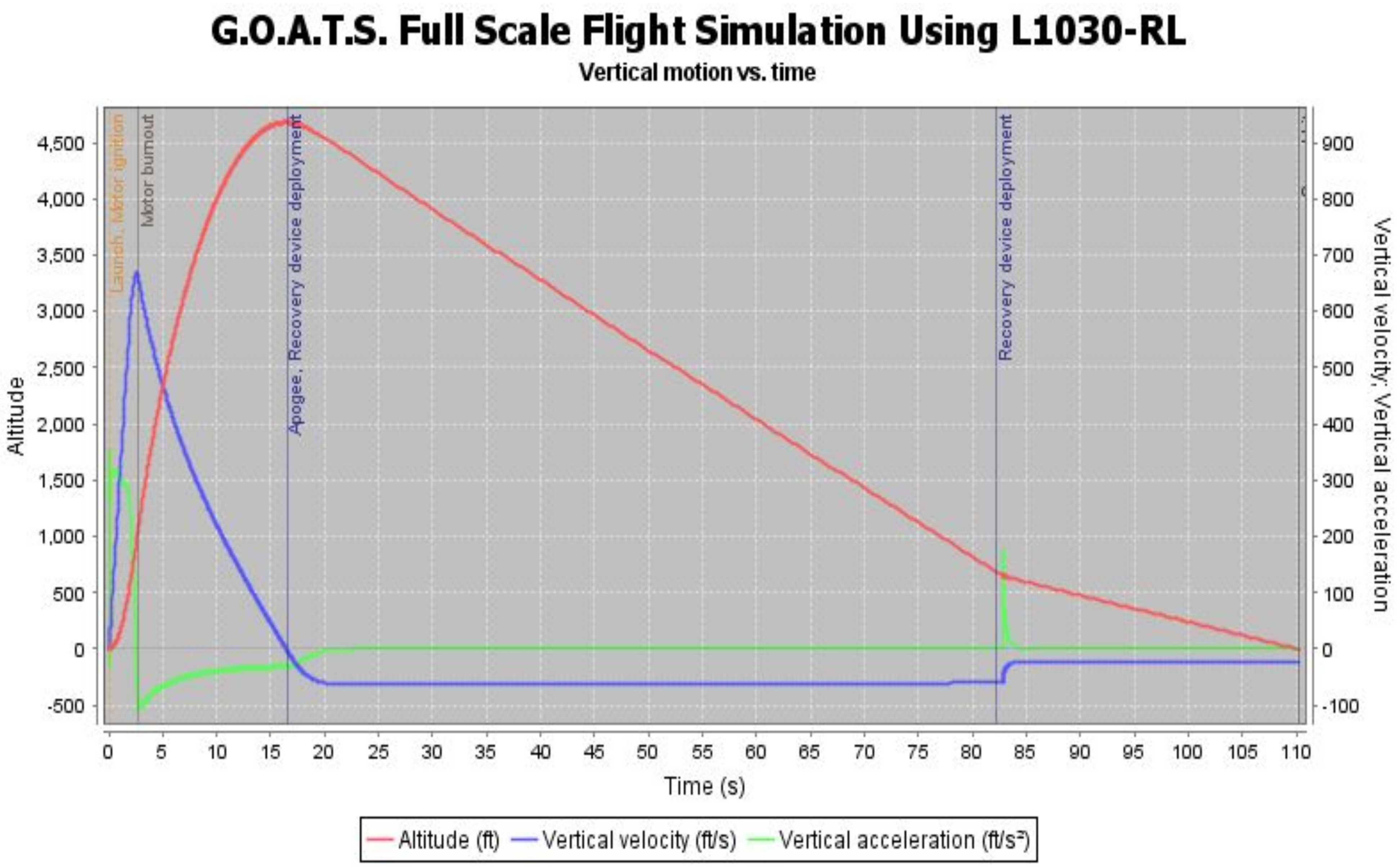
Avg. thrust: 1,028.5 N

Thrust duration: 2.70s

Total Impulse: 2,781.2 Ns

Weight: 2,338.0 g

Plugged Seconds



Final Primary Motor Selection

Motor: L730-0

Manufacturer: CTI

Class: 8% L

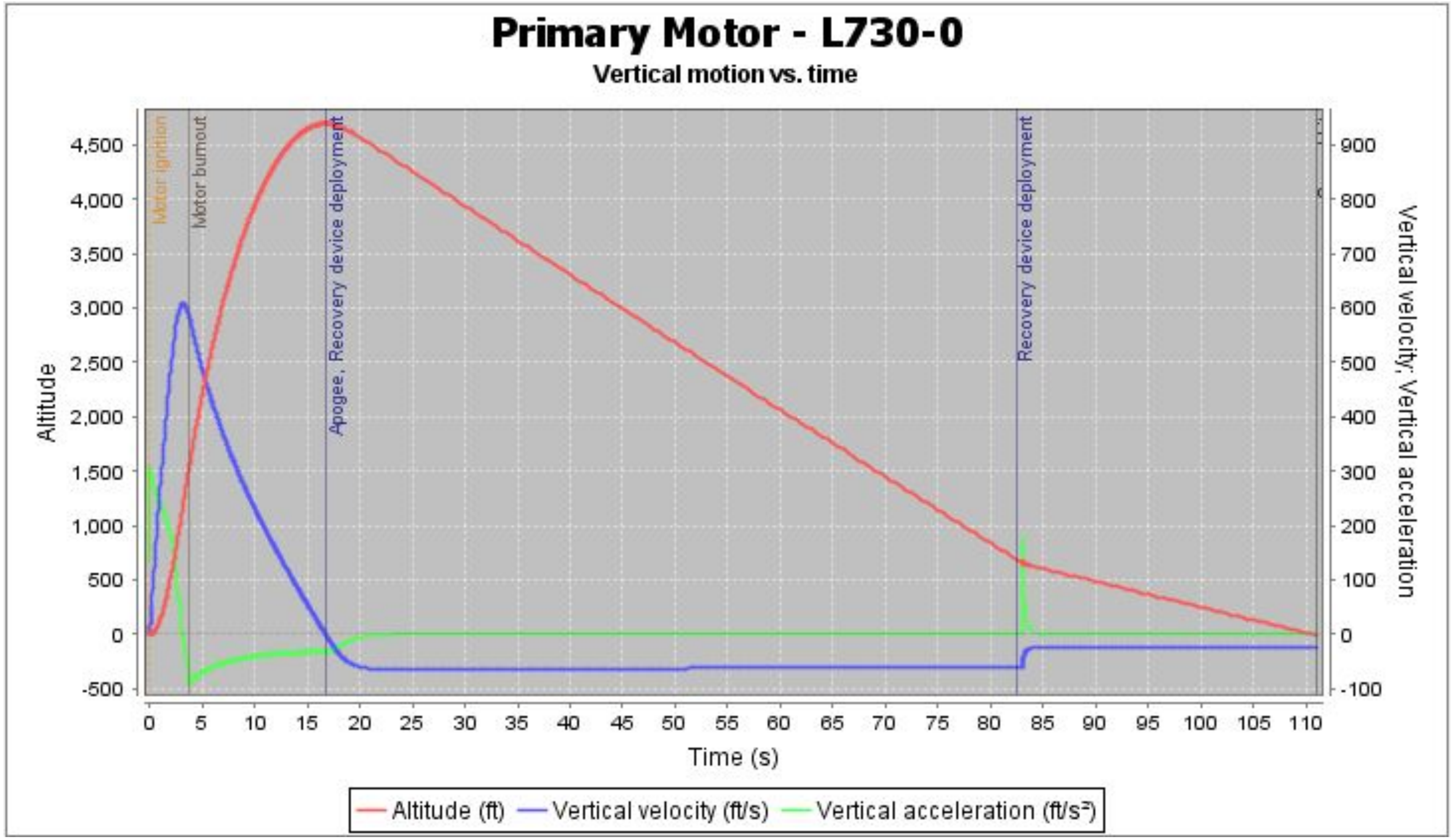
Avg. thrust: 732.9 N

Thrust duration: 3.77 s

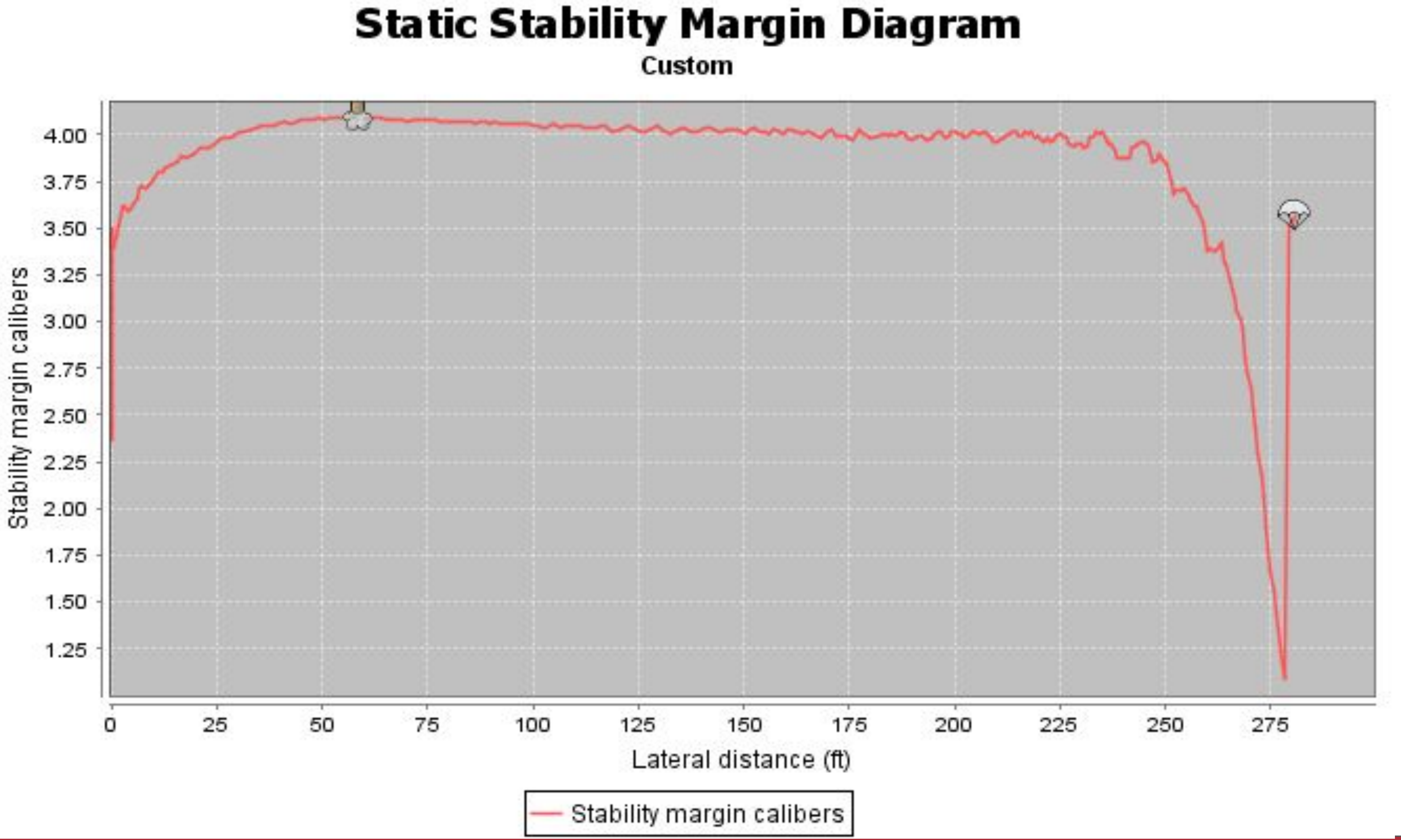
Total Impulse: 2763.2 Ns

Weight: 2,247.0g

Plugged Seconds



Rocket Flight Stability in Static Margin Diagram



Stability Values,Thrust-to-weight Ratio and Rail Exit Velocity

Static Stability Margin (on pad): **2.00 cal**

Static Stability Margin (at rail exit): **3.36 cal**

Thrust-to-weight Ratio: **6.46:1**

Rail Exit Velocity: **85.3 ft/s**

CG: **81.187 in**

CP: **101in**

Predicted Drift from Launch Pad

Wind Speed:	Section 1 (Main Tethered Section):	Section 2 (Nose Cone):
