Critical Design Review

January 23, 2025

Presentation Overview

- Launch Vehicle Final Design
- Recovery System Final Design
- Payload Final Design
- Air Brakes Final Design
- Subscale Flight Results
- Requirement Verification and Status
- Test Plans and Procedures
- Questions

Team Introductions

Katelyn
Team Lead

James
Structures Lead

Aubri
Aerodynamics Lead

Trent
Recovery Lead

Megan
Safety Officer

Connor
Payload Software Lead

Ryan
Payload Structural Integration Lead

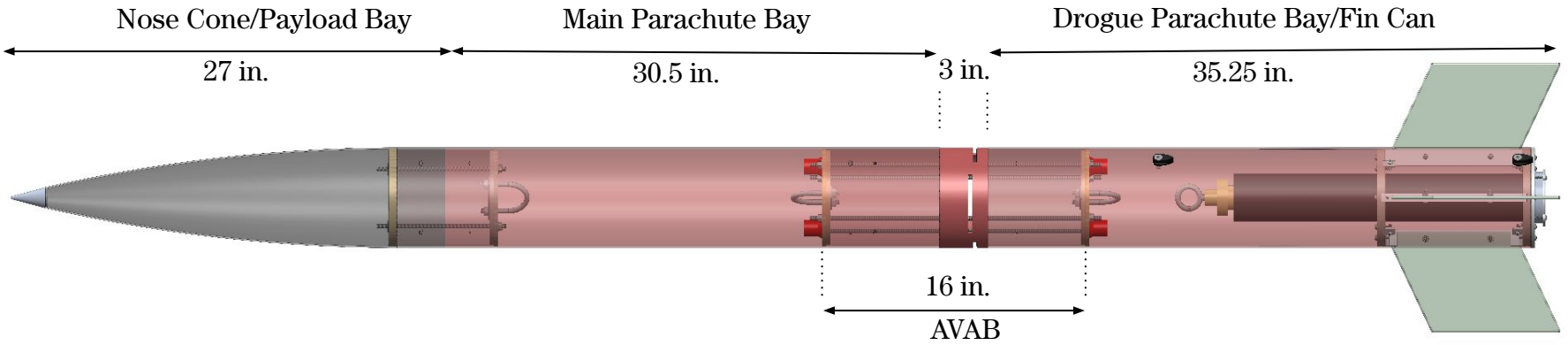
Samuel
Payload Electronics Lead

Abigail
Integration Lead

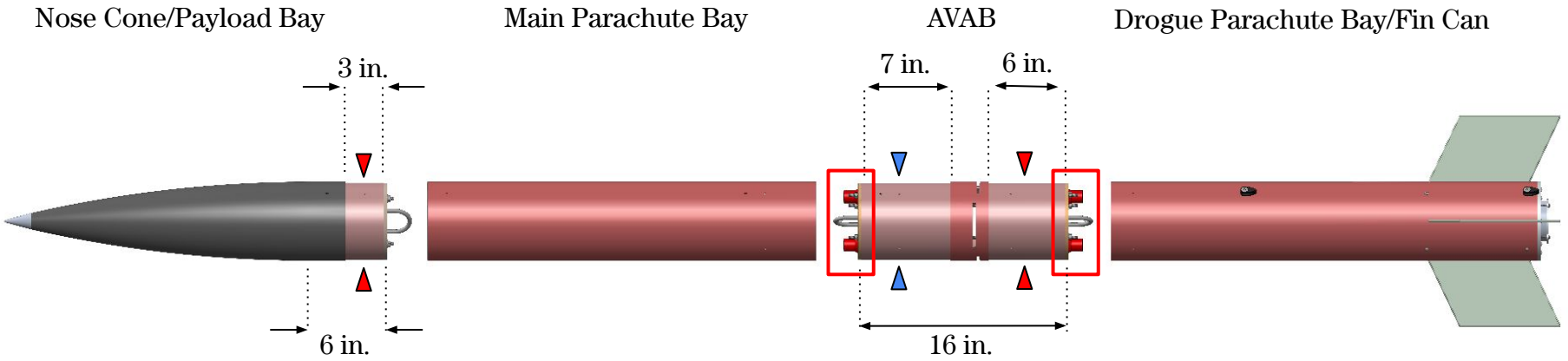
Launch Vehicle Design

Final Launch Vehicle Dimensions

- Total Length: 95.75 in.
- Body Diameter: 6.17 in.
- Aspect Ratio: 16:1



Points of Separation



- Dual deploy system
- Drogue parachute aft of the AVAB
- Main parachute forward of the AVAB
- AVAB contains all recovery electronics

In-flight Separation Point

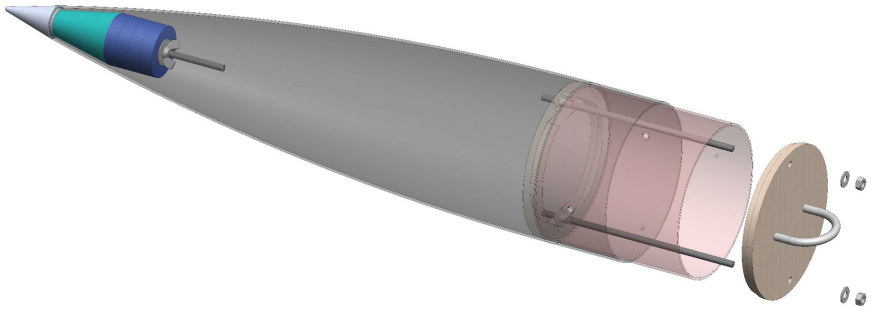
Non-in-flight Separation Point

Location of Energetics

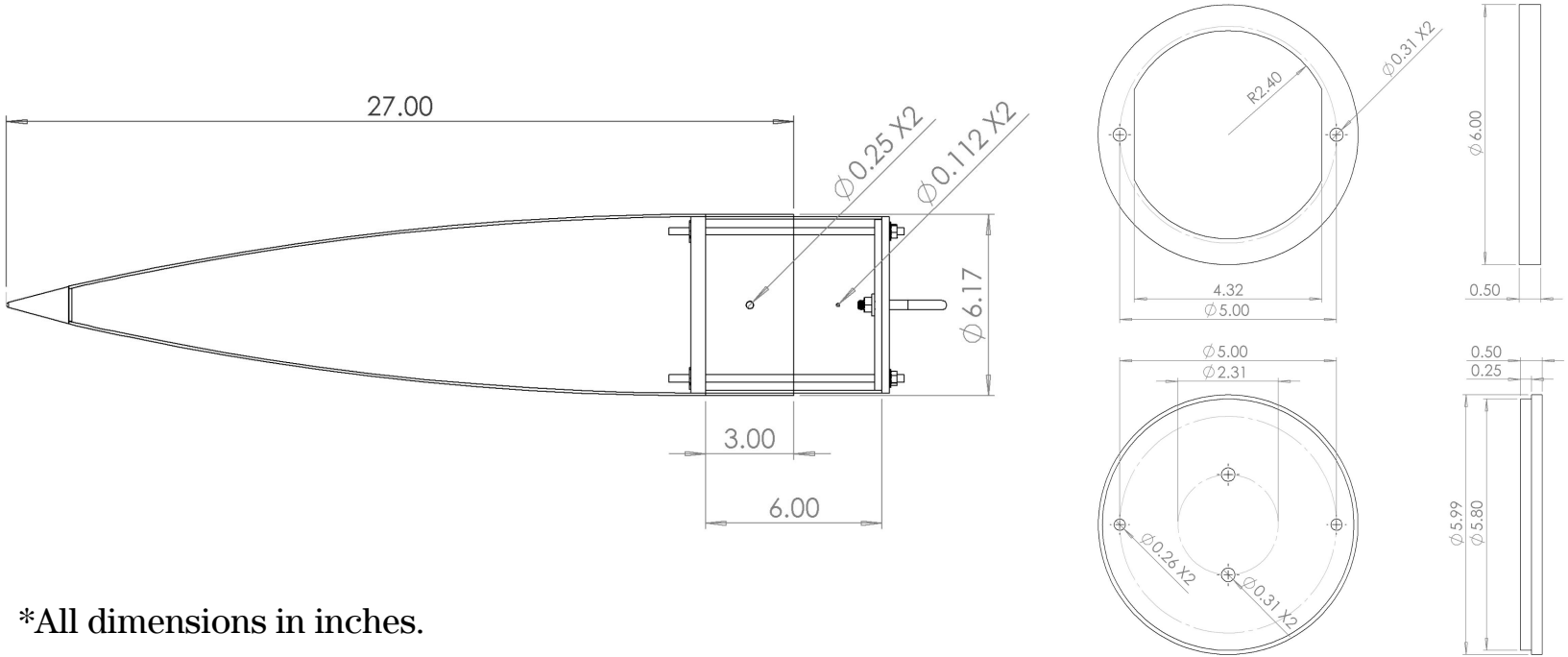
Nose Cone / Payload Bay

Houses primary STEMCRaFT Payload

- G12 Fiberglass w/ aluminum tip
- 27 in. length, 4:1 Tangent Ogive
- STEMCRaFT capsule mounts on threaded rods between permanent and removable bulkhead
- Pressure ports for data collection
- RF transparent for data transmission
- Adjustable ballast system if required



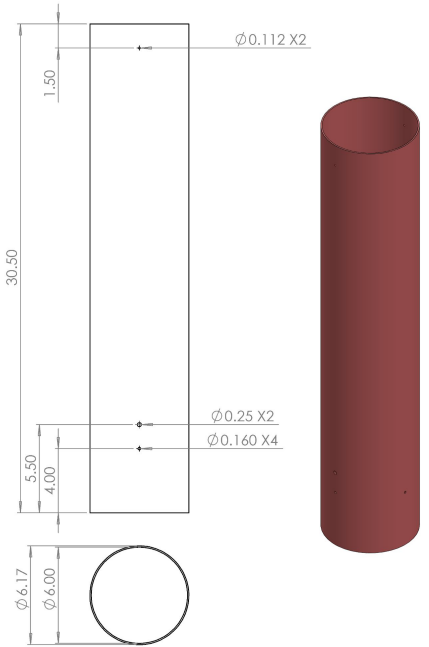
Nose Cone / Payload Bay Dimensions



*All dimensions in inches.

Main Parachute Bay

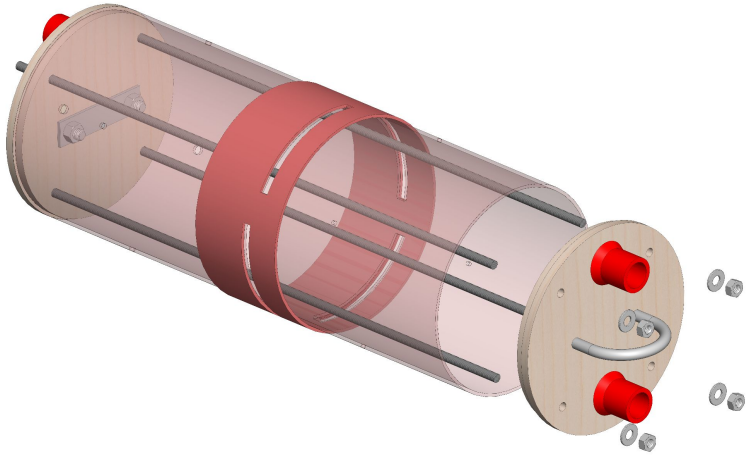
- 30.5 in. section of G12 fiberglass airframe
- Contains Main Parachute recovery gear
- Connects to forward AVAB coupler section
- Two pressure port holes through Main Bay and AVAB for recovery system altimeters



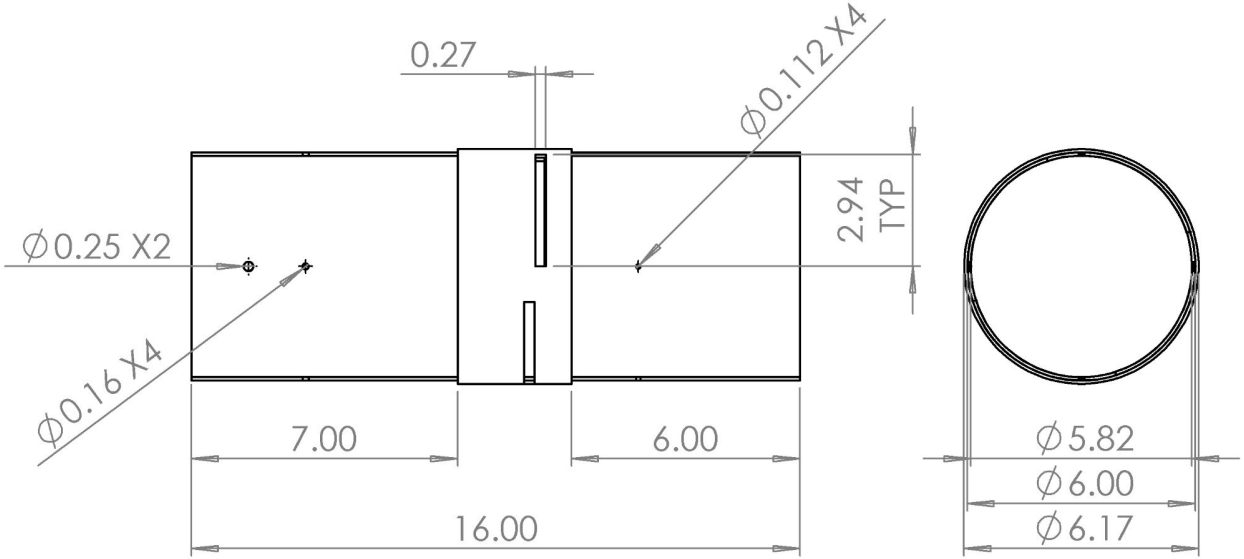
*All dimensions in inches.

