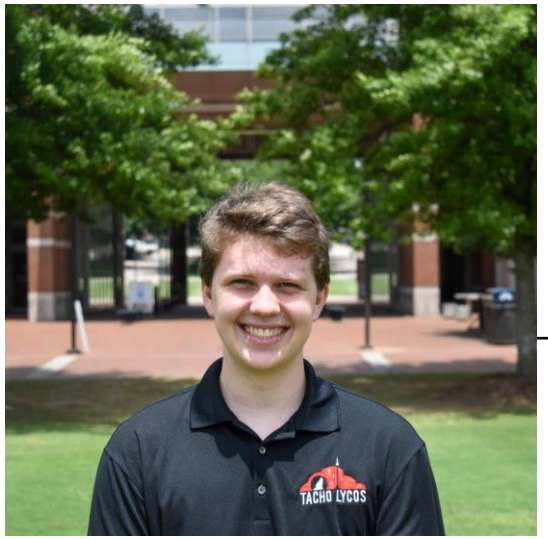
Preliminary Design Review

November 23rd, 2021



Sean Aiton
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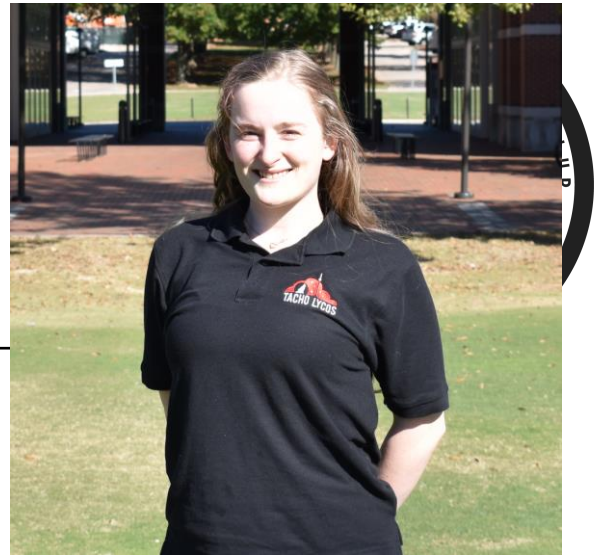
Myers Harinson
Structures Lead

Haydn Spurell
Aerodynamics Lead



Frances McBride
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Presentation Overview

- Launch Vehicle Leading Design
- Recovery System Leading Design
- Payload Leading Design
- Mission Performance Predictions
- Requirements Compliance Plan

Launch Vehicle Leading Design

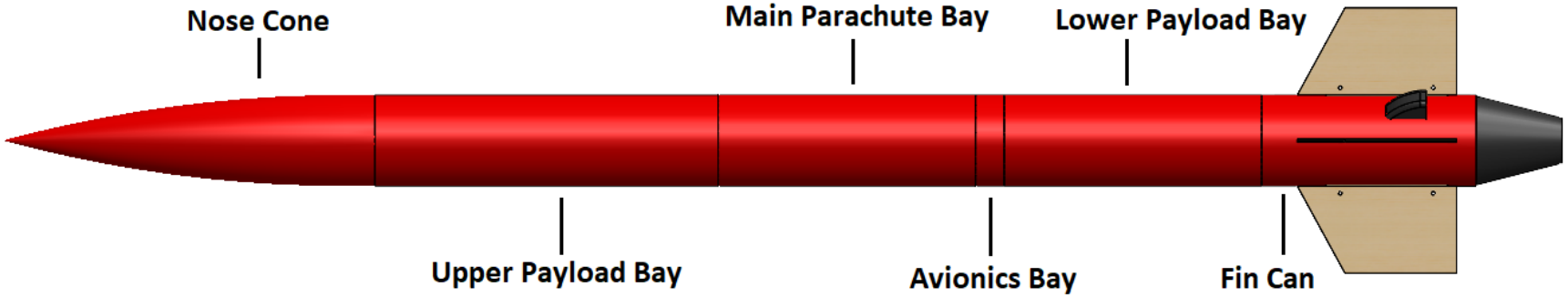
Material Selection

Airframe Sections

Fin Configuration

Launch Vehicle Dimensions

- Length: 109.25"
- Diameter: 6"
- Launch Weight: 40.69 lb
- Empty Weight: 36.34 lb



Launch Vehicle Dimensions

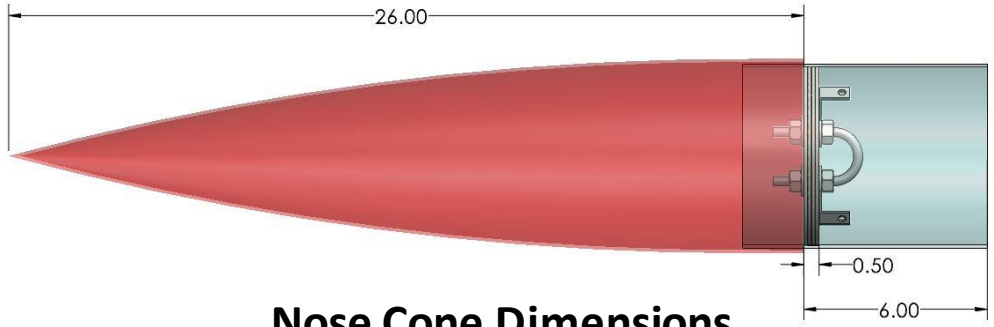
Chosen Material: G12 Fiberglass

- Blue Tube 2.0
  - Vulcanized fiber-based
  - Abrasion resistant and durable material properties
  - Inexpensive
  - Lightweight
  - Prone to water damage without additional treatment
- G12 Fiberglass
  - Fiber-reinforced plastic composite
  - Highly durable and damage resistant
  - $29 more per foot than Blue Tube
  - Heavier than other options
  - Water resistant

Chosen Nose Cone: 4:1 Ogive

- Conical
  - Simple design
  - Not optimal for subsonic speeds
- Elliptical Design
  - Optimal for subsonic speeds
  - Minimizes skin friction drag
  - Not commercially available

- Ogive
  - Many geometries available and sold by large retailers
  - 4:1 Ogive gives a desirable stability margin in RockSim simulations



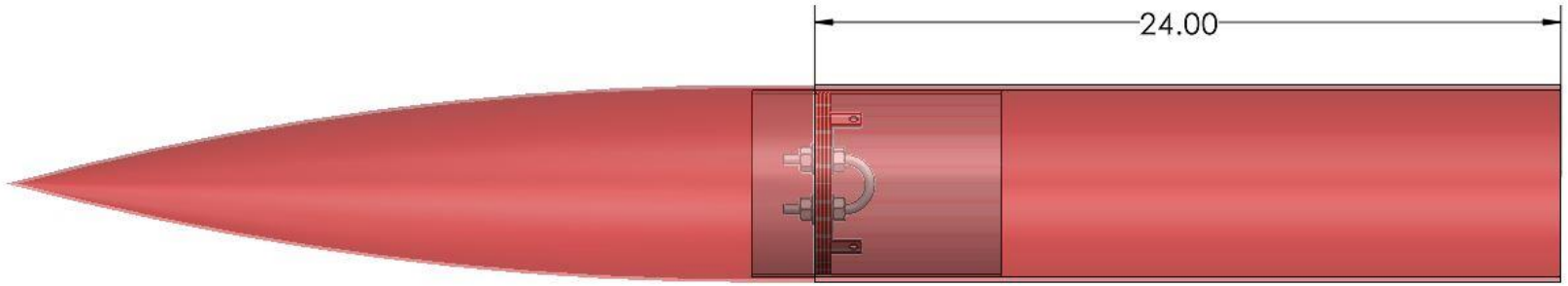
Nose Cone Dimensions

Chosen Nose Cone Bulkhead: Removable

- Fixed
  - Has additional strength and stress distribution due to the epoxy bond to the airframe
  - One-time installation
  - Difficult to remove if any changes need to be made
- Removable
  - Stress concentration at the bolted connections
  - Allows for accessibility to adjust ballast on the forward side
  - Allows additional space and accessibility for payload integration electronics

Upper Payload Bay

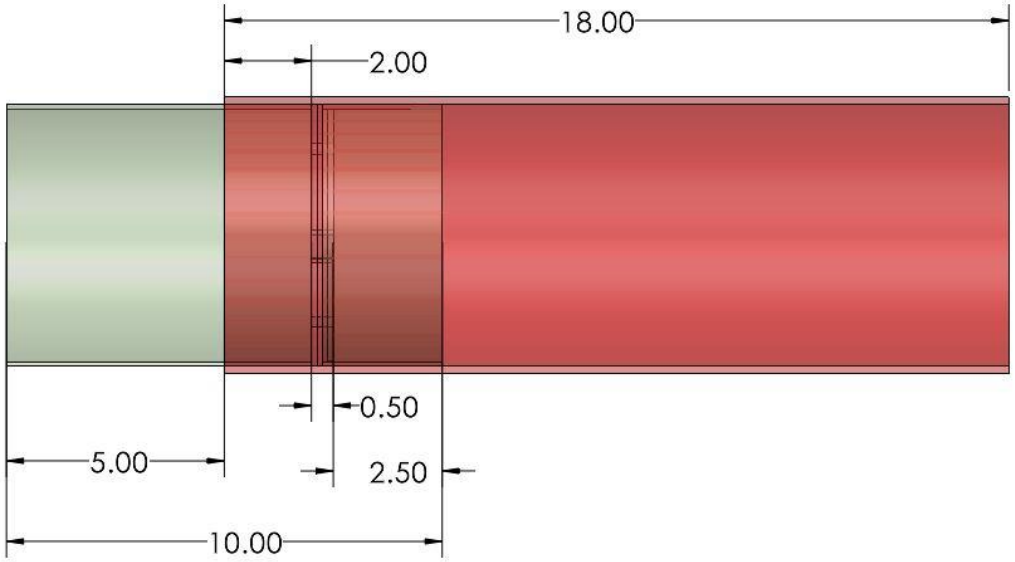
- Located between the nose cone and main parachute bay
- Forward location shifts the CG forward, improving the stability
- Shear pins through the body hold the payload in place