0 mph:	0 ft	0 ft
5 mph	710 ft	689 ft
10 mph:	1420 ft	1378 ft
15 mph:	2130 ft	2067 ft
20 mph:	2840 ft	2756 ft

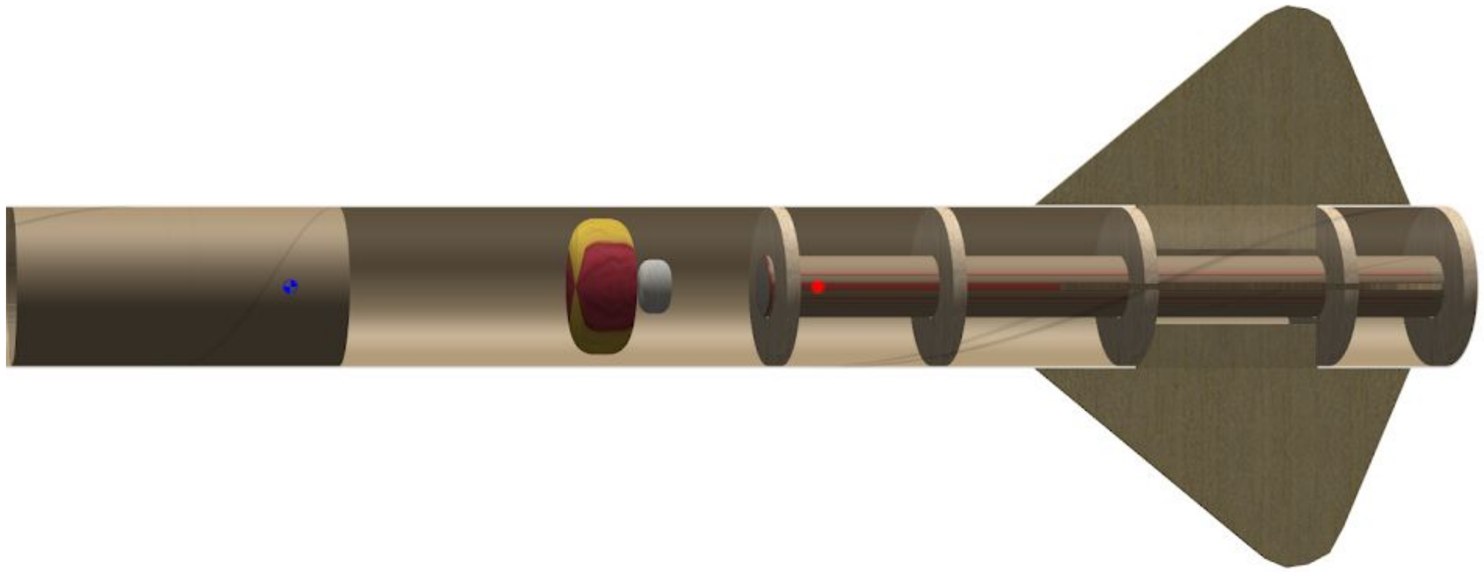
Mass Statement and Mass Margin - Upper

Gross Lift Off Weight	**25.47 lb**
Motor Mass Before Burn	**4.95 lb**
Nose Cone Mass	**435 g**
Upper Airframe Mass	**1346 g**

• Inner Tube	**300 g**
• Main Parachute	**243 g**
• Payload	**1056 g**
• Nose Cone Parachute	**47.2 g**
• Nose Cone Shock Cord	**11.6 g**
• 2 Shock Cords	**456 g (228g each)**

Mass Statement and Mass Margin - Lower

Electronics Bay	**29.3 g**
Tube coupler	**200 g**
Lower Airframe Mass	**1354 g**
• 5 Centering Rings	**29.3 g**
• Fin set	**1750 g**
• Drogue Parachute	**47.2 g**
• Inner Tube	**232 g**
• Shock cord	**228 g**
Total Mass	**11.601 kg**
Total Weighted Mass	**11.935 kg**