Avionics and Air Brakes Bay (AVAB)

- 16 in. G12 fiberglass coupler and 3 in. G12 airframe switchband
- Forward section houses Avionics
- Aft section houses Air Brakes payload
- 3 in. switch band for Avionics arming and Air Brakes fin deployment
- Primary and secondary ejection charges contained on each bulkhead



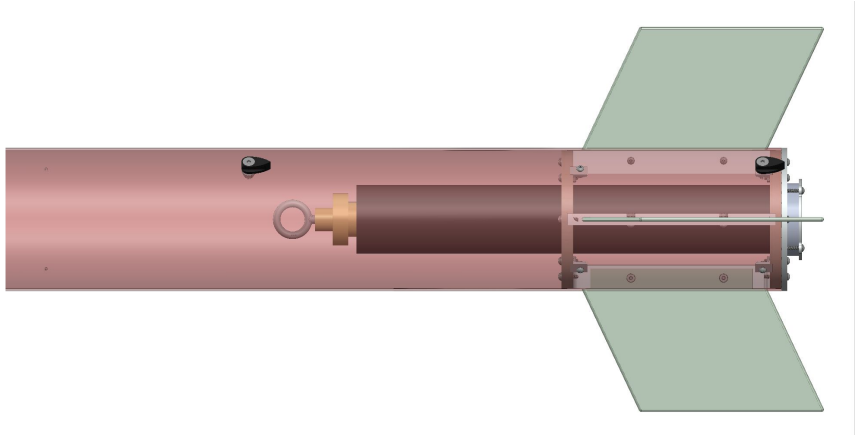
AVAB Dimensions



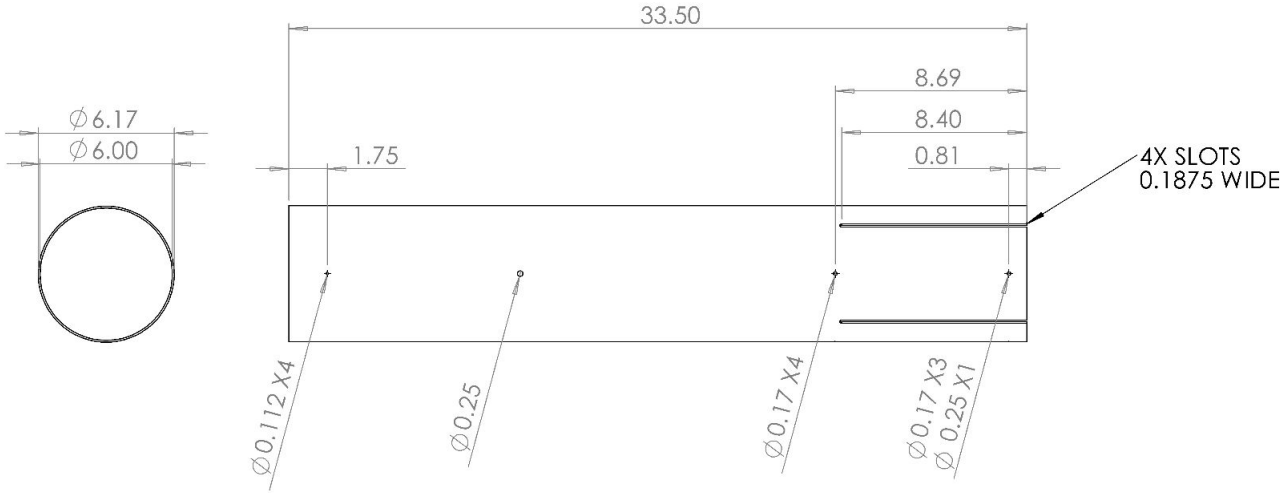
*All dimensions in inches.

Drogue Parachute Bay / Fin Can

- G12 fiberglass airframe
- 35.25 in. overall section length
- Drogue recovery gear housed in forward portion, anchors to motor casing
- End-cut fin slots for Removable Modular Fin System (RMFS)
- Two 1515 airfoiled rail buttons mounted on this section



Drogue Parachute Bay / Fin Can Dimensions



*All dimensions in inches.

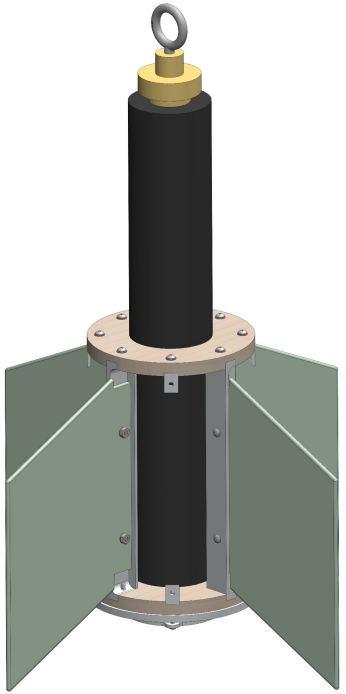
Removable Modular Fin System

Multipurpose structural assembly

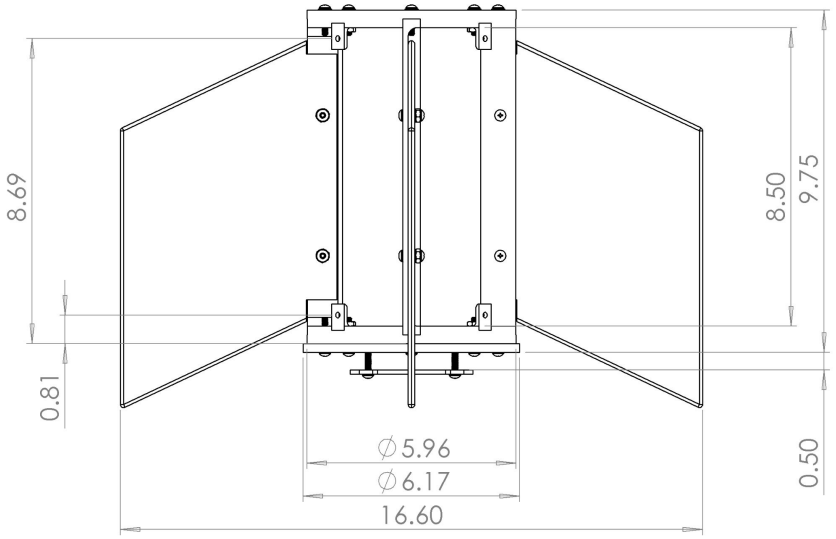
- 4-fins attached in cruciform pattern
- Motor centering and retention
- Drogue recovery gear anchor
- Thrust distribution to airframe

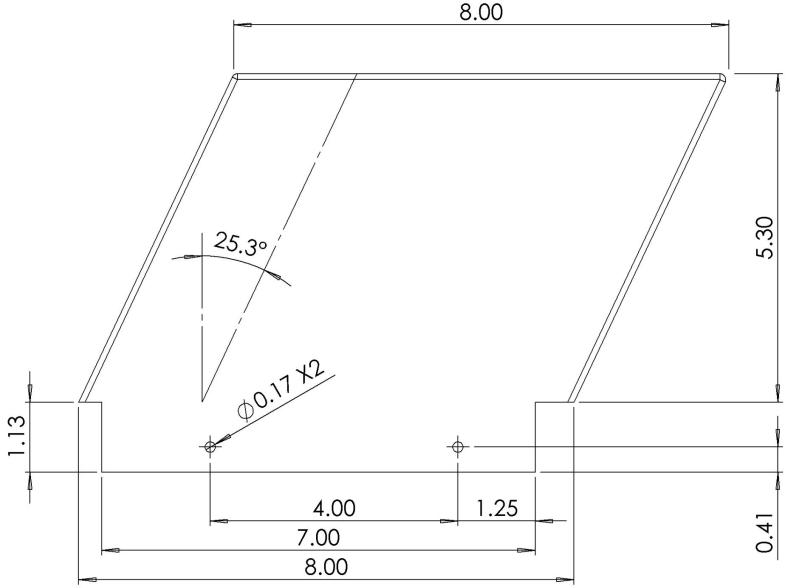
Materials

- ½ in. thick birch plywood centering rings
- 6061-T6 aluminum fin runners, L-brackets, and thrust plate
- 3/16 in. thick G10 fiberglass fins



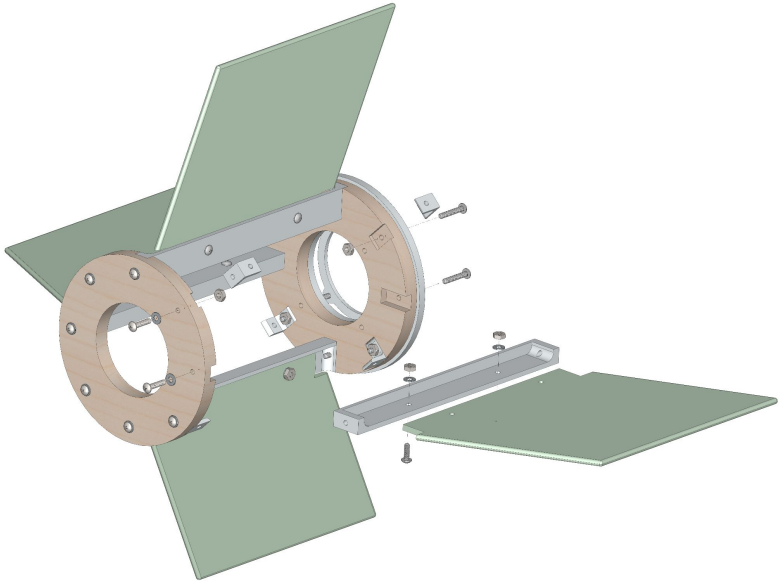
RMFS and Fin Dimensions



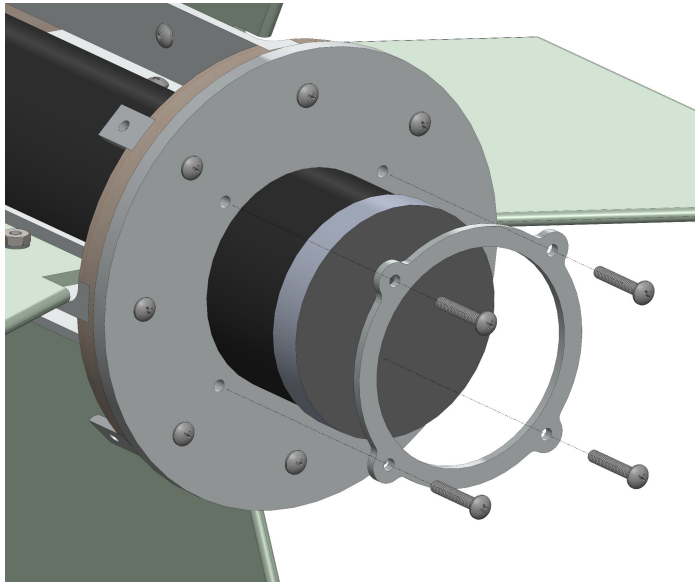


*All dimensions in inches.

Removable Modular Fin System

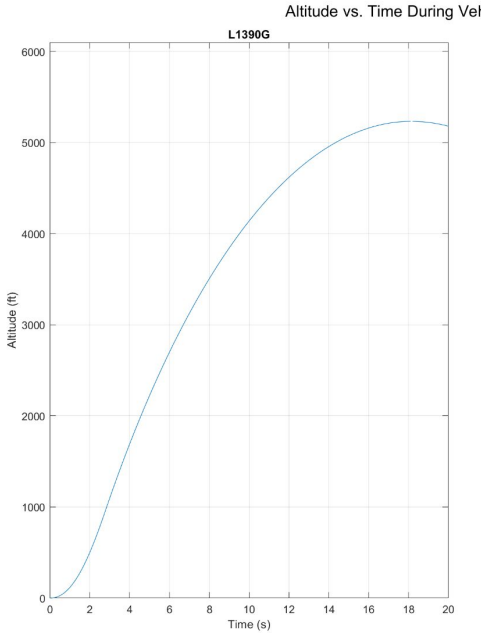


Fin runner assembly

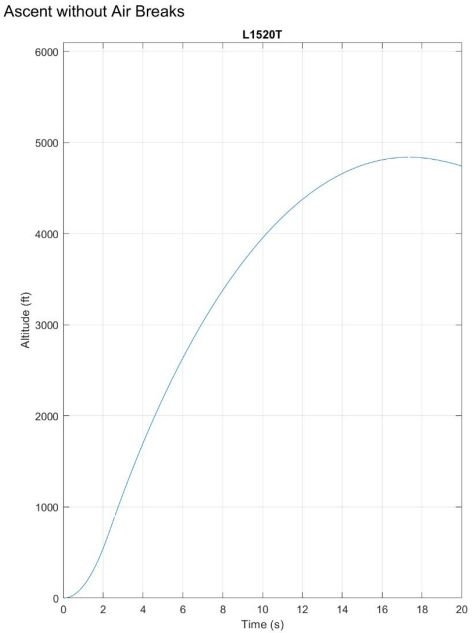


Motor retainer assembly

Motor Selection



Backup Motor

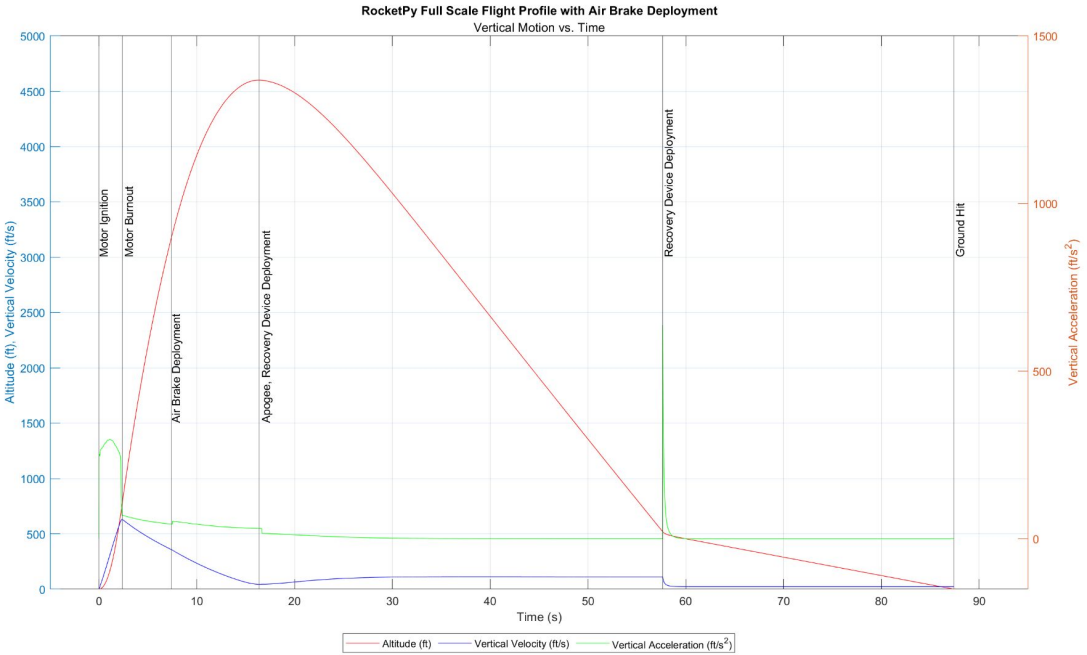


Selected Motor

Motor	L1520T	L1390G
Total Impulse	835.37 lbf-s	887.77 lbf-s
Average Thrust	352 lbf	312.48 lbf
Burn Time	2.4 s	2.6 s
Thrust to Weight Ratio	9.05	8.19
Rail Exit Velocity	71.79 fps	75.4 fps

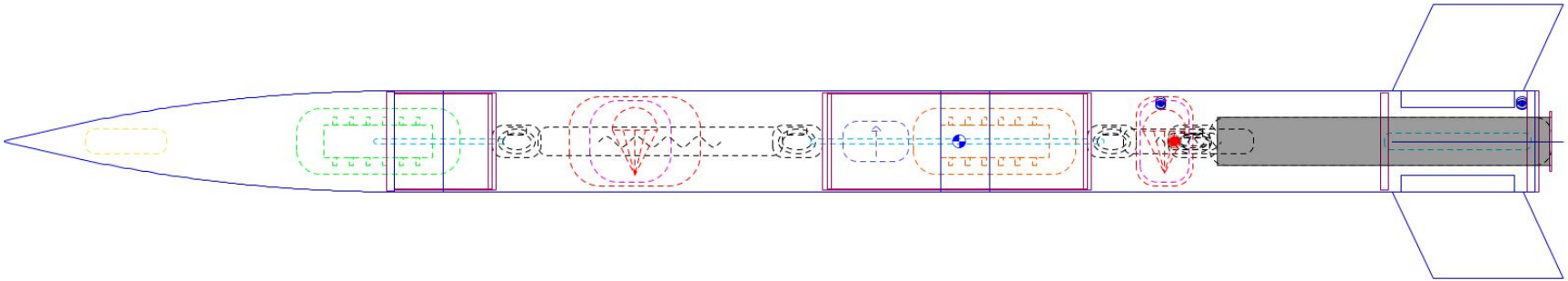
Official Target Altitude

- Predicted Apogee: 4808.76 ft
- Declared Apogee: 4600 ft
- To reach this, deploy air brakes at 3184 ft.



