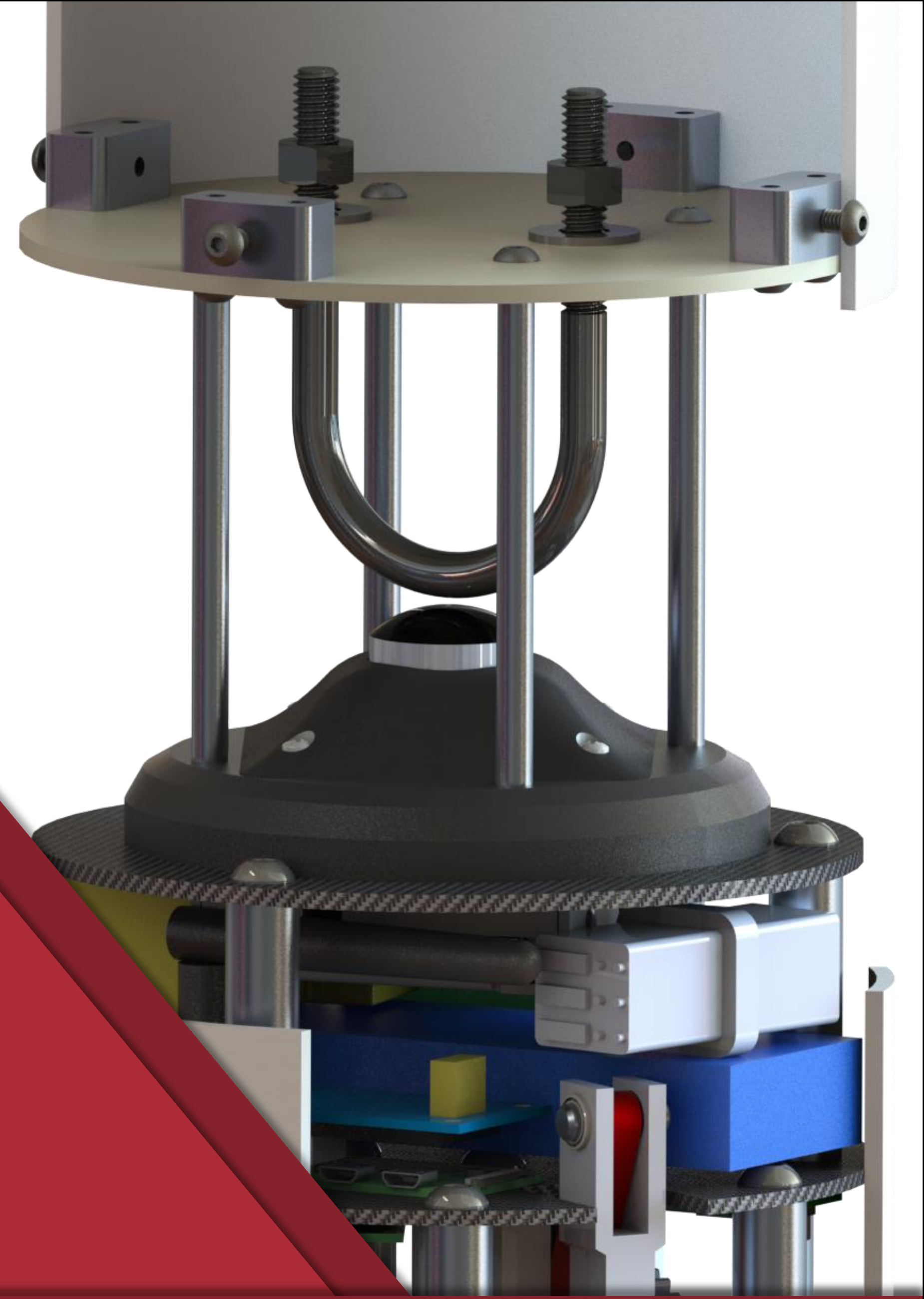
Critical Design Review

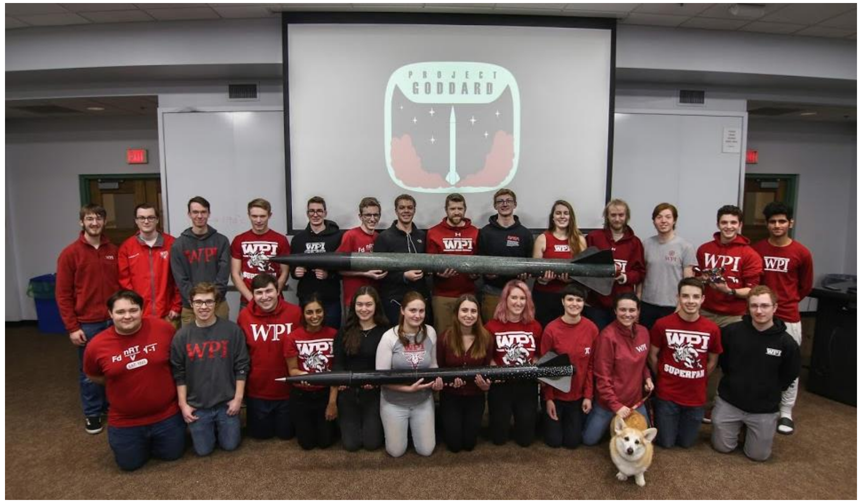
2/22/2021



The Team

WPI High Power Rocketry Club

- Who are we?
  - A team of over 40 passionate undergraduate engineering students devoted to the research and development of space launch vehicles, payloads, and exploration
- Our project this year?
  - Complete NASA University Student Launch Initiative (USLI) rocketry competition goals



Officer Board


Captain
Kirsten Bowers


Rocket Lead
Troy Otter


Payload Lead
Thierry de Crespigny


Treasurer
Kevin Schultz


Sponsorship
Julia Sheats


Safety
Michael Beskid


Public Relations
Chris Davenport


Documentation
Max Schrader

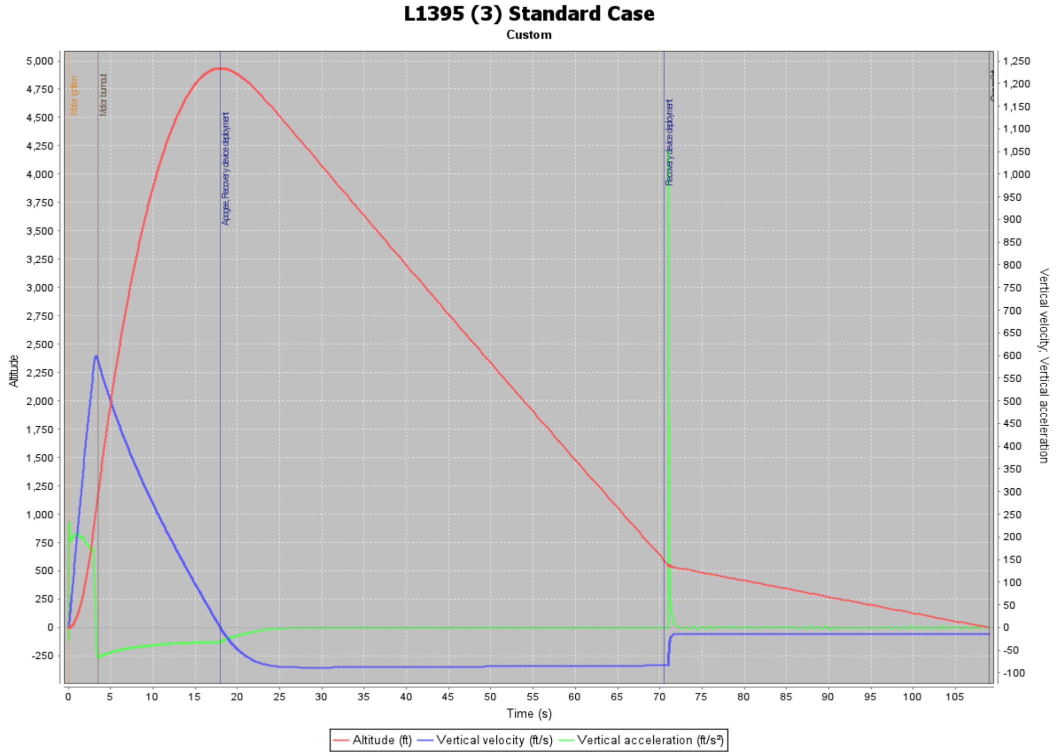

Engagement
Connor Walsh


Logistics
Nikita Jagdish

Mission Performance Predictions

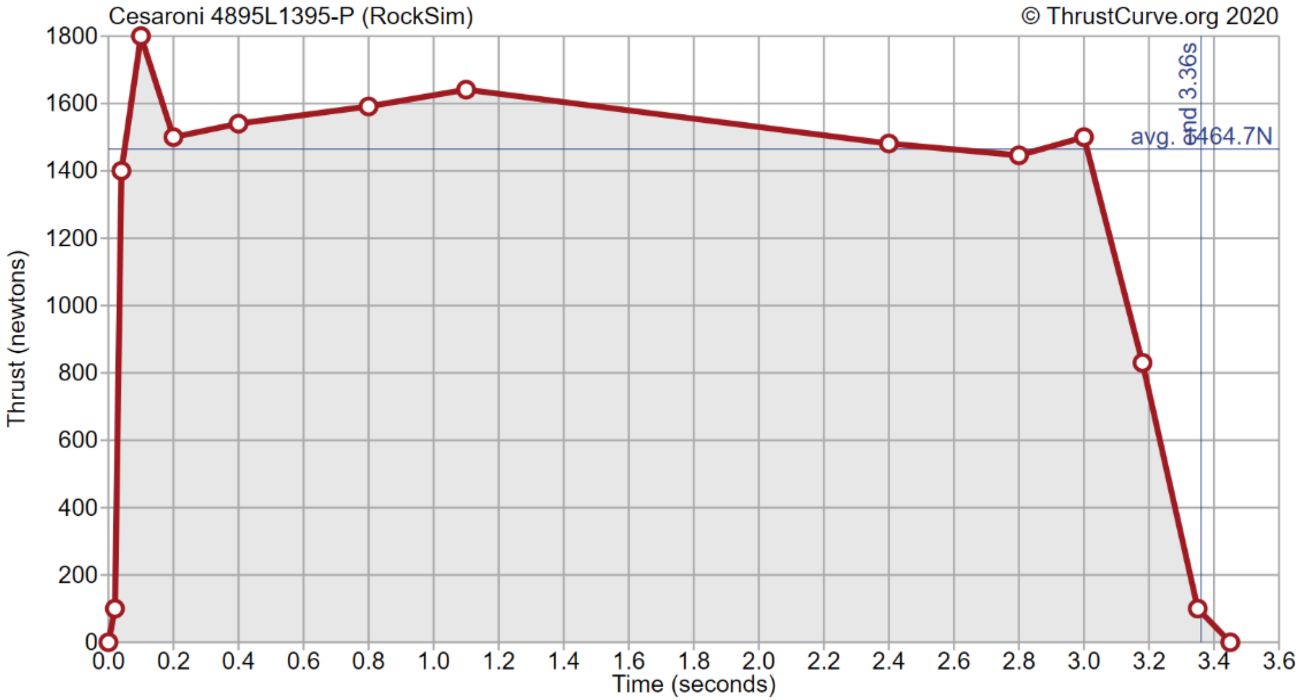
Mission Performance Predictions

- Target apogee set to 4550 ft
  - Active airbrakes will reduce unguided apogee of 4934 ft
- Vehicle will descend in 91.2 seconds
  - Maximum landing KE is 52.27 ft*lbf
  - Payload descent time: 90.8 sec
- Vehicle will drift 2675.2 ft at 20 mph winds



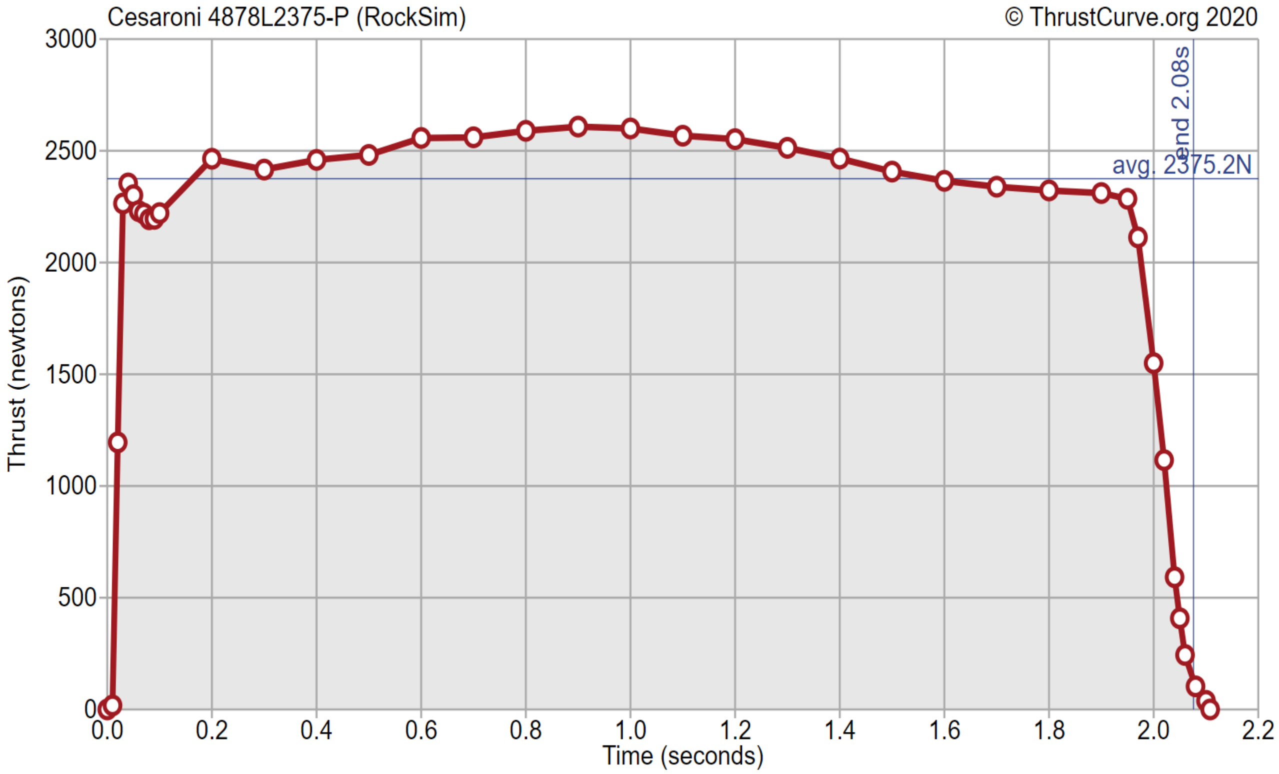
Primary Motor

- Motor: L1395
- Manufacturer: CTI
- Class: 91% L
- Avg. Thrust: 1418.86 N
- Thrust Duration: 3.45 s
- Total Impulse: 4895.40 Ns
- Weight: 4323 g

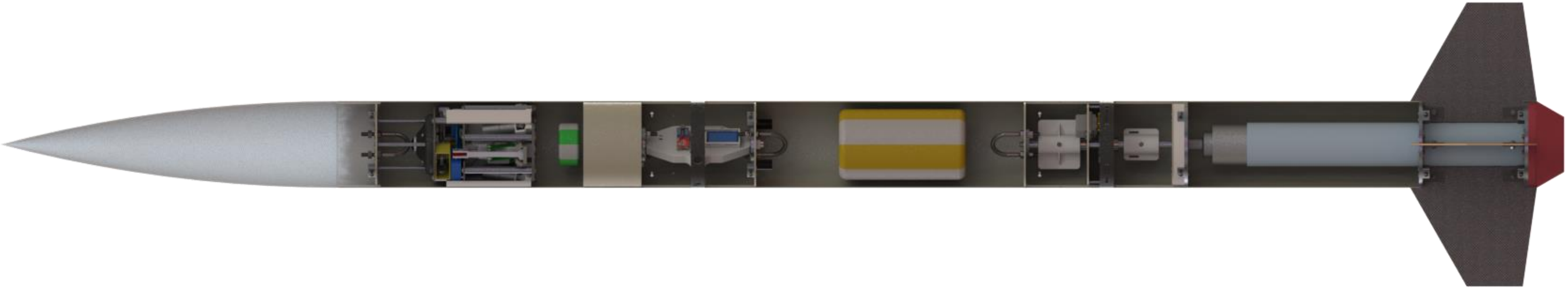


Secondary Motor

- Motor: L2375
- Manufacturer: CTI
- Class: 92% L
- Avg. Thrust: 2324.7 N
- Thrust Duration: 2.11 s
- Total Impulse: 4905.2 Ns
- Weight: 4161 g



Launch Vehicle Overview



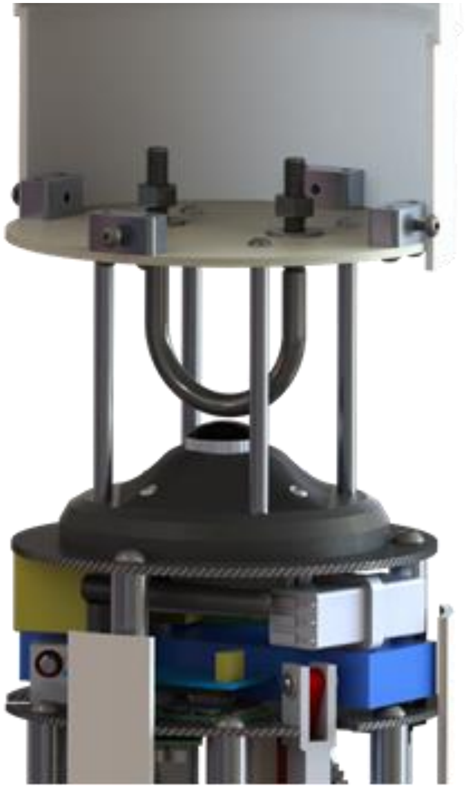
- Length: 111 in
- Diameter: 6.17 in
- Cg: 66.435 in
- Cp: 86.307 in

- Stability Margin: 3.22 cal
- Vehicle Wet Mass: 48.75 lb
- Rail Exit Velocity: 64.5 ft/s
- TWR: 7.12

Aerostructures

Nose Cone

- No changes to nosecone design
  - 24-in, 4:1 ogive
  - Filament-wound fiberglass
- Bulkhead attached with radial brackets
  - Mounts shock cord with U-bolt
  - Four pins to help secure payload during flight



Airframe

- Will be made of G12 Filament Wound Fiberglass
  - Purchased from Madcow Rocketry
  - Provides considerable strength and is lightweight.
  - Also, it is radio transparent and high heat resistance.
- Divided into upper, middle, and lower airframe.
  - Lengths: upper is 24 in, middle is 28 in, and lower is 30 in
  - Lower airframe length was changed from 29.95 in to 30

Airframe Verification

- Last year, NC State University tested the same airframe we will be using for bolt shearing.
  - Results were published in their 2020 Flight Readiness Review.
- Found that 4 #6 bolts held approximately 1500lb before failure.
- Proves that our airframes will not fail due to bolt shearing, as the maximum applied load is 400 lbf at the thrust plate.

Fins

- Trapezoidal shaped
  - Root chord of 10 in, tip chord of 3.5 in, sweep length of 4.5 in, and a height of 7 in.
  - Trapezoidal shaped will be easy to manufacture and provide favorable aerodynamic properties.
- Material consists of birch plywood core, and carbon fiber overlay on the exterior.
  - Materials were chosen for their ideal stiffness to weight ratio.
- Secured to the fin can using two bolts through the fin brackets.