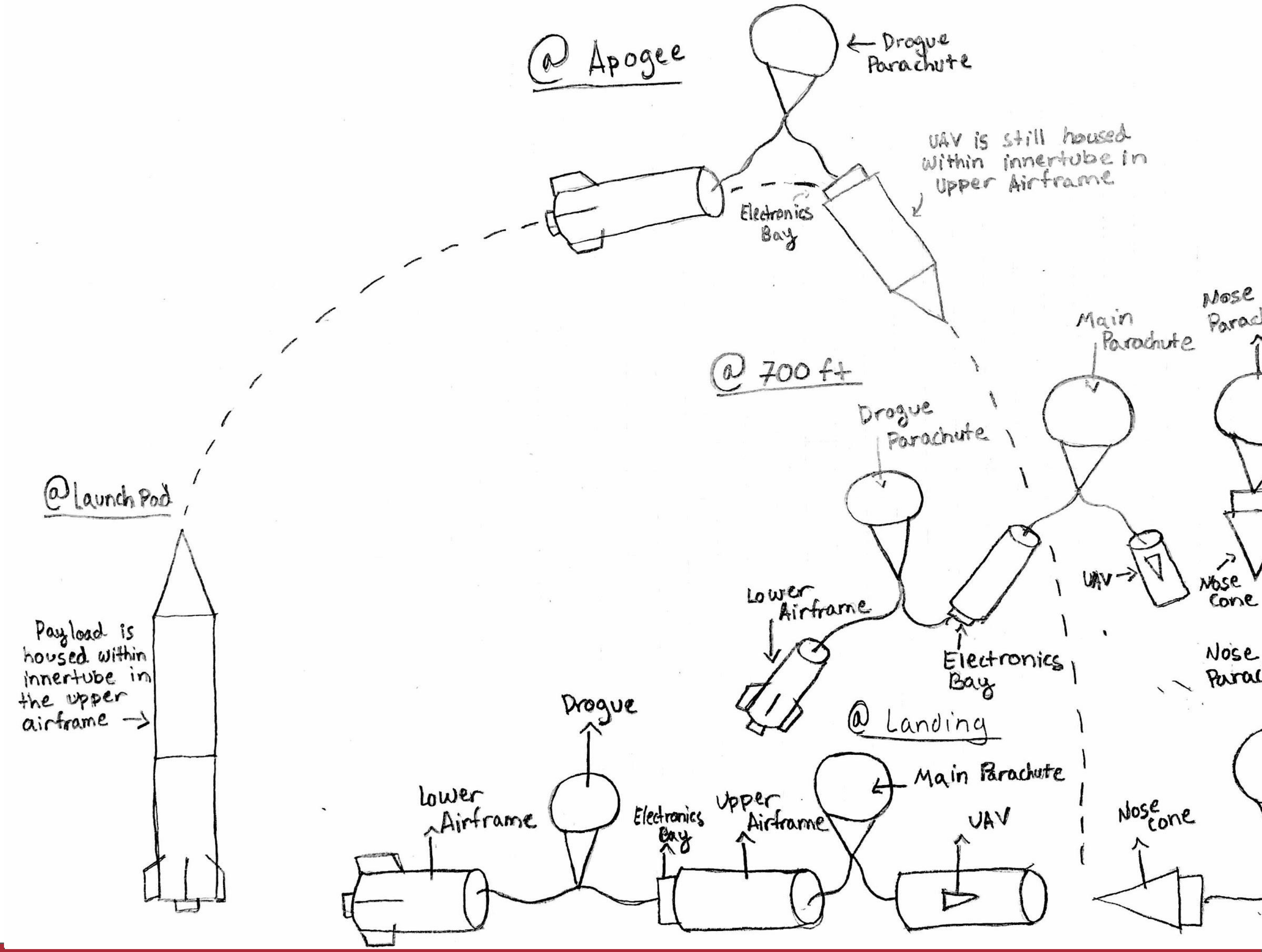
Recovery System

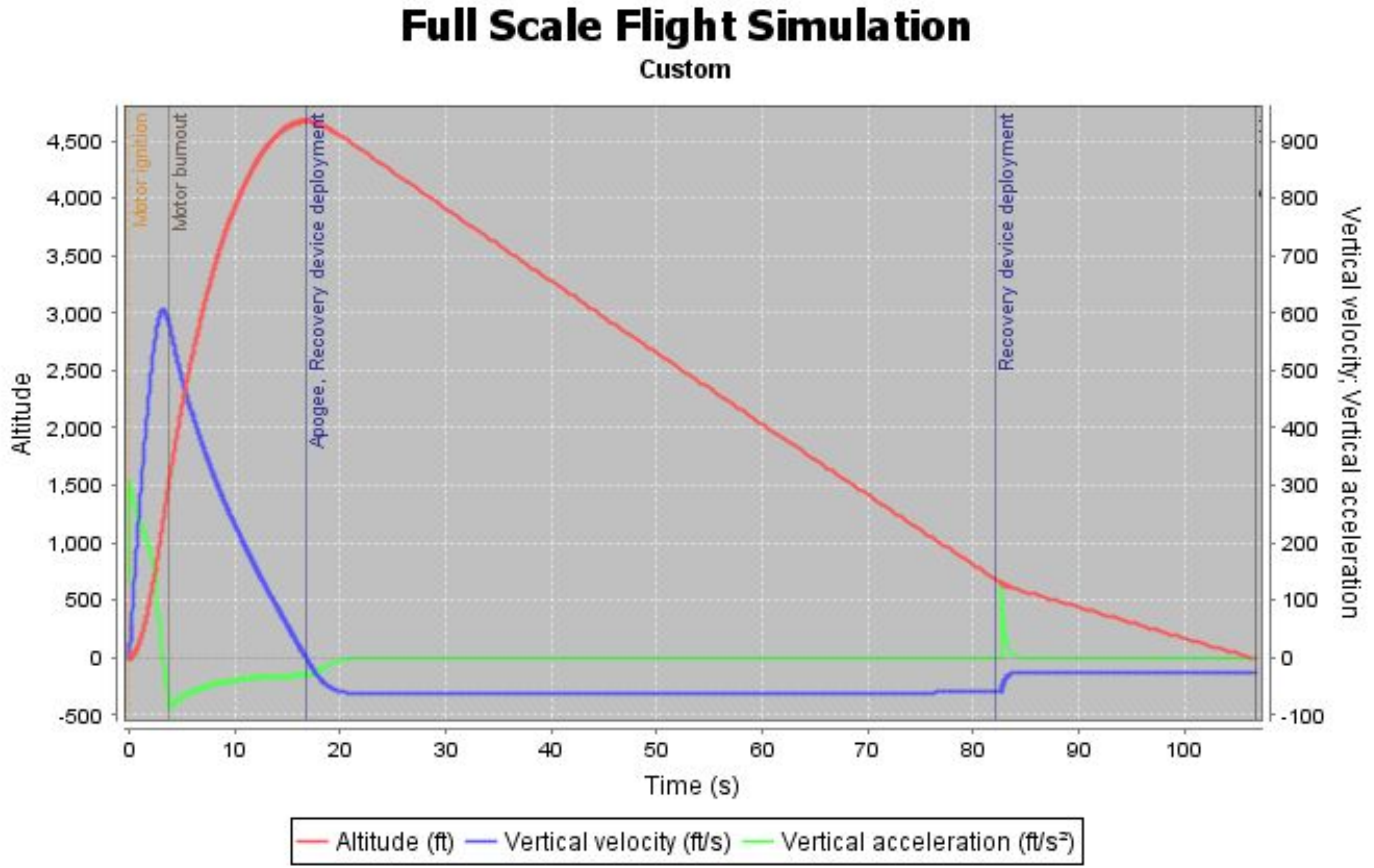
Vehicle Flight Plan

- Apogee: **4683 ft**
- Goal Apogee: **4500 ft**

- Charges go off at **700 ft**
- **Dual Deployment System**

- Nose Cone will land separately from UAV, Lower and Upper Airframes



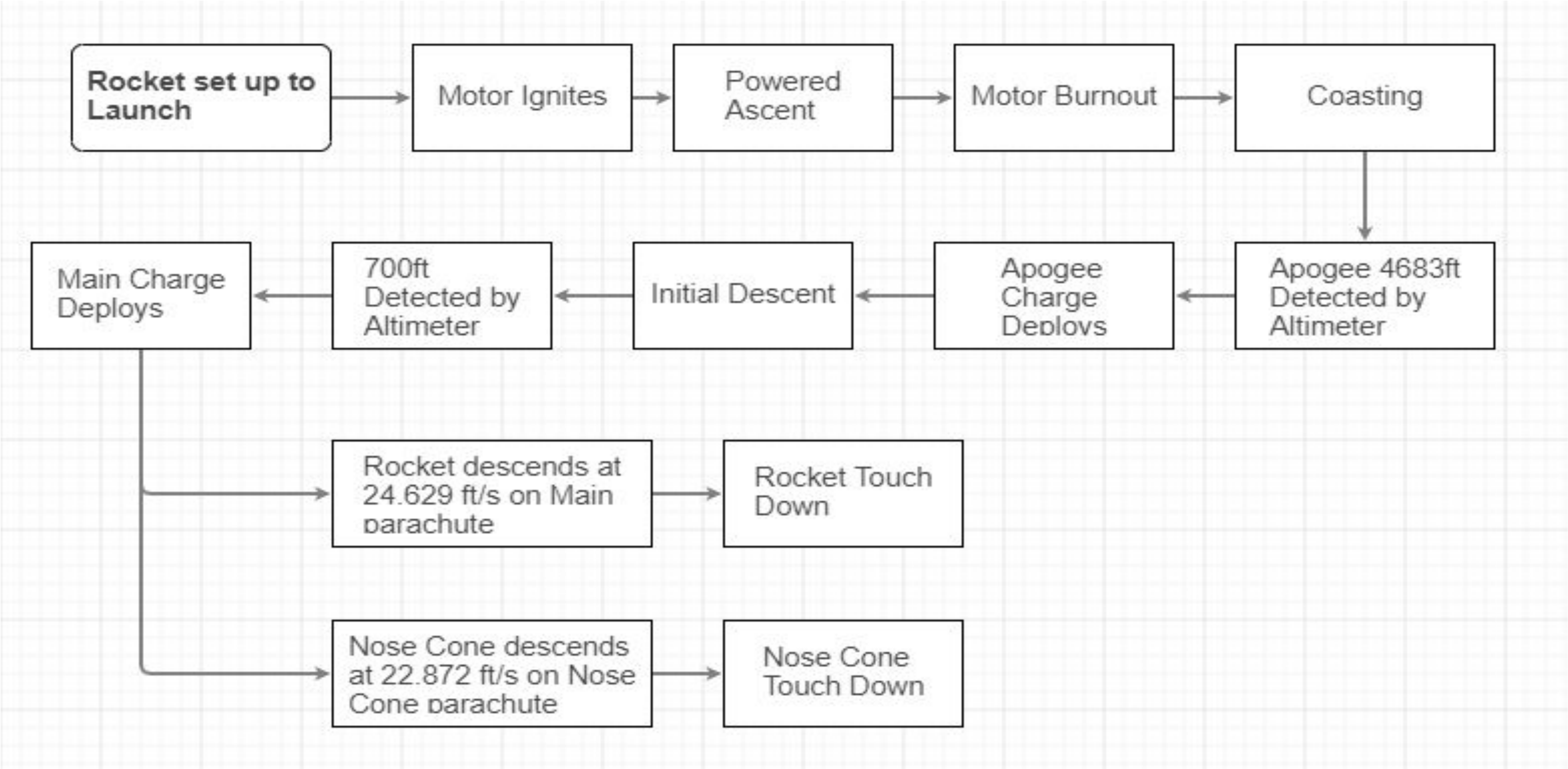


Full Scale Flight Simulation
Custom
Motor ignition
Motor burnout
Apogee , Recovery device deployment
Recovery device deployment
Altitude
Vertical velocity; Vertical acceleration
Time (s)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
900
800
700
600
500
400
300
200
100
0
-100
0
10
20
30
40
50
60
70
80
90
100
Altitude (ft)
Vertical velocity (ft/s)
Vertical acceleration (ft/s²)

Full Scale Flight Simulation Data

Motor Configuration:	L730-0
Velocity off Rod:	85.3 ft/s
Apogee:	4683 ft
Optimum delay:	13 s
Max Velocity:	605 ft/s
Max Acceleration:	307 ft/s^2
Flight time:	107 s
Decent time:	90.2 s
Ground Hit Velocity:	26.8 ft/s