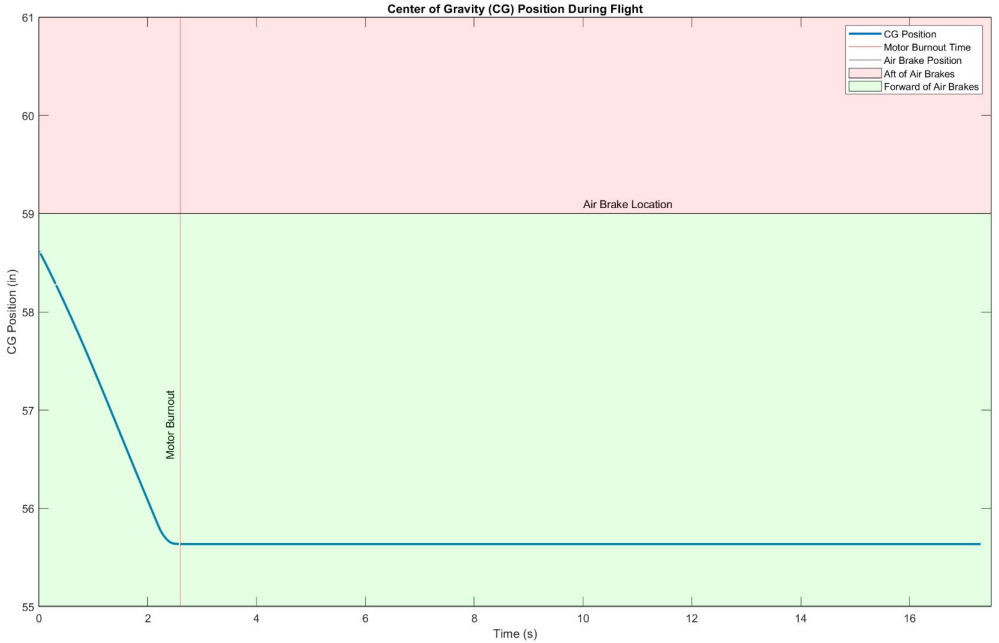
Static Stability Margin

Software	Center of Pressure	Center of Gravity	Stability Margin
OpenRocket	71.82 in.	58.62 in.	2.14 Calibers
RasAero II	71.71 in.	58.62 in.	2.12 Calibers
RocketPy	71.89 in.	58.78 in.	2.13 Calibers



Center of Gravity During Flight

- Center of Gravity is always forward of the Air Brakes
- Static CG is 58.78 in.
- Burnout CG is 55.49 in.
- Air Brake location is 59 in.
- Locations are measured from the forward end of the vehicle



Launch Vehicle Mass Estimates

Fully Integrated Wet Masses	
Nose Cone/Payload Bay	8.81 lbs
Main Parachute Bay	5.47 lbs
AVAB	6.60 lbs
Drogue Parachute Bay/Fin Can	17.51 lbs
TOTAL	38.39 lbs

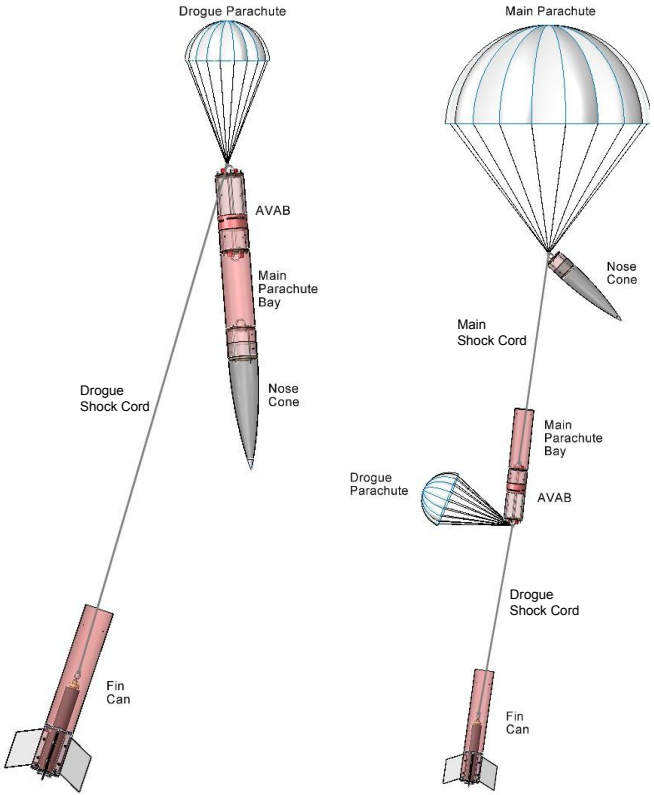
Additional Mass Values	
Burnout & Landing Mass	34.37 lbs
Dry Mass	30.41 lbs
Allowable Dry Mass Limit*	36.6 lbs
Mass Margin	6.19 lbs

*Limited by 4000 ft. altitude requirement.

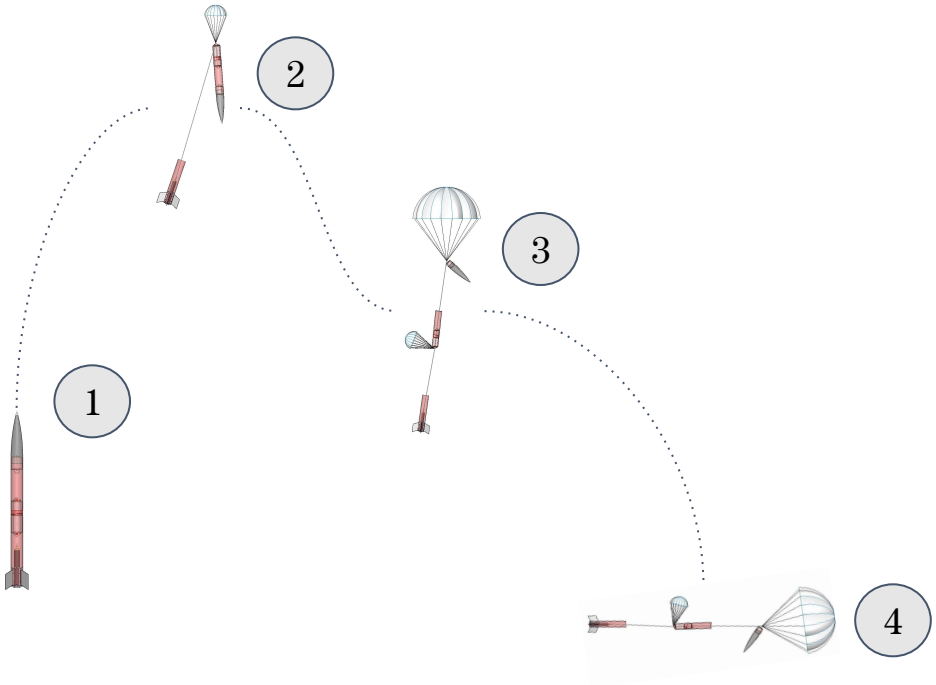
Recovery System Design

Recovery Overview

- Drogue deploys at apogee
  - Secondary charge set to one second after apogee
- Main deploys at 550 feet
  - Secondary charge set to 500 feet
- At least 10 feet of separation between all descending sections of the Launch Vehicle
- All sections of the Launch Vehicle remain tethered together



Recovery System CONOPS



1 - Launch	• Primary and secondary altimeters are armed on the launch pad and continuity is confirmed • GPS Transmission confirmed
2 - Drogue Descent	• Drogue primary charge ignites at apogee • Drogue secondary charge ignites one second after apogee • Drogue parachute ejects from the Launch Vehicle and inflates • Launch vehicle descends under drogue parachute such that the forward end of the Launch Vehicle is at least 10 feet above the Fin Can.
3 - Main Descent	• Main primary charge ignites at 550 feet • Main secondary charge ignites at 500 feet • Main parachute ejects from the Launch Vehicle and inflates • Launch vehicle descends under main parachute such that all sections of the Launch Vehicle have at least 10 feet of separation between them
4 - Landing	• Launch Vehicle lands undamaged • Kinetic energy at landing is below 65 ft-lb • Total descent time is below 80 seconds • Total drift distance is under 2500 feet

Parachute Selection

- Drogue
  - Fruity Chutes 18” Elliptical Parachute
  - Protected by Nomex Blanket
- Main
  - Fruity Chutes Iris Ultra 96” Compact Parachute
  - Protected by Fruity Chutes Deployment Bag
- Kinetic energy below 65 ft-lb
- Descent time below 80 seconds

Recovery Harness

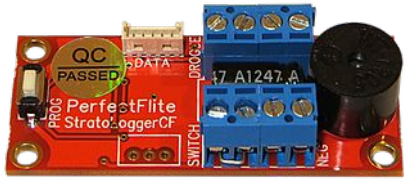
- 5/8" Kevlar Shock Cord
- Strength Rating of 6600 lbs
- At shock cord connection points, the shock cord is secured to quick links with a bowline knot, which are then attached to bulkhead U-bolts or eye bolts.

- Drogue Shock Cord Length: 216 inches
- Main Shock Cord Length: 192 inches
- Allows for 10 feet of separation between descending sections

- Force of Parachute Opening: 320.75 lbs
- Factor of Safety: 20

Avionics

Primary Altimeter: PerfectFlite StratologgerCF
- Drogue charge at apogee
- Main charge at 550 ft

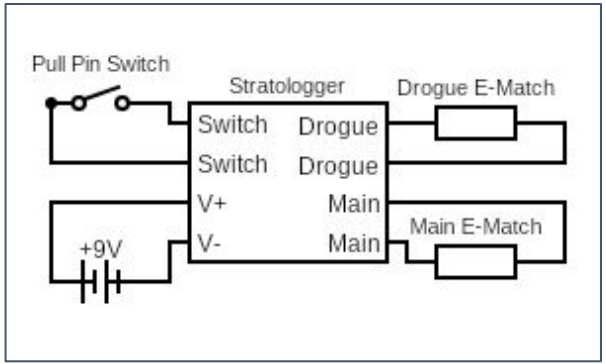


Secondary Altimeter: Altus Metrum EasyMini
- Drogue charge 1 second after apogee
- Main charge at 500 ft

GPS Tracker: Eggfinder Mini
- Transmitter frequency of 919 MHz
- Paired with Eggfinder LCD Receiver

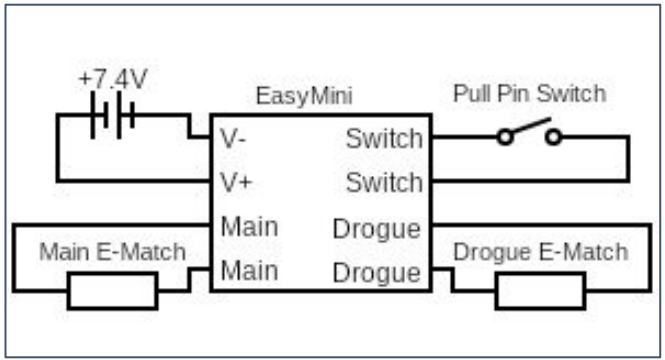
Wiring Diagrams

Primary Altimeter



PerfectFlite StratologgerCF powered by a 9V alkaline battery controlled by a pull pin switch

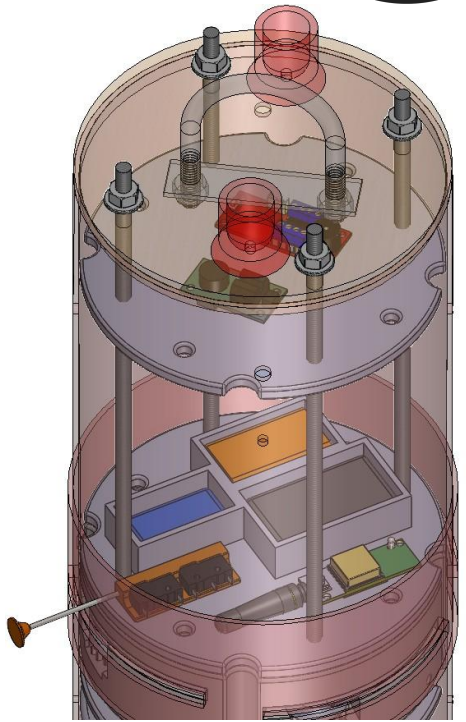
Secondary Altimeter



Altus Metrum EasyMini powered by a 7.4V 400mAh LiPo controlled by a pull pin switch.

