CDR Presentation

Stony Brook University

NASA USLI 2019-2020

SHAPING THE FUTURE OF AEROSPACE

Stony Brook University
113 Light Engineering Building
Stony Brook, New York 11794-2300

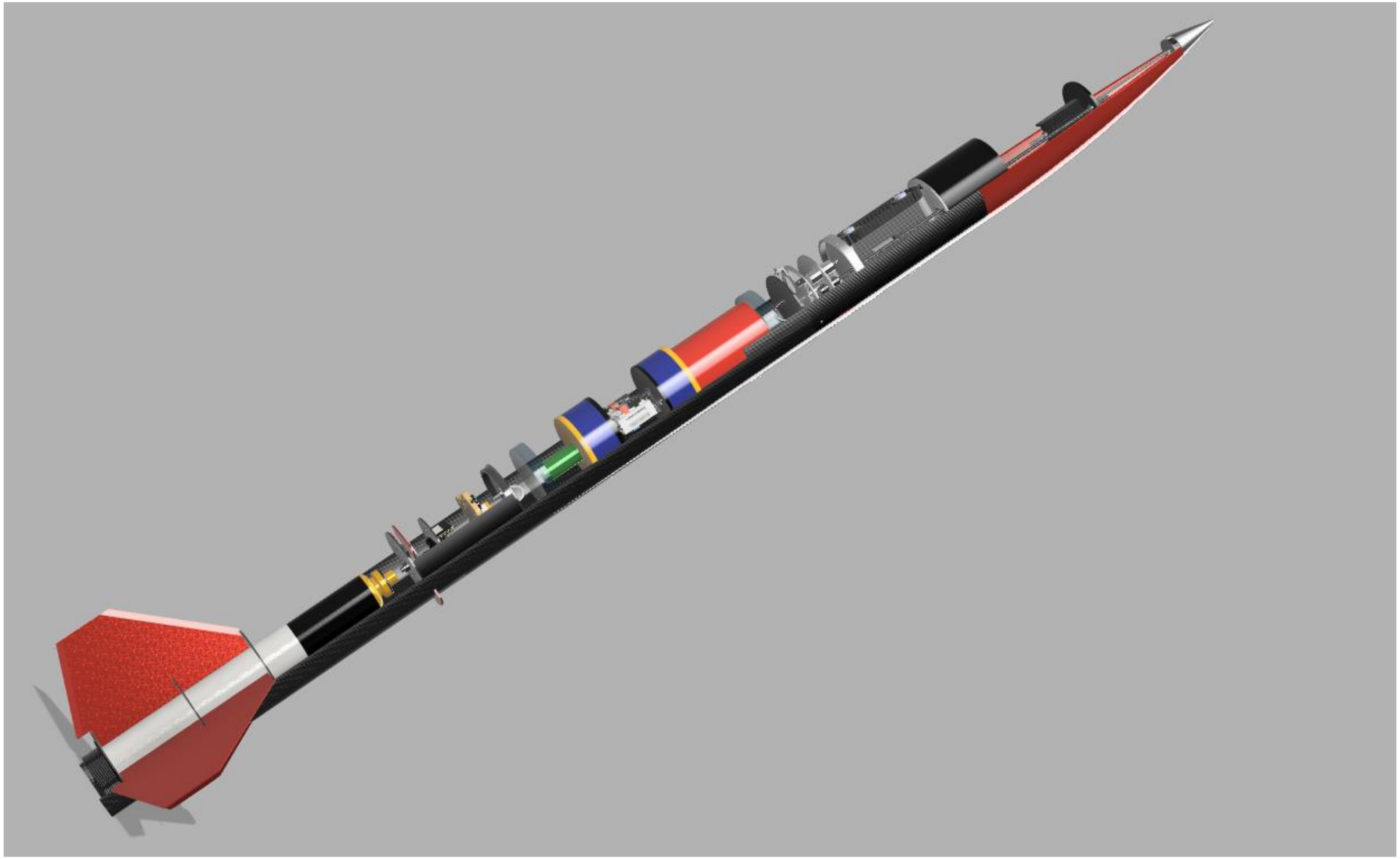
Agenda

i. **Launch Vehicle Design**
ii. Recovery Subsystem
iii. Payload Design
iv. Integration & Summary
v. Subscale Launch
vi. Requirements Verification & Safety

Launch Vehicle Design: Overview

Total Length (in)	Diameter (in)	Lift Off Weight (lb)	Airframe Material	Fin Material & Thickness	Coupler Lengths
107	6.17	47.1	Braided CF	1/8” (G10 Fiberglass)	9”/6” Shoulder

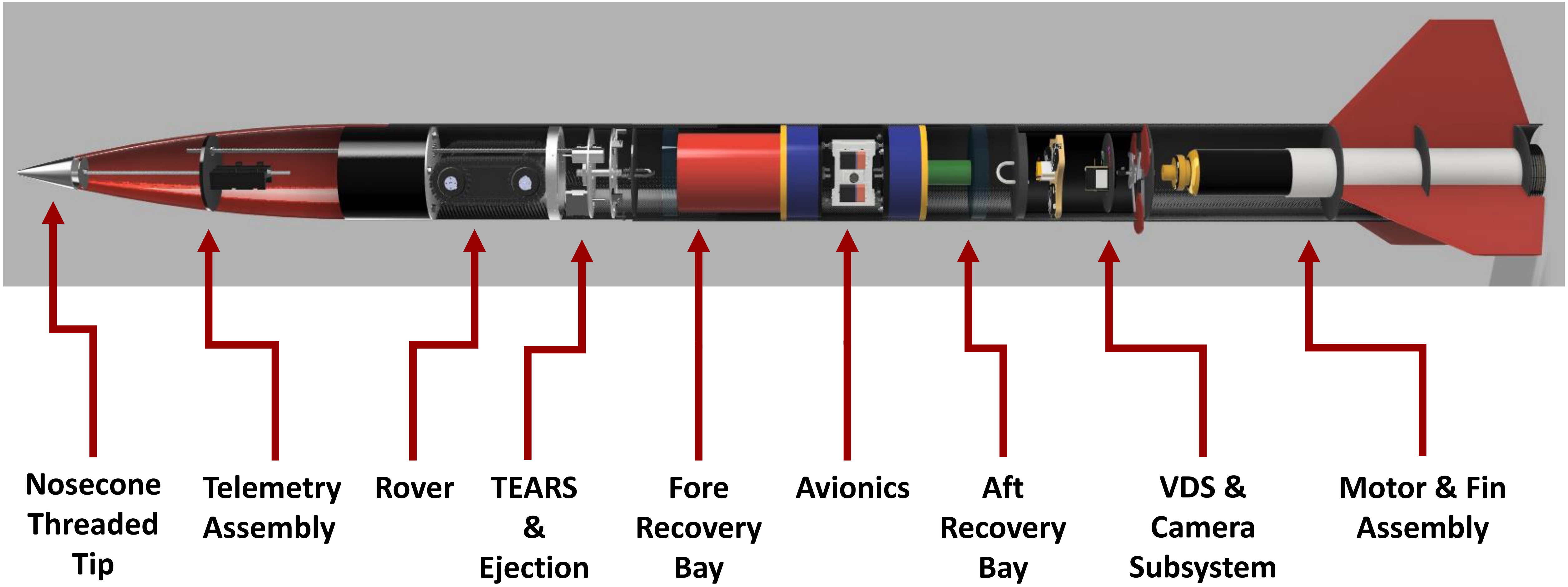
Launch Vehicle Design: Overview



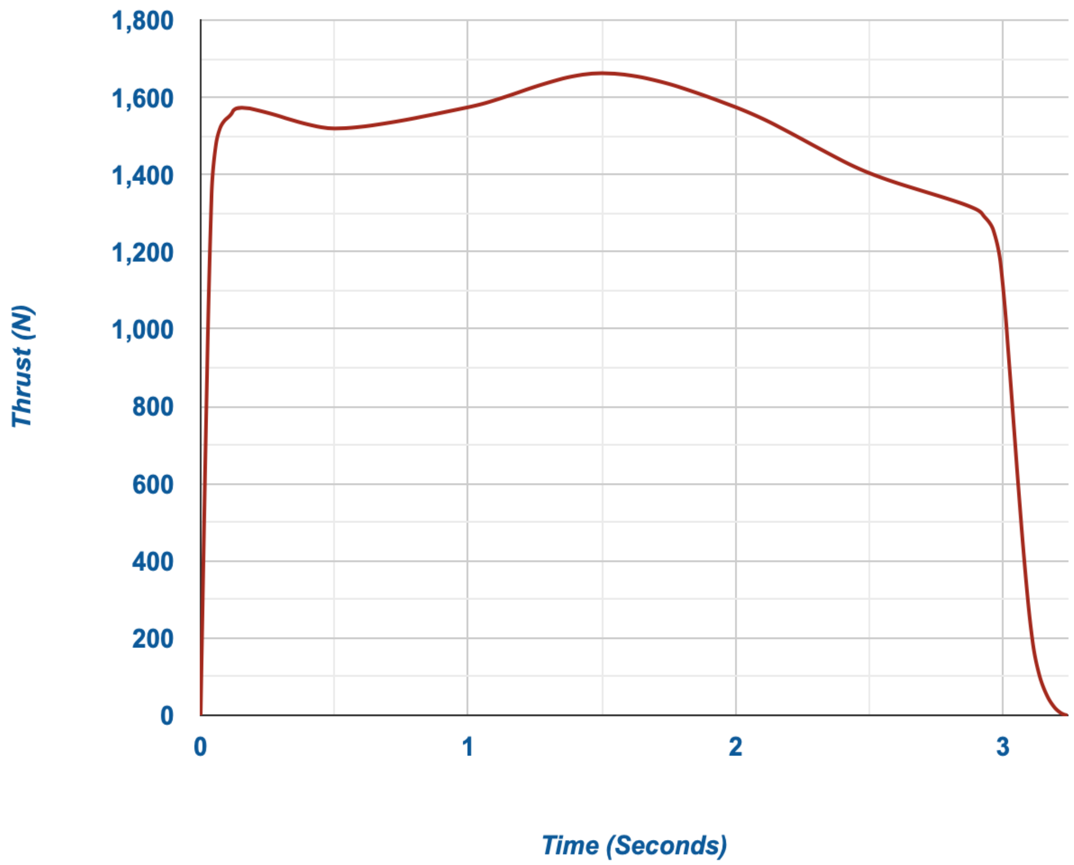
Key Changes Since PDR

- Length increased by 2”
- Mass decreased by 2.2 lbs
- Airframe tubing changed from G12 fiberglass to braided carbon fiber
- Size of main chute increased to 120”
- Size of drogue chute decreased to 18”

Launch Vehicle Design: Overview

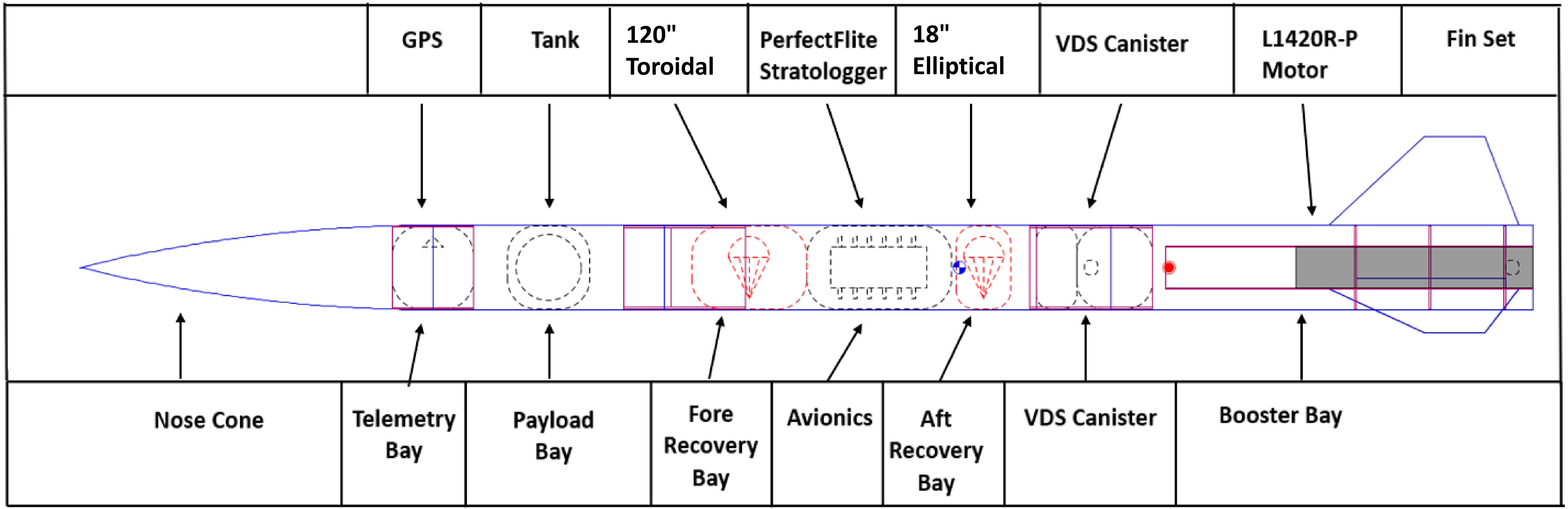


Launch Vehicle Design: Motor Properties



Motor Properties	
Brand	Aerotech L1420R-P
Max/Average Thrust (lbf)	407.8/319.9
Total Impulse (lbf-sec)	1035
Mass Before/After Burn (lbm)	10.05/4.47
Motor Retention Method	Screw On Retainer (Aeropack)

Launch Vehicle Design: Stability Analysis



CP (in from nose)	CG (in from nose)	Static Stability Margin (on pad)	Static Stability Margin (at rail exit)	Thrust-To-Weight Ratio	Rail Exit Velocity (ft/s)
80.139	64.721	2.50	2.5625	8.66	59.9

Launch Vehicle Design: Altitude Predictions

Launch Rod At 7.5 Degrees

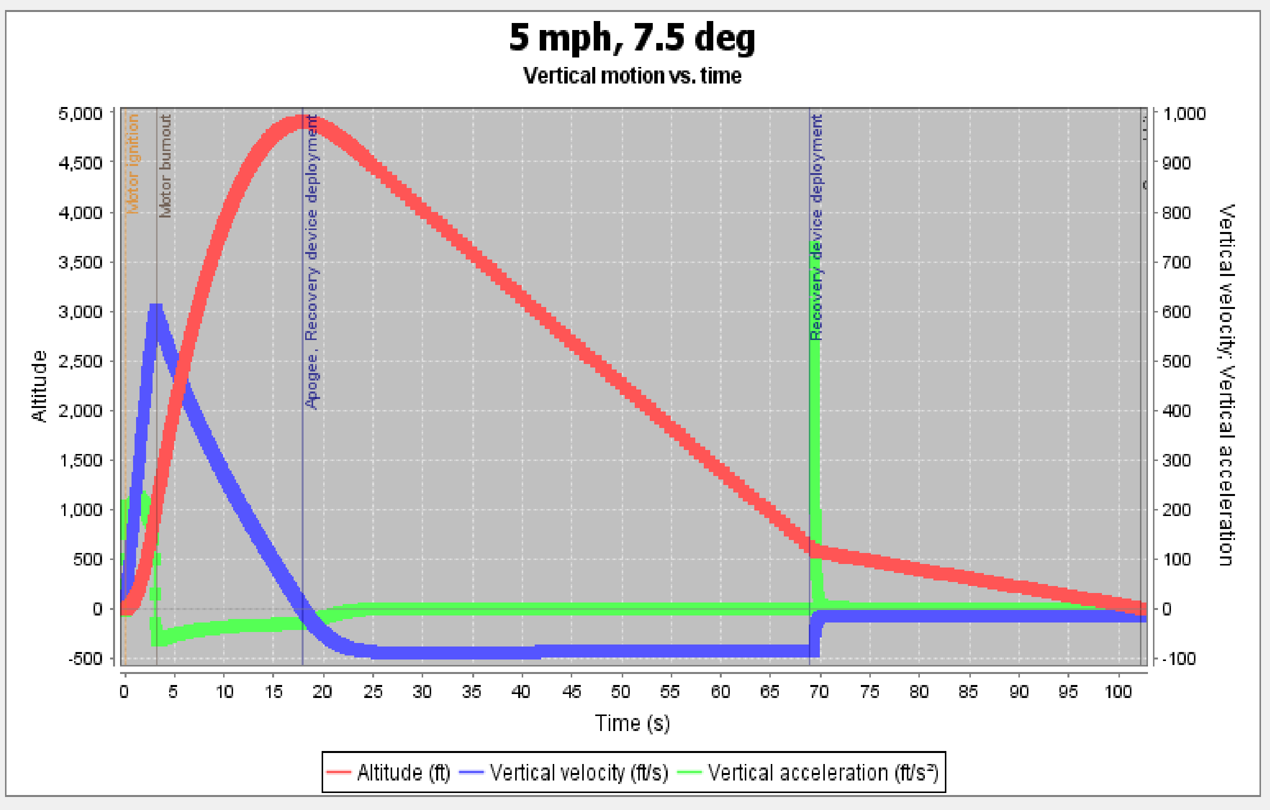
	Apogee (ft)	Velocity off Rod (ft/s)	Time to Apogee (s)	Flight Time (s)	Descent Time (s)
0 mph	4986	59.9	18.0	103	85
5 mph	4908	59.9	17.9	102	84.1
10 mph	4800	59.9	17.7	101	83.3
15 mph	4720	59.9	17.5	99.8	82.3
20 mph	4611	59.9	17.3	99.7	82.4

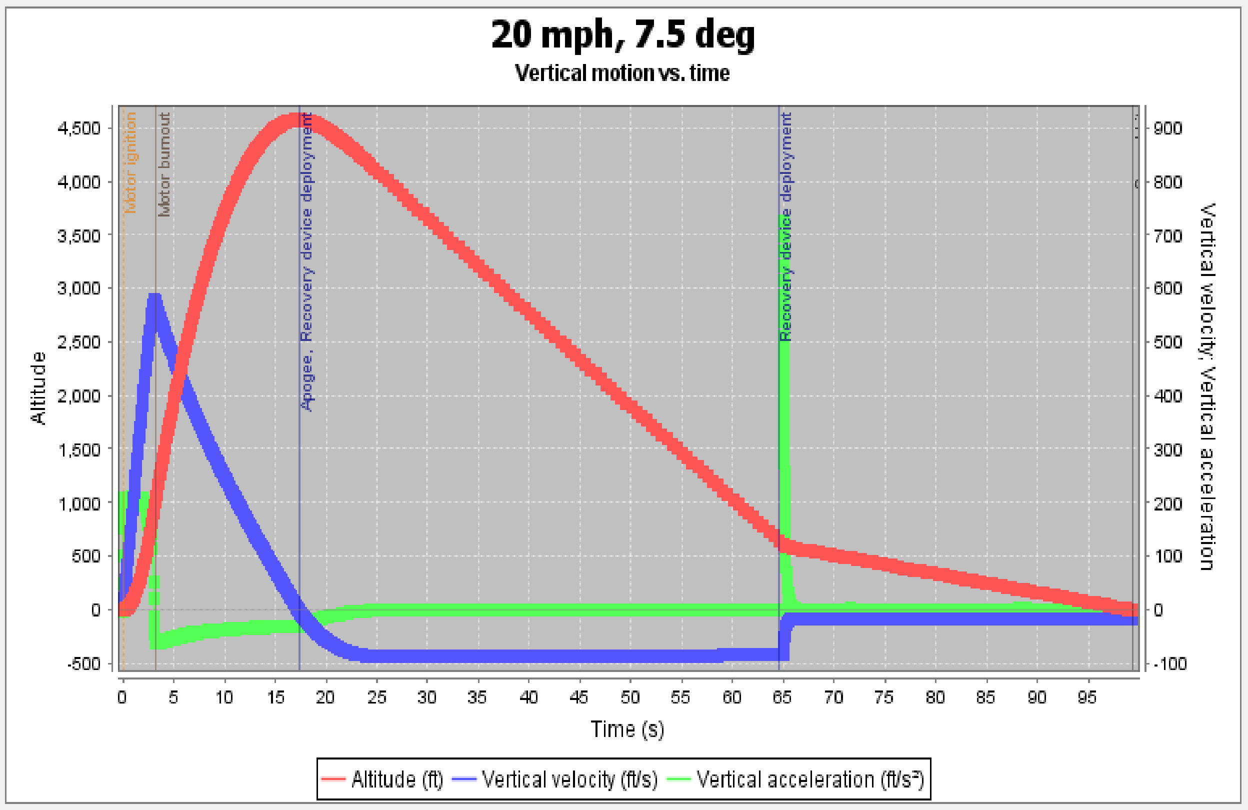
Launch Rod At 10.0 Degrees

	Apogee (ft)	Velocity off Rod (ft/s)	Time to Apogee (s)	Flight Time (s)	Descent Time (s)
0 mph	4895	60	17.9	103	85.1
5 mph	4800	60	17.7	101	83.3
10 mph	4712	60	17.5	99.9	82.4
15 mph	4571	59.9	17.2	98	80.8
20 mph	4484	59.9	17.1	96.8	79.7

Max Velocity (ft/s)	Max Mach Number	Max Acceleration (ft/s^2)	Target Apogee (ft)	Best Case Projected Apogee (ft)
615.0	0.55	231	4500	5104

Launch Vehicle Design: Ascent Analysis





Launch Vehicle Design: Mass Breakdown

Avionics Bay Mass Breakdown	
32.9" Airframe	2.54 lb
Avionics Equipment	2.98 lb
Main Bay	1.78 lb
Drogue Bay	0.286 lb
Subtotal	7.586

Payload Bay Mass Breakdown	
19" PAY Airframe	1.47 lb
Rover & PAY Assemblies	8.7 lb
Bulkhead & U-Bolts	0.37 lb
9" Coupler	1.27 lb
Subtotal	11.81

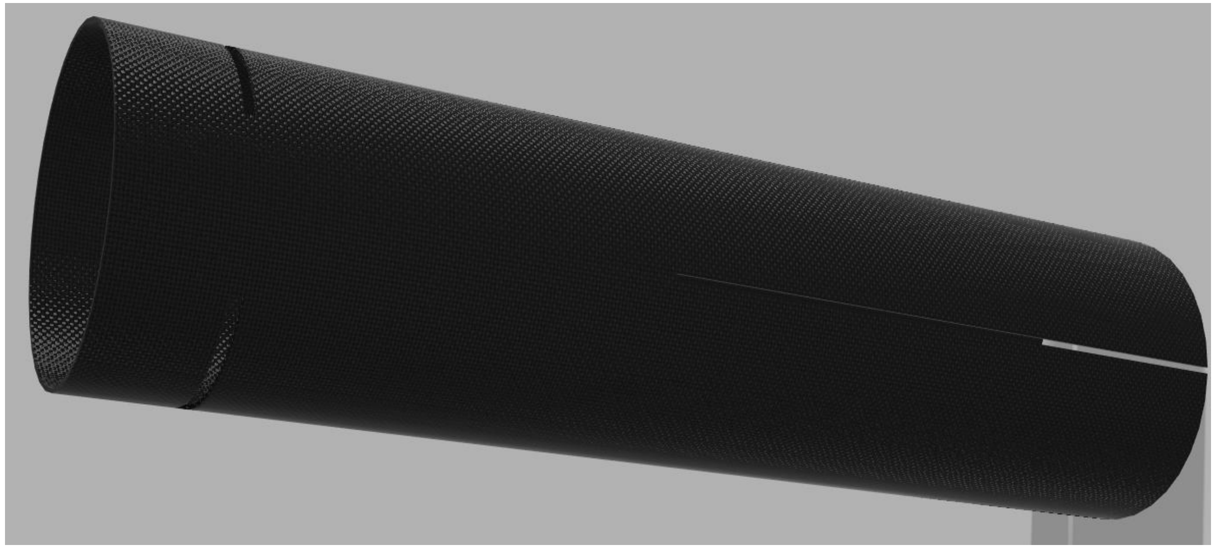
Booster Bay Mass Breakdown	
33" Airframe	2.4 lb
Centering Rings	0.57 lb
16" Motor Tube	0.786 lb
VDS	2.2 lb
Camera Bay	0.5 lb
Fins	2.4 lb
Epoxy	2.5 lb
9" Coupler	1.27 lb
Motor & Hardware	10.1 lb
Motor Retainer	0.31 lb
Total	23.036 lb

Nosecone & Telemetry Bay	
Nosecone	3.0 lb
6" Coupler	0.829 lb
Telemetry & PAY	0.8 lb
Subtotal	4.629 lb

Total Vehicle Mass Breakdown	
NC & Telemetry	4.629 lb
PAY Bay	11.81 lb
Avionics Bay	7.586 lb
Booster Bay	23.036 lb
Total Unloaded Mass	41.5
Total Loaded Mass	47.1

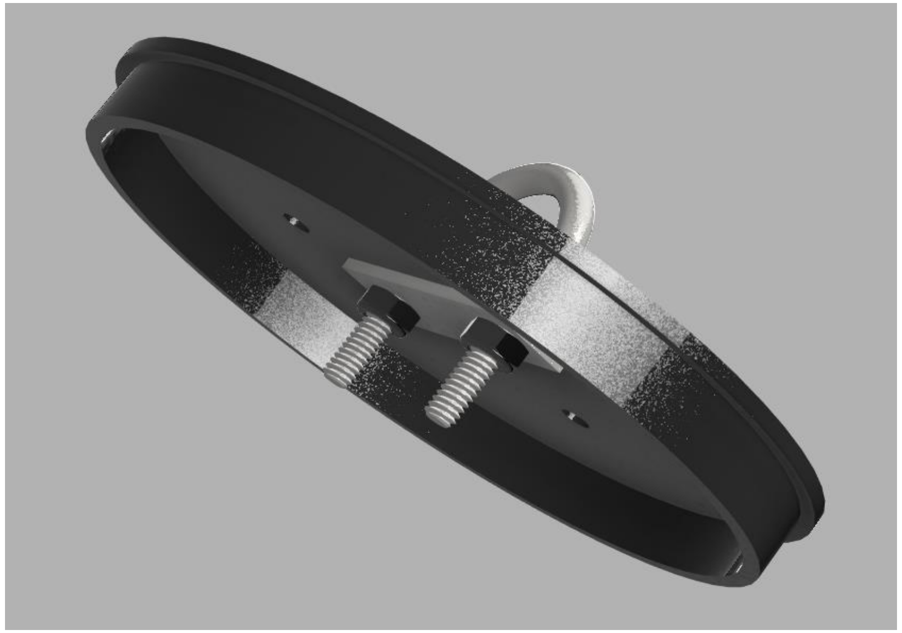
Mass Margin ~ 1.5 lbs (3.18%)

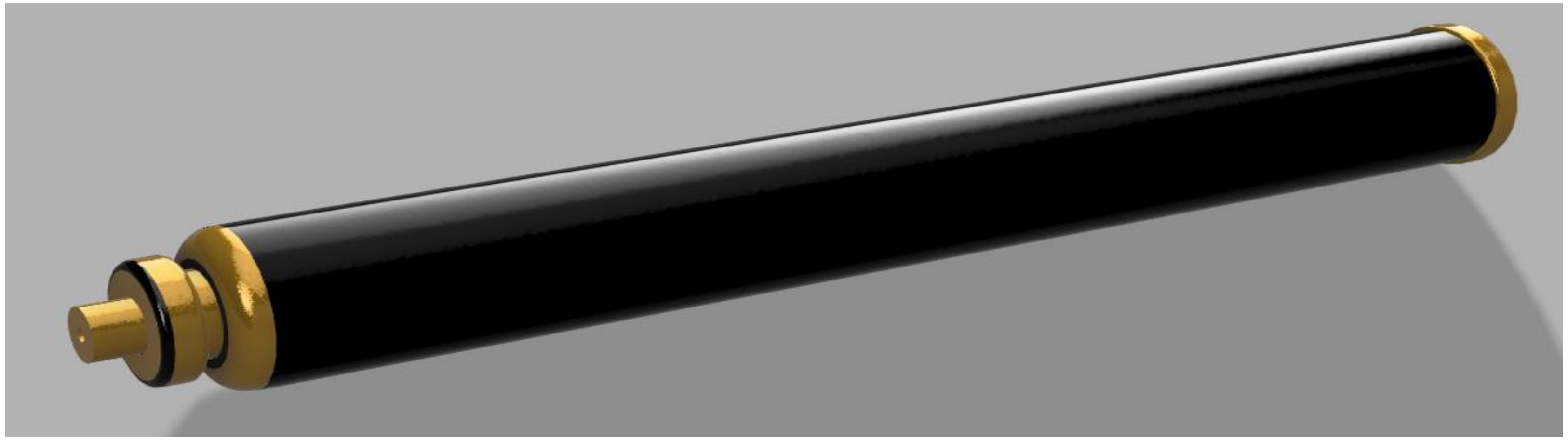
Launch Vehicle Design: Braided CF Airframe

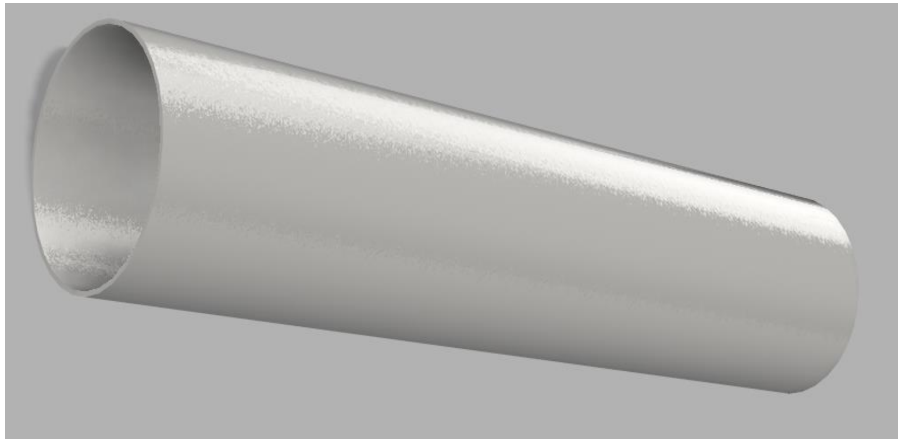


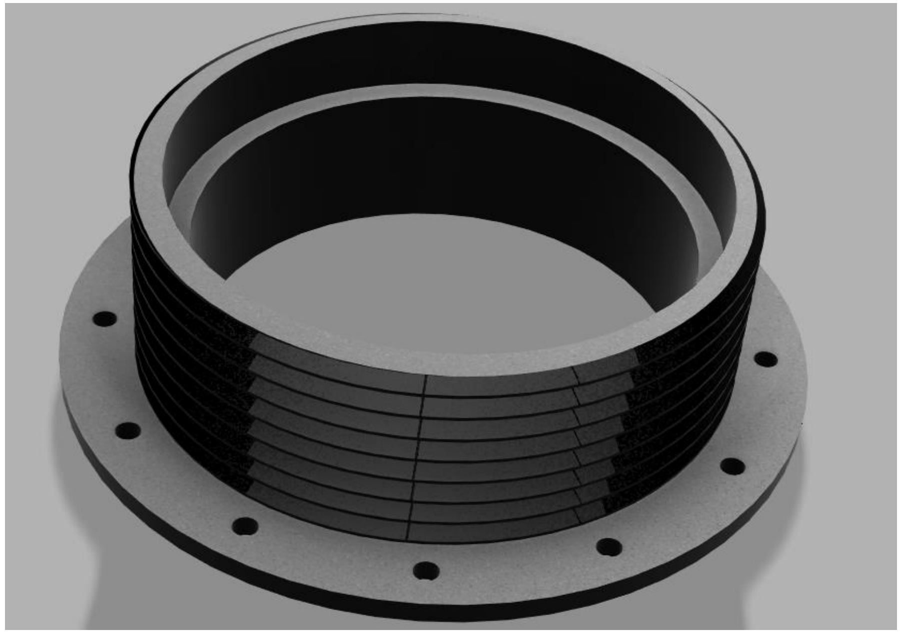
1. 40% Cheaper than conventional quasi-isotropic CF Tubing
2. Stronger than conventional G12 fiberglass tubing
3. Smooth inner surface (6” ID)
4. Somewhat rough OD (a tad bit more friction drag)

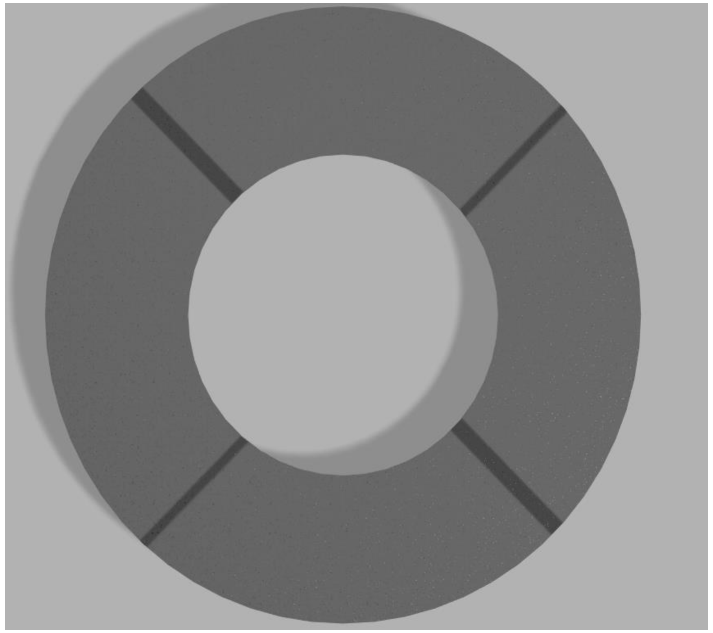
Launch Vehicle Design: Bulkheads & Hardware