Recovery System

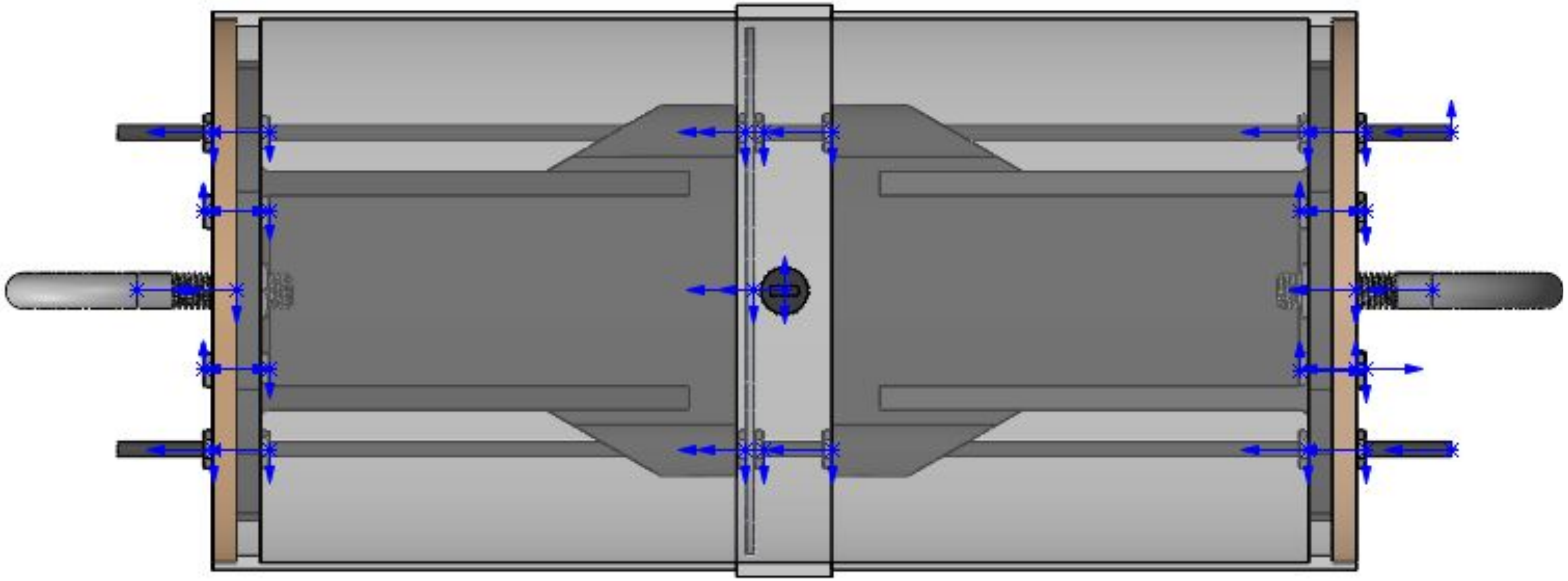


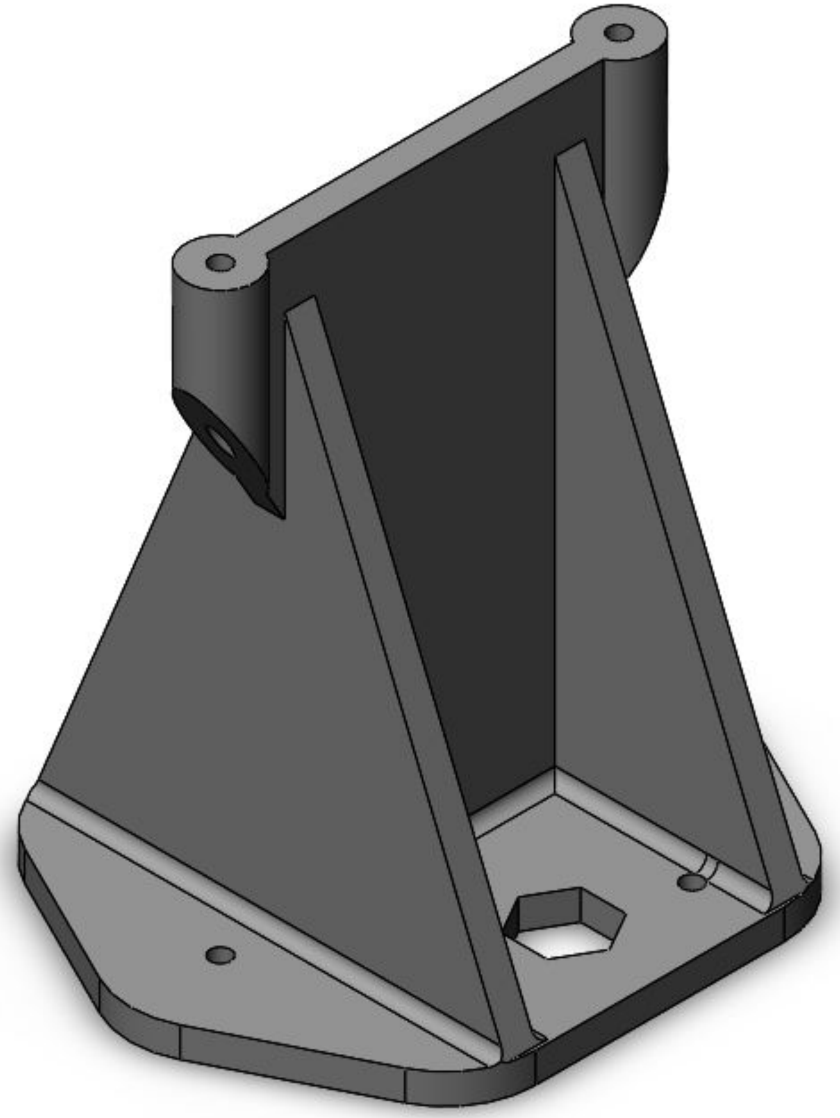
Recovery System

- Current Parachute Diameters
  - Main Parachute: 72 in
  - Drogue Parachute: 36 in
  - Nose Cone Parachute: 36 in
- Shock Cord
  - Material: Tubular Nylon
  - Length:
    - Main Parachute: 137.55 in
    - Drogue Parachute: 138.45 in

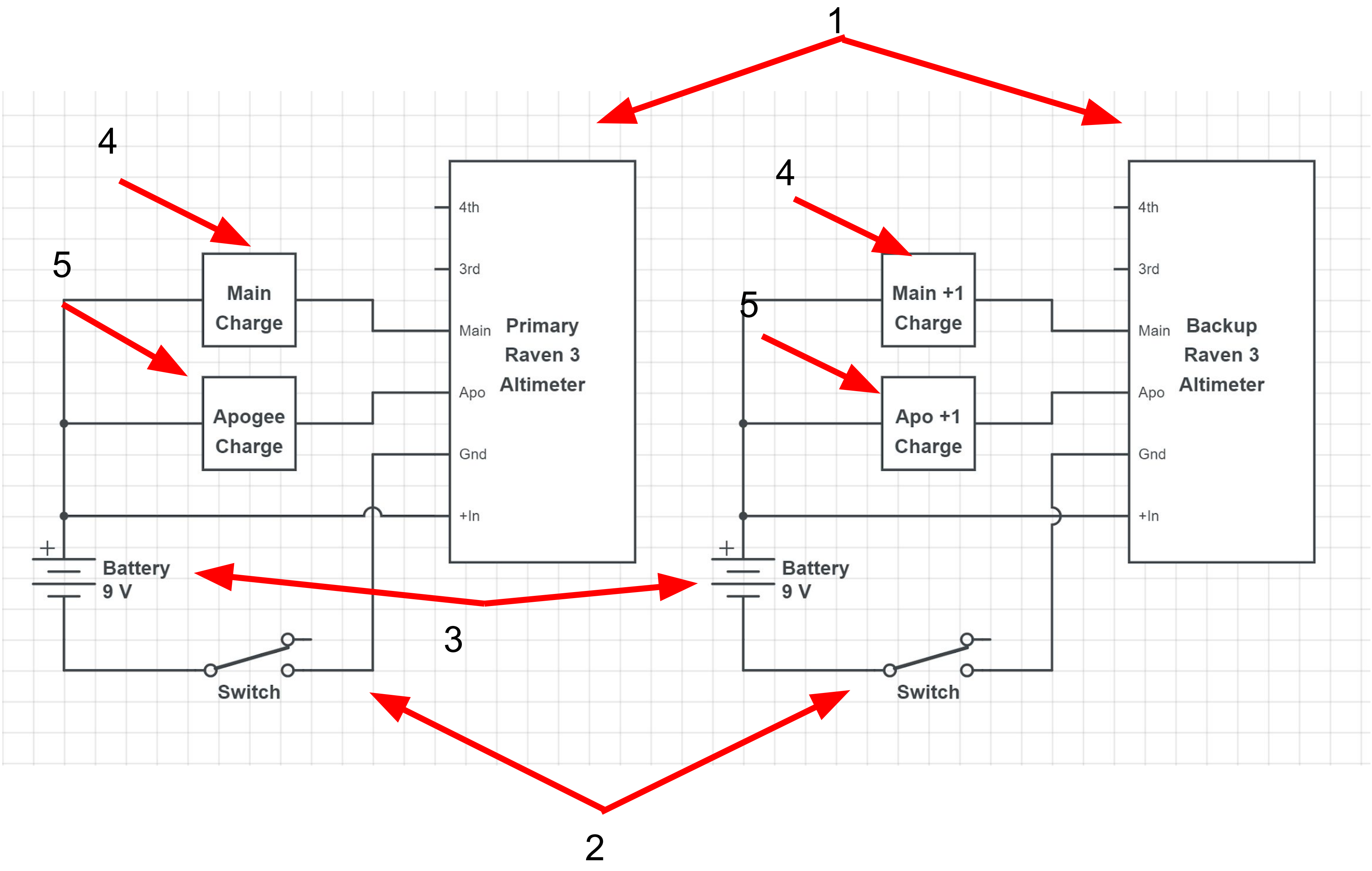
Via
http://spherachutes.com/

Electronics Bay





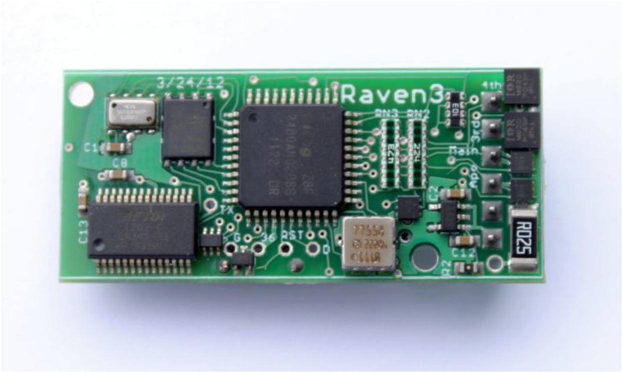
Electronics Bay Wiring



Component number	Component name
1	Raven 3 Altimeters
2	Rotary Switches
3	9V batteries
4	Main Parachute Charges
5	Apogee Charges

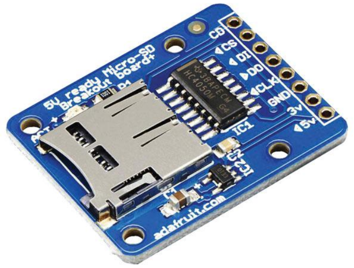
Electronics Bay Components

- Raven 3 Altimeter 9V
    - To log the altitude of the rocket

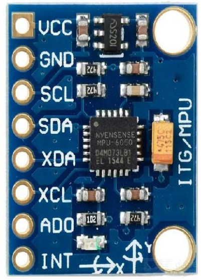


- GPS NEO-6MV2
    - Used to track the upper airframe, lower airframe, payload, and nose cone

- Micro SD card and Breakout Board
    - Data from gyroscope and accelerometer logged here

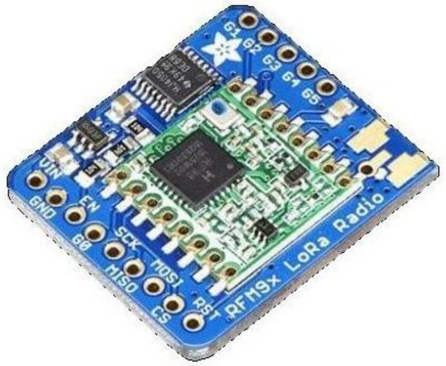


- MPU-6050
    - A combined gyroscope and accelerometer

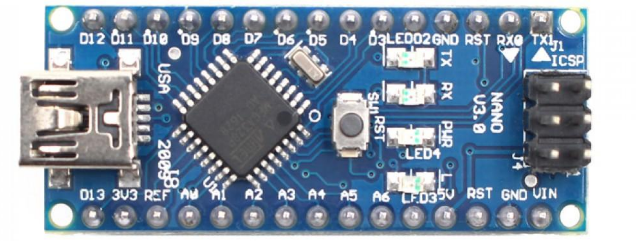


Electronics Bay Components

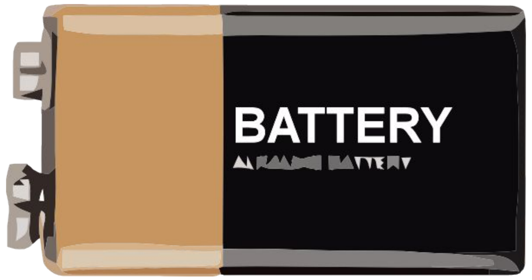
- Adafruit RFM95W LoRa 915MHz Radio Transceiver
  - Receives and sends transmissions from base station



- Arduino Nano
  - Receives data from GPS and sends it to the RF Transceiver



- Nine Volt Battery
  - Power supply



Parachute size, length,

Main parachute

- Ripstop nylon with elastic cord shroud lines
- Diameter: 72 in
- Recovery harness
  - Type: 1 in tubular nylon shock cord
  - Length: 137.55 in
- Descent rate
  - Velocity at deployment: 63.95 ft/s
  - Terminal velocity: 24.629 ft/s

Drogue parachute

- Ripstop nylon with elastic cord shroud lines
- Diameter: 36 in
- Recovery harness
  - Type: 1 in tubular nylon shock cord
  - Length: 138.45 in
- Descent rate
  - Velocity at deployment: 0
  - Terminal velocity: 63.95 ft/s

Parachute size, length, cont.

