Oregon State University
High Altitude Rocket Team
2019 - 2020

Vehicle Specifications

Overview of the Design, Testing, Performance, and Flight Profile

Project Sponsors:
American Institute of Aeronautics and Astronautics
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Project Introduction

The 2019-2020 Oregon State University High Altitude Rocket Team (HART) has designed, manufactured, and tested a two-stage, solid motor rocket with the goal of reaching an altitude of 150,000 ft above ground level (AGL). This document encompasses the summary of all mission critical designs, testing results, performance specifications, and the ideal anticipated flight profile.

Vehicle Overview and Performance

Below is an overview of the vehicle dimensions, parameters, and the anticipated flight profile metrics.

Vehicle Specifications	
Apogee (ft AGL)	131453
Maximum Velocity (ft/s, Mach)	3336, 3.22
Time to Apogee (s)	98.2
Total Flight Time (min)	10.93
Airframe Diameter (in)	4.11
Total Length (ft)	13.83
Total Weight (lb)	81.4
Total Impulse (N-s)	29,323
Minimum Stability (calibers)	2.14
Rail Departure Velocity (ft/s)	140
Ground Hit Velocity (ft/s)	19.2 / 20.0
Estimated Drift Distance (miles)	5.68

Stage Weight and Dimensions			
	Booster	**Sustainer**	**Overall**
Wet Weight (lb)	39.42	41.96	81.38
Dry Weight (lb)	24.28	25.57	49.85
No Motor (lb)	10.28	11.46	21.74
Diameter (in)	4.11	4.11	4.11
Length (in)	78	88 (93**)	166

** Includes the 5 inches of sustainer motor casing protruding from the bottom of the sustainer stage

Operational Specifications

General performance and operational specifications are provided below for each of the major systems within the vehicle.

Propulsion

These are the overall motor characteristics for both stages of the vehicle. For the purposes of our simulations, we have chosen to use our static fire test data instead of the BurnSim outputs since our static fire data yields improved vehicle performance.

Both propellant formulations were developed specifically for our program by Jim Baker, a chemist who previously worked at Aerojet Rocketdyne. All sub-scale and full-scale fire data was reviewed by him during the development process. The motors were also reviewed by Steve Cutonilli, an L3 Tripoli certified member.

Motor Characteristics*		
	Booster	**Sustainer**
Classification	37% N-3262	49% N-2036
Total Impulse (N-s)	14027	15367
Burn Time (s)	4.6	8.3
Average Thrust (N)	3262	2036
Launch Weight (lb)	29.15	30.50
Dry Weight (lb)	14.00	14.11
Propellant Weight (lb)	15.15	16.39
Nozzle Exit Diameter (in)	3.01	2.29
Nozzle Throat Diameter (in)	1.05	0.8906

*Simulations use data from the static fires, not the BurnSim output

Recovery

The recovery system has been designed to ensure reliability and consistency. Both stages will utilize a parachute architecture with the drogue parachute being attached to the top of the main parachute. This greatly reduces the risk of tangling shroud lines and makes shock cord management more simple. Both stages also utilize an “out-the-end” design where both the drogue and main parachutes are housed in the same compartment.

The booster recovery system is protected from the separation charges and the incoming airstream after separation by a bulkhead, held into the airframe with shear pins. The main parachutes on both stages are retained by 2 Tender Descender, linked in series for redundancy if one should fail to separate.The sustainer drogue is deployed during nosecone separation at apogee by the high altitude straight tube charge.

The descent rate was calculated using both a custom spreadsheet-based calculator and the parachute-specific descent rate calculator on the manufacturer website for verification. The drogue parachute velocities were calculated with an air density 1.007 kg/m^3 at 2000m (6500 ft, 1900 ft AGL), to estimate the velocity of the stage during main parachute deployment. The main parachute velocities calculated with air density 1.056 kg/m^3 at 1500m (4900 ft, 0 ft AGL), to estimate the velocity of the stage during touchdown.

Recovery System Specifications			
		Booster	**Sustainer**
Minimum Stage Weight (lb)		24.28	25.57
Maximum Stage Weight (lb)		24.28	41.96
Drogue Parachute	**Cd**	0.97	0.97
	Geometry	Parabolic	Parabolic
	Diameter (in)	36	24
	Shock Cord Length (ft)	19	19
	Minimum Fall Velocity (ft/s)	66.9	92.7
	Maximum* Fall Velocity (ft/s)	66.9	123.0
Main Parachute	**Cd**	2.20	2.20
	Geometry	Toroidal	Toroidal
	Diameter (in)	72	72
	Shock Cord Length (ft)	19	19
	Minimum Fall Velocity (ft/s)	19.8	21.7
	Maximum* Fall Velocity (ft/s)	19.8	26.6

*Maximum fall rate is calculated using the maximum stage weight

Structures

The airframe dimensions are detailed in the Vehicle Overview and Performance section. The sustainer fins are attached to the bottom of the airframe, and are 5 inches from the bottom of the sustainer motor casing, which protrudes past the base of the sustainer airframe for interstage coupling. The fins for each stage are detailed below.

Fin Dimensions		
	Booster	**Sustainer**
Fin Count	3	3
Root Chord (in)	15	15
Sweep Distance (in)	13	15
Tip Chord (in)	2	2
Span (in)	4.25	4.50
Thickness (in)	0.34	0.34
Distance from Base (in)	0	5**
Airfoil Type	Hexagonal	Hexagonal
Leading Edge Length (in)	0.875	0.875
Trailing Edge Length (in)	0.875	0.875

**5 inches from bottom of motor tube

Avionics

Each stage is controlled by both an Altus Metrum Telemega primary flight computer with an Altus Metrus Easymega as the backup flight computer for redundancy. A Big Red Bee SBD will also be located in the sustainer as additional tracking. There is a student developed chip in each stage that is run independently of the flight computers, used only to record data from the pressure transducer attached to the motor. A backup student-developed wireless launch system was developed and will be used in the case the provided launch controller cannot be used.

Tracking is completed using the Altus Metrus commercially provided software and a yagi dedicated to tracking each stage. The Telemega and Easymega chips are used to control the deployment charges, separation charges, and sustainer ignition. Sustainer ignition is restricted to ensure sustainer ignition only occurs in an acceptable scenario; those parameters are detailed below.

The Telemega will record pressure and acceleration data and the Easymega will provide acceleration data, all of which will be used to verify apogee after flight. The triggers for all deployment and ignition events as well as the size of charges is shown below.

Deployment Systems				
		Trigger	**Booster**	**Sustainer**
Stage Separation	**Main Charge** (g)	Burnout +1s	4.0	-
	Backup Charge (g)	Burnout +1.25s	6.0	-
	Charge Type	-	Surgical Tubing	Surgical Tubing
Drogue Parachute	**Main Charge** (g)	Apogee	4.0	1.0
	Backup Charge (g)	Apogee +1s	6.0	1.5
	Charge Type	-	Surgical Tubing	Straight Tube (High Altitude)
Main Parachute	**Main TD* Charge** (g)	1500 ft AGL	0.25	0.25
	Backup TD* Charge (g)	1500 ft AGL	0.25	0.25
	Main Charge (g)	1400 ft AGL	4.0	4.0
	Backup Charge (g)	1400 ft AGL	6.0	6.0
	Charge Type	-	Surgical Tubing	Surgical Tubing

*TD stands for "Tender Descender"

Flight Profile

OpenRocket was used to create a detailed model of the vehicle and determine the center of gravity (COG) and verify the rail departure velocity. All other flight profile information was generated using RasAero II.

Simulation Parameters

Below are the simulation and launch site settings used for our analysis. These come from physical data and recommendations from project mentors for maximum possible accuracy.

RasAero II Simulation Flight Conditions	
Location	Black Rock, NV
Elevation (ft)	3900
Temperature (℉)	85
Wind (mph)	0
Barometric Pressure (in-hg)	30.00
Launch Rail Length (ft)	30
Launch Angle (degrees)	0
Surface Finish	Smooth Paint
Miscellaneous Settings	All Turbulent Flow Rogers Modified Borrowman

Staging Conditions

Stage separation will occur 4 seconds after booster motor burnout has been detected. This will ensure there is no residual thrust in the booster stage that could cause the stages to contact after separation. After separation, the sustainer will coast for 1.5 seconds until ignition of the sustainer. It is expected to take 3 seconds for the sustainer motor to come up to pressure. This sequence will result in a coasting time of approximately 8.5 seconds, resulting in a vertical velocity of 700 ft/s when the sustainer reaches operating pressure.

Sustainer ignition will be locked out until the vehicle is moving faster than 500 ft/s, is higher than 7000 ft AGL, and has a tilt angle less than 12 degrees from vertical.

Motor State and Staging Conditions				
	Booster Burnout	**Stage Separation**	**Sustainer Ignition**	**Sustainer Burnout**
Delay (s)	-	4.0	4.5	-
T+ (s)	4.6	8.6	13.1	21.4
Altitude (ft)	3500	8000	11300	31300
Velocity (ft/s, Mach)	1175, 1.04	925, 0.83	717, 0.65	3268, 3.21

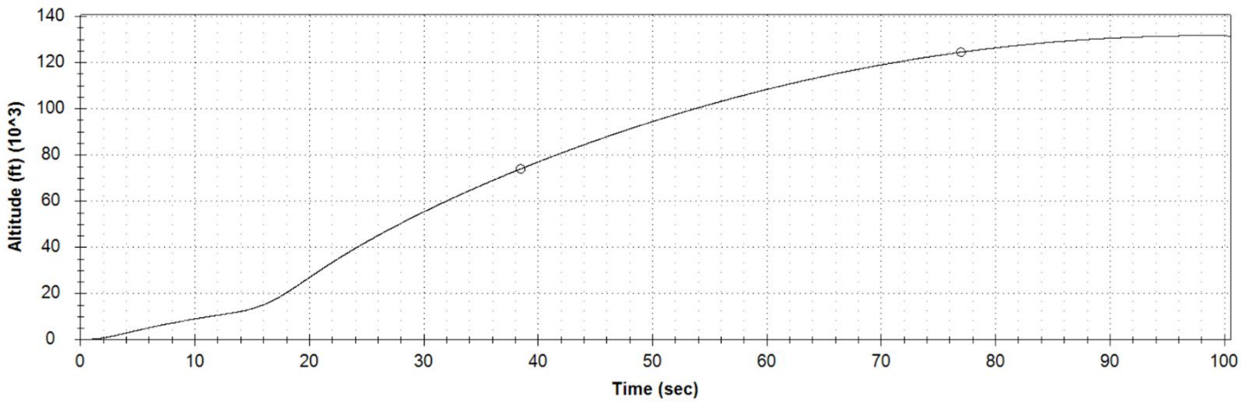
Flight Conditions`

The table below lists parameters related to maximum aerodynamics pressure and the maximum velocity.