Upper Payload Bay Dimensions

Main Parachute Bay

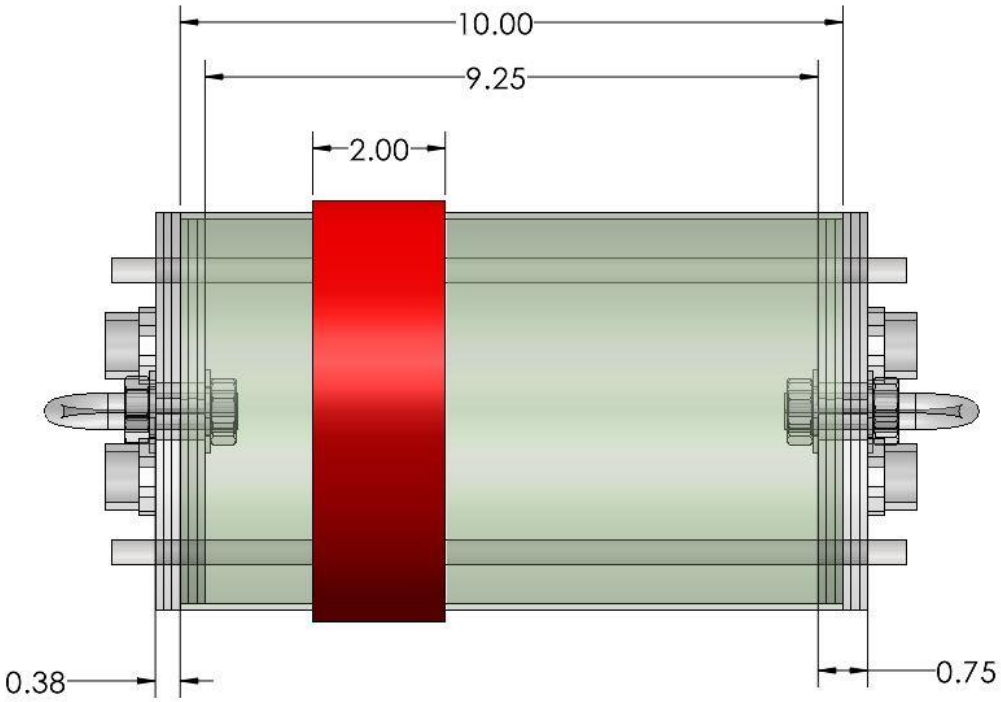
- Located between the upper payload bay and avionics bay
  - Shear pin connection to upper payload bay
  - Bolted connection to avionics bay
- Main parachute packing volume: _" D, _" L
- Recovery harness takes up __" of main parachute bay length



Main Parachute Bay Dimensions

Avionics Bay

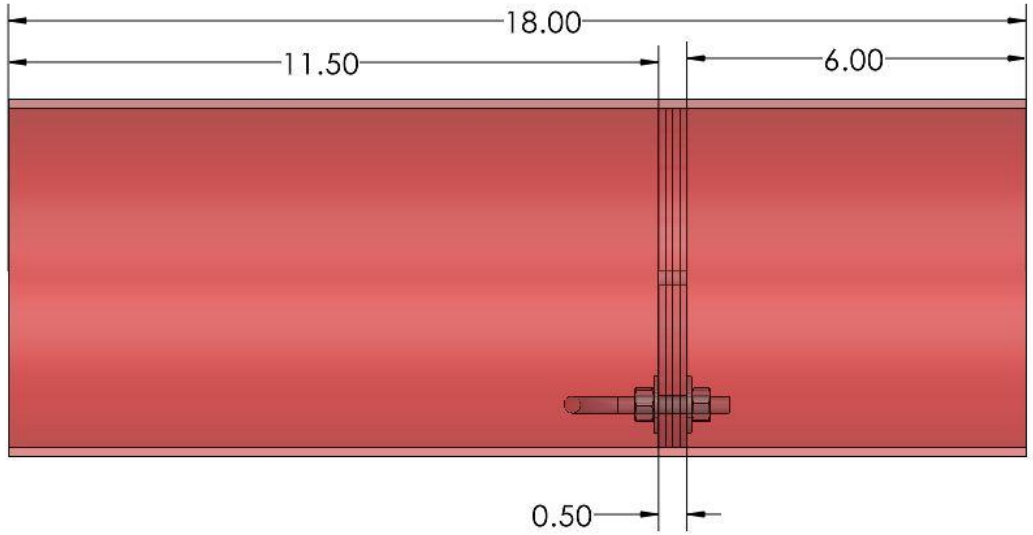
- Between the main parachute bay and lower payload bay
- Modular, 2 bulkhead design allows for accessibility to the avionics sled
- Allows for simultaneous assembly alongside launch vehicle
- Easily accessible blast caps and U-bolts



Avionics Bay Dimensions

Lower Payload Bay

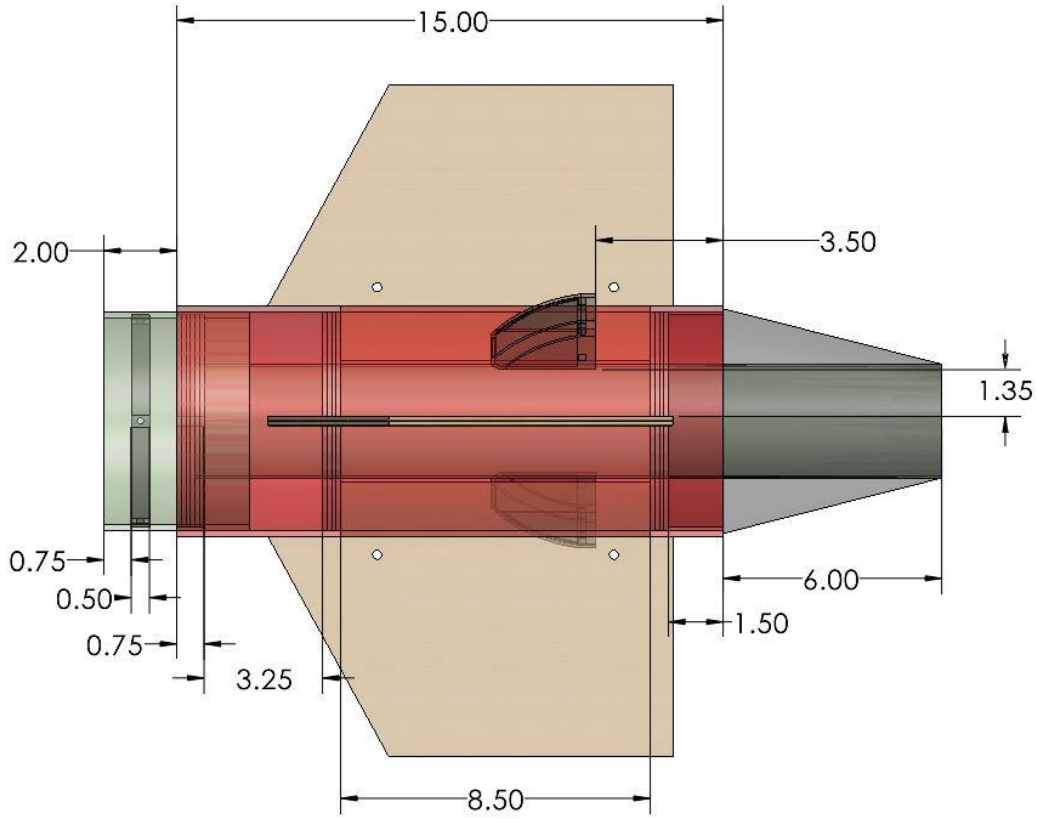
- Between the avionics bay and the fin can
  - Shear pin connection to avionics bay
  - Bolted connection to the fin can
- Forward end has a compartment for the drogue parachute
- Aft end has a compartment for the lower payload sled



Lower Payload Bay Dimensions

Fin Can

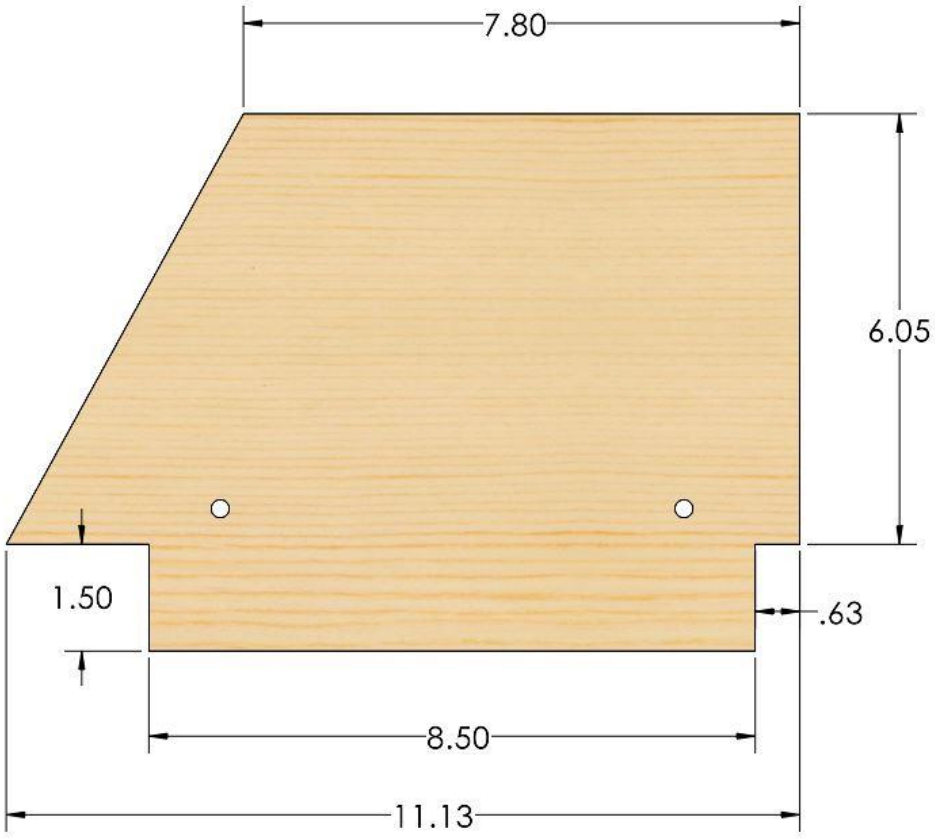
- Engine block and two centering rings are used to align and secure the motor tube
- Centering rings used to align and support fins
- 3D Printed centering ring in coupler used to support bolted connections
- 6" conical tail cone used to reduce turbulent airflow
- Symmetrical camera housings located between fins