Avionics Sled Design

- Located at the forward end of the AVAB
- All avionics hardware mounted on two flat plates separated by 5.5 in.
- Wires run freely through wire holes along the outside of the flat plates
- Maximize separation of altimeters from frequency emitting devices
  - 5.5 in. from GPS
  - 7.18 in. from Air Brakes Servo
- Line the bottom of the altimeter plate in aluminum foil for extra shielding



Launch Vehicle Kinetic Energy

- Max KE at landing is 56.555 ft-lb
- Meeting bonus point threshold of 65 ft-lbs

Section	Mass (lbm)	Drogue Descent Velocity (fps)	Drogue Kinetic Energy (ft-lbf)	Descent Velocity (fps)	Kinetic Energy (ft-lbf)
Nose Cone	8.81	106.582	3685.179	16.424	36.932
AVAB + Main Bay	12.065			16.424	50.577
Fin Can + Drogue Bay	13.491	106.582	2381.641	16.424	56.555

Descent Time and Drift Distance

Assuming nominal flight - Apogee of 4600 feet and main parachute deployment at 550 feet.

- Descent Time: 71.49 s
- Meeting bonus point threshold of 80 s

- Max Wind Drift: 2096.93 ft
- Meeting 2500 ft requirement

Wind Speed (mph)	Drift Distance (ft)
0	0.00
5	524.23
10	1048.47
15	1572.70
20	2096.93

Payload Design

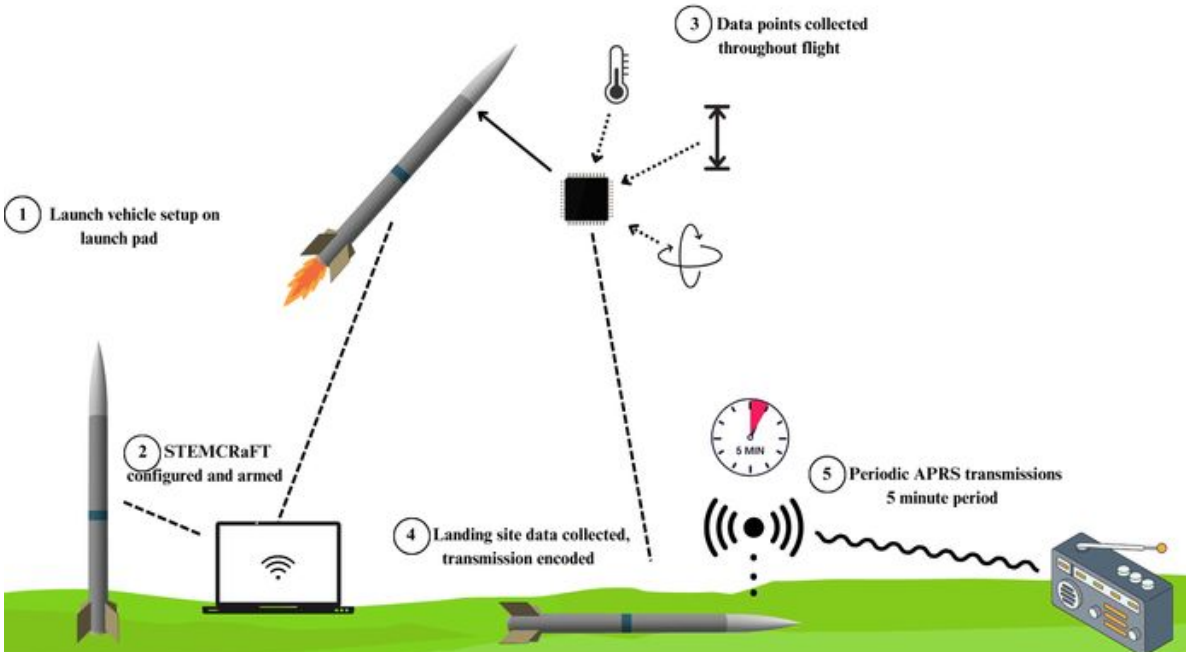
Changes since PDR

- Added an ESP32
  - Implemented as a buffer between sensors and Raspberry Pi
- Changed transmission system to include the SA858 module
  - Replaces both the transmitter and amplifier
- Ventilation Fan
  - Circulates air so that an accurate temperature reading can be made
- Capsule Design
  - Capsule shell added to create a sealed container

Design Overview

- The STEMCRaFT has two electronic subsystems
  - Data Collection subsystem
  - Data Transmission subsystem
- STEMCRaFT controlled via two payload computers
  - Raspberry Pi (primary computer)
  - ESP32 (secondary computer)
- Raspberry Pi serves as primary payload computer
  - Dictates overall payload functionality
  - Delegates certain tasks to secondary payload computer

Payload Mission CONOPS



1 - Pre-Flight	• STEMCRaFT assembly and integration • Systems check
2 - Initialization	• Arm electronics and initialize payload software
3 - Flight	• Data collected throughout flight
4 - Landing Detected	• Take final measurements • Start transmission
5 - Transmit	• Automatically start transmission • Ability to stop and start transmission remotely

STEMCRaFT Design Overview

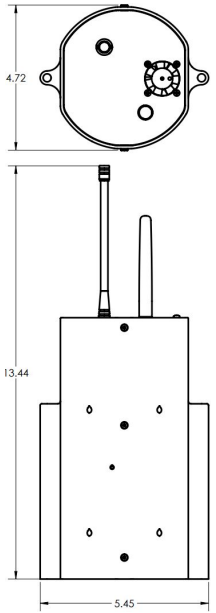
Structural components:

- Capsule shell
- Sled
- Top bulkhead
- Bottom bulkhead

Dimensions:

- Height: 13.44”
  - 8.50” without antenna
- Width: 5.45”
- Length: 4.72”
- Weight: 2.25 lbs

STEMCRaFT dimensions [in.]



Capsule Shell

Threaded rod holes

- Mounting STEMCRaFT to the Nose Cone

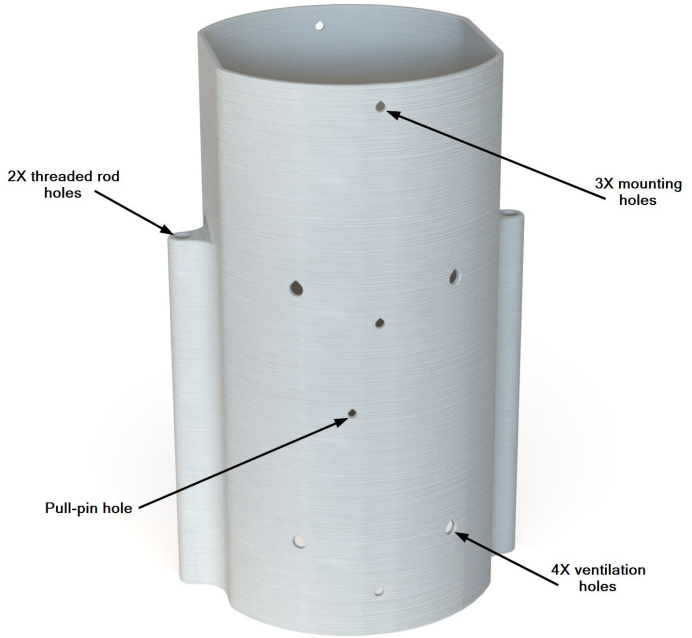
Mounting holes

- Assembling STEMCRaFT

Ventilation holes

- Brings in fresh air and prevents overheating

Pull-pin hole



Sled

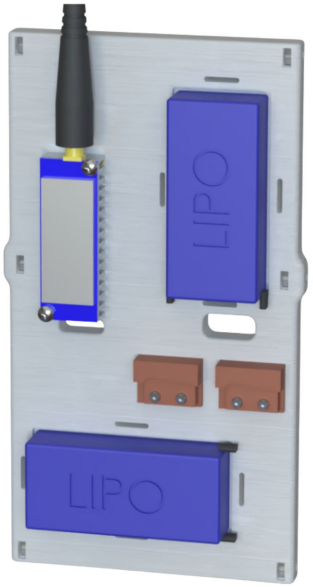
Electronics side:

- XBee with antenna
- Raspberry Pi
- Custom PCB

Transmission antenna side:

- SA858 with antenna
- Pull-pin switches
- LiPo batteries

Electronics side



Transmission antenna side

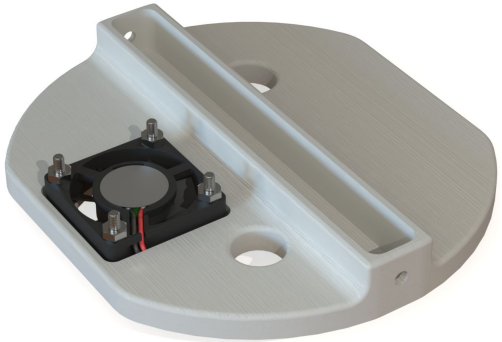
Bulkheads

Top bulkhead:

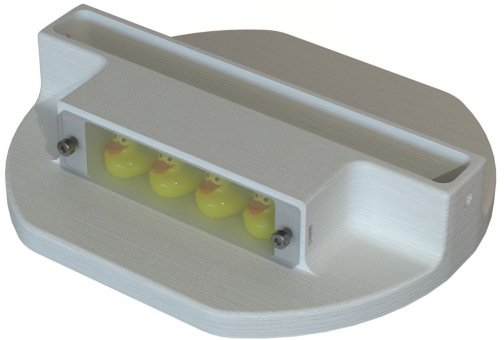
- Ventilation fan
- XBee antenna hole
- Transmission antenna hole
- Slot for sled

Bottom bulkhead:

- STEMnaut housing
  - Acrylic window
  - 4 STEMnauts
- Slot for sled

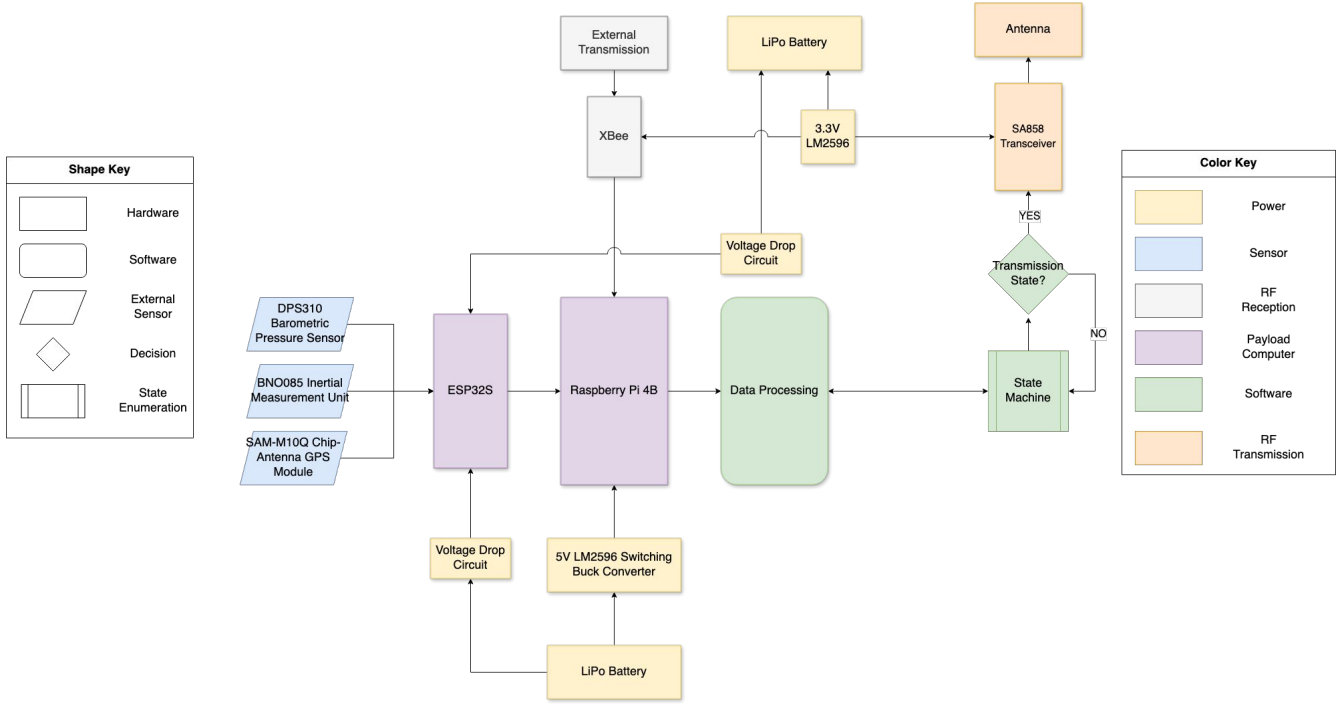


Top bulkhead



Bottom bulkhead

STEMCRaFT Functional Overview



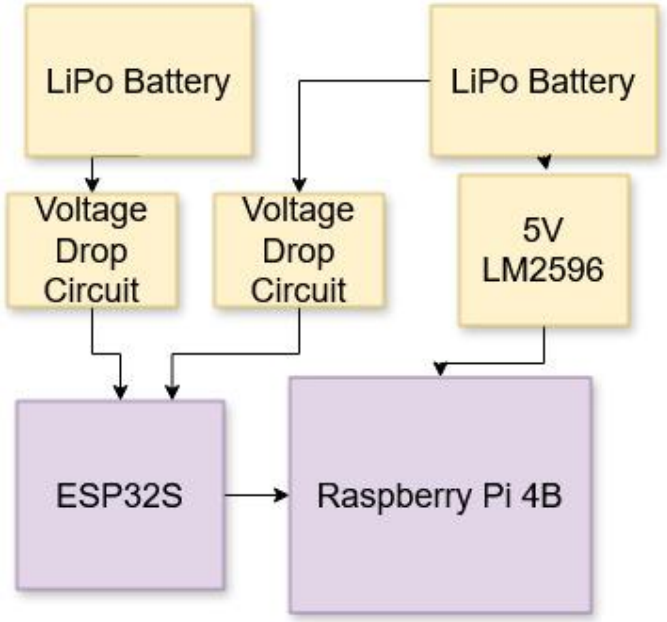

HIGH-POWERED ROCKETRY CLUB
TACHO LYCOS

Batteries & Switches

2200mAh 2S Lithium Polymer Battery

Pull Pin Switches

- Rated to 5 amps (42 Watts)



Data Collection :

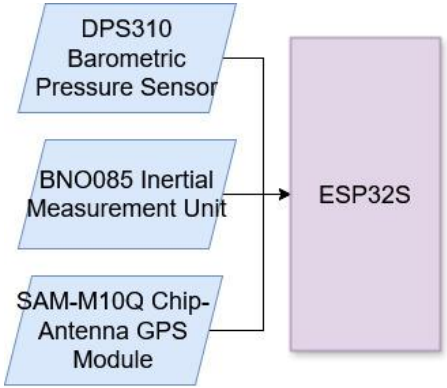
- 4 hours idle
- Switching Buck Converter