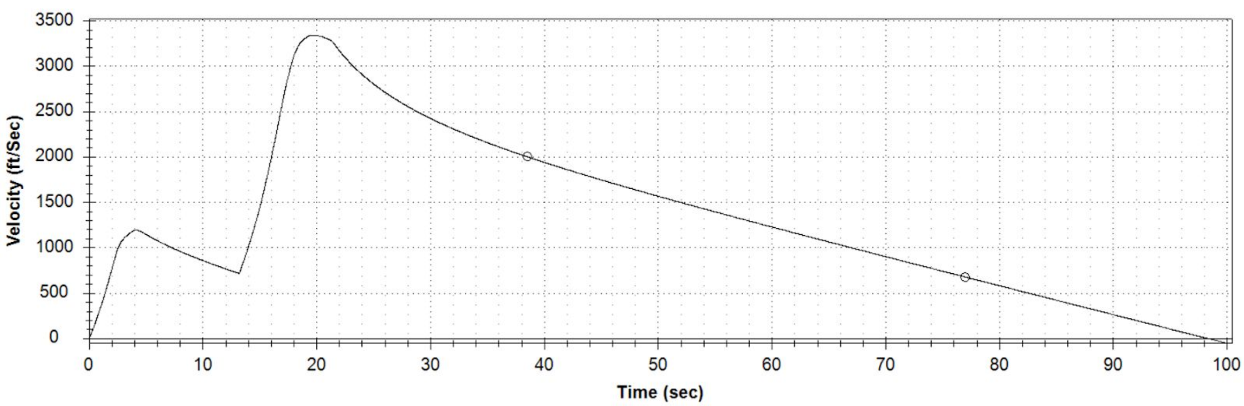
Simulated Flight Conditions	
Max Q T+ (s)	18.53
Altitude at Max Q (ft)	21800
Velocity at Max Q (ft/s, Mach)	3245, 3.06
Aerodynamic Pressure at Max Q (psi)	43.98
Maximum Velocity T+ (s)	19.61
Altitude at Maximum Velocity (ft)	25400
Maximum Velocity (ft/s, Mach)	3336, 3.22

Flight Overview

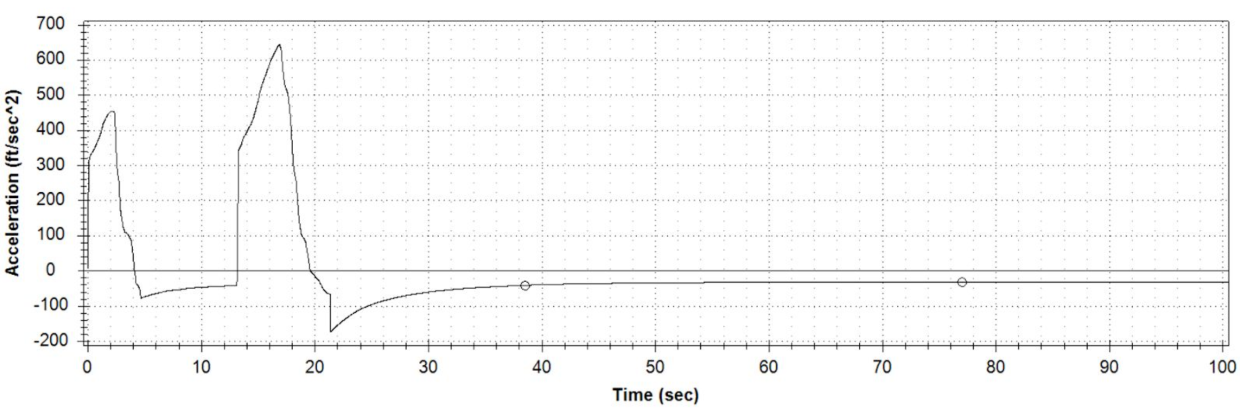
The simulated flight characteristics from RasAero II are shown below from launch to apogee.



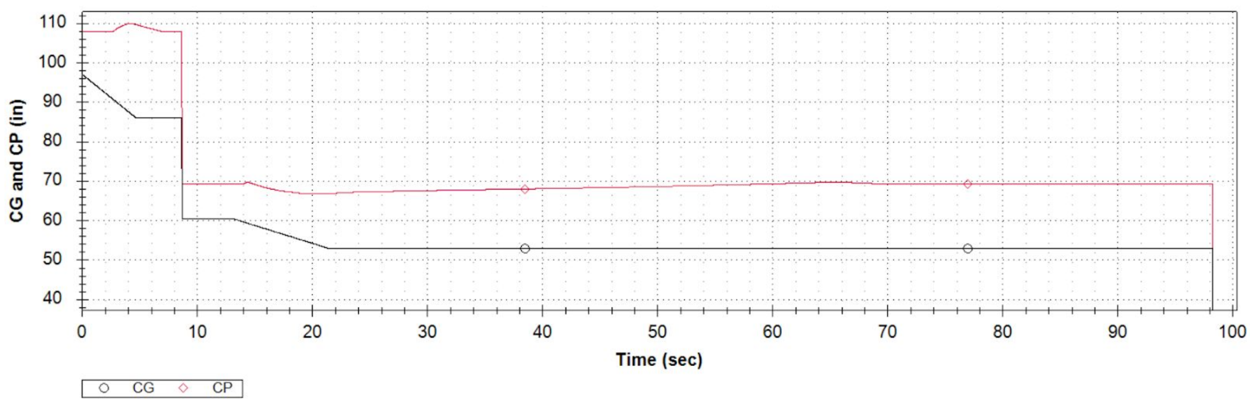
Time vs Altitude



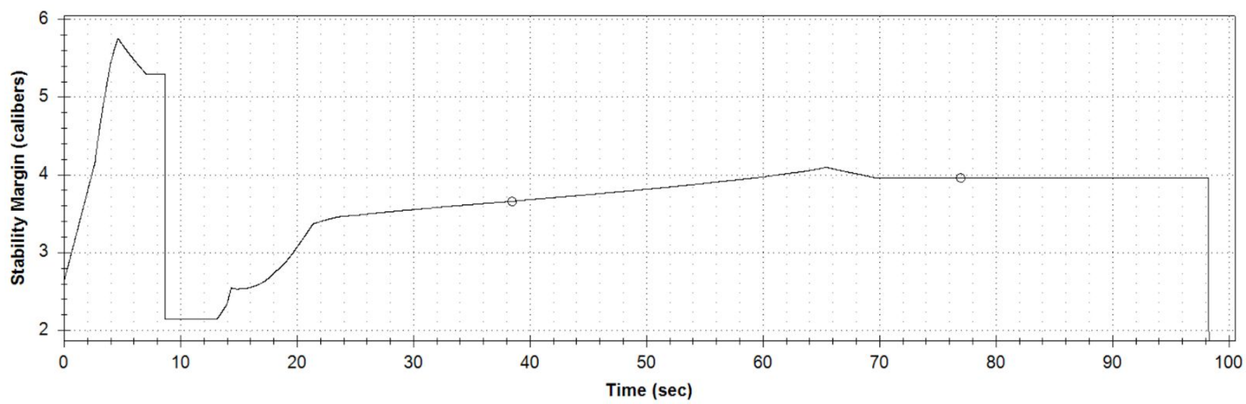
Time vs Velocity



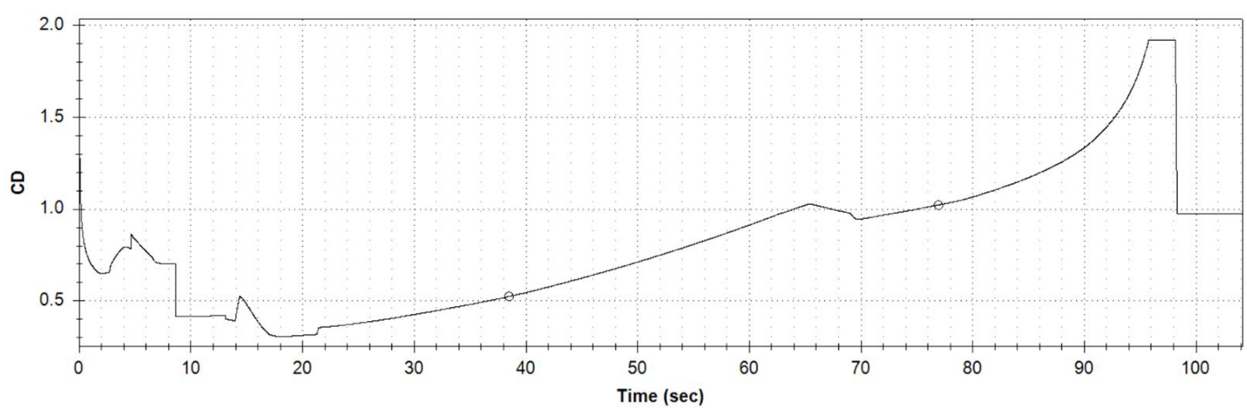
Time vs Acceleration



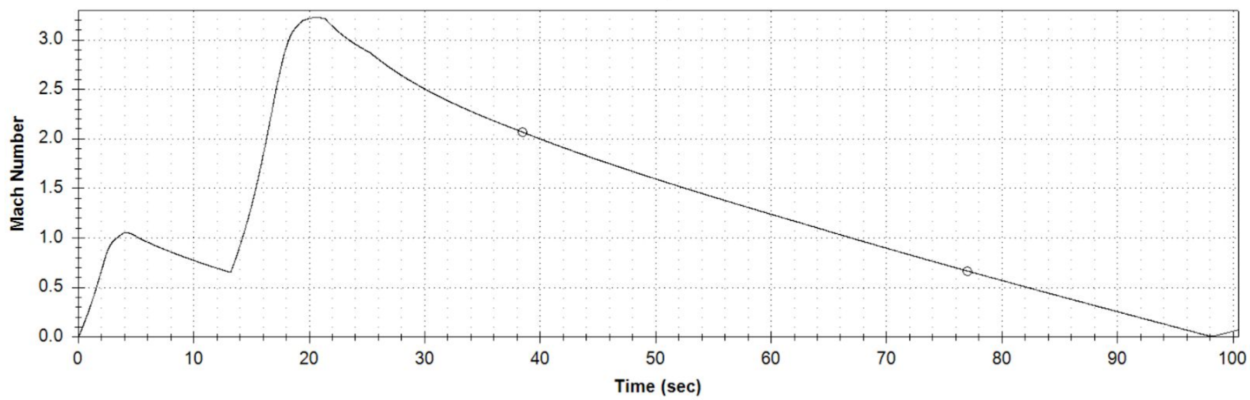
Time vs CG/CP Location



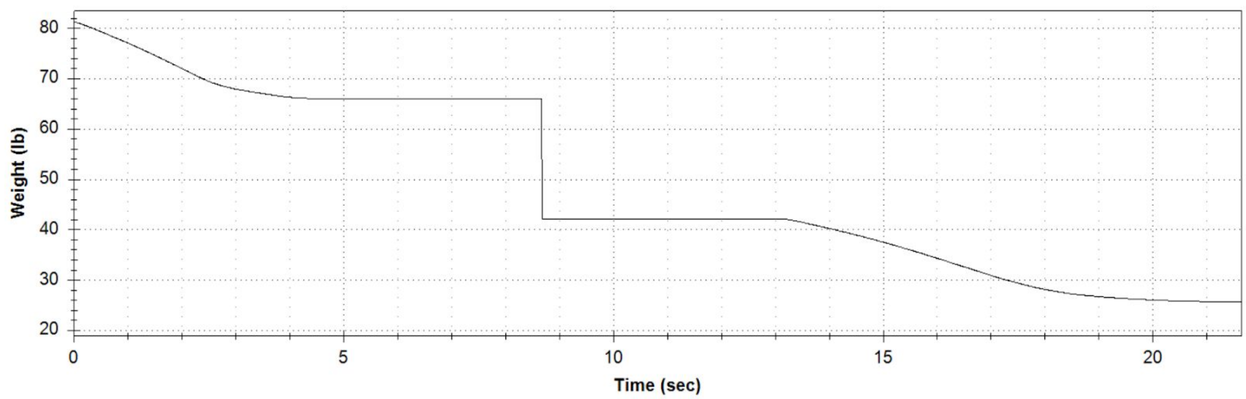
Time vs Stability Margin



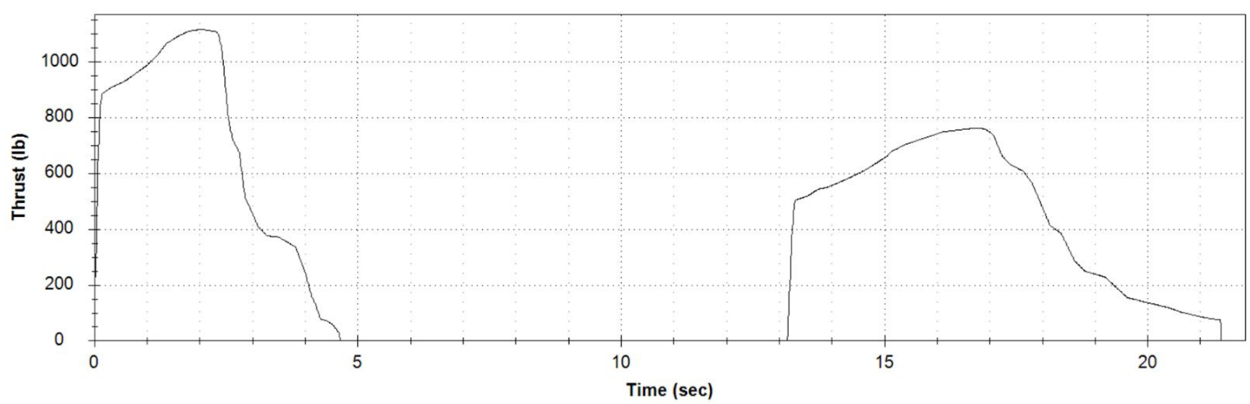
Time vs CD



Time vs Mach Number



Time vs Weight (until motor burnout)