Fin Can Dimensions

Four Fin Configuration

- Four fin configuration primarily chosen for camera housing symmetry to balance aerodynamic forces
- Leading-edge sweep reduces drag, pushes CP aftwards, and increases stability

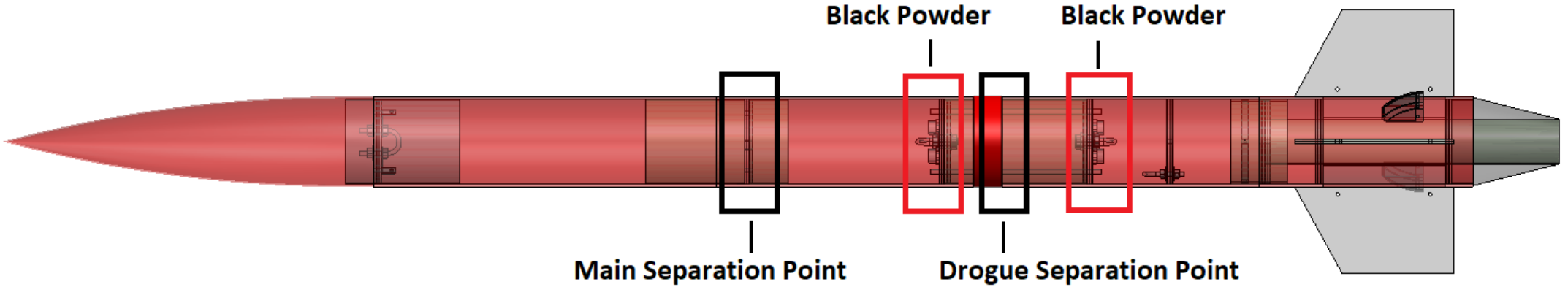


Fin Dimensions

Recovery Subsystem Leading Design

Recovery Locations

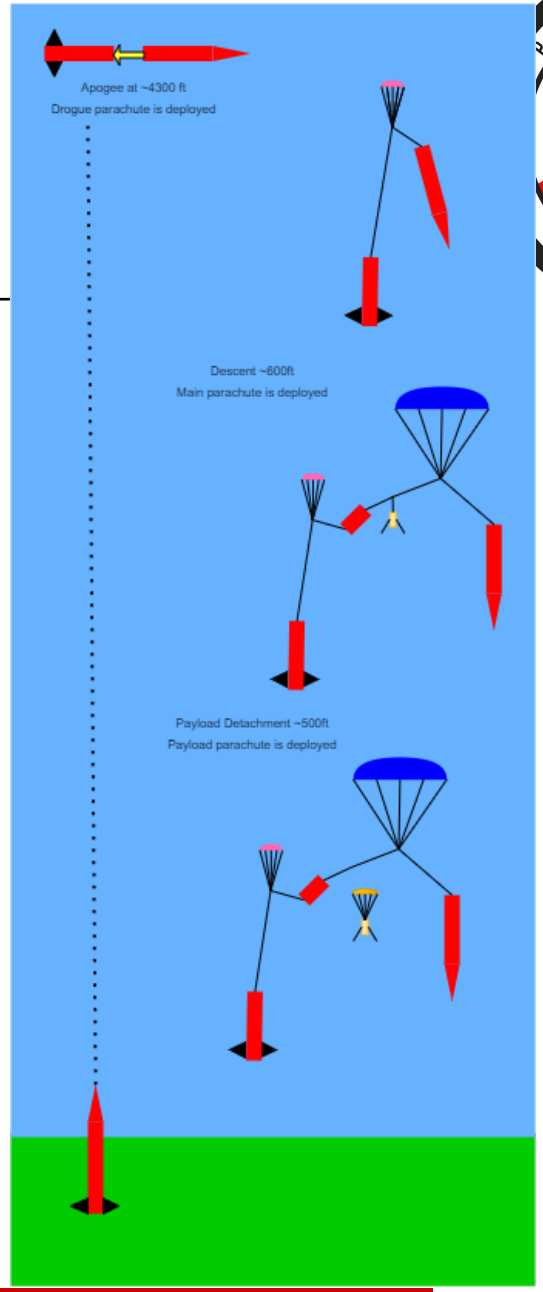
- Drogue Parachute is found in the lower payload bay
- Main Parachute is found in the Main parachute bay
- AV is where all recovery electronics are



Launch Vehicle Separation Points

Recovery Overview

- Drogue deploys at Apogee
  - Secondary is approximately 1 sec after apogee
- Main deploys at 600 feet
  - Secondary charge at 575 feet
- Payload Jettison at 500 feet
  - With RSO Approval
- Objective is the safe recovery of all parts of the launch vehicle and payload



Recovery Profile

Altimeter Comparison Table

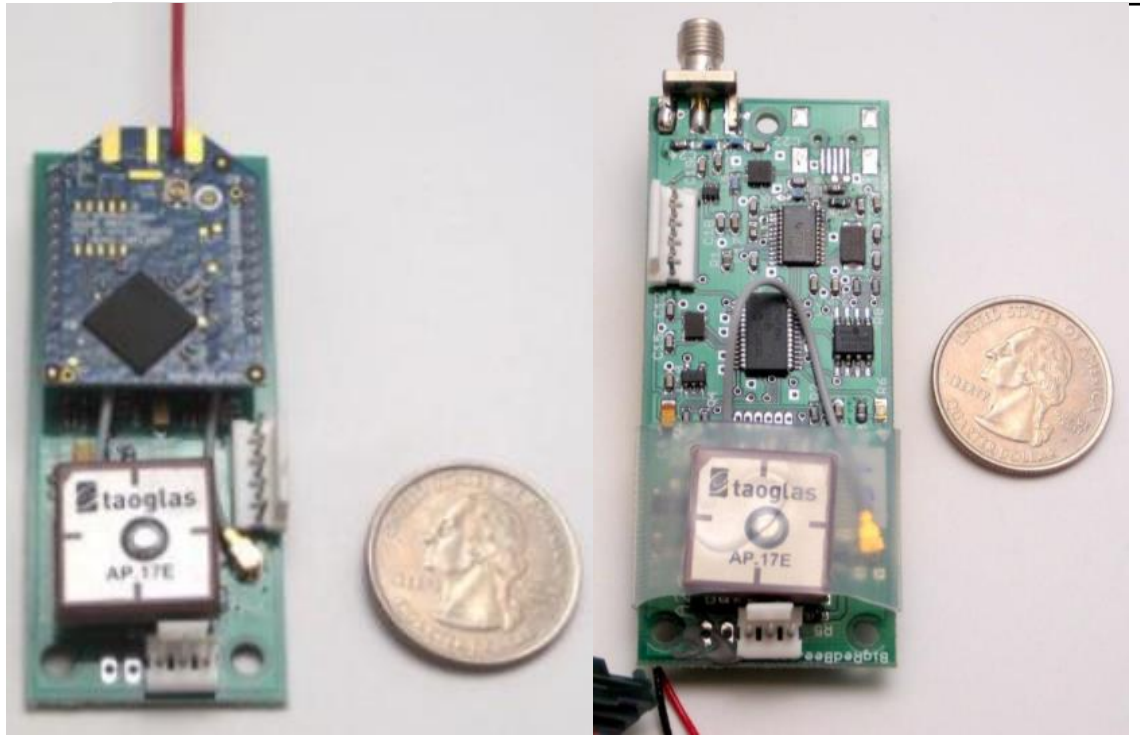
	RRC3 Sport	Aim 3	StratoLogger CF	EasyMini	TeleMega
Manufacturer	Missile Works	Entacore	PerfectFlight	Altus Metrum	Altus Metrum
Main Deployment Variability	300-3000ft adjustable in increments of 100ft	100-999 increments of 1 ft	100-9999 increments of 1ft	Any Altitude	Any Altitude
Delay After Apogee	1-30 seconds in increments of 1 second	Available	0-5 seconds increments of 1 second	Available	Available
Minimum Apogee	100-300 ft	N/A	100 ft	N/A	N/A
Altitude Logging Resolution	1ft	1ft	1ft	8 in	8in
Dimensions	3.92"L x 0.925"W	2.56"L x 098"W x 0.59"H	2.0"L x 0.84"W x 0.5"H	1.5"L x 0.8"W x 0.6"H	3.25"L x 1.25"W x 0.625"H
Data Logged	Altitude, Velocity, Time to Apogee	Altitude, Velocity	Altitude, Velocity	Altitude, velocity, acceleration, Time to apogee, Total Flight time	Altitude, Velocity, Acceleration
Sampling Rate	20/s	10/s	20/s	100/s Ascent 10/s Descent	100/s Ascent 10/s Descent
Battery Requirements	3.5-10V	3.7-12V	4-16V	3.7-12V	3.7V LiPo
Owned By Team	Yes	Yes	Yes	No	No
Price	92.07	115.00	58.50	85.60	428.00
Additional Info	Can measure telemetry with additional add-ons	Barometric pressure sensor only	Most often used in past years	Barometric pressure sensor only	Also includes GPS tracker, Accelerometer, magnetic direction sensor, and gyro. Requires HAM radio license