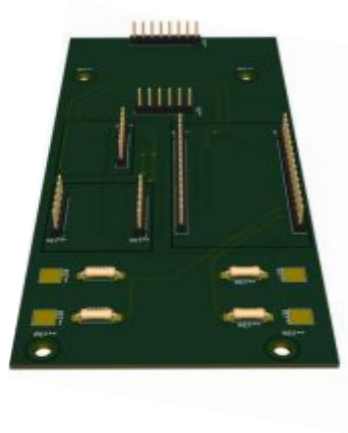
Transmission :

- 10 hours idle
- Switching Buck Converter

Sensors

- Mounted To PCB via Pin Headers
- Records Data to the ESP32
- Covers all 9 Data-points
  - Temperature of landing site
  - Apogee reached
  - Battery check/ power status
  - Orientation of on-board STEMnauts
  - Landing coordinates
  - Time of landing
  - Maximum velocity
  - Landing velocity, G-forces sustained
  - Calculated STEMnaut crew survivability





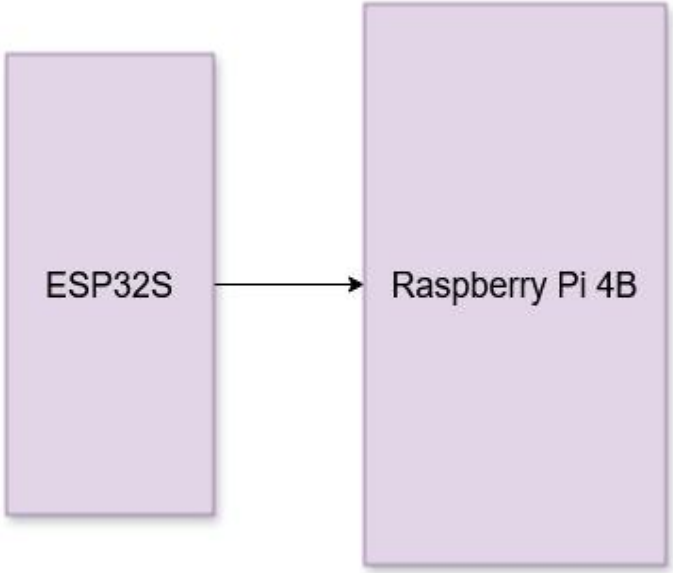
Payload Computers

Raspberry Pi 4 Model B

- Python code-base
- Allows for heavier processing loads to be handled e.g. Direwolf
- FSM

ESP32

- C/C++ code-base
- Increased sensor compatibility due to clock stretching
- Provides sensor data to Raspberry Pi via serial connection



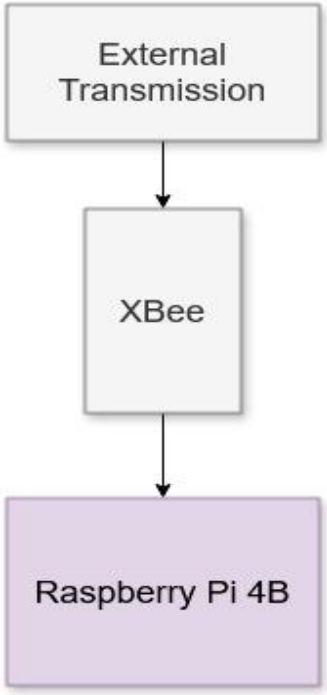
XBee & Ground Station

XBee Pro S3B Transceiver

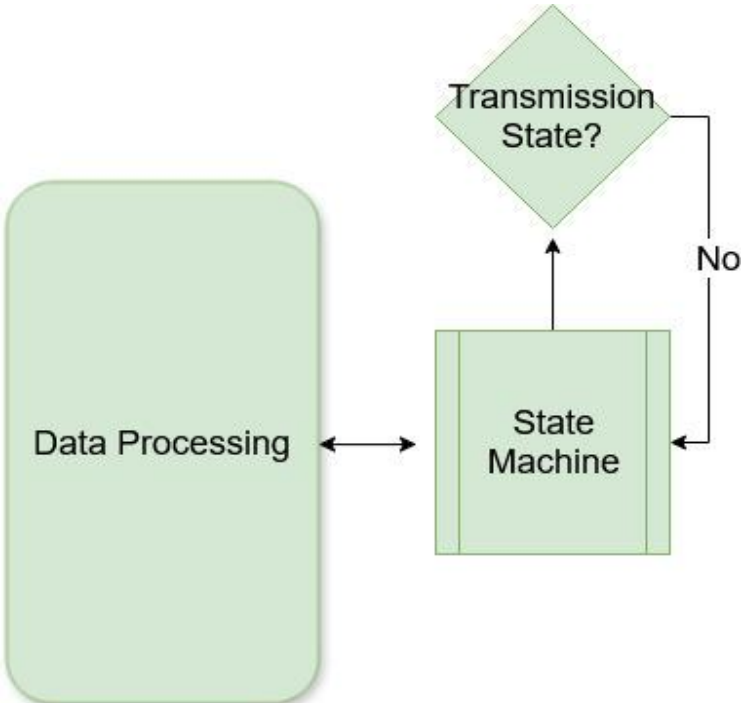
- Monitors for ground station commands allowing manual transmission overrides to be performed
- Frequency Hopping (902MHz - 928MHz)
- No transmission being performed

Ground station

- 2M band APRS monitor
- XTend 900MHz RF Modem (Fat XBee)



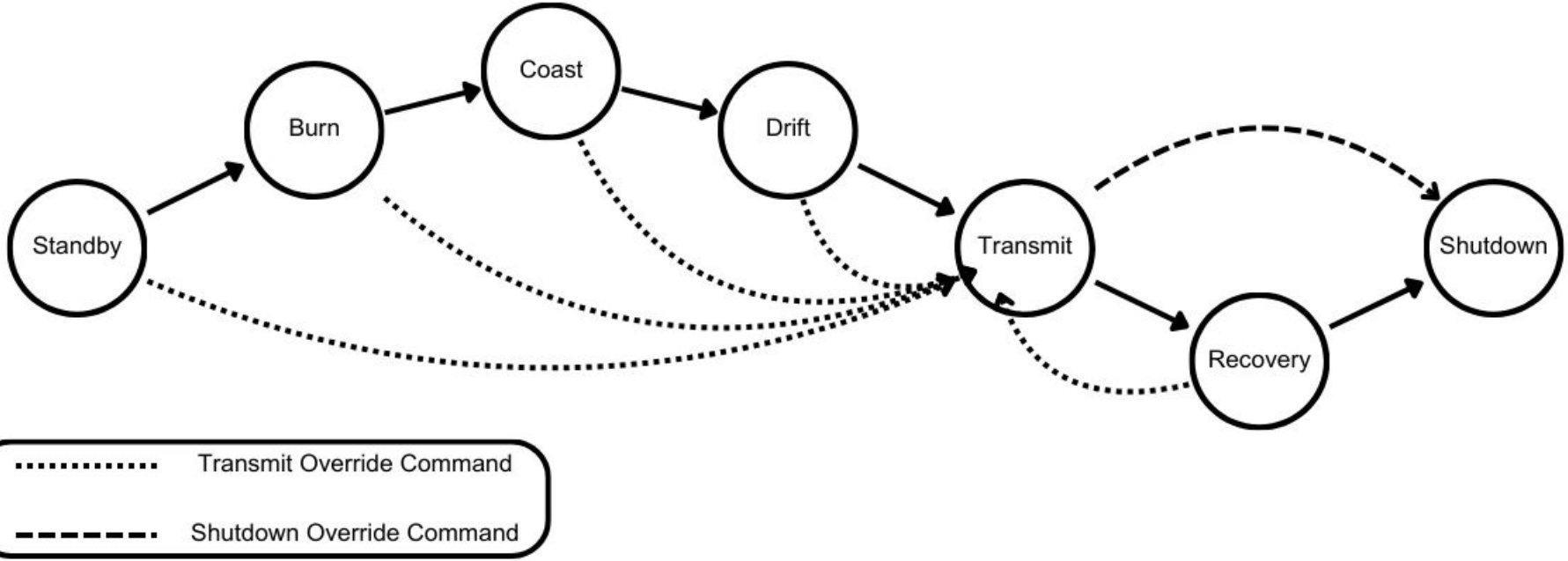
Data Processing



Finite State Machine

- Use sensors data in order to progress mission state
- Dictate functionality of STEMCRaFT

Finite State Machine



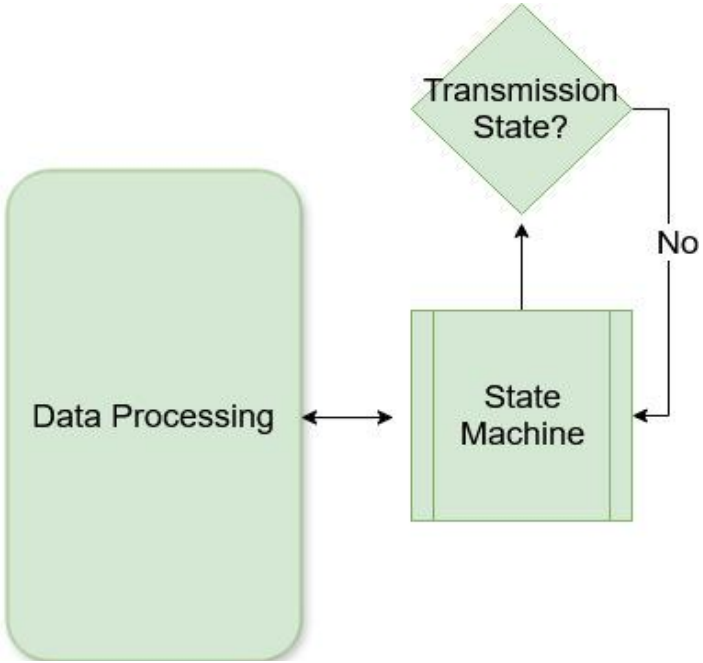
Data Processing

Direwolf

- Software TNC
- Convert digital data into APRS format using underlying AFSK

Prepare Flight Data for Transmission

- Compute various transmission data points
- STEMnaut survivability using landing conditions, and high sustained G-forces



Transmission

From Pi:

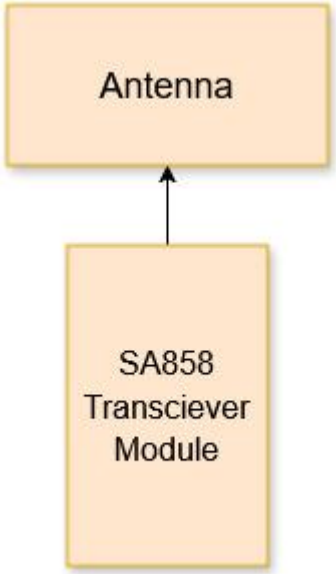
- Receives modulated audio signal

Built in RF Amplifier

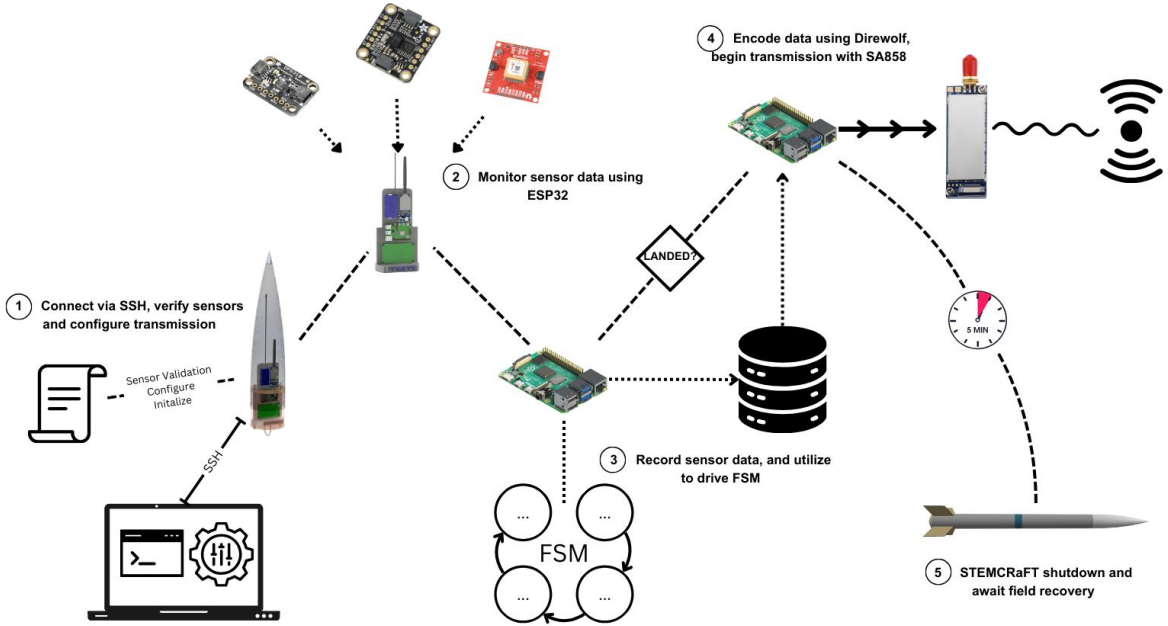
- 4W Signal Strength
- Additional signal filtering