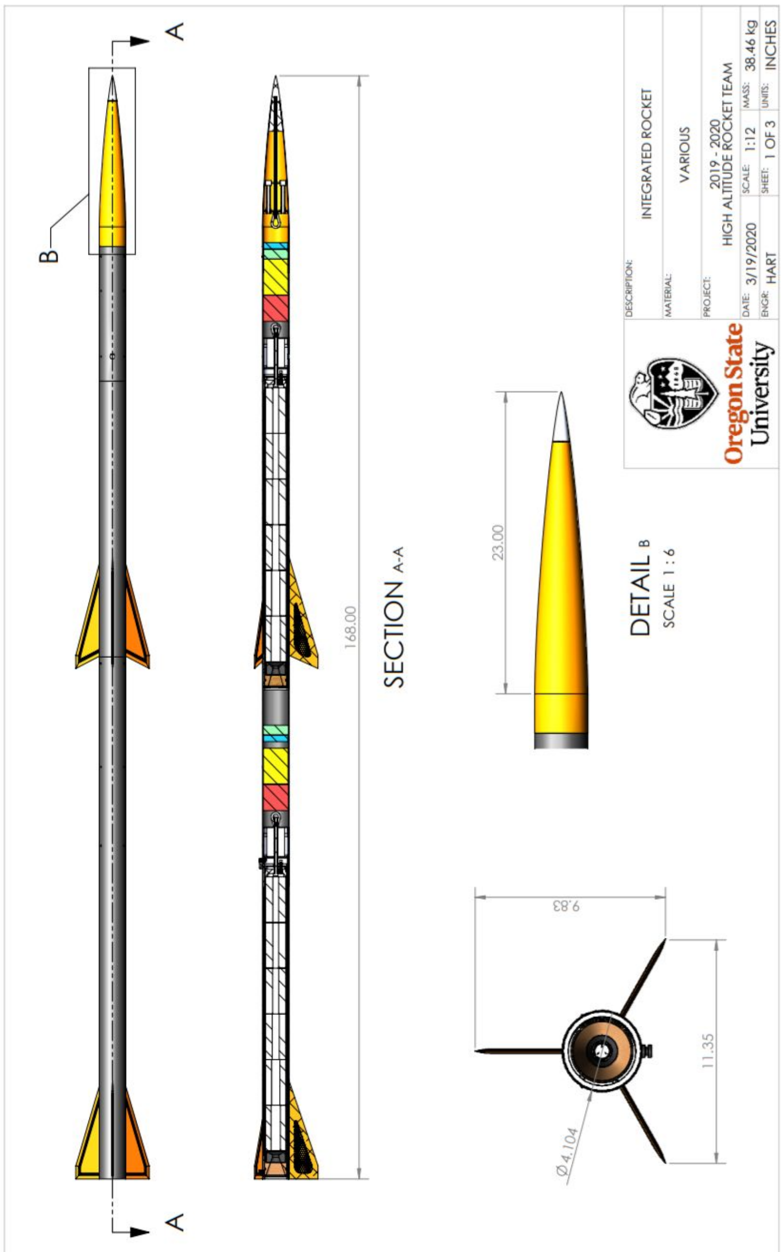


Time vs Thrust (until motor burnout)

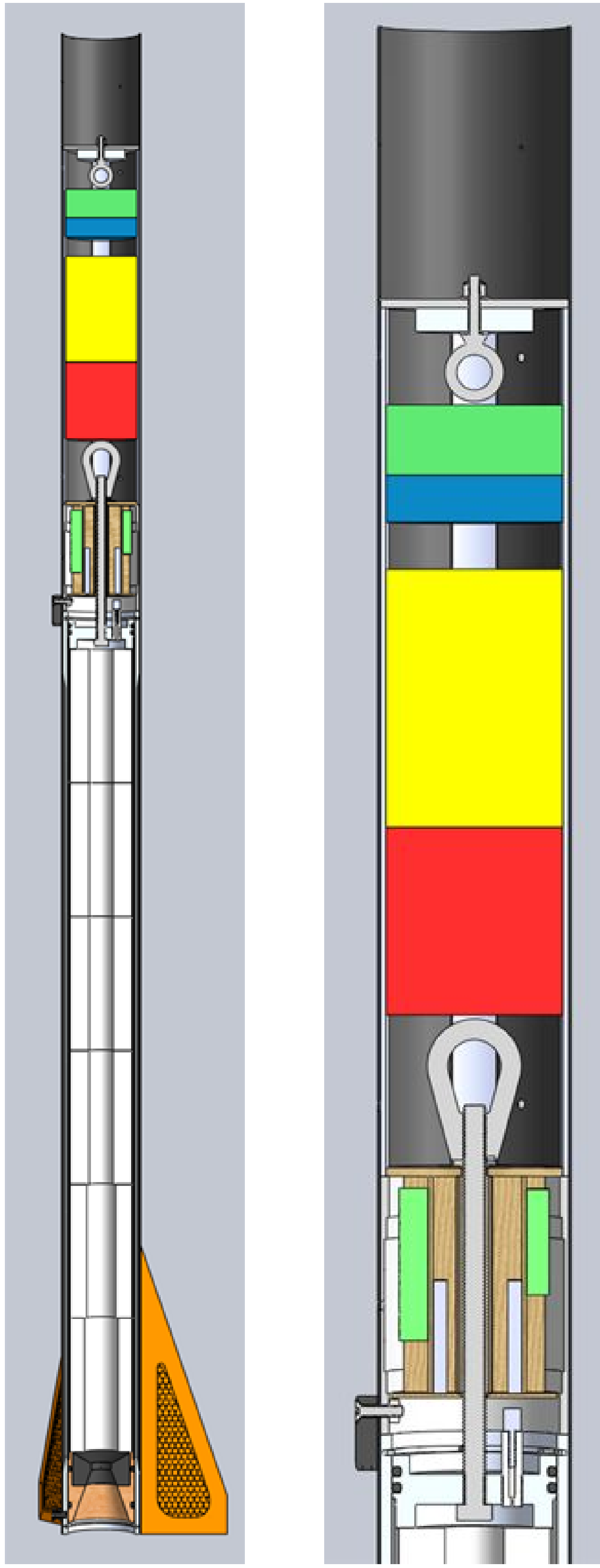
Vehicle Design

Key for the following diagrams: green are drogue shock cords, blue are drogue parachutes, red are main shock cords, yellow are main parachutes. The avionics bays are located below the main parachute and above the forward closure of the motor. A bolt passes through the center of them for retention.