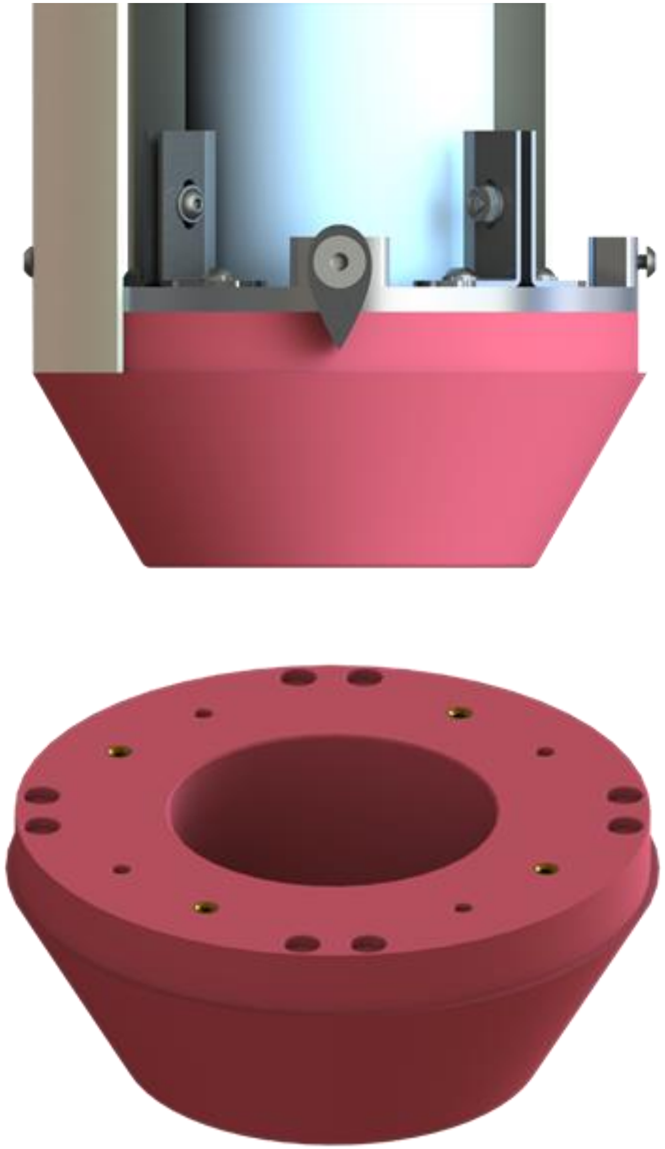
Fin Verification

- Used the equation shown to calculate the flutter velocity of our fins.
- Calculated flutter velocity is 1027.6 ft/s.
- The maximum velocity our vehicle achieves is 618 ft/s.
- Therefore, the fins will not flutter as the safety factor is 1.66.

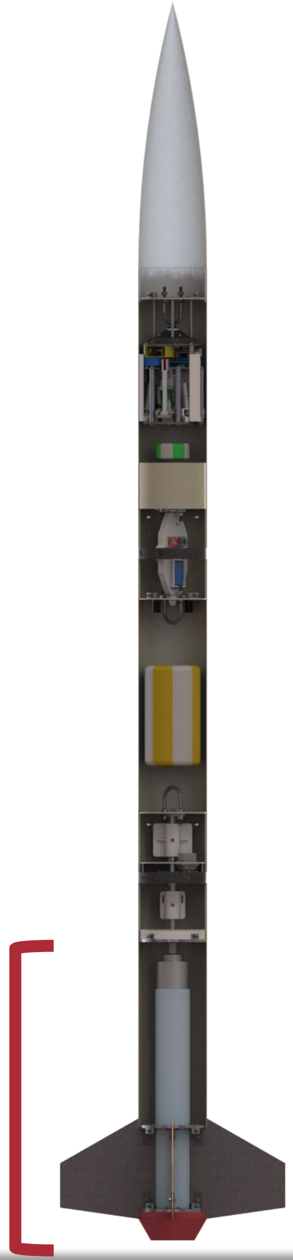
$$V_f = a\sqrt{\frac{G}{\frac{1.337AR^3P(\lambda+1)}{2\left(AR+2\right)\left(\frac{t}{c}\right)^3}}}$$

Tail Cone

- Changed material to Polyethylene terephthalate (PETG) filament
  - Fulfills the same strength requirements as Nylon X
  - Cheaper cost
- Attached using threaded inserts through the fin ring
  - The tail cone will fit flat on the fin ring
  - 11/32-inch holes on the top provide clearance for other screws

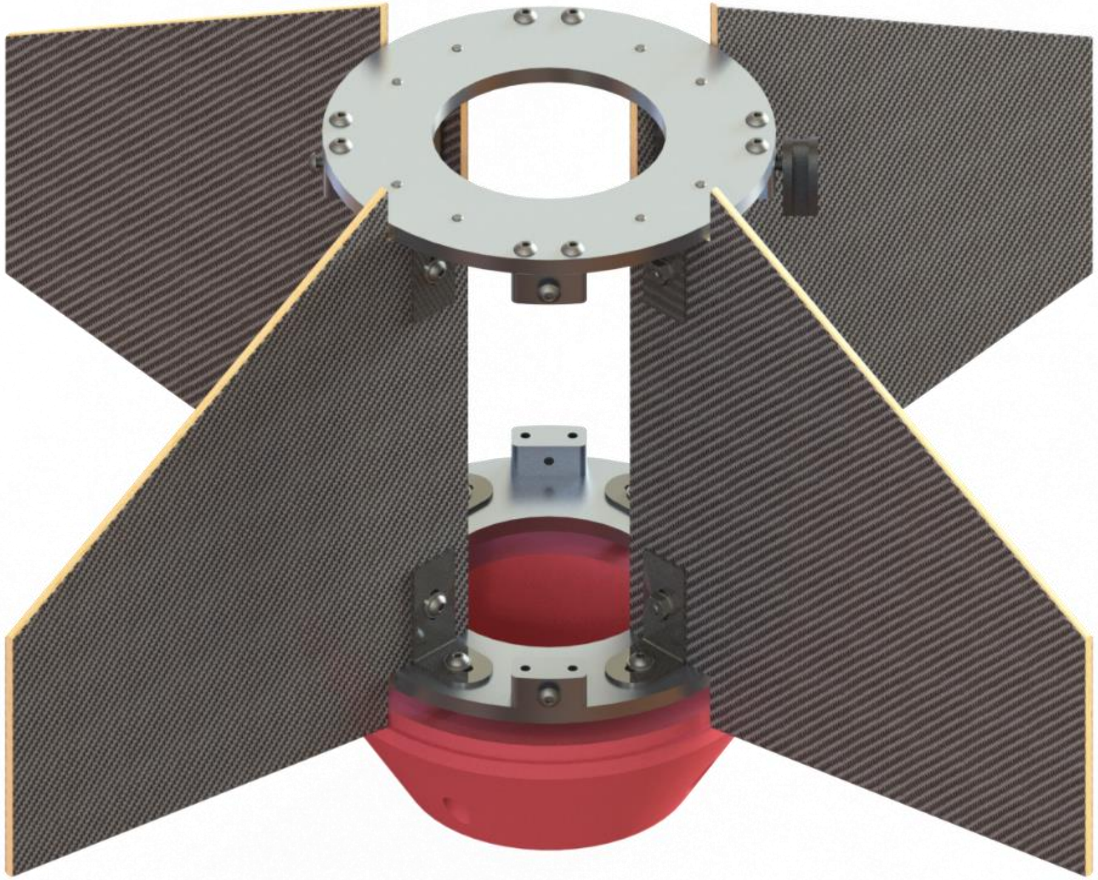


Propulsion



Fin Can

- Lightweight, modular, manufacturable
- Two 6061-T6 aluminum rings center the motor
- Right-angle brackets secure fins to rings
- Radial brackets secure rings to airframe

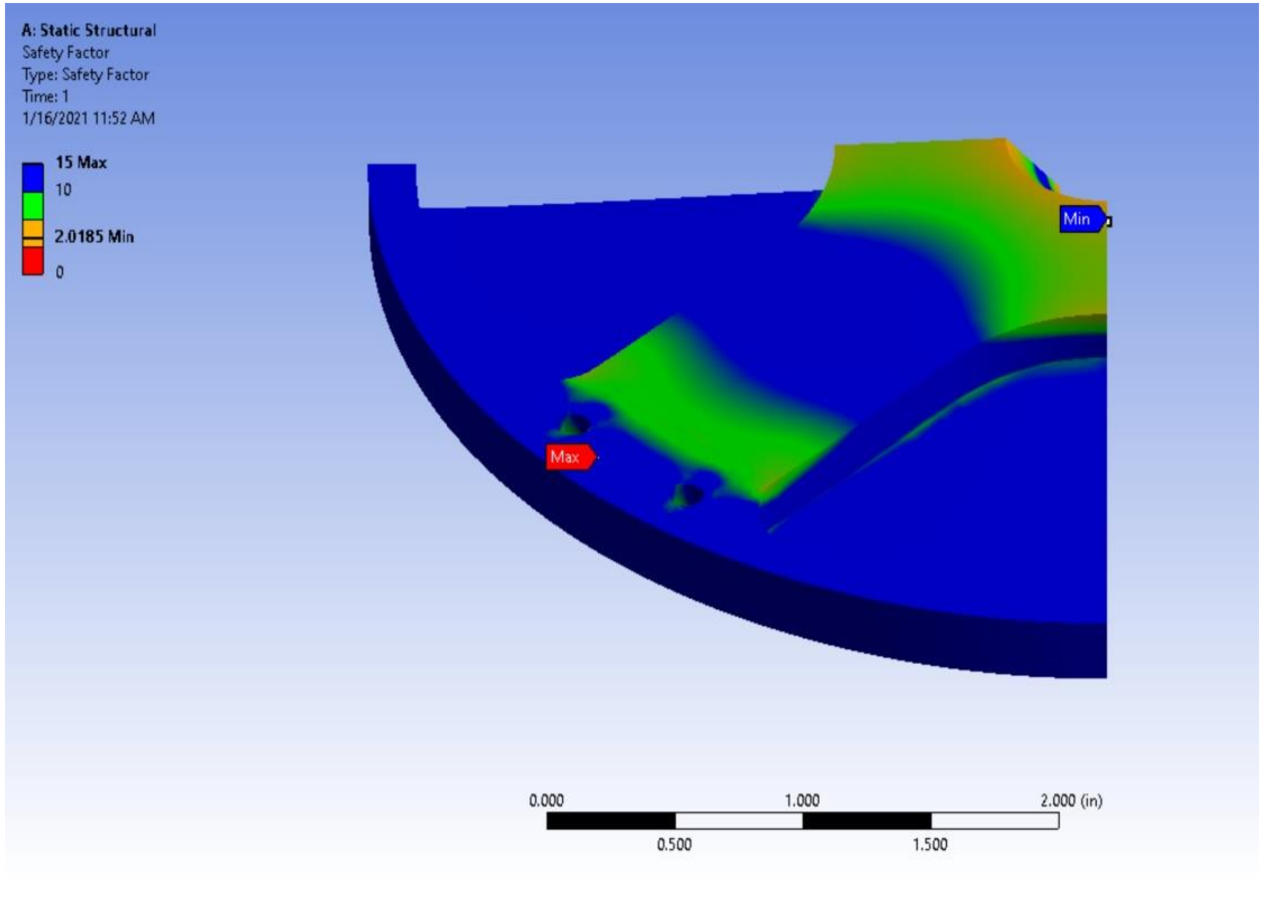


Motor Retention

- Consists of thrust plate, radial brackets, motor tube and casing
- Lightweight and modular design for easy manufacturing
- Centers the motor and keeps it from moving out of place
- Thrust plate transfers thrust to the airframe while securing the motor in place

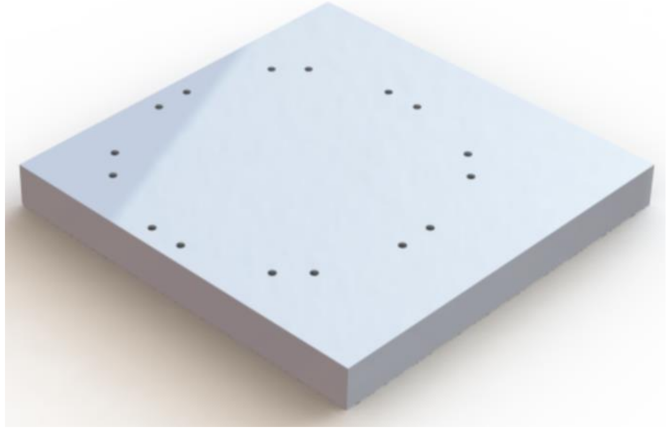
Thrust Plate Verification

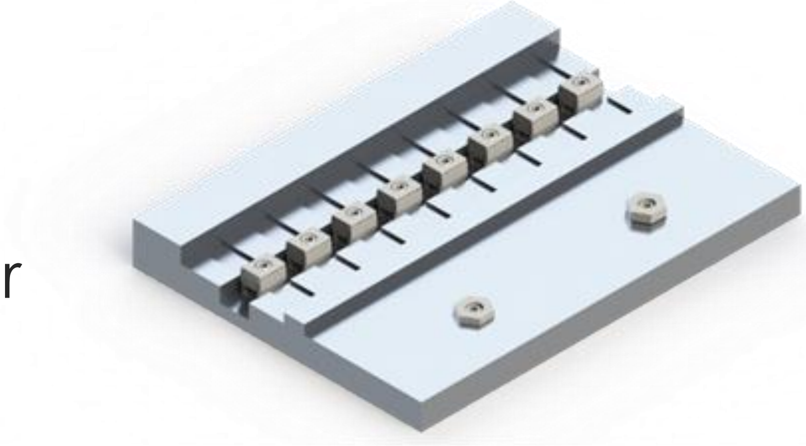
- Minimum Safety Factor of 2.02 where the plate bolts onto the motor casing
- Safety Factor above 3 everywhere else
- Max deformation of .0085 inches
- Equivalent Stress converges to approximately 19,817 psi



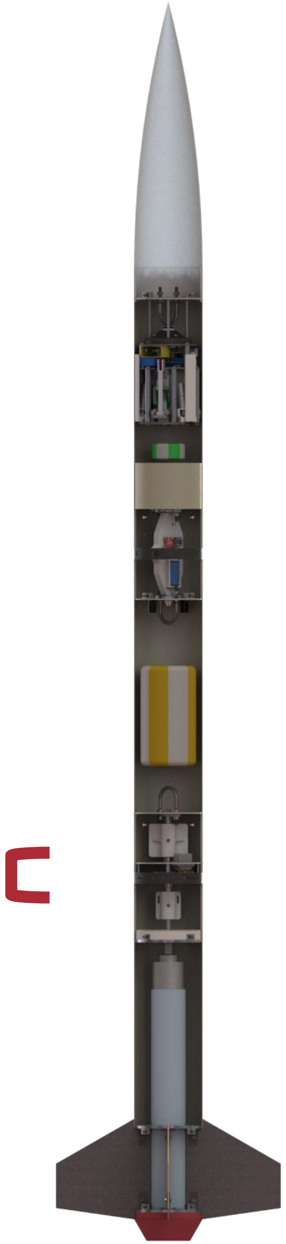
Manufacturing

- **Thrust plate** will be machined using the fixture shown, clamped to the fixture, drilled, secured using eight screws, and contoured
- **Centering rings** will be water jet cut, if a water jet cannot be accessed then they will be machined using the same fixture as the thrust plate
- **Radial brackets** will be milled in 3 step pallet system and fixtures by fixture clamps and dual fixture clamps
- **Right angle brackets** will be made with a water jet cut, and a bending break to create the 90-degree angle bend in the steel plate