Transmits on RF

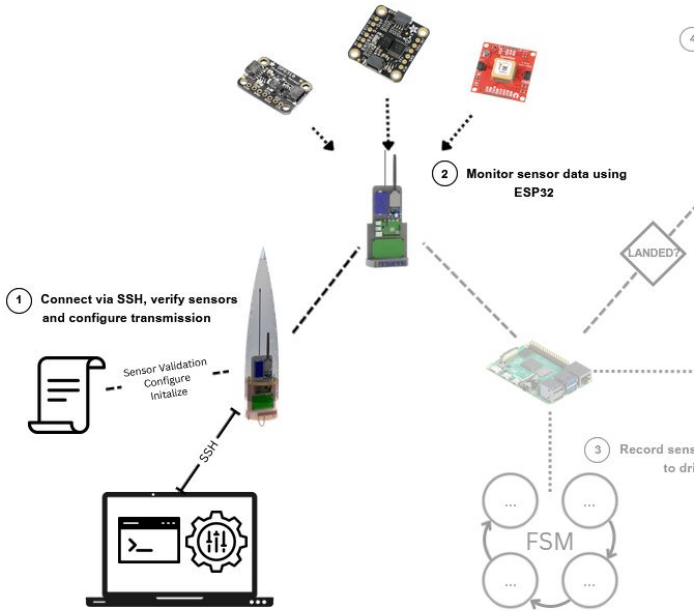
- 144.390MHz fixed broadcast frequency

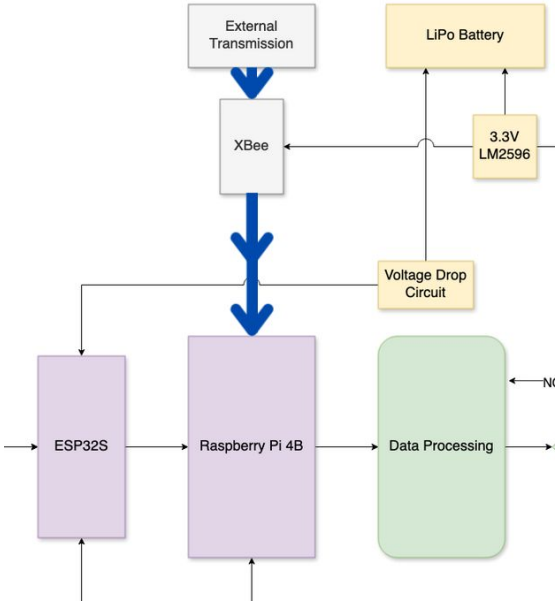


STEMCRaFT Onboard CONOPS

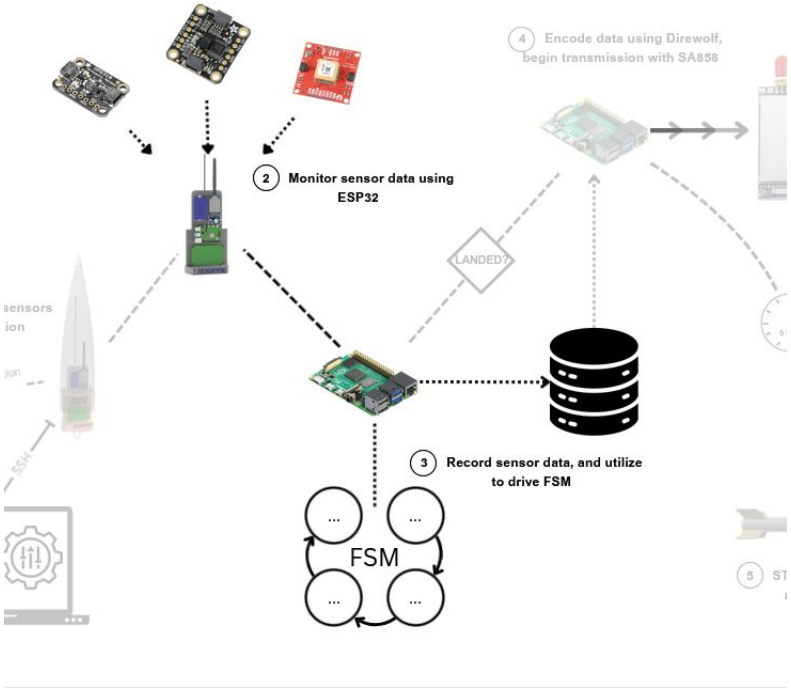


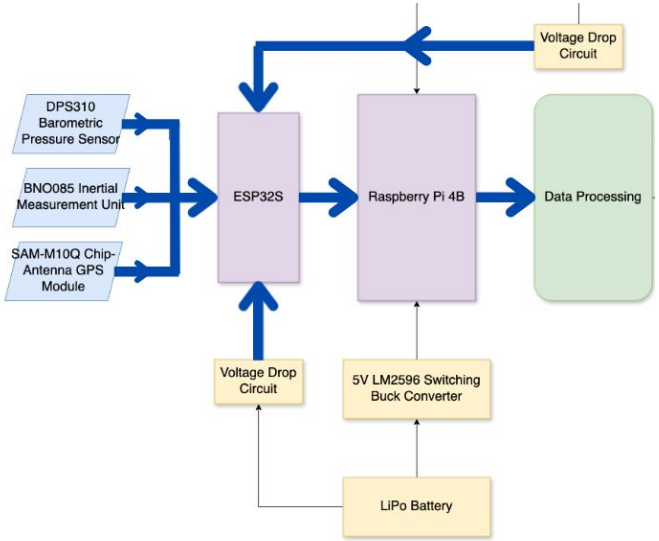
STEMCRaFT Onboard CONOPS



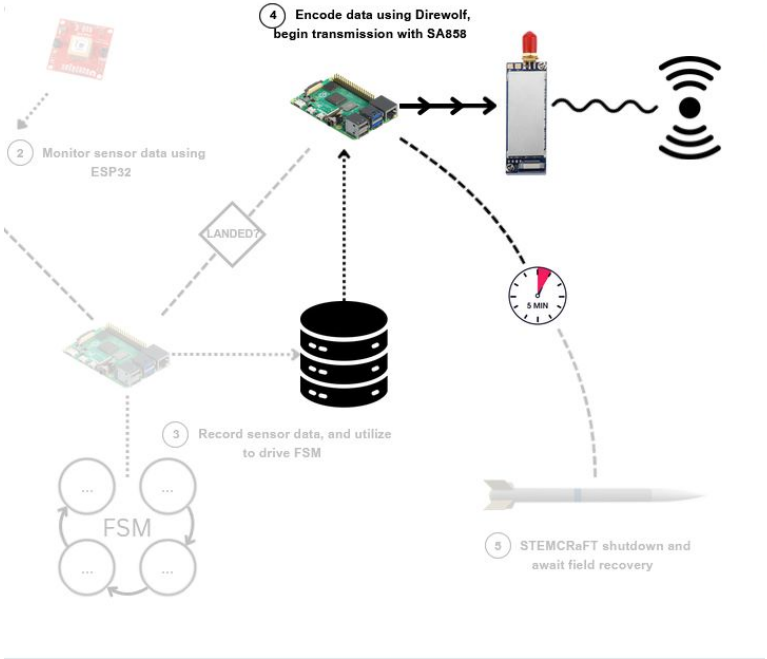


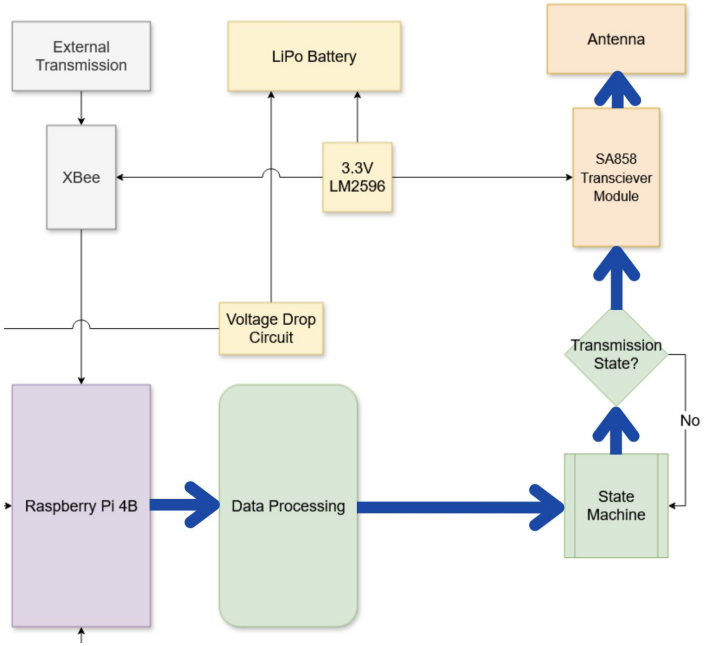
STEMCRaFT Onboard CONOPS





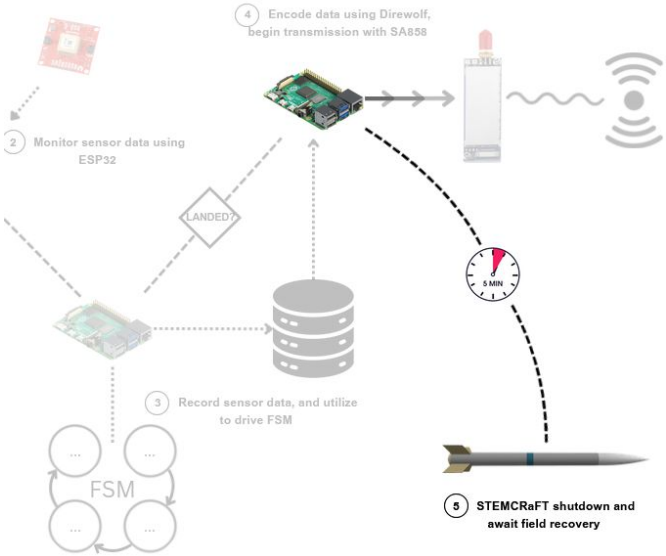
STEMCRaFT Onboard CONOPS





STEMCRaFT Onboard CONOPS

- TX Period Elapsed
- Inactive State
  - Continue monitoring XBee for override signals
- Shutdown
  - Pull pins inserted during field recovery



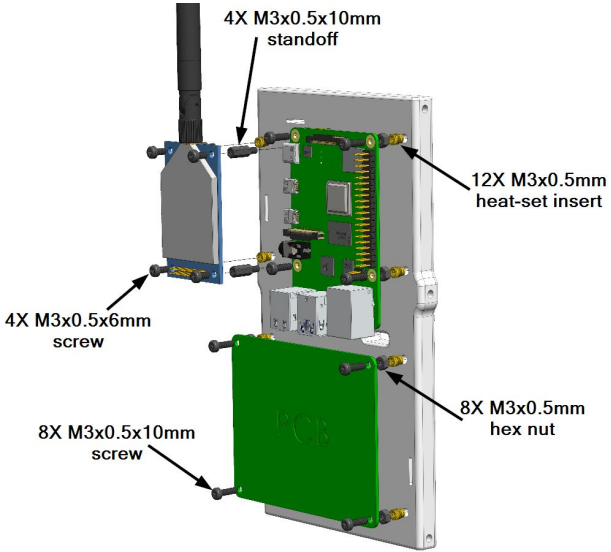
Electronics mounting

Electronics mounting:

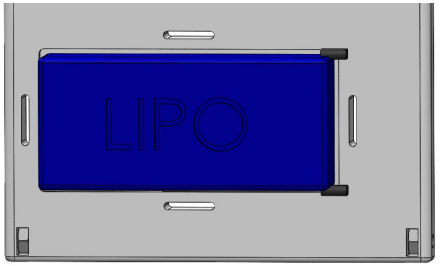
- Standoffs (Nylon)
- Hex nuts (Nylon)
- Screws (Nylon)
- Heat-set inserts (Brass)

Battery mounting:

- Velcro straps



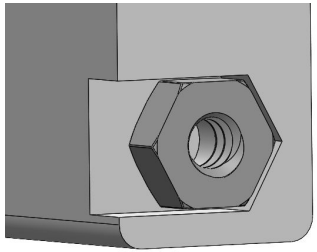
Electronics mounting



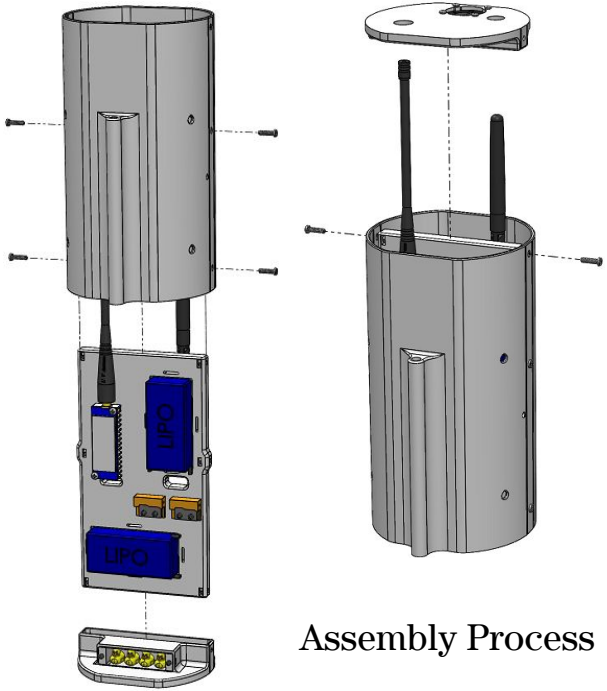
Battery mounting

STEMCRaFT Assembly

- Mounting screws secure sled and bulkheads to capsule shell
  - Low-profile screws
  - Hex nut embedded in sled



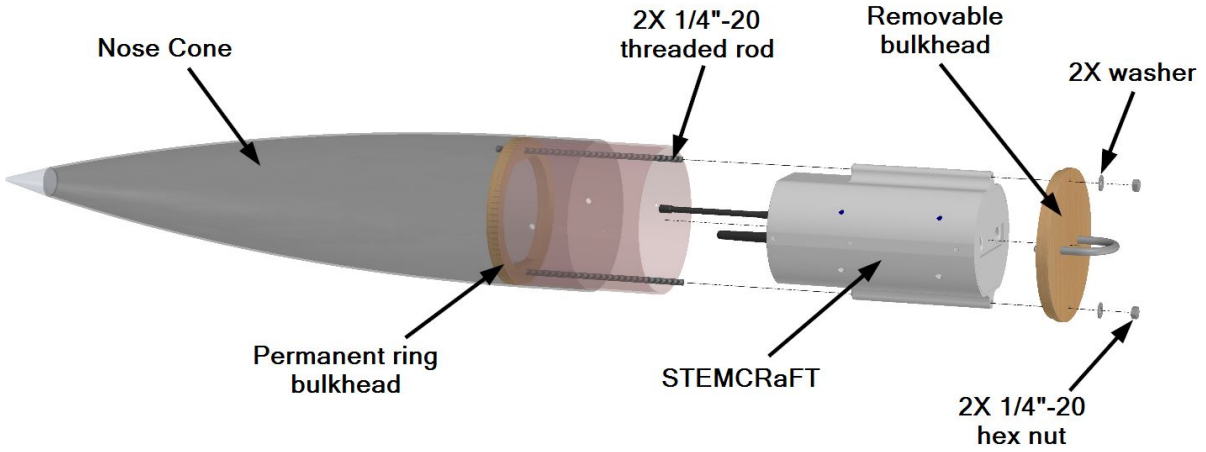
Section view of embedded hex nut



Assembly Process

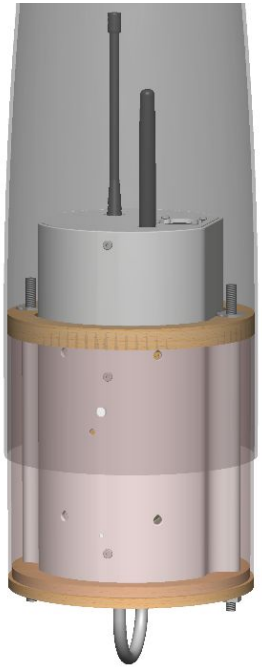
Payload Retention

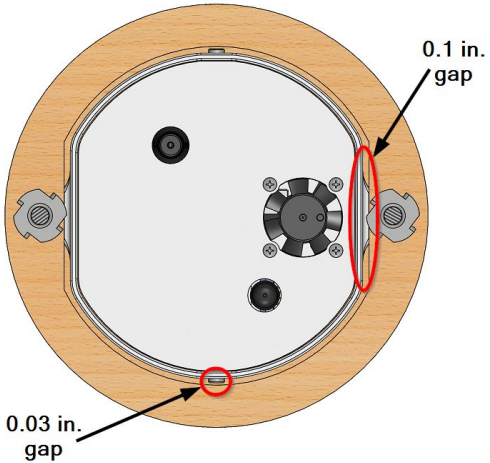
- STEMCRaFT inserted into Nose Cone via two threaded rods
- Removable bulkhead attached to threaded rod aft of STEMCRaFT
- Washer and nut used on each threaded rod to secure STEMCRaFT