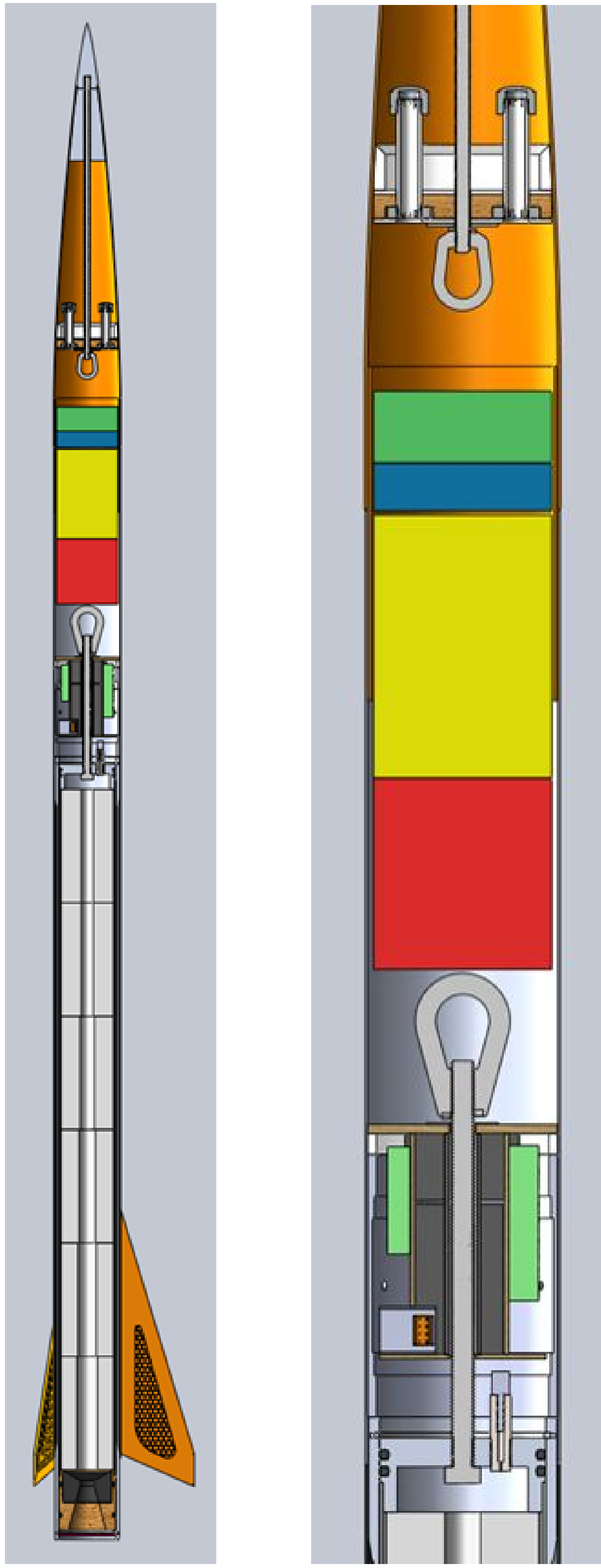
Overall



Booster



Sustainer



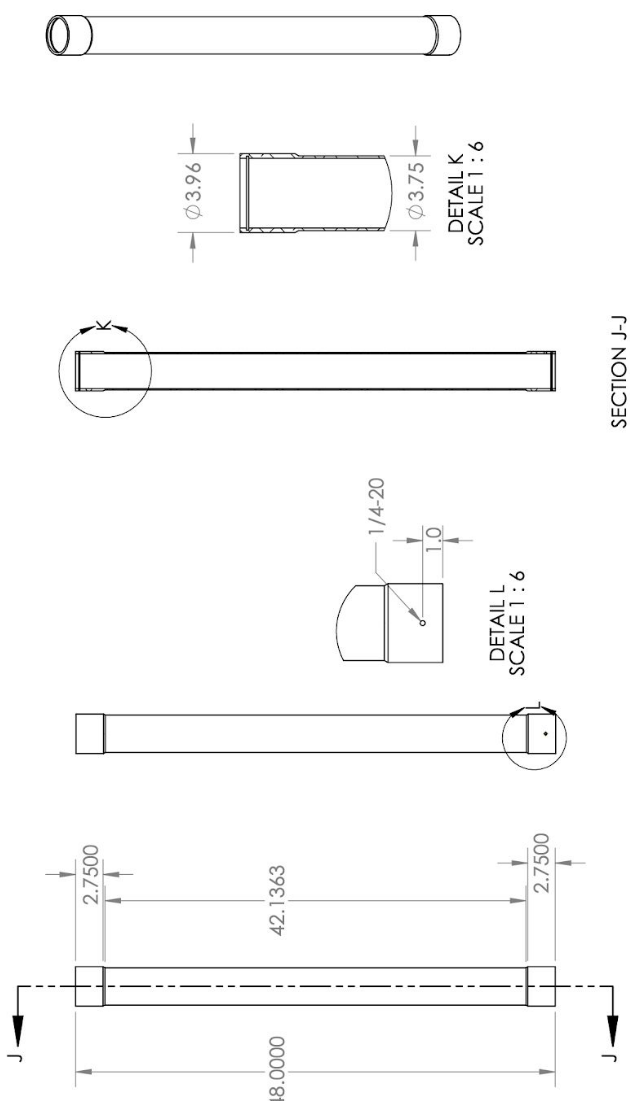
Propulsion

Booster Motor

The motor is comprised of the following components:

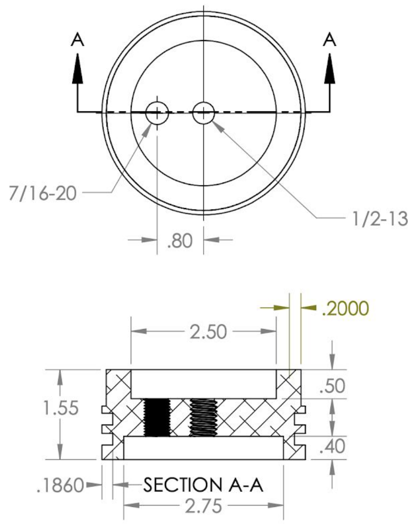
1. Motor casing
2. Forward closure
3. Nozzle
4. 6 booster propellant grains
5. Insulating liner
6. 4 sealing o-rings
7. 2 retention snap-rings

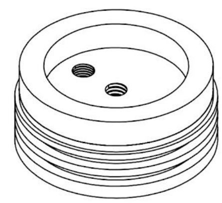
Motor Casing



Forward Closure

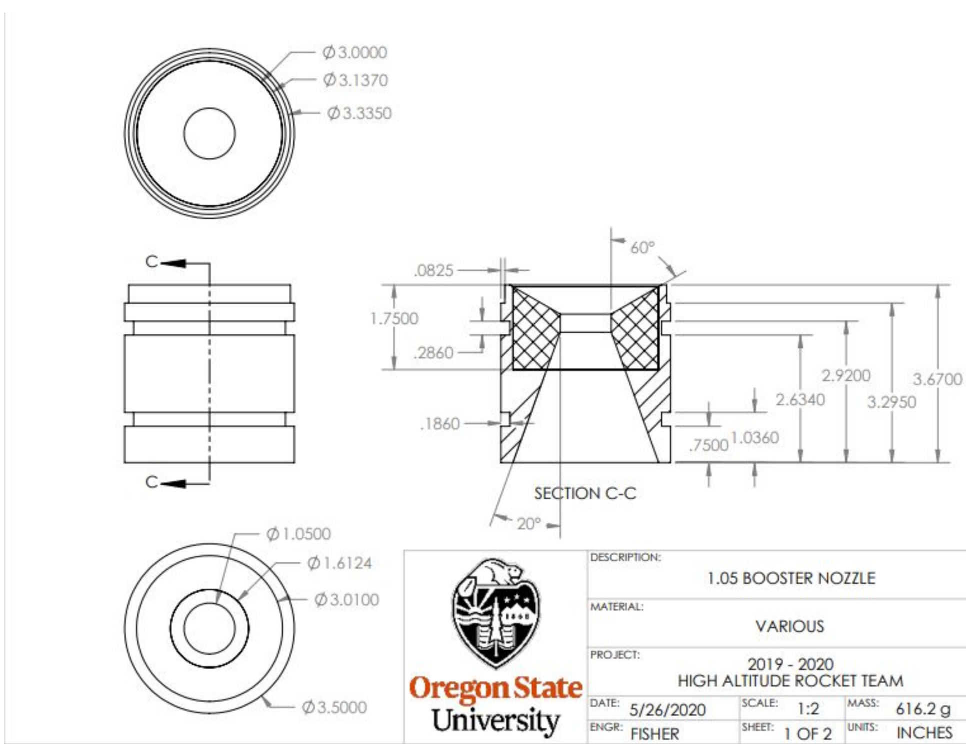
The forward enclosures include a threaded hole for a pressure transducer as well as a threaded hole for a threaded rod that is used to hold in the motor inside the air frame.





Nozzle

The booster nozzle uses a 1.05” throat diameter and is made from canvas phenolic rod and graphite.

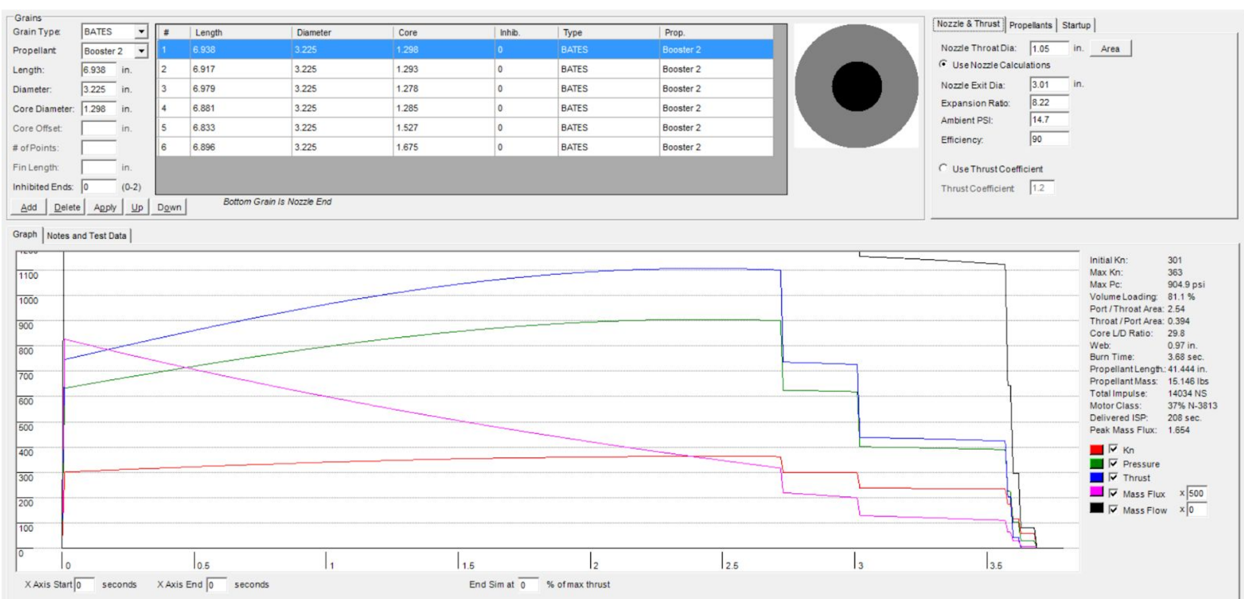


Propellant

The booster propellant is called "Red Ryder" and the formulation is shown below.

Chemical	Function	Weight Percentage
Ammonium perchlorate (AP)	Oxidizer	78.5%
Hydroxyl-terminated polybutadiene resin (HTPB)	Binder	12.99%
Modified MDI isocyanate curative	Curative	2.61%
Aluminum powder	Fuel	2.0%
Red iron oxide	Catalyst	0.5%
Isodecyl pelargonate plasticizer (IDP)	Plasticizer	3.0%
Castor oil	Chain-linking agent	0.2%
Lecithin	viscosity reducer	0.2%
Silicon oil	Surface tension reducer	1 drop

Booster grain geometry and estimated motor performance is shown in the BurnSim output below. They were measured after casting and cleaning and before gluing into the phenolic liner.



Motor Hardware

The used insulating liner is a Convolute LE Phenolic Liner purchased from Loki Research. The sealing o-rings are High-Temperature Silicone O-Rings with 3.5 inch outer diameter. The retention mechanism in the motor casing for both the nozzle end and the forward enclosure end is a steel internal snap ring with an outer diameter of 3.5 inches

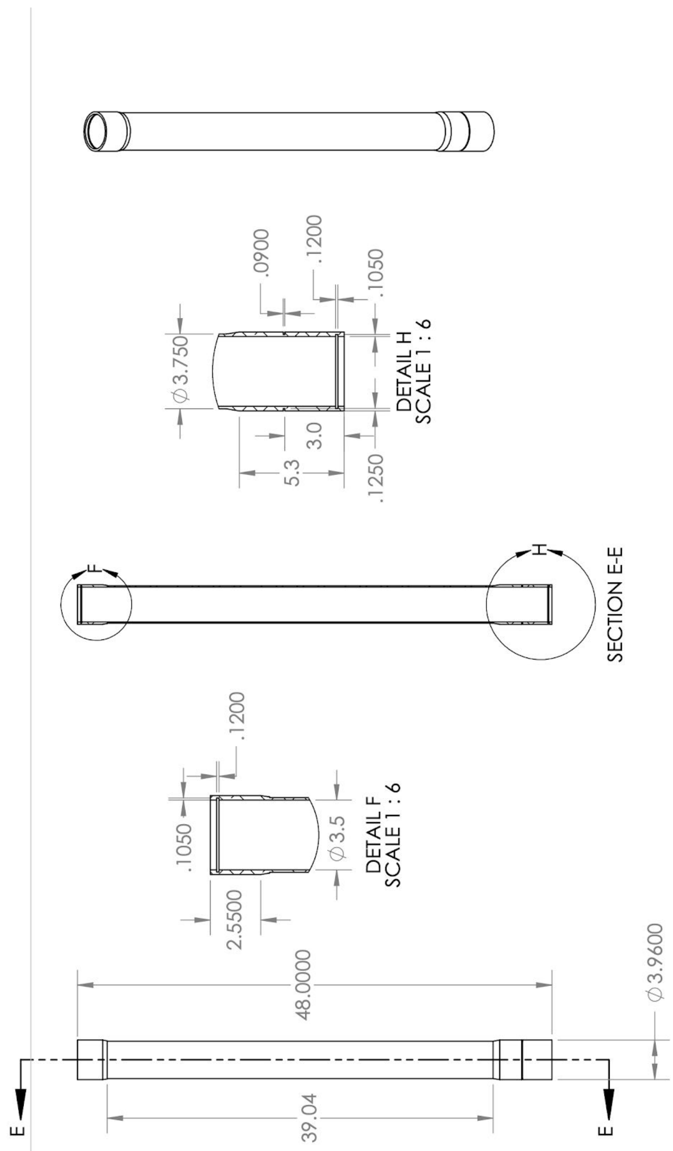
Sustainer Motor

The motor is comprised of the following components:

1. Motor casing
2. Forward closure
3. Nozzle
4. 6 sustainer propellant grains
5. Insulating liner
6. 4 sealing o-rings
7. 2 retention snap-rings

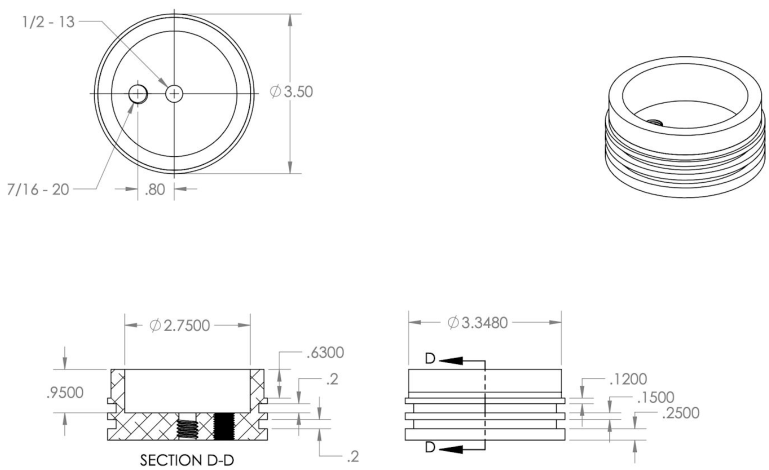
Motor Casing

The bottom section of the sustainer motor casing is used to attach the two stages of the rocket.