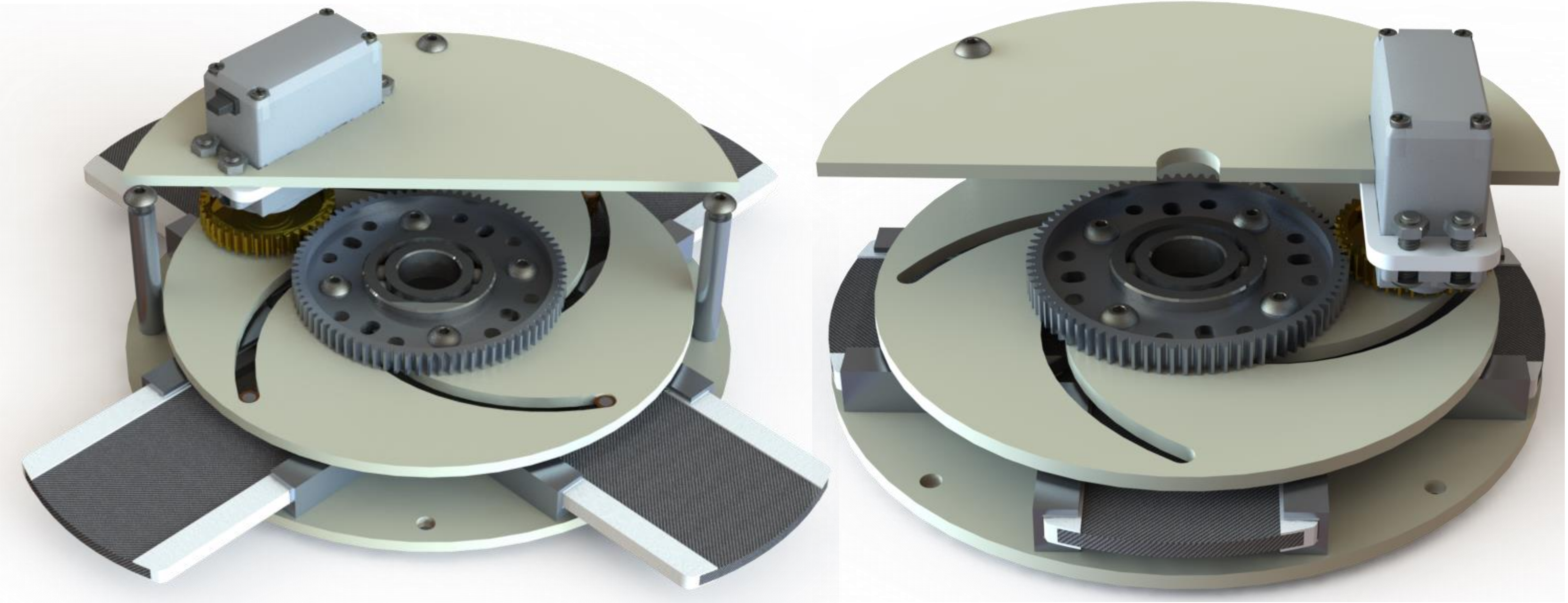




Mechanical Systems

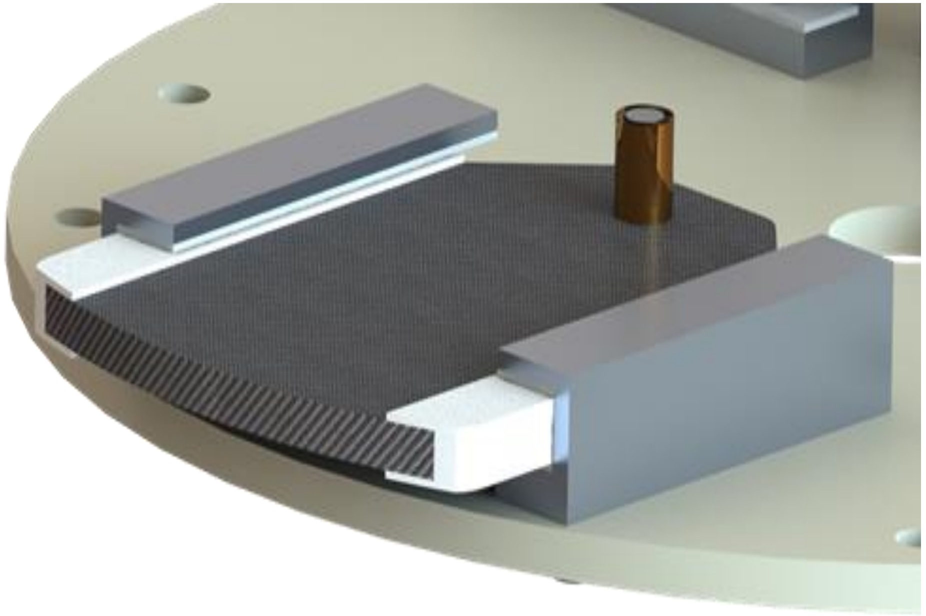


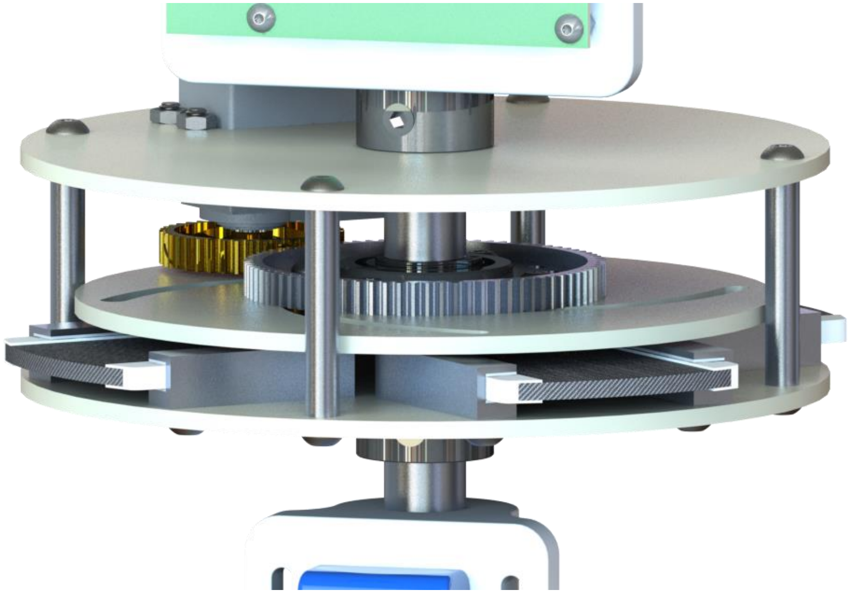
Airbrake System



Structural Design

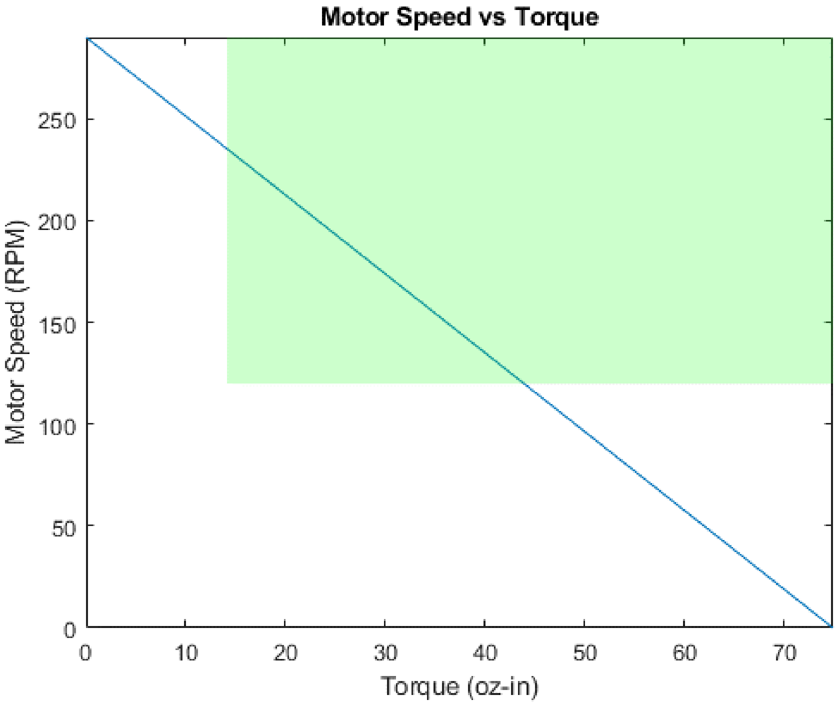
- **Structural plates** consist of a guide, actuator, and servo plate all made from a 1/8in G10 fiberglass plate. The plates will be cut to size via a waterjet.
- **Fin rails** made from U-shaped channels of 6061-T6 aluminum alloy, with top and bottom surfaces both covered by adhesive backed PTFE film.
- **Spine connection** will be made using two spine collars and two snap rings.





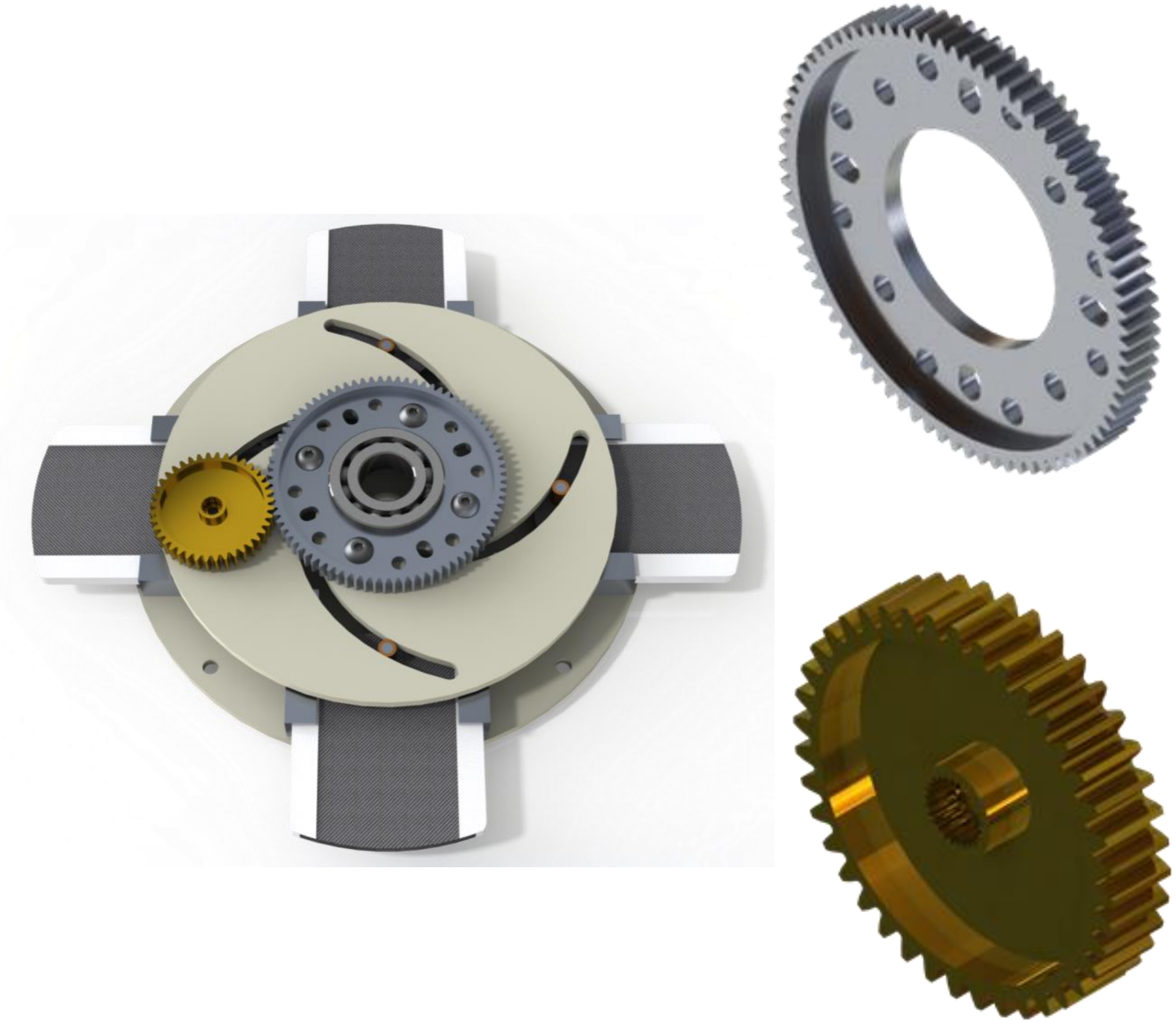
Servo Selection

- Goal: Full actuation in under .25 seconds (instant acceleration)
- Knowing the required torque output(14.18 oz-in) and rotational speed defines an operating region
- Out of goBILDA's standard servo line, the Super speed servo enables the fastest deployment speed within the servo requirements
- Using the super speed servo allows for a minimum deployment time of .153 seconds under a worst-case scenario



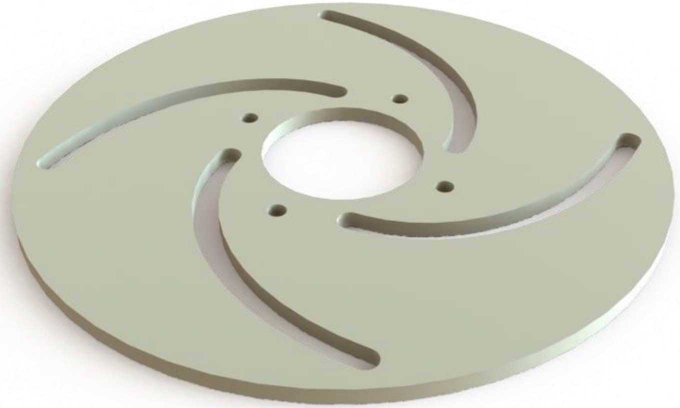
Gear System

- The goal of the gearing system is to transfer rotational power from the servo to the actuator plate using two spur gears
- The gearing ratio of 2:1 was chosen by analysis of the servo's performance curve
- The trade-off between servo speed and torque dictates the gearing ratio
- Interfacing with the actuation system via the driving gear

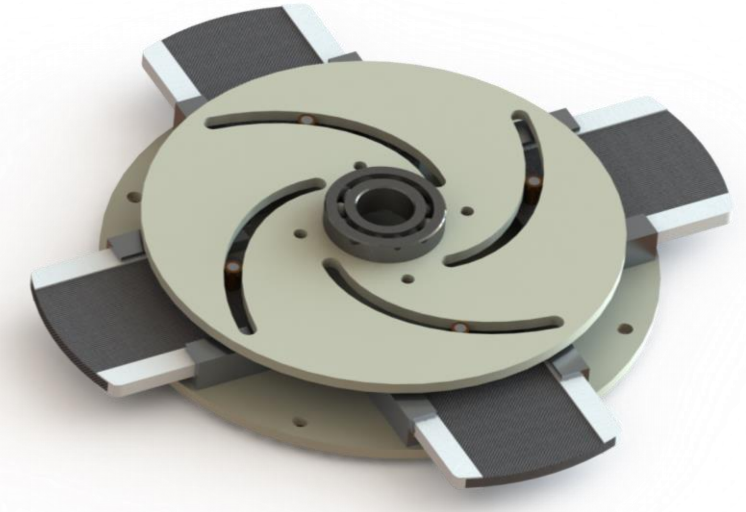


Actuation System

- The goal of the actuation system is to resolve rotational motion of the actuator plate to linear motion of the airbrake fins
- Actuator plate connected to fins by equiangular slots in which the fin pins are placed
- Allows for constant torque produced by servo to be translated linearly to each fin at all possible extensions
- Using the geometry of the slots, the required torque the servo must produce to deploy the airbrakes can be calculated



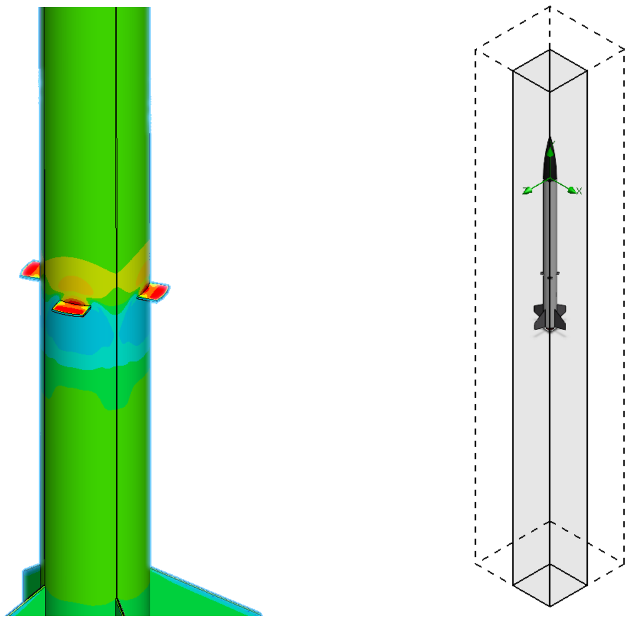
Actuator Plate

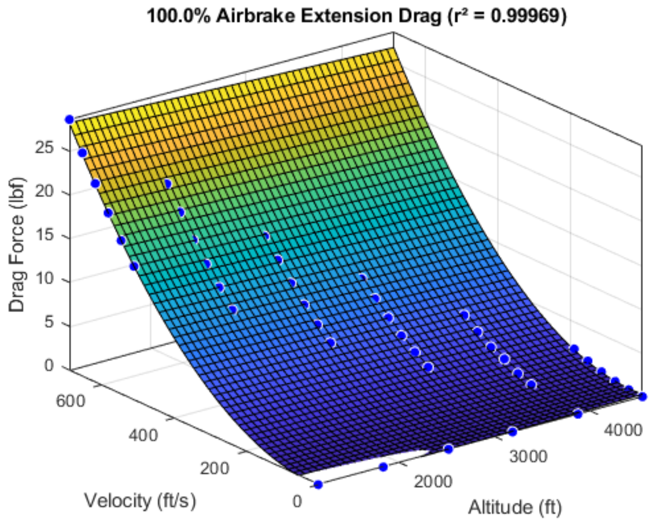


Actuation System

Aerodynamic Analysis

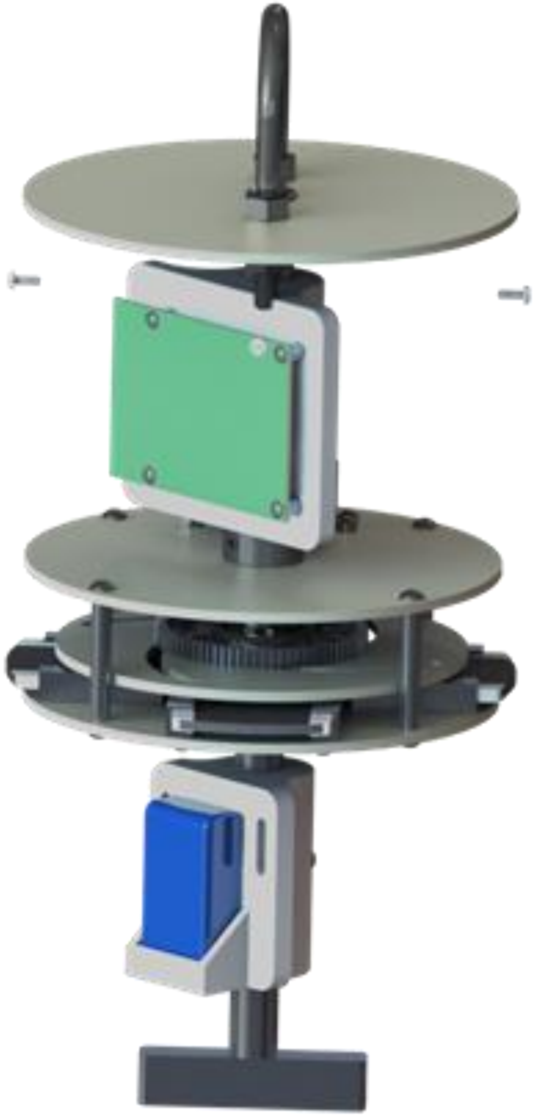
- CFD simulations were run at to estimate the drag of the airbrakes
- Results were analyzed to generate equations for drag as a function of altitude, velocity, and extension
- Functions are used to bound max drag for simulation and to determine fin extension during flight





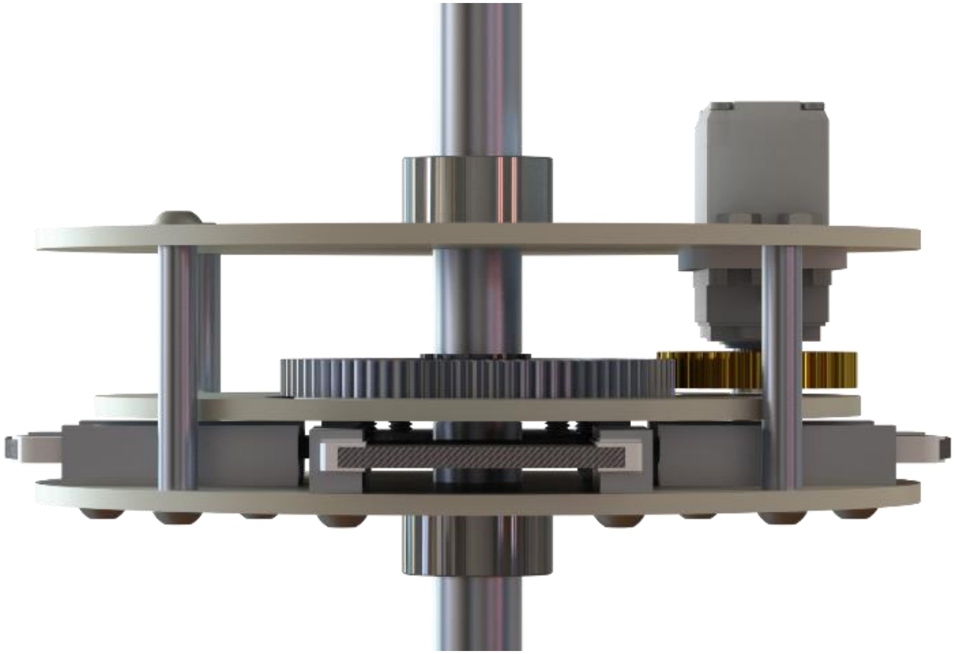
Avionics Bay

- A cylindrical spine made of 6061-T6 aluminum provides structure and mounting surfaces for airbrake and avionics systems.
- At the top of the spine a 5/16 U-Bolt is connected to an adapter plate made of ¼ inch thick 6061-T6 aluminum.
- Located at the bottom of the spine is an aluminum cross bar allowing for a twist lock mechanism for access to electronics.



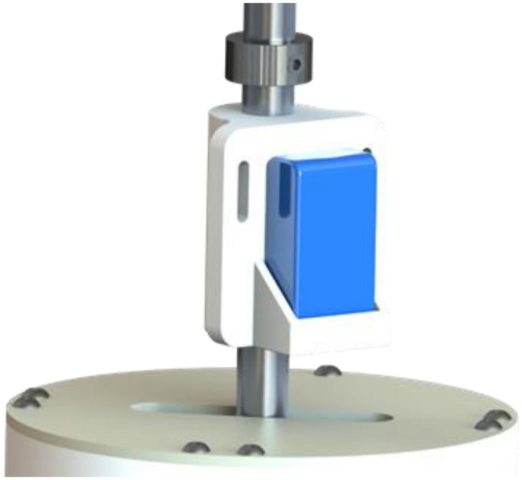
Airbrake Retention

- The airbrake system is held in place using snap rings and shaft collars made of plain carbon steel.
- The snap rings retain the actuator plate, by holding the bearing in place on the spine.
- Two shaft collars hold the guide plate and motor retention plate in place.