Payload Integration

- STEMCRaFT rests between the permanent ring bulkhead and removable bulkhead
- Clearance between STEMCRaFT and permanent ring bulkhead
  - 0.1” along the sides
  - 0.03” on front and back when screws pass through





Air Brakes

Overview

Objective

- Control the ascent rate of the rocket
- Hit a target apogee with 96% accuracy

Strategy

- Employ a prediction and control algorithm
- Dynamically adjust the reference area via deployable fins

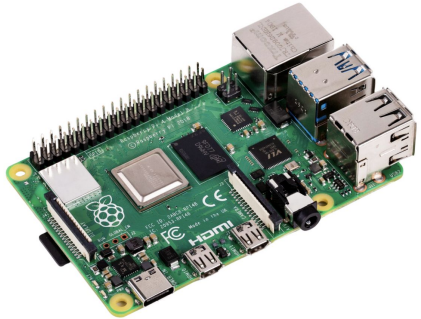
Electronics

IMU - 3DMCX5-AR

- IMU has a sampling rate up to 1000Hz
- Operated at 500Hz
  - Accelerations
  - Quaternions
  - Gyros
  - Altitude

Controller- Raspberry Pi

- Python code-base provides large access to libraries
  - Finite state machine is based on data from IMU
- 4 Cores, 4 Processes
  - Apogee prediction
  - Controller
  - Main process
  - Logging



Electronics

Servo - DS2685BLHV

Rotary Encoder

DS2685BLHV	7.4V	8.4V	11.1V	12.0V	15.0V
Speed	0.297sec/60°	0.262sec/60°	0.207sec/60°	0.182sec/60°	0.139sec/60°
Torque	1455oz-in	1600oz-in	2075oz-in	2215oz-in	2685oz-in
Current (idle)	10mA	10mA	11mA	11mA	12mA
Current (no load)	320mA	350mA	470mA	510mA	850mA
Current (stalled)	6.0A	6.5A	8.2A	9.0A	10.0A

Electronics

2s LiPo

- 7.4 volts; 2200mAh
- Powers Raspberry Pi & IMU
- ~5 hours at idle current draw

4s LiPo

- 14.8 volts; 2200mAh
- Powers the Servo
- ~6 hours at idle current draw

Manufacturing & Assembly

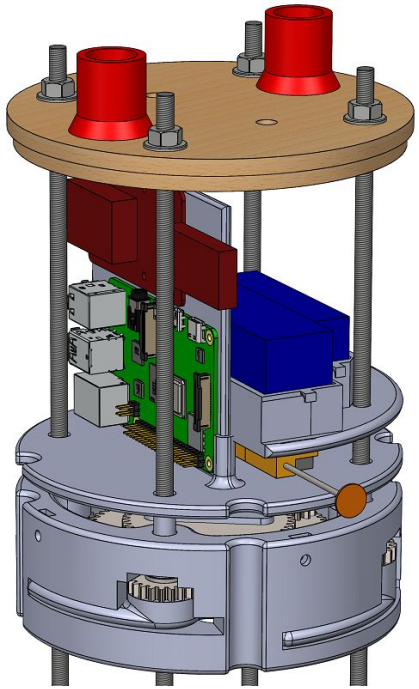
Designed in Solidworks

3D printed components:

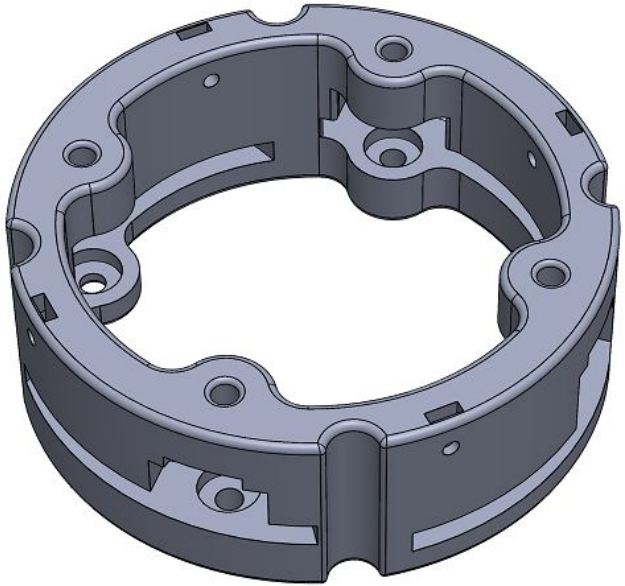
- AB housing
- AB fins
- Gears
- Sleds

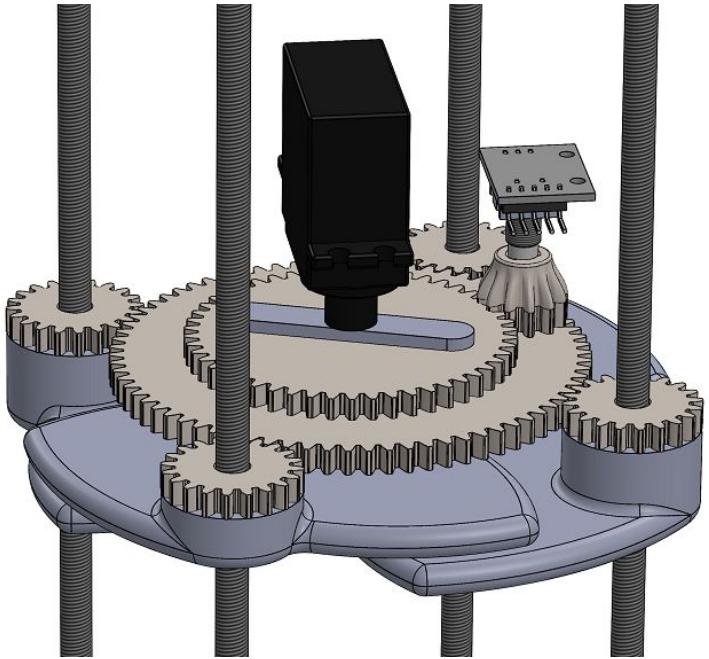
Bought components:

- Bearings
- Threaded Rod
- Electronics

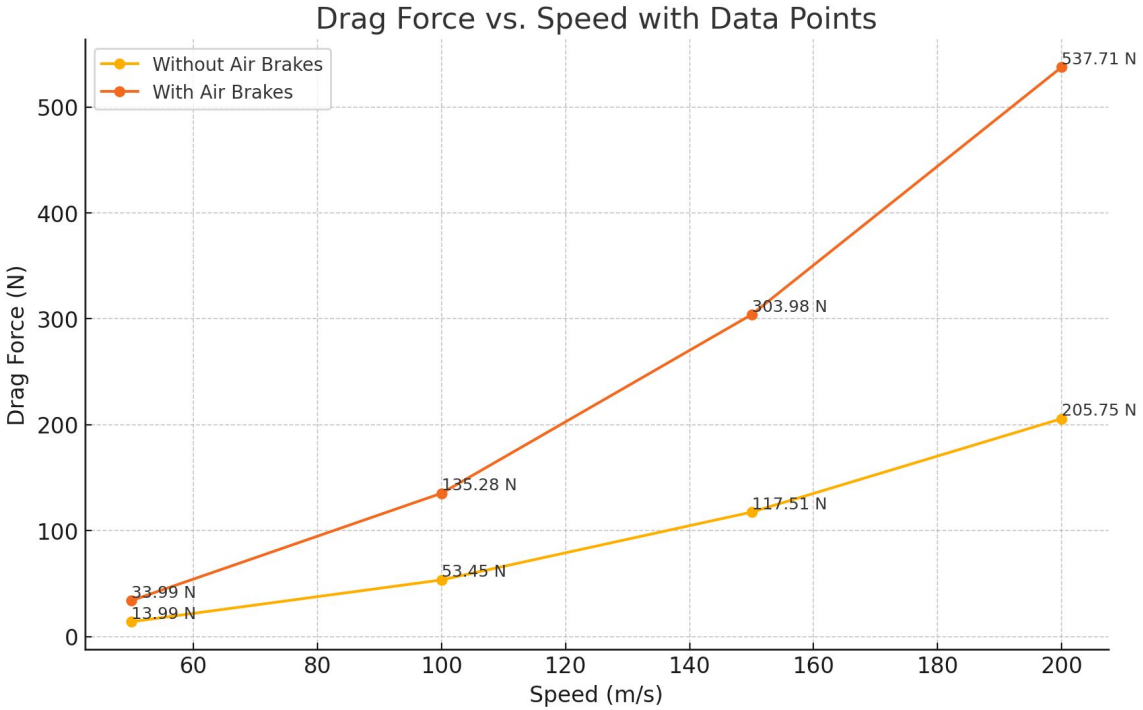


Manufacturing & Assembly





Drag Analysis



Drag from AB:

- 330N at 200m/s

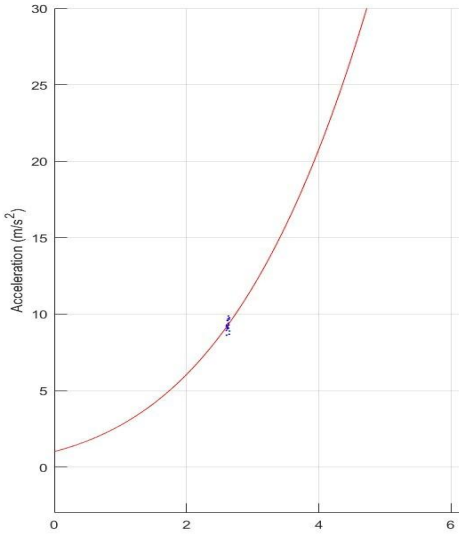
Per Fin

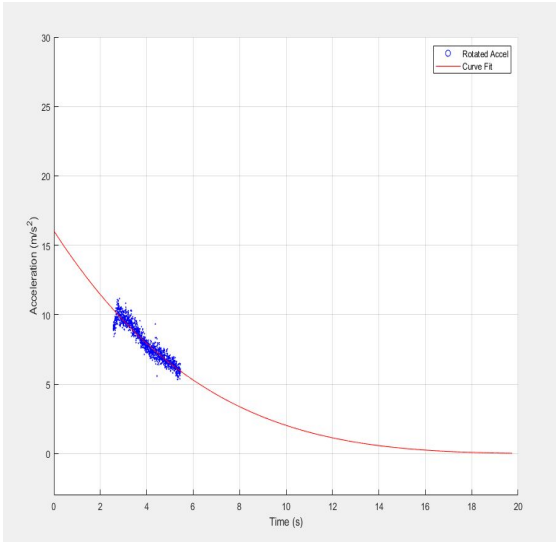
- 82.5N at 200m/s

Software

Apogee prediction algorithm

- Curve fit to vertical acceleration
- Equation: Y=A(1-Bt)^4
- Extrapolates data to apogee



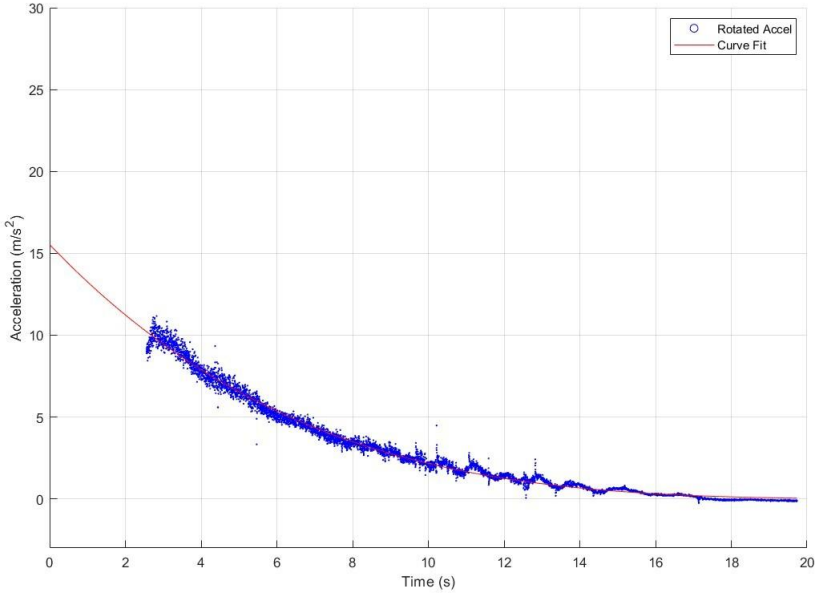


Software

Apogee prediction algorithm

- ~2 seconds to converge
- 98% accurate to 6000 ft
- Backtested on flight data

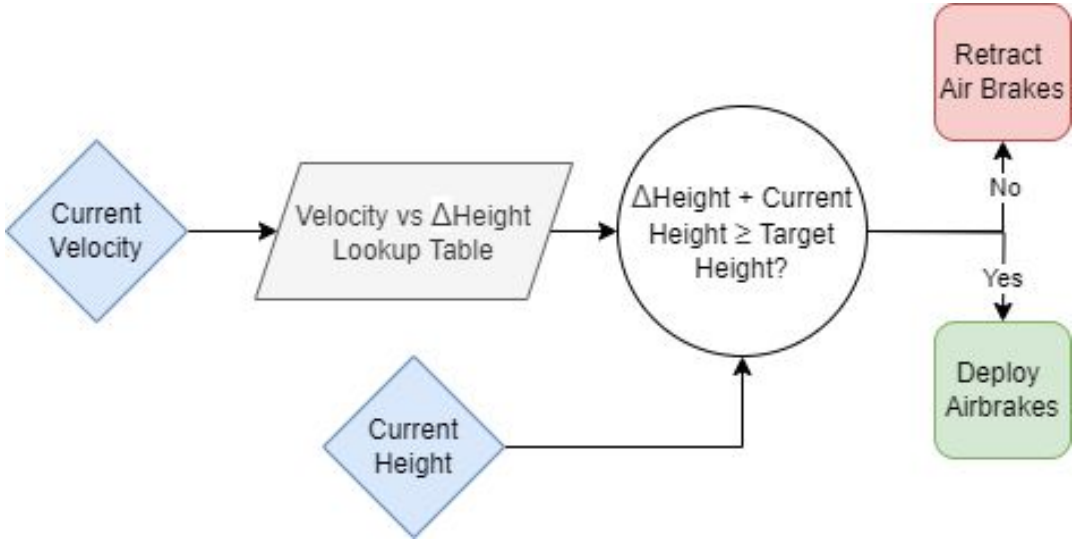
Launch Name	Convergence Time (sec)	Predicted Apogee (m)	Actual Apogee (m)
Interest Launch	1.60	1896	1855
Genesis Launch 1	1.78	454	459.3
Genesis Launch 2	1.50	459	463