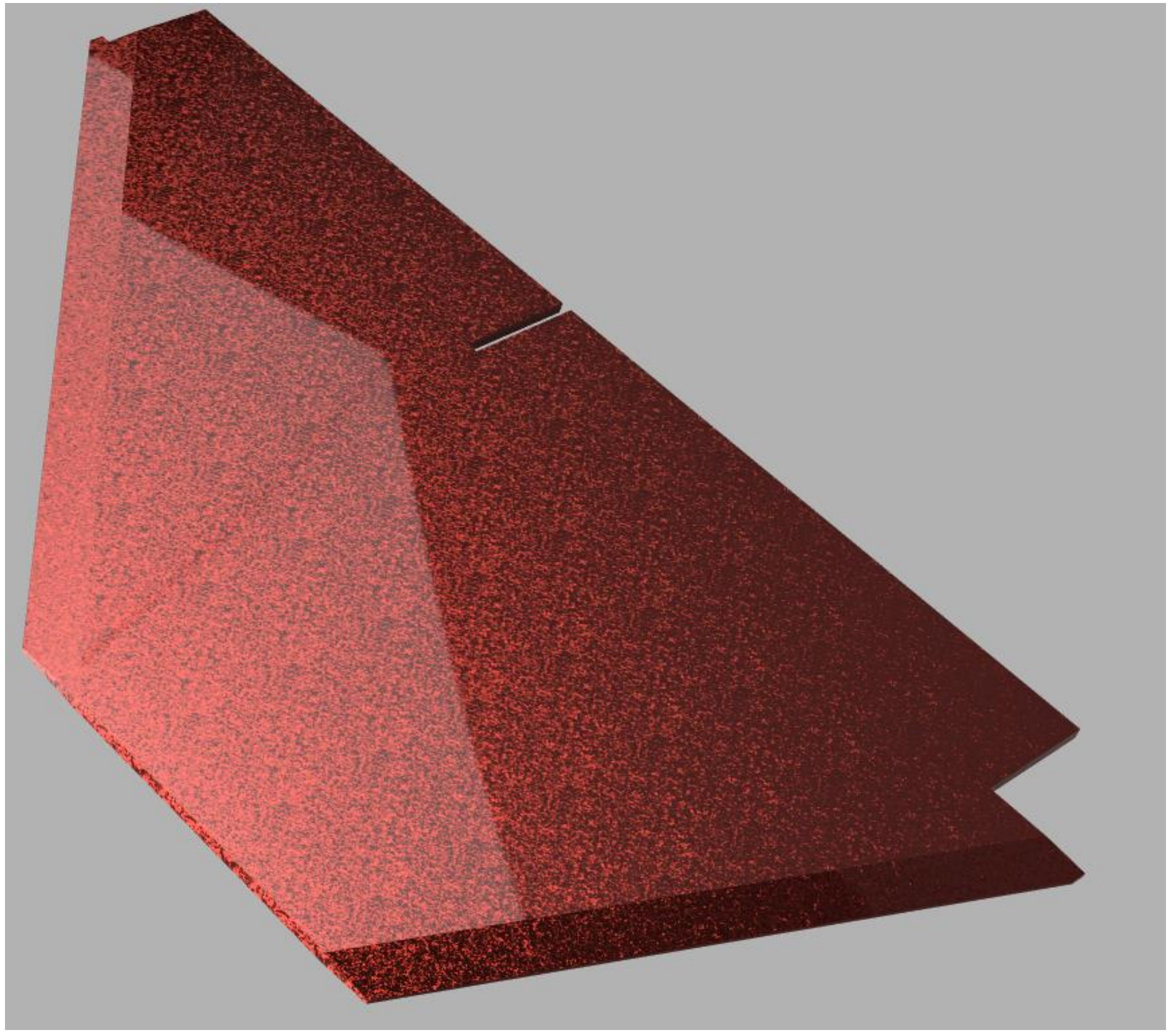


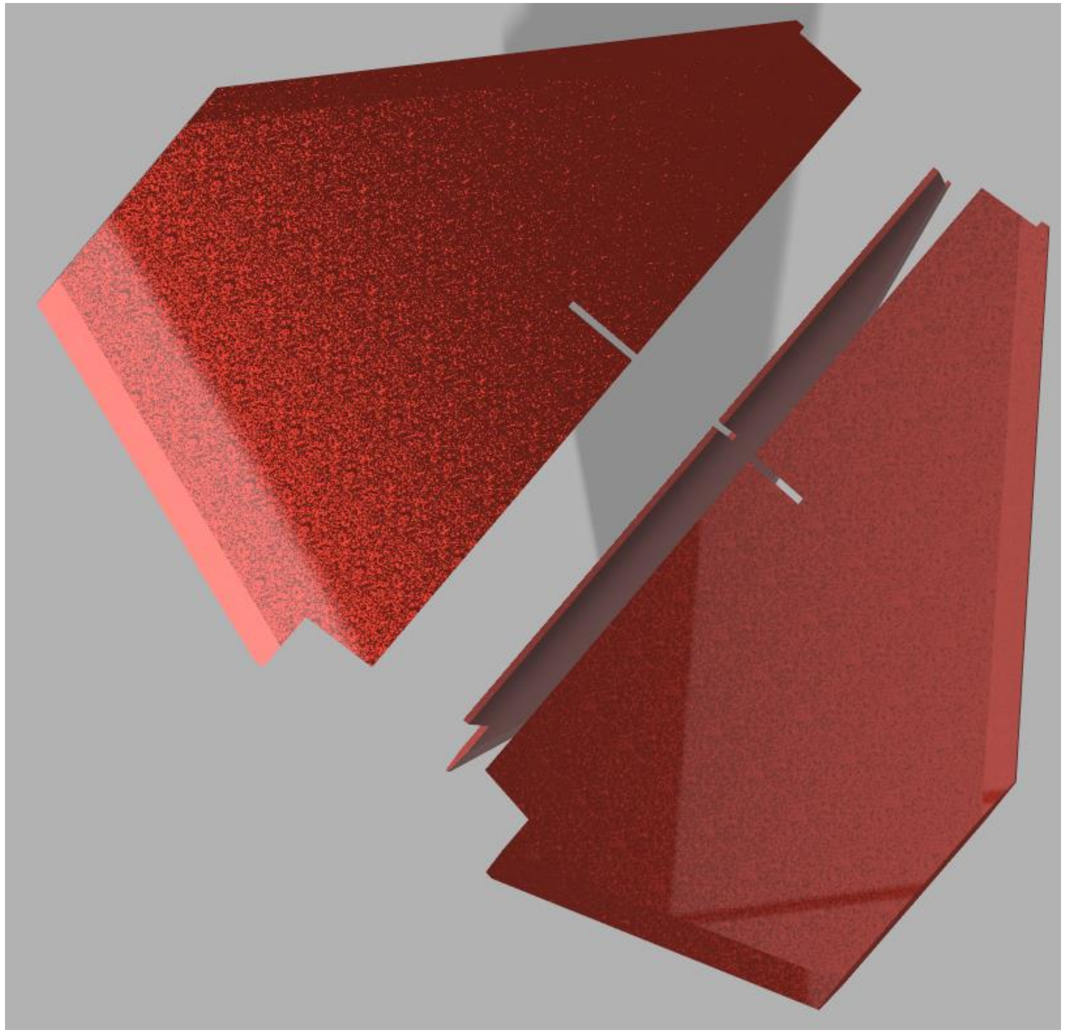






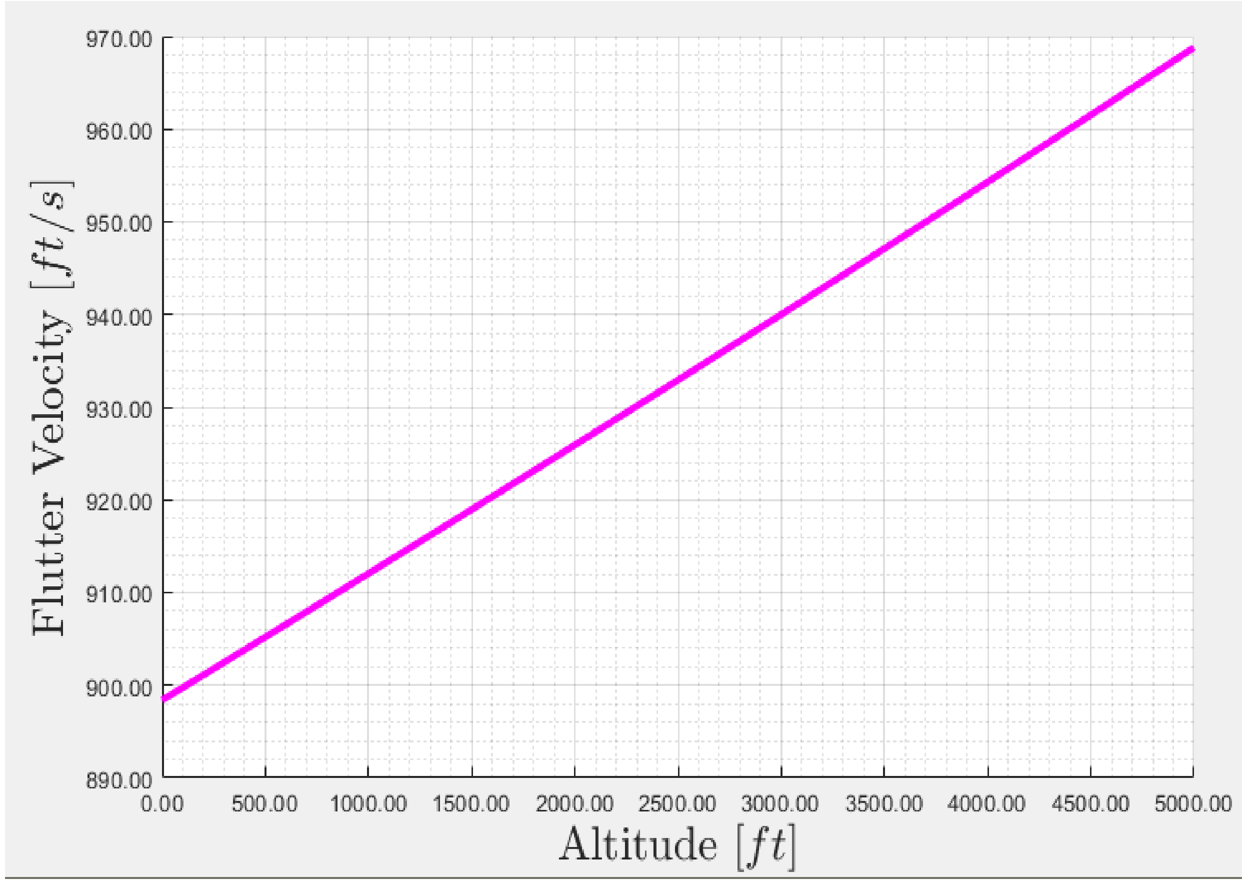
Launch Vehicle Design: Fins





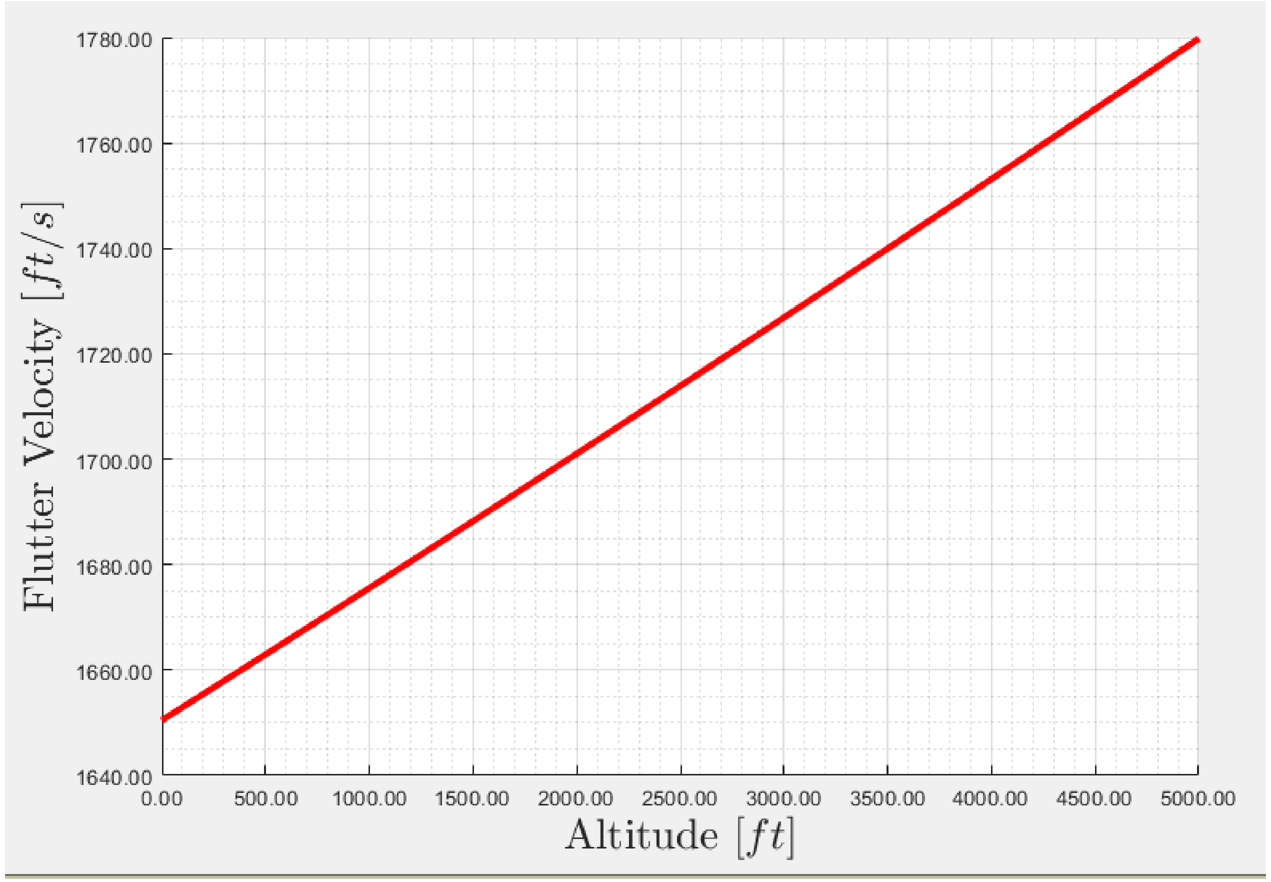
Launch Vehicle Design: Fin Flutter

0.125” G10 Fiberglass



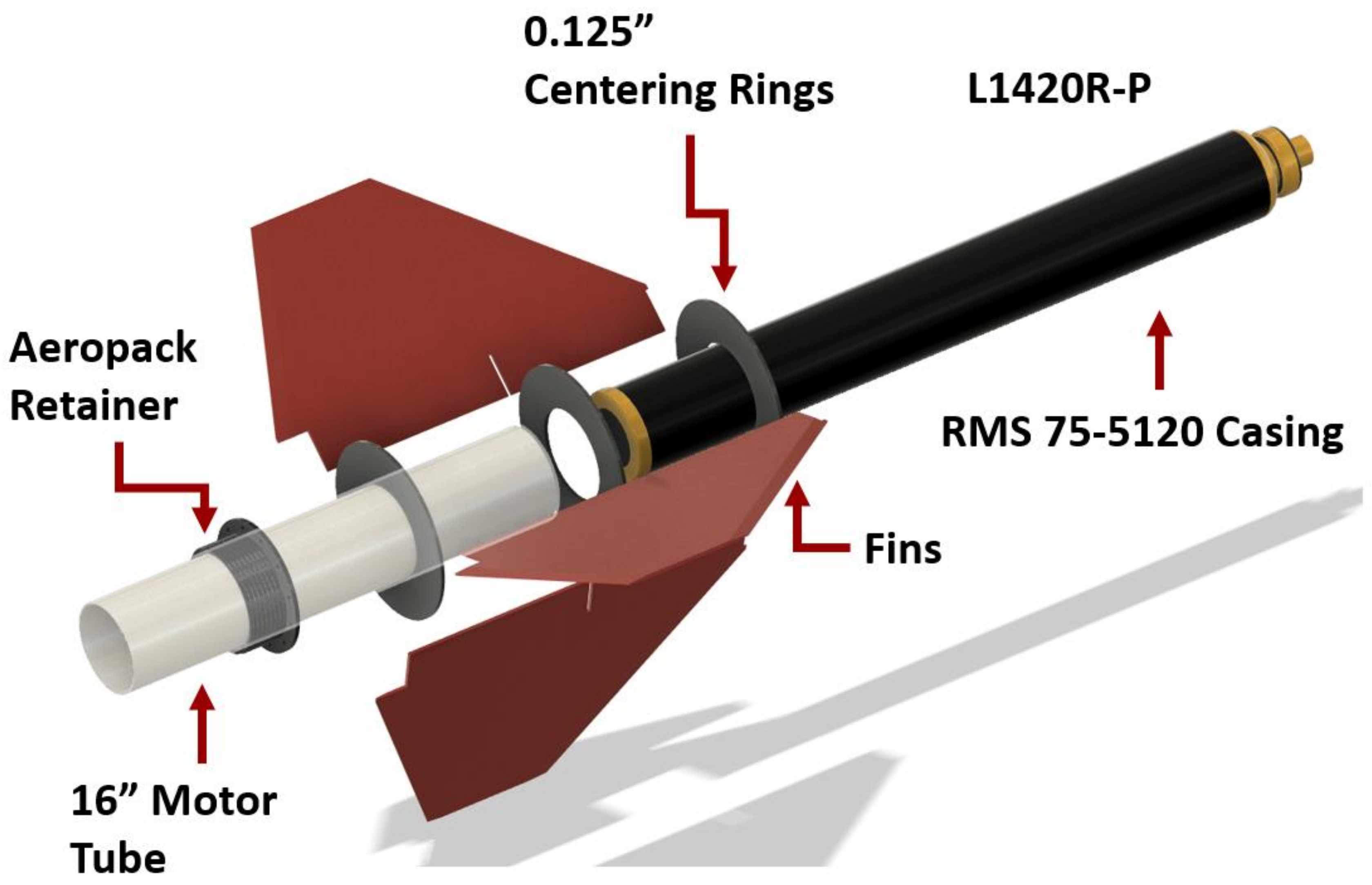
Flutter Velocity: 940 ft/s
SF: 1.53

0.1875” G10 Fiberglass

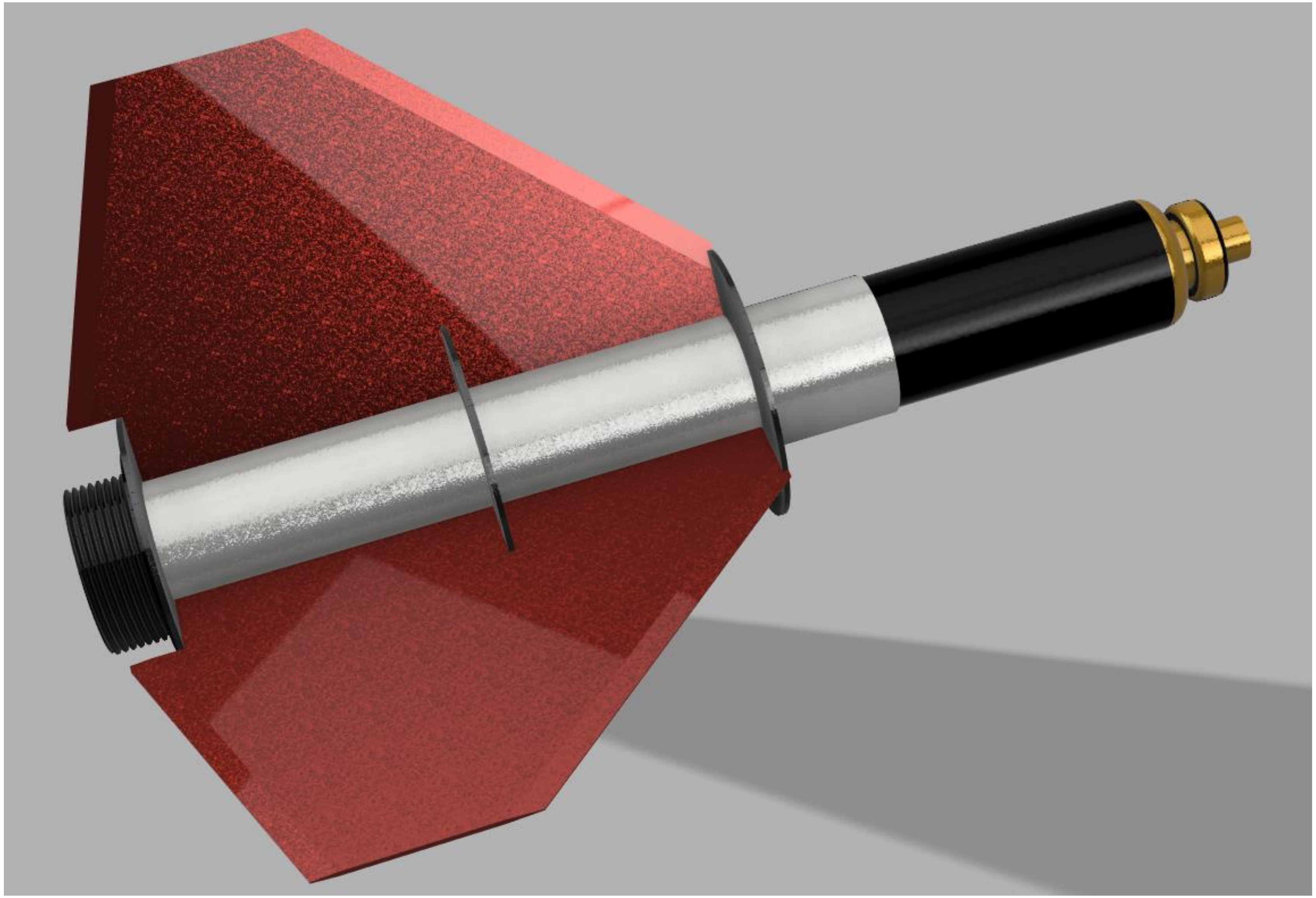


Flutter Velocity: 1727 ft/s
SF: 2.81

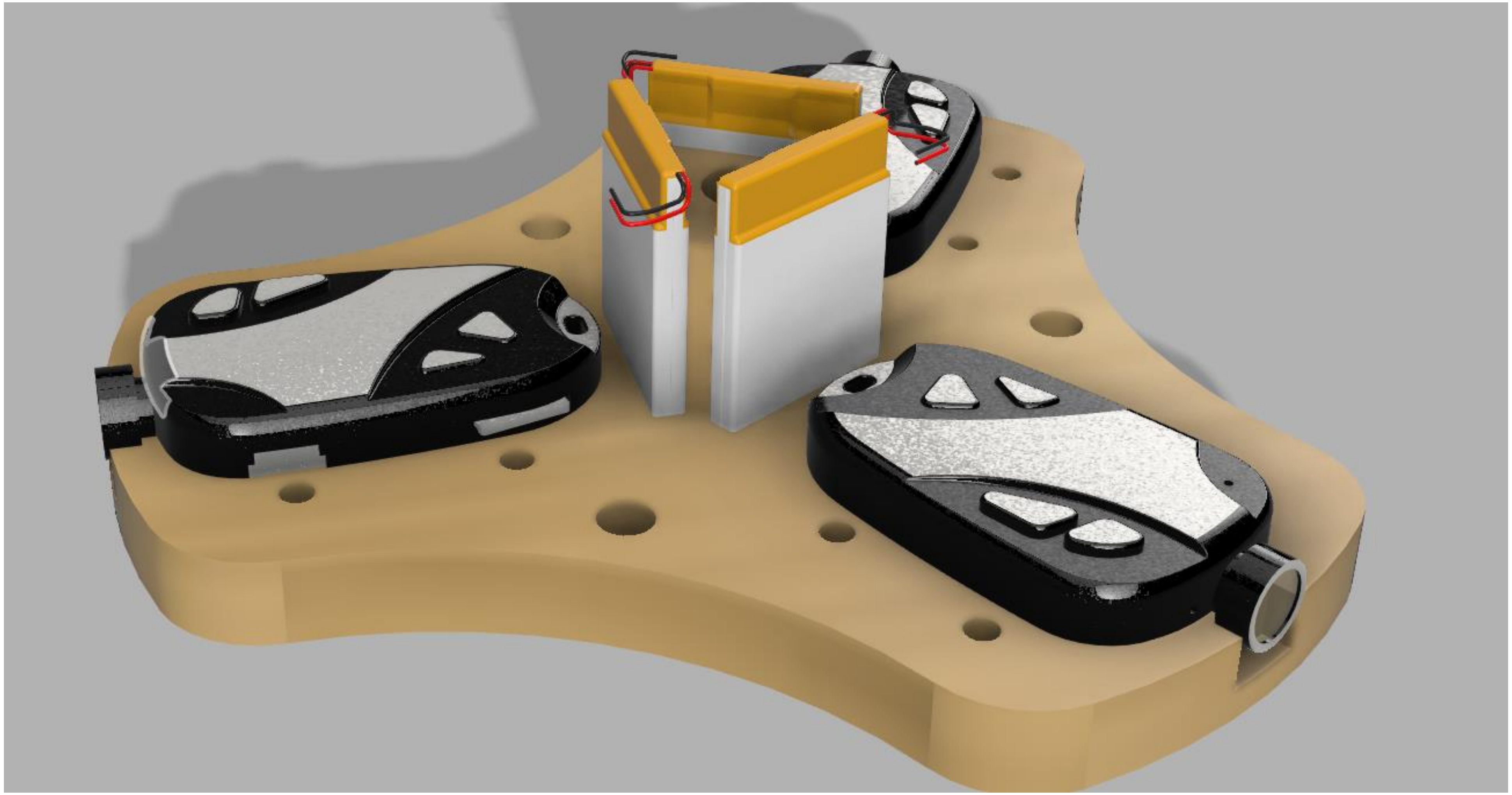
Launch Vehicle Design: Fins Assembly



Launch Vehicle Design: Motor & Fins Assembly

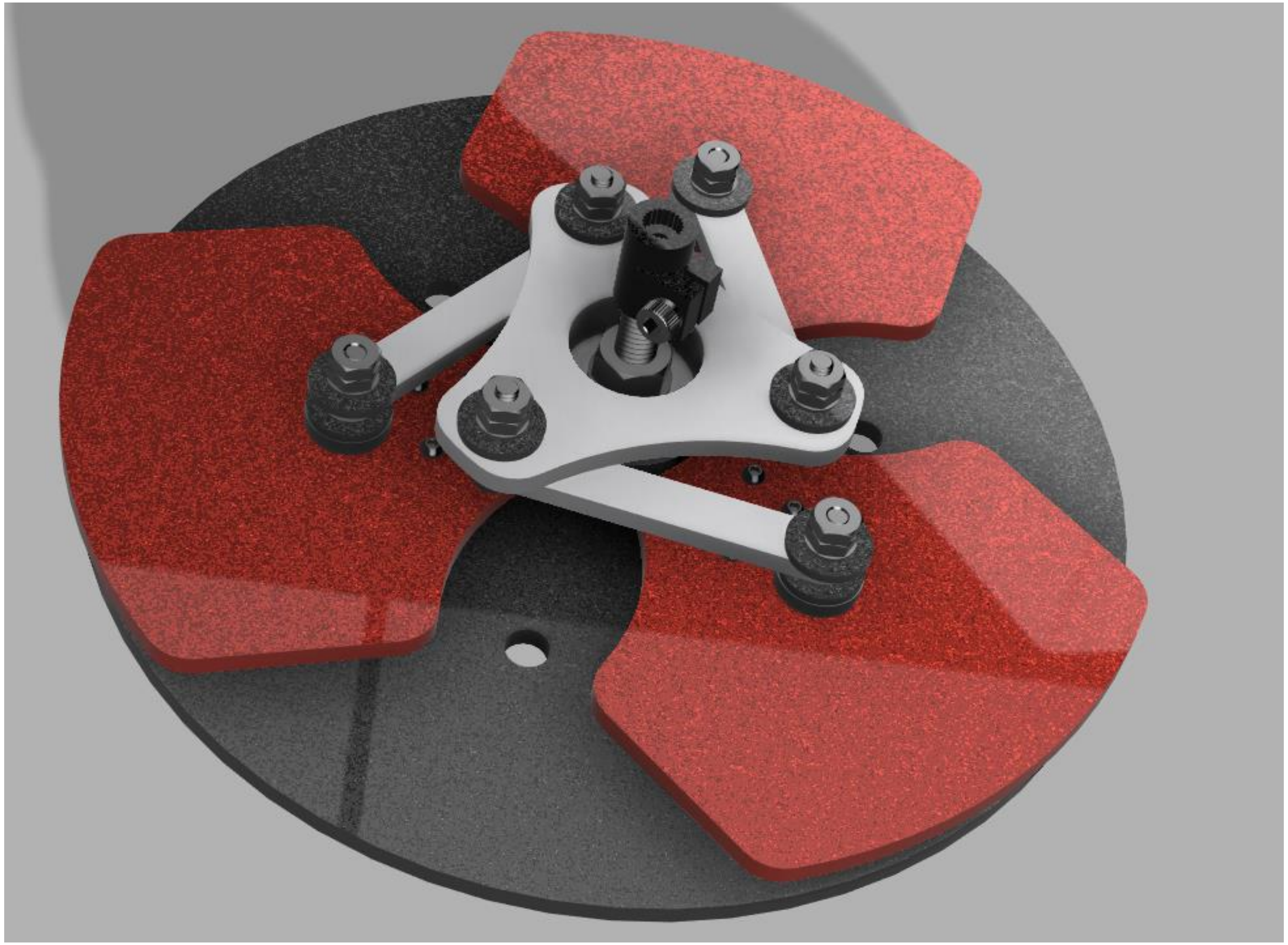


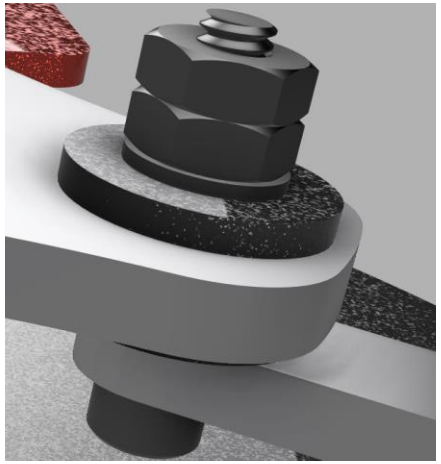
Launch Vehicle Design: Camera Bay

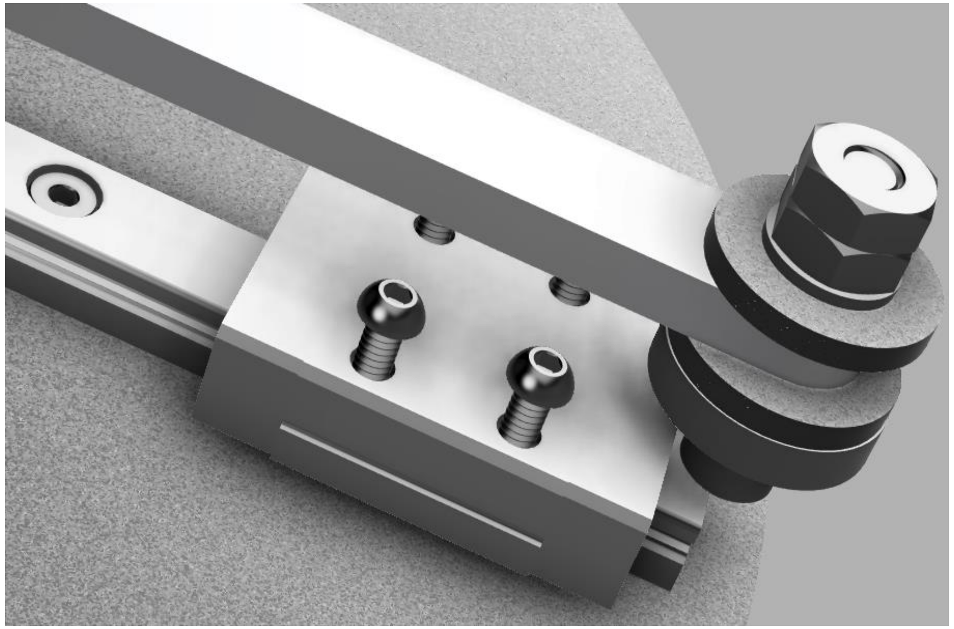


1. 3x 808 #16 Keychain Cameras
2. Boosted with 700 mAh Batteries
3. ~3 hr Recording Time at 60 FPS
4. Retained w/ 3D Printed Housing

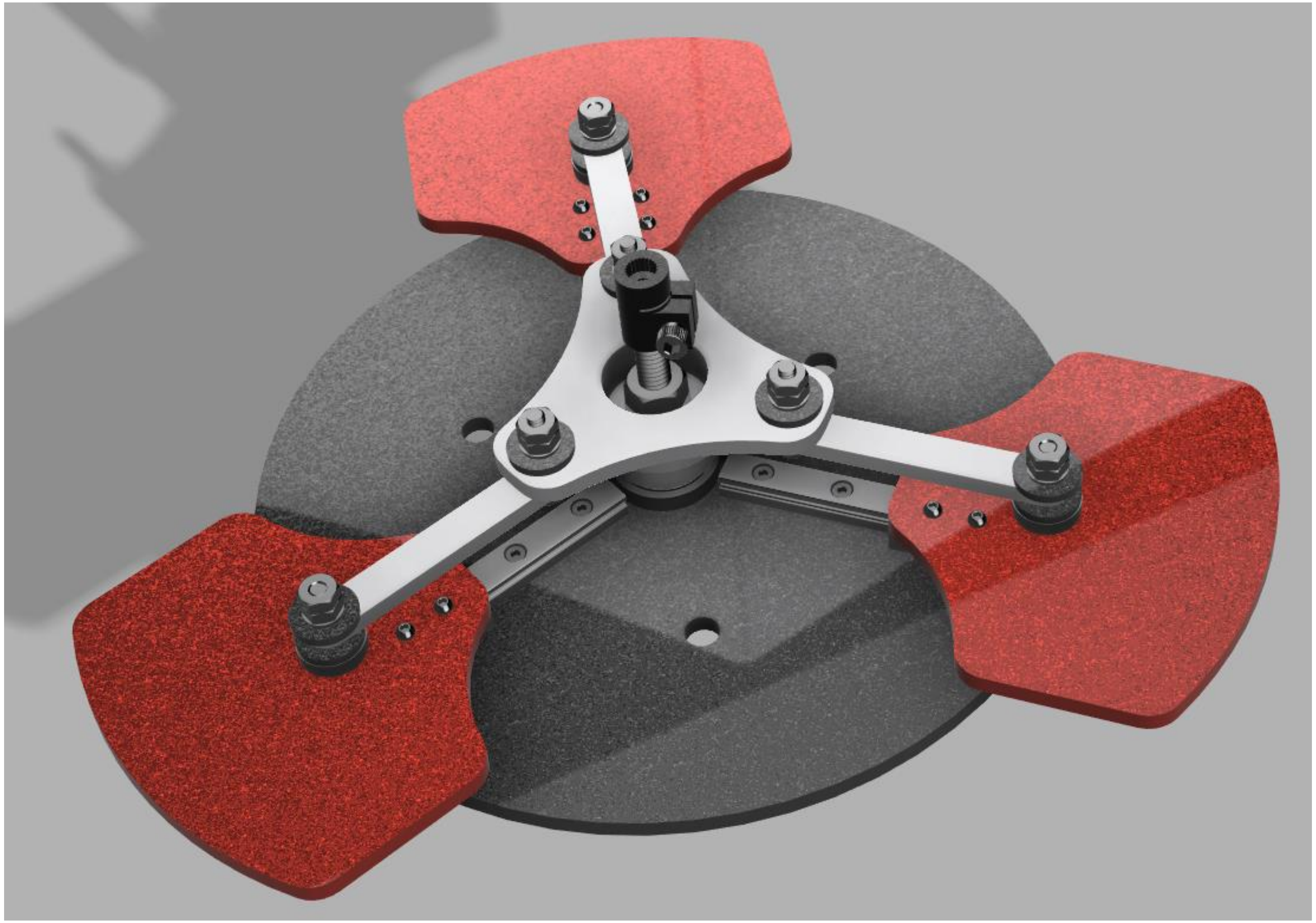
Launch Vehicle Design: VDS

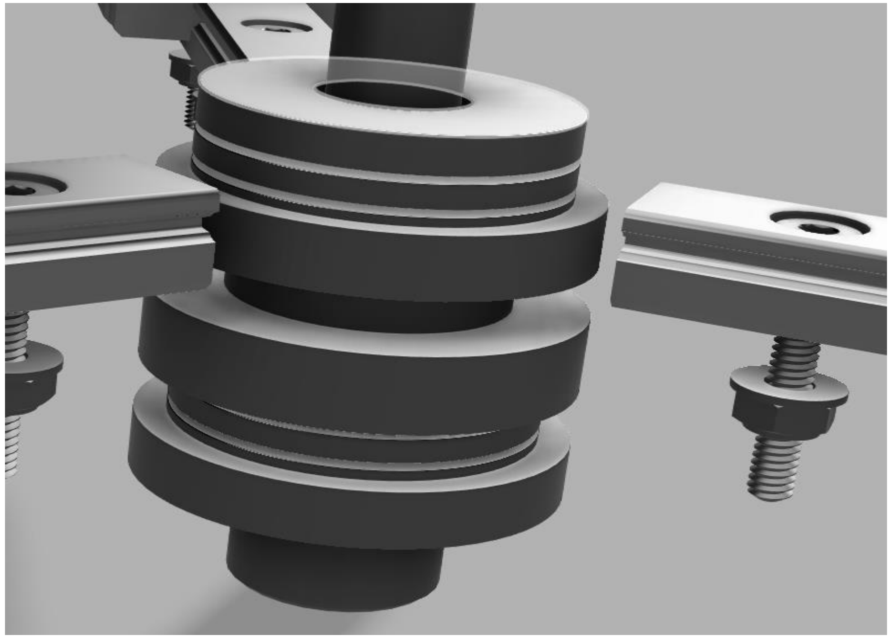


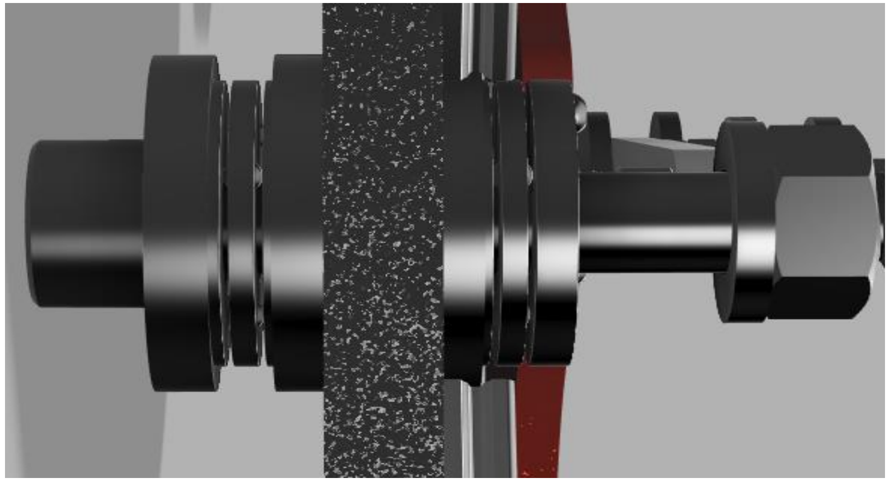




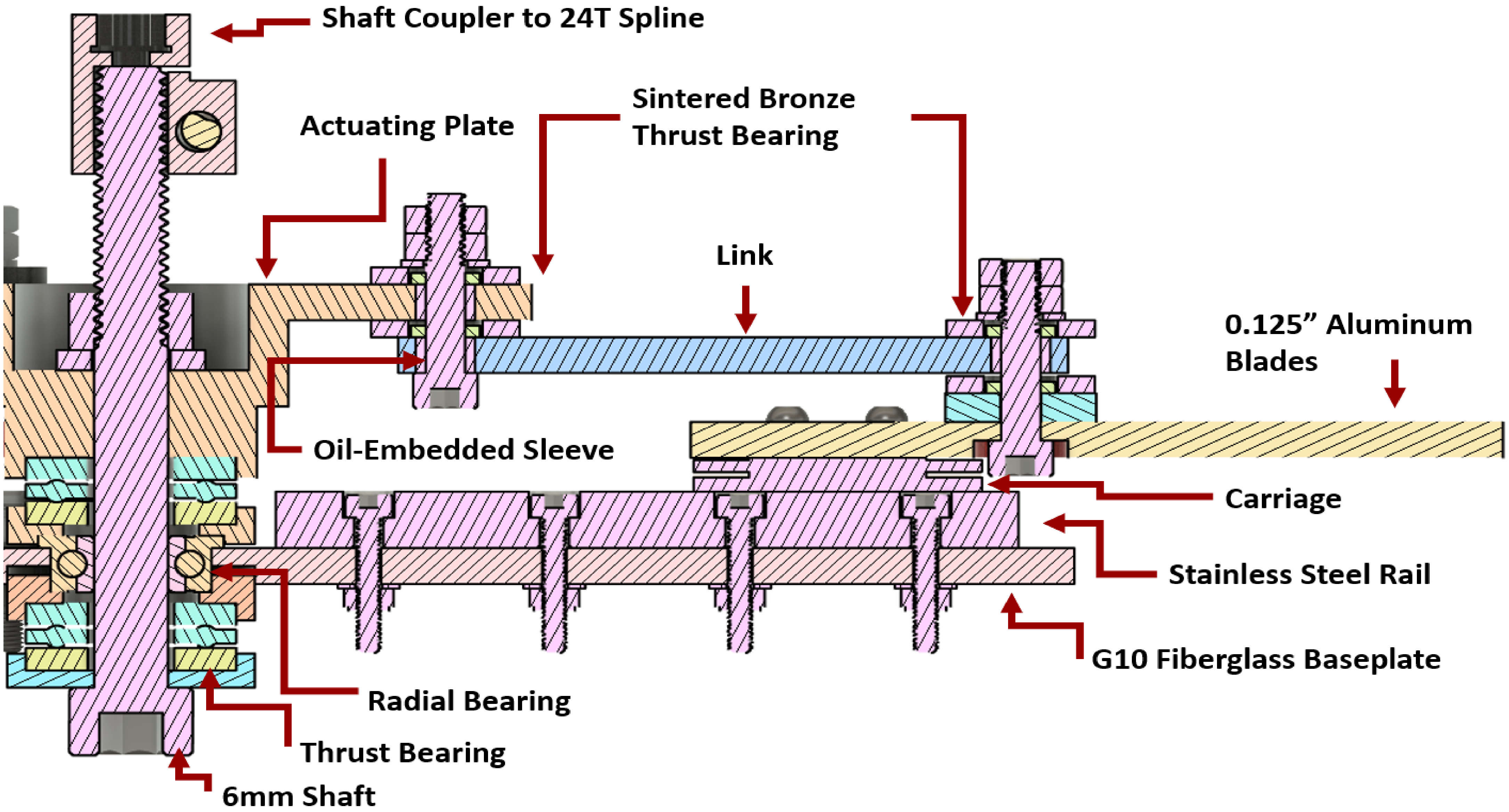
Launch Vehicle Design: VDS





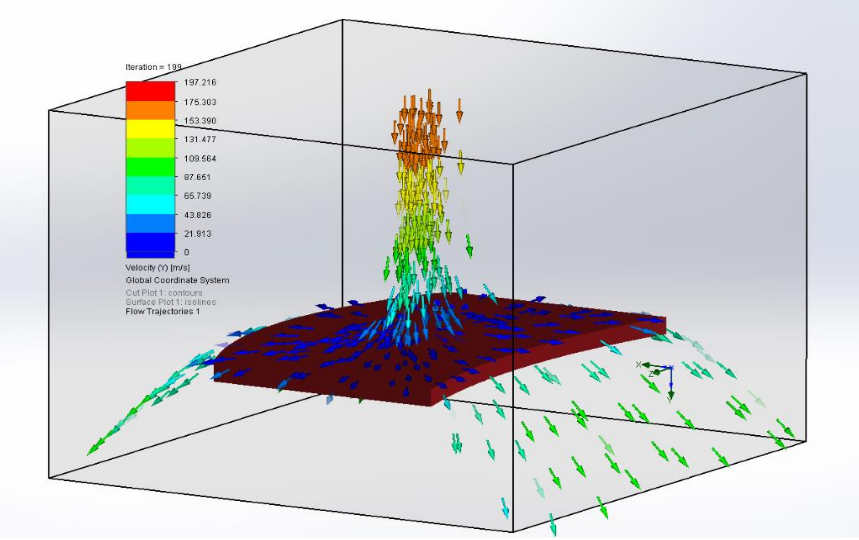


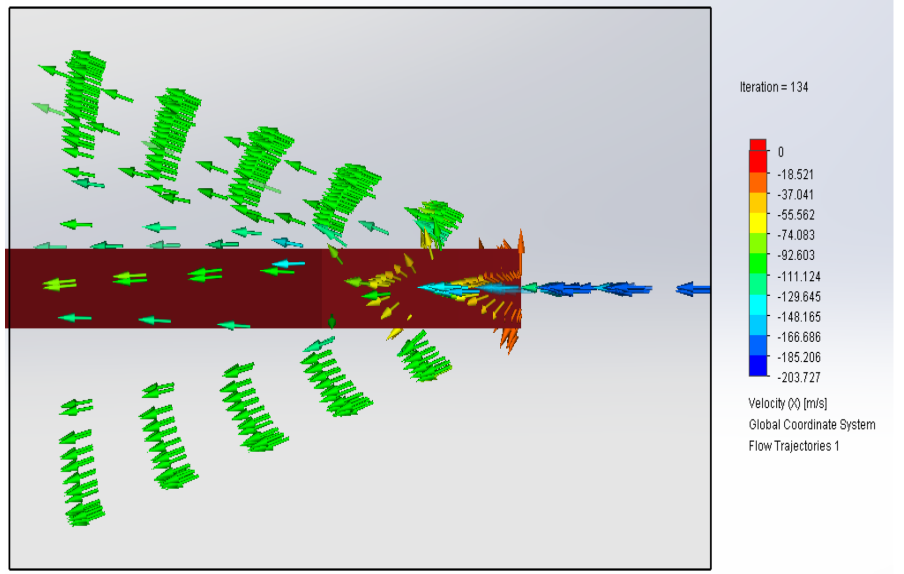
Launch Vehicle Design: VDS



Launch Vehicle Design: VDS CFD Results

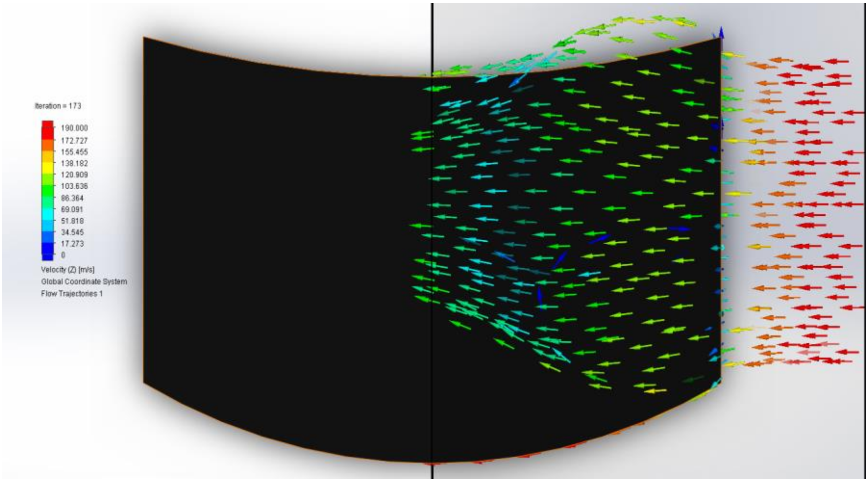
VDS CFD Results (z-flow)	
Final Drag Force (lbf)	19.35
Final Drag Coefficient	18.55
Max Drag Force (lbf)	19.97
Max Drag Coefficient	1.22
Iterations	150