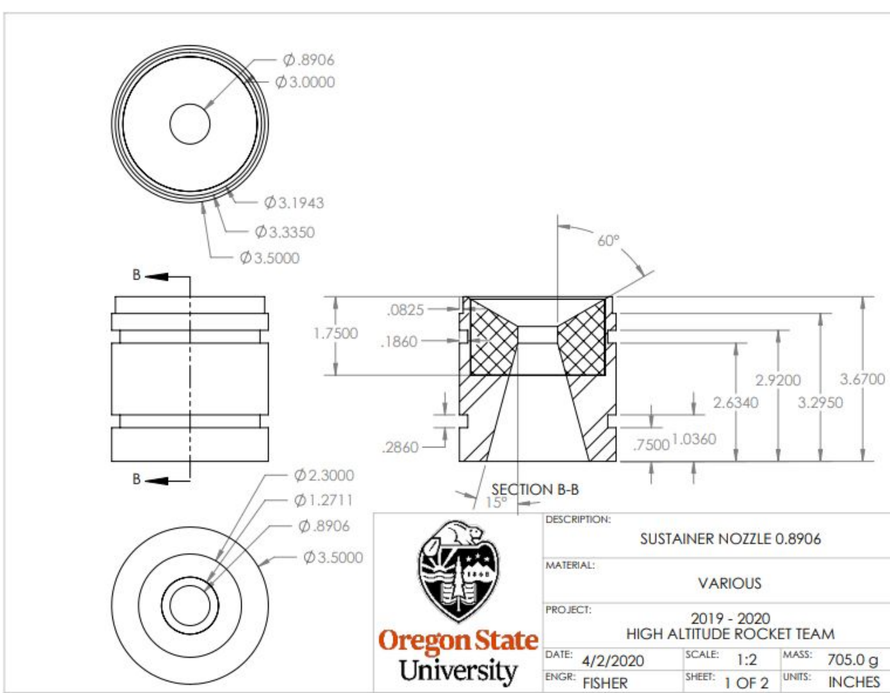
Forward Closure

The sustainer is modified to allow for more room for front end ignition on the sustainer. The ignitor is an e-match, wrapped with a flammable material and coated with the same propellant the sustainer motor is made from. There are small holes drilled through the forward closure that the wires for ignition pass through; they are sealed with a high temperature sealant. There is both a switch and a shunt to prevent accidental ignition. The retaining snap ring on the nozzle end is not inserted until the vehicle is at the pad.



Nozzle

The sustainer nozzle uses a 0.8906” throat and is made from canvas phenolic rod and graphite.

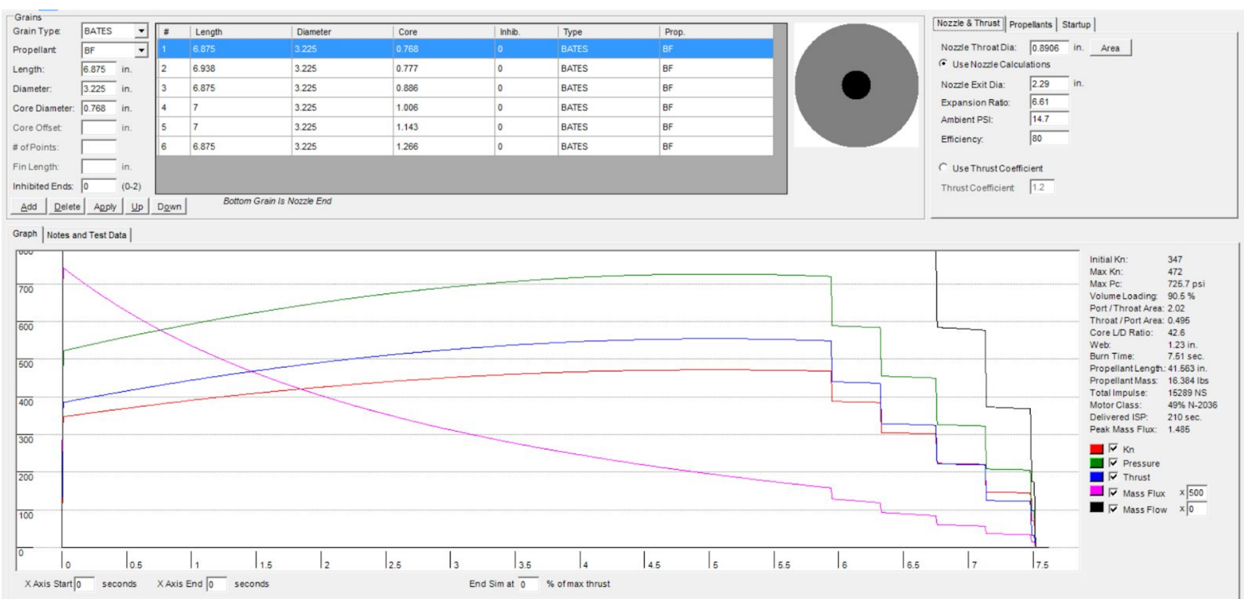


Propellant

The sustainer propellant is called “Black Flame” and the formulation is shown below.

Chemical name	Function	Weight percentage
Ammonium perchlorate (AP)	Oxidizer	74.5%
Hydroxyl-terminated polybutadiene resin (HTPB)	Binder	12.99%
Modified MDI isocyanate curative	Curative	2.61%
Oxamide	Burn-rate suppressant	6.0%
Carbon activated powder	Opacifier	0.5%
Isodecyl pelargonate plasticizer (IDP)	Plasticizer	3.0%
Castor oil	Chain-linking agent	0.2%
Lecithin	Viscosity reducer	0.2%
Silicon oil	Surface tension reducer	1 drop

Sustainer grain geometry and estimated motor performance is shown in the BurnSim output below. They were measured after casting and cleaning and before gluing into the phenolic liner.



Motor Hardware

The used insulating liner is a Convolute LE Phenolic Liner purchased from Loki Research. The sealing o-rings are High-Temperature Silicone O-Rings with 3.5 inch outer diameter. The retention mechanism in the motor casing for both the nozzle end and the forward enclosure end is a steel internal snap ring with an outer diameter of 3.5 inches.

Aerodynamics and Recovery

All recovery system components were designed for a target loading scenario of 50 G's. The weakest component in the system has a load rating of 47.7 G's This was calculated using the weight of the sustainer with fuel, the heaviest possible configuration, in the scenario no sustainer ignition occurs.

Main Parachutes

The main parachutes used for both stages are Fruity Chutes Iris Ultra Light 72" Toroidal Parachutes. Each of the 24 shroud lines are made from #200 Spectra material, with a rating of 200 lb/line. The canopy is made from 0.66 oz ripstop nylon. This parachute is packed into a kevlar and nomex deployment bag for fire protection.

Iris Ultra Light Parachute from [Fruity Chutes]

Drogue Parachutes

The drogue parachutes for the booster and sustainer are 36" and 24" kevlar flame proof parachutes respectively. The sustainer drogue is smaller to ensure a faster descent to minimize drift distance from apogee.

Kevlar Flame Proof Parachute from [Rocketman]

Recovery Hardware

Main Parachute Retention

Redundant L2 Tender Descenders are used to retain the main parachutes, in both stages, in the airframe until the stages descend to the desired deployment altitude. L2 tender descenders are rated for a maximum shock load of 2000 lbf by the manufacturer.

L2 Tender Descender from Tinder Rocketry

Swivels

One swivel is connected between each drogue and main parachute and between each main parachute and the eye nut to prevent tangling of the recovery system. Main parachute swivels are rated to 3,000 lb and drogue parachute swivels are rated to 1,500 lb; all purchased from Rocketman Parachutes.

Quick Links

Two quick links, not including those part of Tender Descender assembly, are used in the recovery system. One quick link connects the recovery system in each stage to the eye bolt via a small loop of shock cord. The shock cord loop is the middle link in the structural chain between the eye nut and quick link. This prevents the quick link and eye bolt from transferring force through each other which is intended to lower the stress concentration on the two pieces of hardware. Quick links are rated to 2,200 lb and purchased from Rocketman Parachutes.