Nose Cone Parachute

- Ripstop nylon with elastic cord shroud lines
- Diameter: 36 in
- Recovery harness
  - Type: 1 in tubular nylon shock cord
  - Length: 138.45 in
- Descent rate
  - Velocity at deployment: 0
  - Terminal velocity: 63.95 ft/s

Kinetic Energy at Landing

Section 1 Payload Retention:

18.772 lbf*ft

Section 2 Nose Cone:

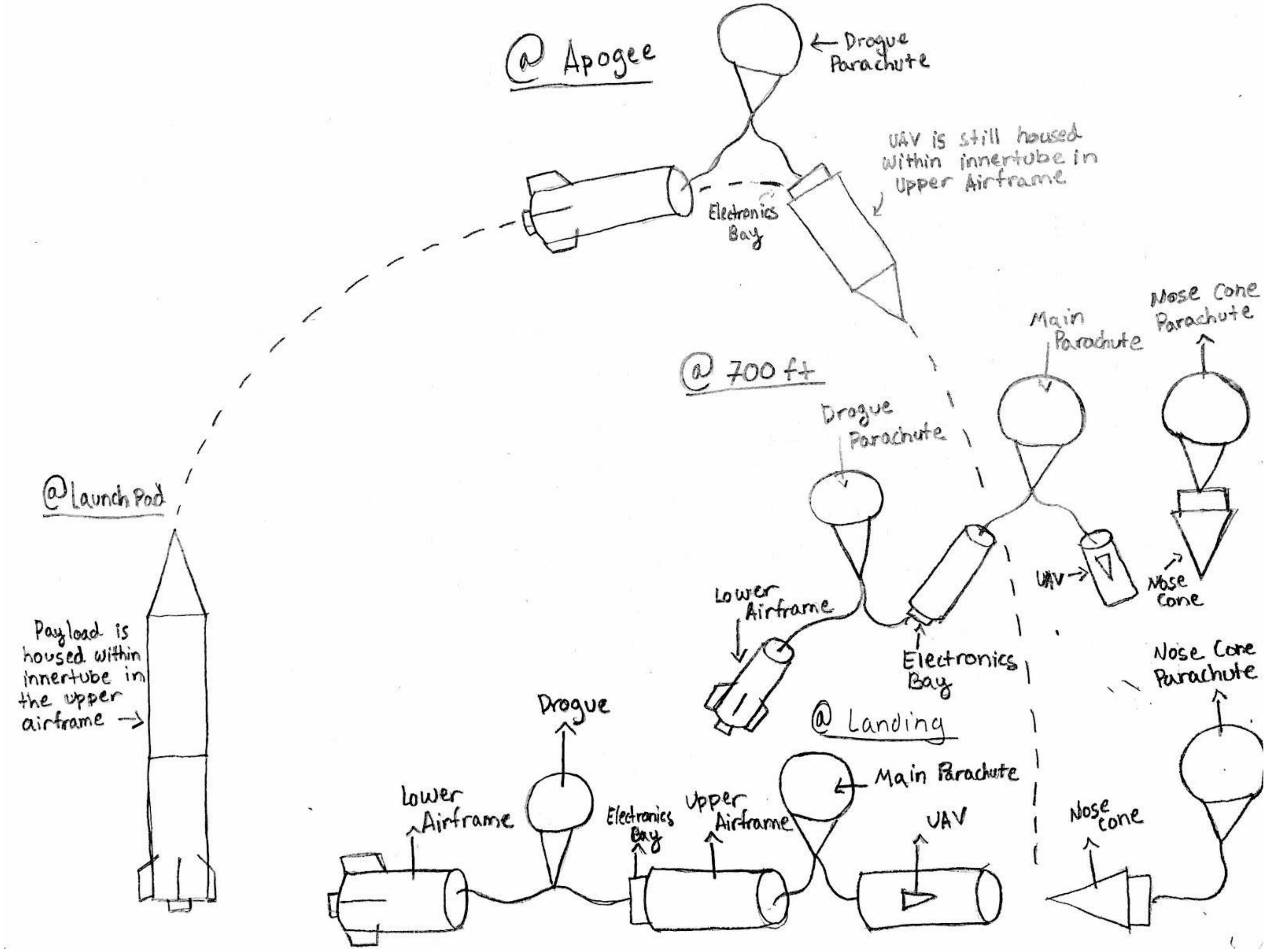
39.479 lbf*ft

Section 3 Lower Airframe:

74.857 lbf*ft

Section 4 Upper Airframe:

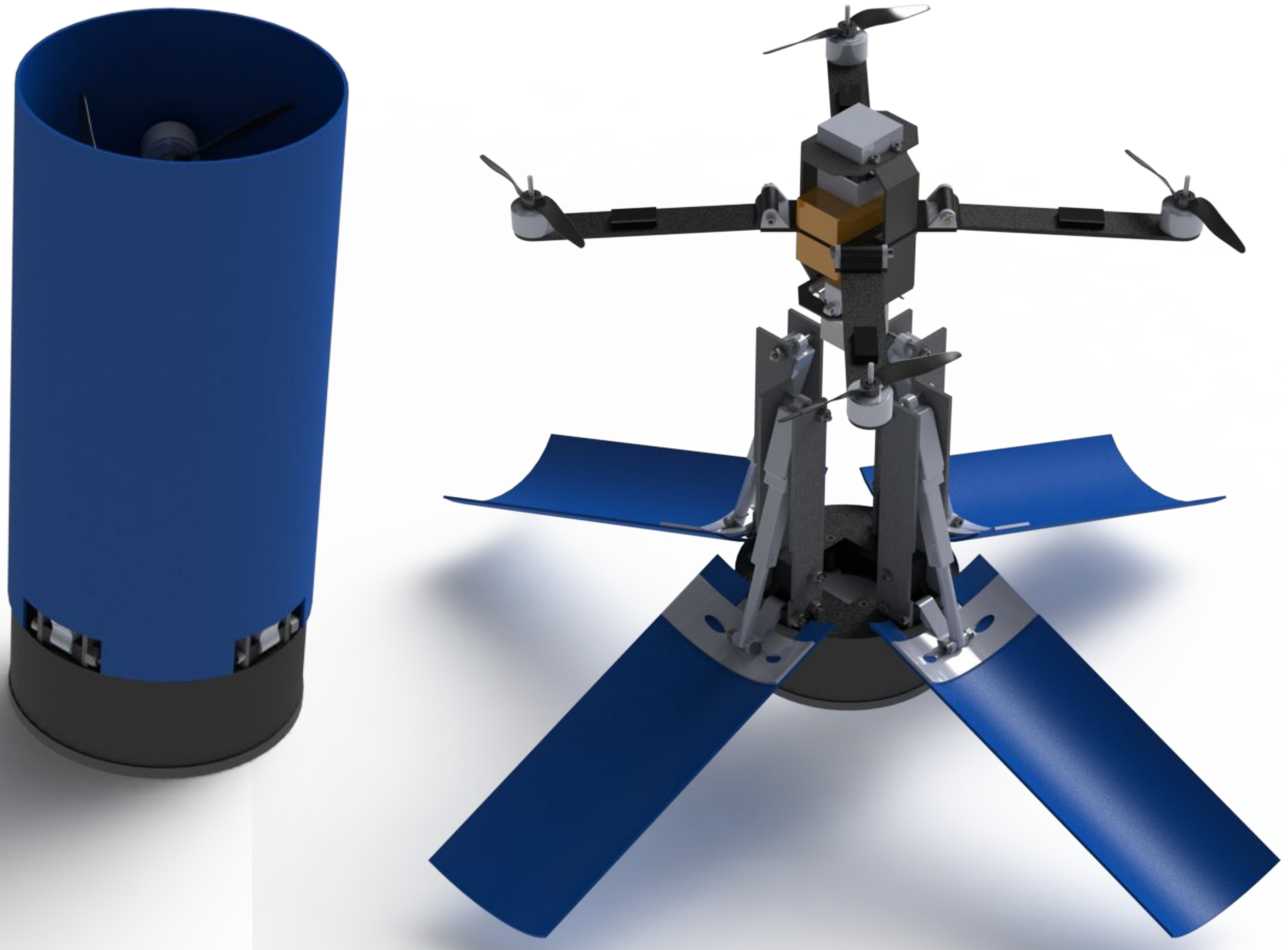
56.838 lbf*ft



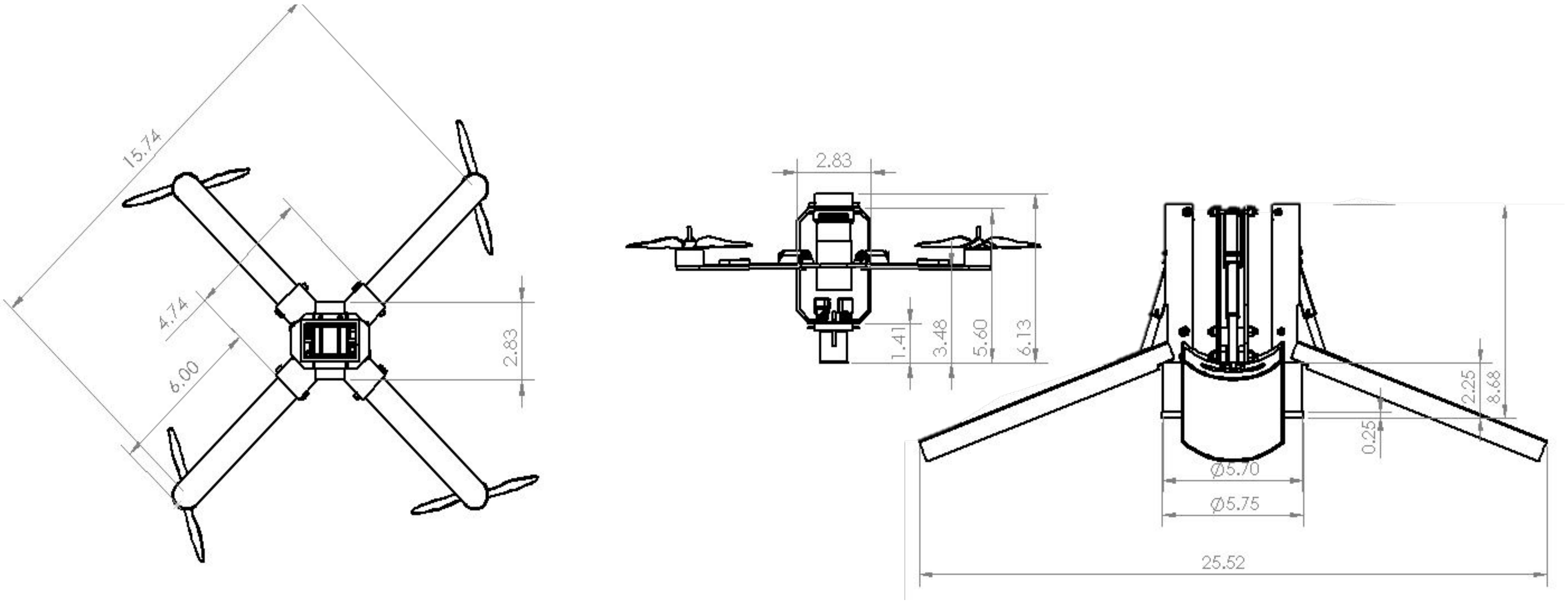
Payload

Retention System Design

- Unfolding inner tube retention system housed within the rocket airframe
- Orients itself upright from any initial landing configuration to deploy the UAV