VDS CFD Results (x-flow)	
Final Drag Force (lbf)	1.086
Final Drag Coefficient	0.621
Min Drag Force (lbf)	1.05
Max Drag Force (lbf)	1.11
Max Drag Coefficient	0.633
Iterations	135

VDS CFD Results (y-flow)	
Final Drag Force (lbf)	0.59
Final Drag Coefficient	0.62
Max Drag Force (lbf)	0.59
Max Drag Coefficient	0.62
Iterations	150



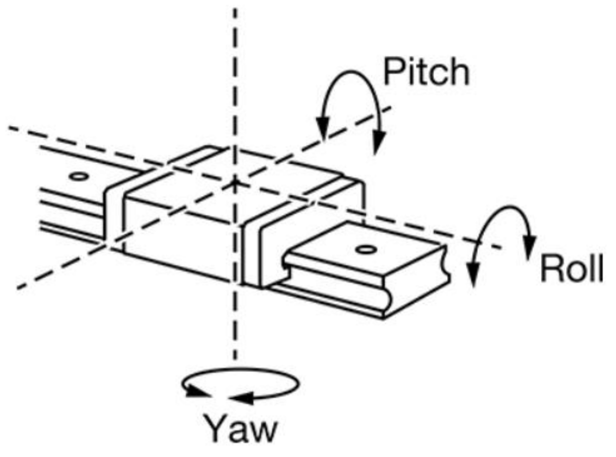
Launch Vehicle Design: VDS CFD Results

Max Moments (lbf-ft)	
Yaw	0.023
Pitch	1.73
Roll	0.021

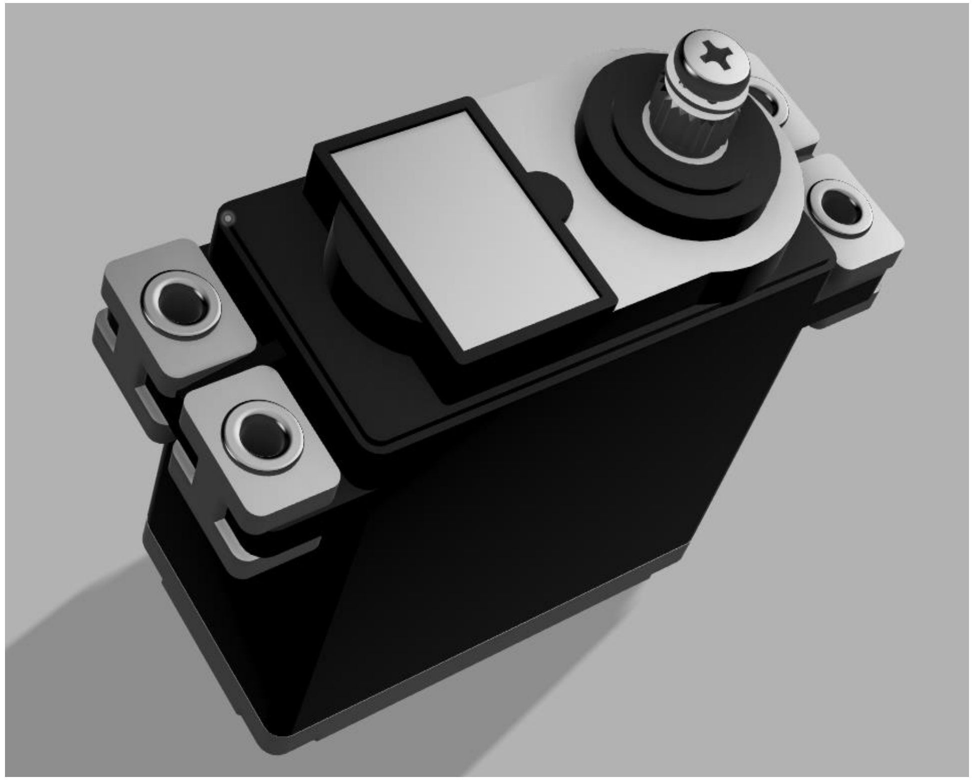
Max Capacities (lbf-ft)	
Yaw	2.8
Pitch	3.4
Roll	5.0

Max Moments SF	
Yaw	121.7
Pitch	1.97
Roll	41.3

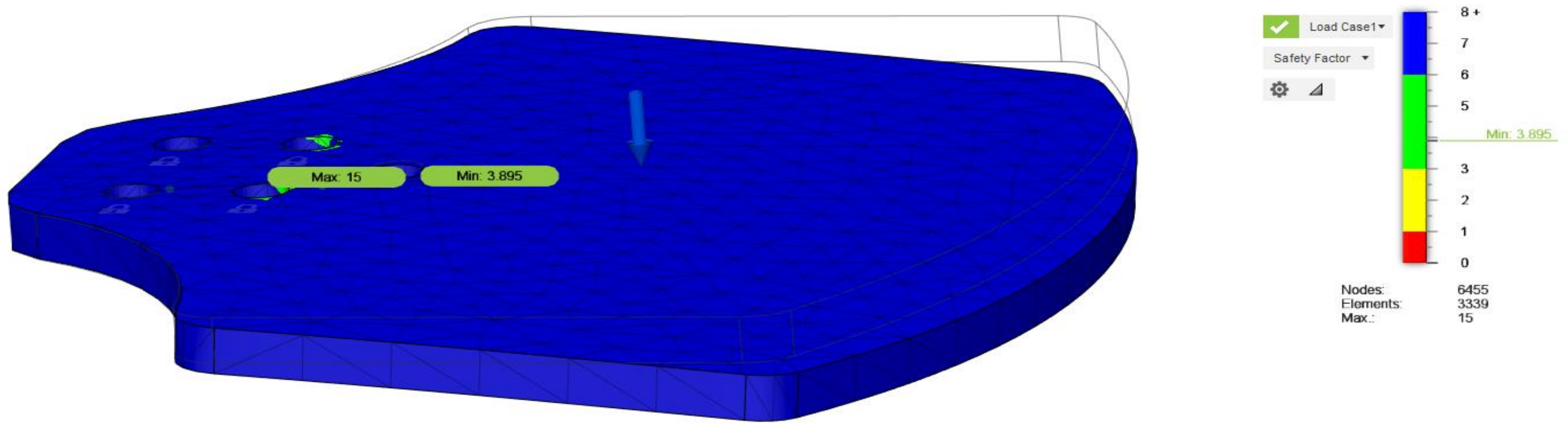
VDS Motor Characteristics	
Voltage Range	6.0V – 7.4V
Stall Torque (6.0V)	194 oz-in
Stall Torque (7.4V)	236 oz-in
Required Torque	86.5
SF	2.73

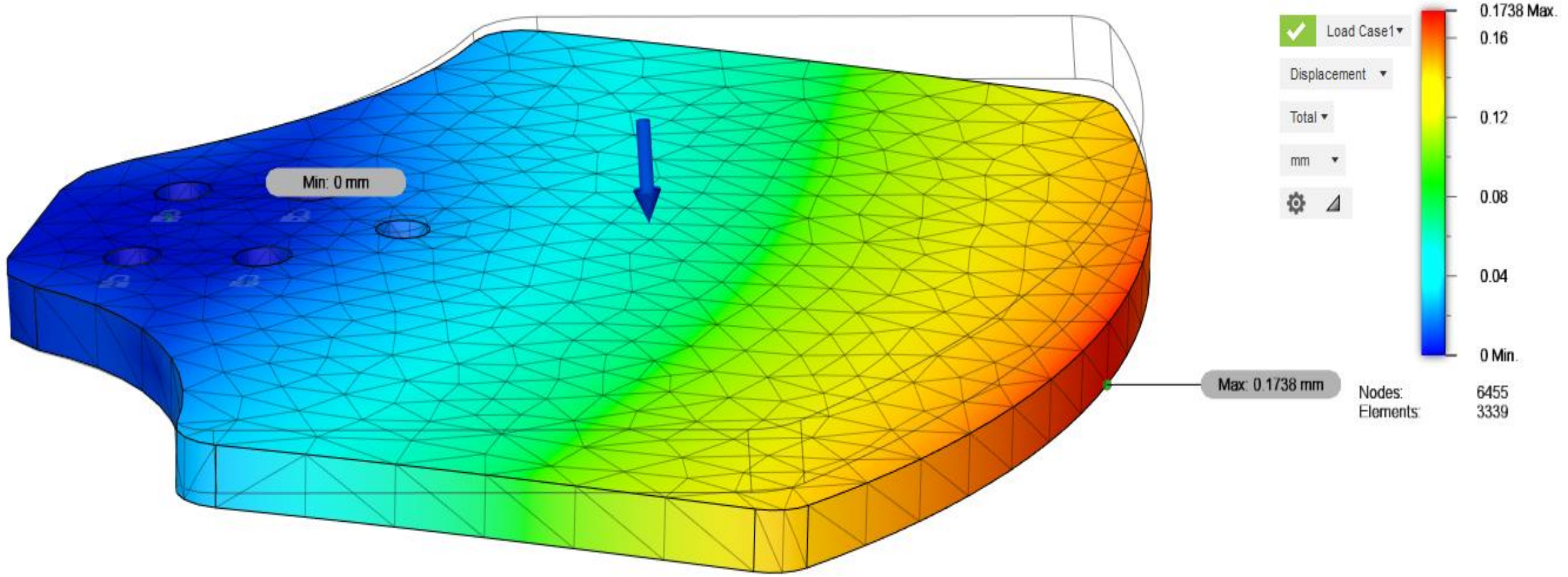


Moment Loads



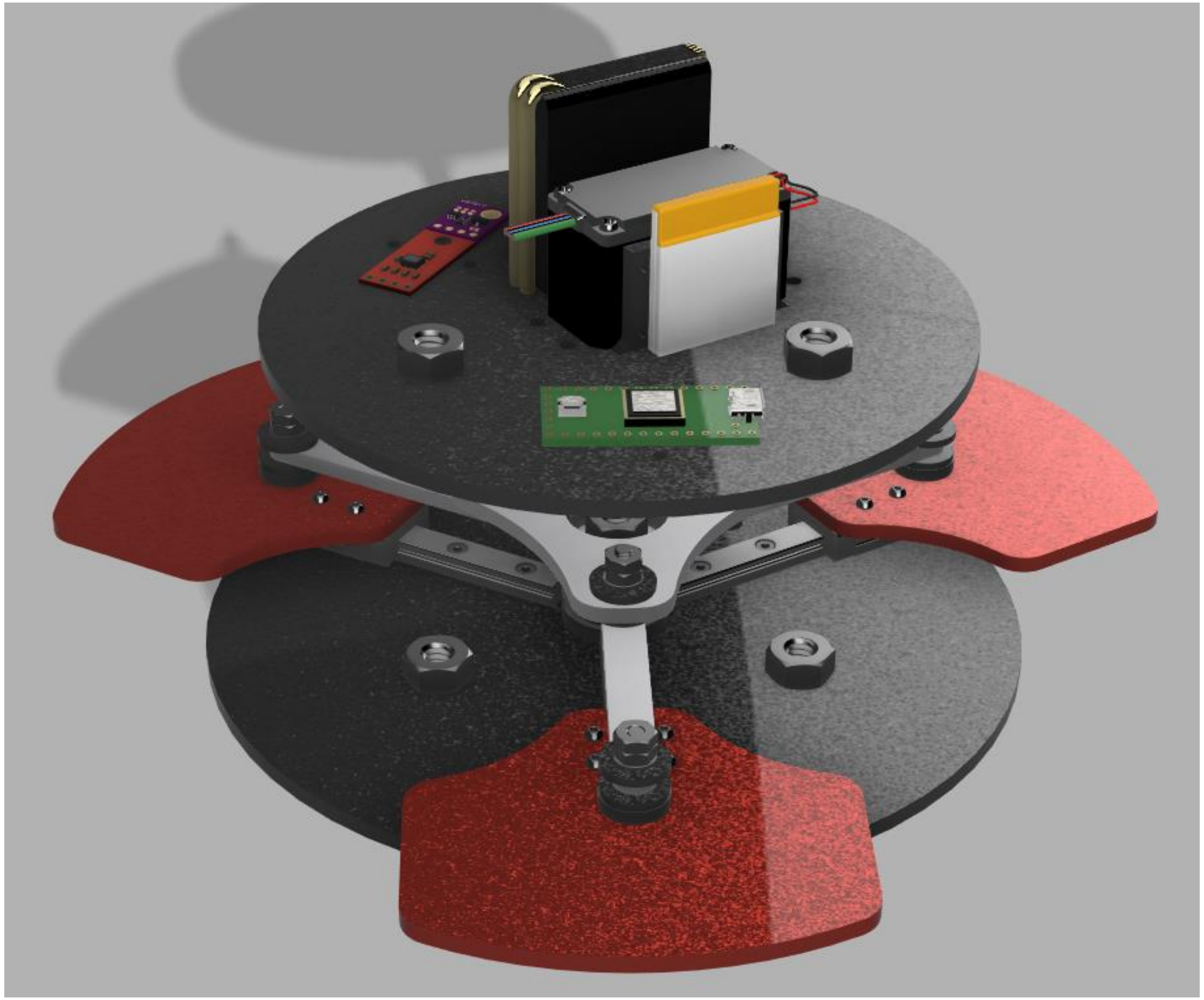
Launch Vehicle Design: FEA VDS Blades

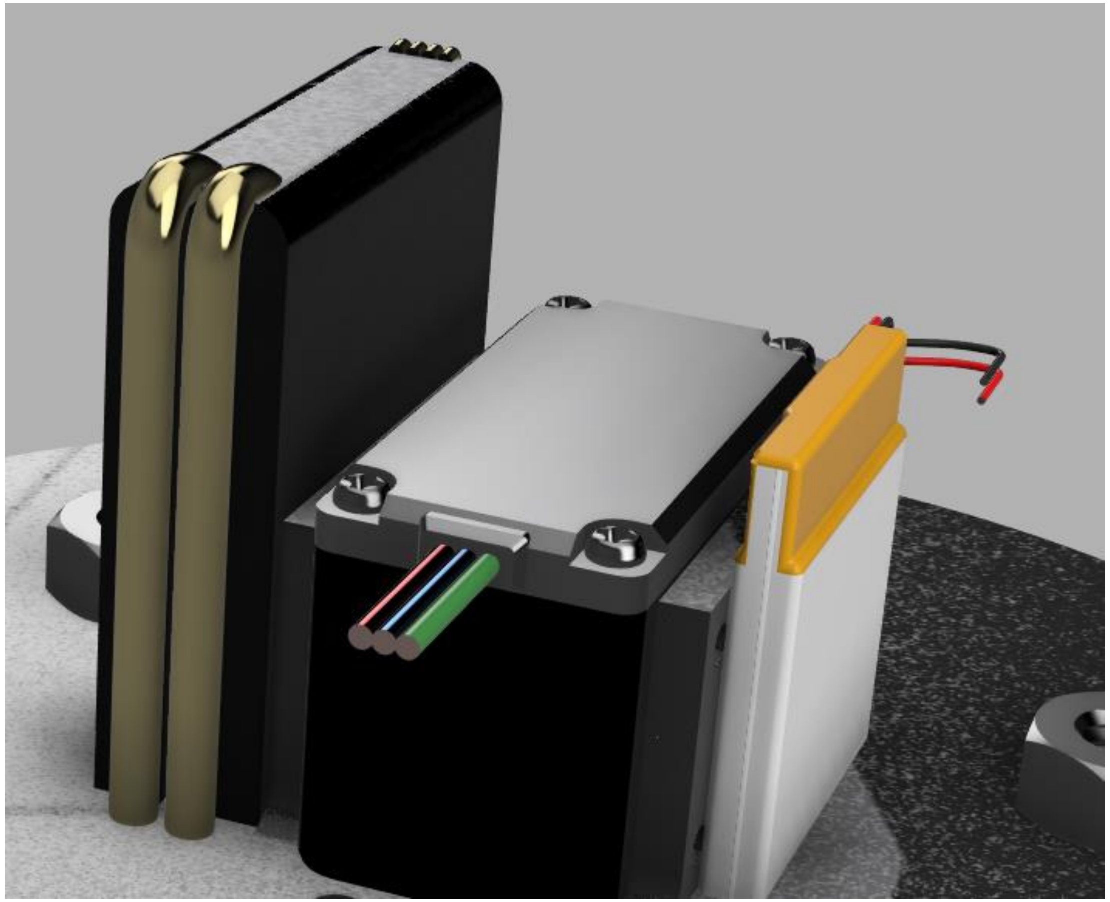




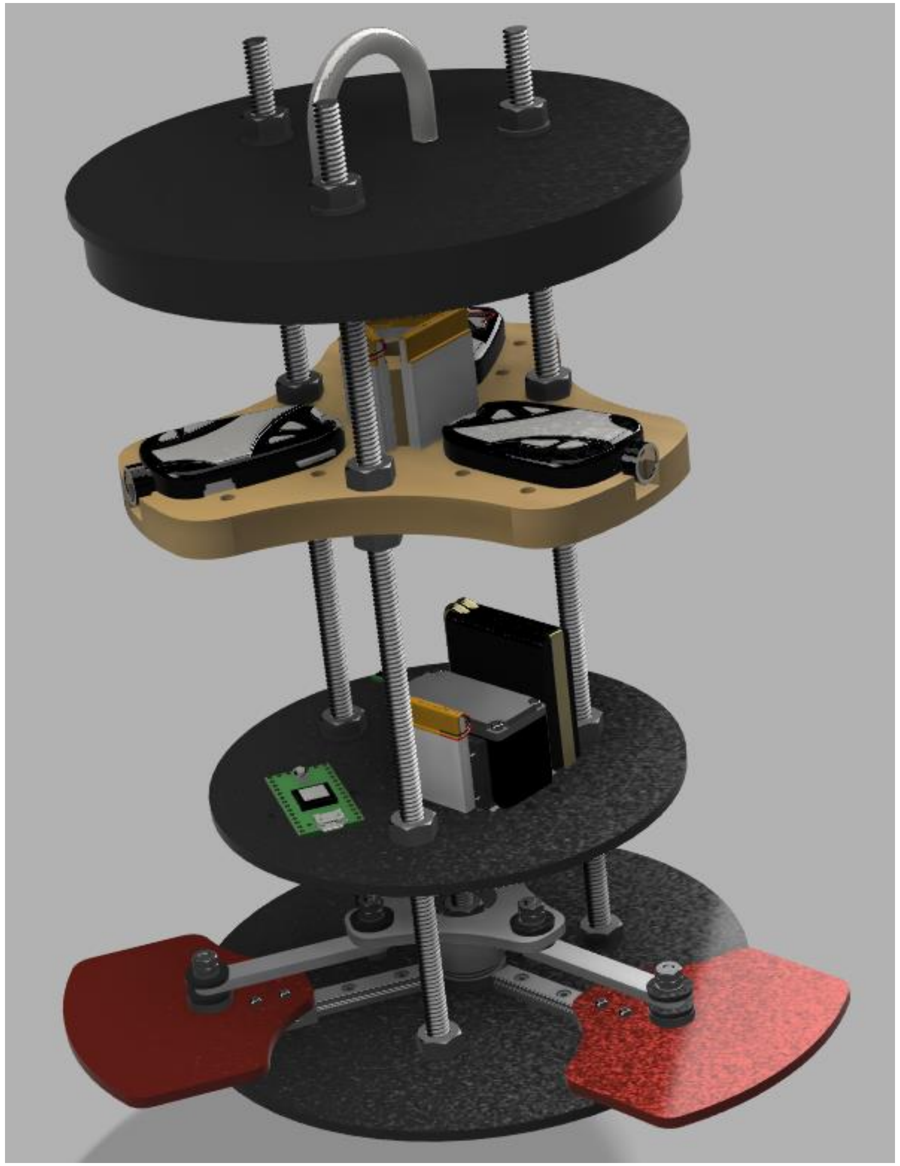
VDS FEA Results	
Simulation Axial Velocity	600 ft/s
Min SF	3.895
Max Displacement	0.17 mm

Launch Vehicle Design: VDS Canister Assembly



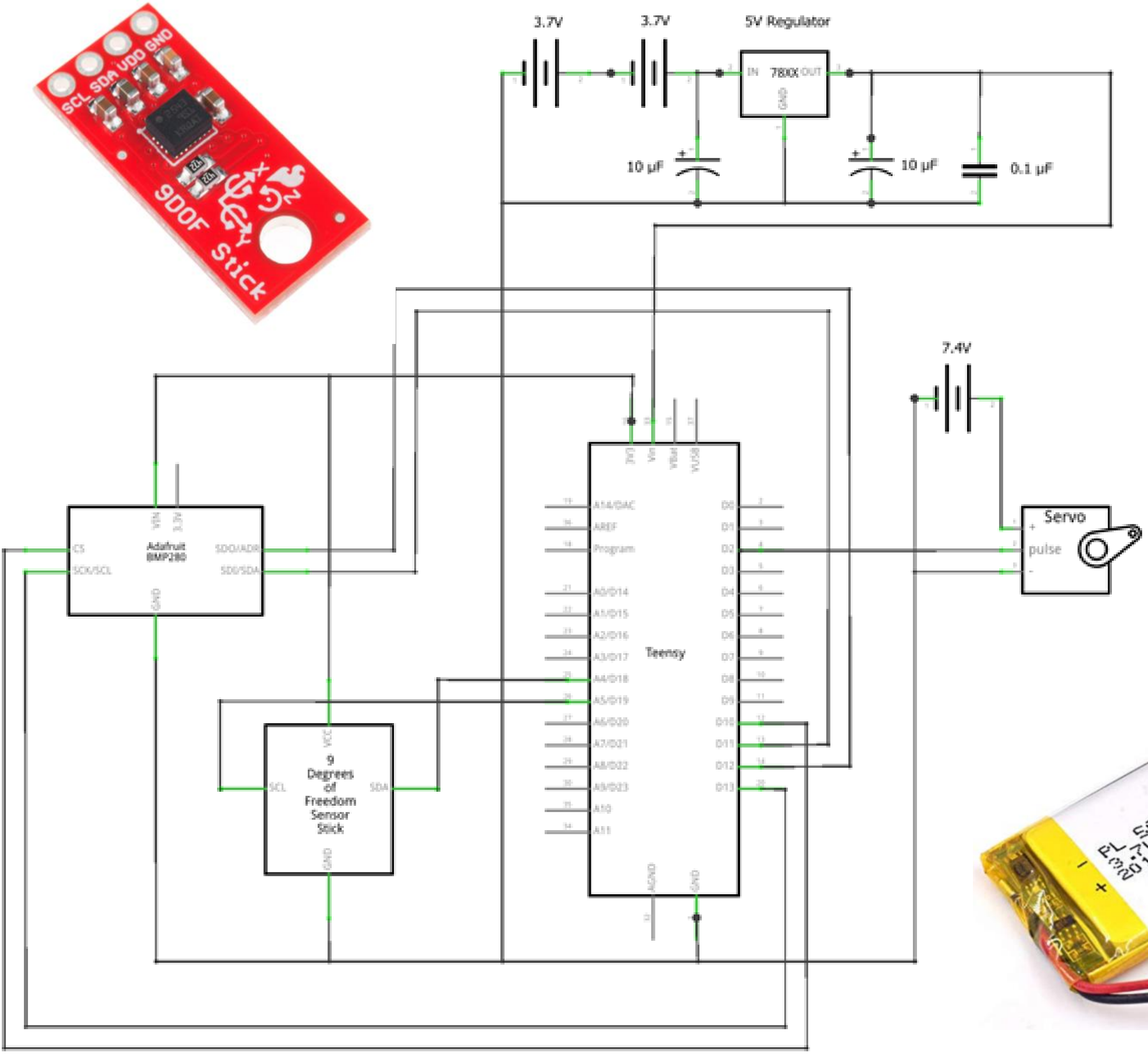


Launch Vehicle Design: VDS Canister Assembly

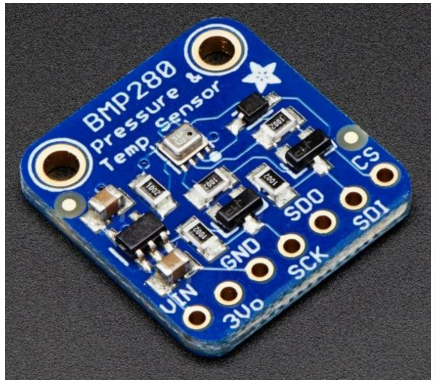


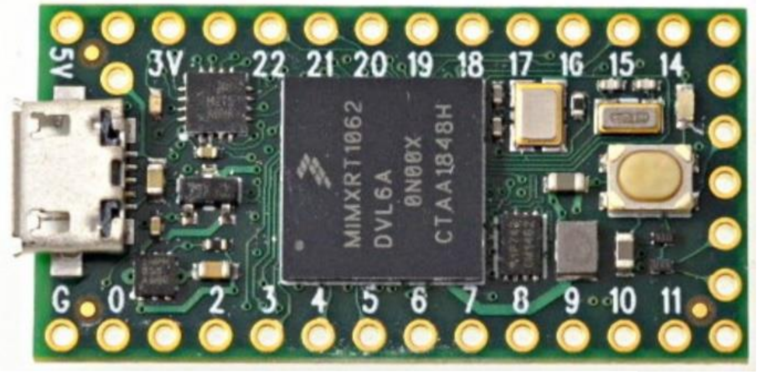
1. Using the “empty” space in the coupler for VDS and cameras allow to save 6” of length from the vehicle, therefore cutting mass
2. Using 9” couplers with 6” shoulders allow to cut 0.86 lbs of mass
3. A coupler bulkhead will be modified and attached to an airframe bulkhead with RocketPoxy in order to provide a locating surface for the VDS canister
4. 3x ¼-20 threaded rods (tensile strength: 40 ksi) will be used to clamp the bulkhead w/ respect to VDS baseplate. Stress ends up being in the treaded rods and airframe
5. Additional 6-32 bolts will be used through the airframe to rigidly connect the coupler to airframe

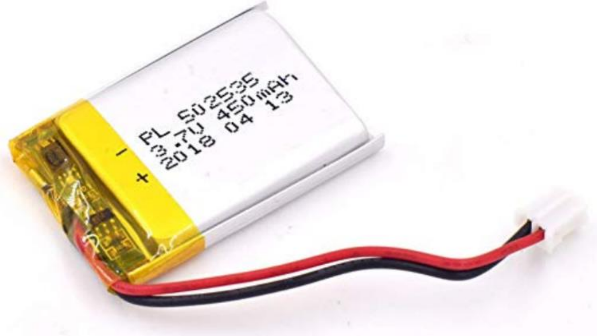
Launch Vehicle Design: VDS Electrical Schematic



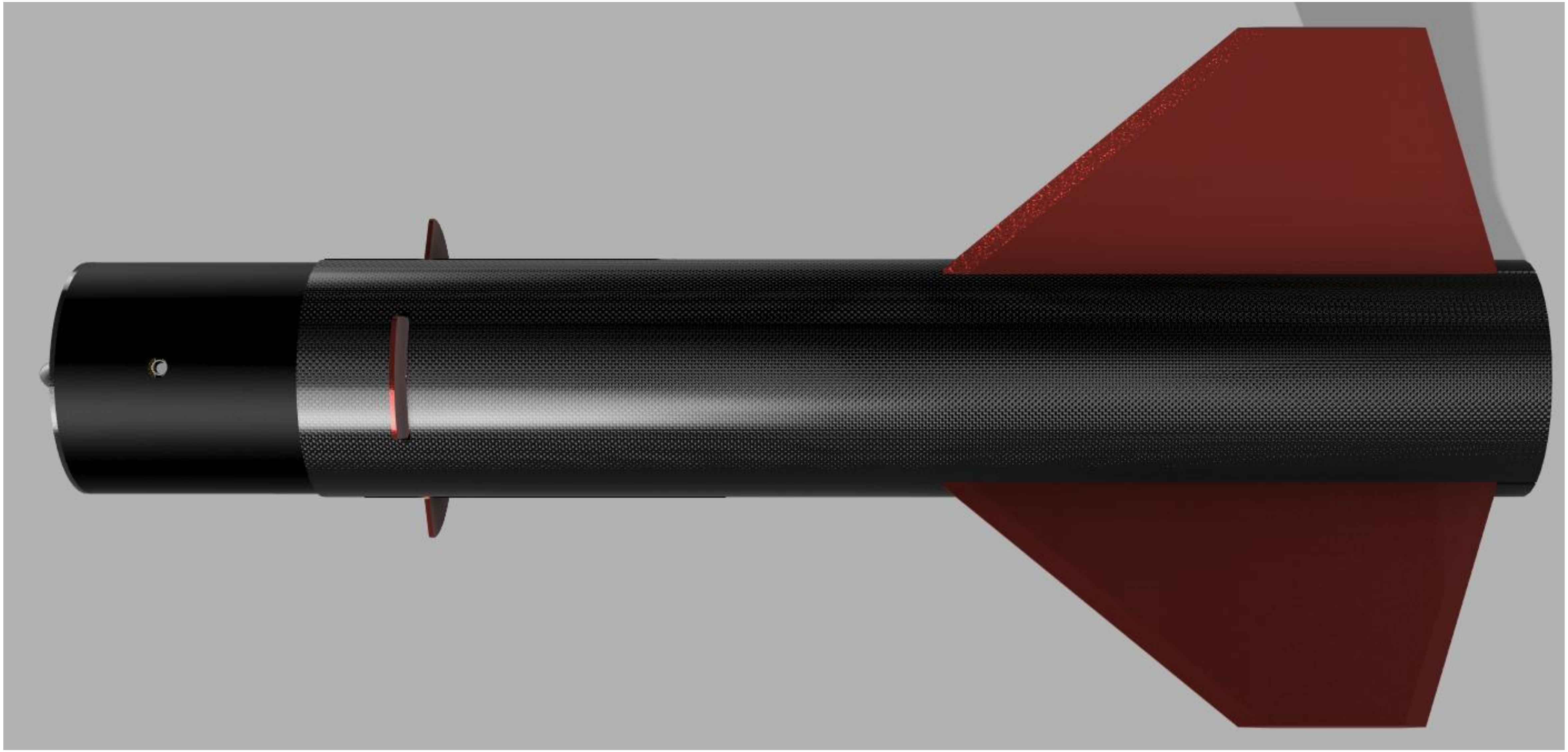
1. BMP 280 Barometric Pressure & Altitude Sensor
2. 9 DoF Sensor: 3x accelerometer, 3x gyroscope, 2x magnetometer
3. Teensy 4.0 – ARM Cortex M7 Processor @ 600 MHz