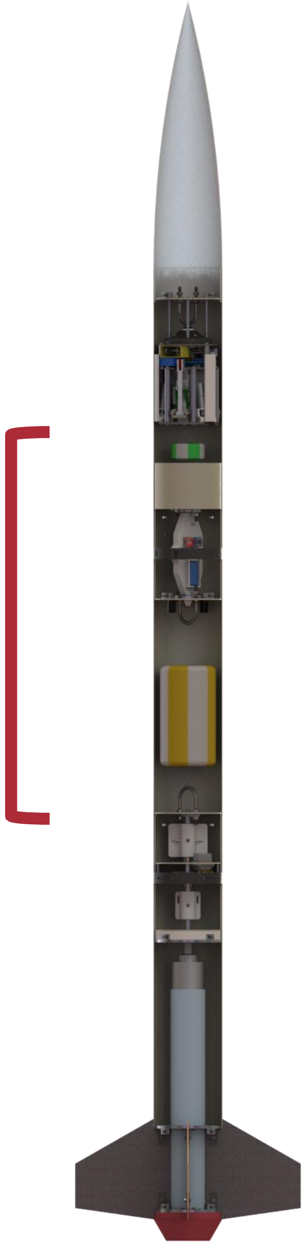


Avionics Retention

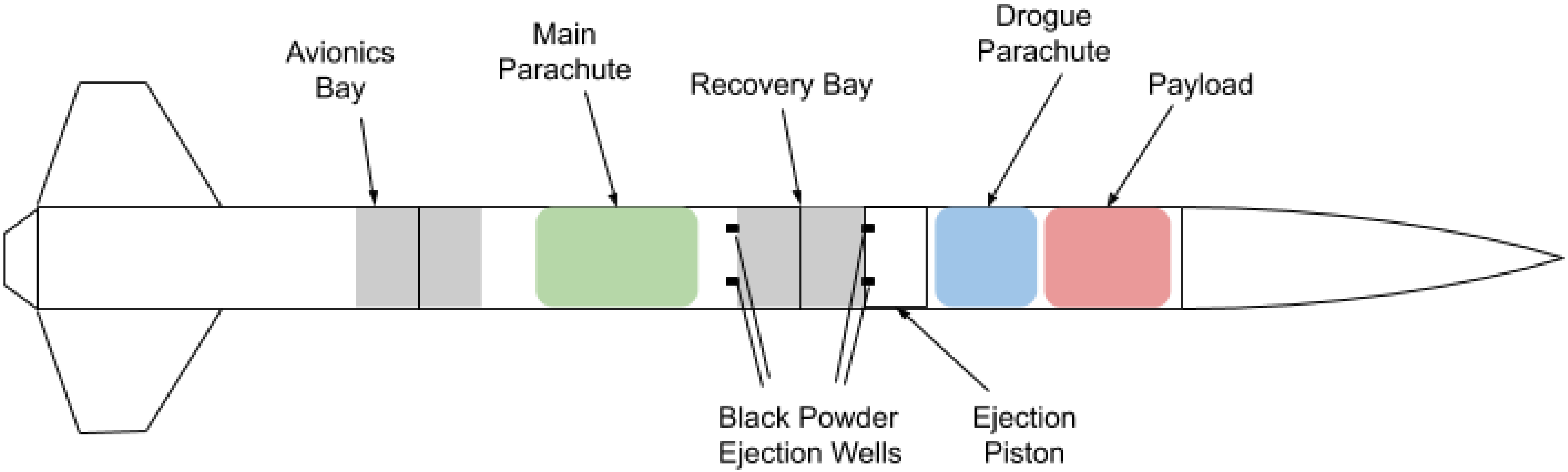
- The avionics components will be attached to the spine using a custom PLA 3D printed sled above the airbrake system.
- The sled will fit around the spine with a set screw to hold it in place.
- 4 threaded inserts will mount standoffs will allow clearance for any electrical components.
- Battery will mount on sled below airbrake system, secured with Velcro strap



Recovery System



Recovery Configuration



Recovery Bay

- Located in the coupler between middle and upper airframes
- Holds primary & backup electronics
- Switch band for external access
- Electronics sled can be removed
- Attachment hardware for parachutes

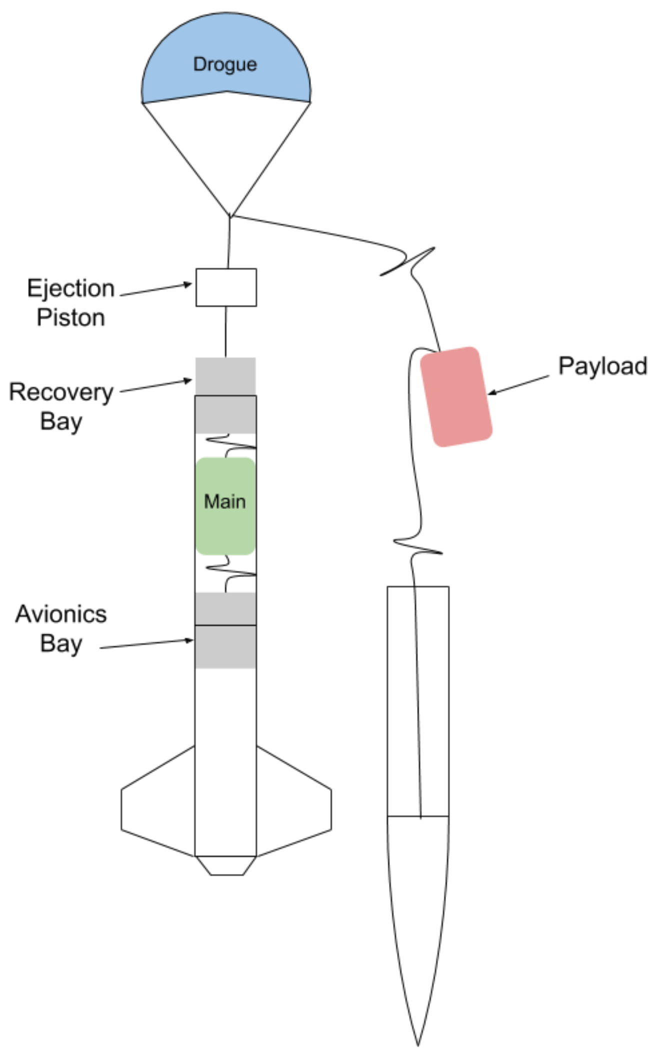
Recovery Bay

- 1/8" fiberglass bulkheads
- ¼" aluminum adapter plates
- ½" aluminum central hex spine
- Opening shock goes through adapter, U-bolt, and spine
- Bulkheads and adapters can be easily removed to access electronics

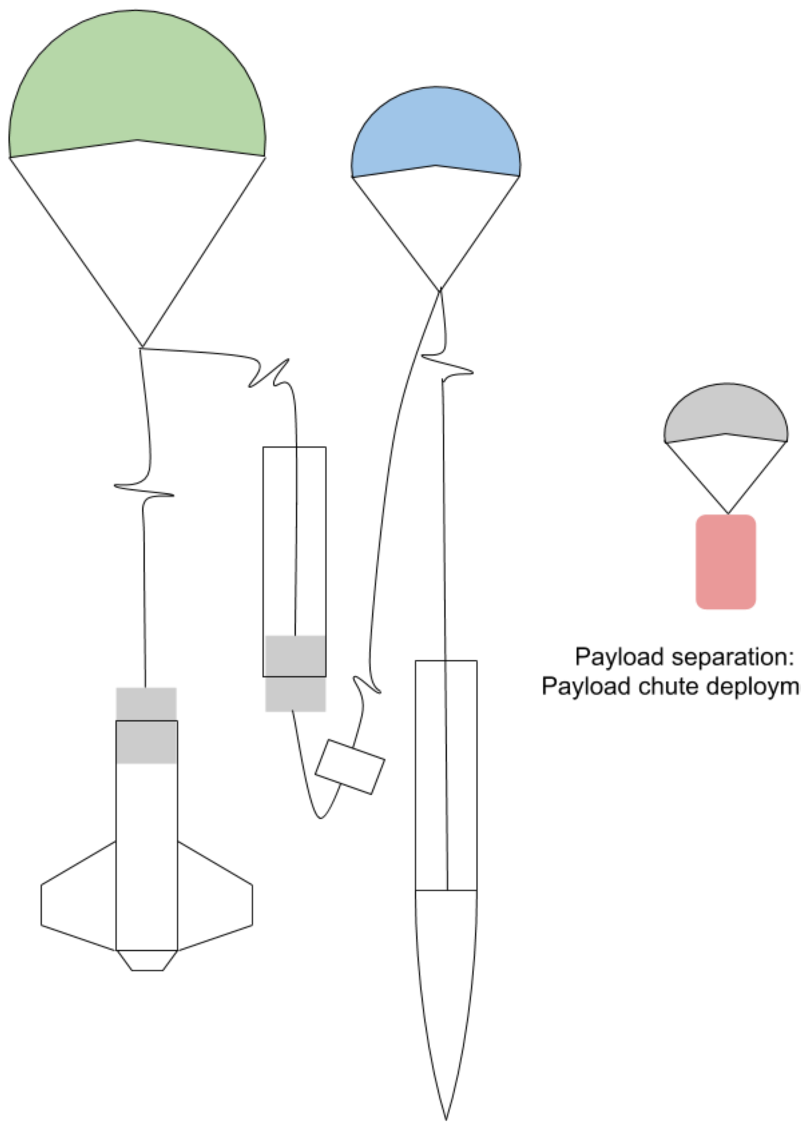
Deployment Stages

- Apogee
  - Drogue deployment
  - Split between the recovery bay and upper airframe
  - Ejection piston to protect drogue and payload
- 1000 ft
  - Payload detaches from launch vehicle
- 600 ft
  - Main deployment
  - Split between avionics bay and middle airframe

Drogue Deployment (Apogee)



Main Deployment (600 ft)



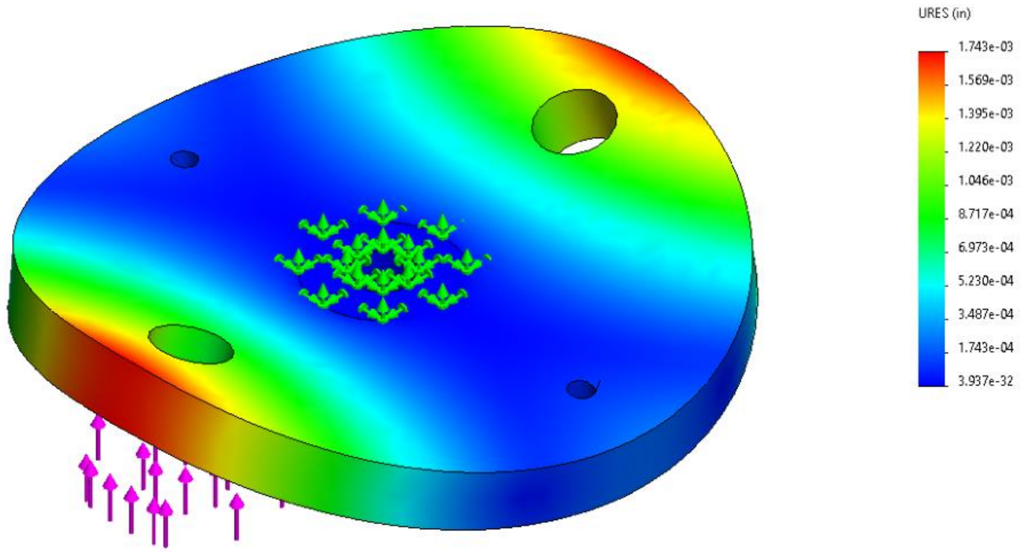
Payload separation: 1000 ft
Payload chute deployment: 850 ft

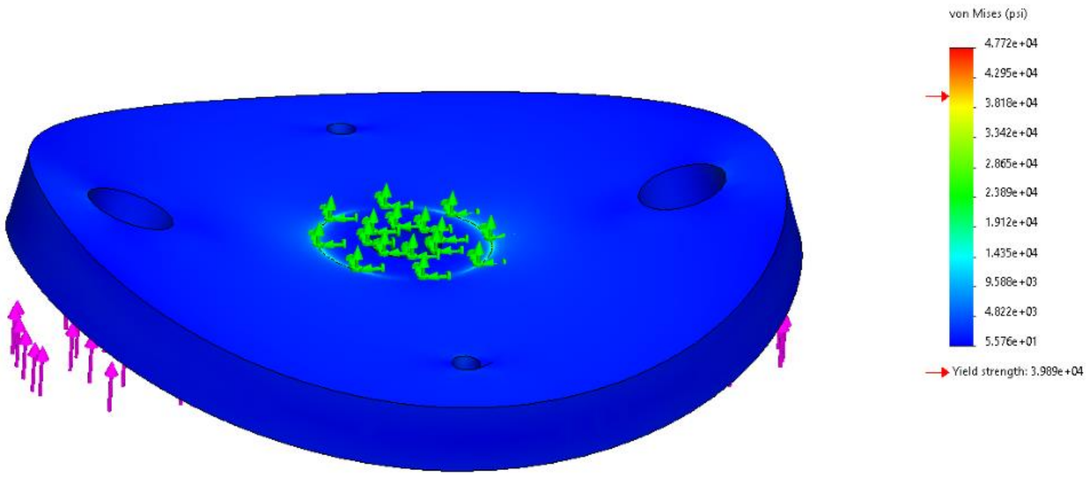
Parachute Selection

- Drogue
  - 36 in diameter
  - $C_d = 0.75$
- Main
  - 120 in diameter
  - $C_d = 2.20$
  - Reefing ring

Verification

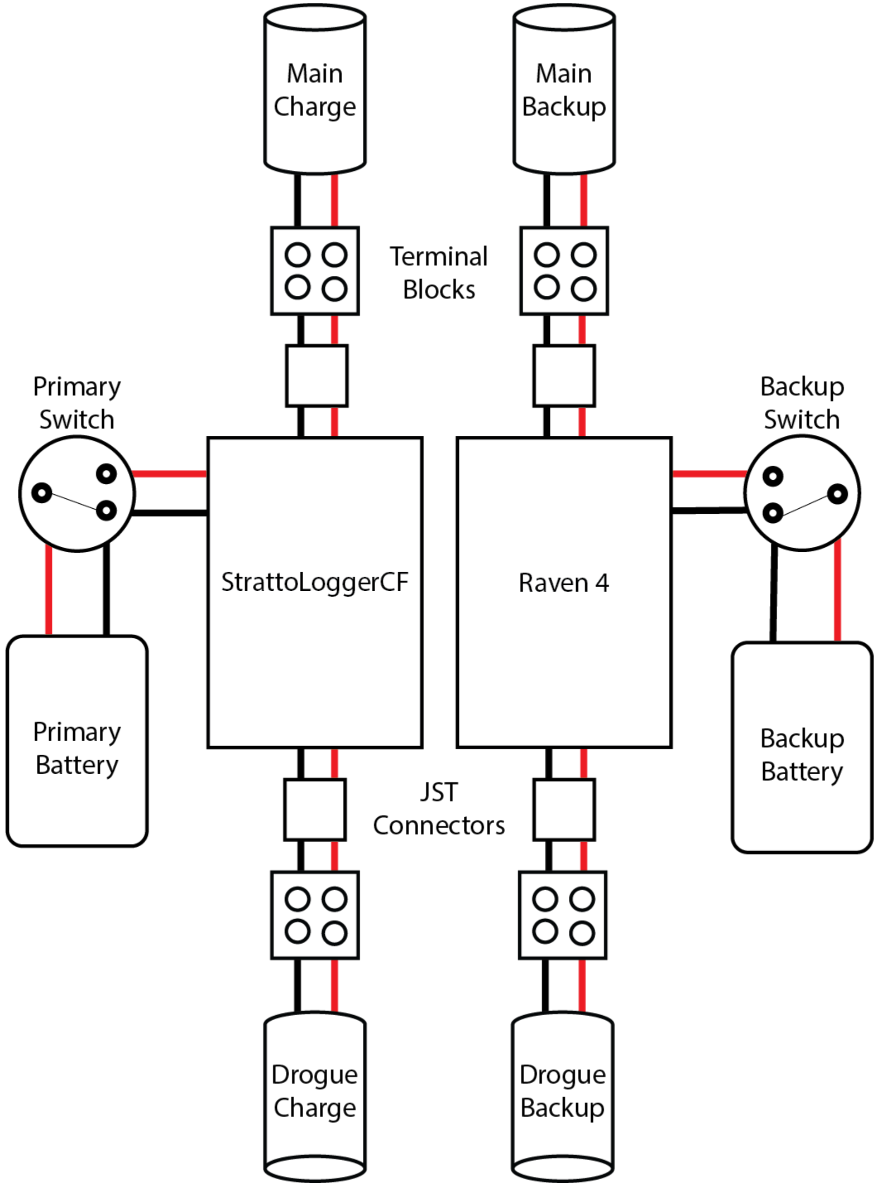
- Maximum opening shock load: 214.32 lbf
- Maximum displacement: 0.0017 in
- Maximum von Mises stress: 10400 psi
- Safety factor: 3.85





Electronics

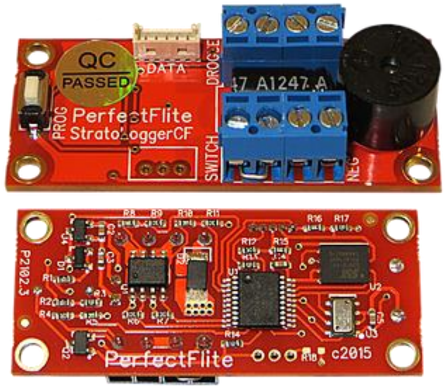
- Primary & backup altimeters
  - PerfectFlite StratoLoggerCF (SLCF)
  - Featherweight Raven 4
- LiPo batteries
  - SLCF: 370 mAh 2S
  - Raven 4: 300 mAh 1S
- Rotary switches
  - Two modes: safe/armed
- Ejection charge wells
  - Black powder



Altimeters

StratoLoggerCF

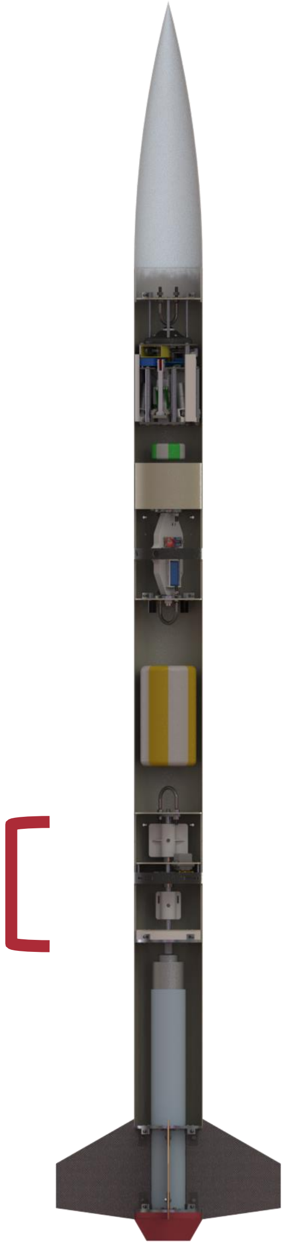
- 2 outputs at 5 A
- Pressure-based:
  - 1’ altitude resolution up to 38,000’ MSL



Raven 4

- 4 outputs at 25 A
- Pressure & IMU-based:
  - 20 Hz baro data at ±0.3% accuracy
  - 400 Hz axial accelerometer
  - 200 Hz lateral accelerometer
  - Accelerometer range of ±105 Gs

Avionics



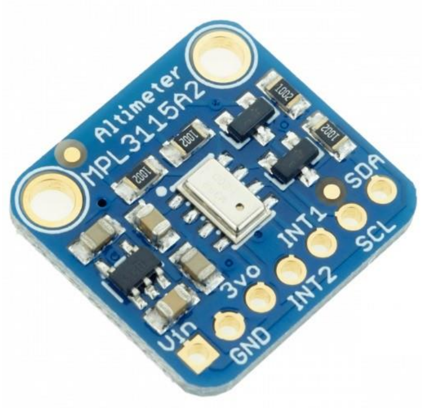
Components

- Teensy 3.2 Microcontroller
- MPU-6050 Accelerometer
- MLX90393 Magnetometer
- MPL3115A2 Barometer

Teensy 3.2

MPU-6050

MLX90393



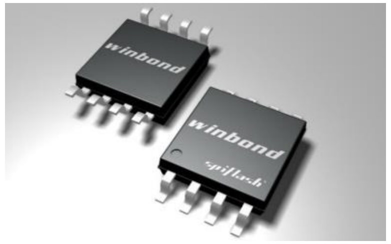
MPL3115A2

Components

- NEO-M9N GPS
- ES32-915T30S LoRa Transceiver
- 128M-Bit Serial Flash Memory
- 11.1V 450mAh LiPo Battery