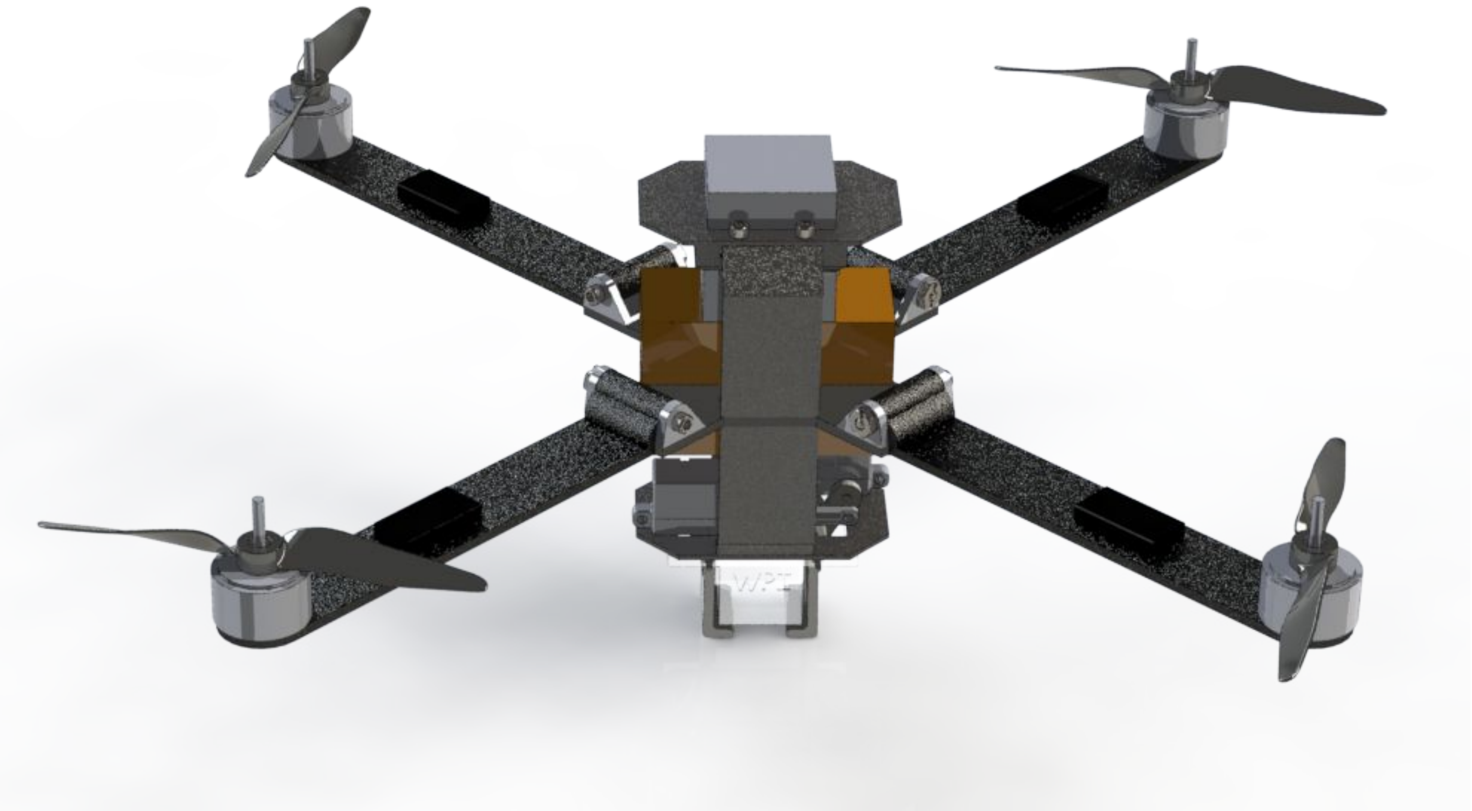
Final Payload Design



Units are in inches unless otherwise specified

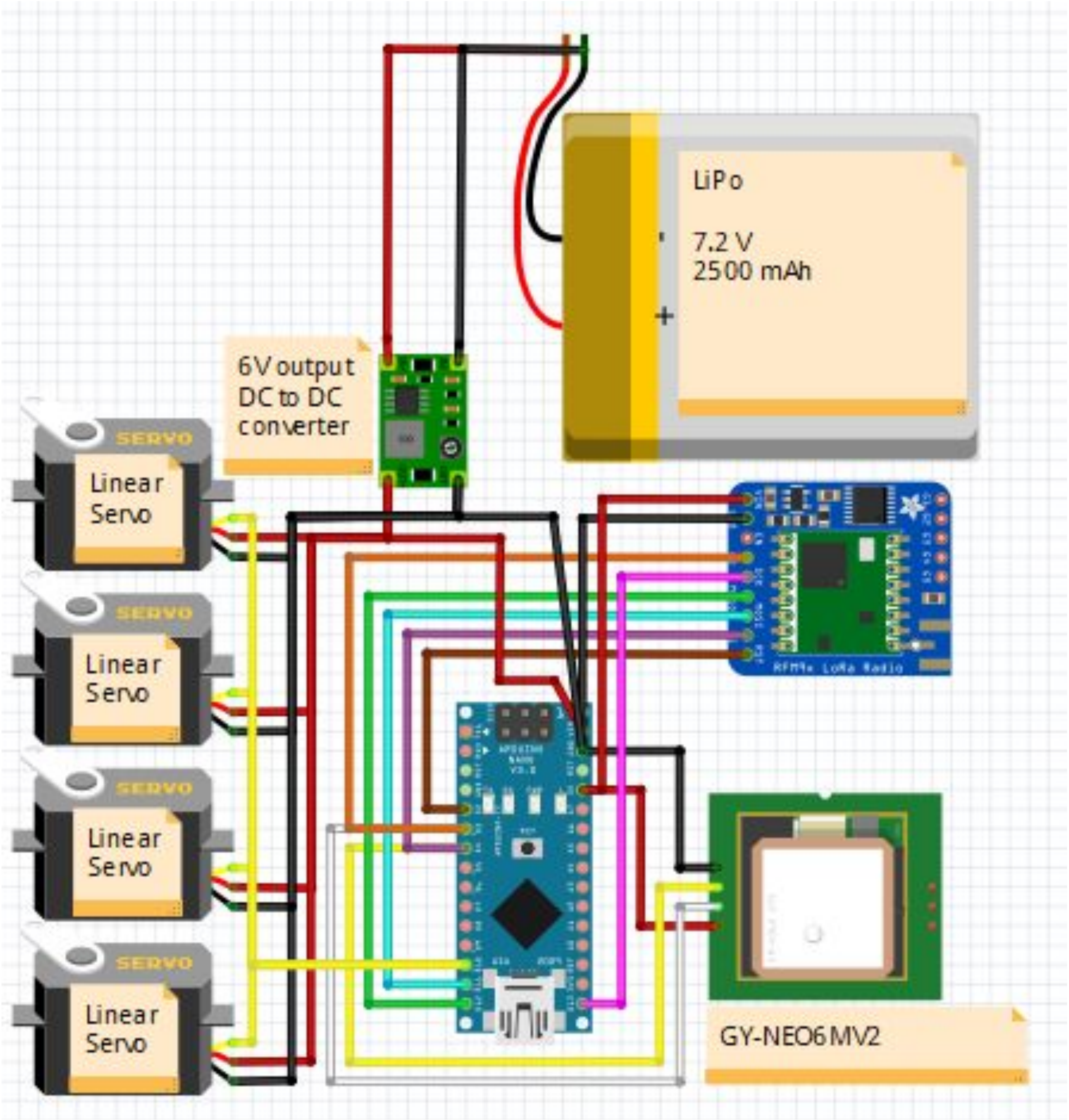
Quadrotor UAV

- Total weight of about 632 g
- Maximum thrust to weight ratio of 4 to 1
- 10 minute maximum flight time
- 6 in diameter and 4.5 in pitch propellers
- 3DR Pixhawk mini with GPS module and Holybro telemetry system for real time data logging and monitoring



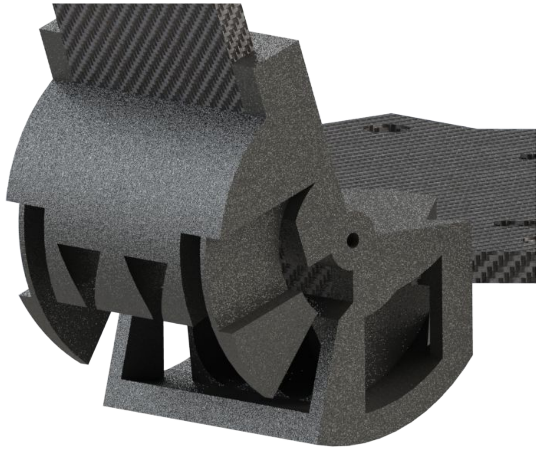
Payload Electrical system

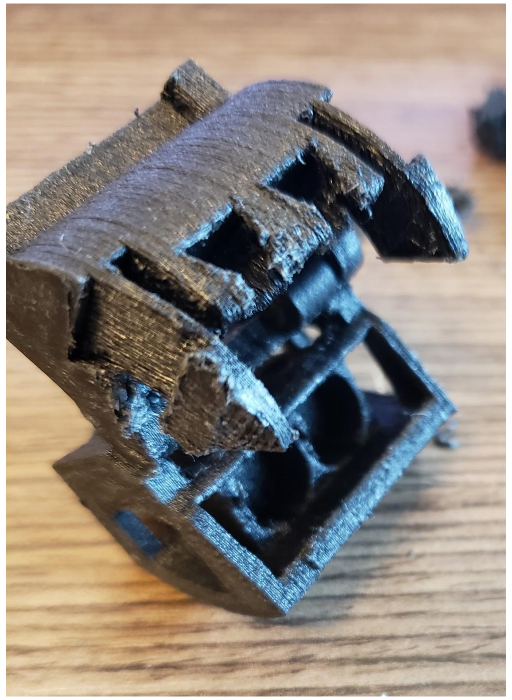
- 2 cell LiPo battery with DC-DC converter to regulate 6V output to the Arduino Nano and linear servos
- Constantly listens for the ground station signaling it to unfold and power on the UAV
- Contact pads on the lowest plate of the UAV and the retention system base allow the relay coil to be energized to power it on