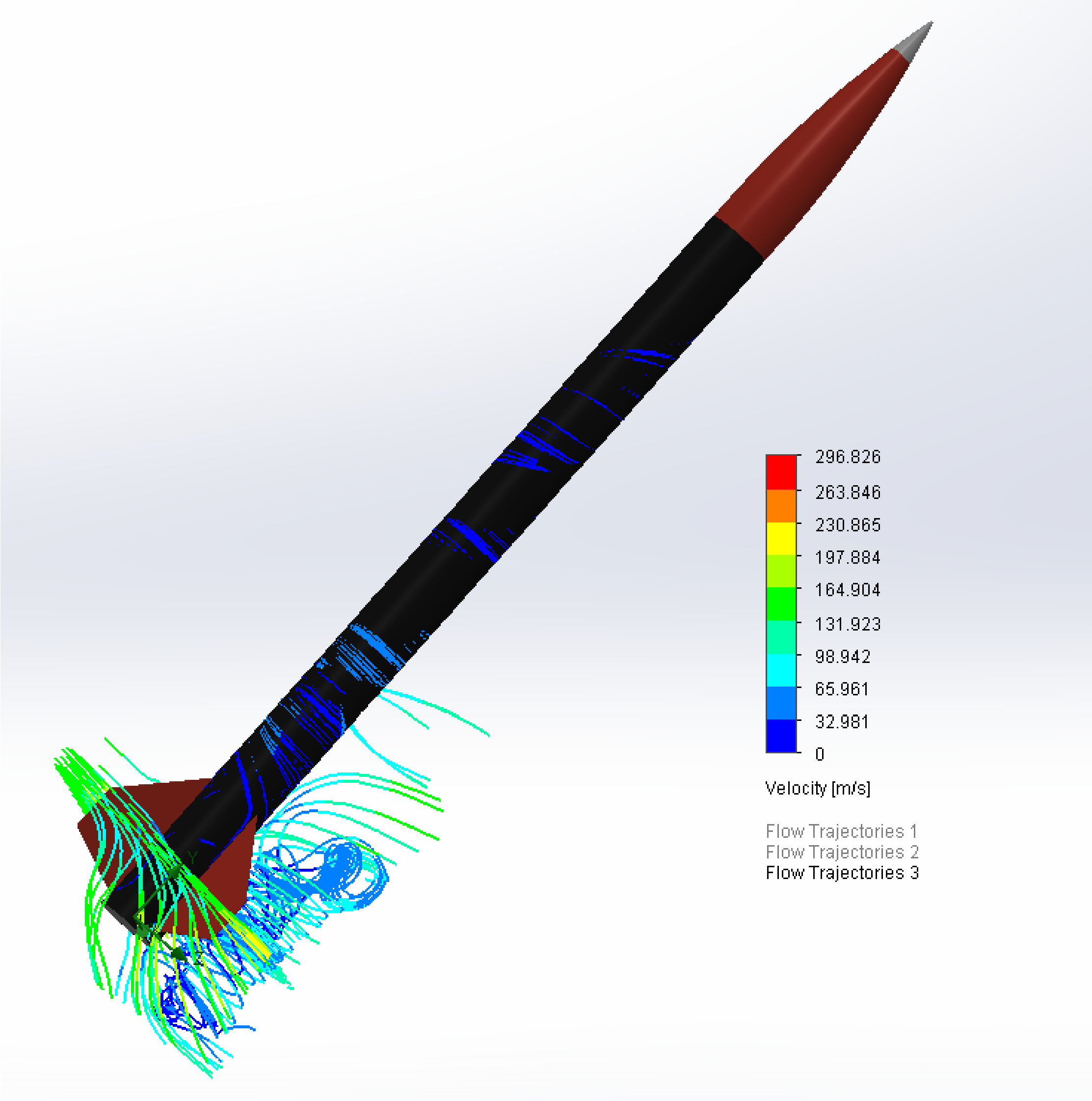




Launch Vehicle Design: Booster Bay



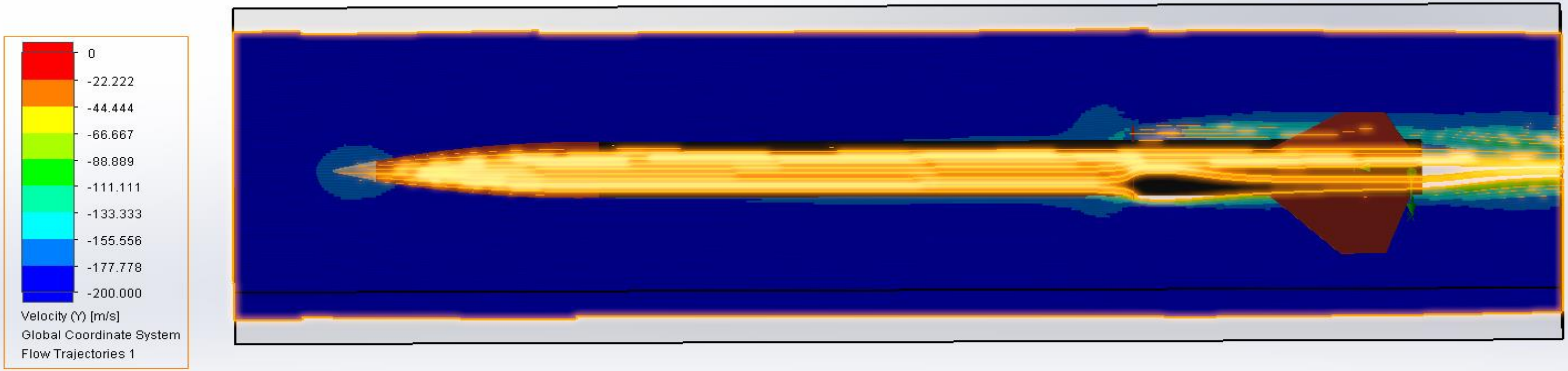
Launch Vehicle Design: CP Through CFD

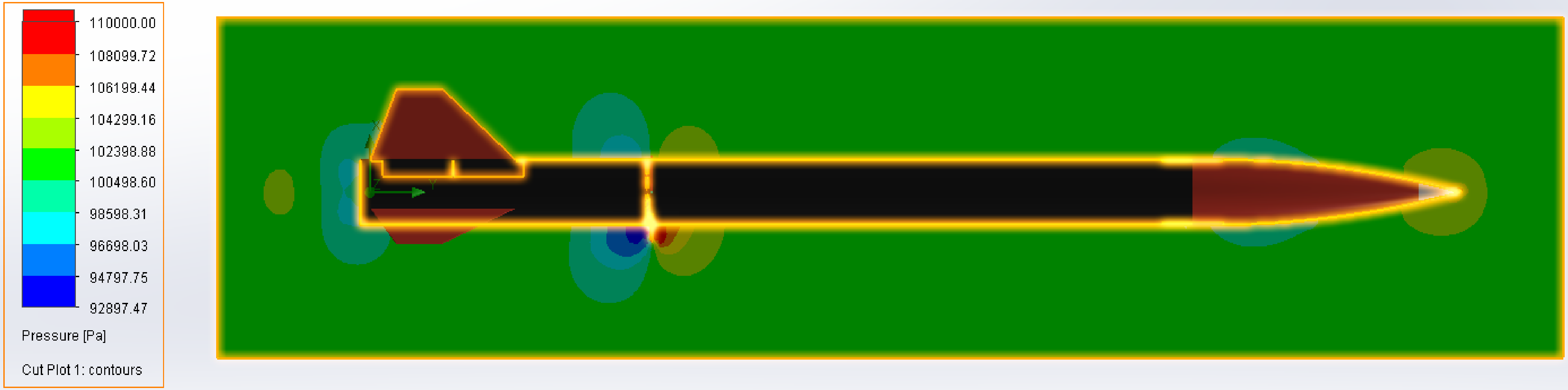


CP Values	
Simulated CP	77.5”
Openrocket CP	80.14”
Percent Difference	3.29%

Simulation Conditions	
Global Goals	Perpendicular Torque & Forces
Temp	293.2 K
Static Pressure	101.325 kPa
Velocity (x)	200 m/s
Velocity (y)	0 m/s
Velocity (z)	200 m/s

Launch Vehicle Design: Velocity & Pressure Profile



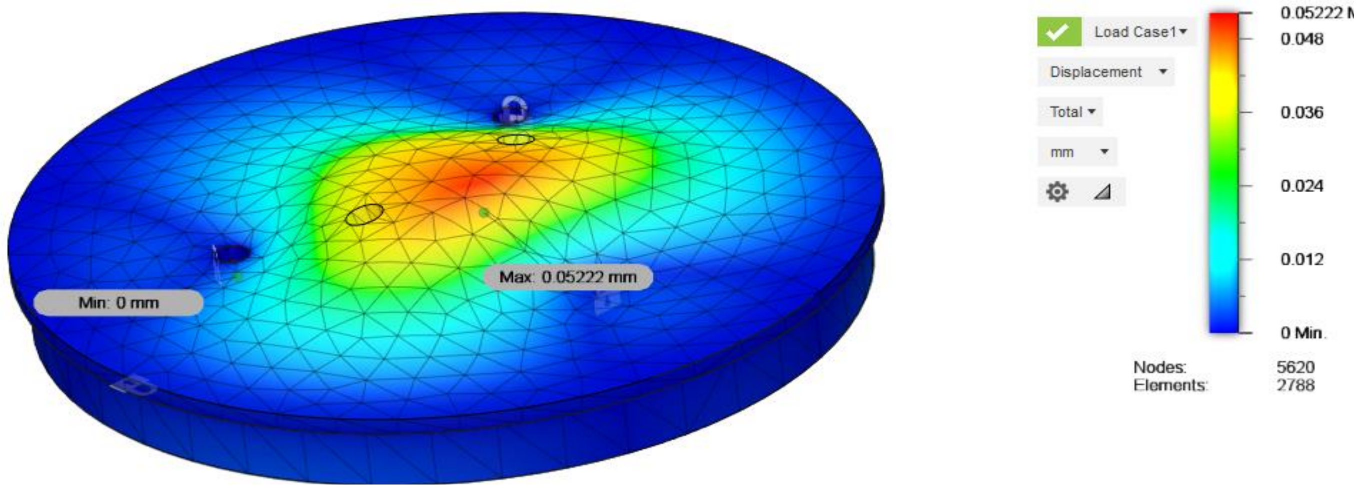


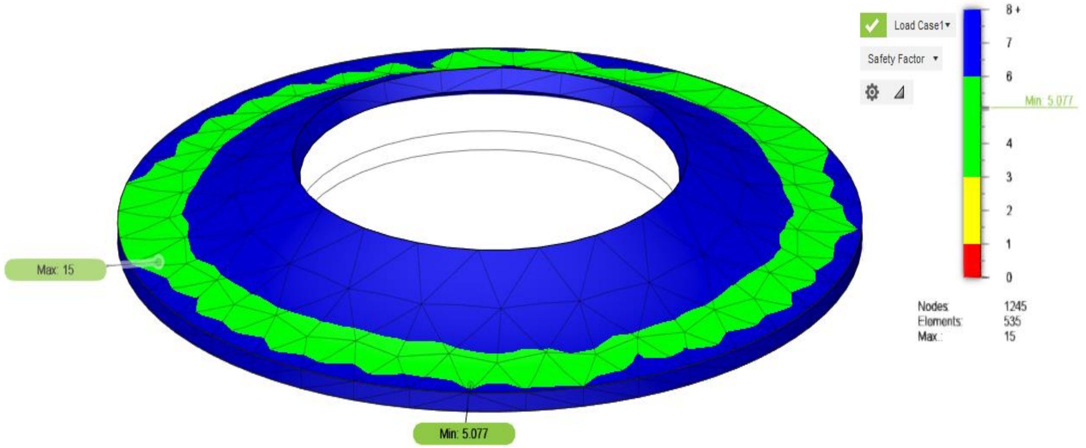
Launch Vehicle Design: Cd Estimation

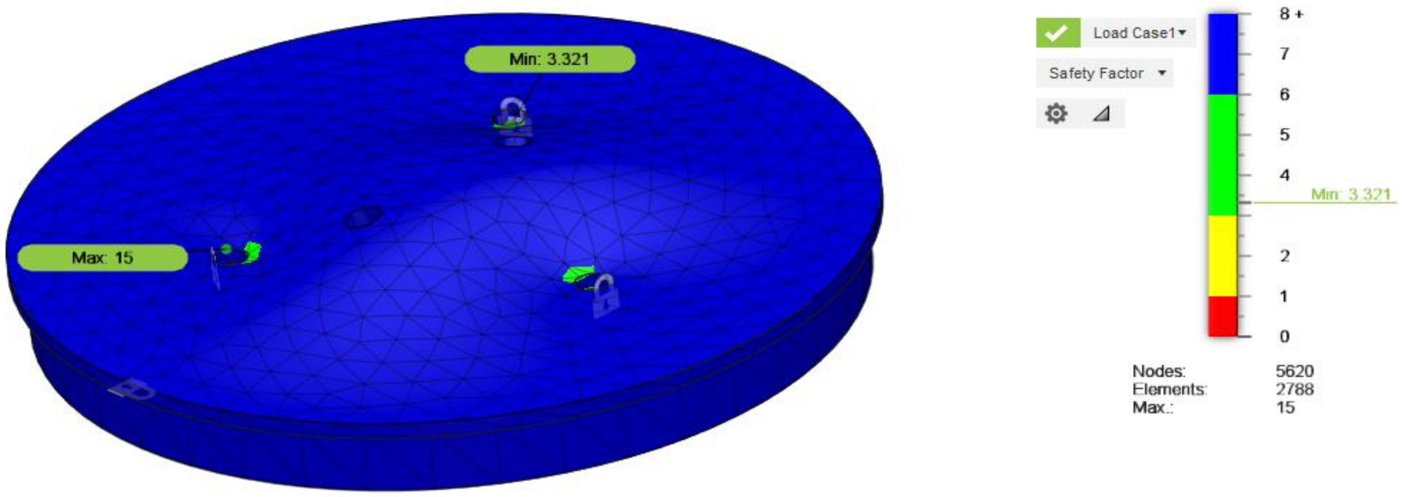
Simulation Conditions	
Global Goals	Cd & Fd
Temp	293.2 K
Static Pressure	101.325 kPa
Velocity (x)	0 m/s
Velocity (y)	183 m/s
Velocity (z)	0 m/s

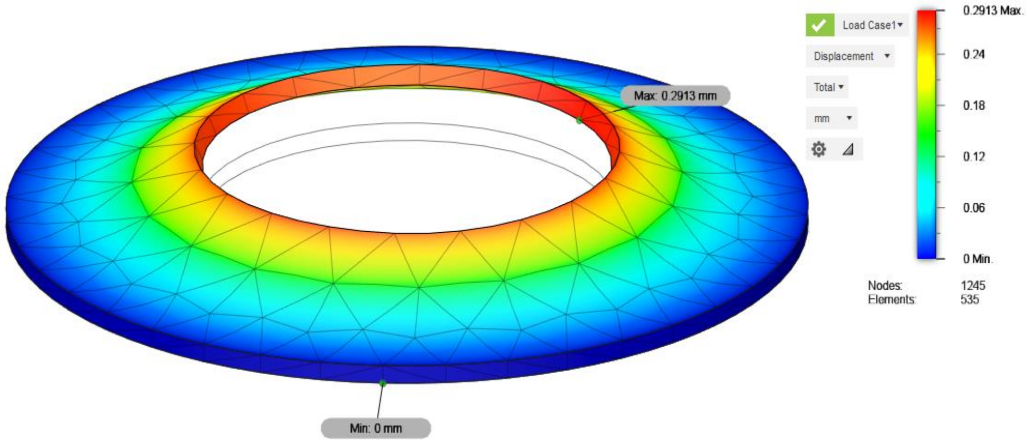
Cd Estimation Results	
Cd w/o VDS	0.435
Cd w/ VDS	0.71
Cd Increase Factor	1.63

Launch Vehicle Design: FEA

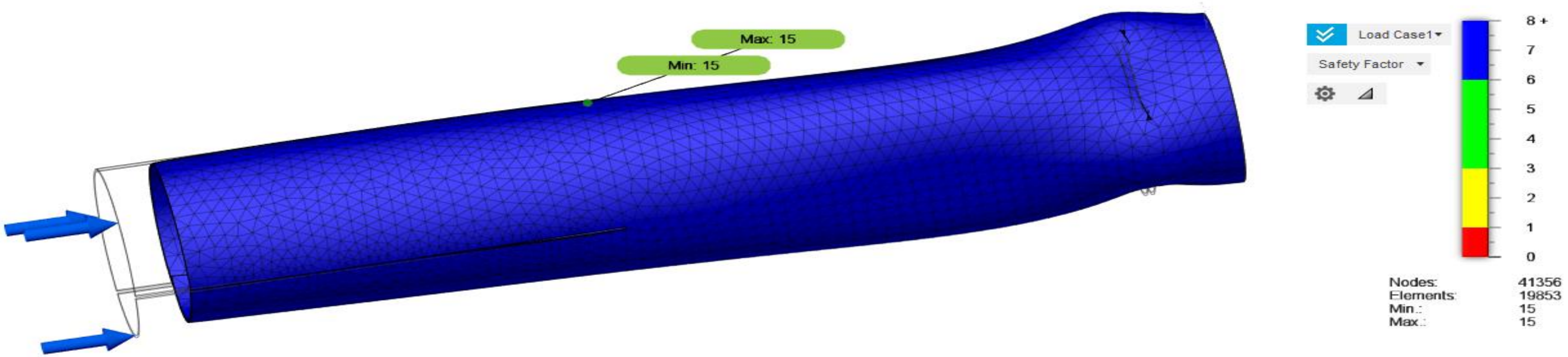


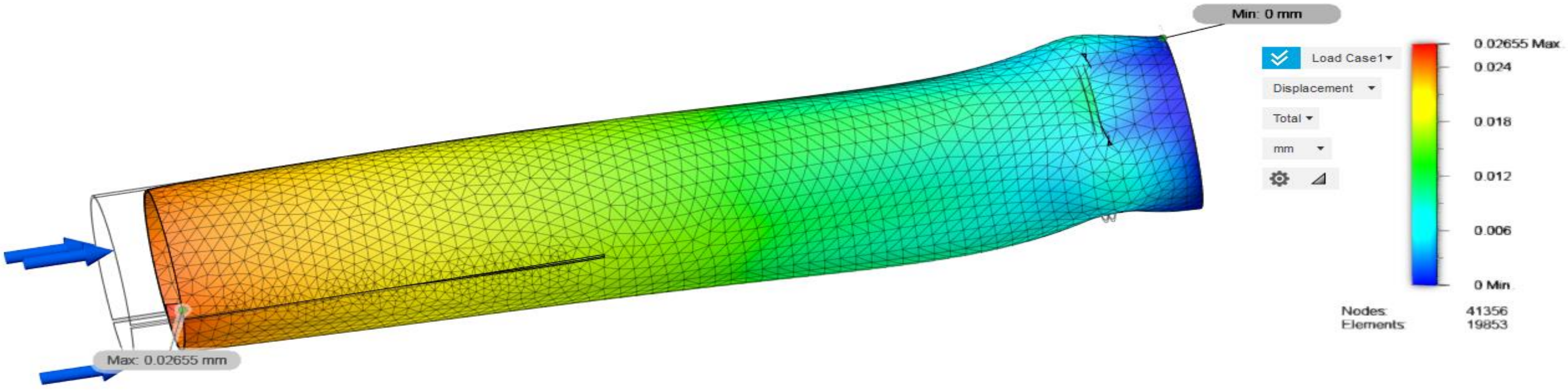




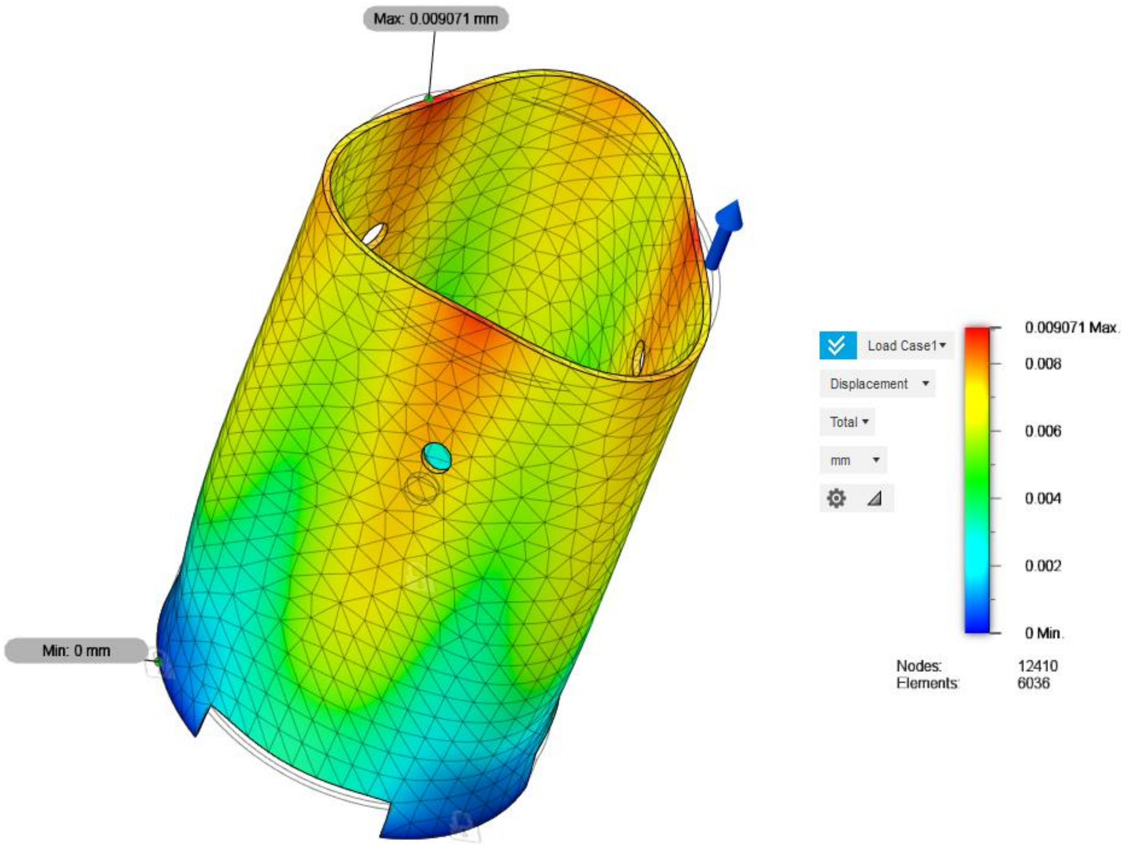


Launch Vehicle Design: FEA

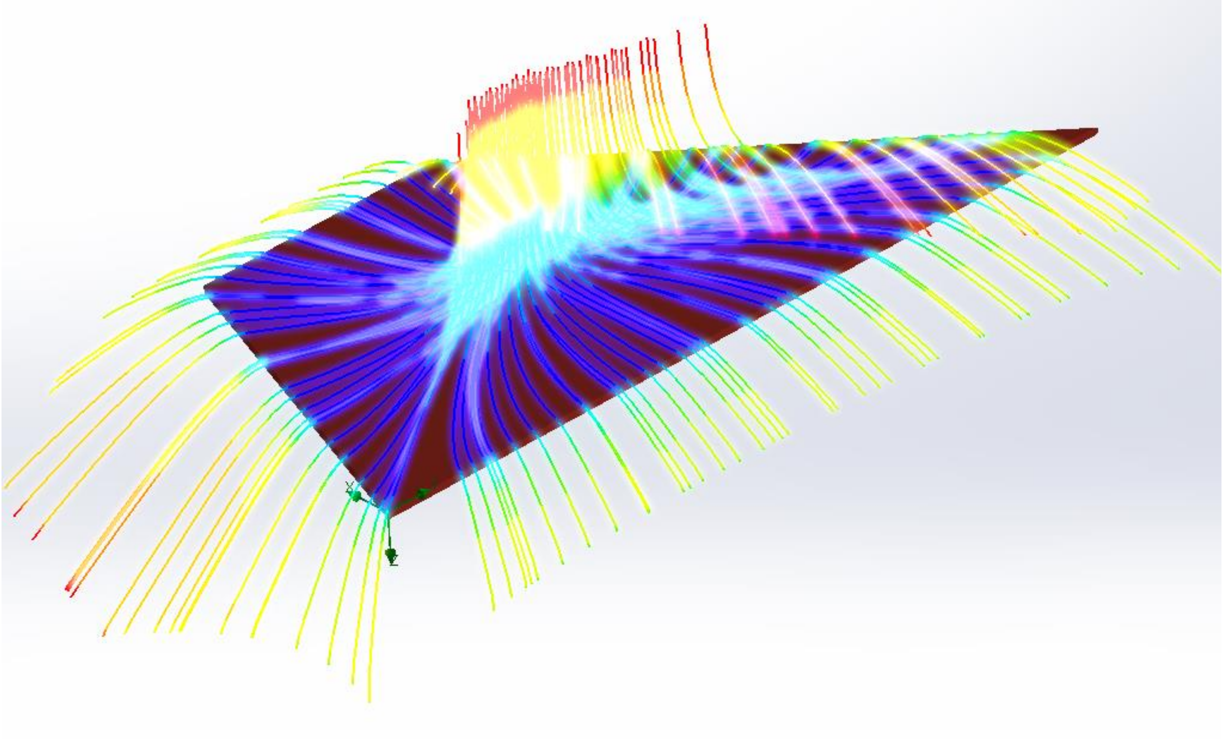


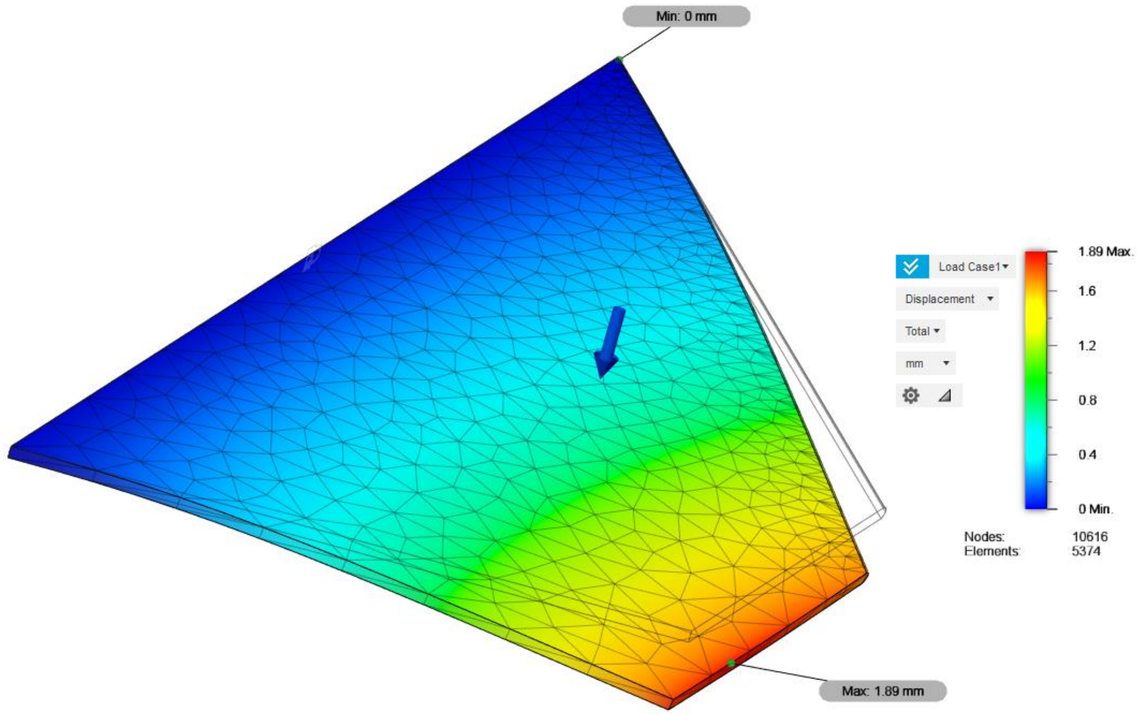


Launch Vehicle Design: FEA



Launch Vehicle Design: Fin Torque CFD & FEA





CFD & FEA Results	
Simulation Velocity	200 ft/s
Max Displacement	5.67 mm
Min Safety Factor	9.3

Agenda

i. Launch Vehicle Design
ii. Recovery Subsystem
iii. Payload Design
iv. Integration & Summary
v. Subscale Launch
vi. Requirements Verification & Safety

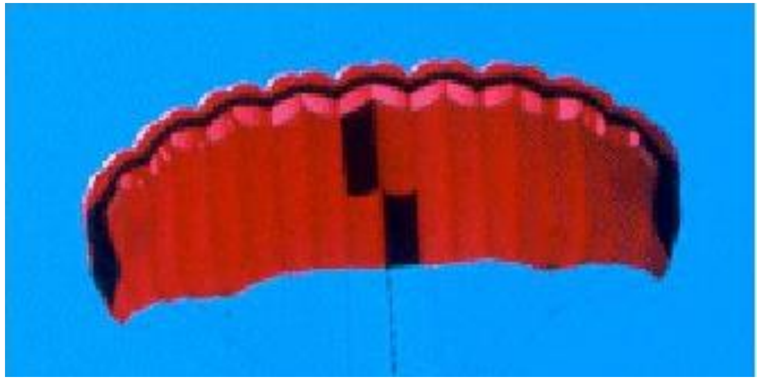
Recovery Subsystem: Parachute Design

Main Parachute: 120'' Rocketman High Performance Parachute

- Annular/Toroidal Design
- Rating: 82.3lbf at 20fps
- Cd = 2.2
- Deployment at 600 ft AGL

Drogue Parachute: 18'' Compact Elliptical Parachute

- Rating: 1.2lb @ 20fps
- Cd = 1.5-1.6
- Deployment at 4500 ft AGL



Recovery Subsystem: Parachute Design

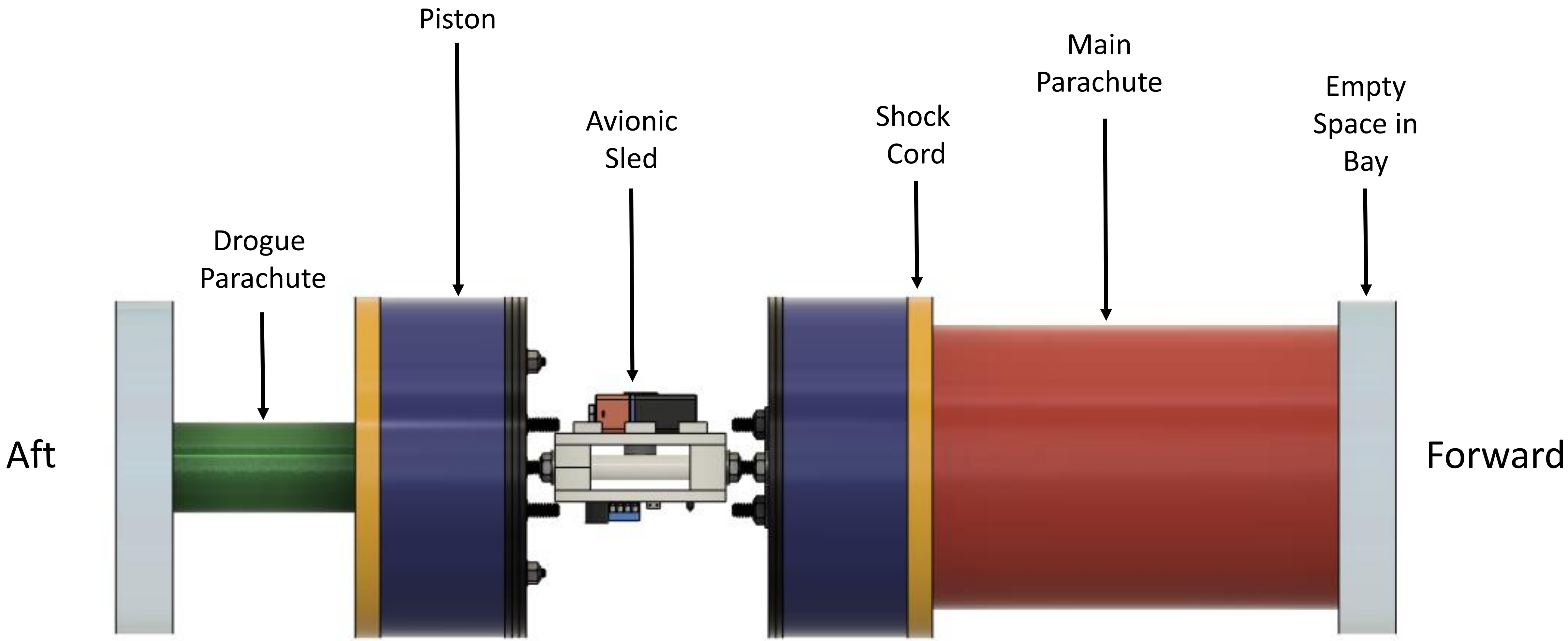
Wind Speed (mph)	Wind Speed (ft/s)	Drift(ft)
20	29.33	2337.9
15	22	1753.4
10	14.67	1168.9
5	7.33	584.5
0	0	0

Distance of Drift based on Wind Speed and 79.9s descent time from descent time numerical calculation.

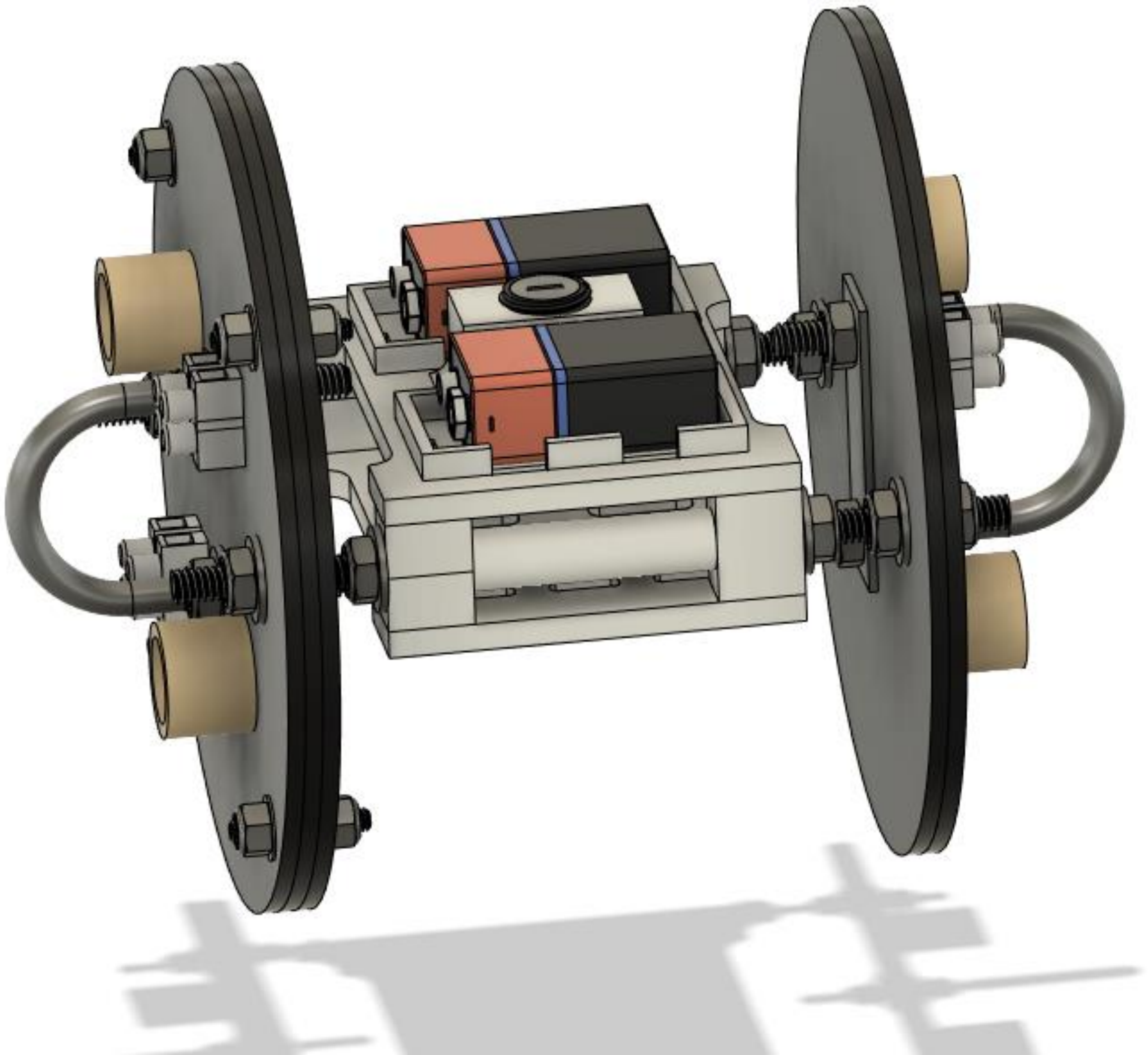
Recovery Subsystem: Parachute Design

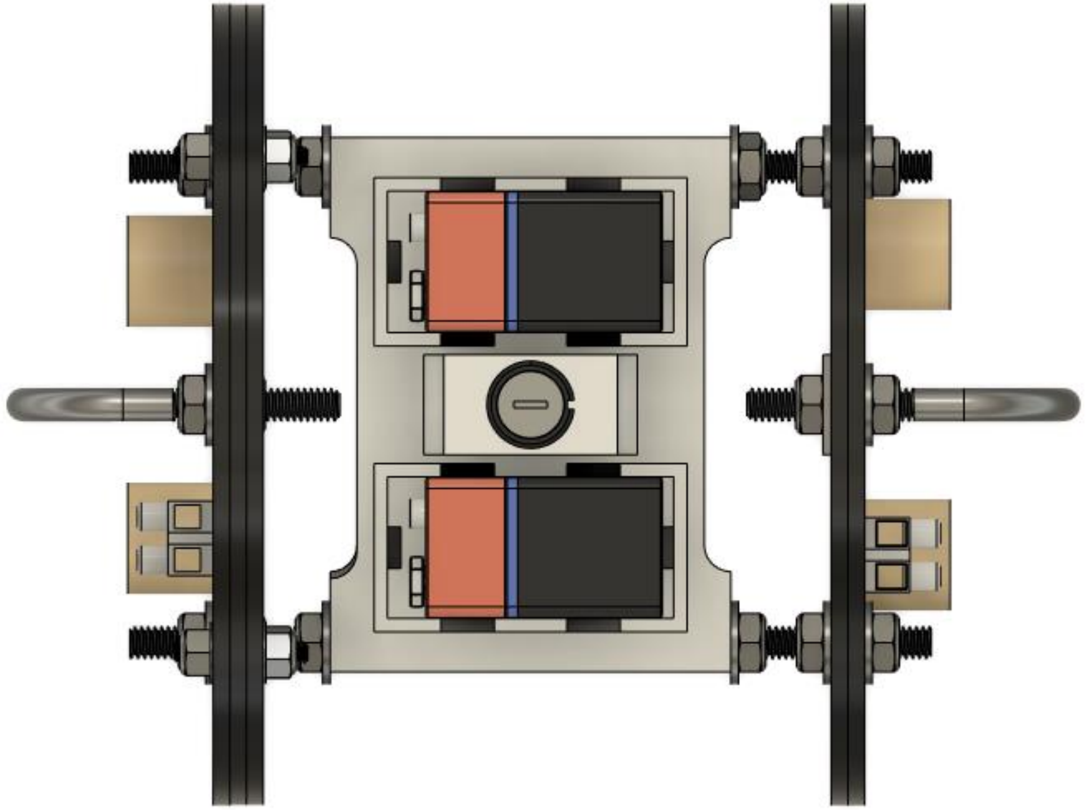
Section	Mass (slug)	Max Kinetic Energy (ft*lb)
Payload	0.5105	52.1989
Avionics	0.2382	24.3758
Booster Bay	0.5421	55.4282