NEO-M9N

ES32-915T30S

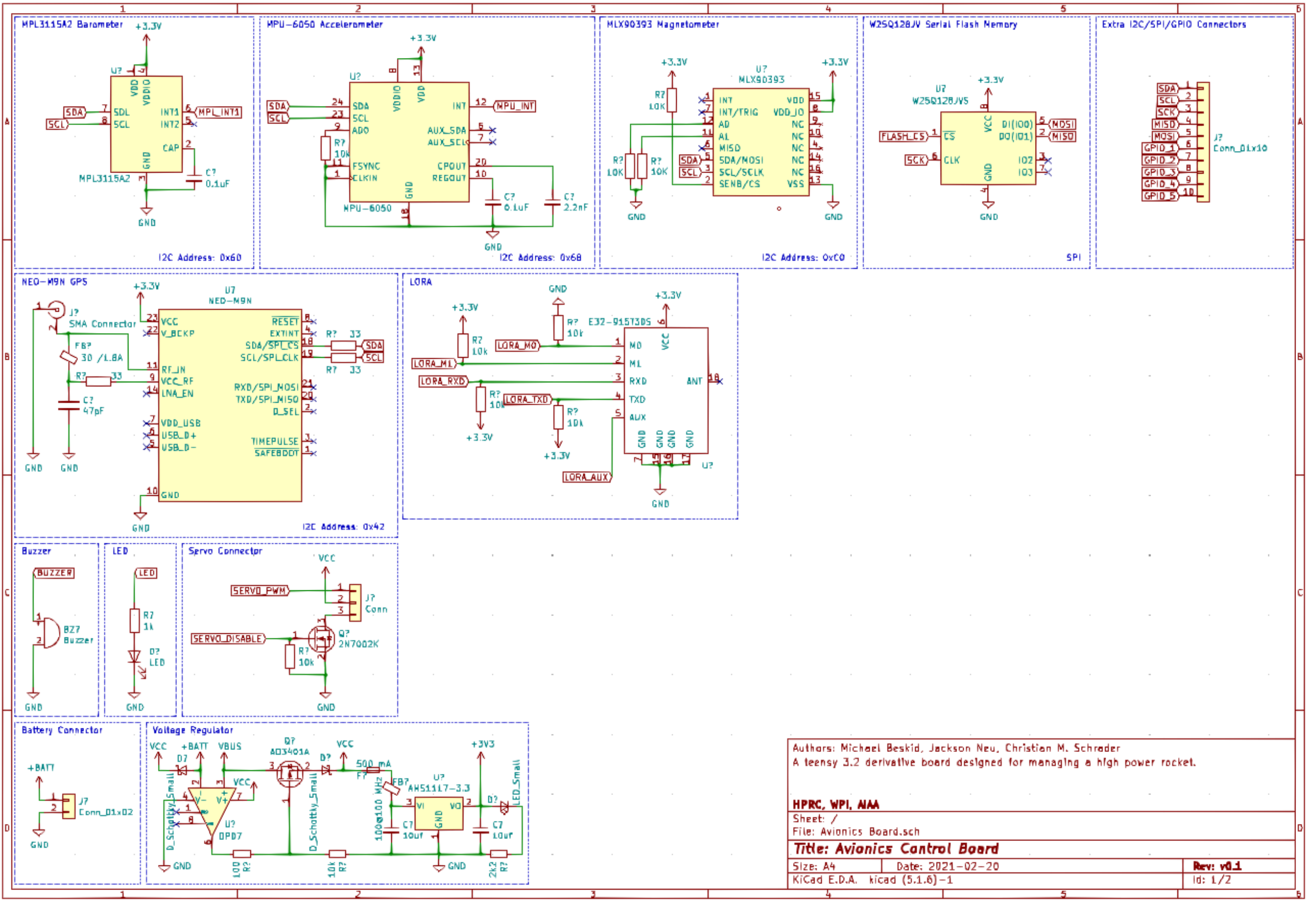


Serial Flash

LiPo Battery

Printed Circuit Board

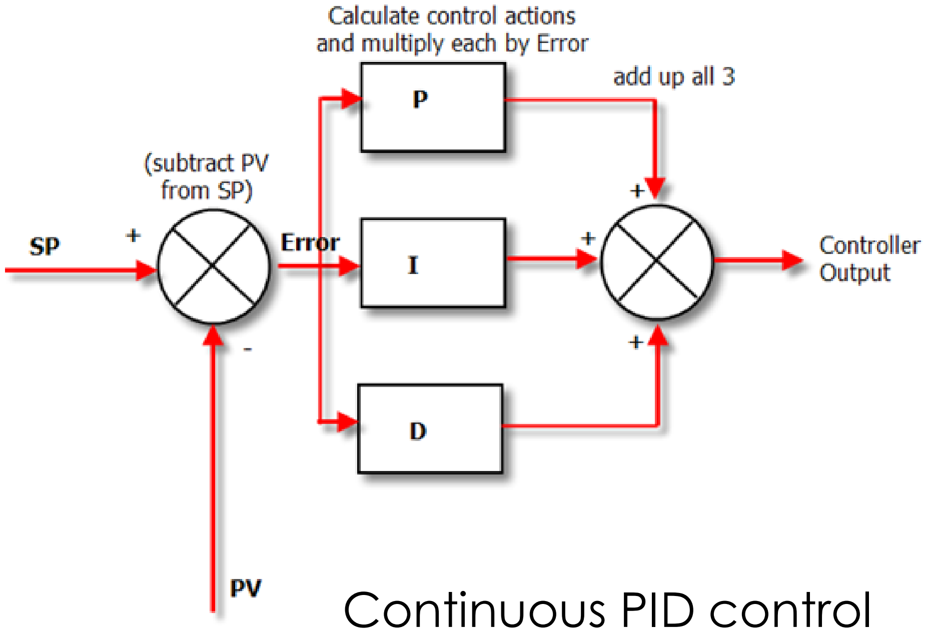
- Our final assembly will consist of a single PCB containing our microcontroller, sensors, memory, and all other components
- Creating a PCB will keep the avionics system well organized
- The board is designed in KiCad and will be manufactured by JLCPBC



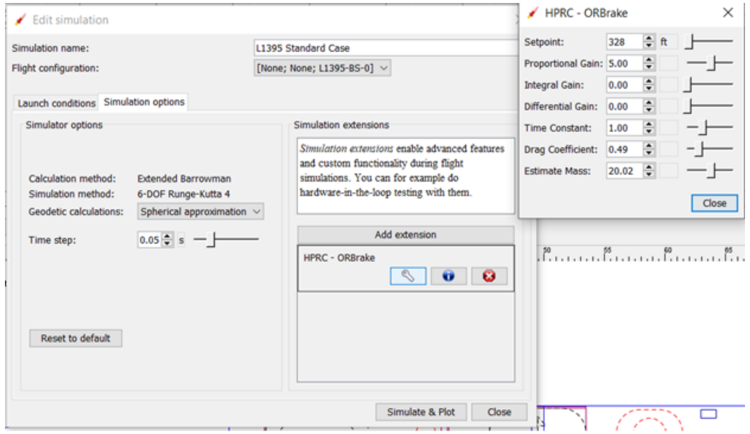
Current KiCad schematic

Control System

- Proportional Integral Derivative (PID) Controller
  - **Setpoint (SP):** target apogee
  - **Process variable (PV):** predicted apogee
  - **Output:** required drag force
- Software uses discrete PID control
  - Bilinear transform to convert it from a continuous function
- Adjustments to gains (tuning) will modify how quickly PV converges to SP
  - Modify these values through OpenRocket



Continuous PID control



Simulation name: L1395 Standard Case
Flight configuration: [None; None; L1395-BS-0]

Calculation method: Extended Barrowman
Simulation method: 6-DOF Runge-Kutta 4
Geodetic calculations: Spherical approximation
Time step: 0.05 s

Simulation extensions enable advanced features and custom functionality during flight simulations. You can for example do hardware-in-the-loop testing with them.

HPRC - ORBrake

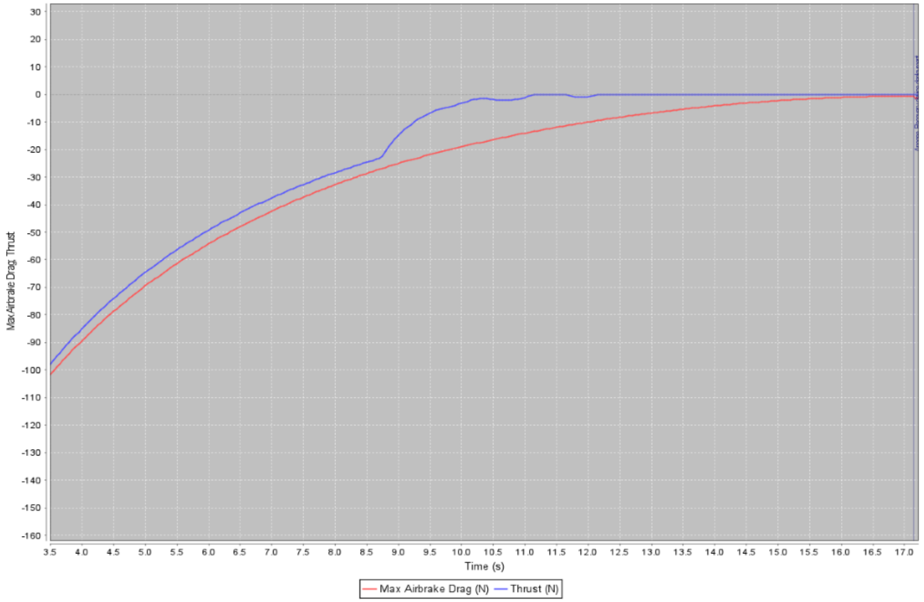
Setpoint: 328 ft
Proportional Gain: 5.00
Integral Gain: 0.00
Differential Gain: 0.00
Time Constant: 1.00
Drag Coefficient: 0.49
Estimate Mass: 20.02

Controller variable modifications in OpenRocket

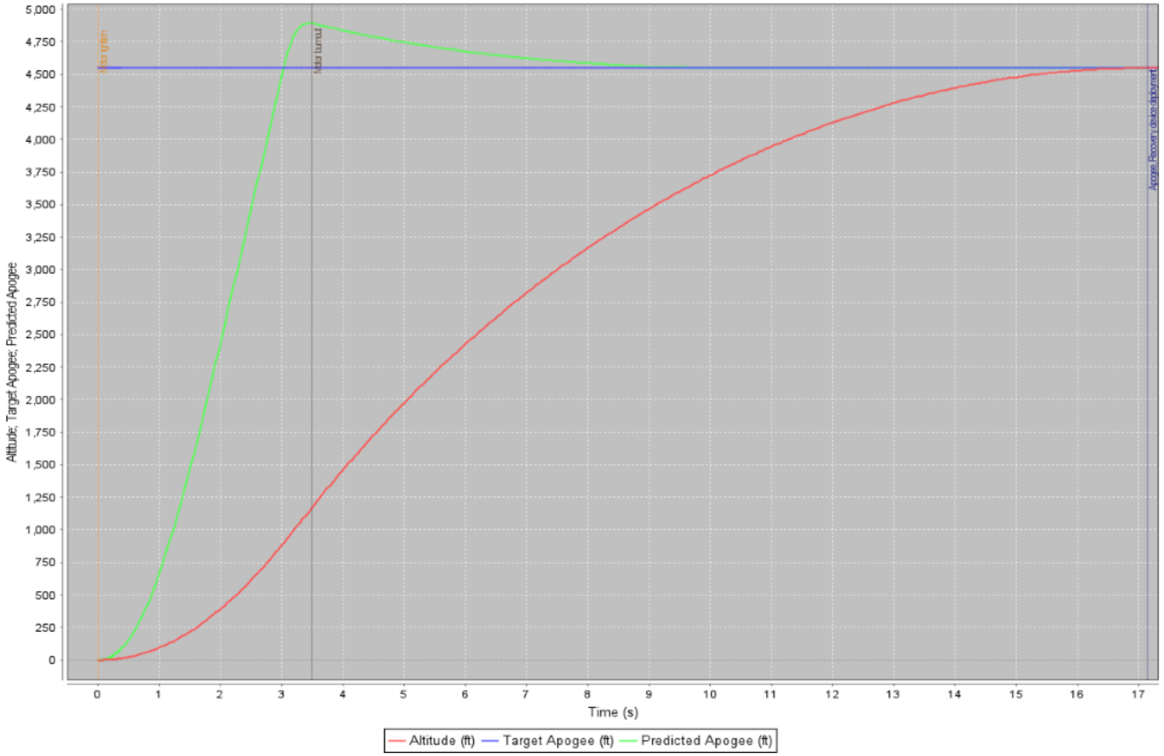
Control System

- Required drag force in software modifies thrust in OpenRocket
  - Applies negative thrust

Maximum Possible Drag (red) and Actual Drag (blue)



Altitude (red), Target Apogee (blue), and Predicted Apogee (green)



Control System Implementation

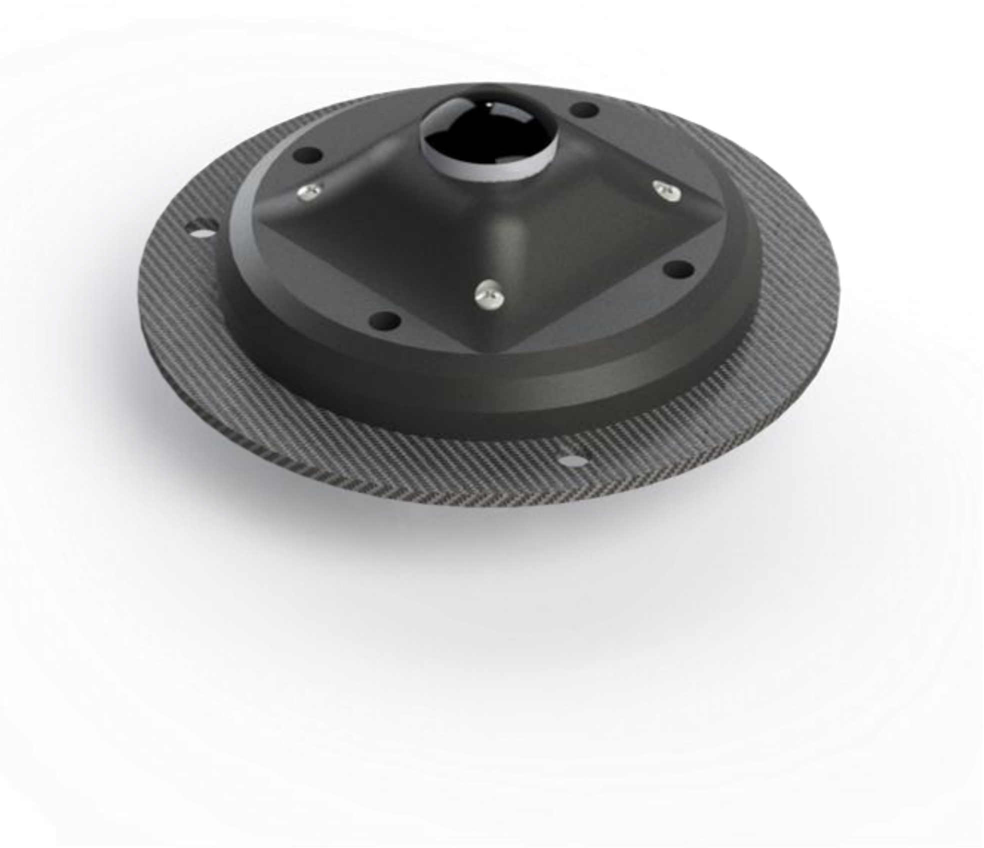
- The PID controller is simple to implement in C++
- Unlike the simulation, required drag cannot be produced on demand.
  - Actuation time of the airbrakes affects the drag.
  - We plan on implementing this within the simulation.
- Will be implemented as a subsystem object within the firmware.
  - Takes in state information from sensors as input for PID.
  - Required drag will be converted to airbrake extension based on interpolation on pre-simulated CFD data.