Altimeter Comparison

Selection between
- RRC3
- AIM 3
- StratoLogger CF
- EasyMini
- TeleMega

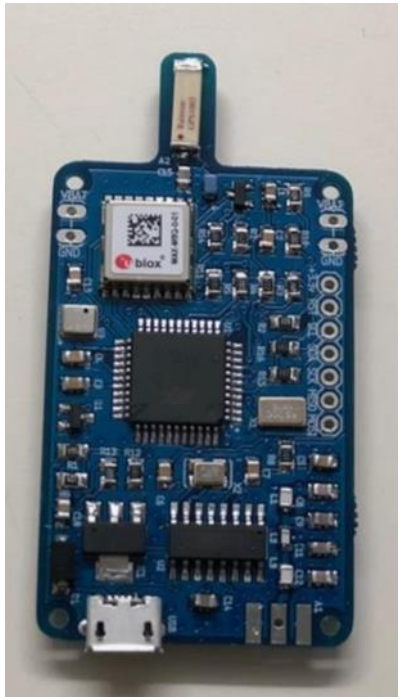
Selection Criteria
- Form Factor
- Ease of Wiring
- Reliability
- Adaptability

Tracker Alternatives

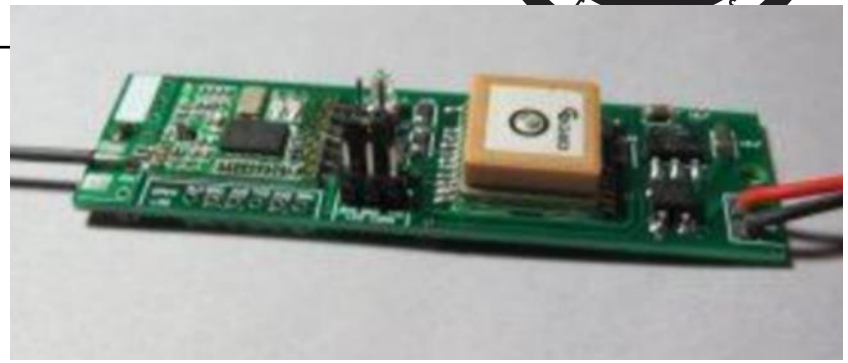


BigRedBee 900

BigRedBee Beeline

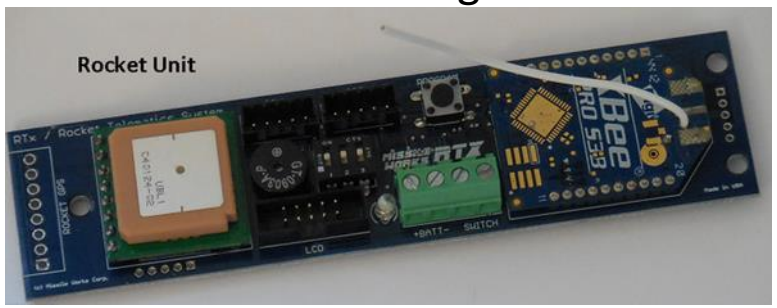


LightAPRS+W



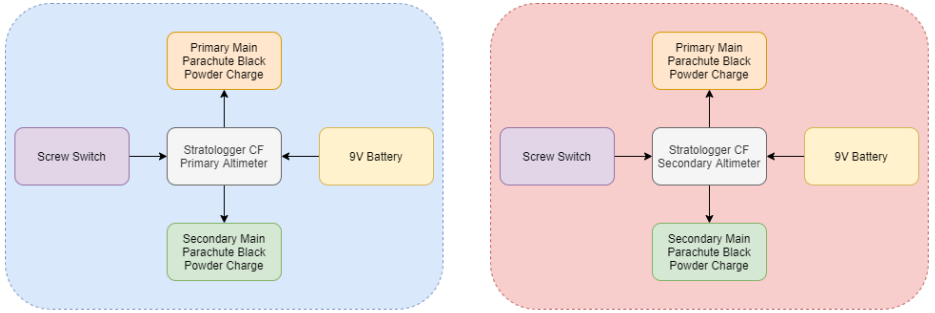
Eggfinder GPS

Featherweight GPS



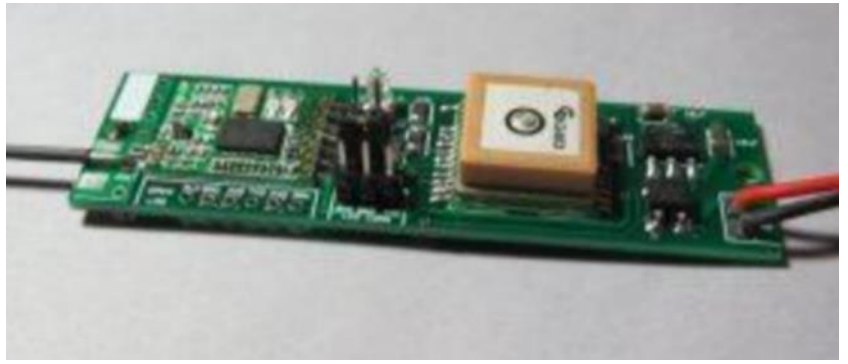
Missileworks RTx/GPS

Leading Avionics Design

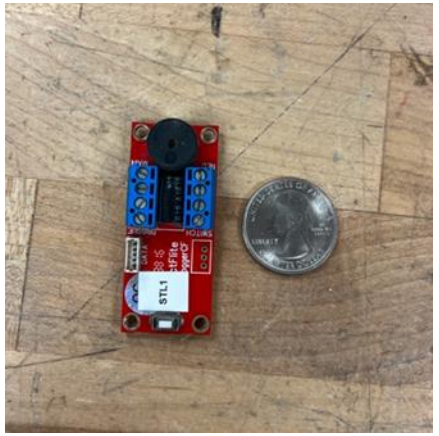


AV Bay Electronics Diagram

2 Strattoogger Altimeters
1 EggFinder Tracker
2 independent systems for the altimeters



Eggfinder GPS



StratoLogger CF

Drogue Parachute Alternatives

Parachute	Drag Coefficient	Descent Velocity	Descent Time from Apogee to Main Deployment	Wind Drift to Main Deployment
Fruity Chutes 18 inch Compact Elliptical	1.43	110.1 ft/s	34.1 s	330.50 ft
Fruity Chutes 24 inch Classic Elliptical	1.47	81.3 ft/s	46.1 s	661.01 ft
Fruity Chutes 24 inch Compact Elliptical	1.41	83.2 ft/s	45.1 s	991.51 ft
Fruity Chutes 30 inch Classic Elliptical	1.41	66.4 ft/s	56.5 s	1322.02 ft

Main Parachute Alternatives

Parachute	Drag Coefficient	Descent Velocity	Maximum Section Kinetic Energy	Decent time from Main Deployment	Wind Drift at 20 MPH
Fruity Chutes 96-inch Iris UltraCompact	2.09	17.1 ft/s	74.8 ft-lbf	38.1 s	1116.9 ft
Fruity Chutes 120-inch Iris UltraCompact	2.11	13.6 ft/s	47.5 ft-lbf	47.8 s	1402.0 ft
Fruity Chutes 144-inch Rocketman Pro-X	0.82	18.1 ft/s	84.5 ft-lbf	35.8 s	1050.9 ft

Main Parachute Comparisons with Lander Still Attached

Parachute	Drag Coefficient	Descent Velocity	Maximum Section Kinetic Energy	Decent time from Main Deployment	Wind Drift at 20 MPH
Fruity Chutes 84-inch Iris UltraCompact	2.13	16.7 ft/s	54.4 ft-lbf	34.9 s	1104.4 ft
Fruity Chutes 96-inch Iris UltraCompact	2.09	14.8 ft/s	42.6 ft-lbf	39.4 s	1248.2 ft
Fruity Chutes 120-inch Iris UltraCompact	2.11	11.8 ft/s	27. ft-lbf	49.5 s	1566.9 ft
Fruity Chutes 144-inch Iris UltraCompact	2.12	9.8 ft/s	18.7 ft-lbf	59.6 s	1885.9 ft
Fruity Chutes 144-inch Rocketman Pro-X	0.82	15.7 ft/s	48.1 ft-lbf	37.1 s	1174.5 ft

Main Parachute Comparisons with Lander has Detached

Payload Parachute Alternatives

Parachute	Drag Coefficient	Landing Velocity	Maximum Section Kinetic Energy	Wind Drift from jettison deployment (20 MPH)
Fruity Chutes 48-inch Classic Elliptical	1.44	20.5 ft/s	58.5 ft-lbf	717 ft
Fruity Chutes 60-inch Classic Elliptical	1.39	16.6 ft/s	38.7 ft-lbf	881 ft
Fruity Chutes 60-inch Iris UltraCompact	2.16	13.4 ft/s	25. ft-lbf	1098 ft
Fruity Chutes 72-inch Iris UltraCompact	2.03	11.5 ft/s	18.4 ft-lbf	1278 ft

Payload Parachute Comparisons for Lander

Leading Parachute Ideas

- Drogue
  - Fruity Chutes 24” Compact Elliptical
  - Nomex Sheet Protected
- Main
  - Fruity Chutes 96” Iris UltraCompact
  - Can accommodate both failed deployment and normal deployment
- Payload
  - Fruity Chutes 48” Classic Elliptical
  - In a deployment bag
  - Allows for minimal payload drift

Fruity Chute Classic Elliptical

Wind Drift and Descent Time

Calculated based on constant wind down range.