Recovery Subsystem: Avionics Bay and Parachutes

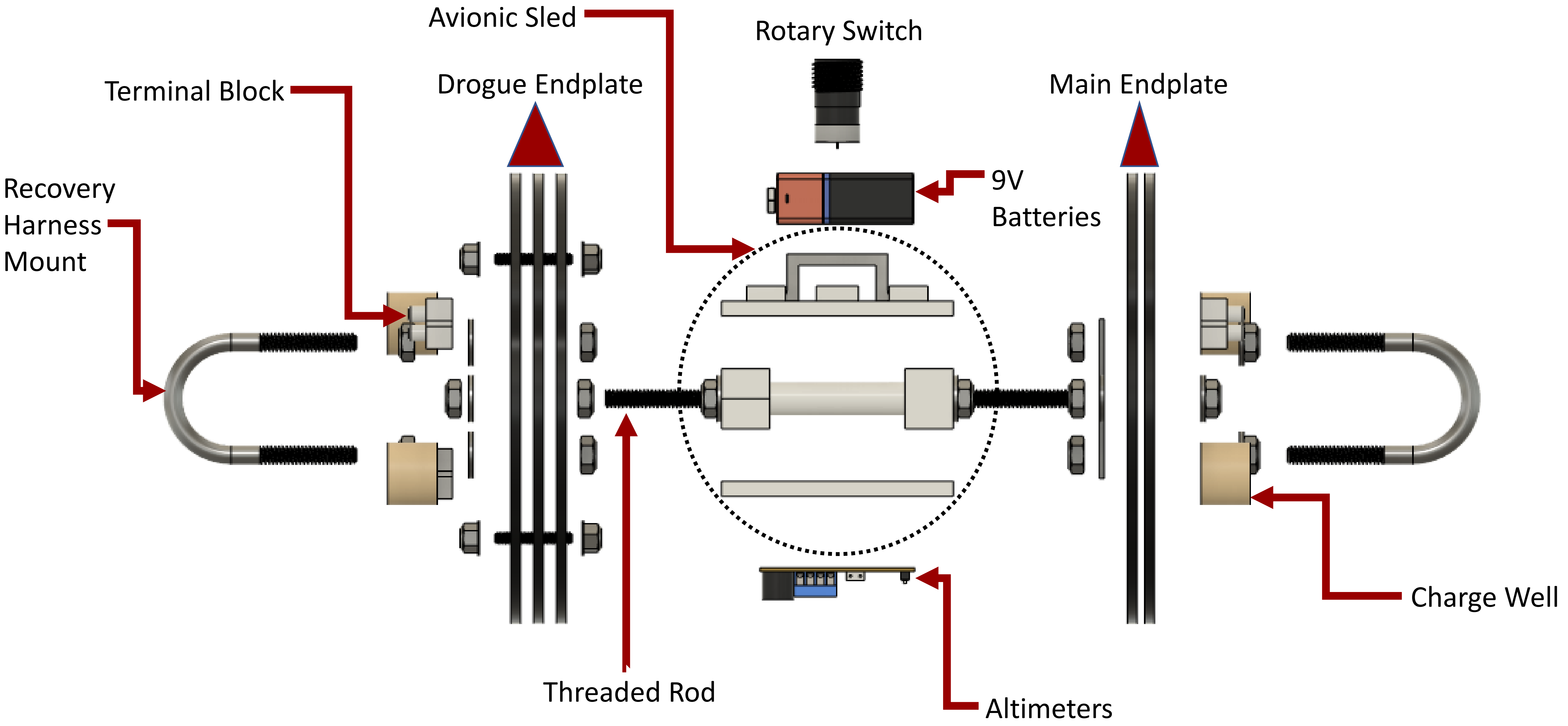


Recovery Subsystem: Avionics Bay

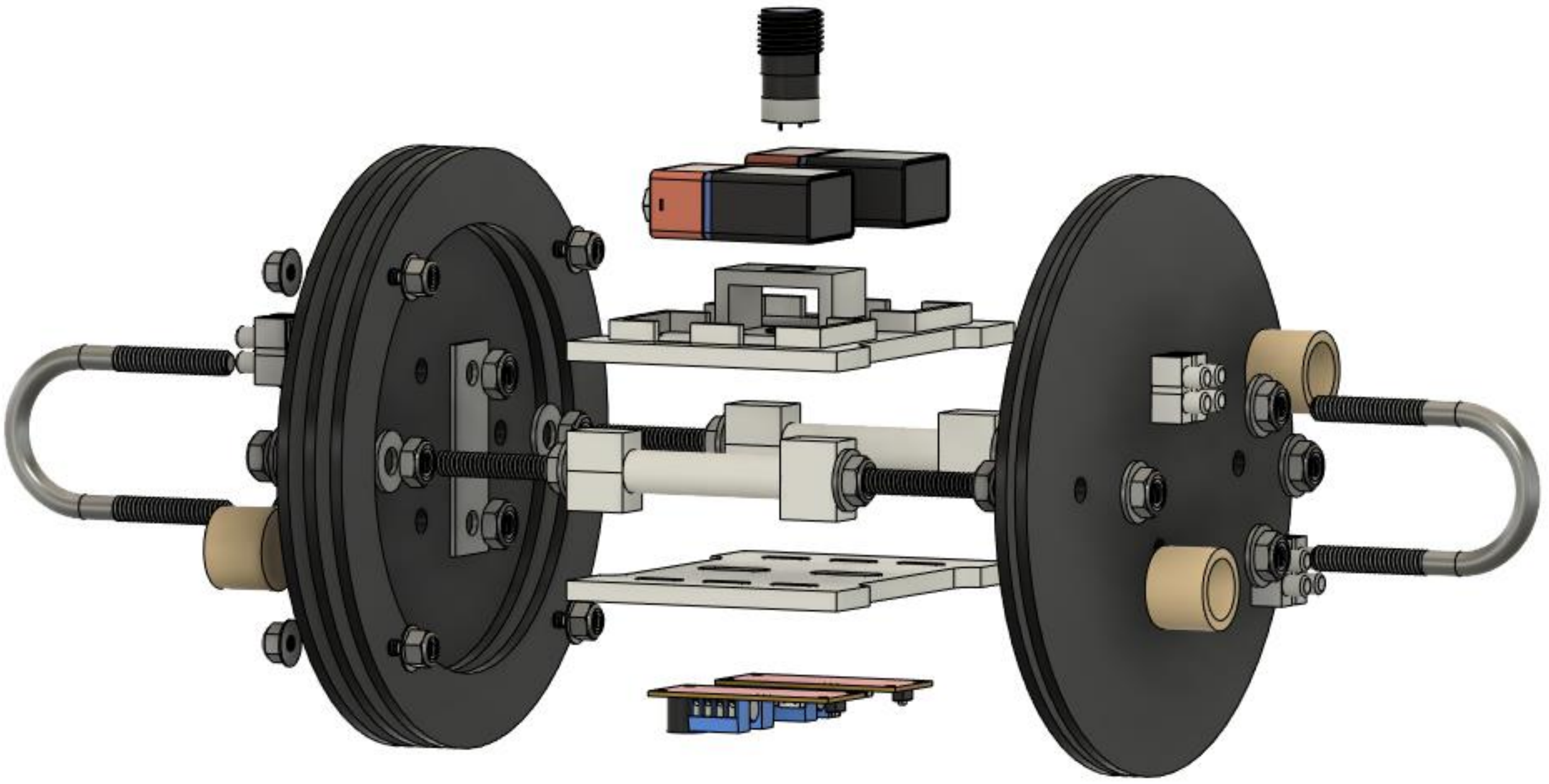




Recovery Subsystem: Avionics Bay Exploded View

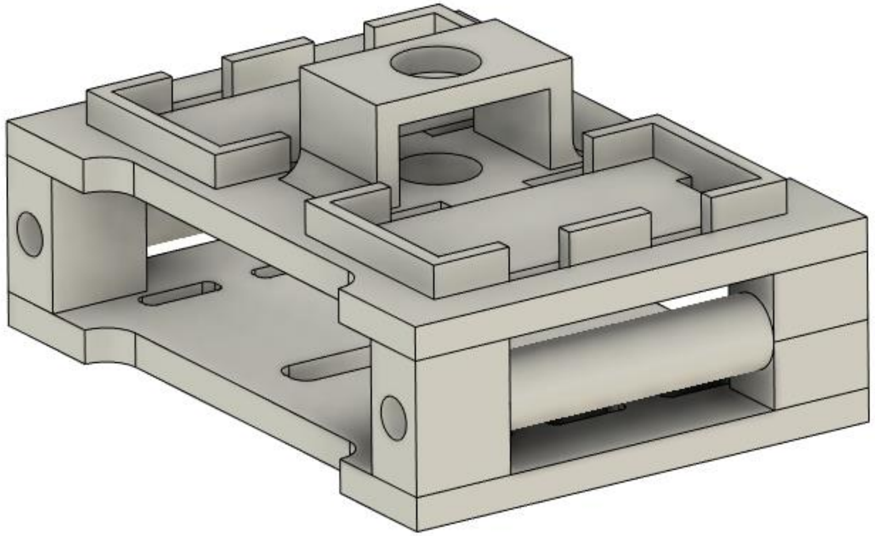


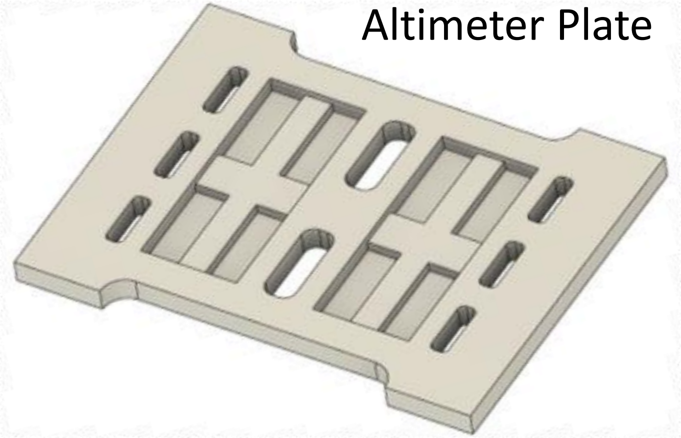
Recovery Subsystem: Avionics Bay Exploded View

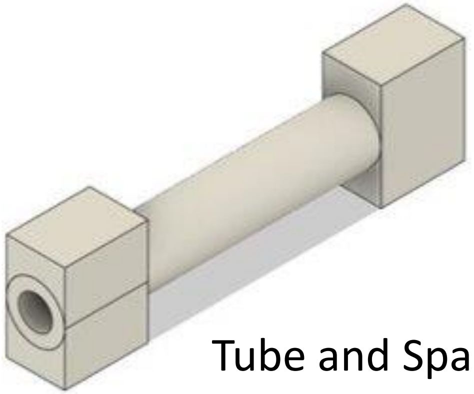


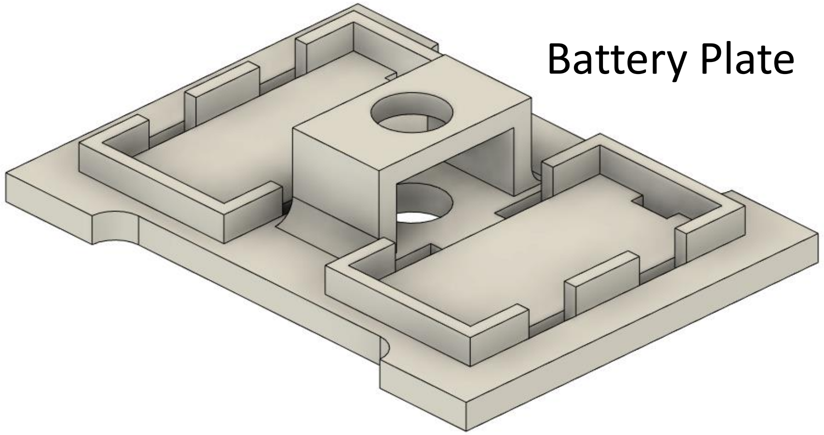
Recovery Subsystem: Avionic Sled

- Indentations and walls in sled help constrain electronics.
- PLA plastic avionic sled is machinable, strong, and easily fabricated.
- Slots allow for the use of cable ties for battery security.
- Consists of four parts that are epoxied together.
- ¼" hole in airframe for pressure sampling and switch access.









Recovery Subsystem: Main Endplate

- Two 1/8" thick fiberglass retention bulk plates are epoxied to the inside of the airframe to ensure that avionics bay is stable.

- Structurally sound even under 600 lbf.

Recovery Subsystem: Drogue Endplate

- 1/8" Fiberglass outer plate protects inner avionics bay from hot ejection gases, fiberglass centering rings are used as attachment points to the airframe with epoxy.

- Plates connected together with #8 threaded rods, nuts, and washers.

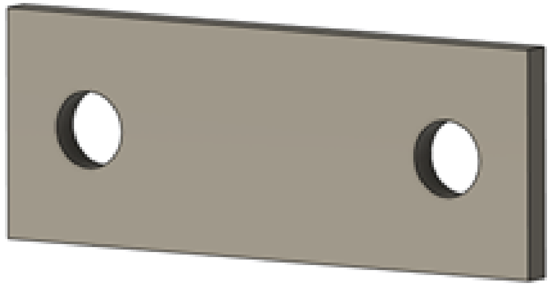
Ejection and Deployment: Recovery Harness & Mounts

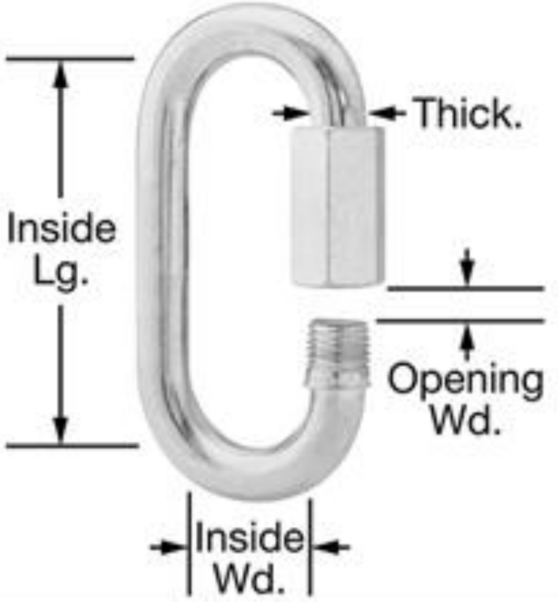
- ¼" U-bolt spreads force out over a larger area than eyebolts.

- Kevlar Recovery Harness:
  - 25', 7/16" wide main shock cord.
  - 30', 7/16" wide drogue shock cord

- Mounting plate assists in spreading out ejection forces.

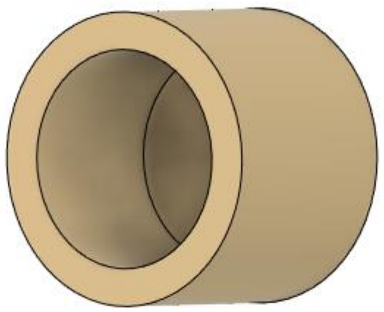
- ¼" Quicklink allows for easy assembly and disassembly.





Recovery Subsystem: Avionics Bay-Ejection

- PVC charge wells support 2 grams of black powder.
  - Requires 0.71g of black powder for drogue deployment and 1.75g for main chute deployment.
  - Lighter than aluminum wells.

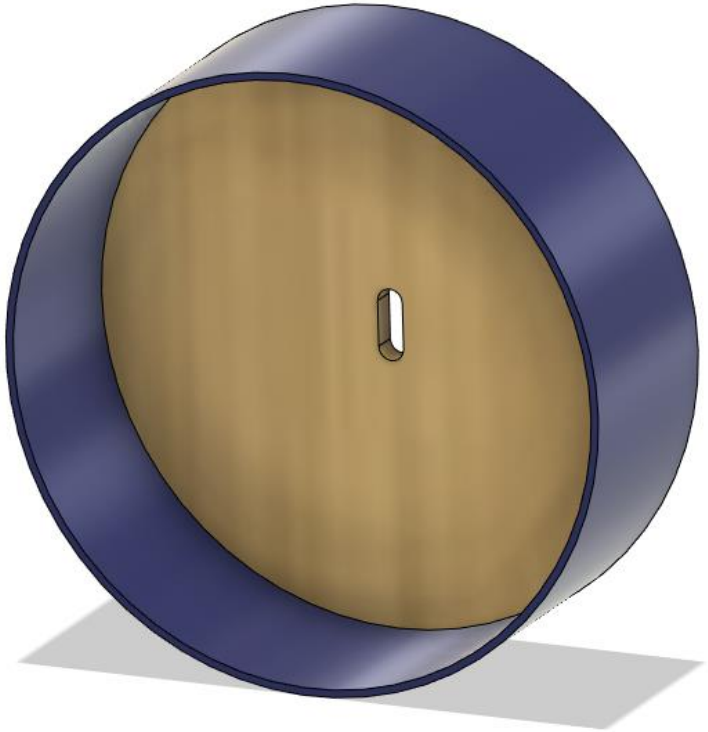


- Electric matches pre-dipped in pyrogen chemical for easier and safer operation.

Recovery Subsystem: Ejection

- Piston system consists of a plywood plate and blue tubing, epoxied together.

- Hole machined through wooden plate for passage of the shock cord.



- 4-40 X 5/16" long Fillister Nylon Slotted Machine Screws
  - Max shear strength of about 38lbf each when three or more are used.

Recovery Subsystem: Ejection

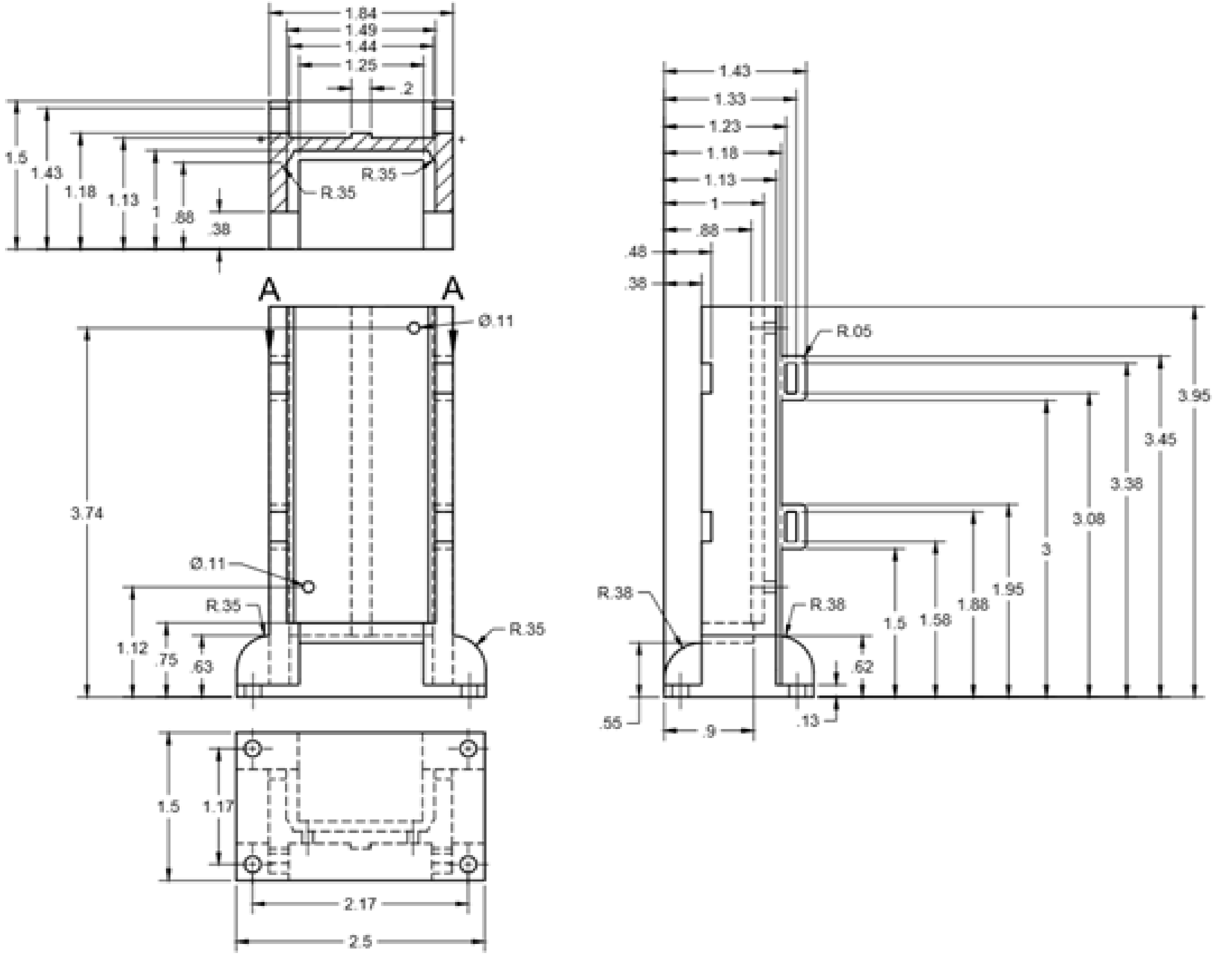
	Drogue Charge	Main Charge
Black Powder (g)	0.71	1.75
Pressure (psi)	7	10.43
Force of Charge (lbf)	197.92	294
# of Shear Pins	3	5

Recovery Subsystem: Telemetry Bay

- Sled slots through a threaded rod attached to nosecone tip.
- Telemetry plate is now 3D printed in the same piece as the sled.
- Payload lead screw passes through telemetry plate/sled.

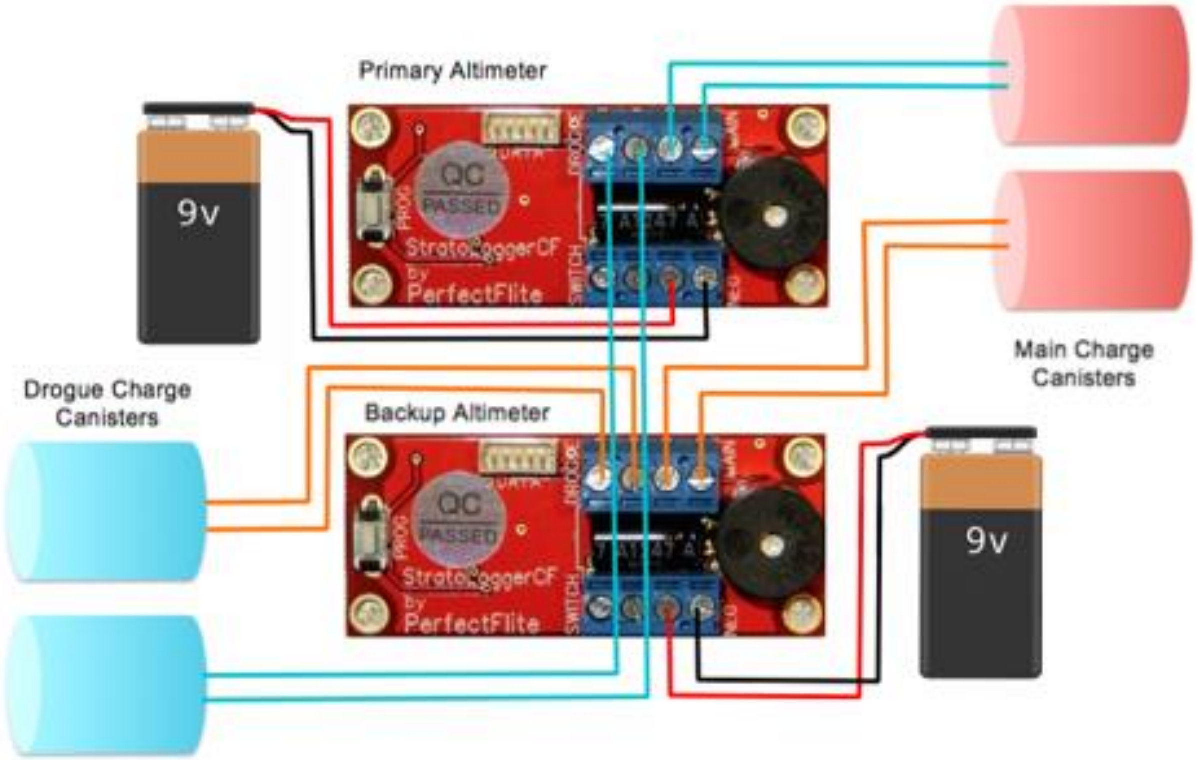
Recovery Subsystem: Telemetry Sled

- PLA plastic telemetry sled is strong, easily fabricated, machinable, and flexible.
- One compartment for the GPS Transmitter and LiPo battery.
- Holes for nylon screws to attach transmitter board.
- Slots cut through front and added to back of sled to implement zip ties.

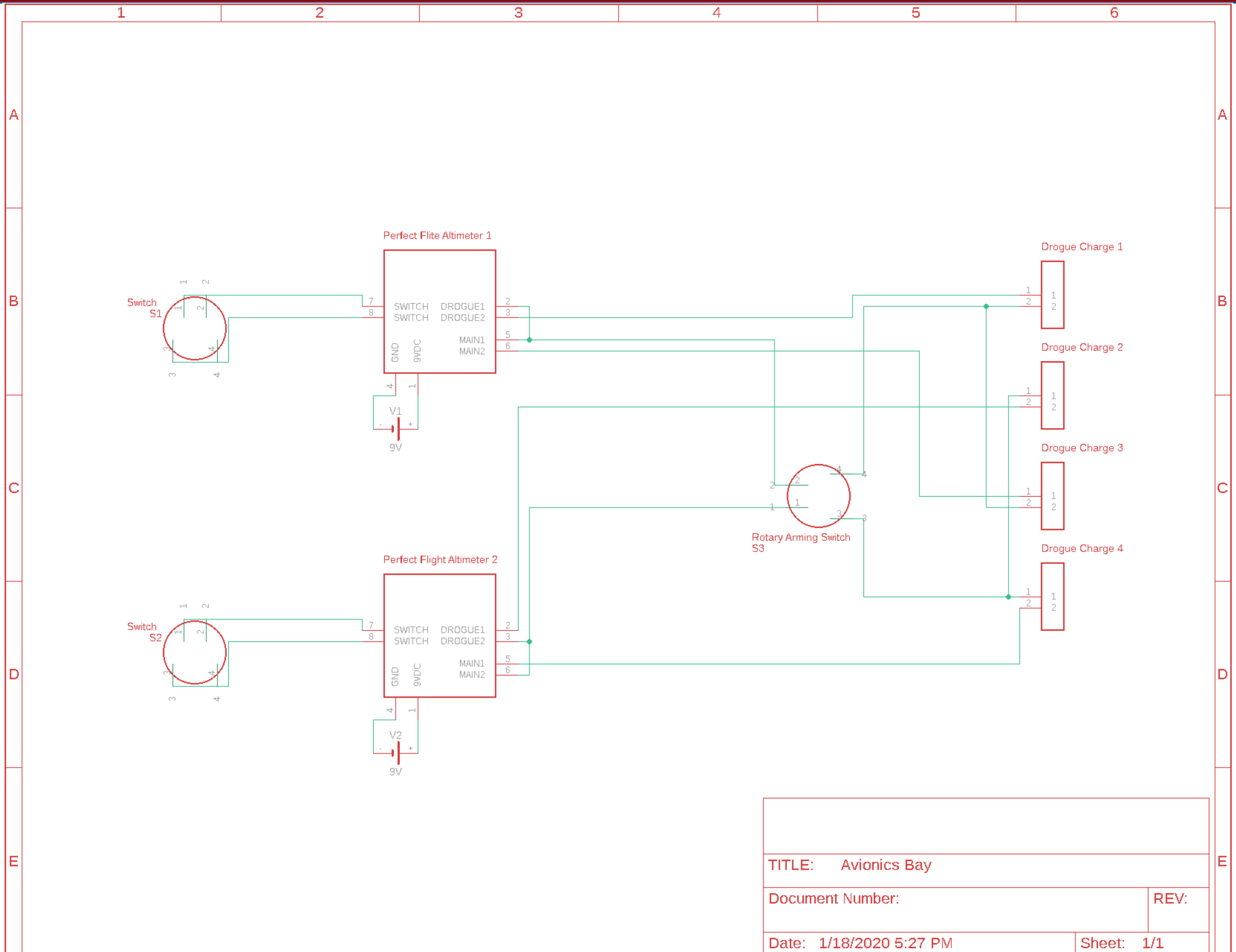


Recovery Subsystem: Avionics Circuit

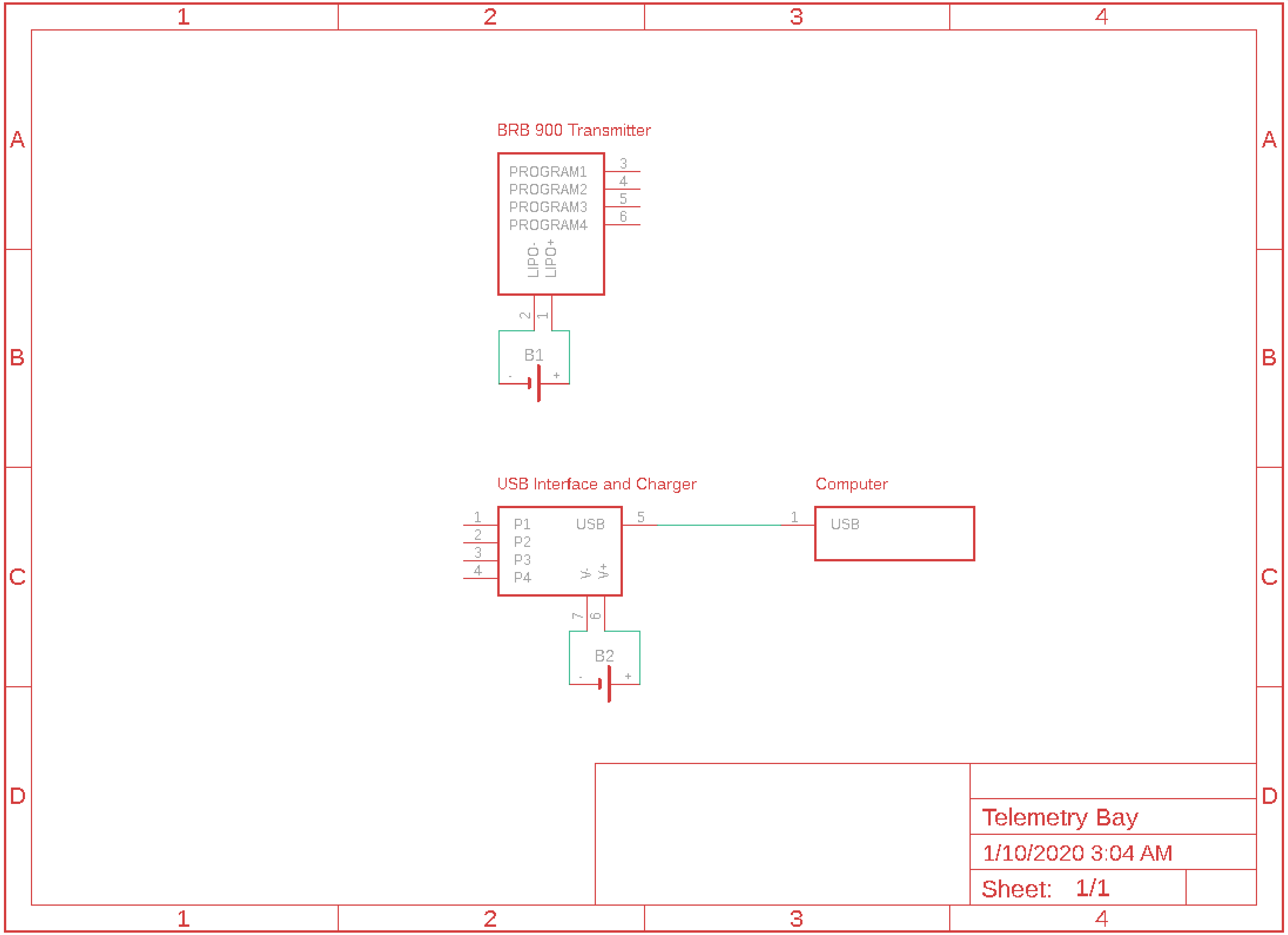
- Circuit is redundant with independent power sources for each altimeter.
- Independent of other electrical systems.



Recovery Subsystem: Avionics Circuit Schematic



Recovery Subsystem: Telemetry Circuit Schematic



Recovery Subsystem: Altimeters, GPS, Arming Switch

- PerfectFlite StratoLoggerCF Altimeter
    - 0.1% accuracy
    - Stores 16 flights of 18 minutes each
    - Brownout protection
    - Resistant to false trigger by strong winds (100+ mph)
    - 9,999 ft AGL range
    - Dual Deployment
    - Runs for weeks on 9V battery

- BRB900 GPS Telemetry System
    - 6 mile range
    - Battery add-on prevents overcharge.
    - Receiver/Transmitter pairing
    - Does not require HAM license
    - 900 MHz Spectrum
    - Can stay on launch pad for 2.5 hours or more

- Rotary Switch Arming Device
    - Does not require a specific key
    - Can be operated by screwdriver, Allen key, etc.
    - Will not activate avionics due to flight forces

Agenda

i. Launch Vehicle Design
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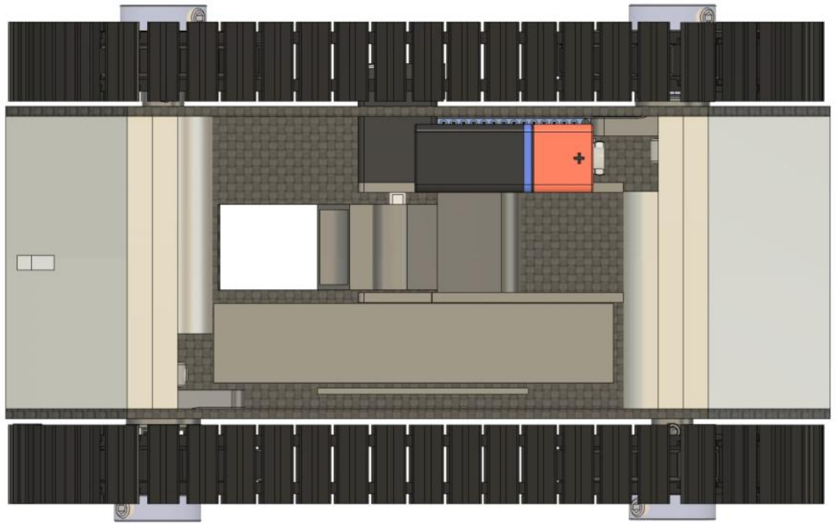
Payload Overview

Key Changes From PDR

- Single Lead Screw Exiting
- Lead Screw End Support Assembly
- Reorientation Axle Assembly.
- Idler Sprockets in Tank Drive

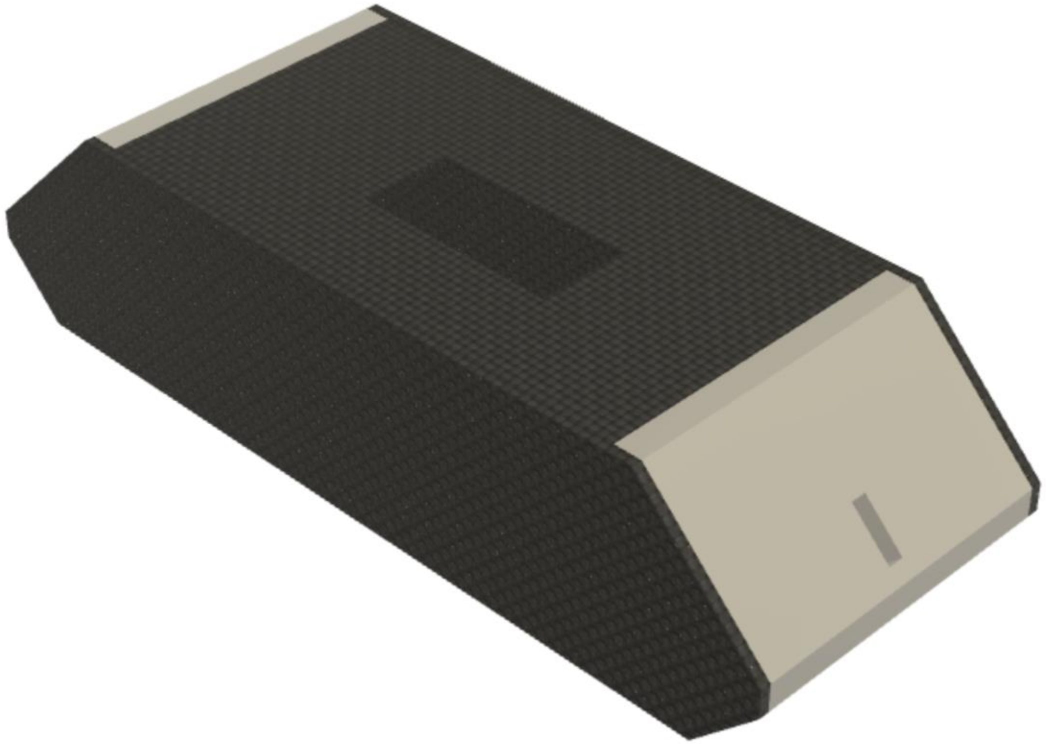
Final Tank Design

- Length: 8.20 inches
- Width: 5.13 inches
- Height: 3 inches
- Tank Weight: 4 lbs

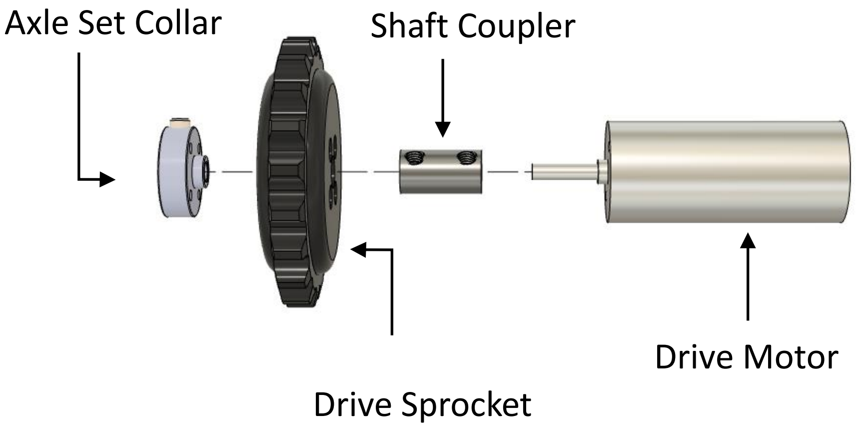


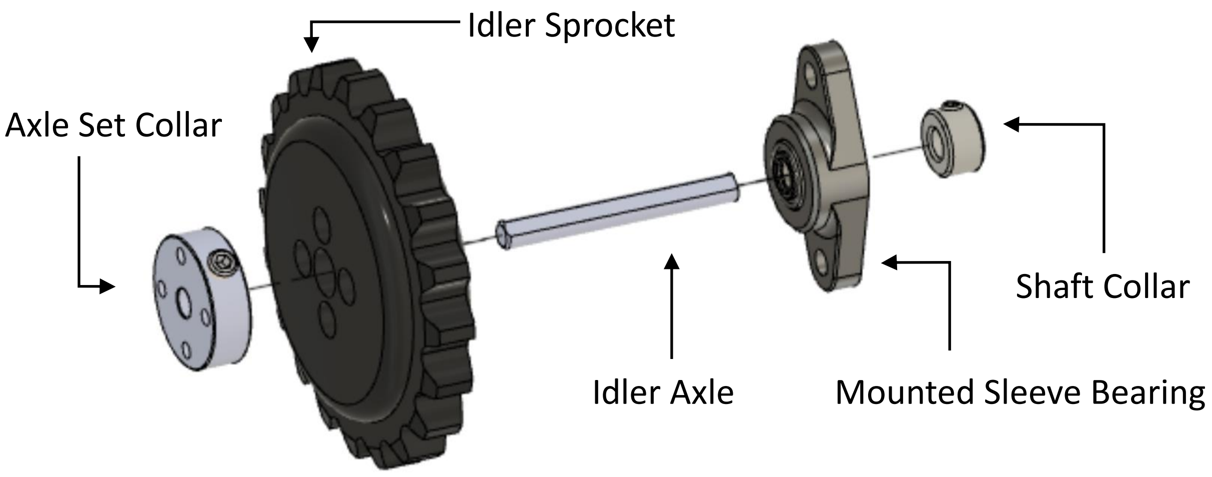
Final Tank Design: Chassis

- Top, bottom, and side chassis plates made from Carbon Fiber
- Front and rear chassis blocks made from Aluminum
- Lightweight chassis with high strength.