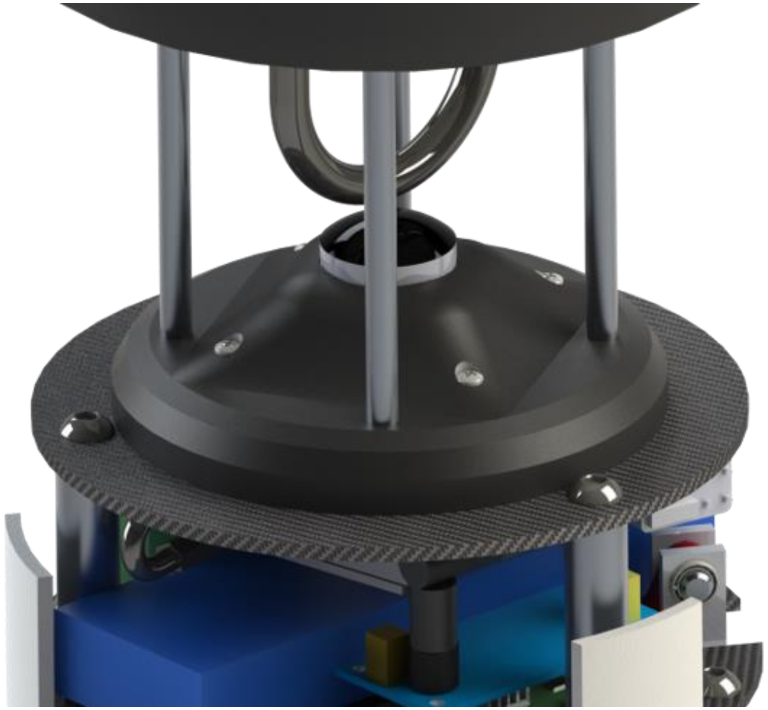
Payload

Payload Overview

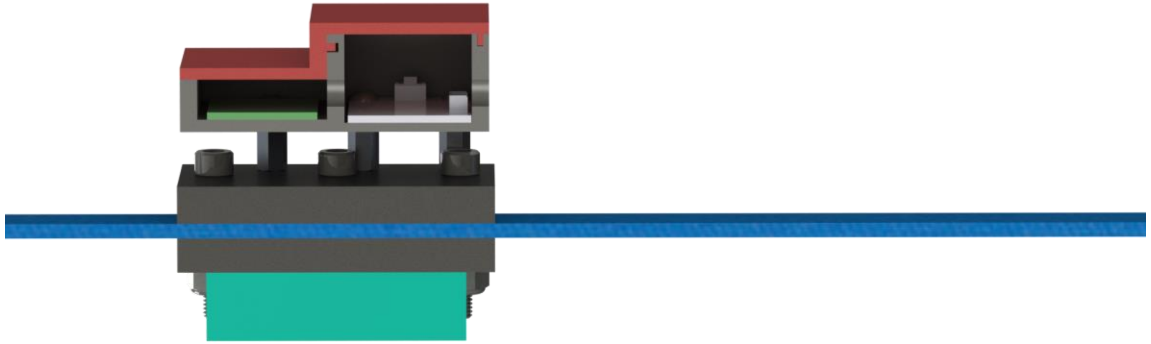
Payload Retention

Alignment Standoffs

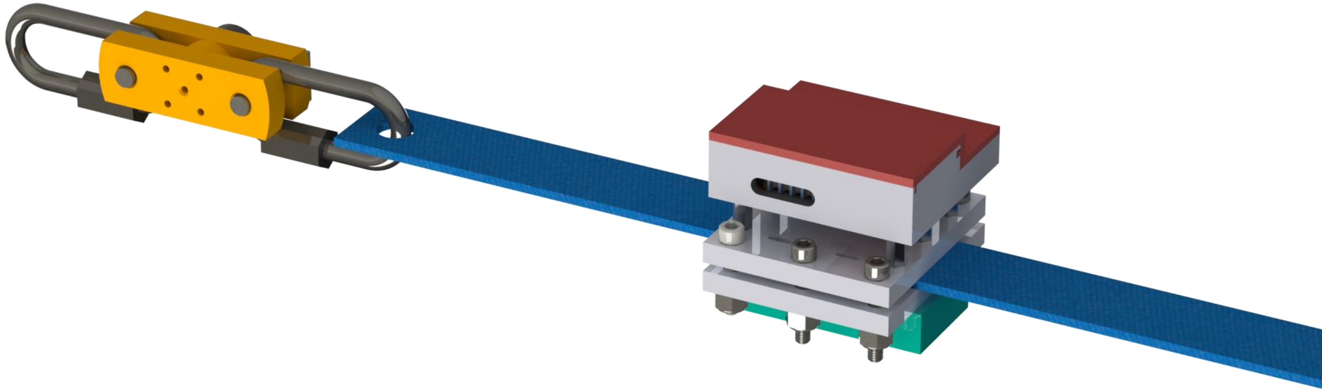




Tender Descender & StratoLogger CF



Cross-sectional view

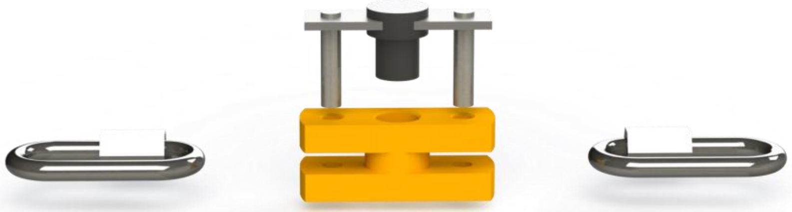


Side view

How The Tender Descender Works

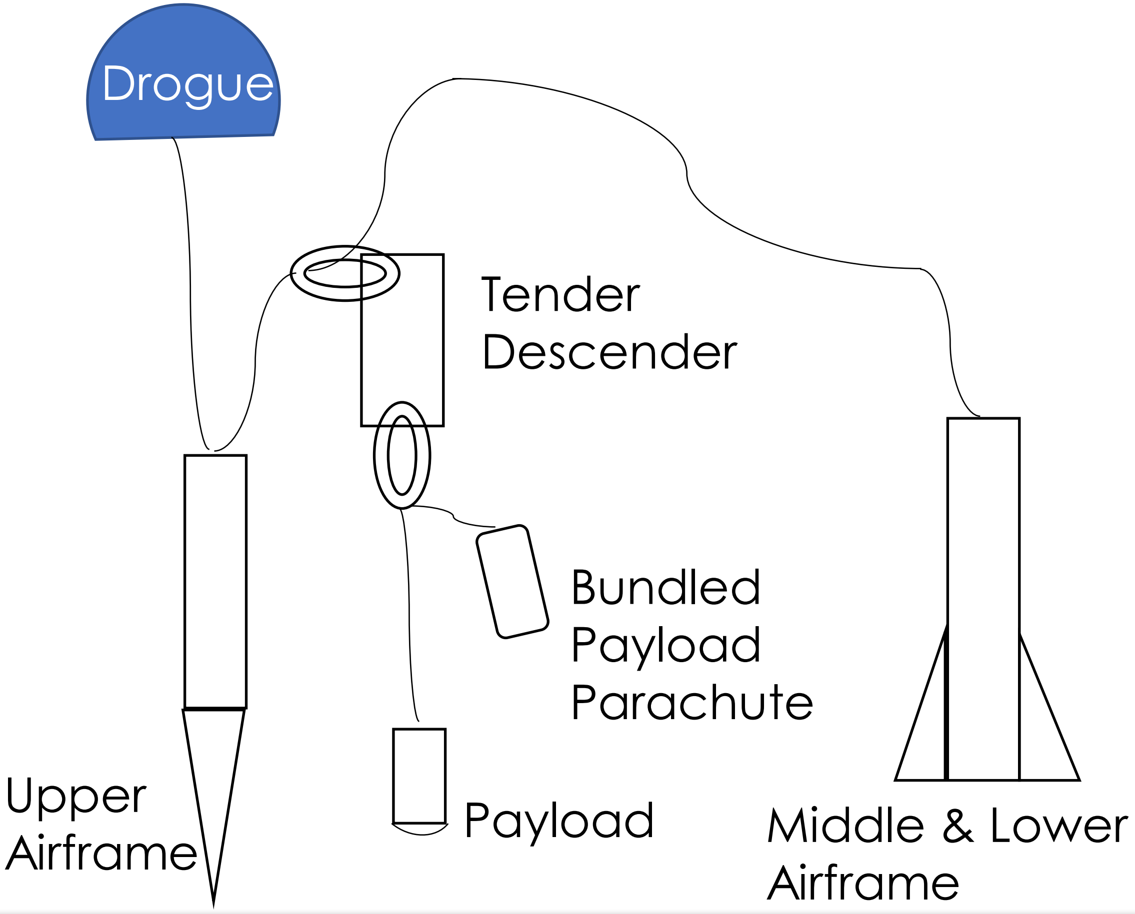
Before explosion

After explosion

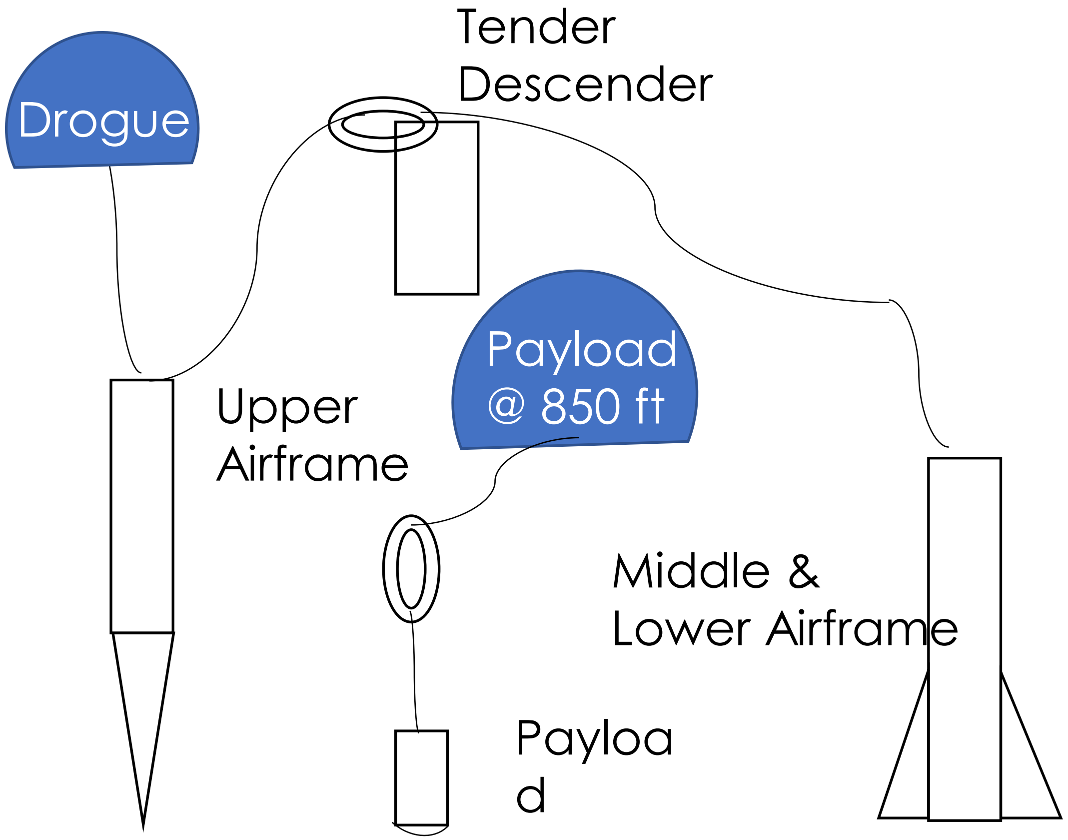


Parachute Cable Diagrams

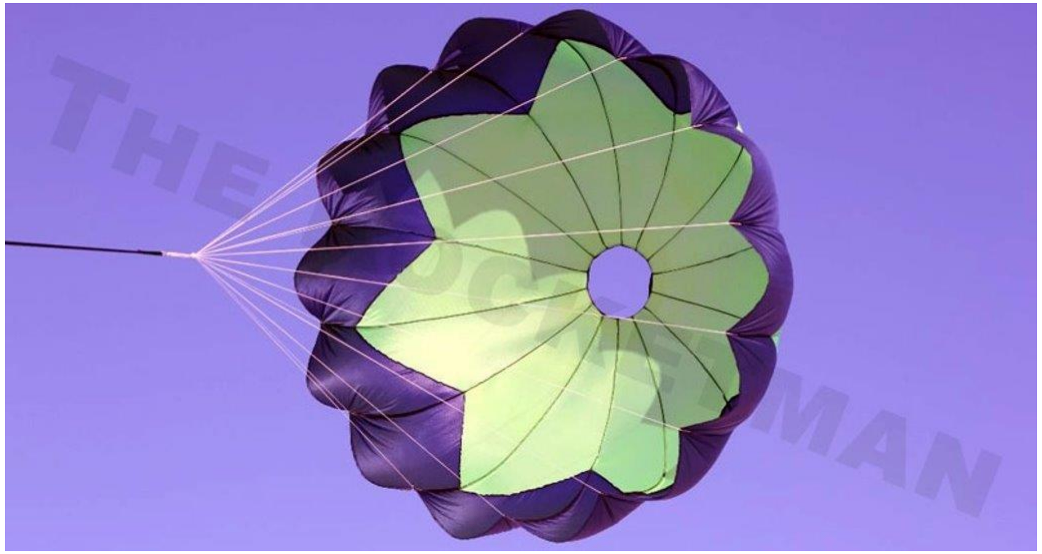
- Upon Drogue Deployment



- After Tender Descender Deployment at 1000 ft AGL



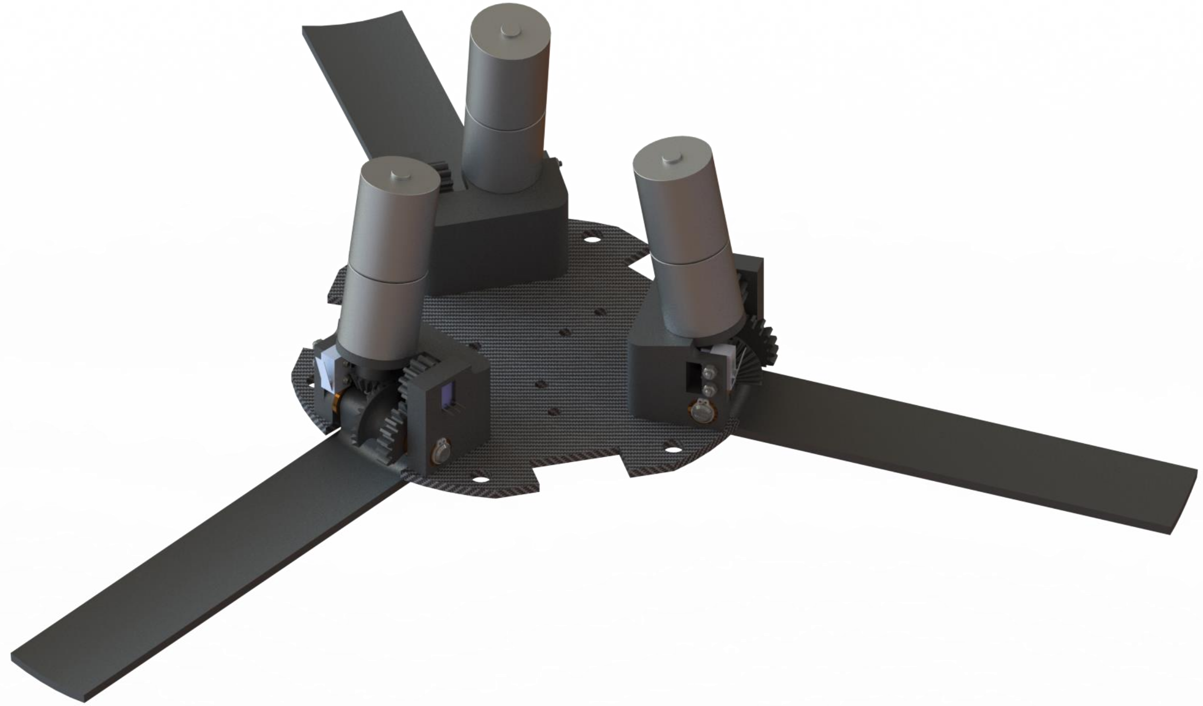
Parachute & Chute Release



Payload Self Righting

Design Overview

- The self-righting system brings the payload to upright position after landing
- Three petal arms deploy once the payload lands
  - Arms act as levers to push the payload upright
  - Each arm has its own drive system
- A limit switch and potentiometer sense the position of the petals for controls
- 3D printed out of Nylon-X

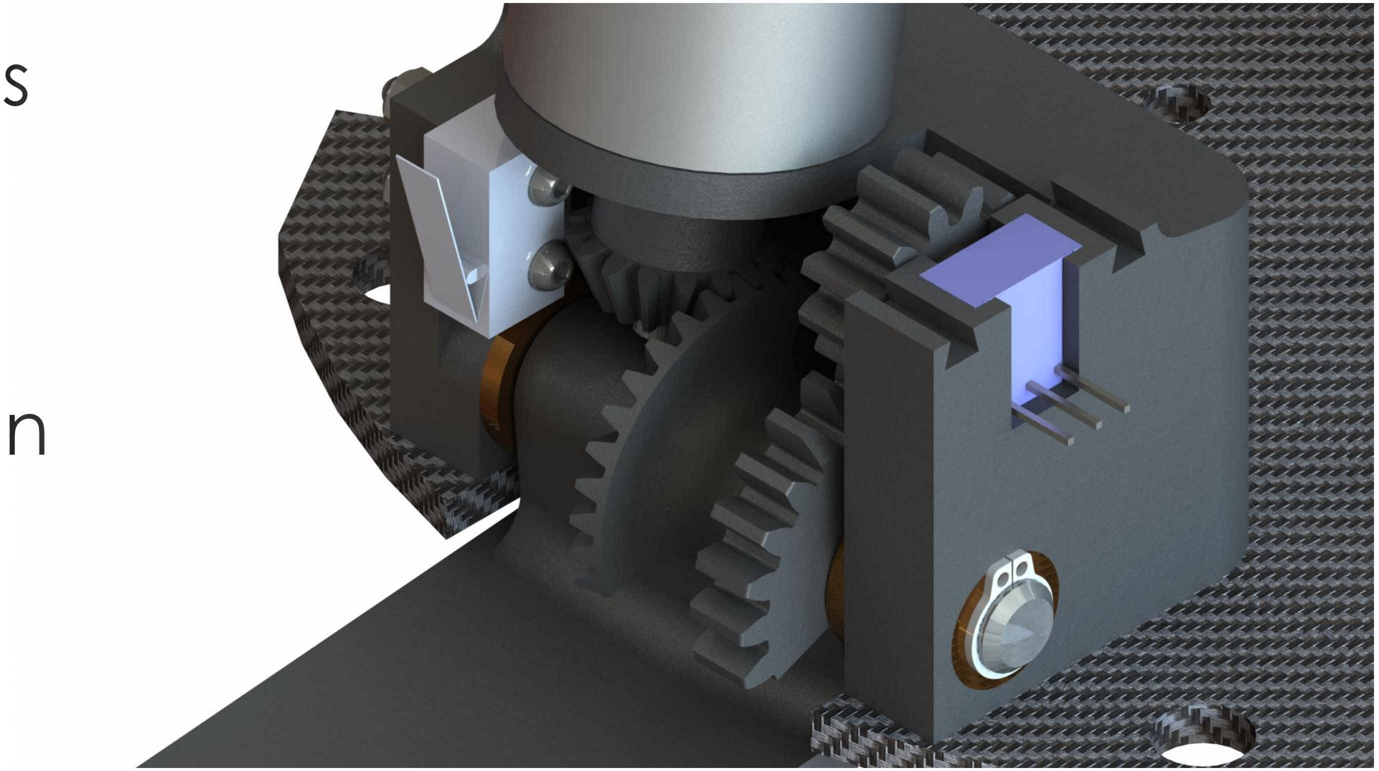


Drive System

- Each petal driven using 19RPM Actobotics Econ Gearmotor, 499:1 gear ratio
- 2:1 bevel gear drive connects motor shaft to petal, NylonX gears
  - Petal driven w/ 84 in-lbs torque
- 3D printed motor mount houses drive gears and all sensors below motor
  - Hinge pin connected to mount holds petals in place, secured by set screws

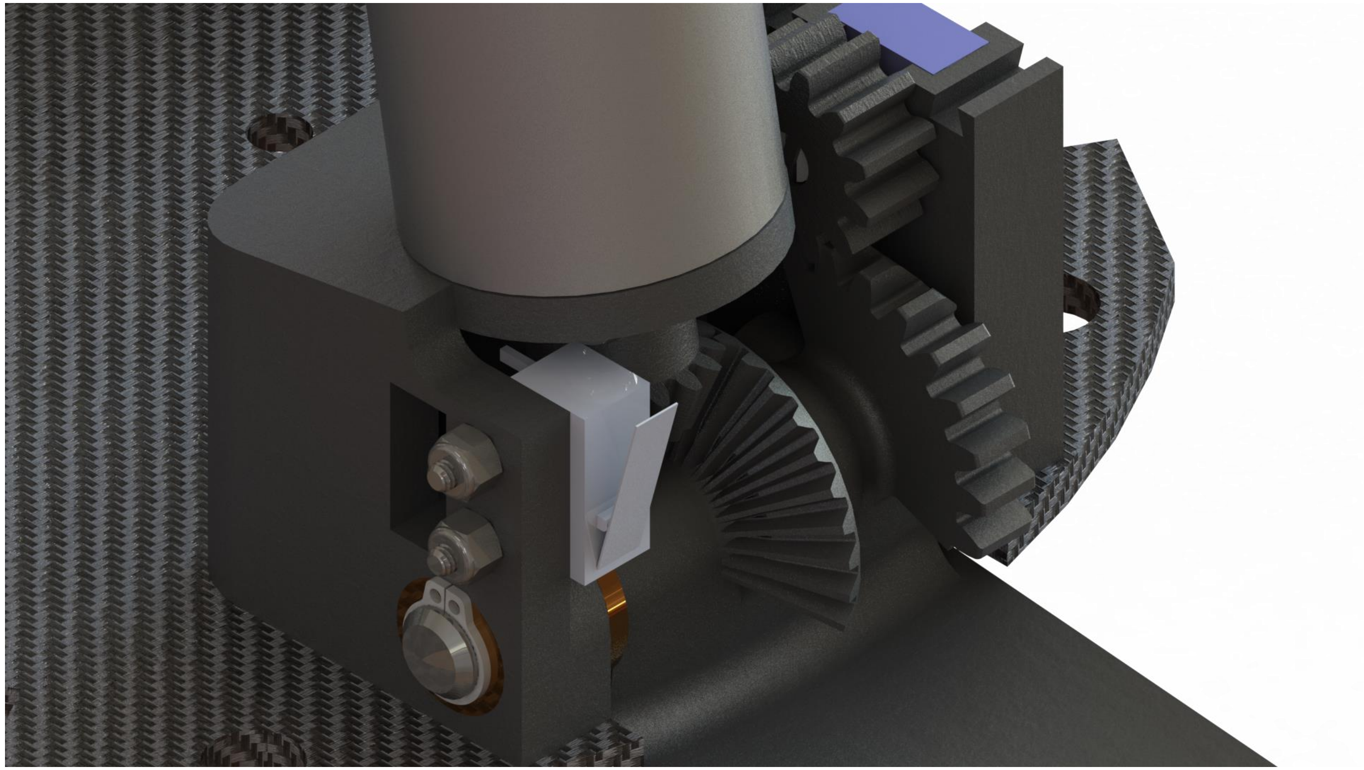
Sensors

- Potentiometer increases resistance as petal extends through gear system
- Dovetailed cap to retain potentiometer
- Bourns 10kΩ Trim Potentiometer