Software

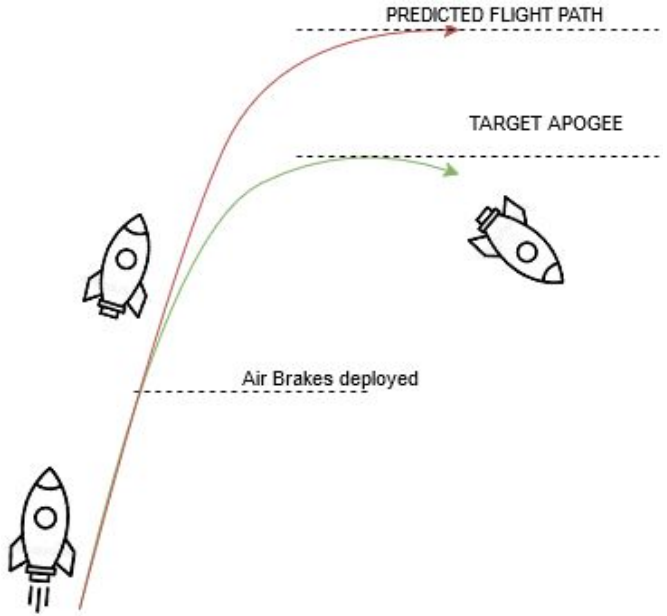
Control algorithm

- Generates a predicted flight profile of altitude and velocity
- Deploys once
- Retracts once



Overview

1. Set up to overshoot target apogee
2. Flight profile is generated
3. Controller deploys fins
4. Controller retracts fins
5. Rocket coasts to target apogee

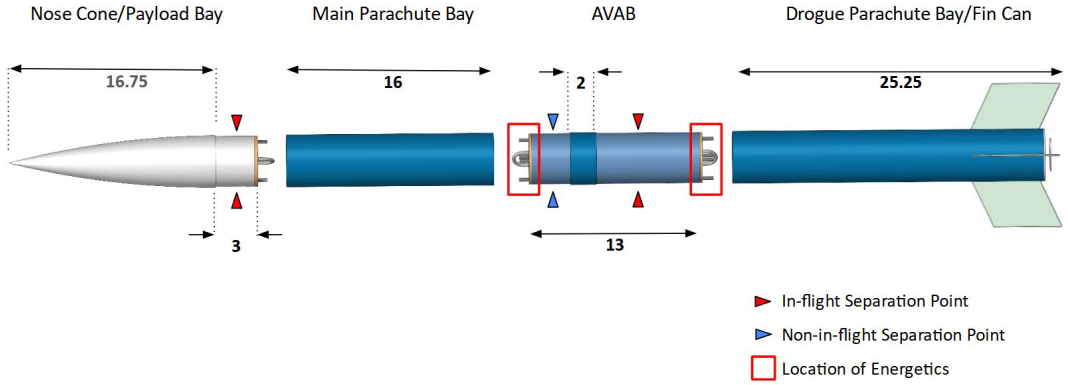


Subscale Flight Results

Subscale Design

Launch Vehicle: Approximate 66.6% geometric scale

Payload: Electronics sled used to test data collection sensors



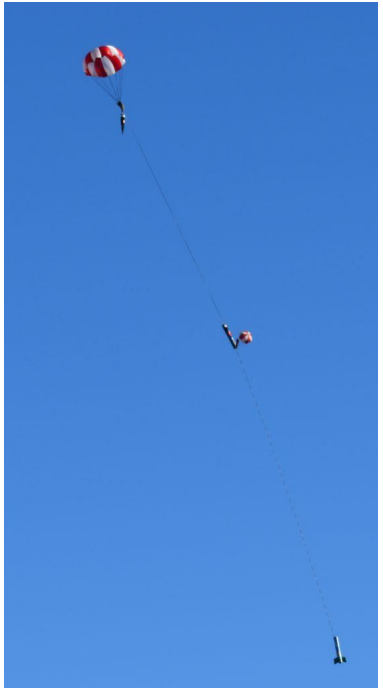
Parameter	Subscale	Full Scale	Scaling Factor
Total Length	60.0 in.	95.75 in	62.7 %
Body Diameter	4.02 in.	6.17 in.	65.2 %
Fin Chord	5.33 in	8.0 in	66.6 %
Fin Span	11.08 in	16.77 in	66.1 %
CG	33.25 in.	58.9 in	56.5 %
CP	45.1 in.	71.8 in.	62.7 %
Static Stability	2.95	2.10	N/A
Payload Mass	0.86 lbs.	2.25 lbs.	38.2 %
Total Mass	14.6 lbs.	38.39 lbs	38.0 %

Flight Conditions

Field Conditions	
Wind Speed	9.8 mph to the South
Pressure	101500 Pa
Temperature	60°F
Launch Rail Cant	5°

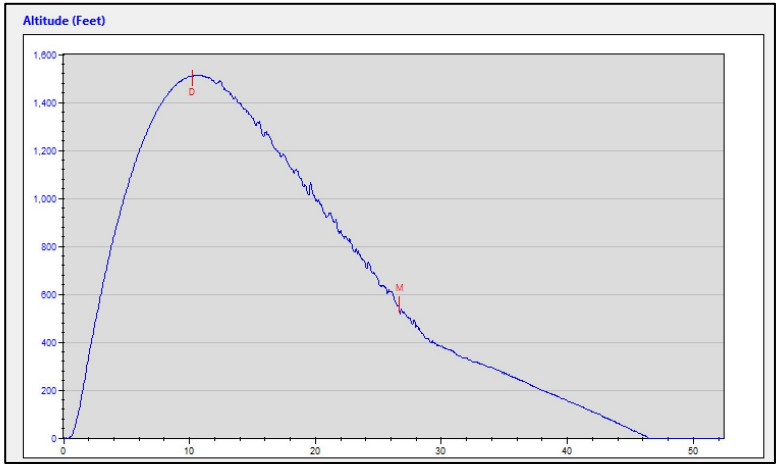
Vehicle Conditions	
Weight	14.6 lbs
Center of Gravity	33.25 in.
Center of Pressure	45.15 in.
Stability Margin	2.975

Subscale Launch

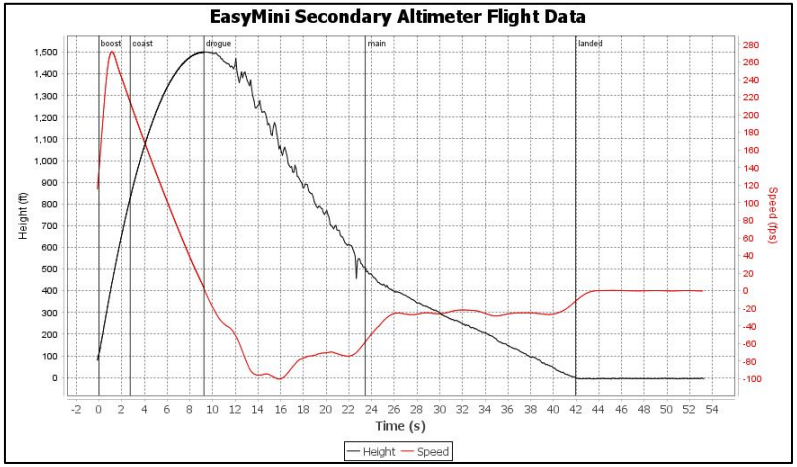


Flight Results

Primary Altimeter

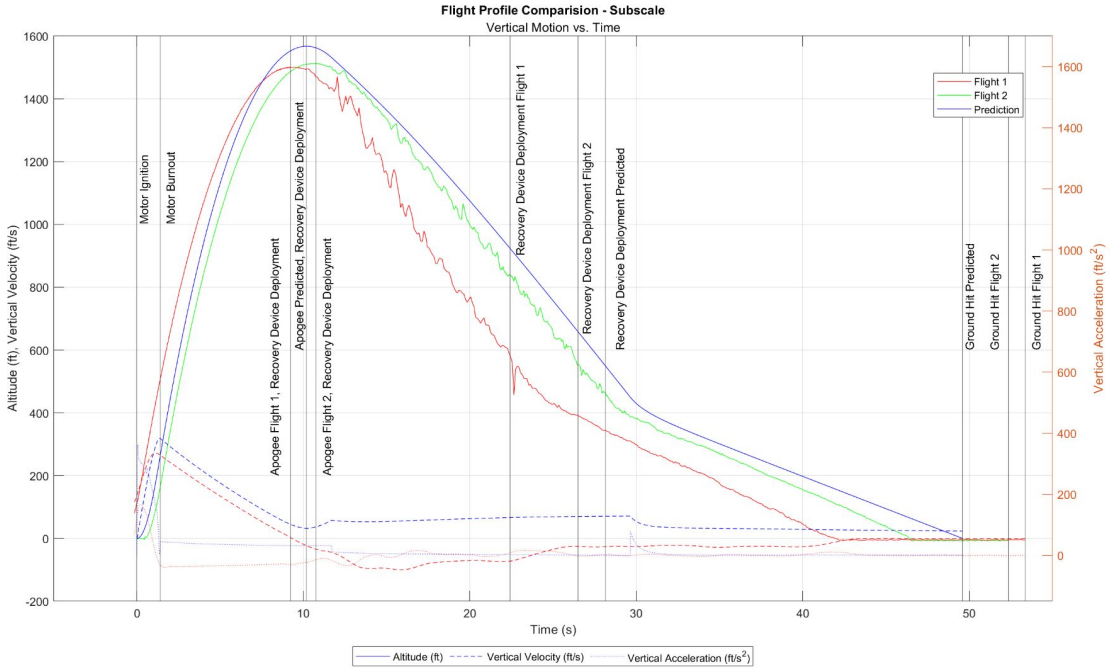


Secondary Altimeter



- Recovery system behaved nominally
  - Drogue parachute deployment at apogee, secondary charge one second after apogee
  - Main parachute deployment at 550 feet, secondary charge at 500 feet

Predicted vs Actual Flight Data



	Flight 1	Flight 2	Prediction
Apogee (ft)	1500	1513	1567
Time to Apogee (s)	9.23	10.75	10.193
Main Parachute Deployment (s)	22.43	26.5	28.14
Time to Ground (s)	53.35	52.35	49.589

Recovery Landing Configuration




Requirement Verification

Requirement Compliance Update

- Subscale Fabrication & Full Scale Design Requirements = Completed
- Testing Verifications = Planned tests & completion dates
- Location: Section 7 of CDR to view testing plans & requirement verification

NASA Requirements

Fully Verified	Partially Verified	In Progress	Not Verified	N/A
35.77% (49)	45.26% (62)	4.38% (6)	12.41% (17)	2.19% (3)

Team-Derived Requirements

Fully Verified	Partially Verified	In Progress	Not Verified	N/A
26.5% 31	53.85% 63	17.95% 21	0	1.71% 2

Test Plans and Procedures

Launch Vehicle Testing Suite

Test	Requirement Verified	Date	Status
Subscale Ejection Test	NASA Req. 3.2, TDR RF.10, TDR RF.24	November 15, 2024	Verified
Subscale Dry Run	TDR LVF.2, TDR LVF.3	November 15, 2024	Verified
Subscale Demonstration Flight	NASA Req. 2.18	November 16, 2024	Verified
Moment of Inertia Test	TDR LVD.1	February 10, 2025	Not Verified
Nose Cone Bulkhead Tensile Test	TDR LVD.1	January 28, 2025	Not Verified
AVAB Bay Tensile Test	TDR LVD.1	January 28, 2025	Not Verified
Rivet Shear Loading Test	TDR LVF.11	February 4, 2025	Not Verified
Shear Pin Shear Loading Test	TDR LVF.12	February 4, 2025	Not Verified
Fin Can Impact Test	TDR LVD.1	February 3, 2025	Not Verified
Altimeter Test	TDR RF.13	January 13, 2025	Not Verified
GPS Test	TDR RD.6	January 27, 2025	Not Verified
Parachute Deployment/ STEMnaut Containment Test	TDR RF.18	January 15, 2025	Not Verified
Full-scale Ejection Test	NASA Req. 3.2, TDR RF.10, TDR RF.24	February 14, 2025	Not Verified
Full-scale Dry Run	TDR LVF.2	February 14, 2024	Not Verified
Full-scale Demonstration Flight	NASA Req. 2.19, TDR PF.5, TDR PF.6, TDR PF.7, TDR PF.8, TDR PF.9, TDR PF.10, TDR PF.11, TDR PF.12, TDR PF.13	February 22, 2024	Not Verified

Payload Testing Suite

Test	Requirement Verified	Date	Status
Payload Data Collection Test	TDR PF.5, TDR PF.6, TDR PF.7, TDR PF.8, TDR PF.9, TDR PF.10, TDR PF.11, TDR PF.12, TDR PF.13	January 25, 2025	Not Verified
Payload Flight Simulation Transmission Test	TDR PF.1	February 14, 2025	Not Verified
Remote Override Test	TDR PF.1	February 14, 2025	Not Verified
Data Transmission Verification	TDR PF.1	January 31, 2025	Not Verified
Battery Capacity Verification	TDR PF.9	January 30, 2025	Not Verified
Nose Cone with STEMCRaFT Impact Test	TDR PF.7	February 6, 2025	Not Verified
Air Brakes Deployment Test	TDR ABF.1, TDR ABF.2	February 13, 2025	Not Verified
Air Brakes Flight Simulation Test	TDR ABF.4, TDR ABF.5	January 31, 2025	Not Verified
Air Brakes Effectiveness Flight Test	TDR ABF.1, TDR ABF.2, TDR ABF.3, TDR ABF.4	January 25, 2025	Not Verified

Questions?