Maximum Wind Drift
- 2501.9 ft

Descent Time
- 85.3 s

MPH	Apogee	Descent Time	Wind Drift
0	4400 ft	85.3 s	0 ft
5	4400 ft	85.3 s	625.5 ft
10	4400 ft	85.3 s	1251. ft
15	4400 ft	85.3 s	1876.5 ft
20	4400 ft	85.3 s	2501.9 ft

Drift and Descent time

Kinetic Energy

Section	Mass	Descent Velocity with Lander	Descent Velocity	Kinetic Energy at Landing with Lander	Kinetic Energy
Nosecone	.2334 slugs	17.07 ft/s	14.81 ft/s	34.0 ft-lbf	25.6 ft-lbf
Nosecone + Lander	.5131 slugs	17.07 ft/s	N/A	74.8 ft-lbf	N/A
Lander	.2797 slugs	17.07 ft/s	N/A	40.8 ft-lbf	N/A
Midsection	.2281 slugs	17.07 ft/s	14.81 ft/s	33.2 ft-lbf	25.0 ft-lbf
Fin Can	.3885 slugs	17.07 ft/s	14.81 ft/s	56.6 ft-lbf	42.6 ft-lbf

Body Section Kinetic Energy at Landing

Considered the three scenarios

- Lander fully deploys
- Lander leaves payload bay but does not deploy
- Lander gets stuck in the payload bay

Worst Case Scenario

Lander does not leave the payload bay

- Mass: .5131
- Max kinetic energy:74.8 ft-lbf

Opening Shock

Making sure the recovery harness will withstand main deployment shock

- Full mass of launch vehicle
  - 194.29 lbf
- Kevlar Rated at 6600 lbf
- Factor of Safety: 34

Section	Mass	Opening Shock
Nose cone and Payload	.5131 slugs	88.243 lbf
Midsection and Fin can	.6166 slugs	146.181 lbf

Main Deployment Opening Shock

Leading Payload Designs

Baseline 1

Baseline 2

Image Processing

Baseline Solution 1: State-Space Tracking

- Method for location determination using flight data.
- Objectives:
  - Record visual, altitude, and IMU (Inertial Measurement Unit) data.
  - Perform image processing to extract information from images taken during flight.
  - Synthesize data using an EKF (Extended Kalman Filter) to track the launch vehicle's position and orientation from launch to landing.

Visual Measurement

- 2 externally mounted cameras
- Will be able to take images of the ground which can then be used to gain information of the vehicle's location and movement

Altitude Measurement

- Adafruit DPS310 will record pressure and temperature information which can then be used to find the density altitude of the vehicle.
- The launch / calibration altitude will be used as the reference for 0 elevation.

IMU / Inertial Measurement

- Yost 3-Space LX IMU will be used to record acceleration, angular velocity, and absolute orientation.
- These measurements will serve as the main data source for tracking the movement of the rocket.
  - Other, absolute, measurements are required, because the imprecision of higher order measurements will compound drastically over time.

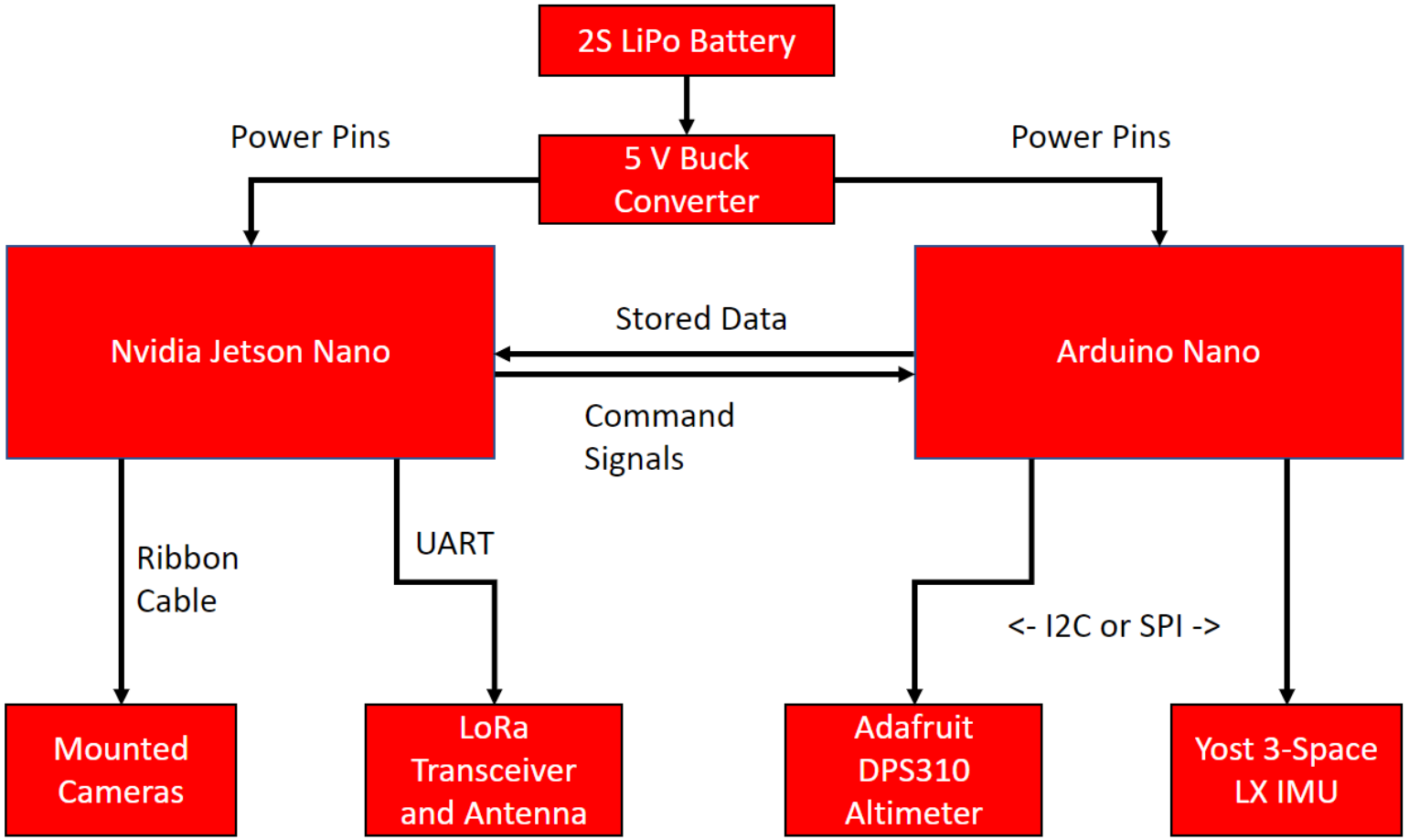
Data Fusion: Extended Kalman Filter

- The Extended Kalman Filter is a variation of the Kalman Filter for tracking the state space of a system.
- The method keeps track of the current estimate and uncertainty of the vehicle's inertial state space.
- With each update, the estimate is advanced using theoretical knowledge of the system and synthesized with new measurements.

Jetson Nano

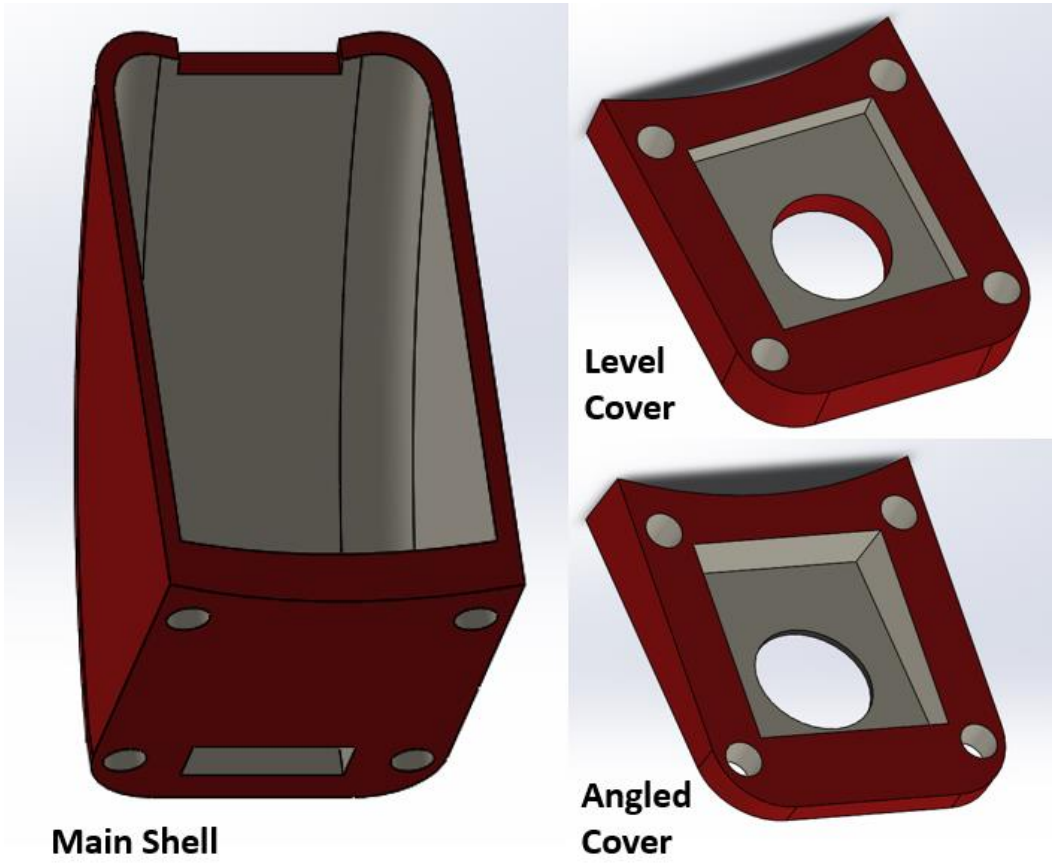
Arduino Nano

Electronics Onboard LPB



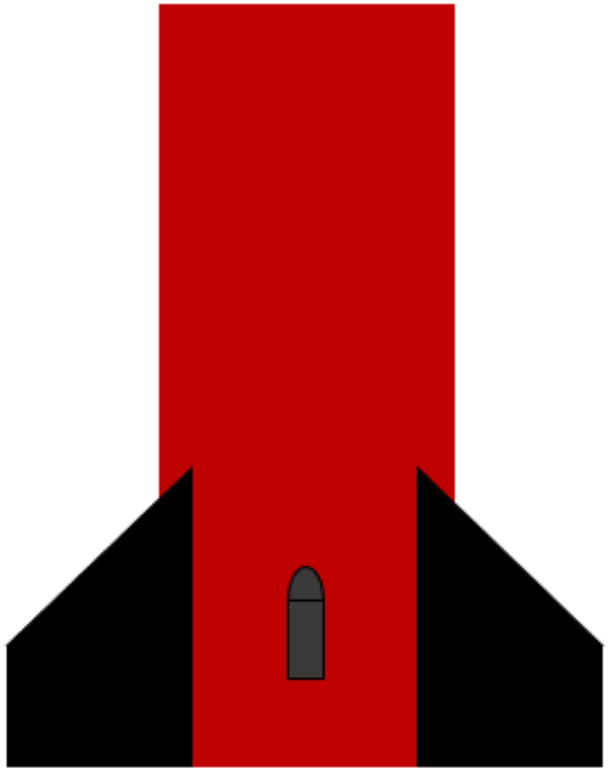
Camera Housings

- Secures and protects cameras during flight
- 3D printed for customizability
- Aerodynamic design
  - Gentle curved exterior
  - Composite coating for smoothness
- Modularity allows for different camera angles
- Cover allows for easy installation and removal of cameras