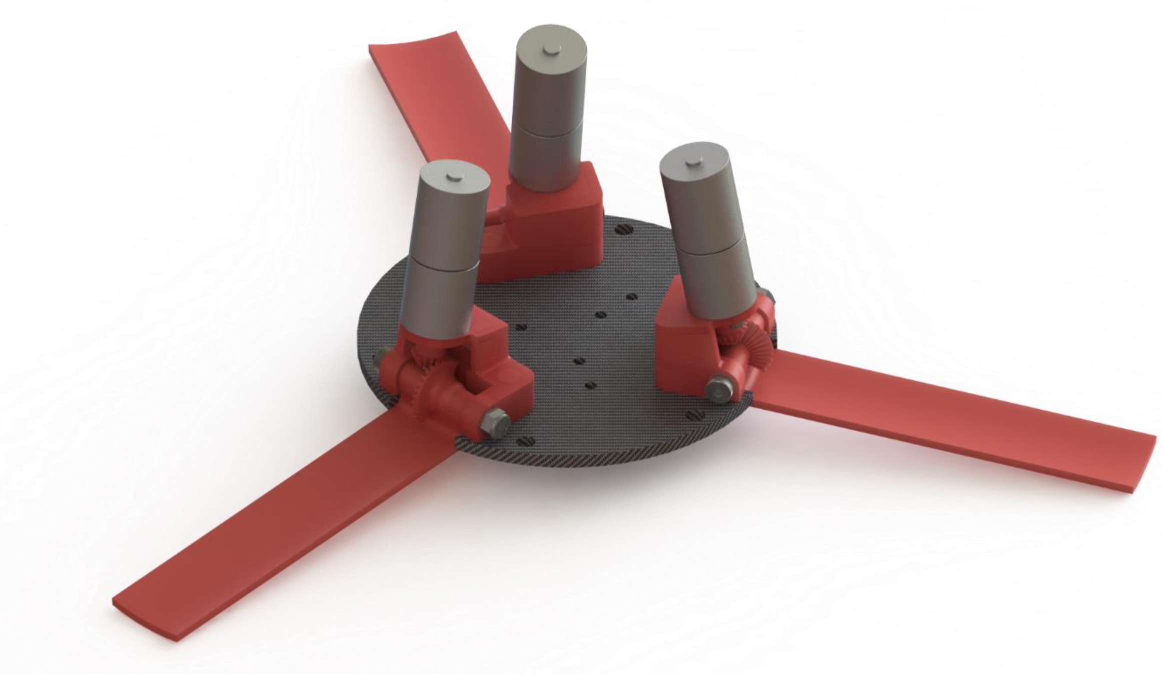


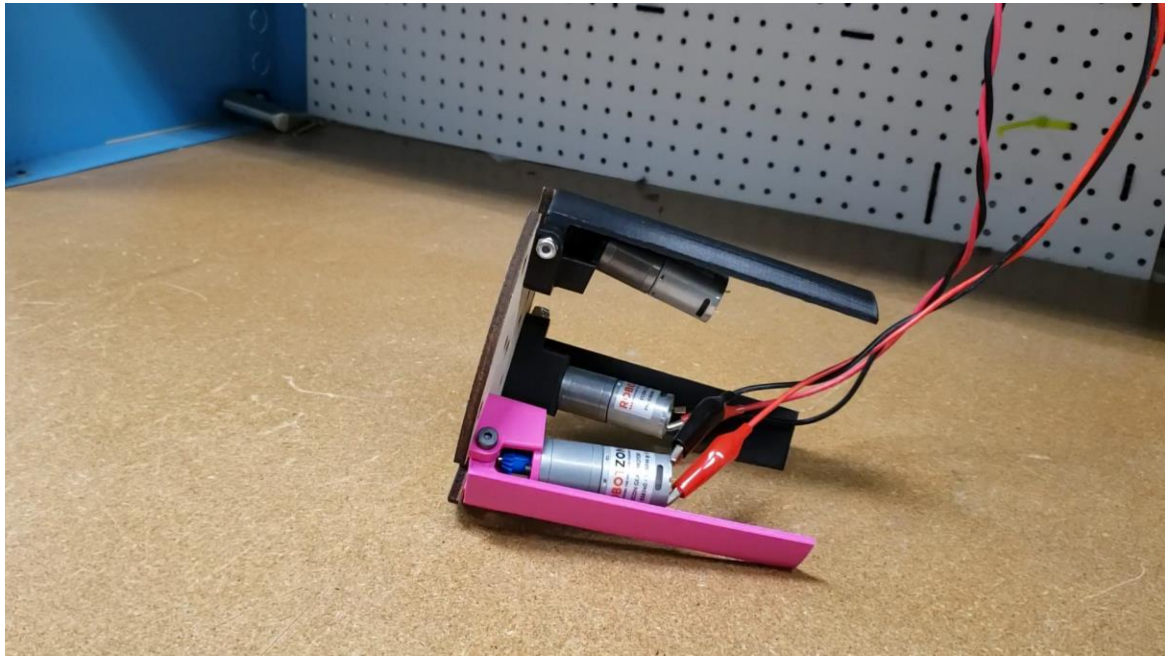
Sensors

- Limit switch activates when petal is closed
- Bolts through integrated mounting holes
- Mouser UP01DTANLA04 Micro Snap Action Switch



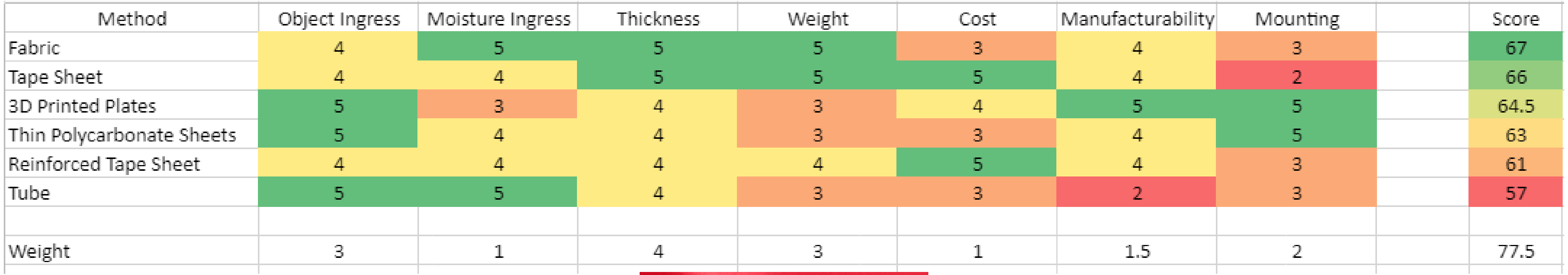
Prototype





Payload Sheath

- Objective of the sheath is to protect the interior components of the payload from the environment of the landing site

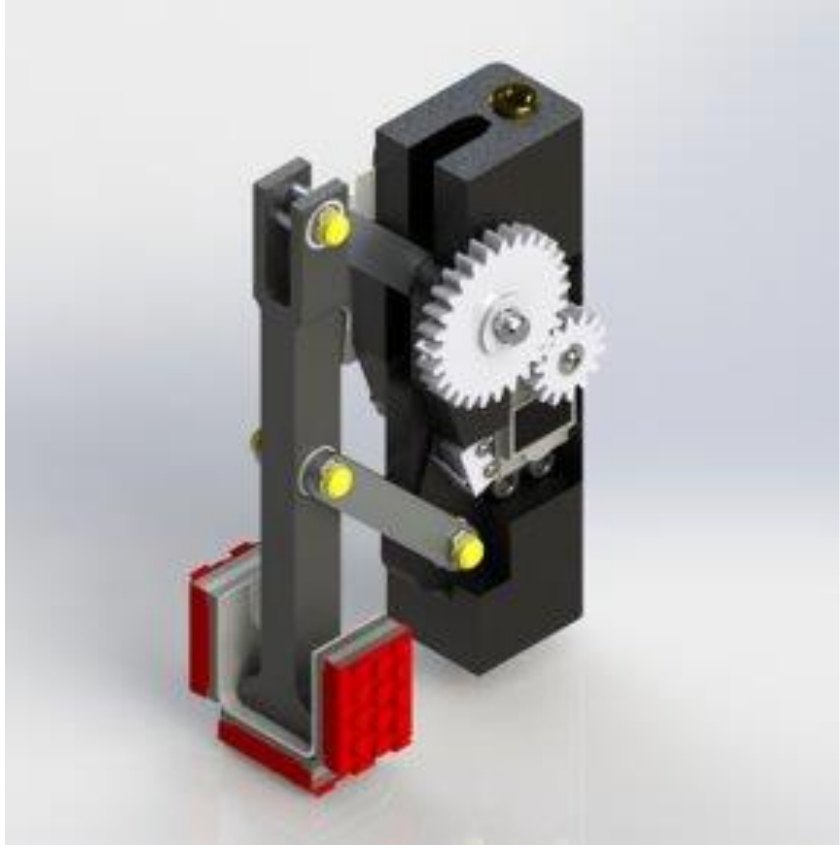


Method	Object Ingress	Moisture Ingress	Thickness	Weight	Cost	Manufacturability	Mounting		Score
Fabric	4	5	5	5	3	4	3		67
Tape Sheet	4	4	5	5	5	4	2		66
3D Printed Plates	5	3	4	3	4	5	5		64.5
Thin Polycarbonate Sheets	5	4	4	3	3	4	5		63
Reinforced Tape Sheet	4	4	4	4	5	4	3		61
Tube	5	5	4	3	3	2	3		57
Weight	3	1	4	3	1	1.5	2		77.5

Payload Stabilization

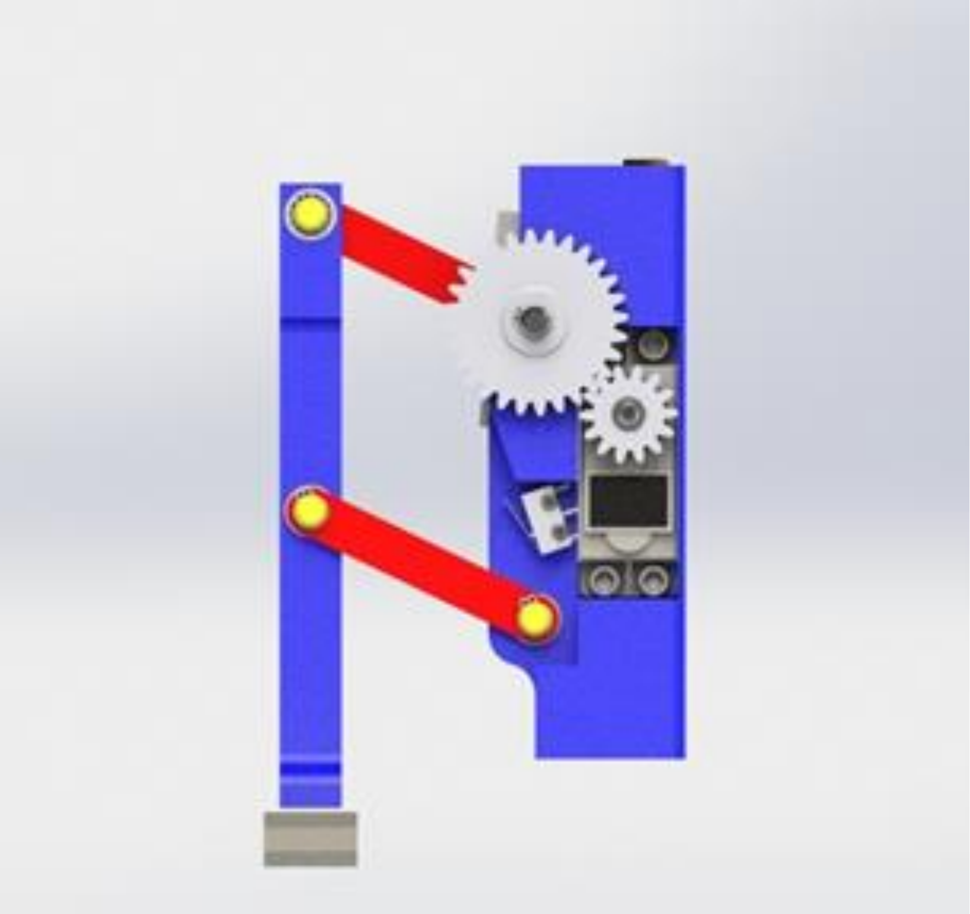
Design Overview

- Orient & support payload during panorama
  - Within five degrees of vertical
- Four bar linkage + compliant foot asm.
- Sensors used to control linkage
- Mostly 3D-printed, possibly aluminum



Lift Mechanism

- Four Bar Linkage
  - Red links: 2" long
  - Blue links: 2.375" long
  - Simple motion profile, familiar design
- Requires 11.43 in-lbf to rotate
- Materials
  - Red Links: Al 6061-T6 **OR** NylonX
  - Blue Links: ABS



Drive System

- goBILDA Continuous-Rotation Servo
  - High torque-weight ratio
  - Adequate power output
- 1:2 Power Transmission
  - Single-stage, 14T-28T gears
  - 20 pitch
  - NylonX **OR** Al 6061-T6 construction
- 5.73 in-lbf @ 42.5 RPM, 31% Stall Current
  - FoS = 1.78

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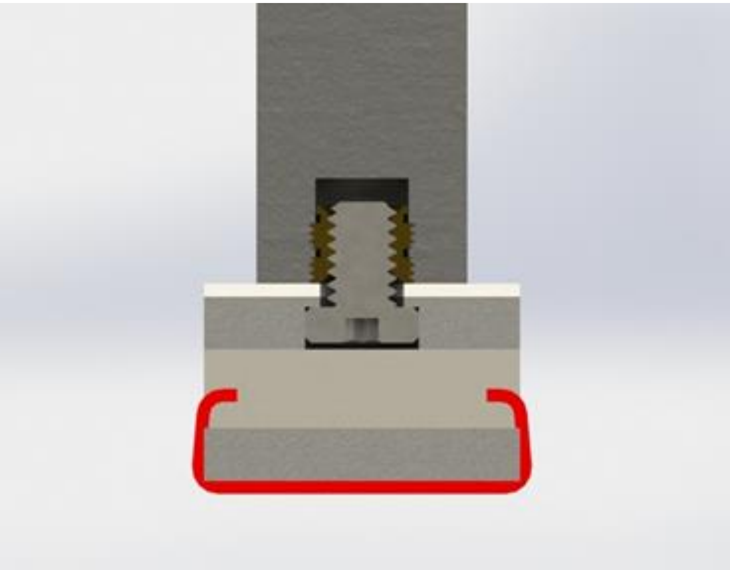
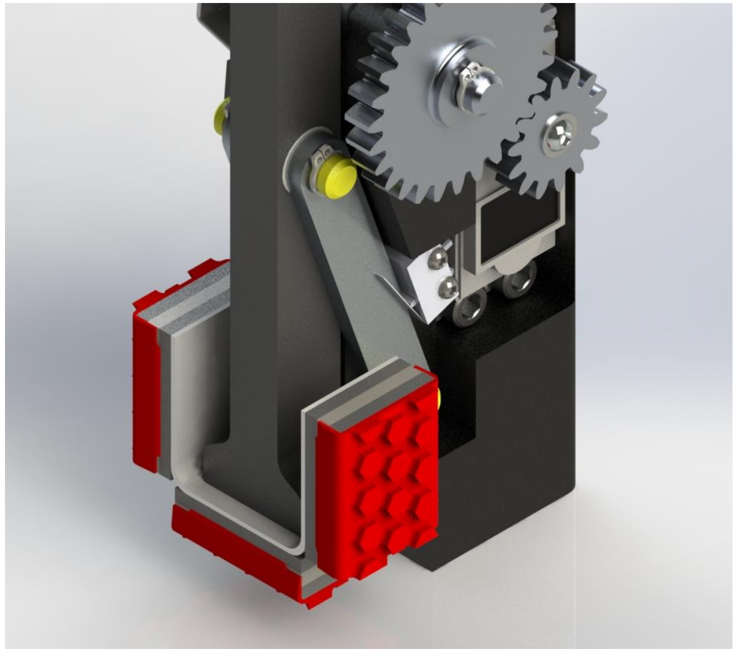
Foot System

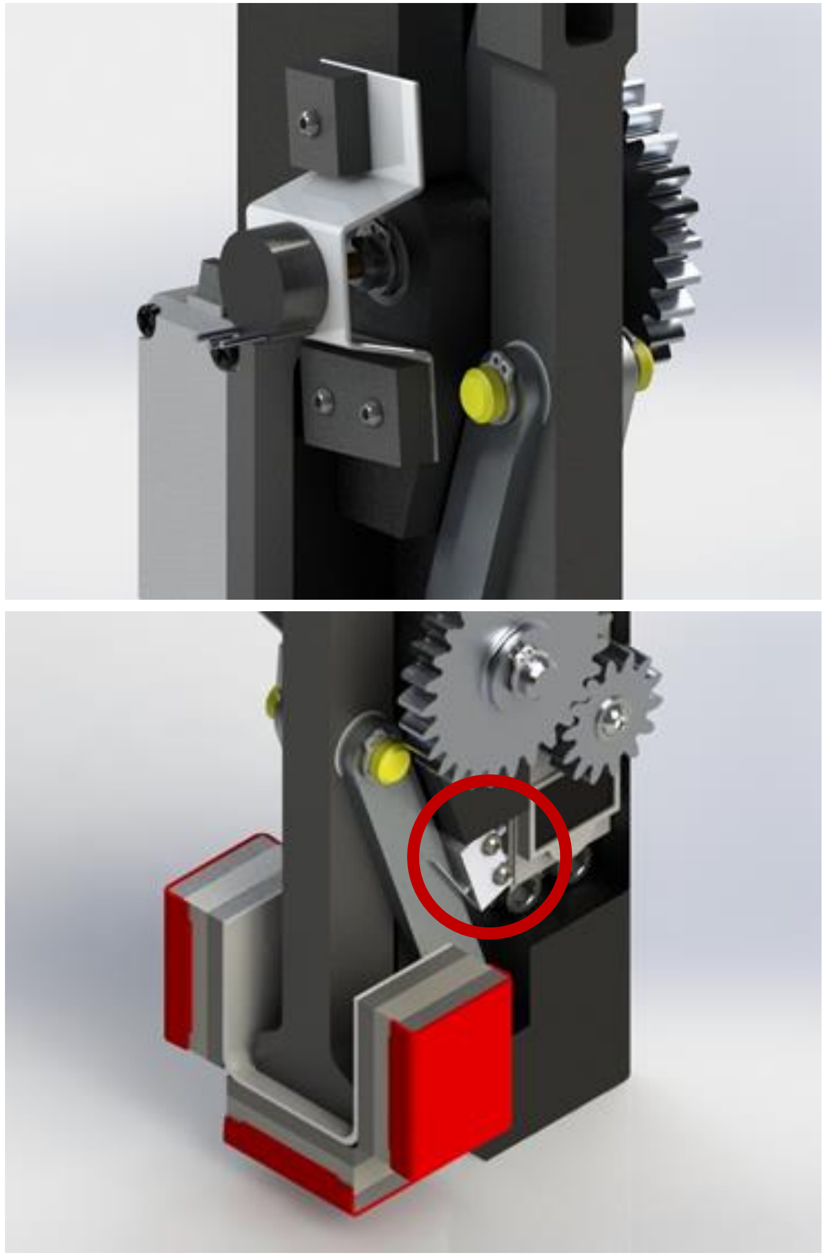
- Compliant foam sandwich composite
  - Cross-linked Polyethylene outer layers
  - Polyurethane inner layer
- Polycarbonate hinge-plate
  - 1/16-in plate, hand-bendable
- Compliant Traction Layer
  - NinjaTek CheetahFlex filament
  - Hex or Spike tread options
  - Easily swappable for testing purposes