UAV arm locking mechanism

- Attached to each UAV arm, allows folded up launch vehicle flight configuration and transition to UAV flight configuration
- Driven down by torsion springs and pulled into place by neodymium magnets
- Lock like a buckle, prevent UAV arms from moving during its flight
- Prototype print pictured on this slide



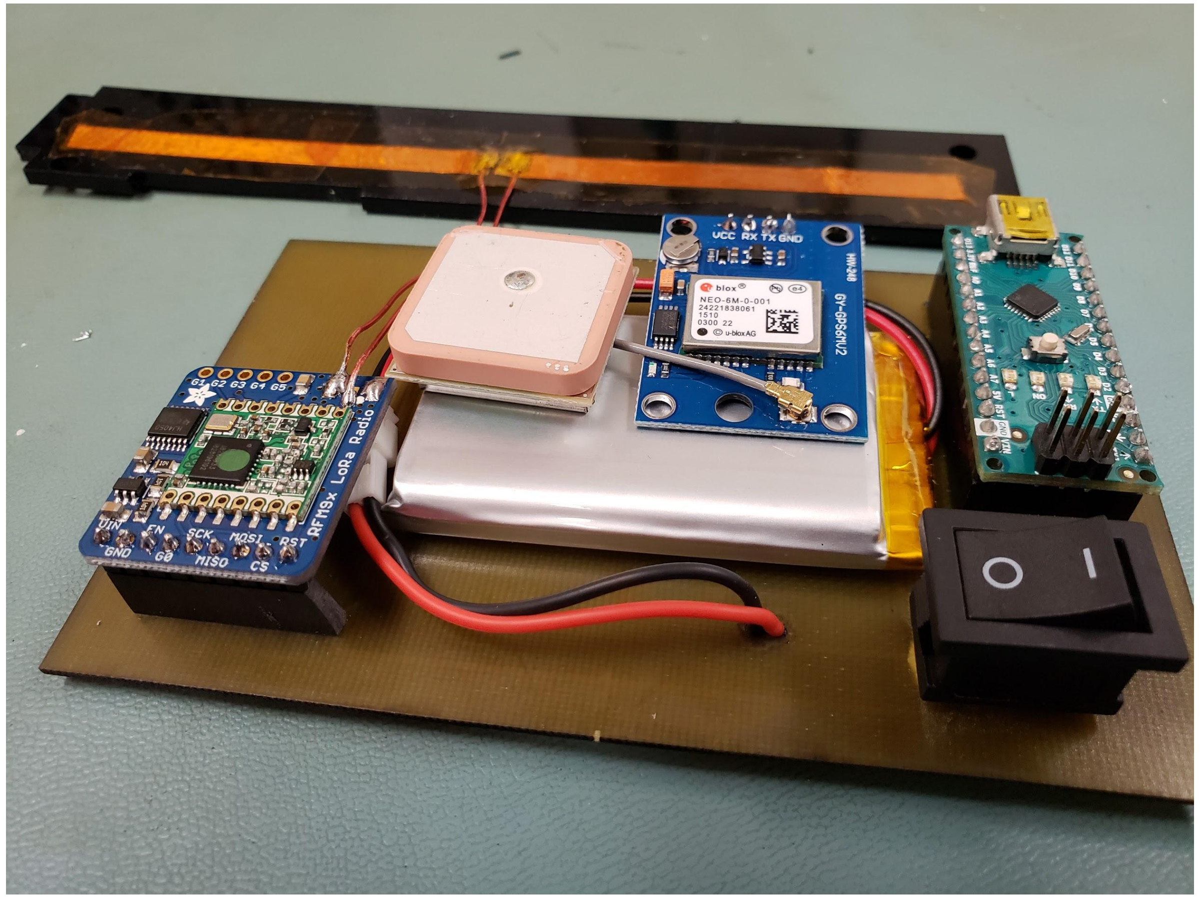


Integration with launch vehicle

- Blue Tube inner tube divided into 4 sections
- Attached to linear actuators to hold it together and unfold to right itself and deploy the UAV
- 3D printed NylonX bulkhead secured to its base, successful flight

Interfaces with Ground Systems

- Adafruit RFM95W LoRa 915MHz transceivers used for radio communication between the rocket and ground station
- GPS trackers in the launch vehicle and payload communication system
- Custom PCBs designed and manufactured in house
- Copper tape tuned dipole antenna



Flight Test

Vehicle Flight Test plan and Procedures

- Safety Checklists were used to prepare for the flight test.
- Safety Checklists include a list of all required tasks, required personnel, PPE warnings, and hazard warnings

Recovery Checklist		
Task	**Required Personnel**	**Initials**
Put nomex blankets on shock cord. ⚠️ Operation Hazard: If blankets are not fastened correctly, parachutes could be damaged leading to the rocket free falling.		Safety Officer
Ensure all bodies are secured with shock cord. ⚠️Operation Hazard: If a body is not connected properly, it could separate and free fall.	Launch Vehicle Lead	Safety Officer

Ground Ejection Test

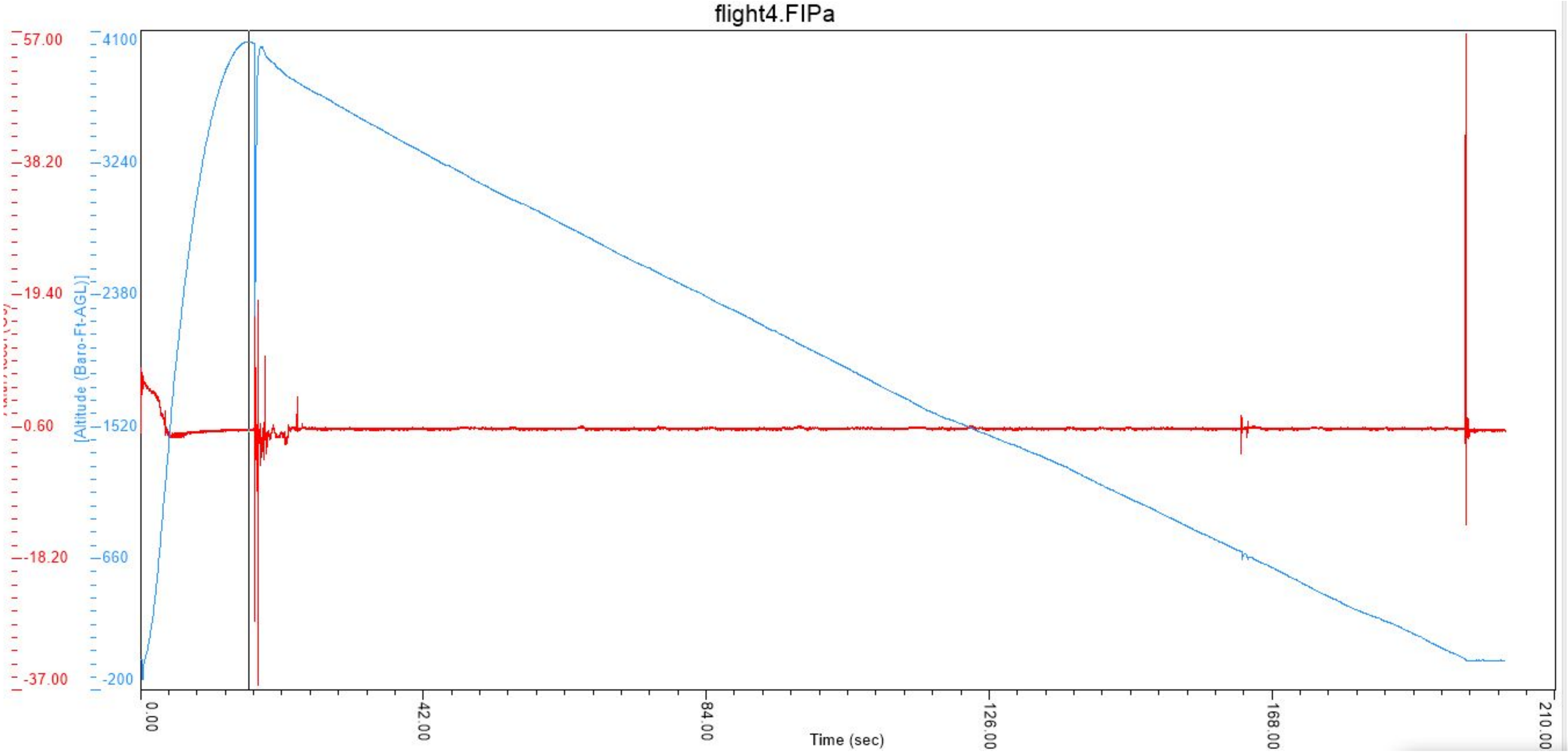
- **Ground Ejection Test was performed at Lake winnipesaukee and was successful**
- **Black Powder Charge Values:**
- 4.0 g apogee primary
- 5.4 g main primary
- 4.5 g apogee secondary
- 5.7 g main secondary

USLI

Full Scale Vehicle Flight

- The subscale launch vehicle was launched on March 3rd, 2019 at Lake Winnipesaukee
- Ice was safe to launch on at 26 inches thick
- The launch vehicle was launched around 1:15p.m.
- external temperature was about 30 ℉,
- wind speeds of about 9 mph towards the south-east.
- Charges detonated successfully on both Primary and Secondary Altimeters

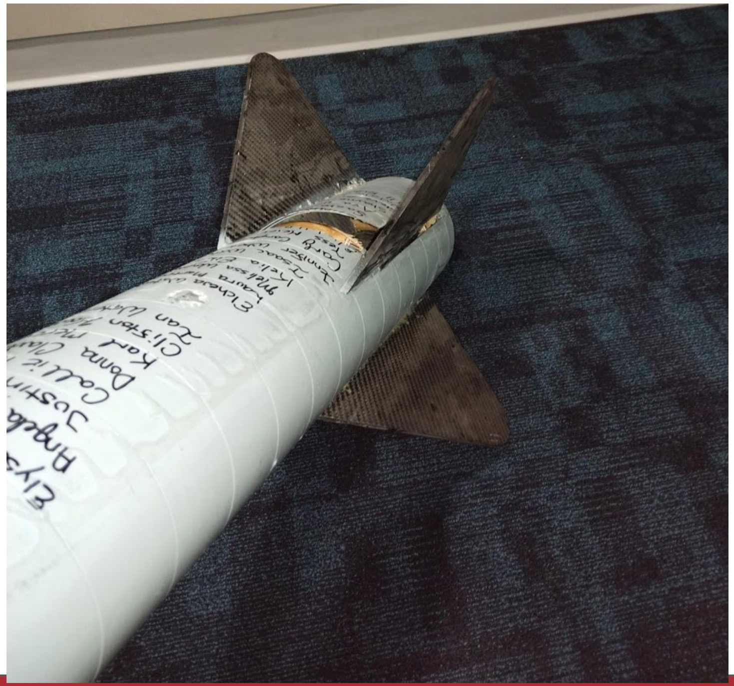
Vehicle Flight Results



USLI

Failure Modes Analysis

- Premature Deployment of Main Parachute and Nose Cone
  - Shear pins sheared prematurely.
- **Shearing of Lower Airframe U-Bolt Bulkhead**
  - .25in bulkhead did not provide enough strength to decelerate Upper Airframe after separation.
  - Separated Airframe tumbled without parachute. Damage only sustained to Blue Tube.