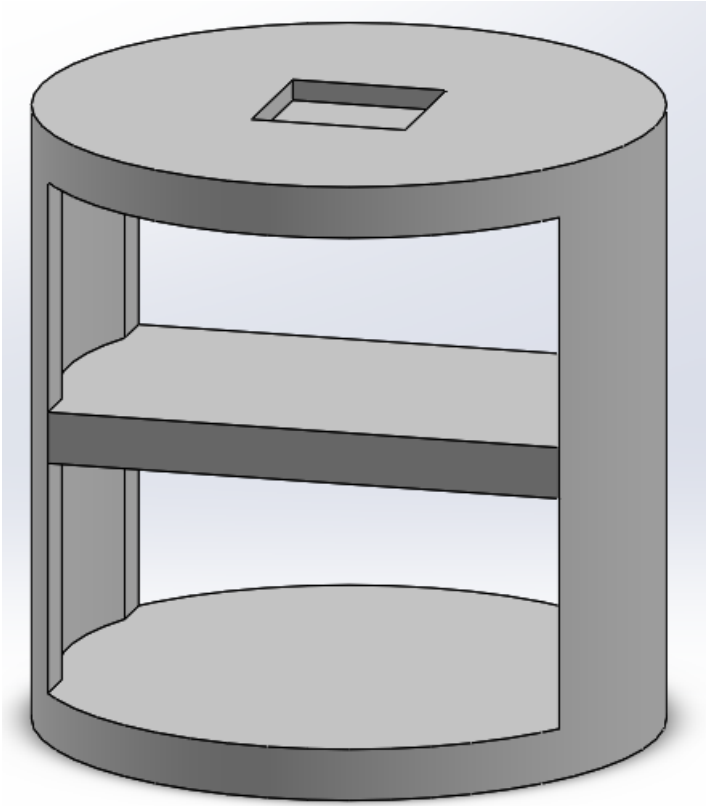
Camera Integration

- Cameras will be located between fins
  - Housings will be epoxied to the vehicle
  - Reduces disruption of airflow over fins
  - Relatively stable section of vehicle
- Ribbon cables will extend along the launch vehicle from housings to LPB
  - Protected by electrical tape
  - Enter LPB through circular entry port
  - May move into the launch vehicle (contingent on further testing)



Lower Payload Bay (LPB) Sled

- Confined to a 6-inch section of vehicle
- Must hold microcontrollers, battery, IMU, and altimeter
- Sled matches LPB compartment size
  - Maximizes space available on sled
  - Limits sled movement in the vehicle
- 3D printed for weight savings and design flexibility
- Horizontal platforms provide support to components

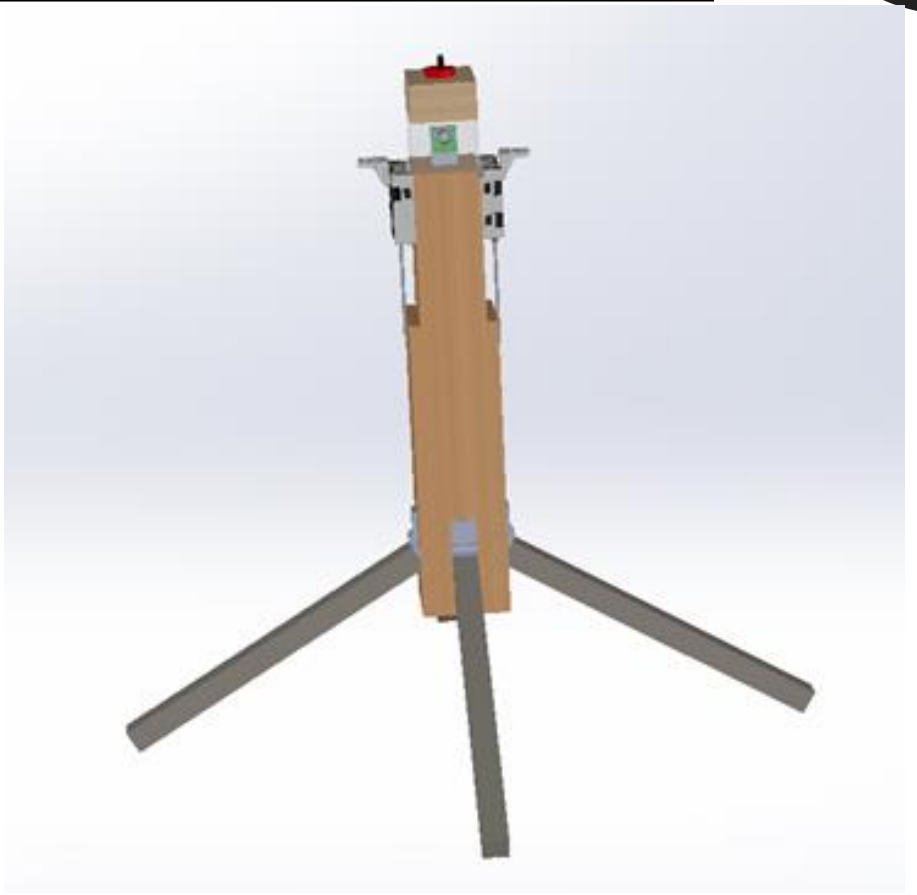


LPB Sled Integration

- LPB sled will match dimensions of the compartment it is confined to
  - Prevents axial and lateral sled motion
- LPB sled will be secured to adjacent bulkheads with hook-and-loop fasteners
  - Prevents rotational sled motion
  - Damps out vibrations from launch vehicle
- Sled can be further secured with bolts or shear pins if deemed necessary

Baseline Solution 2: Lander

- The chosen method for determining launch vehicle location post-flight
- Lander Objectives
  - Land upright and release parachute
  - Gimbal will correct camera orientation to make camera level with ground
  - Camera will take images in different directions
  - Image recognition and IMU data calculate launch vehicle location and transmit it back to launch vehicle



Lander in Deployed Position

Alternative Methods for Determining Position Post-Flight

Drone

- Would deploy once the launch vehicle is on the ground, fly up and take pictures
- Drone would need to fly independently and without GPS
- Drone would need a lot of electronics on it
- Drone would need to deploy properly

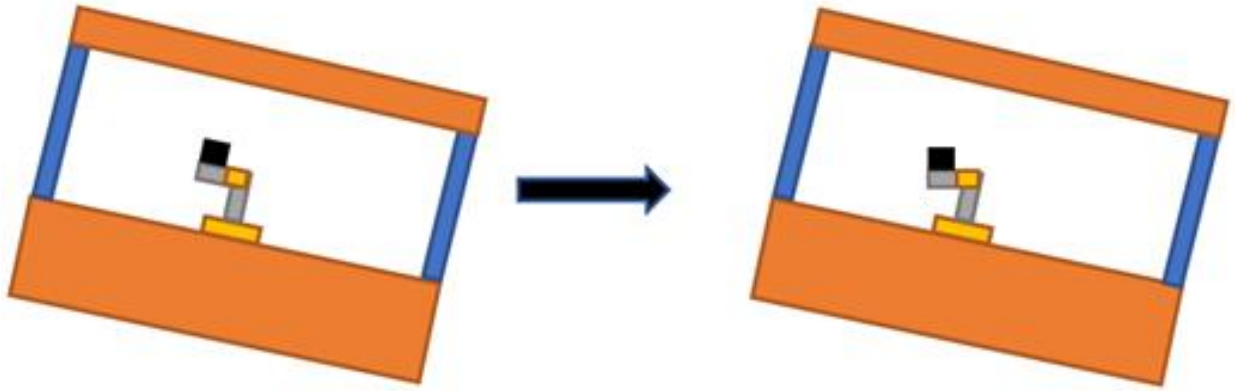
Camera Raised from Launch Vehicle

- A camera would be raised up from the launch vehicle to take pictures
- Concerns with having the 'Stick' setup get out of the rocket
- Would not need to jettison anything
- Difficult to get the camera high enough

Leading Gimbal Design

- A servo motor will rotate the hinge the camera and IMU are on
- The IMU will connect to a Jetson Nano, which will determine if it is level
- The Jetson will communicate the adjustments to the servo motor
- A second servo will rotate the entire camera/gimbal setup

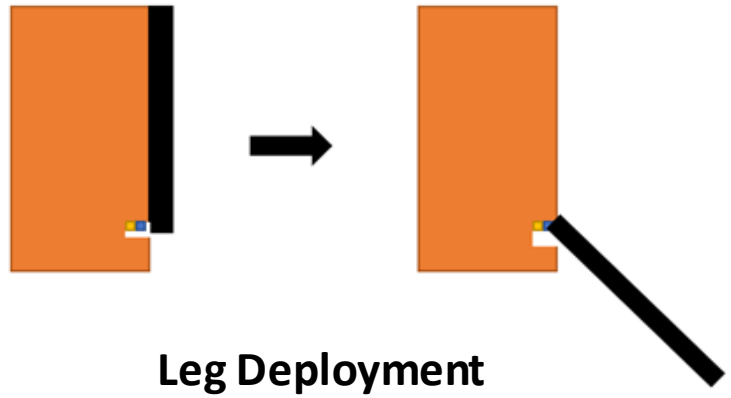
The black box represents the camera and IMU