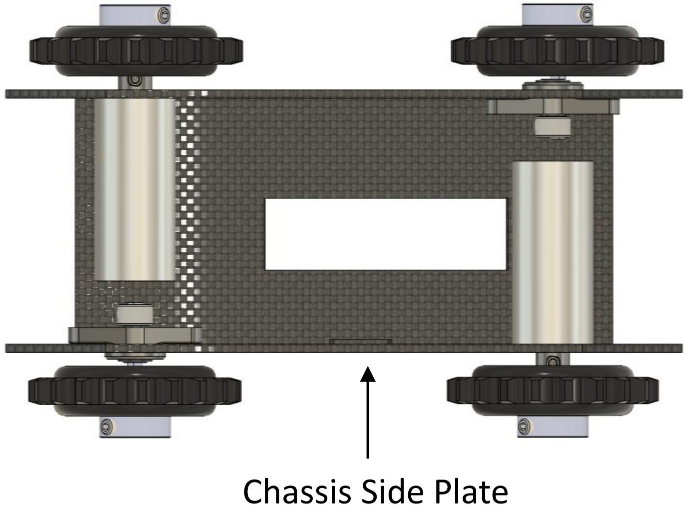


Payload Design: Tank Drivetrain

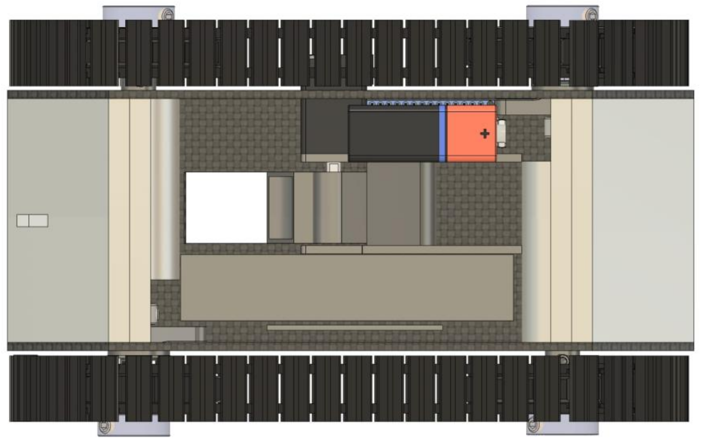


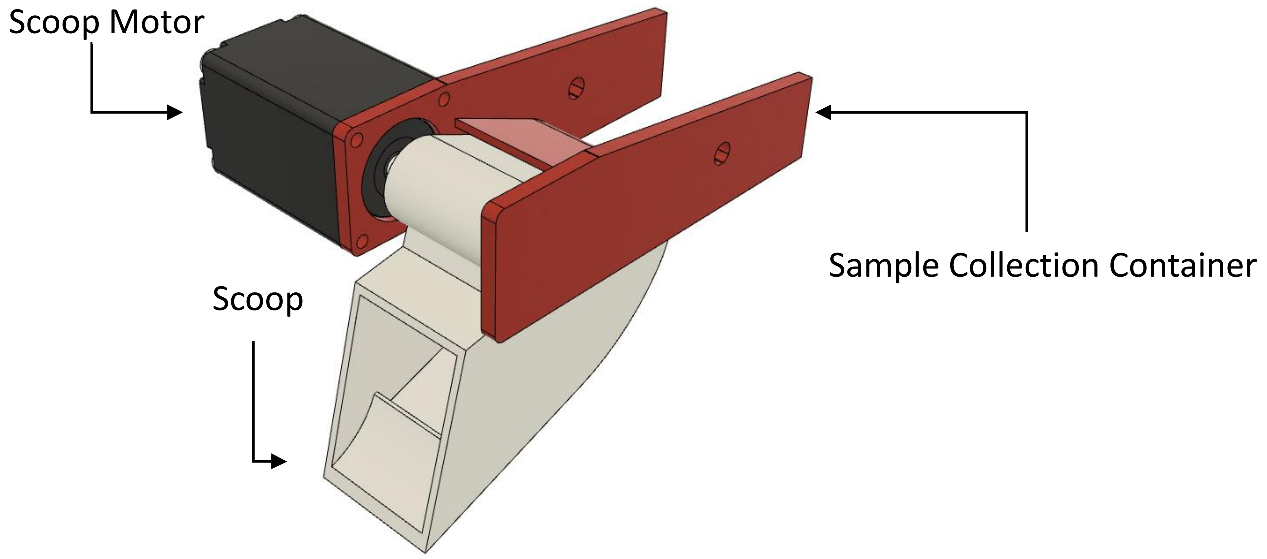


- One driven and one idler sprocket on each side of tank
- Direct drive to drive sprockets with shaft collars and shaft coupler.
- Idler Axle mounted with mountain sleeve ball bearing attached to side of the chassis.

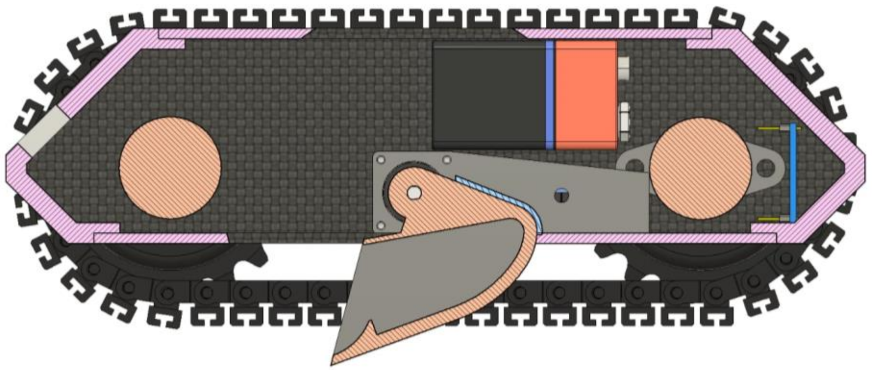


Payload Design: Sample Collection Unit (SCU)





- Sample Collection Unit located in the center of the chassis
- Stepper Motor provides holding torque during sample collection.
- Scoop and SCU are 3D printed.
- SCU serves as motor mount and collection container. Fastened to bottom chassis plate.

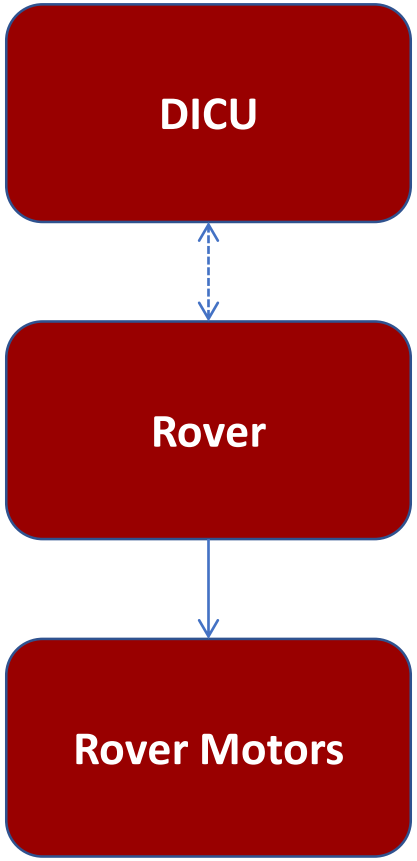


Payload Design: DICU and Rover Electronics

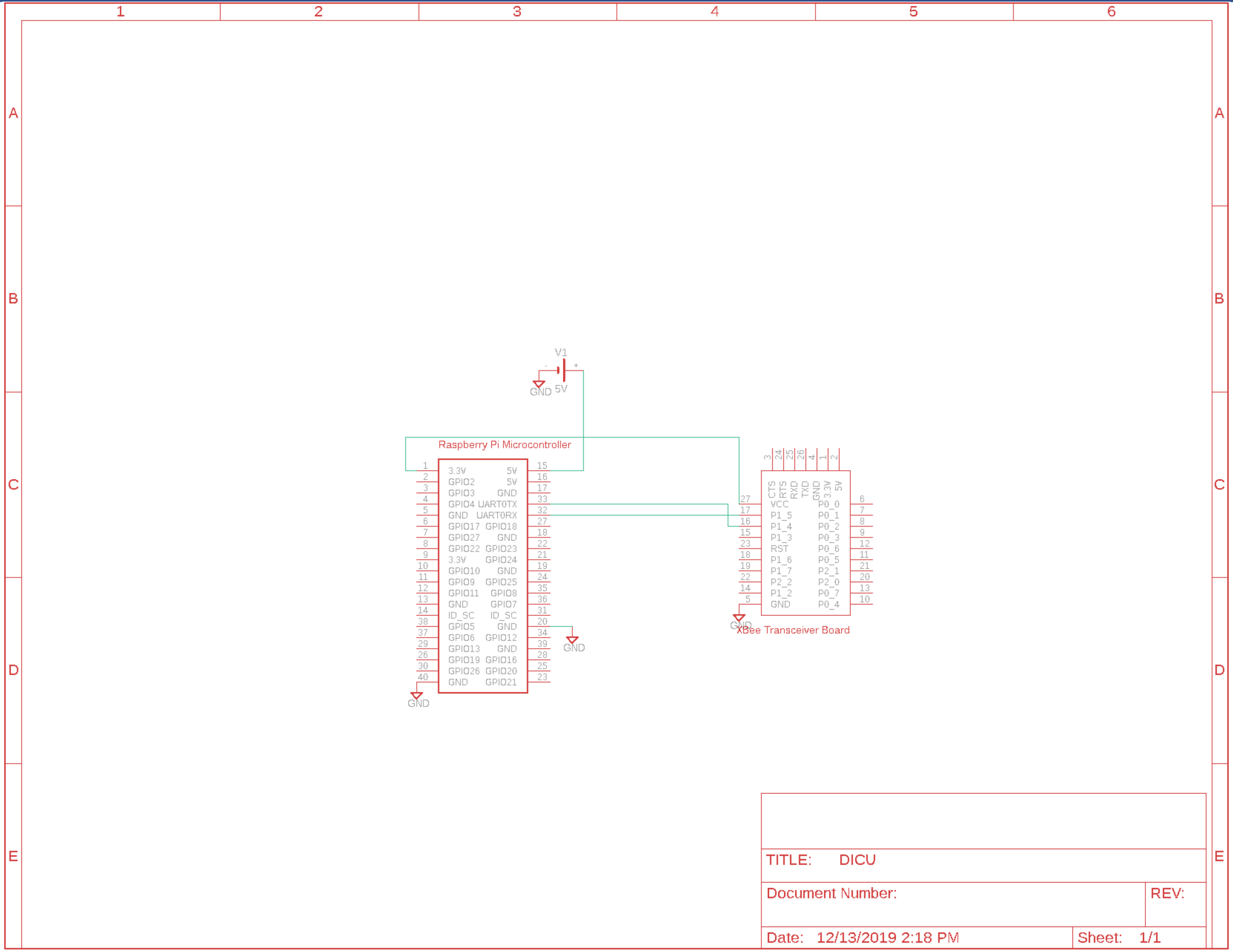
- DICU connected to XBee Transceiver at 2.4Ghz, battery, and display
- DICU controls Rover motors, ping test, communication status
- DICU displays real-time data
- Rover turns once exits rocket
- Rover sends and received DICU data
- Motor commands are sent to FeatherWing motor control

DICU and Rover

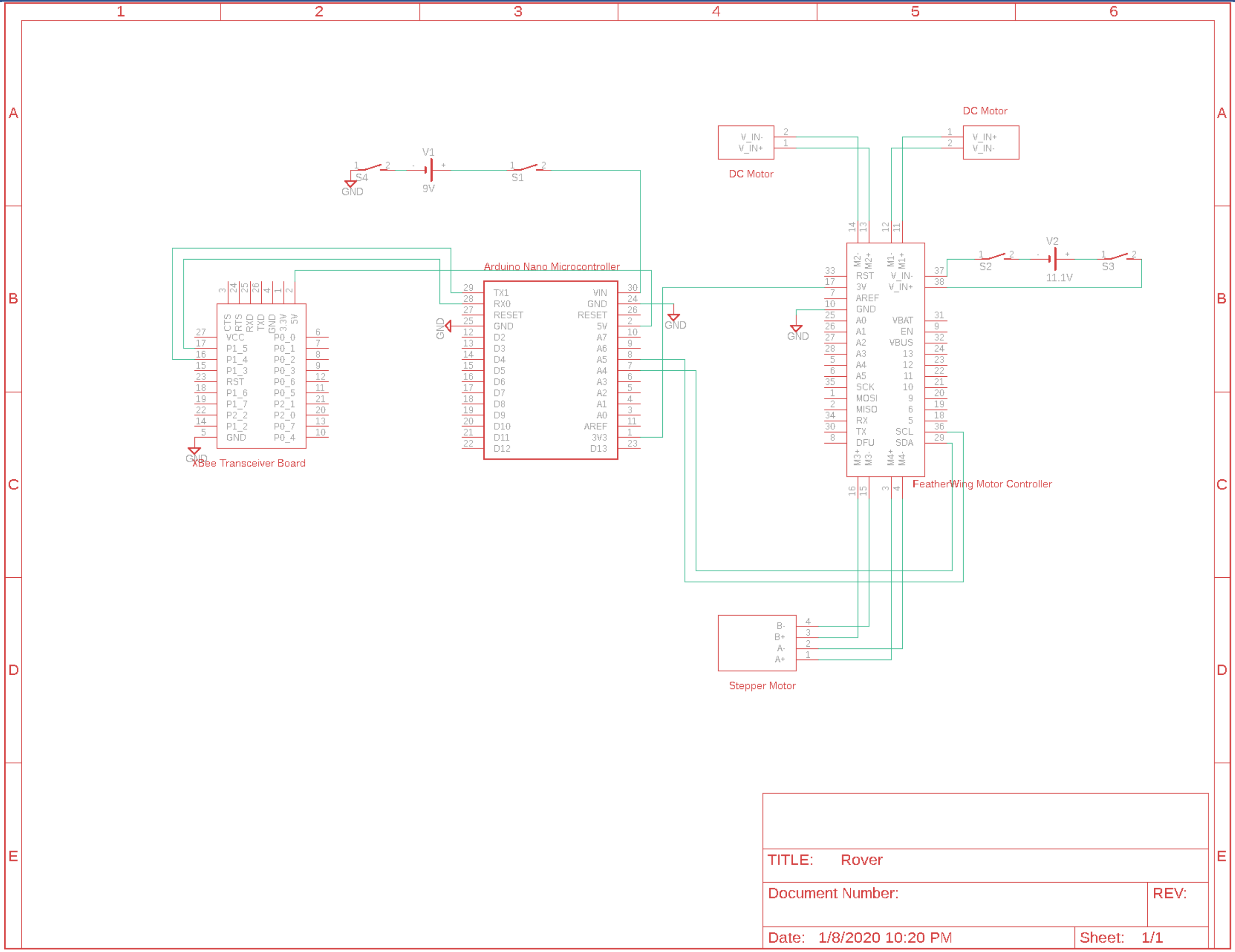
Data Flow Chart



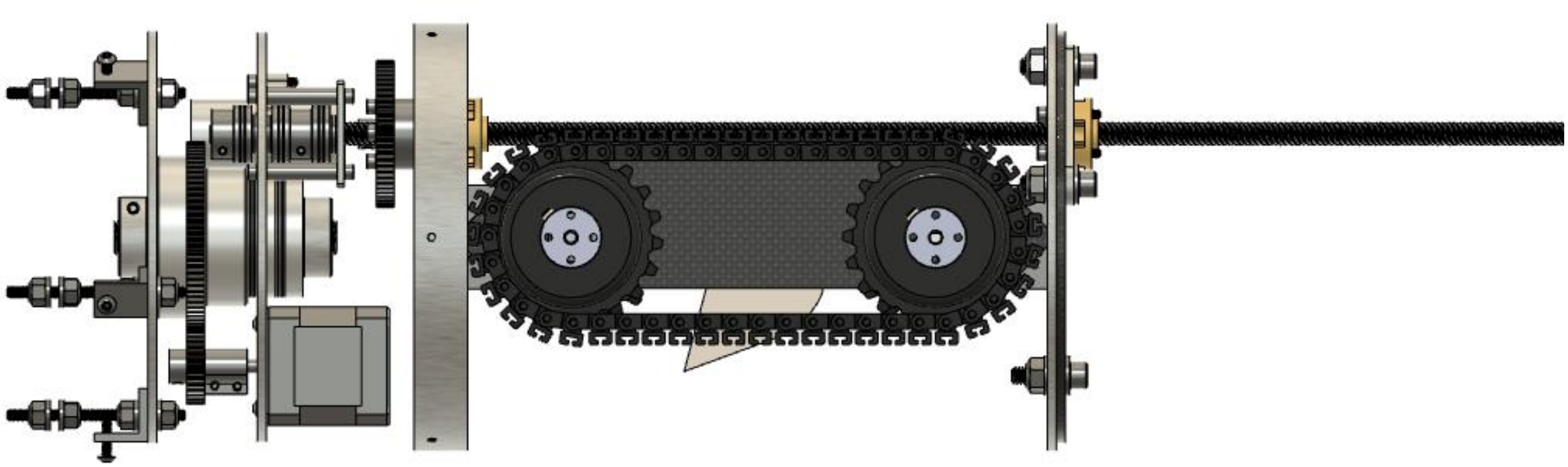
Payload Design: DICU Electrical Schematic



Payload Design: Rover Electrical Schematic



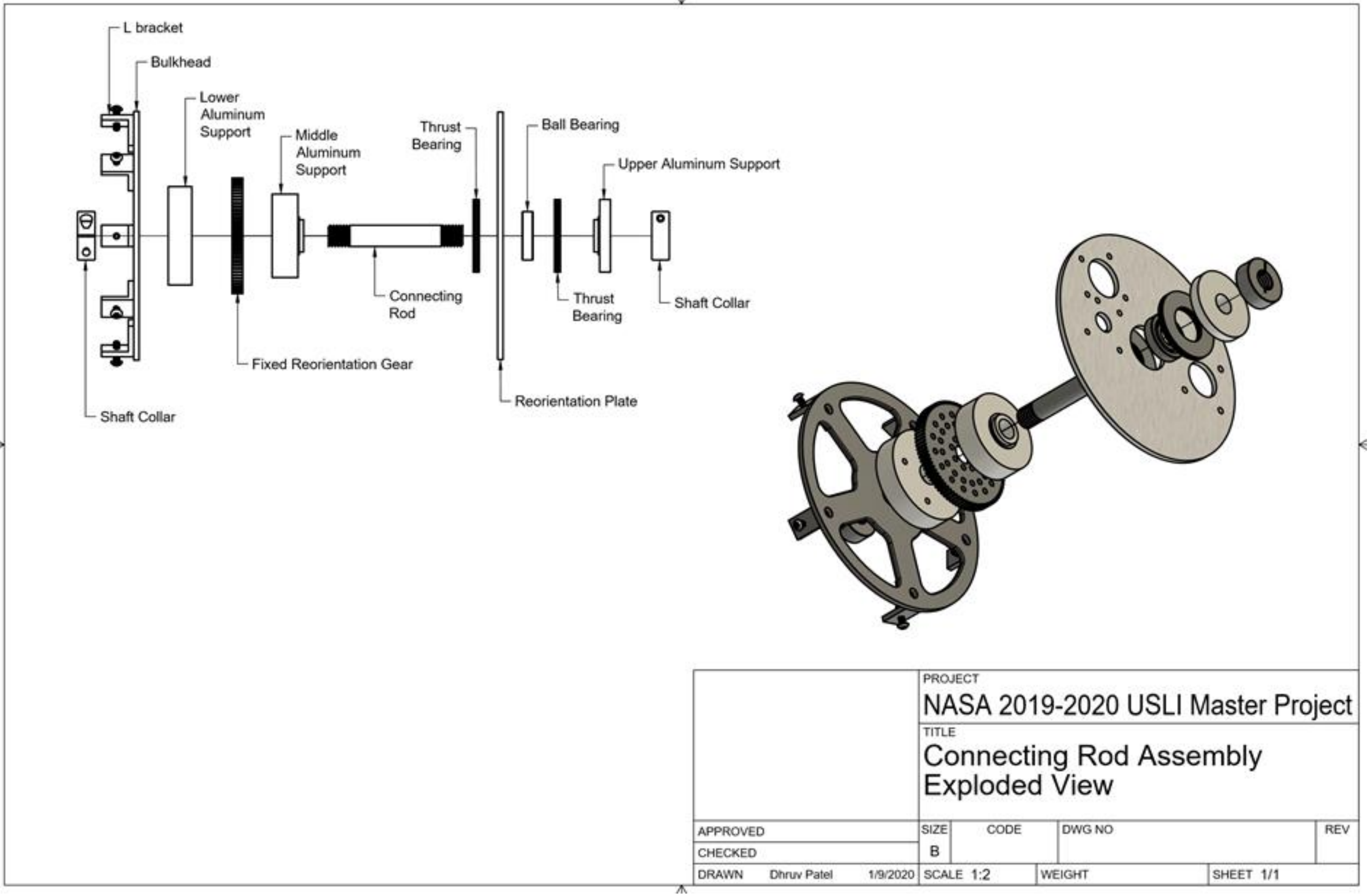
Payload Design: TEARS



Incorporates 3 Systems

- Reorientation
- Exiting
- Retention

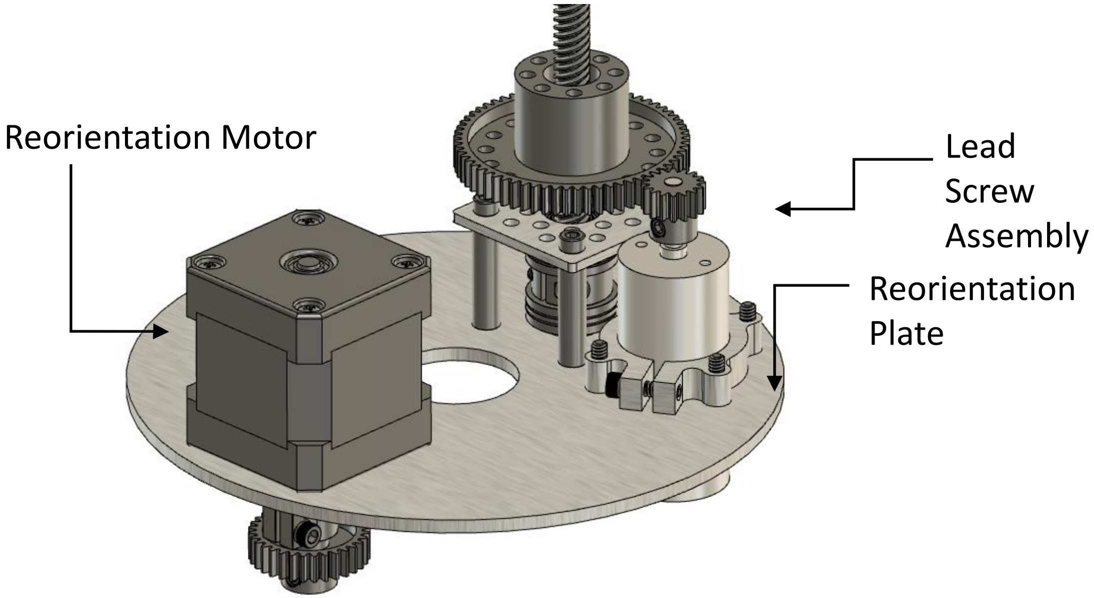
Payload Design: Reorientation

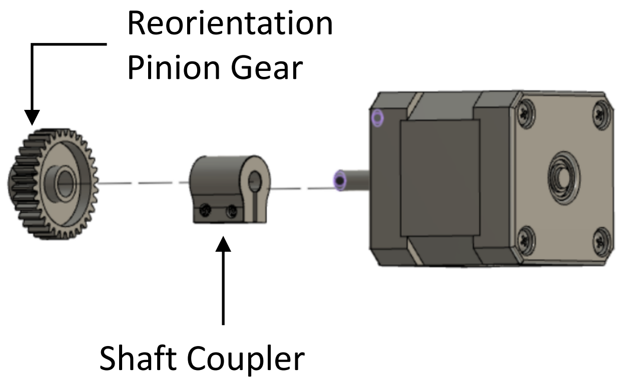


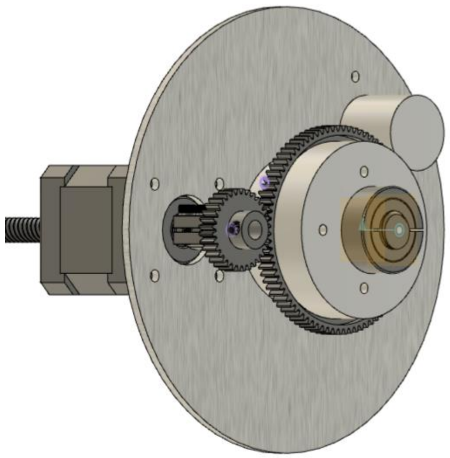
Reorientation Axle Assembly

- Aluminum Rod with threaded ends serves as fixed point of the system.
- Fixed Hub Gear Mounted to the aluminum rod
- Bearings and Aluminum supports serve to minimize load during reorientation.

Payload Design: Reorientation



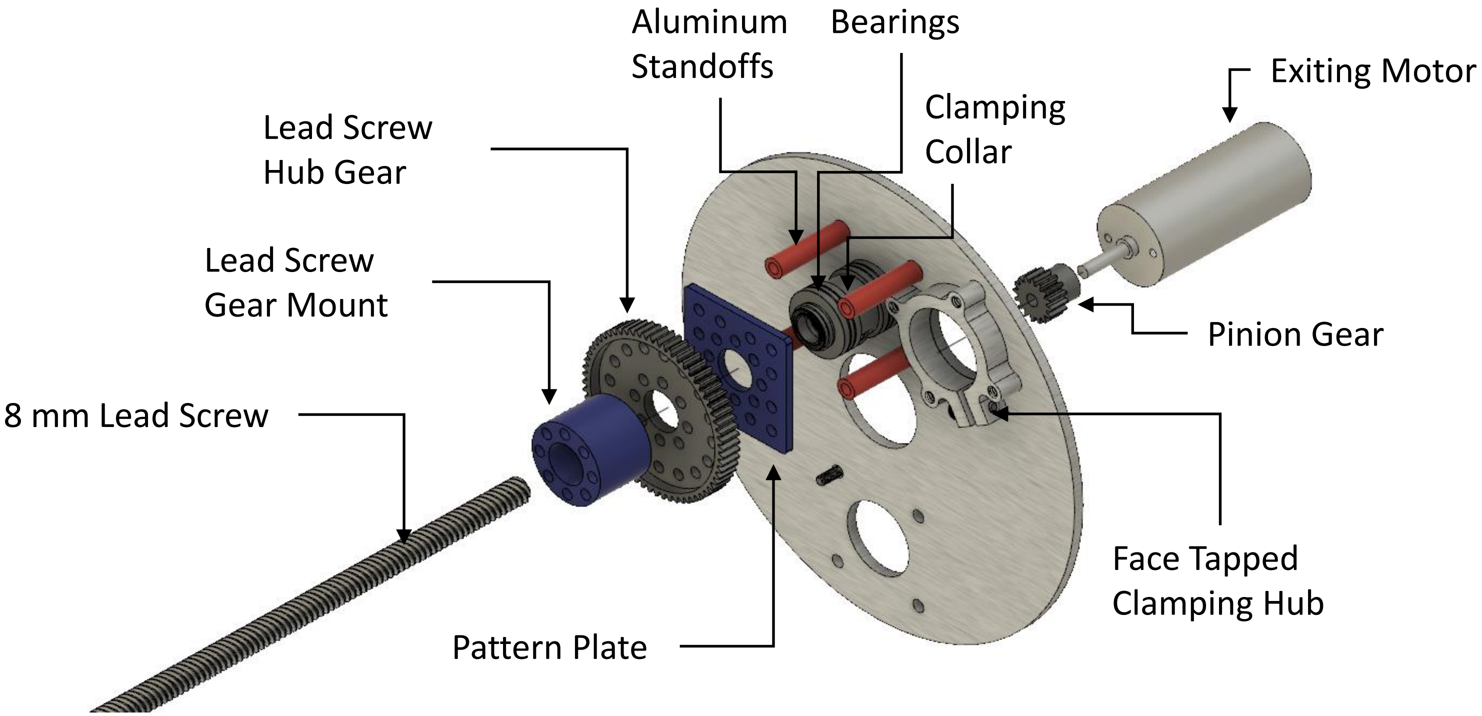




Reorientation Plate

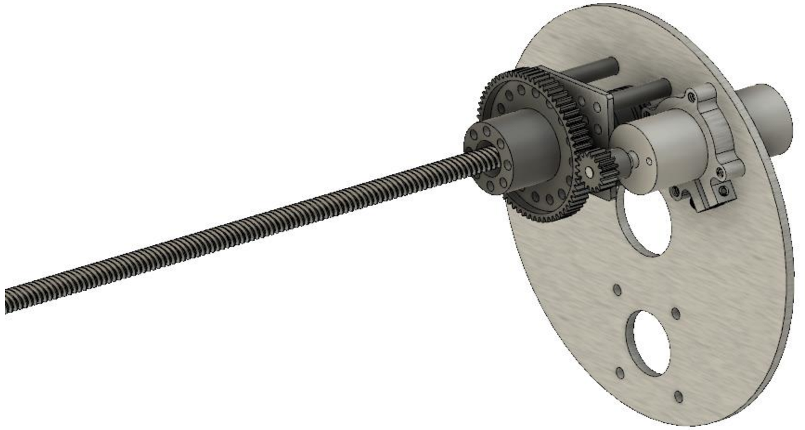
- Mounts the reorientation motor and the exiting assembly.
- Rotates around the fixed reorientation axle.
- Made from 1/8 inch thick Aluminum 6061.

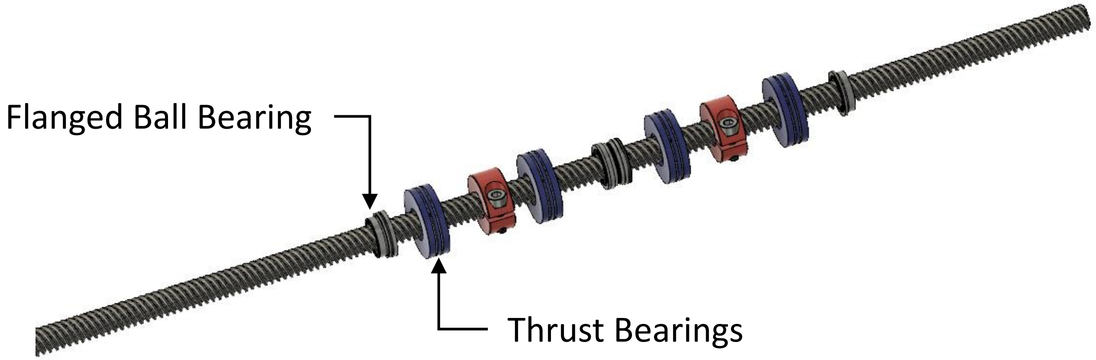
Payload Design: Exiting



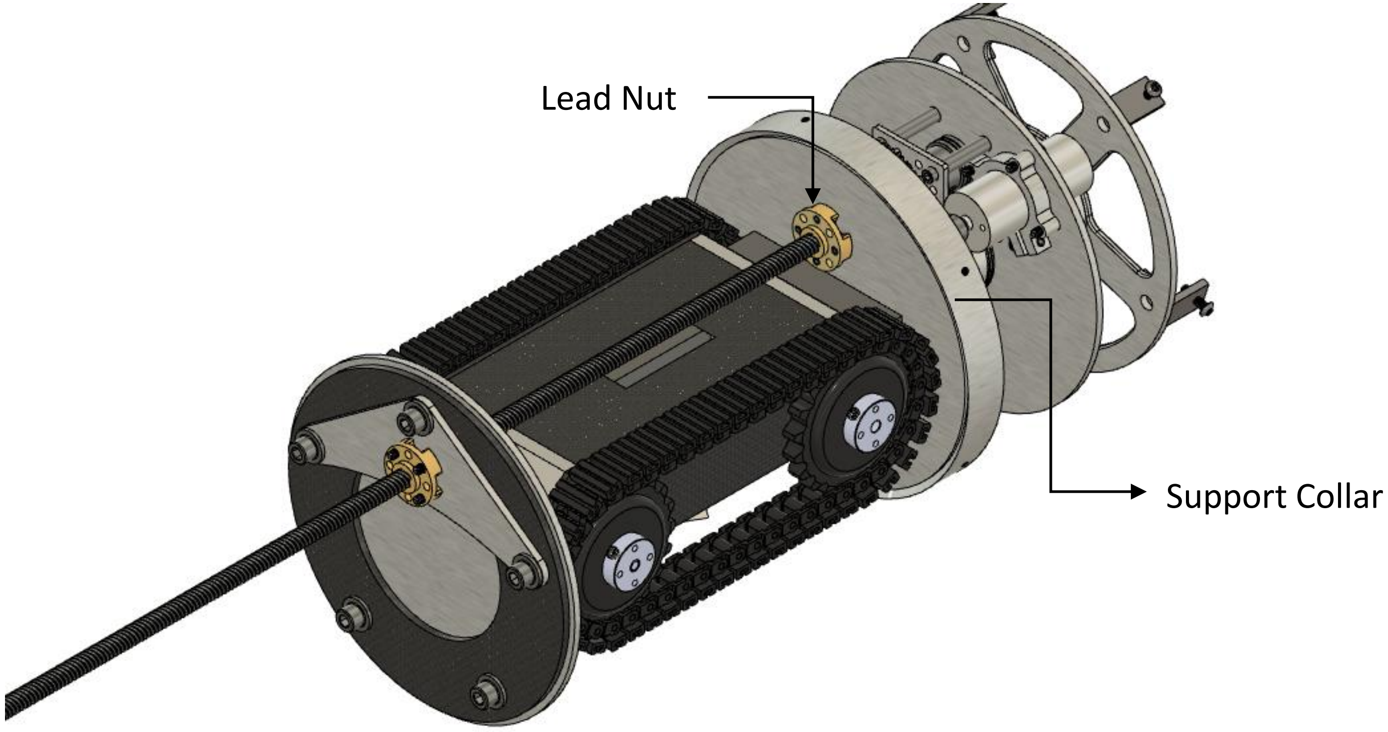
Lead Screw Assembly

- Mounted on Reorientation Plate
- Hub Gear meshes with drive motor pinion gear.
- Aluminum Standoffs, pattern plates, and bearings help address the loads on the lead screw.



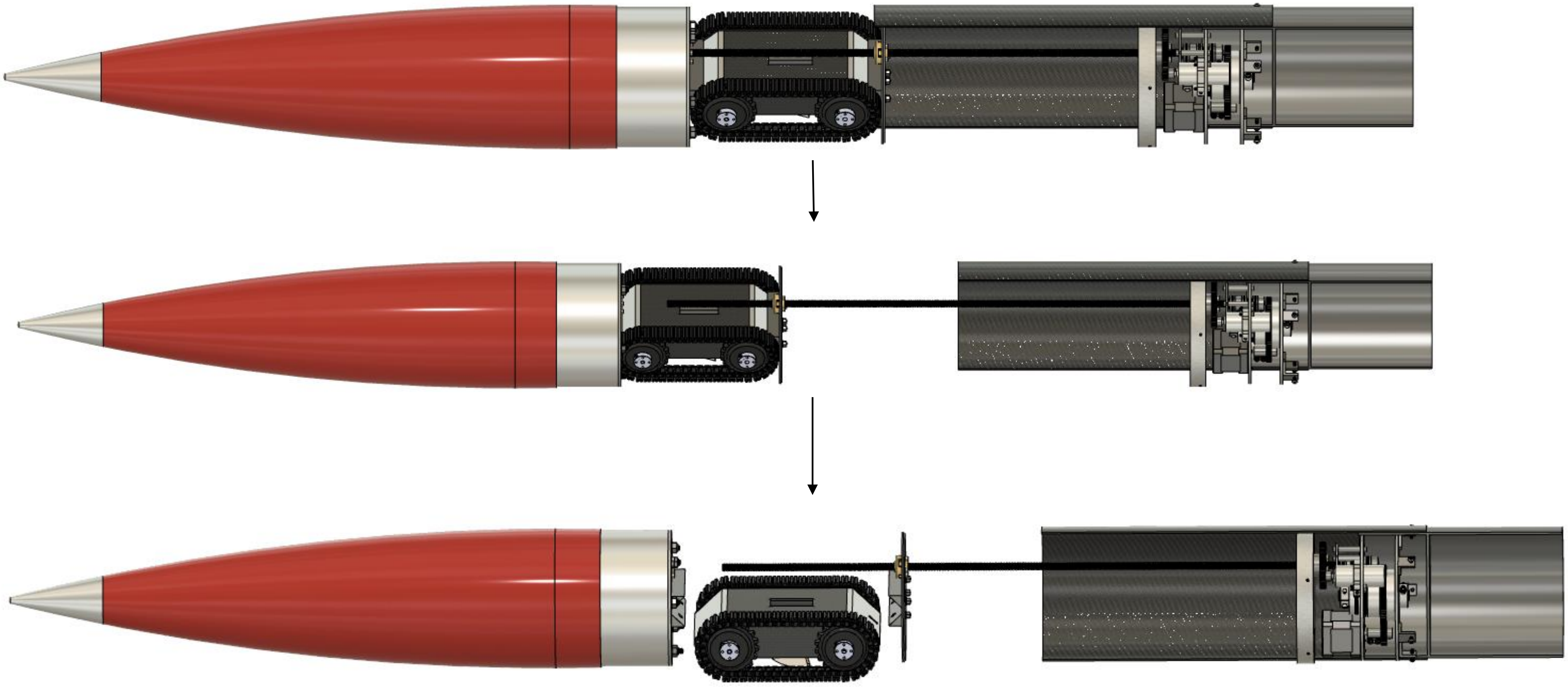


Payload Design: Exiting

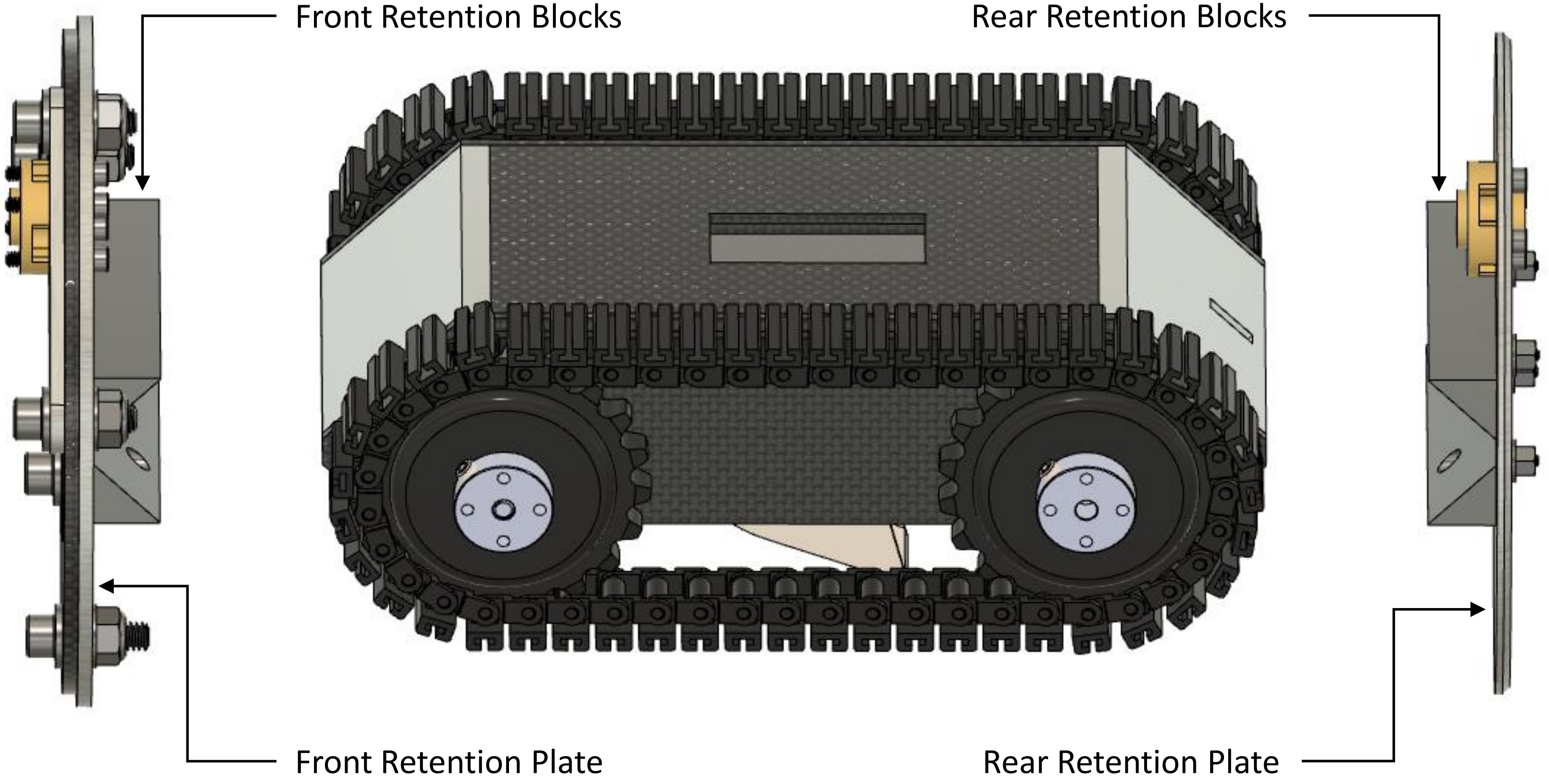


- Tank secured on retention plates.
- Retention Plates have lead nuts mounted on them that travel along the lead screw.
- Aluminum Collar supports the retention plate in flight and during ground impact.