Shock cords

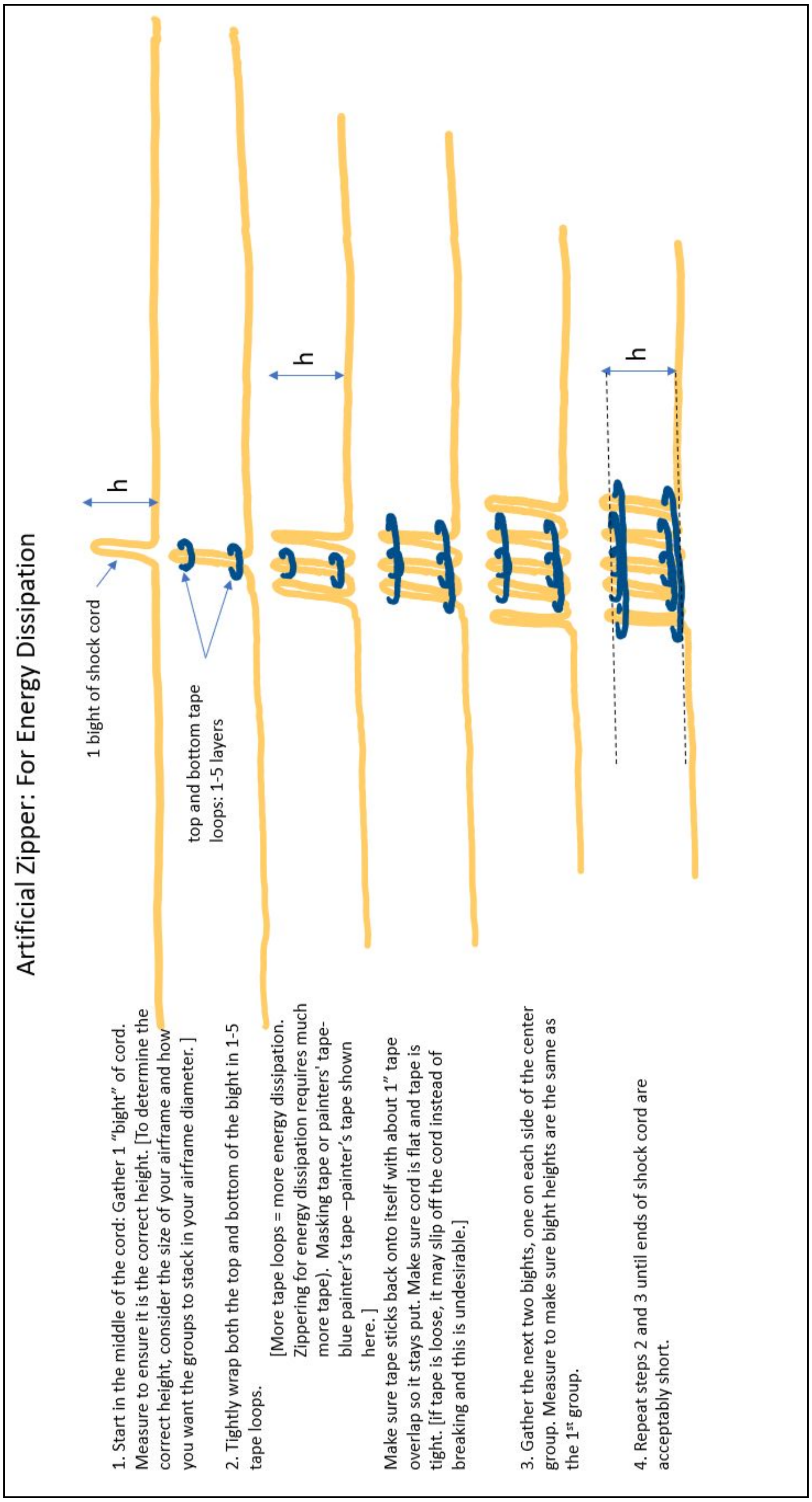
Shock cords are made of kevlar and ¼ inch and ½ inch wide. ¼ inch is used for the drogue lines and ½ inch is used for the main parachute lines. The strengths as listed by the manufacturer are as follows. ¼ inch cord: 3600 lb tested strength, ½ inch cord: 7200 lb tested strength. The shock cord is purchased from Top Flight Rocketry.

Knots

Knots used on the recovery system: Flemish Bend, Figure Eight on a Bight, Figure Eight Follow Through, Girth Hitch. These are all used to reduce or eliminate stress concentrations.

Shock Cord Artificial Zipper

Masking tape or painters tape is used to create an artificial zipper on shock cords to dissipate energy of the parachute deployment.



Deployment Charges

Below is all of the components that comprise the surgical tubing and straight tube black powder deployment charges.

Black Powder

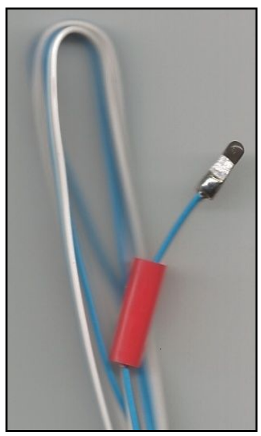
4F black powder from Goex is used for all black powder charges.

Electric Matches

The electric matches used for all black powder events are MJG Firewire initiators. Product information is listed below.

Bridgewire Resistance	Maximum No-Fire Current	Minimum All-Fire Current	Recommended Minimum Firing Current	Recommended Nominal Firing Current	Maximum Test Current
1 ohm ± .2 ohms	.30 amp. (300milliamp.)	.60 amp (600 milliamp.)	.75 amp	1.00 amp	.04 amp (40 milliamp.)

E-match product details by the manufacturer [MJG Technologies]



E-match from [MJG Technologies]

Surgical Tubing Charge

The surgical tubing charges are sized and verified by ejection testing. Charges are built by cutting surgical tubing to length, plugging one end with black rubber stopper material, inserting an e-match, with red flame guard removed, into the center of the powder, and then inserting the other stopper and zip-tying both ends.

Spent surgical tubing black powder charge

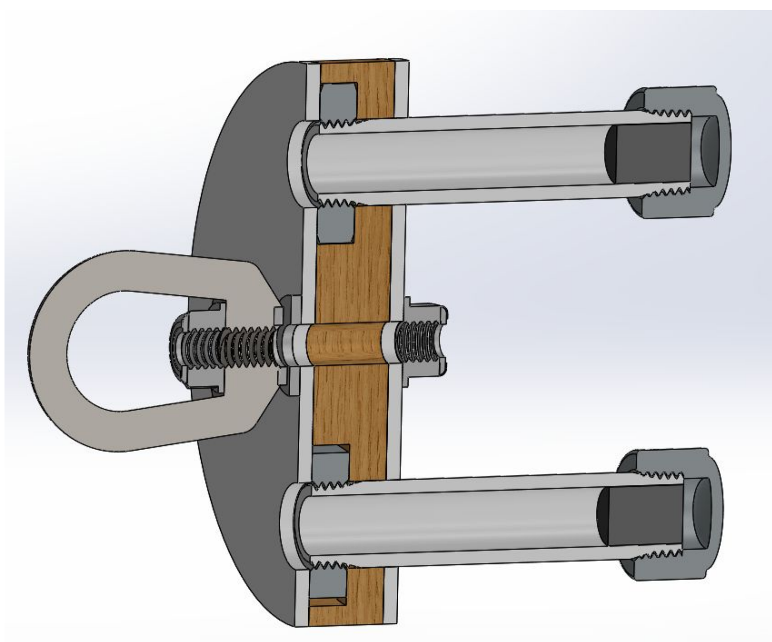
High Altitude Charge

The high altitude charge is used to separate the nosecone and eject the drogue parachute from the sustainer at apogee. The charge design utilizes a long, brass tube to allow the necessary pressure to build and increase the burn rate to ignite all of the black powder. These charges are identical to the ones used by Jim Jarvis in some of his high altitude flights.

The design consists of a 0.38 inch inner diameter brass tube, 2.5 inches long, with a threaded end cap sealing one end; the other end is open with a lock nut for mounting purposes.. The bulkhead is made from 0.50 inch plywood sandwiched on both sides by 0.09 inch G10 fiberglass for added strength. The locknut on the open side of the charge will be recessed into holes of the plywood and the top plate of G10 will clamp down over the lock nut, acting as the retention method.

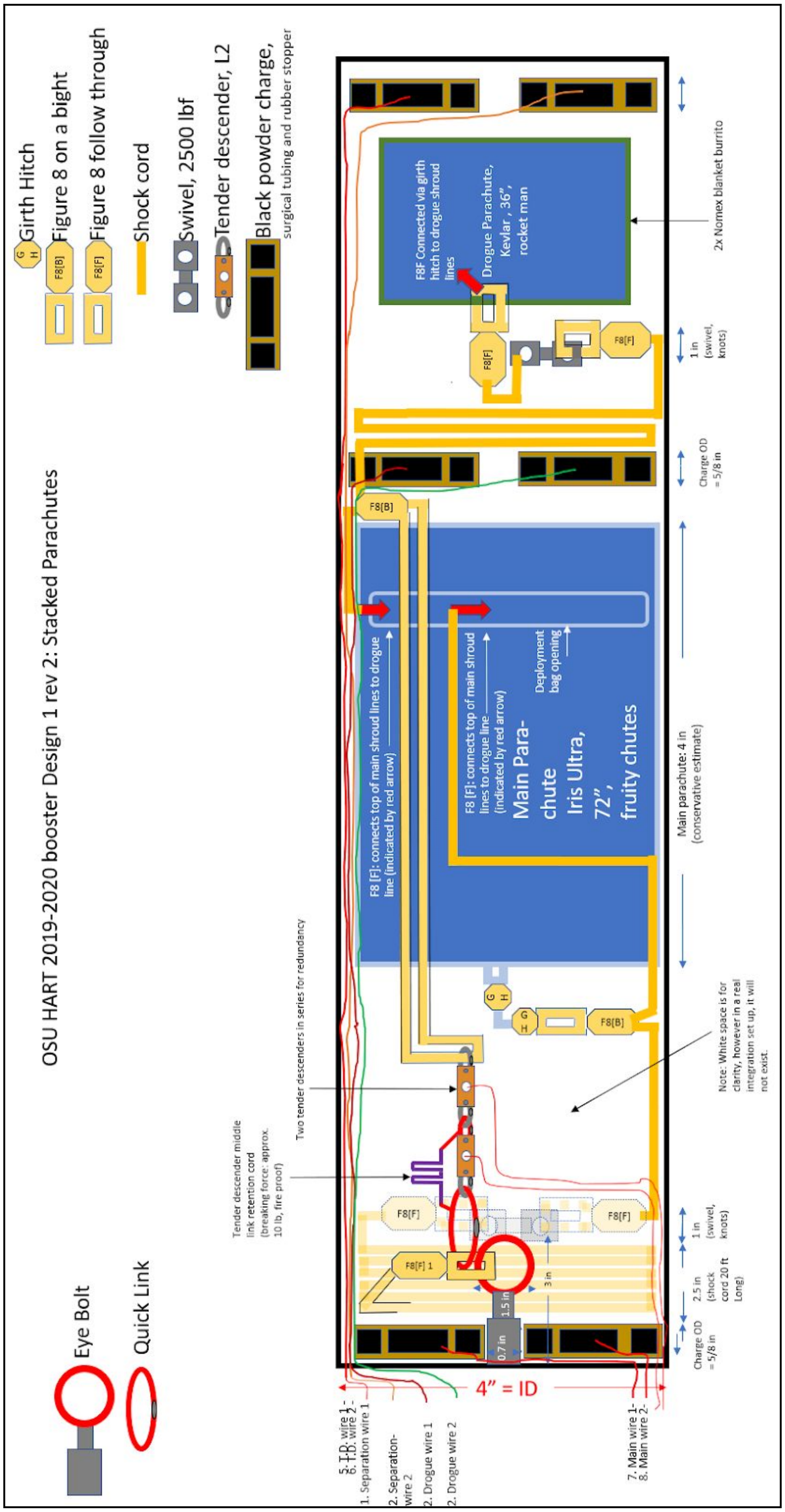
The open end will be capped with a thin layer of epoxy to hold the contents in place and will be covered with two layers of electrical tape. The e-match to ignite the black powder will be fed through a small hole in the epoxy end cap. It will be placed at the top of the black powder and the remaining space in the tube will be filled with Estes wadding.

The complete charge assembly is shown below and will be mounted on the threaded rod in the nosecone. The lock nuts on top and bottom of the bulkhead will hold it securely in place.