Sensors

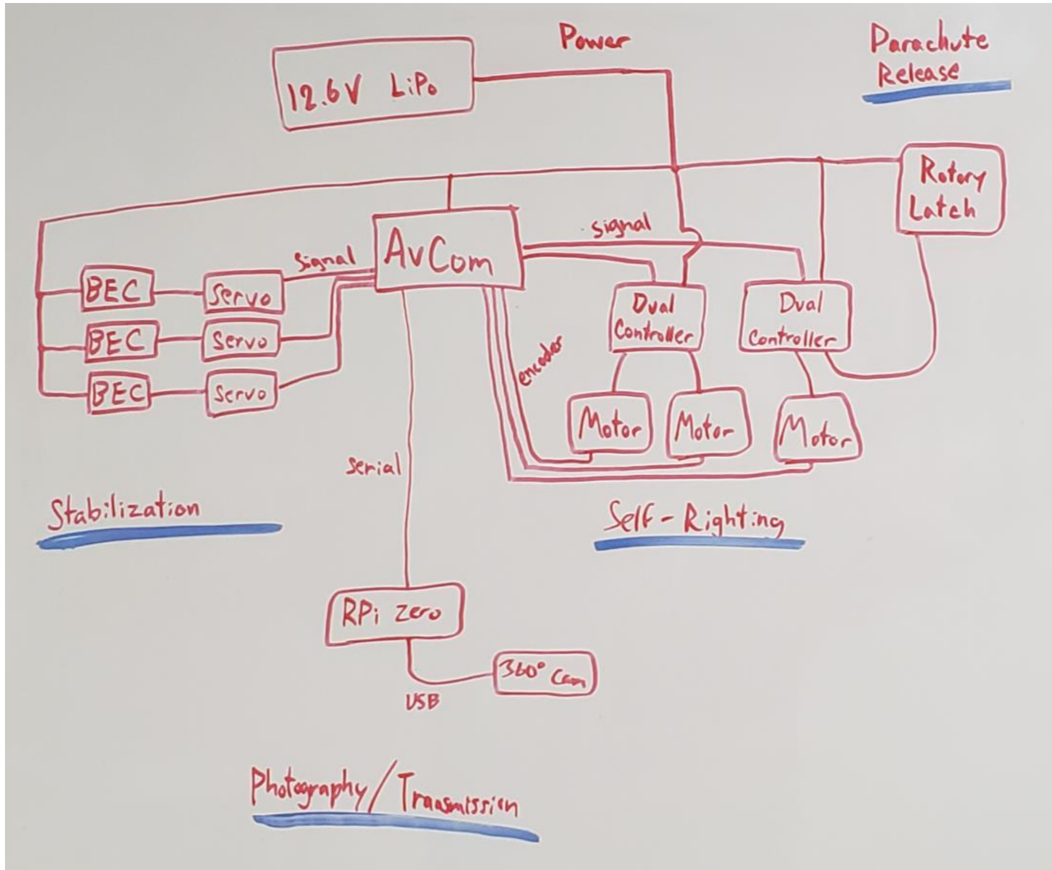
- Bourns 100 kΩ Rotary Potentiometer
  - Mounted to 1/16-in polycarbonate plate
  - Interfaces with crank shaft
  - Relay crank position to central processor
- Mouser Snap Action Limit Switch
  - Mounted to payload base
  - Actuated by right follower link
  - Zero crank position
  - Prevent motor stalling



Payload Electrical

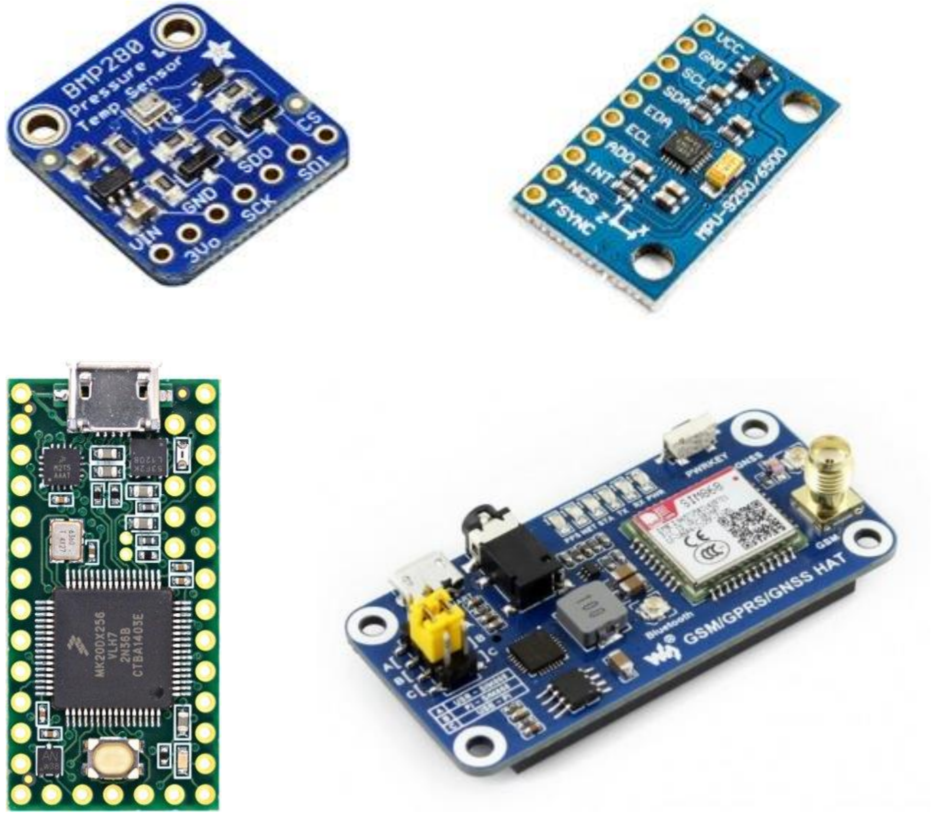
System overview

- Self-righting
  - 3 DC motors with encoders
  - 3 DC motor controllers
- Stabilization
  - 3 Servo motors
  - 3 BECs
- Retention
  - 1 DC motor controller
- Photography
  - Raspberry Pi Zero



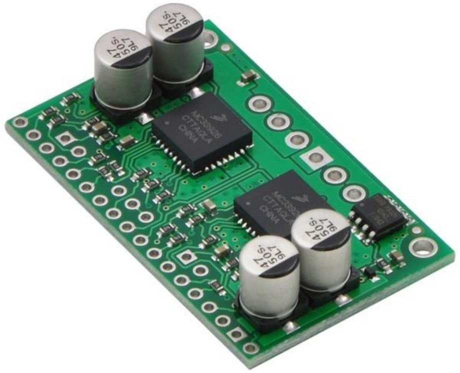
Electrical system overview contd.

- Avionics Computer:
    - Teensy 3.2
    - LoRa transceiver (telemetry)
    - Barometer (altitude)
    - IMU
    - Rotary encoders, limit switches
- Raspberry Pi Zero + shield
    - PICAM360
    - GPS
    - GSM (cellular network communication)



Power system

- BEC 4A continuous
- Pololu dual motor controller 3A continuous
- 12V 2.2Ah LiPo battery

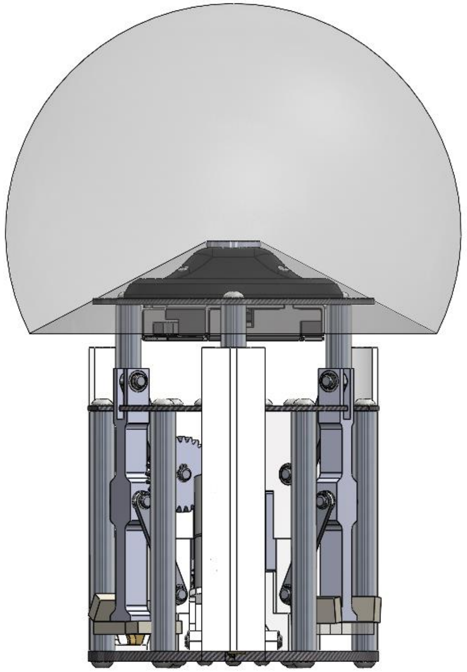


Photography

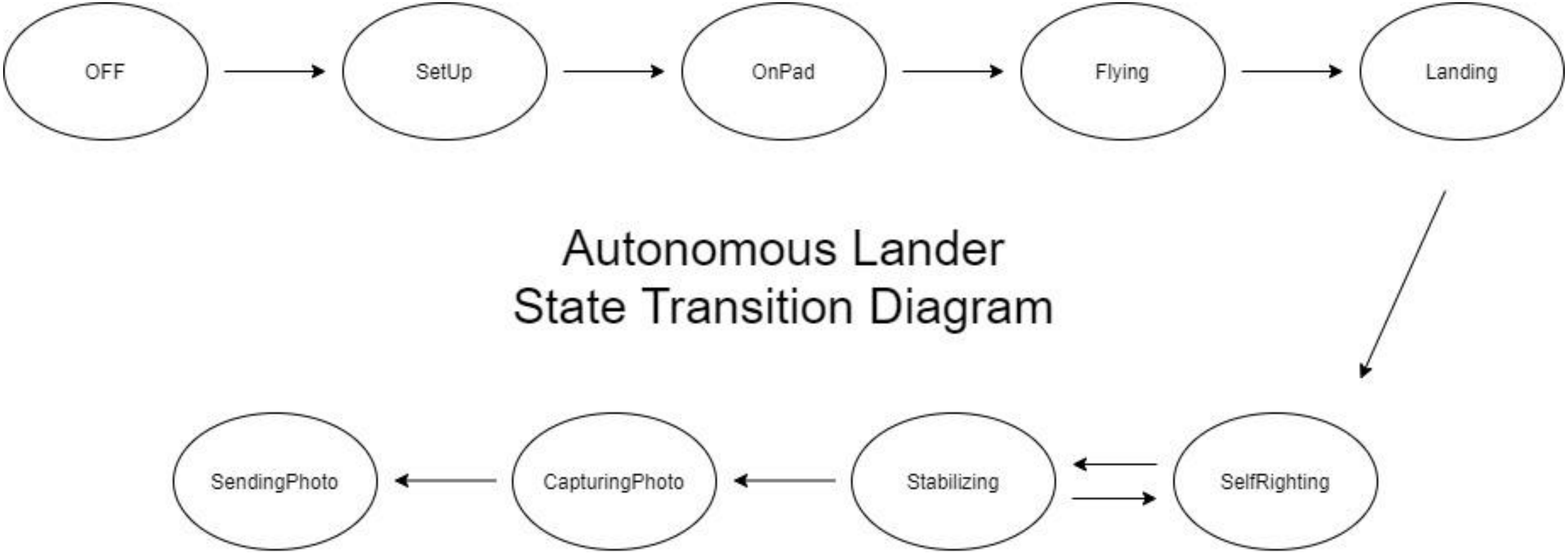
- Raspberry Pi Zero W
  - Interface with PICAM360
  - Acting as a peripheral device to the main controller board
- PICAM360
  - 8-megapixel sensor
  - Offers a 360-degree horizontal field of view with a 235-degree vertical field of view

Photography contd.

Example image capture



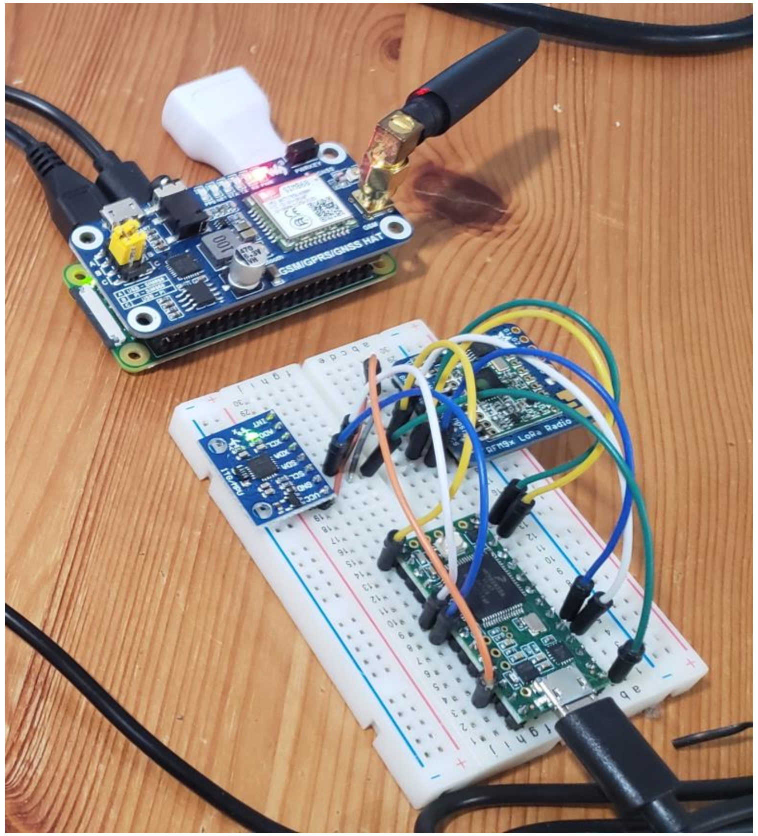
Software



Autonomous Lander
State Transition Diagram

Prototyping and testing

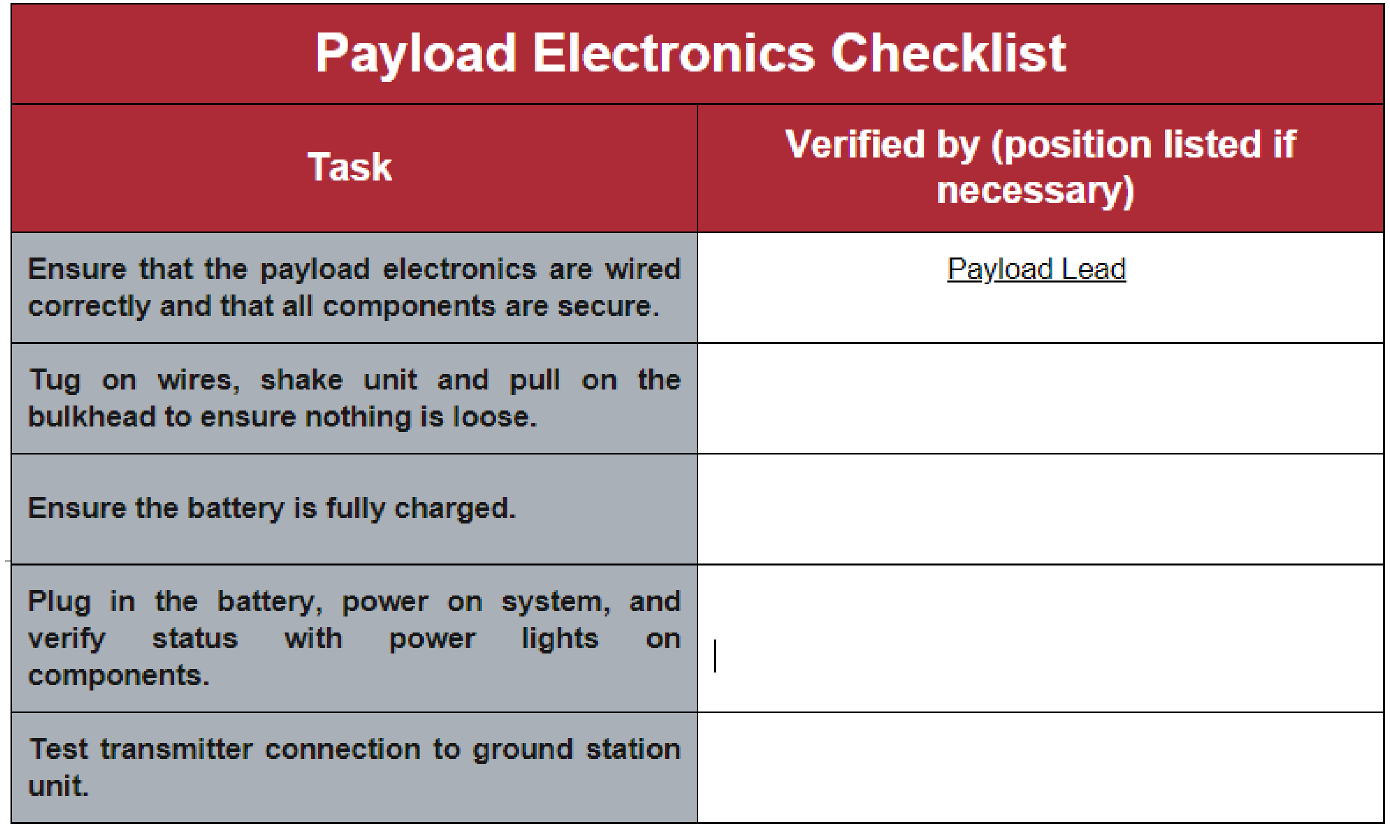
- Remote development for Teensy and Raspberry Pi
- Members cross-compile to hosted server for developing software
- Sensors and actuators tested all together on a breadboard before PCB manufacturing/robot wiring



Safety

Launch Checklists

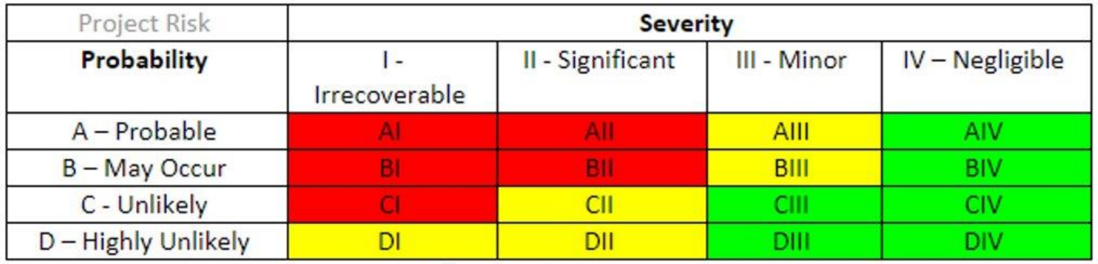
- Checklists were made to ensure no essential procedures for launch were forgotten
- Checklists created:
  - Recovery Bay, Recovery Hardware, Avionics, Payload, Payload Electronics, Motor, Launch, Troubleshooting, and Post-Flight Inspection



Payload Electronics Checklist	
Task	**Verified by (position listed if necessary)**
Ensure that the payload electronics are wired correctly and that all components are secure.	Payload Lead
Tug on wires, shake unit and pull on the bulkhead to ensure nothing is loose.	
Ensure the battery is fully charged.	
Plug in the battery, power on system, and verify status with power lights on components.	
Test transmitter connection to ground station unit.	

Hazard Analyses

- WPI HPRC maintains hazard analysis tables to identify potential risks to the successful completion of the project
- Hazards are categorized by Project Risks, Personnel Hazards, Failure Modes and Effects, and Environmental Concerns
- Each hazard is classified by its probability to occur and the severity of the impact on the project
- A mitigation plan is provided for each hazard identified to minimize risk to the project



Project Risk	Severity			
Probability	I - Irrecoverable	II - Significant	III - Minor	IV – Negligible
A – Probable	AI	AII	AIII	AIV
B – May Occur	BI	BII	BIII	BIV
C - Unlikely	CI	CII	CIII	CIV
D – Highly Unlikely	DI	DII	DIII	DIV

Table 3 Project Risk Assessment Matrix

Project Plan

Budget

Overall Current Budget	
Component Budget	+ $8,860.50
Expenses Thus Far	-$4,399.25
Logistics Budget	+ $4,733.80
Total in Account	$9,195.05

- Things acquired thus far
  - Subscale components, Full-scale components, Body Tubes, Altimeters.
- Future expenses
  - Rocket Motors, Standardized hardware, Avionics Bay, Carbon Plate, Parachutes.

Timeline

- WPI COVID-19 policy bans clubs from meeting in person until February 11th and has been extended
- The team meets virtually until the ban is lifted and full construction and machining can take place
- In the meantime, the team has worked on learning and developing skills to ensure construction can happen as swiftly as possible
- Small construction has been taking place
- Hopeful launch at Lake Winnipesaukee High Powered Rocketry (LWHPR) #834 or Champlain Region Model Rocket Club #643
- Aiming to launch at any point from end March/mid April on

Questions?