Payload Design: Exiting

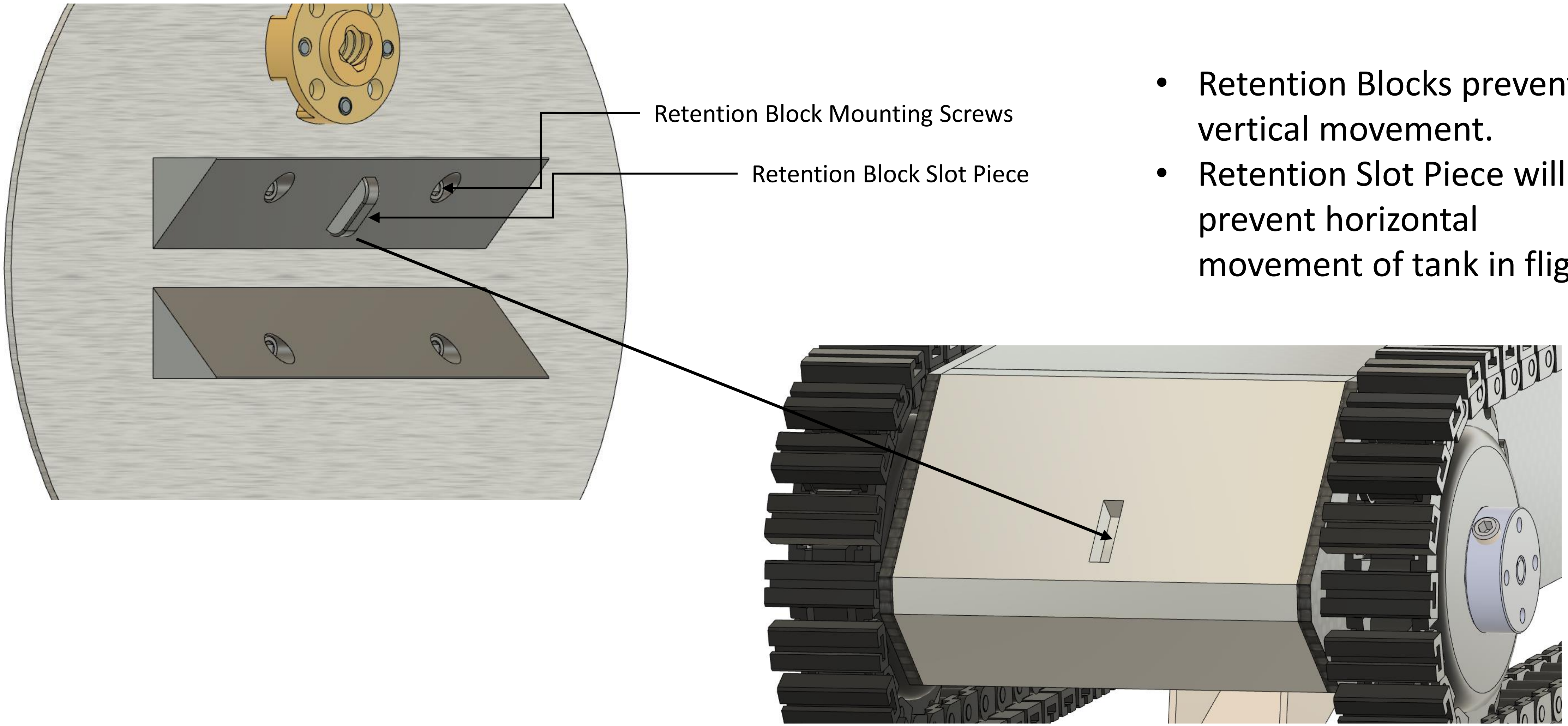


Payload Design: Retention



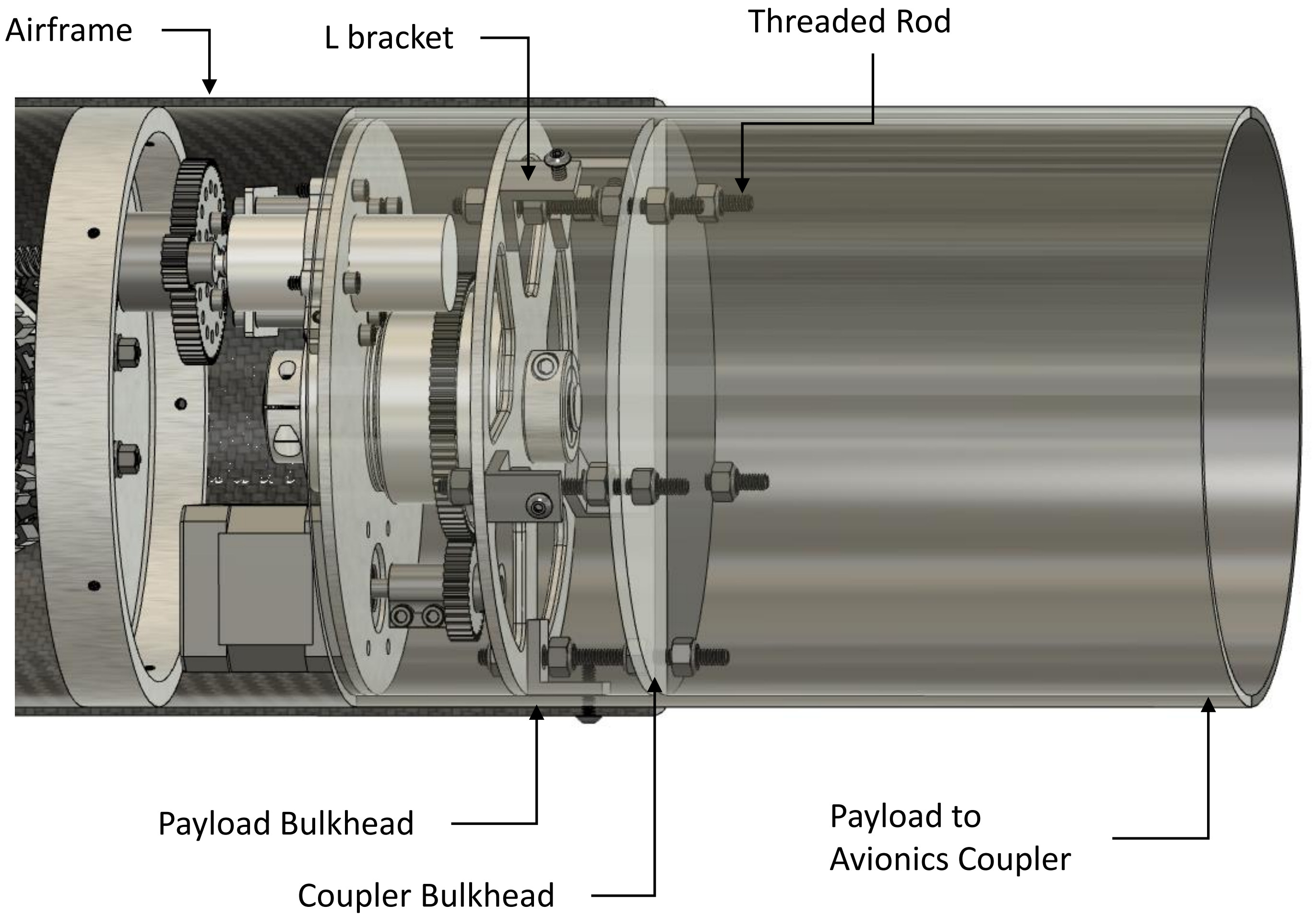
- Aluminum Retention Blocks mounted on front and rear retention plate.
- Retention blocks hold the front and rear parts of the chassis.
- Retention Plates are restricted from motion unless Lead Screw is actuated.

Payload Design: Retention



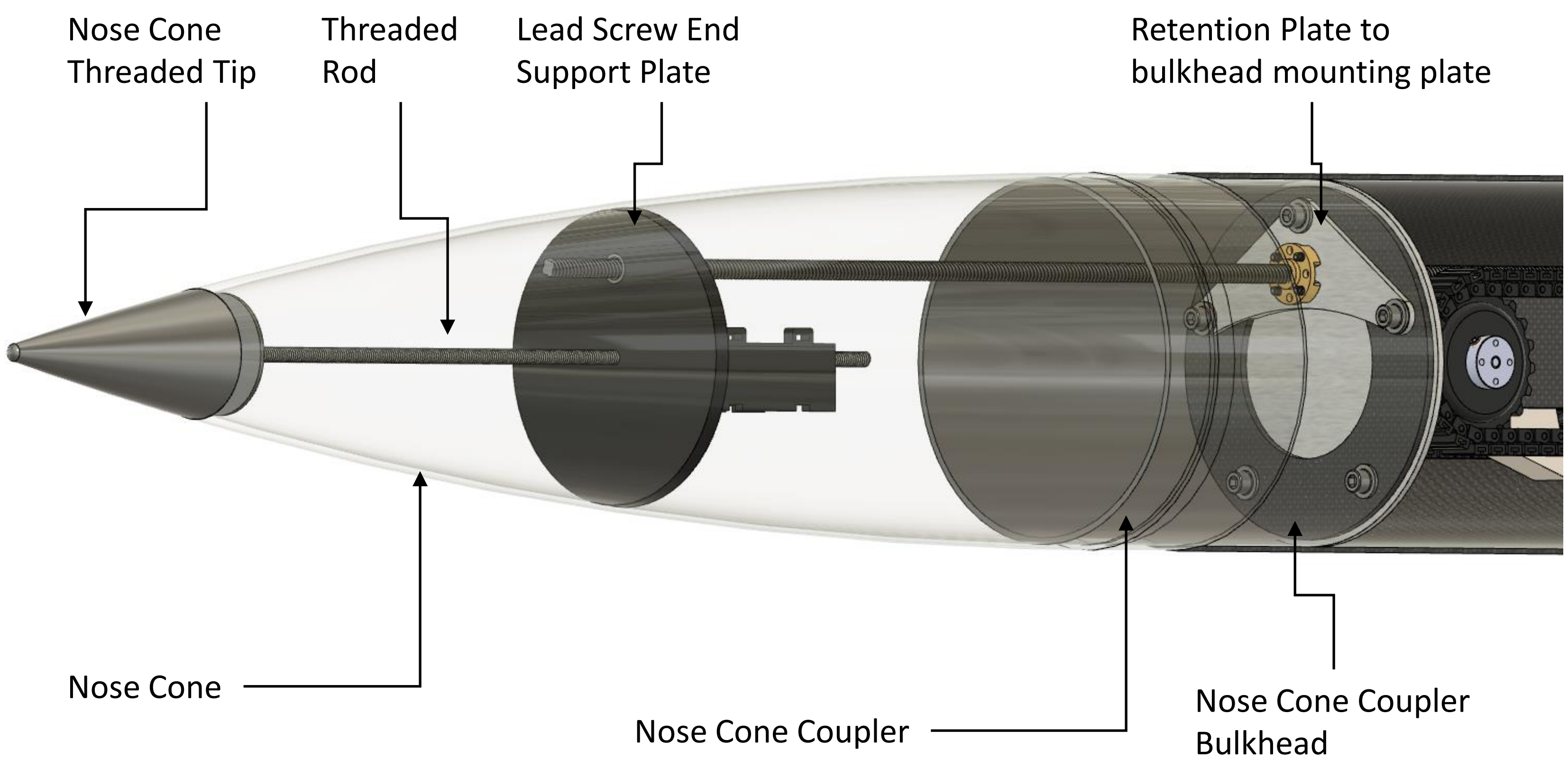
- Retention Blocks prevent vertical movement.
- Retention Slot Piece will prevent horizontal movement of tank in flight.

Payload Design: Payload Integration



- Payload Bulkhead Connected to Avionics Coupler Bulkhead
- L brackets and threaded rods solidify base of payload bay.
- L brackets connect payload bulkhead to airframe and coupler.
- Threaded Rods connect from payload to coupler bulkheads through L brackets.

Payload Design: Payload Integration



- Front Retention Plate mounted to Nose Cone Coupler Bulkhead
- Threaded Rod from Nose Cone Tip extends to Lead Screw End support plate.
- End Support Plate is 3D printed and houses telemetry sled for GPS and bearing for supporting Lead Screw.

Payload Design: TEARS Electronics

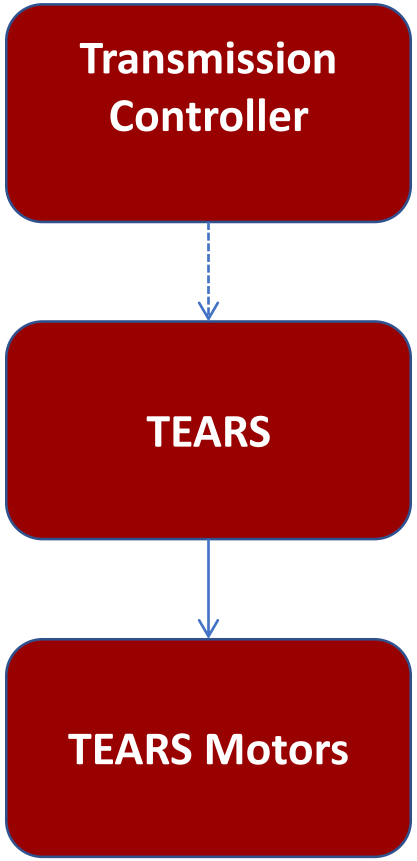
- Transmission controller and TEARS receiver operate at 433Mhz

- Remotely control receiver’s relays

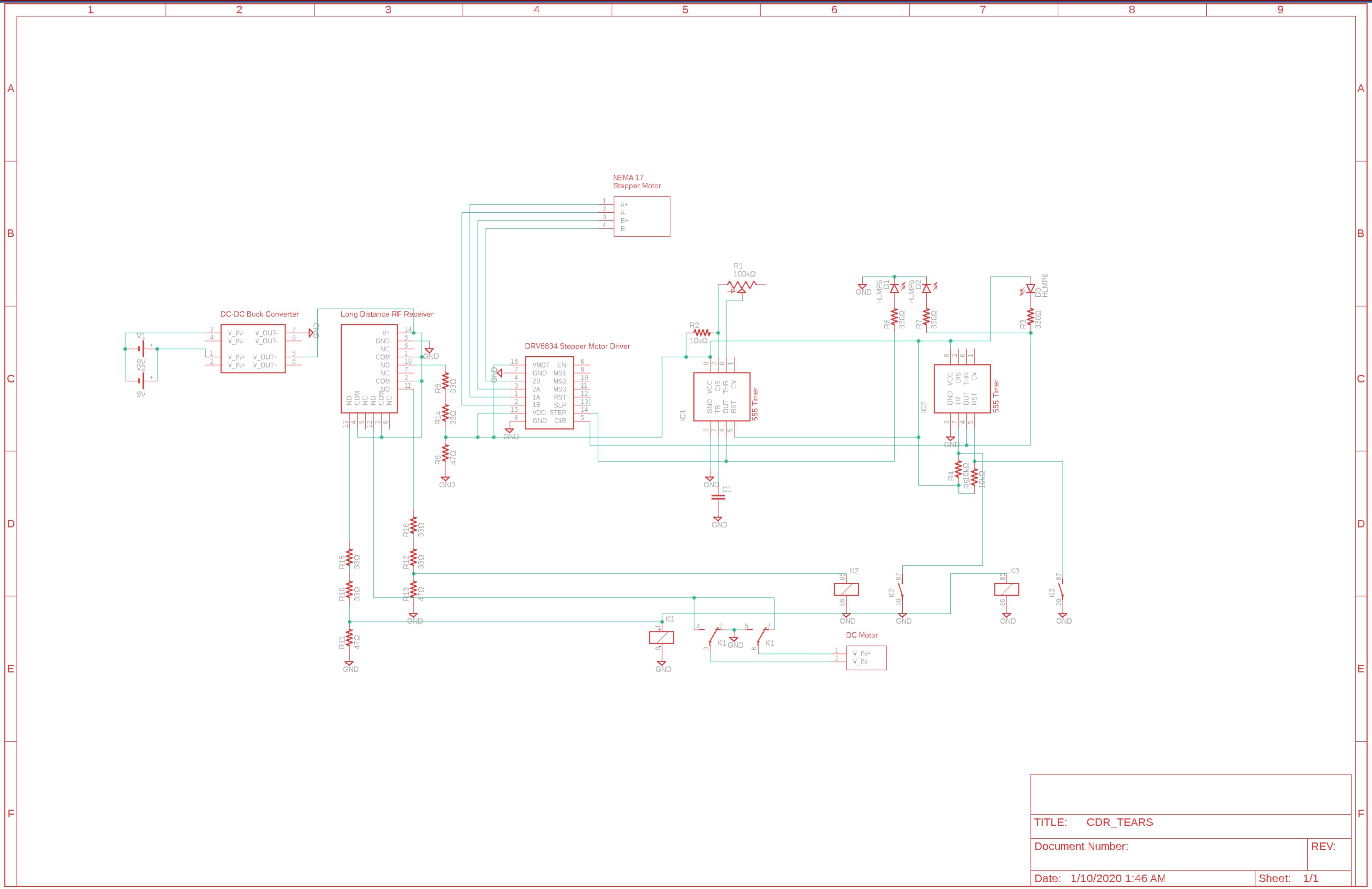
- Relays control TEARS Reorientation motor, Stepper motor, and motor reversal

TEARS

Data Flow Chart



Payload Design: TEARS Electrical Schematic

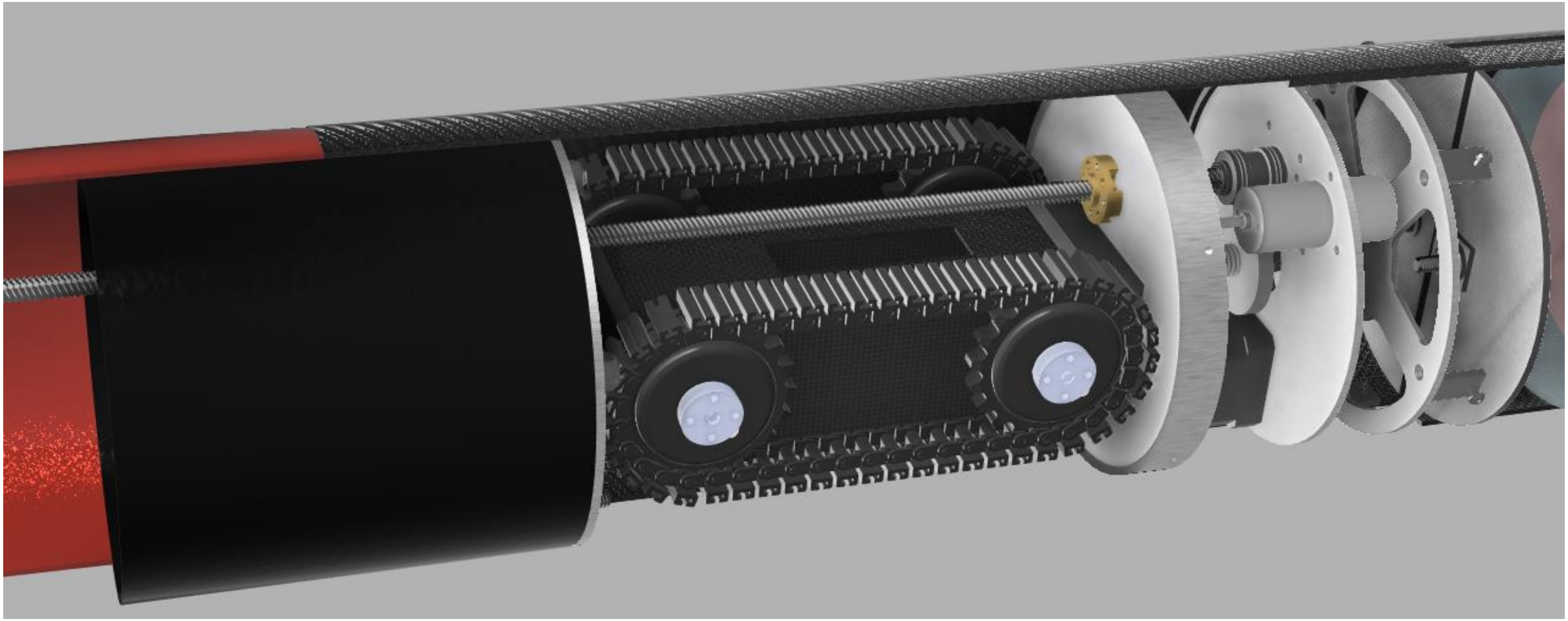


Agenda

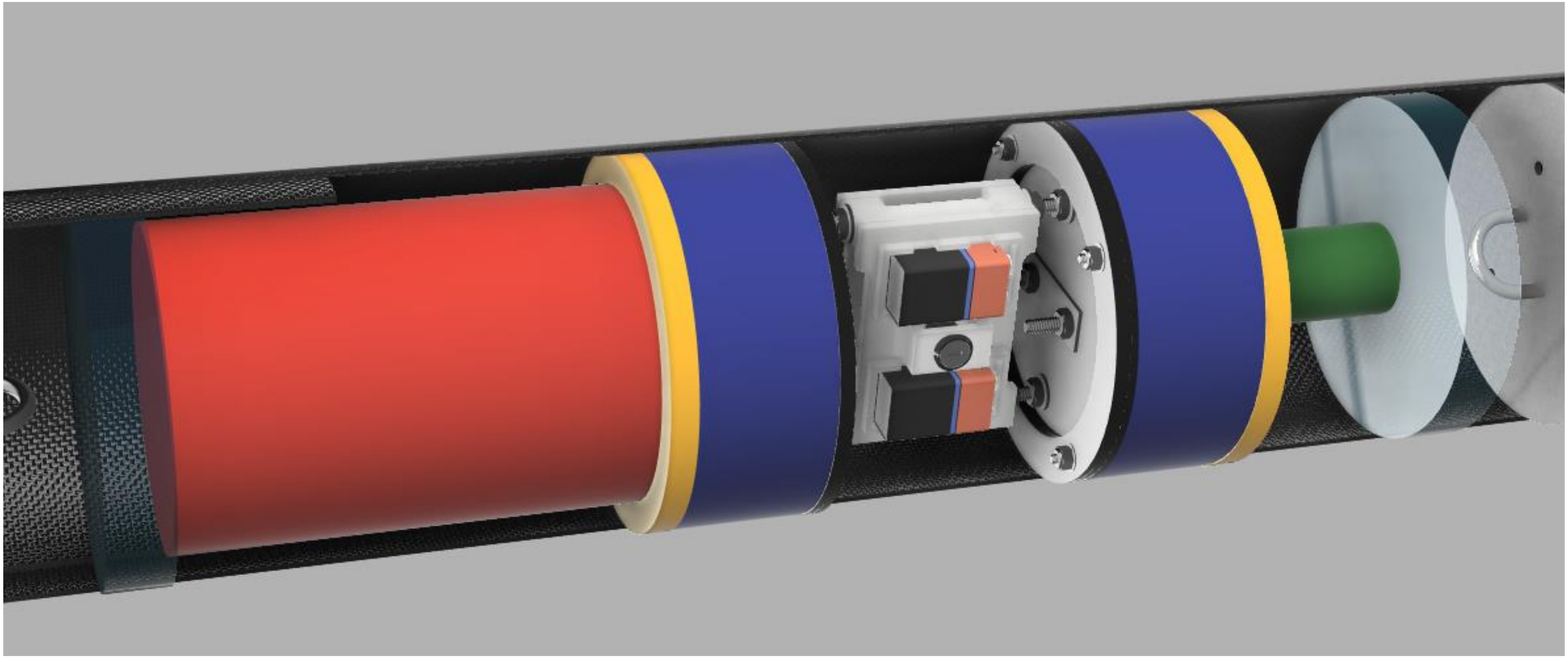
i. Launch Vehicle Design
ii. Recovery Subsystem
iii. Payload Design
iv. **Integration & Summary**
v. Subscale Launch
vi. Requirements Verification & Safety

Integration & Summary

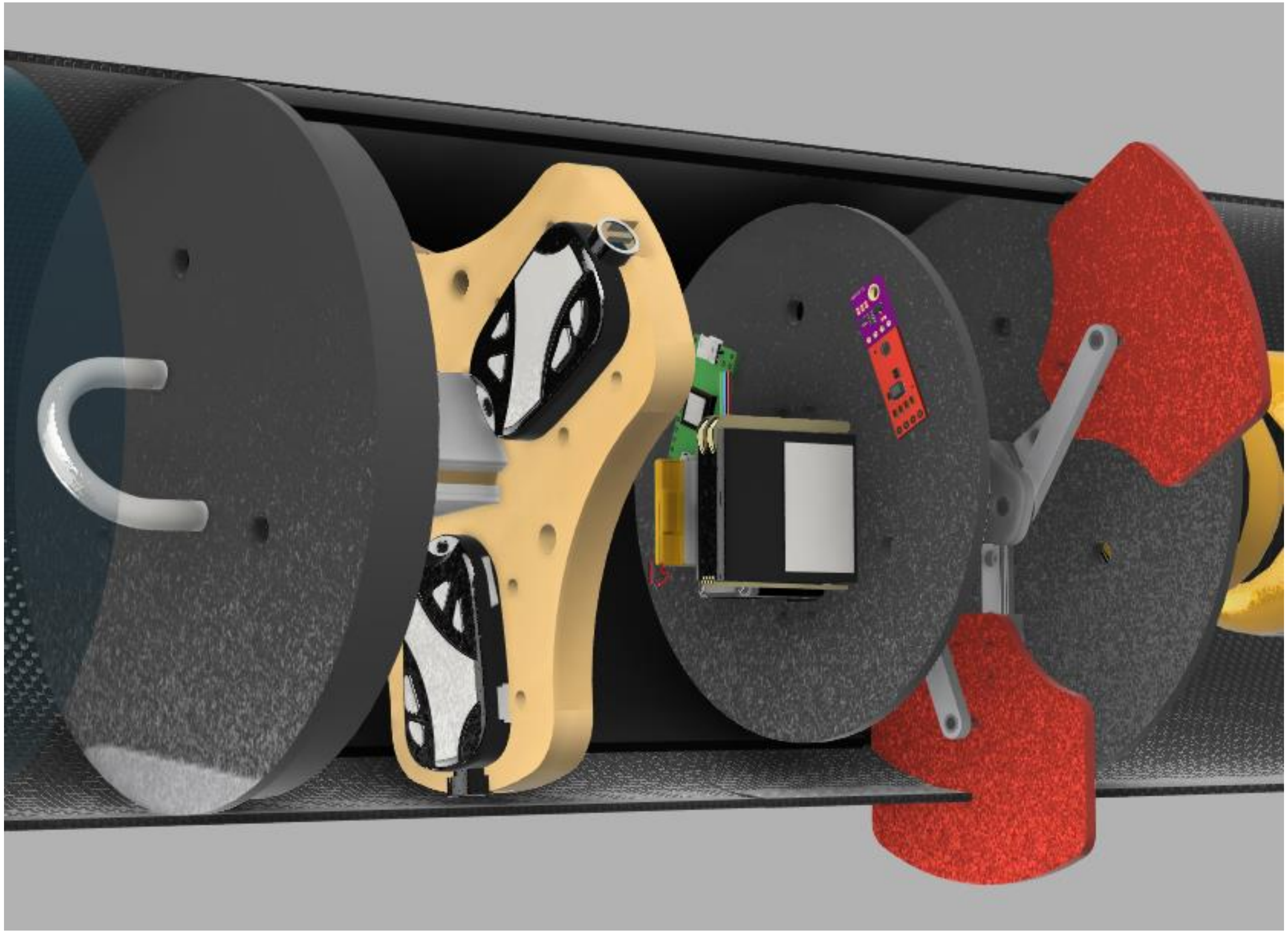
Integration & Summary



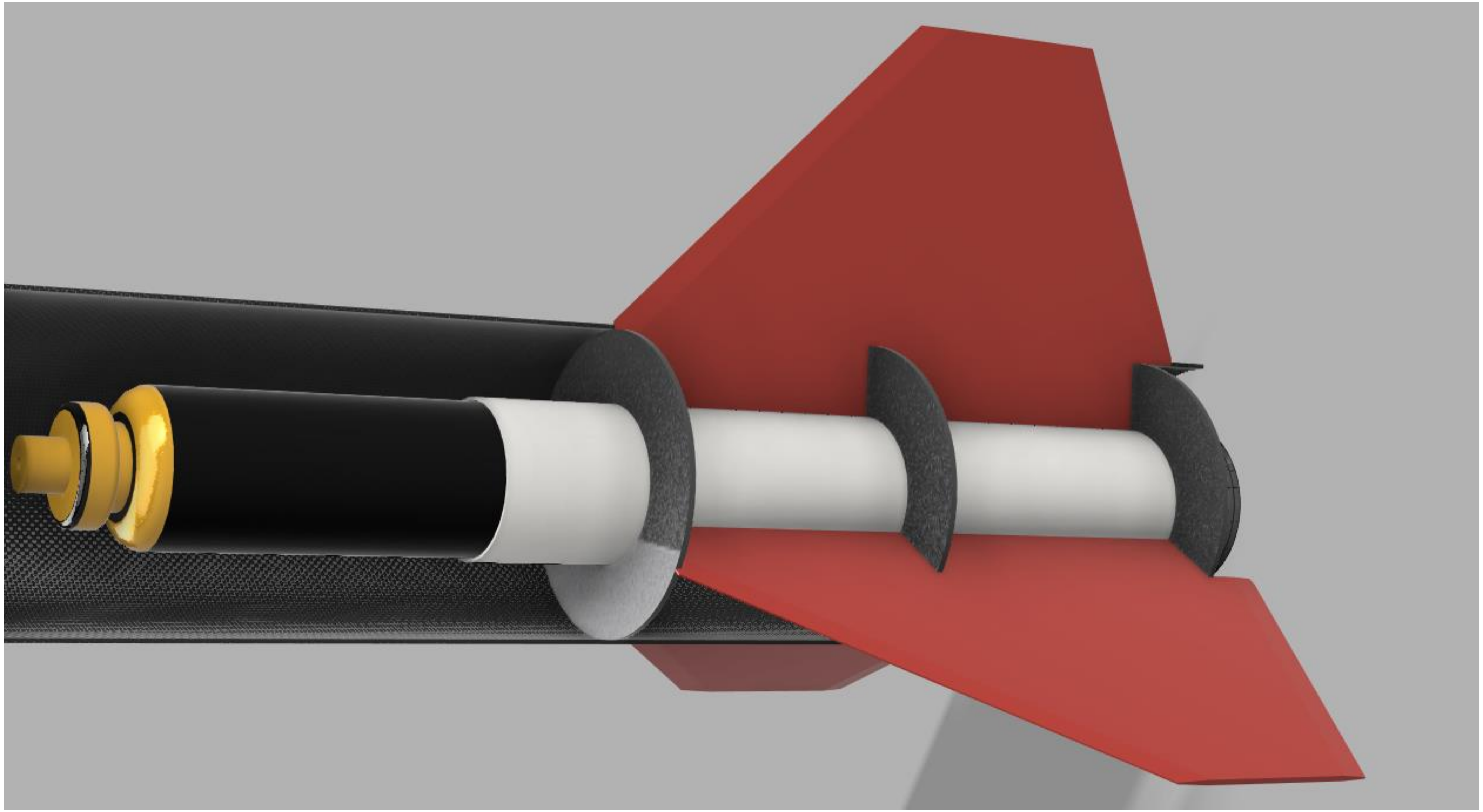
Integration & Summary



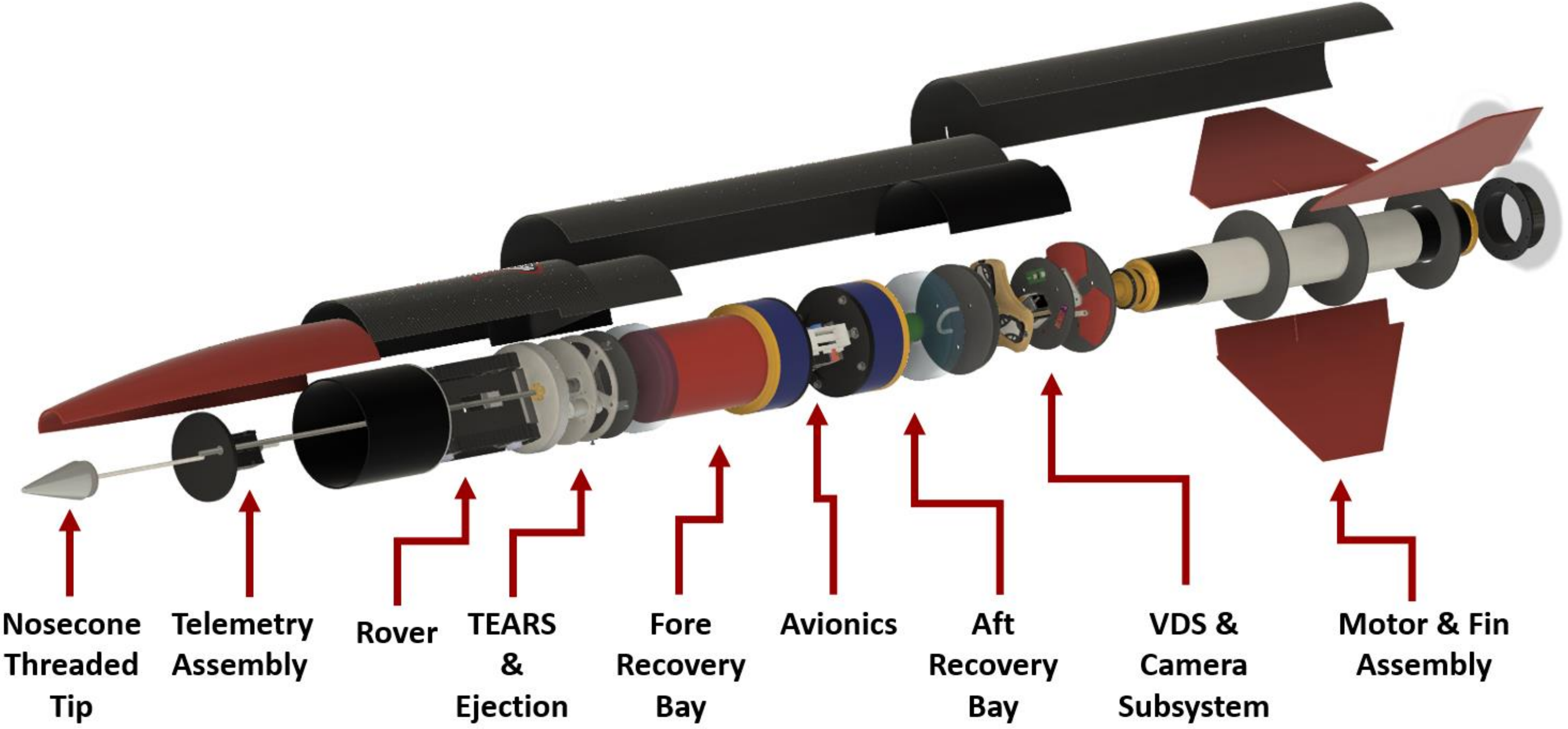
Integration & Summary



Integration & Summary



Integration & Summary



Agenda

i. Launch Vehicle Design
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v. **Subscale Launch**
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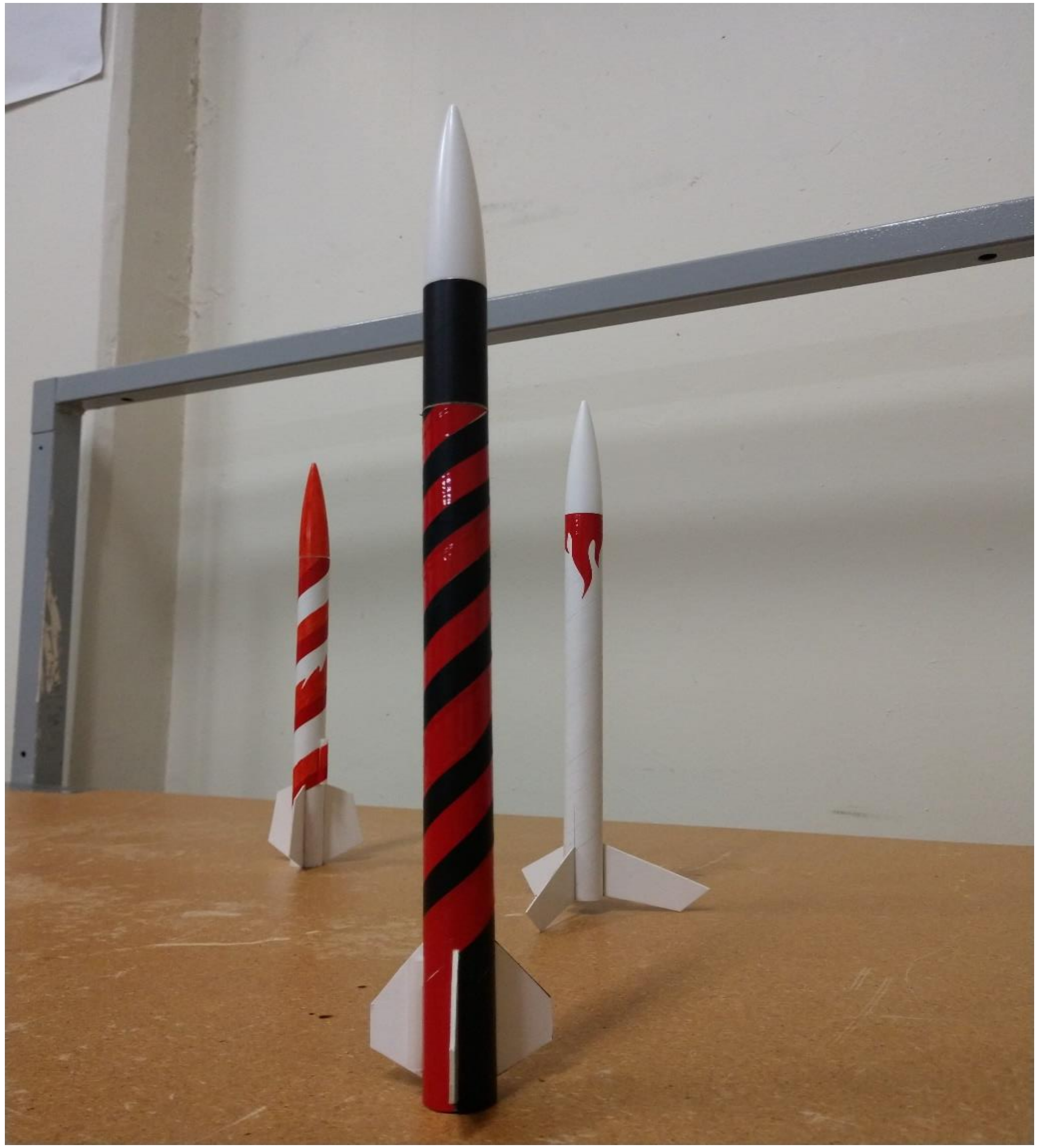
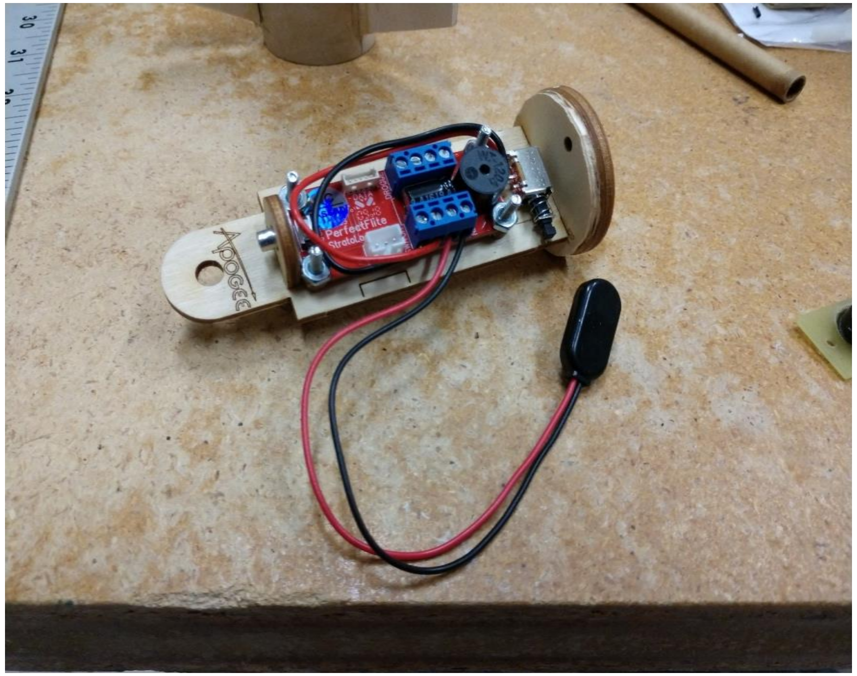
Launch Vehicle Design: Subscale Dimensions