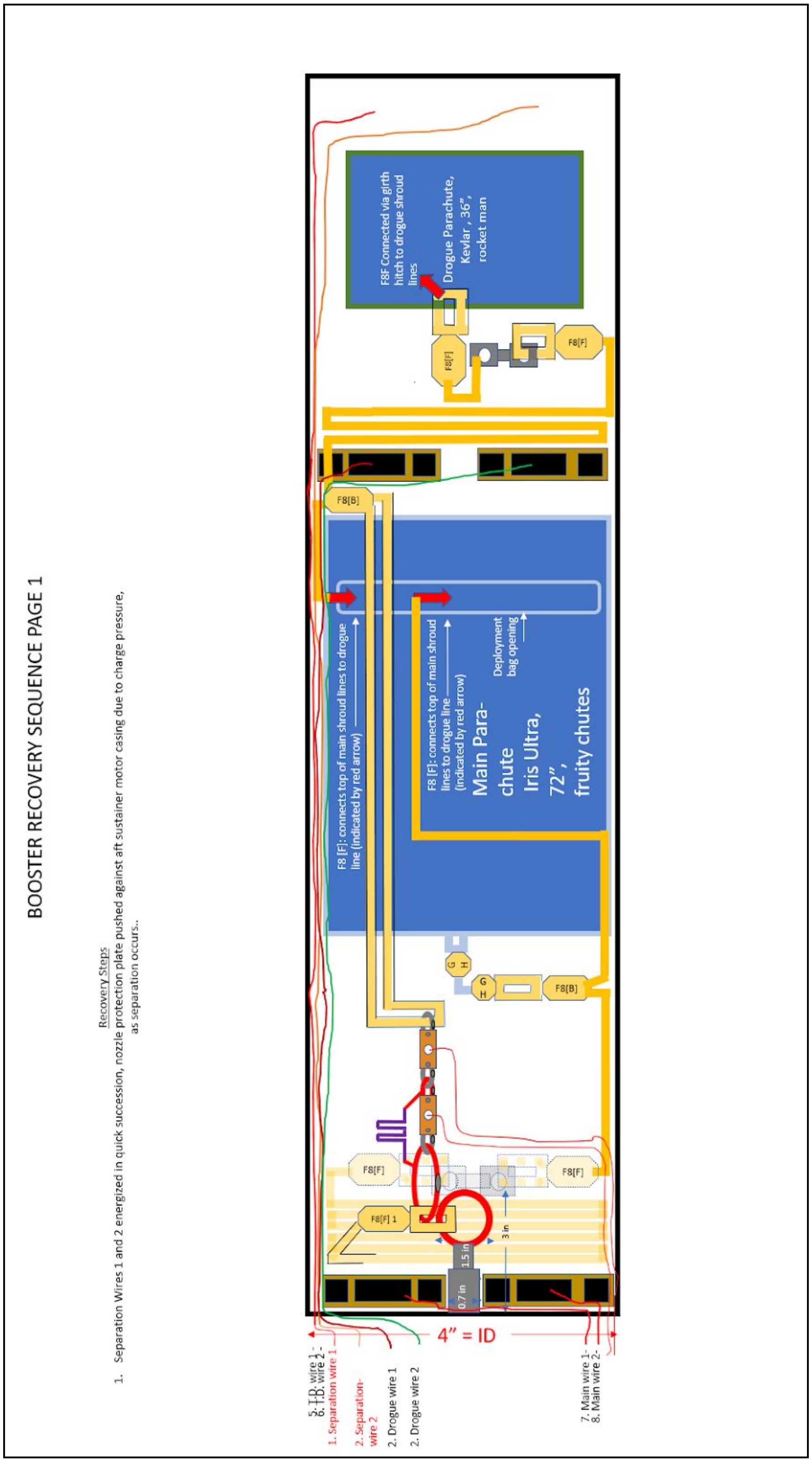


CAD model of the high altitude charge assembly

Booster Recovery System



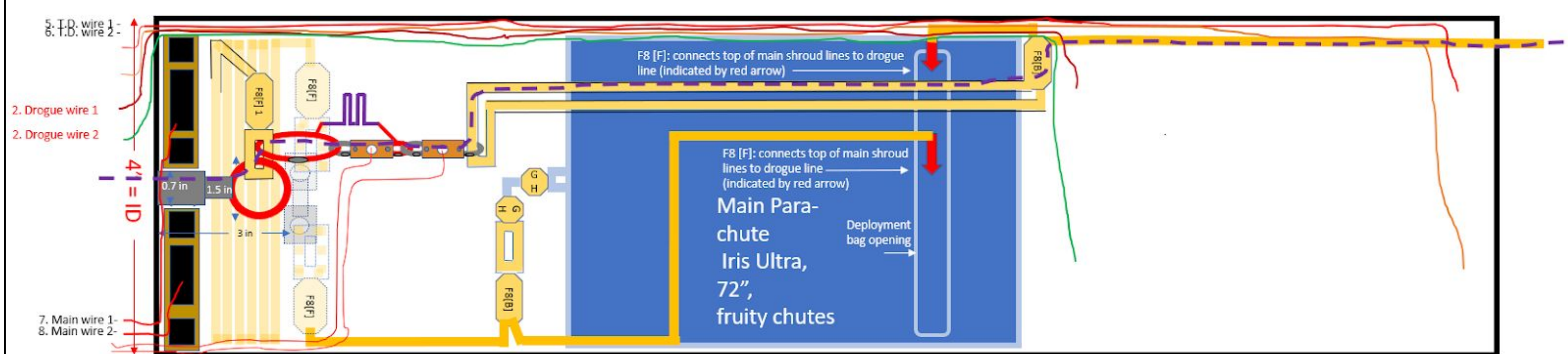
Deployment Sequence



BOOSTER RECOVERY SEQUENCE PAGE 2

Recovery Steps

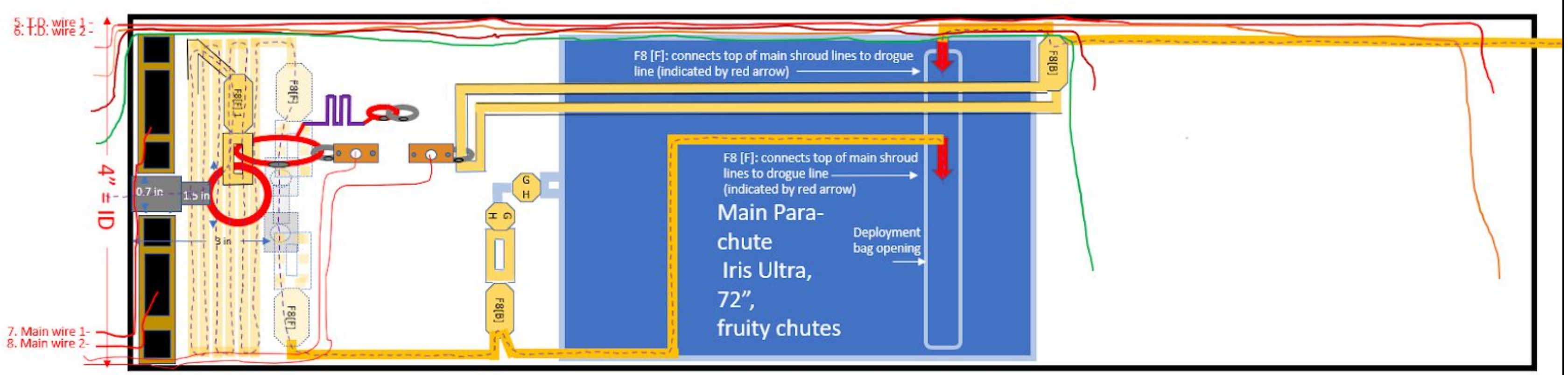
1. Separated Booster Coasts upwards to apogee. Drogue wire 1 and 2 energized in quick succession.
2. Drogue Parachute Ejected from airframe, drogue shock cord now in tension. Tension Marked with



BOOSTER RECOVERY SEQUENCE PAGE 3

Recovery Steps

1. Booster descends to 1500 ft AGL under drogue
2. Tender Descender (T.D.) wires 1 and 2 energized in quick succession. Main parachute no longer retained. Tension switches to main parachute shock cord. Tension marked with
3. Main Charges are fired with a small delay following the Tender Descenders.