Mitigation Plans

- Securing Nose Cone
  - Increase from 2 shear pins to 5 .
  - Additional deployment tests to ensure more shear pins do not inhibit deployment.
  - Test to ensure shear pins can hold the full weight of the nose cone.
  - The team already has enough shear pins a black powder.
  - Time for drilling more shear pin and deployment tests is about one hour.
- Securing Lower Airframe
  - Increase from .25in structural bulkheads to .5in.
  - Use of metal washers and larger epoxy fillets.
  - Motor tube and fins can be salvaged. Other necessary parts for a new lower airframe are already in stock.
  - Time to assemble new airframe is four days to one week.

Payload Test plan and Procedures

- LoRa Transceiver Test
  - Setup one receiver station and moved away with transmitter
  - Maintained connection over half mile
  - RSSI average: -80 dB
- GPS Test
  - GPS system setup
  - Compare pulled location with actual
  - Accurate within 10ft
- Servo Actuation Test
  - Linear Servos actuated to open and right retention system
- Retention System Drop Test
  - Retention System dropped from 5 meters

Payload Flight Results

- March 3rd Launch Results
  - Successful Ejection from Airframe
  - Undamaged Retention System
  - Undamaged Payload
- March 16th Scheduled Launch Plans
  - Actuation to open and self-right
  - Release UAV

Project Plan

Vehicle Status of Requirements Verification

Vehicle Requirements				
Requirement	Justification	Method	Status	Reference
There must be at least one successful full scale launch before competition.	The team will aim for the opportunity to conduct multiple full scale test launches	Testing	In Progress	The data for these test launches will be available by the FRR
All components cut or dremeled will be sanded to ensure edges are smooth such that all pieces fit together as designed.	Every object that needs it will be sanded as needed	Inspection	In Progress	The launch vehicle will be checked for sharp or rough edges during construction
The e-bay will be organized such that devices and wiring are neatly placed and easy to access	The electronics bay has been designed with two compartments to keep everything organized	Inspection	In Progress	This will be verified visually by the rocket lead and payload lead.
All dimensions will be checked with the rocket lead or Director of System Integration before cutting into any component	This limits the amount of errors and ensures the integrity and accuracy of the final design	Inspection	In Progress	This will be confirmed visually and verbally by the rocket lead or Director of System Integration

Recovery Status of Requirements Verification

Recovery Requirements				
Requirement	Justification	Method	Status	Reference
All parachutes will be checked for correct sizes	This is to avoid errors that may affect lateral drift of descent time	Inspection	In Progress	This will be verified using the parachute sizing in simulations as well as by the team members assigned to recovery
Shock cord will be accordion folded and secured using a piece of tape such that it can easily rip apart	To absorb more shock	Inspection	In Progress	This will be verified visually by team members assigned to recovery and can be found in section 3.4
Parachutes will be packed with nomex blankets for protection	To avoid damage due to energetics during flight	Inspection	In Progress	This will be verified visually by recovery team members and tested during test launches.
Altimeters will be triple checked for correct programming and orientation	To avoid any errors in orientation or programming that may cause the launch vehicle to, deploy parachutes incorrectly, or sustain damage	Inspection	In Progress	This will be verified by the team mentor and rocket lead as well with multiple simulated tests and checks
Kinetic Energy of each individual section shall not exceed 75 lbf-ft.	Values have been calculated to ensure this	Analysis	In Progress	Verified via calculations and data

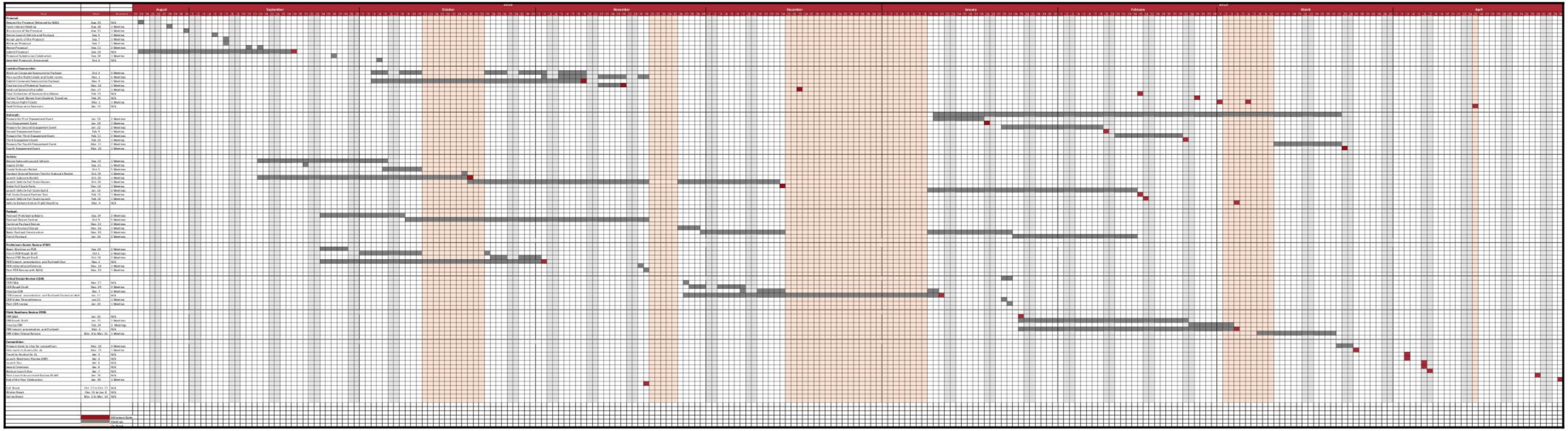
Payload Status of Requirements Verification

Payload Requirements				
Requirement	Justification	Method	Status	Reference
There must be at least one successful full scale test before competition	The team will aim for the opportunity to conduct multiple full scale tests	Testing	In Progress	The data for these tests will be available by the FRR
The UAV will be organized such that all components and electronics are easily accessible	The UAV has been designed to have a minimal form factor and easy access to all parts	Inspection	In Progress	This will be verified visually by payload lead.
Ensure all components of UAV are functioning as desired	The UAV must have all components working to complete beacon delivery	Testing	In Progress	A systems check will be run to ensure all parts are in working order
UAV and beacon will be securely mounted within the retention system	The UAV and beacon must remain undamaged during launch vehicle flight in order to successfully complete beacon delivery	Inspection	In Progress	This will be verified visually by payload lead
The UAV will have a maximum of at least twice the flight time estimated to be needed to complete the mission	Should any abnormalities in the flight of the UAV occur, sufficient time will be allowed for analysis and corrective measures applied by a human operator to aid in the mission	Analysis/testing	In Progress	Sections 5.4 and 6.1.2 provide details regarding the processes by which components were selected to ensure this requirement was met

Milestones

November 20, 2018	Preliminary Design Review (PDR) Presentation
January 4, 2019	Critical Design Review (CDR) report, presentation and flysheet
January 7-22, 2019	CDR Presentation
March 4, 2019	Vehicle Demonstration Flight
March 4, 2019	Flight Readiness Review (FRR) report, presentation and flysheet
March 8-21, 2019	FRR Presentation
March 25, 2019	Payload & Vehicle Demonstration Re-Flight
March 25, 2019	FRR Addendum
April 3, 2019	Travel to Huntsville, AL
April 4, 2019	Launch week kickoff, Launch Readiness Review
April 5, 2019	Launch week activities
April 7, 2019	Backup Launch Day
April 26, 2019	Post-Launch Assessment Review (PLAR)

Timeline


August
September
October
November
December
January
February
March
April

Safety

- Finalized Hazard, Mitigation, and Verification
- All sections revised to be more explicit.

Personnel Hazard Analysis						
Phase	**Hazard**	**Cause**	**Effect**	**Probability/ Severity**	**Mitigation**	**Verification**
Launch	Motor Misfire	Failure of igniter or damage to motor prior to launch	There is a possibility of a delayed ignition which could harm personnel if they approach the launch vehicle too soon.	DII	The motor will only be handled by a certified mentor. The team will wait at least 60 seconds before approaching the launch vehicle and will follow all directions of the RSO.	Motor preparation is included in the Motor Checklist. Team members have been informed of misfire safety procedures in a mandatory safety briefing and will be reminded in mandatory pre-launch safety briefings.

Logistics

- Reservations made for Embassy Suites
- Flights have been purchased
- Bussing is being planned

EMBASSY SUITES by Hilton™

Budget

Subscale	$ 1,533
Fullscale	$ 176
Payload	$ 976
Logistics	$ 13,043
Total	$ 15,728

Funding

Required funding achieved in February, 2019

- SGA granted remaining necessary funds
- Awarded specifically to cover travel costs

Go Fund Me

- Received from Friends and Family
- Helped cover late carbon fiber purchase
- To be used for team shirts

Education Engagement

Outreach Completed:

- Educational collaboration between Robokids and Friendly House elementary schoolers.
- Engineers on the Go educational event through Pre-Collegiate Outreach Program at WPI
- Introduce a Girl to Engineering Day educational event through Pre-Collegiate Outreach Program at WPI
- Multiple educational outreach activities at Friendly House with middle and high school students.

Questions

USLI

WORCESTER POLYTECHNIC INSTITUTE