Component	Full Scale (in)	BT-20 Subscale (in)	BT-60 Subscale (in)
Nosecone	26.0	2.88	6.38
Payload Bay	21.0	2.52	5.58
Avionics Bay	32.9	3.95	8.74
Booster Bay	27.0	3.24	7.18
Fin Root Chord	14.0	1.68	3.72
Fin Tip Chord	4.5	0.54	1.196
Scale	1.0	0.12	0.266

Launch Day Conditions	
Launch Time	3:56 PM EST
Temperature (Fahrenheit)	41.0
Wind Speed (mph)	5.0
Weather	Cloudy
Location	Stony Brook, NY

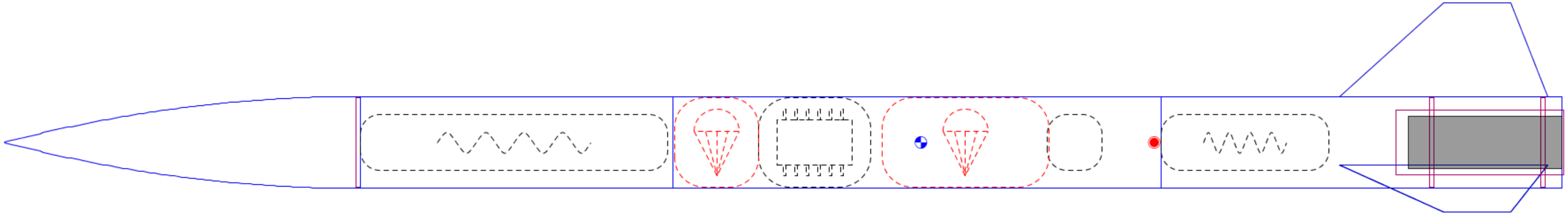


Subscale Launch: Manufacturing



Subscale Launch: Finished Products

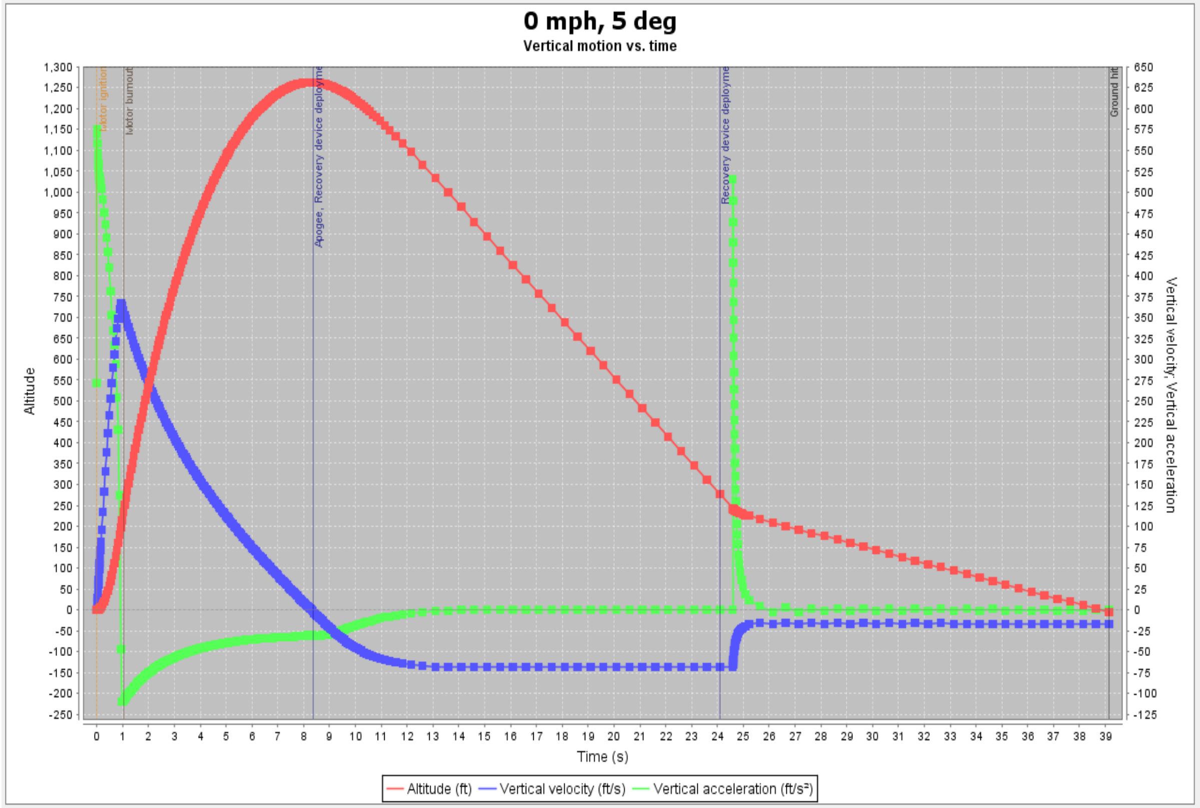
Subscale Launch: Flight Predictions

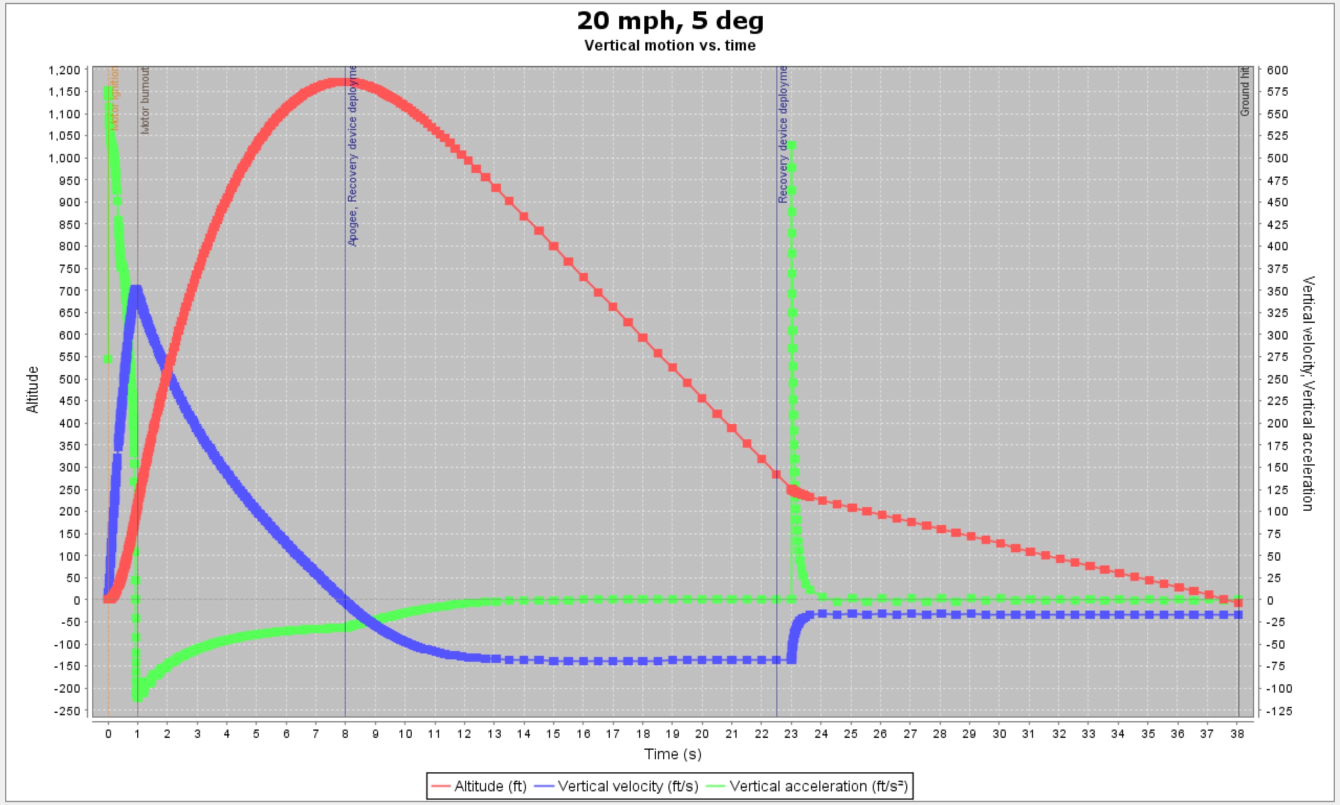


BT-60 Size Subscale	
Mass (lbm)	0.581
Length (in)	27.9
CP (in)	20.577
CG (in)	16.4
Stability (cal)	2.55
Motor	E30-4

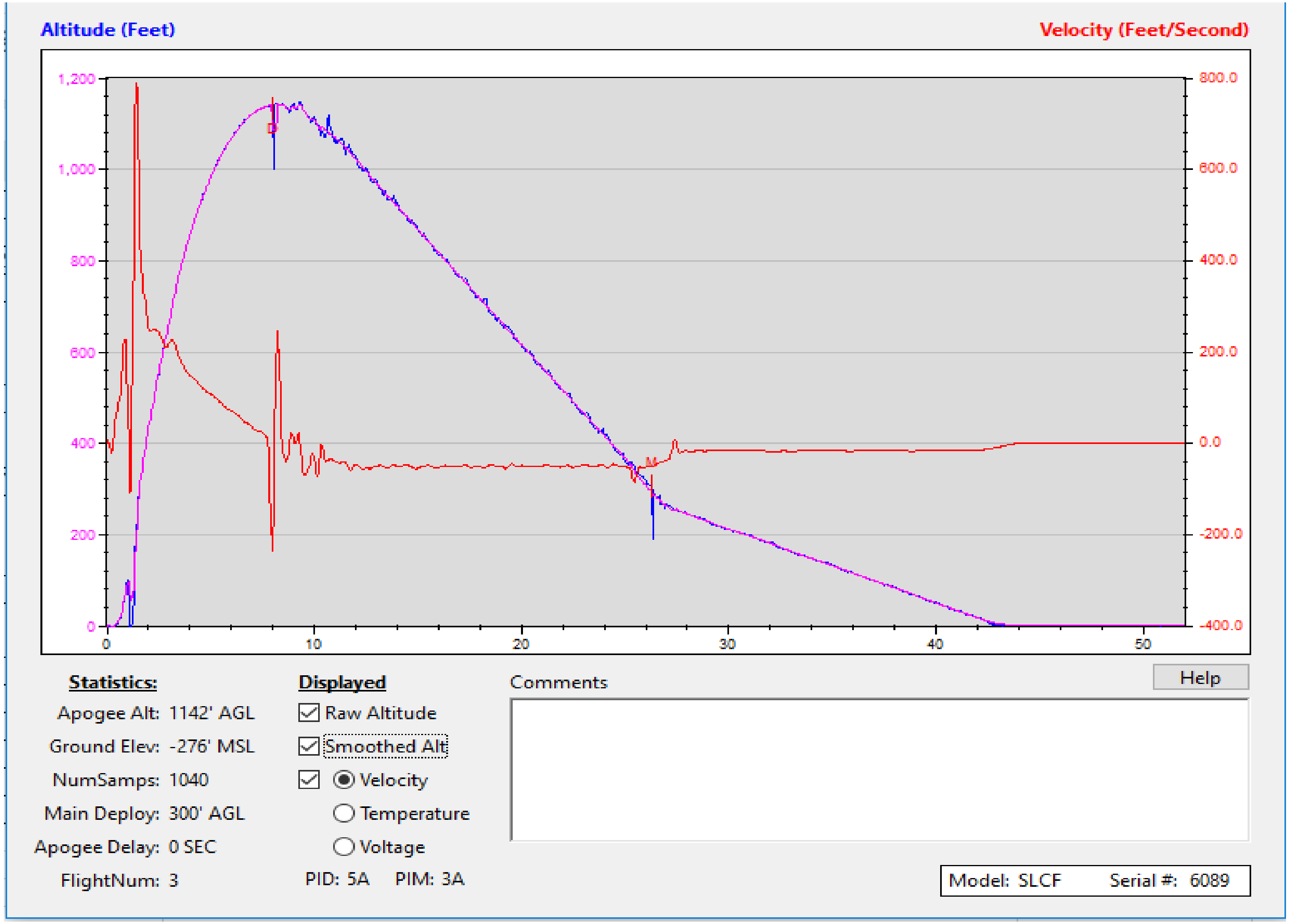
	Apogee (ft)	Velocity Off Rod (ft/s)	Time to Apogee (s)	Flight Time (s)
0 mph	1262	61.6	8.3	39.1
5 mph	1247	61.6	8.22	38.9
10 mph	1266	61.6	8.13	38.6
15 mph	1200	61.6	8.04	38.4
20 mph	1172	61.6	7.91	37.6

Subscale Launch: Flight Predictions

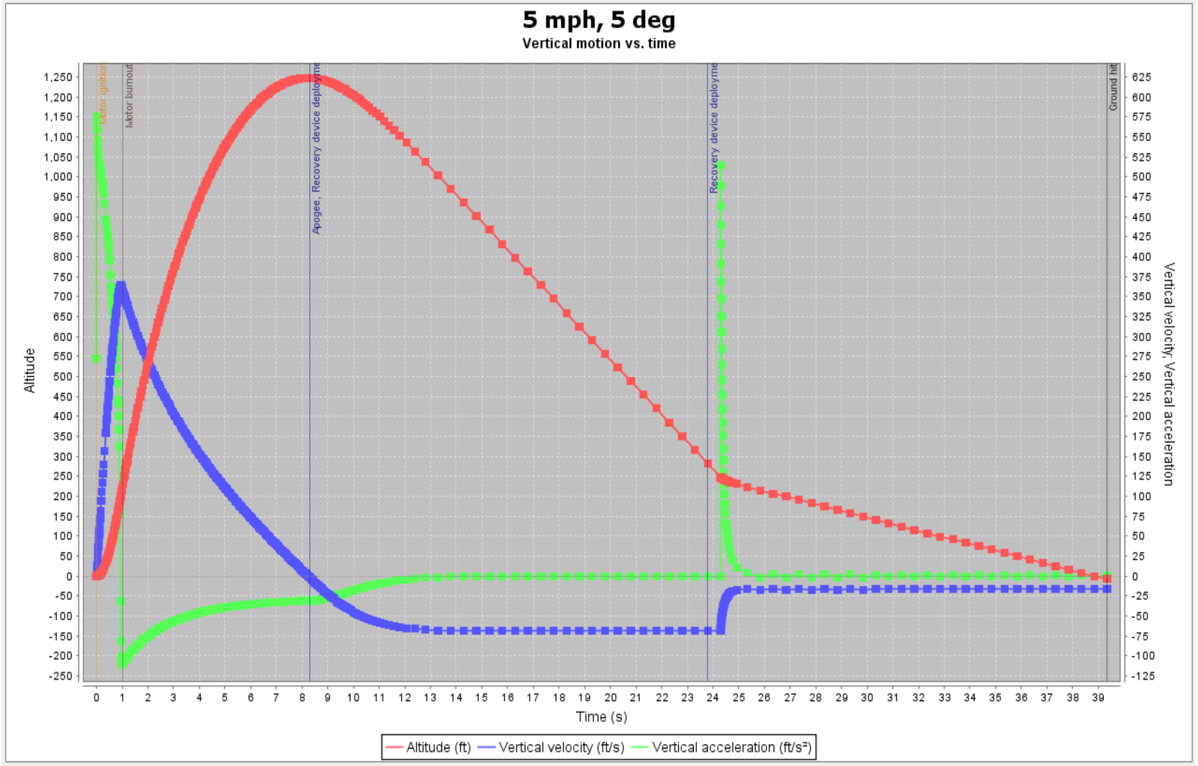


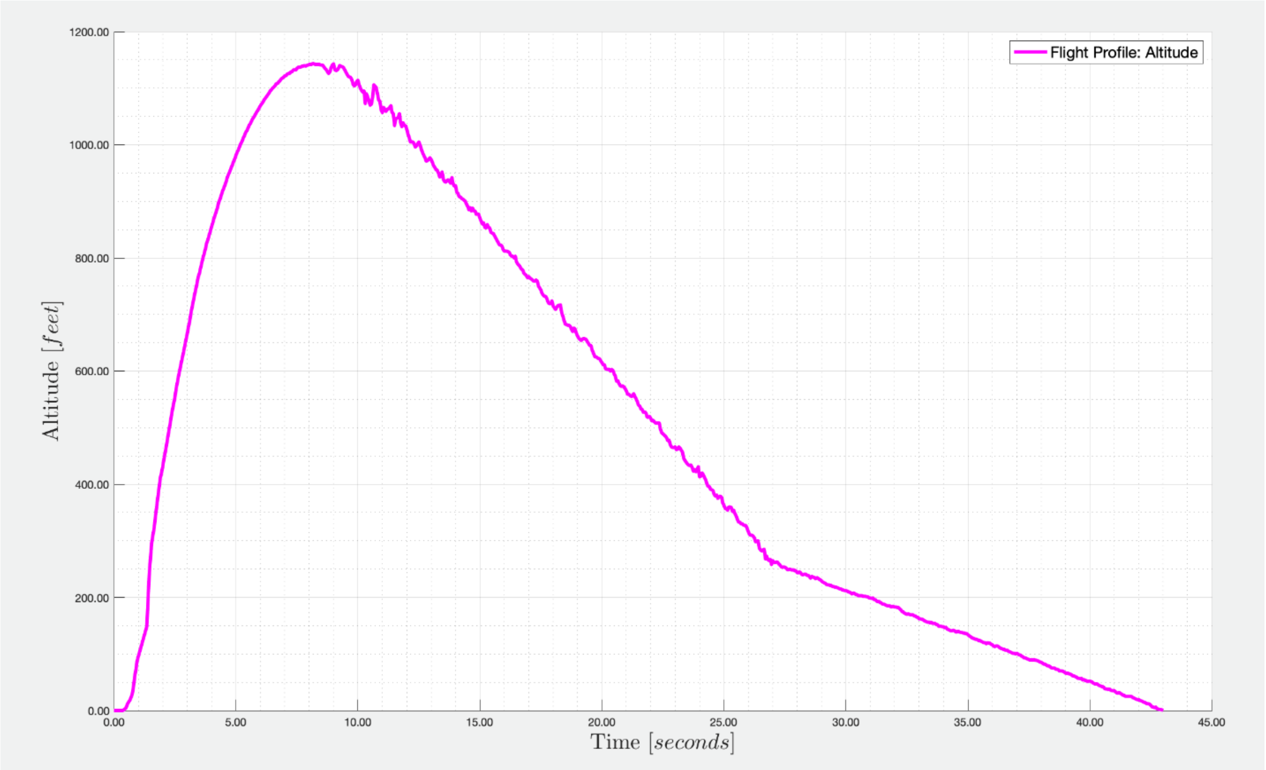


Subscale Launch: Raw Flight Data



Subscale Launch: Flight Comparison





Predictions	
Apogee (ft)	1247
Time to Apogee (s)	8.0
Flight Time (s)	39.4

Actual Results	
Apogee (ft)	1142
Time to Apogee (s)	8.5
Flight Time (s)	43.0

Agenda

i. Launch Vehicle Design
ii. Recovery Subsystem
iii. Payload Design
iv. Integration & Summary
v. Subscale Launch
vi. Requirements Verification & Safety

Safety

- Equipment
- Checklists
- Failure Modes and Effects Analysis
- Hazard Analysis

Safety-Equipment

- Nitrile gloves
- Precision flathead screwdriver
- Garbage bags
- Safety glasses
- Respirators
- Fire extinguisher
- First aid kit

Safety-Checklists

- Master Material Checklist
- Packing Inspection Checklists
- Pre-Flight Inspection Checklists
- Post-Launch Inspection Checklist
- Troubleshooting Checklist
- MSDS of Chemicals

Safety-Troubleshooting

Potential Launch/Assembly Issue	Potential Solution
Unable to have positive control of the electronic remote switches	Return launch vehicle to preparation area. Off load each section and ensure all the circuit is connected correctly. Verify that the battery is in good working condition. Remount the launch vehicle and try again according to all relevant safety checklists and procedures.
Folded parachute appears to have discrepancy due to improperly folding. This causes main or drogue parachute to be unable to properly fit in the bay.	Unfold the parachute by repeating the recovery preparation step 2. Verify the newly folded parachute can be ejective freely.
L type motor installed incorrectly.	Reassemble the motor again using instructions from kit with help from NAR certified mentor according to all relevant safety checklists and procedures.
Launch Vehicle lands more than 2500 ft radius from launch pad in personal property	Inform NASA RSO and wait for instructions on how to retrieve vehicle.
Motor fails to ignite	DO NOT approach rocket if igniter fails for at least 60 seconds. Hang fire could lead to severe injury to personnel that approach prematurely. Contact safety officer. While wearing safety glasses, attempt to visually determine the cause of misfire. If only a minor connection issue, reattach to motor cap. If unable to visibly determine cause of error, remove igniter from motor making sure not to have hands directly under the rocket nor the rocket tail pointed at any handlers. Install backup igniter and reset rocket.

Potential Launch/Assembly Issue	Potential Solution
Altimeter failure to arm	Disarm all active charges. Remove rocket from rail and bring back to assembly table. Check for faulty battery. If not battery remove faulty ejection charge and replace with backup ejection charge and e-match using ejection charge assembly procedure. NOTICE- when dealing with BP make sure to wear safety glasses and nitrile gloves, and ensure those dealing with it are grounded. Premature ignition of ejection charges can lead to serious bodily harm as well as damage to equipment.
GPS fails to turn on or read coordinates.	Remove GPS transmitter from rocket and check for faulty battery. If battery is not faulty, turn the transmitter and receiver off and on again. Hold the configuration button on the receiver to re-lock altitude and wait for coordinates to be obtained again up to about 15 minutes. If this does not work, plug the receiver into a computer and follow the GPS instruction manual to set up alternative ground station using a computer.

Safety-Personnel Hazard Analysis Example

Personnel Hazard	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Unignited ejection charges ignites pre-assembly.	Improper storage or handling of black powder such as overheating, vulnerability to static, vibration, or exposure to flame.	Potential explosion or fire. Injury or death to team members or nearby spectators.	1A	Black Powder will be stored in non-static / non-flammable containers away from any potential heat sources and will be kept with the NAR certified mentors at all times.	Only NAR certified members will be allowed to handle all black powder. All team members will still be required to read all black powder related MSDS and safety procedures.	1E

Safety-Structure and Propulsion FMEA Example

Failure Mode	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Drag system does not function properly during launch.	Drag system could be inaccurately adjusting roll, or fins may not be turning synchronously	The vehicle's flight trajectory will be altered, and apogee may not be reached.	2A	Extensive testing of the launch vehicle avionics along with the VDS to ensure that the system functions as expected.	The drag system will only be used if there is a high success rate during full-scale testing.	2D

Safety-Navigation and Recovery FMEA Example

Failure Mode	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Premature separation due to drag forces	Incorrectly sized main and drogue shear pins are sheared due to larger drag forces generated by lower section of the vehicle relative to the upper section, causing separation after motor burn out.	Parachutes deployed before apogee will withstand excess forces while the rocket travels at high speed, ripping apart the body of the rocket and causing catastrophic failure.	1B	Shear pins must be placed and sized correctly for the drogue and main parachutes.	Simulations and calculations of the launch related to drag caused by fins and other such systems will be carried out in order to determine the forces the shear pins must be able to handle. Thus, the correct shear pin configuration can be ascertained. Ground and sub-scale tests will further verify this.	1C

Safety-Payload FMEA Example

Failure Mode	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Payload becomes loose in payload bay.	Payload mounting system does not immobilize rover during flight.	Payload is damaged, not able to exit payload bay properly due to not utilizing TEARS correctly, and can disrupt projected flight path.	**2D**	Payload will be mounted in x,y and z direction using geometric fit, pins, and lead screws.	Rover mounting will be tested during Full scale test flight.	**2E**

Safety-Hazards from the Environment Example

Hazards from the Environment	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Launch vehicle/ electronics become damaged due to rain/wet ground landings	Water sensitive part of the vehicle like the airframe, motor and the electronics come in contact with water.	The payload or avionics electronics may be damaged and structural integrity of the airframe will be compromised due to epoxy, circuits, and the like being damaged due to water vulnerability.	2C	The mechanical packaging must be designed to adequately seal electronics from wet environments. In addition, epoxy must be used sparingly and in sequestered locations to reduce chance of exposure. Tests and launches will not be performed in heavy rain.	The packaging of the electronics will be tested on the ground and during launches. If such tests occur during light rain, the parts will be inspected for damage, and changes will be made to design if there are such signs.	2E

Safety-Hazards to the Environment Example

Hazards to Environment	Causes	Effects	Pre RAC	Mitigation	Verification Plan	Post RAC
Unintended ejection of pollutants from vehicle.	Not assembling the launch vehicle appropriately; leaving components loose within the rocket body may cause them to be ejected into the environment during flight	Components like brackets, fasteners, and other parts of mechanical packaging that come off during flight would become ground rubble, polluting the environment.	3A	All team members are responsible for taking precaution in ensuring that no loose components are left within the rocket body. Team members will also follow comprehensive checklists pre-field and pre-flight to ensure correct assembly to avoid such cases.	Root cause analysis is in place to avoid such disasters. If root cause points to certain team members violating procedures, they will be given a warning and instructed in how to correct these actions in the future. Repeated offenses will lead to termination from the project.	3D

Test Plans

Test	Purpose
Complete Rocket Center of Mass and Weight Testing	This test is to ensure that the actual mass and center of gravity match up with the estimated values that had been used in calculations for stability and apogee. If there is discrepancy between the actual values and the values being used for calculations it could lead to an inaccurate apogee and or unstable flight.
Bulkplate Security Test	This test is conducted to see if the bulkplate retention system is strong enough to withstand the impulse of the in-flight forces produced by the motor.
Airframe Impact Test	In order to determine if the airframe is strong enough to withstand landing impact this test is implemented.
Fullscale Avionics Ground Ejection Test	Ensure the drogue and main deployment mechanism works: including the parachutes, shock cords, pistons, e-matches, etc. Check if the shear pins break due to the over-pressurization and the pistons pushing against the bulkplates. Ensure the sections separate while not damaging any of the fittings, pistons, bulkplates, shock cords, or parachutes.
Electronics Endurance Test	Ensure all the electronics from the Navigation and Recovery, Payload and Propulsion teams can endure and withstand being on the launch pad for at least sixty minutes without losing any functionality.
GPS Transmitter Location Test	Ensure the transmitter works as intended and parameters are set correctly. The transmitter should work out to a range of at least one mile, and the receiver should be able to read coordinates of a moving target.

Demonstration Plans

Demonstration	Purpose
Full Scale Flight	A full-scale flight is required by section 2.18.1 of the handbook which will be performed using the final design of the launch vehicle complete with payload.
Payload Demonstration Flight	A demonstration of the payload designed to fly in the launch vehicle is required by handbook section 2.18.2 and so will be performed prior to the deadline.

Requirement Compliance Plan-General

Item ID	Verification Method	Verification Plan
General Requirements		
1.1	Inspection	Stony Brook University Rocket team consist exclusively of students who are working on this project as part of their senior design. All work will be completed by students with the exception of motor assembly and handling of black powder ejection charges.
1.2	Demonstration	The project plan is constantly being updated and discussed during team bi-weekly meetings to ensure that all project milestones, personal assignments, events and checklists are followed.
1.3	Inspection	Every team member will be asked about their citizenship status and a list of foreign nationals is to be submitted to NASA by PDR.
1.4	Inspection	A list of all team members and adult educators attending launch week activities is going to be submitted to NASA by CDR.

General Requirements		
1.5	Demonstration	Every educational outreach event will be documented following STEM Engagement Activity Report template provided by NASA.
1.6	Demonstration	Social media accounts will be established and links will be delivered to NASA by October 25th.
1.7	Inspection	Team lead will send all the deliverables to the NASA team by the deadline and verify it with confirmation email from NASA project management team.
1.8	Inspection	All deliverables will be converted to PDF format before submission to NASA.
1.9	Inspection	Every report will have table of contents including major sections and their respective sub-sections.
1.10	Inspection	Every report will have page numbers at the bottom of each page.
1.11	Demonstration	All equipment to have successful video teleconference will be demonstrated during Kickoff video session.
1.12	Demonstration	The launch vehicle will utilize launch pads provided by Student Launch's launch services provider.

Requirement Compliance Plan-Vehicle

Vehicle Requirements		
2.1	Demonstration Testing Analysis	The launch vehicle will reach the target altitude by careful selection of motor, control of vehicle's mass, and overall shape of the rocket. The vehicle will be analyzed using OpenRocket simulations and tested during Vehicle Demonstration Flight.
2.2	Analysis	The target altitude will be identified based on the collected data from simulations and launch vehicle design.
2.3	Demonstration	One commercially available altimeter will be set aside for recording official altitude purposes
2.4	Demonstration Test	The launch vehicle will be designed to ensure it can be reused and launched on the same day.
2.5	Demonstration	The launch vehicle will have 3 independent sections.
2.5.1	Demonstration	Coupler/airframe shoulders will be 6 inches in length.
2.5.2	Demonstration	The nosecone shoulder will be 6 inches in length.

Vehicle Requirements		
2.6	Demonstration Testing	The launch vehicle will be designed to ensure that it can be assembled in under 2 hours. The assembly time will be timed during Vehicle Demonstration Flight.
2.7	Demonstration Testing	Appropriate battery and the overall launch vehicle design is going to be chosen to remain in launch-ready configuration for at least 2 hours.
2.8	Demonstration	Standard 12-volt DC firing system is going to be utilized.
2.9	Demonstration	All electronics will be housed internally and only launch services provider equipment will be used to initiate launch.
2.10	Inspection	The motor certified by NAR and TRA will be used.
2.10.1	Inspection	The final motor selection is going to be declared by CDR.
2.10.2	Inspection	Any motor changes after CDR will be approved by NASA Range Safety Officer.
2.11	Demonstration	Launch vehicle motor will be a single stage motor.
2.12	Inspection	The motor will be L-class or lower.
2.13	Inspection	The launch vehicle will have no pressure vessels.

Requirement Compliance Plan-Recovery

Recovery System Requirements		
3.1	Demonstration Testing	The launch vehicle will deploy its drogue parachute at apogee and the main parachute will be deployed later at the set altitude.
3.1.1	Demonstration Testing	The main parachute deployment altitude will be above 500 feet.
3.1.2	Demonstration Testing	The drogue parachute will be deployed within 2 seconds of reaching apogee.
3.1.3	Inspection	Motor will not be ejected.
3.2	Testing	Ground ejection tests will take place before subscale and full-scale launches.
3.3	Demonstration	Parachutes will be chosen to ensure that each independent section of the launch vehicle will have kinetic energy at landing under 75 ft-lbf.
3.4	Inspection	The launch vehicle will have a redundant altimeter.
3.5	Inspection	Each altimeter will have an independent power supply.
3.6	Inspection	Each altimeter will be armed with a dedicated mechanical switch accessible from the exterior of the rocket airframe.

Recovery System Requirements		
3.7	Inspection	Each arming switch have a locking mechanism.
3.8	Inspection	Recovery and payload bay will be independent sections and have a separate electrical circuits.
3.9	Inspection	Removable shear pins will be used for all parachutes.
3.10	Testing Analysis	Delayed main parachute deployment will limit the drift of the launch vehicle to 2,500 ft radius.
3.11	Testing Analysis	Descent time will be timed during full-scale test flights and estimated in MATLAB.
3.12	Inspection	Tracking device will be attached to the vehicle.
3.12.1	Inspection	Payload will be attached with a tracking device.
3.12.2	Inspection	All tracking devices will be inspected before the official flight.
3.13	Inspection Testing	All recovery system electronics will be properly shielded. Recovery system altimeter will be located in a separate compartment.

Requirement Compliance Plan-Payload

Payload Experiment Requirements		
4.1	N/A	N/A
4.2	Demonstration	Payload will be designed that is capable being launched in a high power rocket, landing safely, and recovering simulated lunar ice from one of several locations on the surface of the launch field.
4.3.1	Inspection	All hardware will be housed inside the launch vehicle airframe.
4.3.2	Demonstration	The rover will recover sample material from one of the five recovery areas.
4.3.3	Demonstration	The recovered ice sample will be at least 10 milliliters.
4.3.4	Demonstration	The rover will safely store and transport recovered material 10 feet away from the recovery area.
4.3.5	Inspection	Team will abide by all FAA and NAR rules and regulations.
4.3.6	Inspection	Payload will utilize no black power or other energetics.
4.3.7	Inspection Testing	Payload will be securely attached to the launch vehicle until deployment. No excessive shear pins will be used in payload deployment mechanism.

Requirement Compliance Plan-Derived

Description	Verification Method	Verification Plan
Vehicle must be able to utilize VDS system independent of ground control.	Analysis Testing	The VDS system will be designed and coded to be able to actuate on its own and will be tested to ensure this function
VDS system must be a closed loop that can actively make adjustments to drag based off of data gathered in flight.	Testing	The system will be coded such that it can actively stabilize the rocket. Testing will be done to fine tune this system and ensure that it works for the actual flight
VDS system must allow for uniform actuation of blades.	Analysis	A VDS system will be designed such that all of the blades are actuated at the same time from the same central actuating disk to ensure uniform actuation

Requirement Compliance Plan-Derived

Description	Verification Method	Verification Plan
The telemetry bay will not interfere with payload deployment.	Inspection	The Recovery team will work closely with the Payload team in order to ensure their designs work in conjunction with one another.
The electronic tracking equipment will not have its signals blocked by sections of the rocket.	Inspection Testing	The telemetry bay will not be surrounded in metal or be housed in a section of airframe or nosecone that is made of carbon fiber or is painted with metallic paint, which would block RF signals of the GPS transmitter. Ground tests and test flights will also verify the transmission of RF signals to the ground receiver.
The electronic tracking equipment will send data to a ground receiver, which will not receive interference from other electronics tracking equipment on other rockets.	Inspection Testing	The tracking system will be connected or coded in such a way that the receiver in use by the SBU team only receives data from the proper GPS tracking device.

Description	Verification Method	Verification Plan
The parachutes will not only be deployed by the expansion of hot gases alone but will be assisted by a mechanical ejection mechanism as well.	Inspection Testing	Parachute deployment will be assisted by pistons that will push the parachutes out of their respective bays. Ground testing and flight tests will ensure the system works.
The parachutes will not be adversely affected by hot ejection gases.	Inspection	The parachutes will be protected by an object or device as nylon parachutes are susceptible to burning or melting.

The End

Questions?