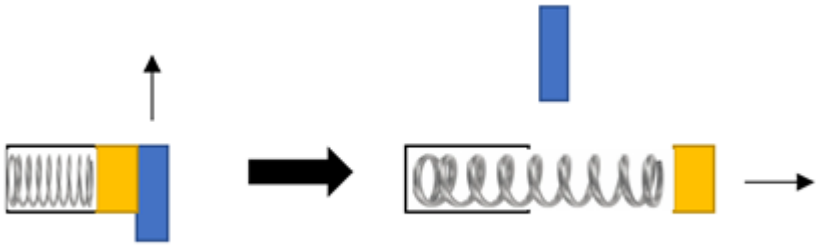
Gimbal Demonstration in Top of Lander

Leading Leg Locking Design

- The legs are spring-loaded so as soon as the lander leaves the launch vehicle the legs will deploy
- The bottoms of the legs will also have weight so gravity will assist in bringing the legs down
- The bottom of the legs will trigger the leg locking mechanism
- The leg will knock the pin out of place and the coiled spring will lock the legs into place
- Each leg will have their own system



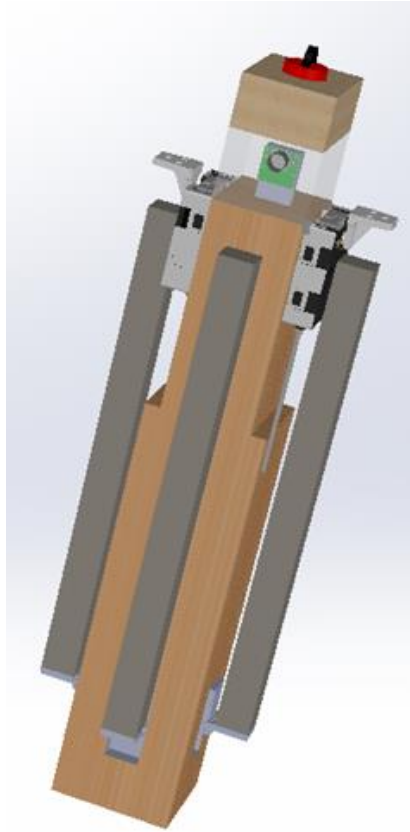
Leg Deployment



Leg Locking Demonstration

Lander Decisions

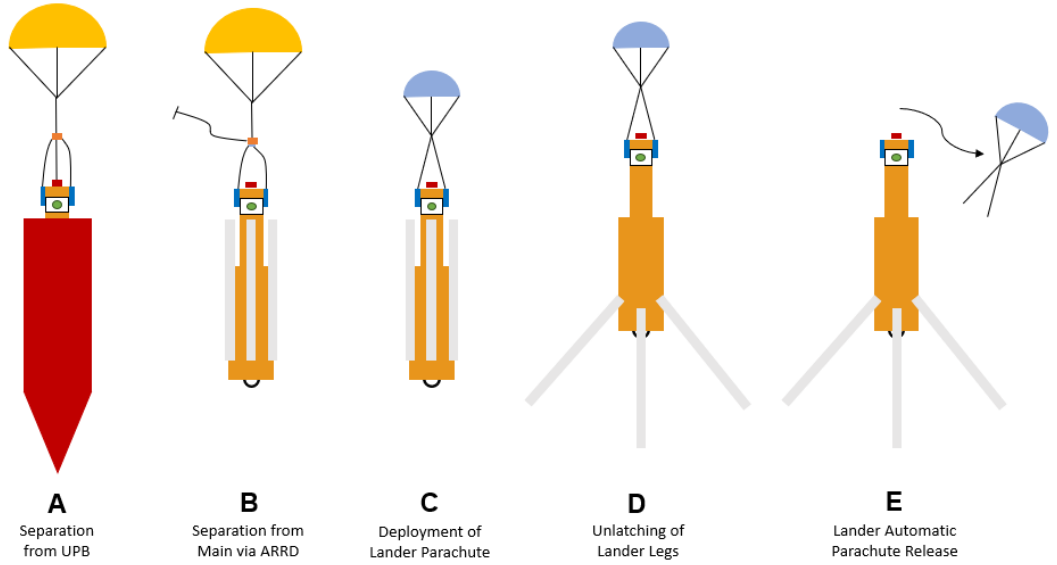
- Lander Body: Aircraft Grade Plywood
  - Lightweight, durable enough, easily altered
- Leg Material: Carbon Fiber
  - Strong, lightweight, already own
- Glass: Acrylic (Plexiglass)
  - Good visibility, less expensive than alternatives, durable



Lander in Stowed Posistion

Lander Retention and Deployment

- Axial motion restricted by electronic rotary latch
  - Releases lander at predetermined altitude during descent
- Lateral and rotational motion restricted with shear pins
  - Pins break as main parachute deploys and pulls lander from UPB
- Lander separation from main parachute with ARRD upon RSO approval



Upper Payload Bay (UPB) Electronics

- UPB electronics are used to facilitate lander retention and release
- Electronics mounted on uppermost bulkhead in the UPB
  - Bulkhead doubles as electronics sled
  - Removable for easy access to electronics
- UPB electronics and their functions
  - Altimeter detects release altitude
  - Microcontroller signals latch to open
  - Battery powers altimeter, latch, and microcontroller

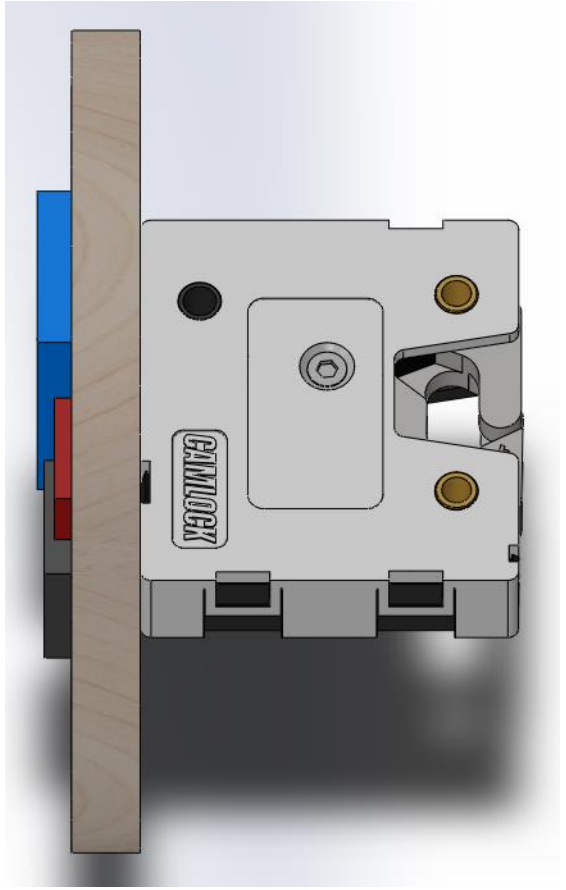
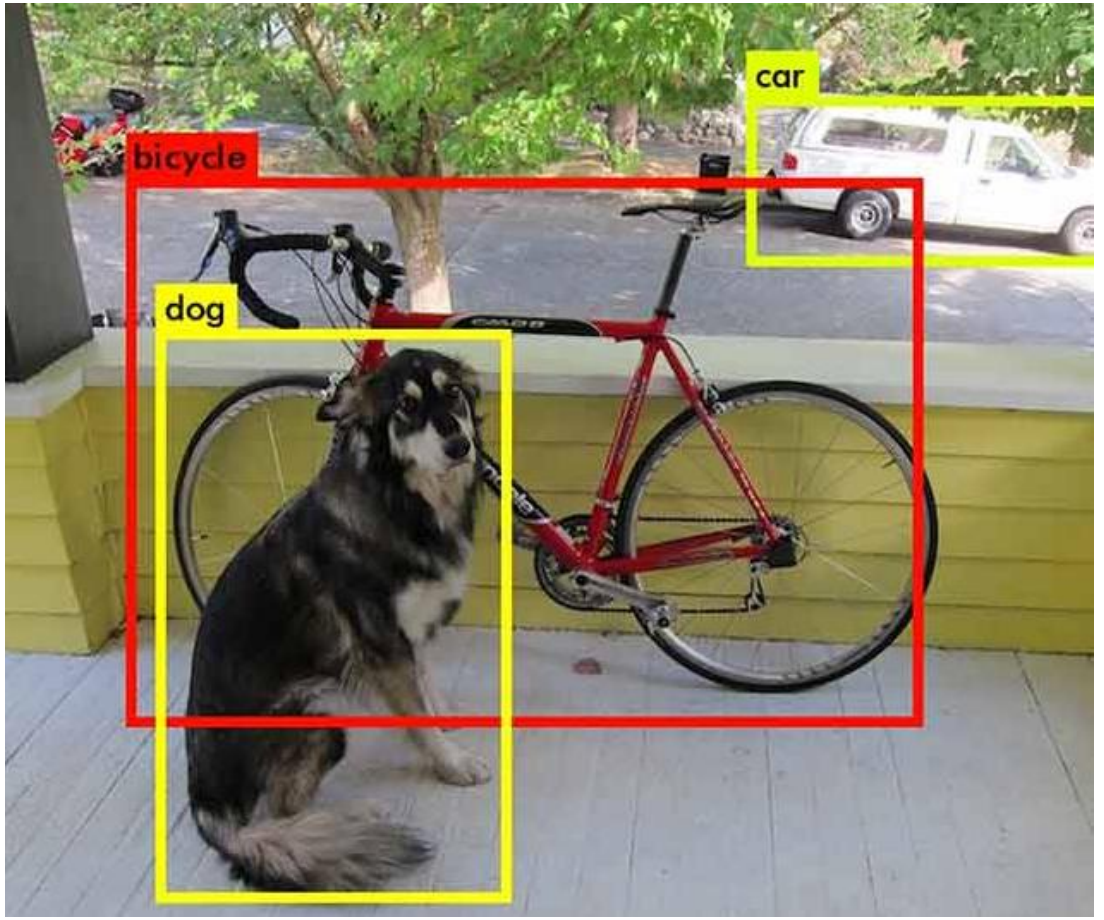


Image Processing

- Object Detection
- Color Detection
- Corner Detection
- Triangle Similarity

Object Detection

- Train CNN to recognize pre-determined landmarks on launch field
- Use a large data set of images with similar landmarks to pre-train
- Finalize training with images of our particular landmarks



Color Detection

- Keep or filter out specific color ranges
- Can be used to filter out noise and only keep the landmarks in an image
- May assist with object detection

Corner Detection

- Identifies the corners of objects in an image
- Can be used to assist in the triangle similarity calculations

Triangle Similarity

- Once the landmarks have been found, triangle similarity will be used to find the distance from the object to the camera
- Requires:
  - Known real world dimensions of the landmark
  - Dimensions of the object in image pixels
  - Focal length of the camera

Mission Performance Predictions

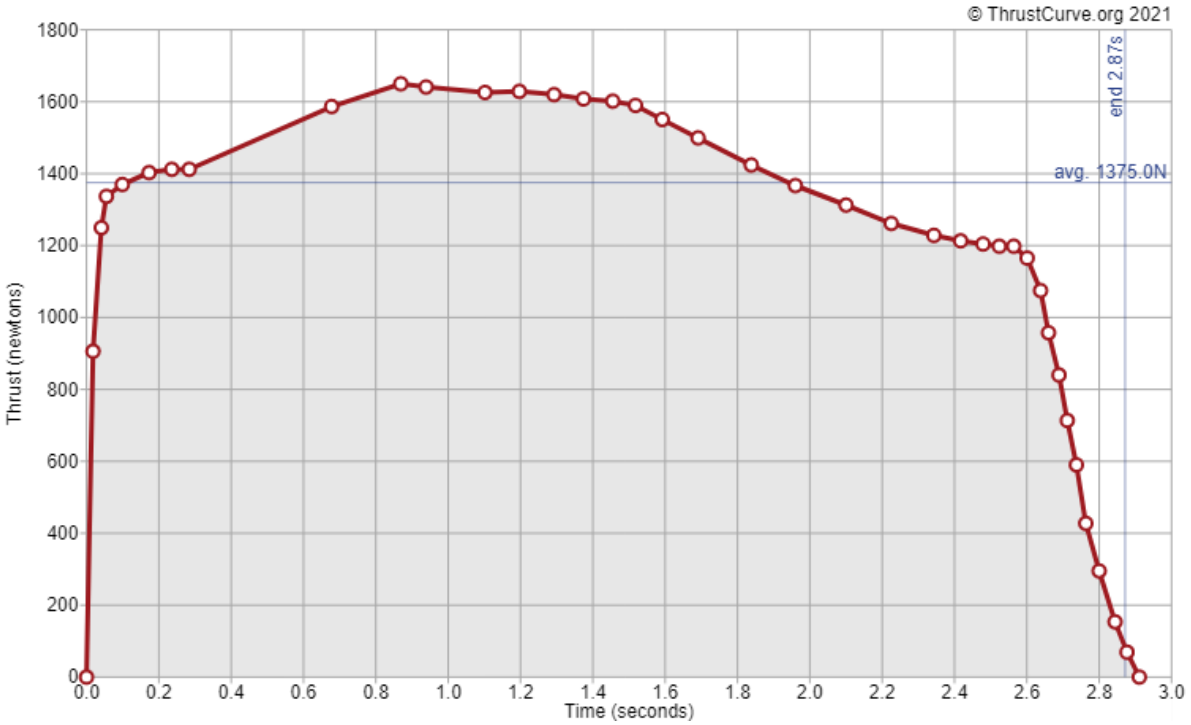
Motor Alternatives

Motor	Total Impulse (lbf-s)	Initial Thrust (N)	Max Thrust (lbf)	Burn Time (s)	Weight (oz)
L1390G	887.8	1416.5	370.8	2.6	136.8
L1520T	835.4	1545.4	396.9	2.4	128.8
L850W	819.7	1001	419.6	4.4	132

- Motors fit RMS-75/3840 motor casing
- Highest impulse most important
- Propellants were legal and had good reputations

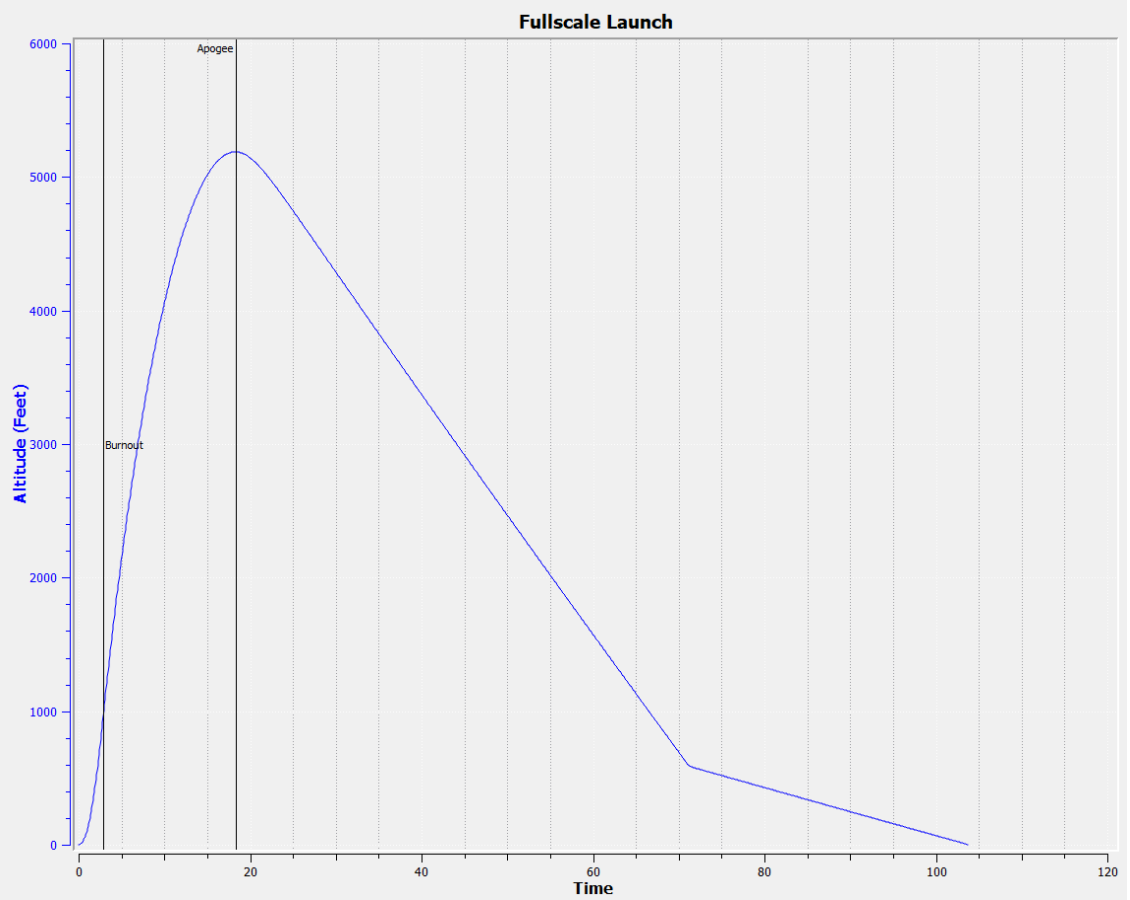
Motor Selection

- Aerotech L1390G
- High Impulse
  - 3949 Ns
- RMS 75/3840
- One of highest impulse for Motor casing



Apogee

- Predicted to be 4,400 feet
- Based on
  - Rocksim model (4,406 feet) with
    - 5-15 MPH winds
    - 5° cant
    - 144" launch rail
  - Hand Calculations (4,322 feet)
- Apogee reduces recovery problems



Rocksim Apogee Study

Year/Scale	Rocksim Apogee (ft)	Actual Apogee (ft)	Percent Error
2020 Fullscale	3500	3000	14.29%
2020 Subscale	2700	1650	38.89%
2019 Fullscale	4173	3373	19.17%
2019 Subscale	1366	1161	15.01%

- Consistent overpredicted apogees
- Data from previous semesters
- Between 15 – 19 percent error
- 2020 subscale ignored as outlier due to weathercocking
- Resulted in 15% error correction for Rocksim apogees

Lander Weight Apogee Study

- How lander weight effects apogee
- Weights between 6 and 11 lb acceptable
- Frames payload weight changes as it relates to apogee

Lander Weight (lb)	Predicted Apogee (ft)
6	4860
6.5	4786
7	4707
7.5	4632
8	4550
8.5	4474
9	4408
9.5	4339
10	4263
10.5	4194
11	4126

Fin Stability Margin Study

- Important stability changer
- Stability Margin adjustments without changing weight
- Small changes in Fin Span equate to large changes in stabiltiy margin

Fin Span (in)	Stability Margin (Calibers)
5.5	1.75
5.7	1.94
5.9	2.1
6.1	2.26
6.3	2.4
6.5	2.52

Requirements Compliance

Requirements Compliance Plan

- Each requirement has its own needs
- Requirements verified by analysis done by CDR
- Test plans supplied with CDR, verified by FRR
- Inspection/Demonstration requirements verified by FRR
- Most require full scale to be built and/or launched

Team Derived Requirements

- Developed for Vehicle, Payload, Recovery and Safety
- Designed to increase chance for success of the launch vehicle and payload and the increased safety of the project
- EX
- RD 4: Recovery section SHALL be able to still fulfil NASA requirement 3.3 in the scenario that the lander does not deploy from the launch vehicle.
- PF 9: The lander SHALL communicate numerical data to the LPB over a range of 800 feet.

Risk Assessment Matrix

- Supplementary hazard analysis
- 79 failure modes = red/orange
- 68 failure modes = yellow/green

		Likelihood of Occurrence			
		1 Very Unlikely	2 Unlikely	3 Likely	4 Very Likely
Level of Severity	A Low Risk	0.68% 1 item	1.38% 2 items	2.72% 4 items	2.04% 3 items
	B Medium Risk	4.08% 6 items	8.84% 13 items	6.80% 10 items	4.08% 6 items
	C High Risk	6.12% 9 items	9.52% 14 items	12.93% 19 items	6.12% 9 items
	D Severe Risk	4.08% 6 items	14.97% 22 items	13.61% 20 items	2.04% 3 items

Questions?