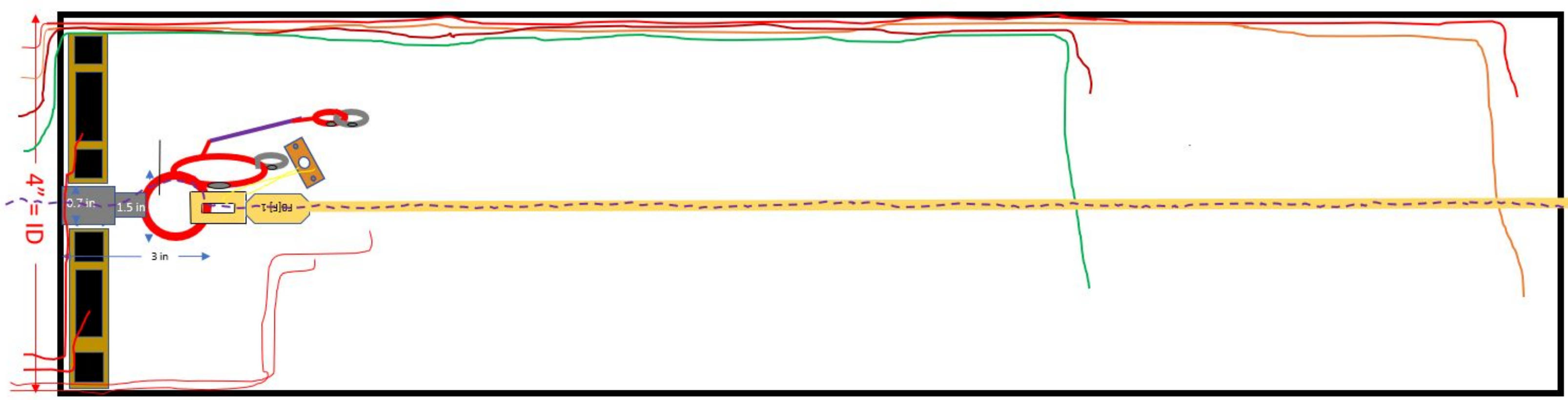


BOOSTER RECOVERY SEQUENCE PAGE 4

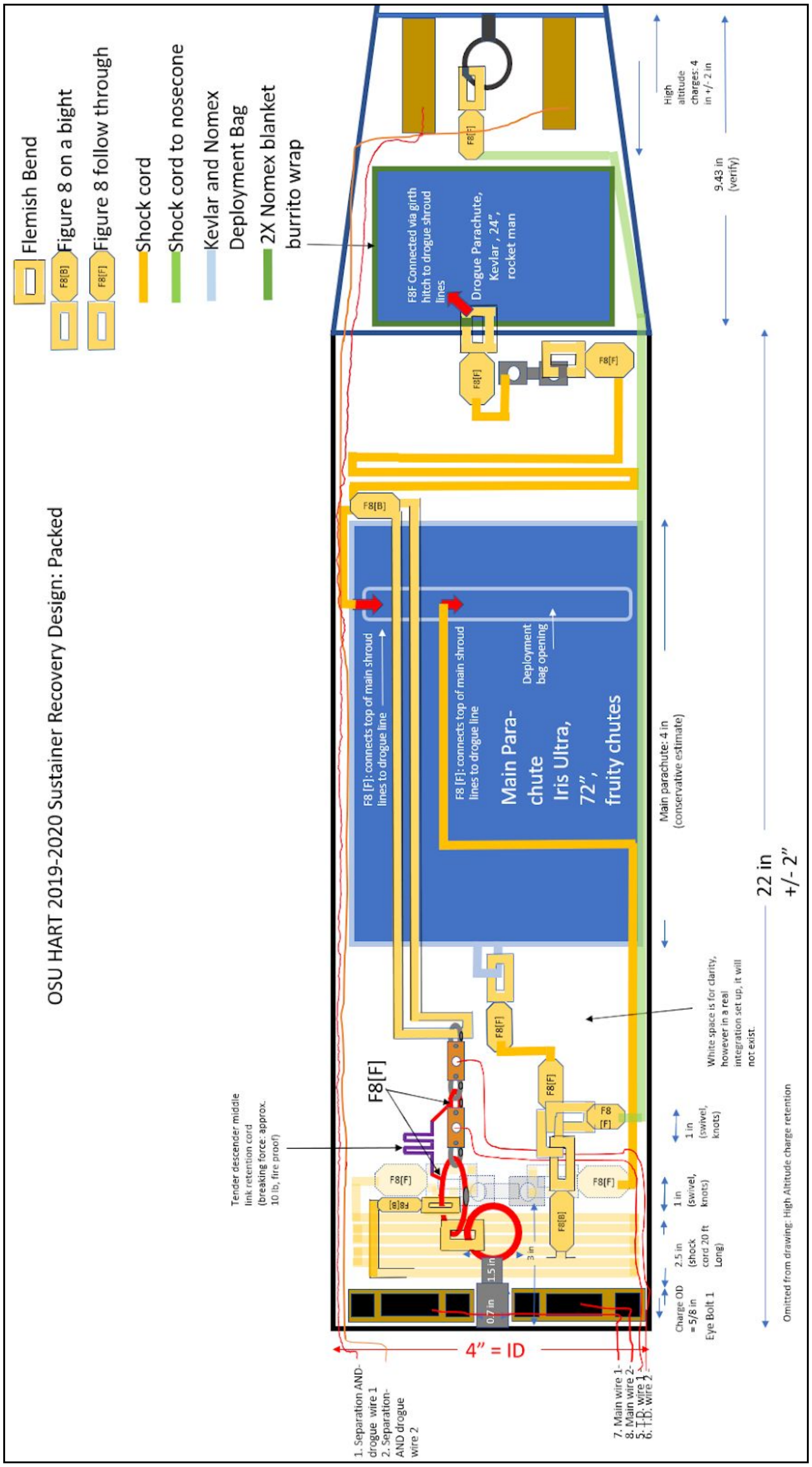
Recovery Steps

1. As tension switches from the Tender Descenders to the main shock cord, main parachute is pulled from airframe with its deployment bag still encasing it.
2. Outside the airframe, as the main shock cord extends to full length, a difference in length between the deployment bag tether and main shock cord pulls the main parachute from bag under tension of drogue parachute drag(not pictured).

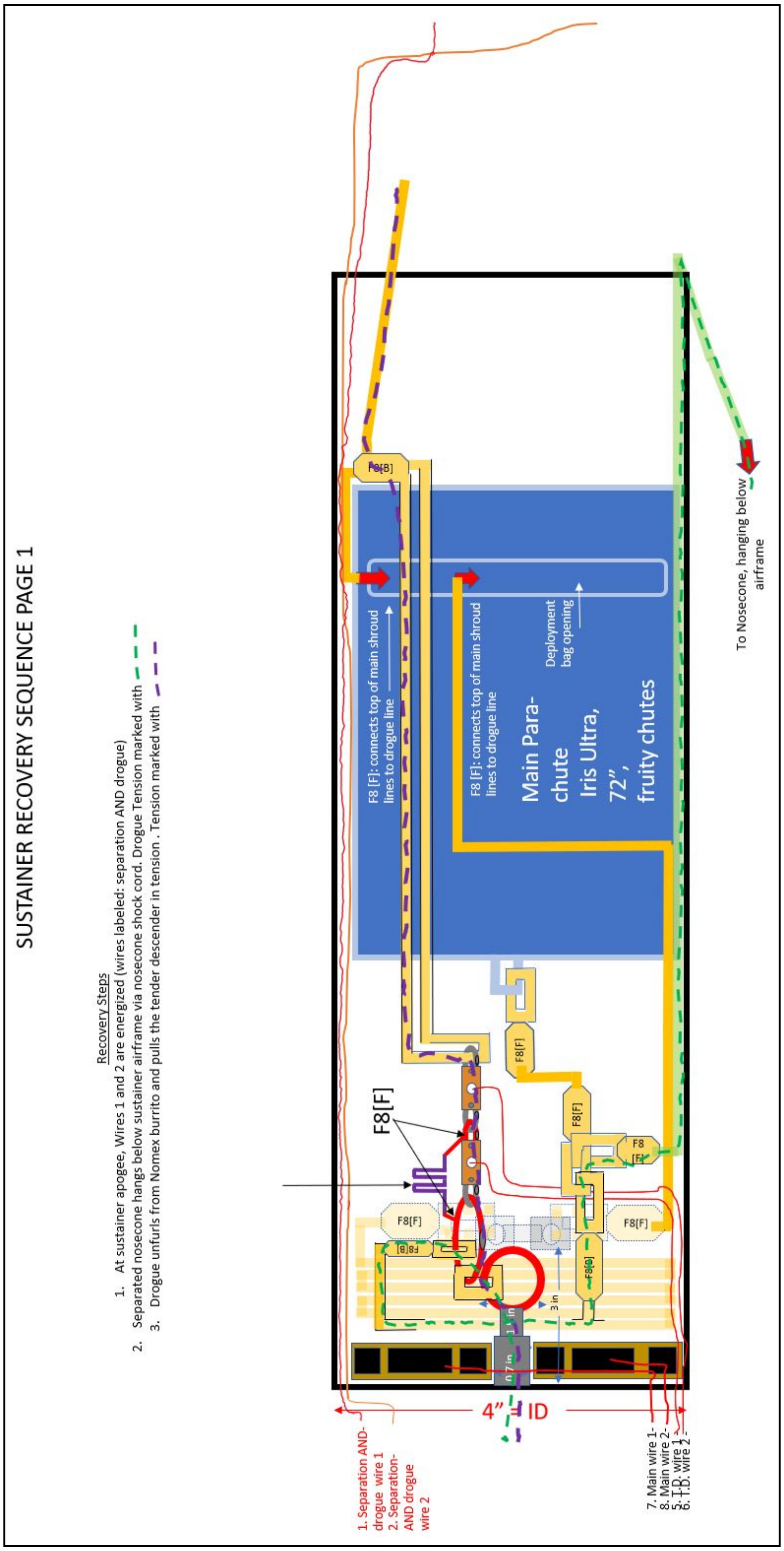
Note: Tender Descender housing in airframe retained via Kevlar shock cord looped through Figure 8 at base of shock cord. Redundant T.D. hosing (not pictured) retained outside airframe, above the main parachute on the shock cord. Middle quick links of T.D. retained by breakaway shock cord (solid purple)



Sustainer Recovery System



Deployment Sequence

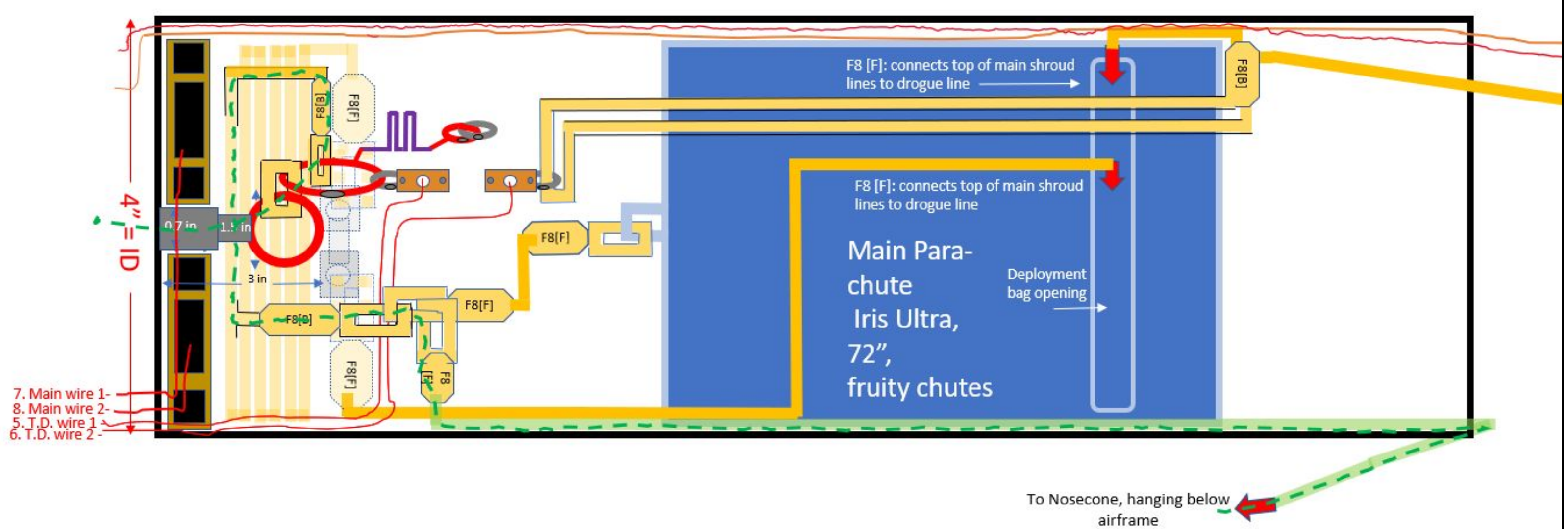


SUSTAINER RECOVERY SEQUENCE PAGE 2

Recovery Steps

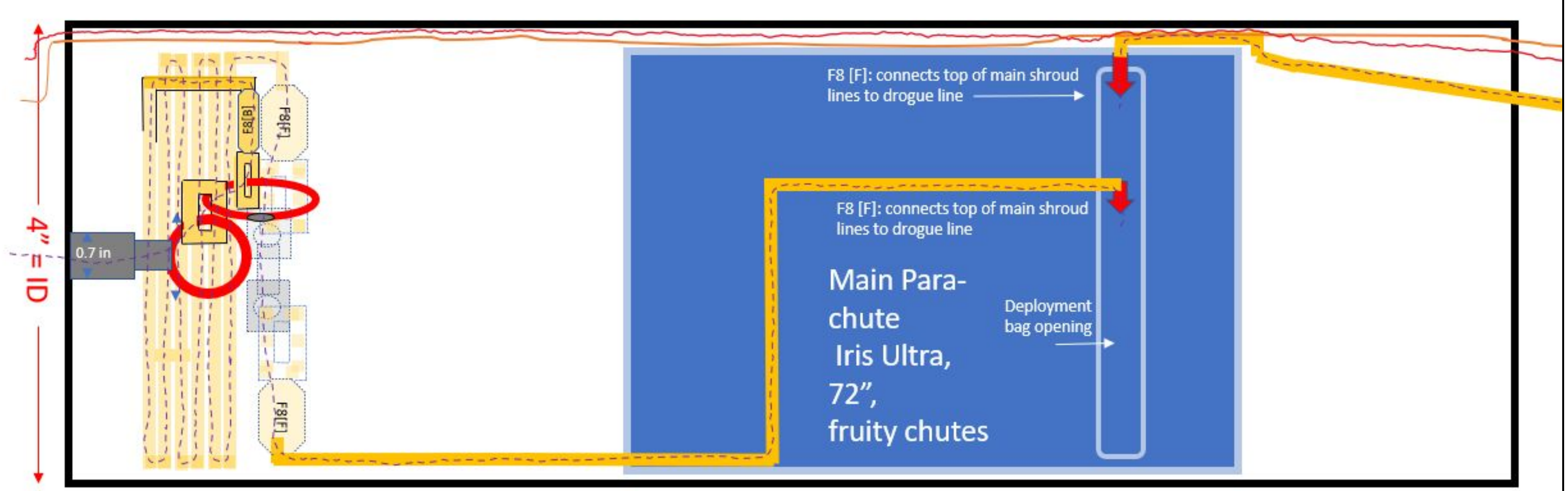
1. At 1500 ft AGL, T.D. wires 1 and 2 are energized. Main parachute is no longer retained.
2. Tension due to drogue transitions to the main shock cord and parachute in deployment bag.
3. Shortly after T.D.'s are released, main charge wires 1 and 2 are energized.

Note that the shapes outlined in dots (1 swivel, two F8F knots, the main shock cord packed behind the main) are connected. See Tension detail through these connected parts on next page.



SUSTAINER RECOVERY SEQUENCE PAGE 3

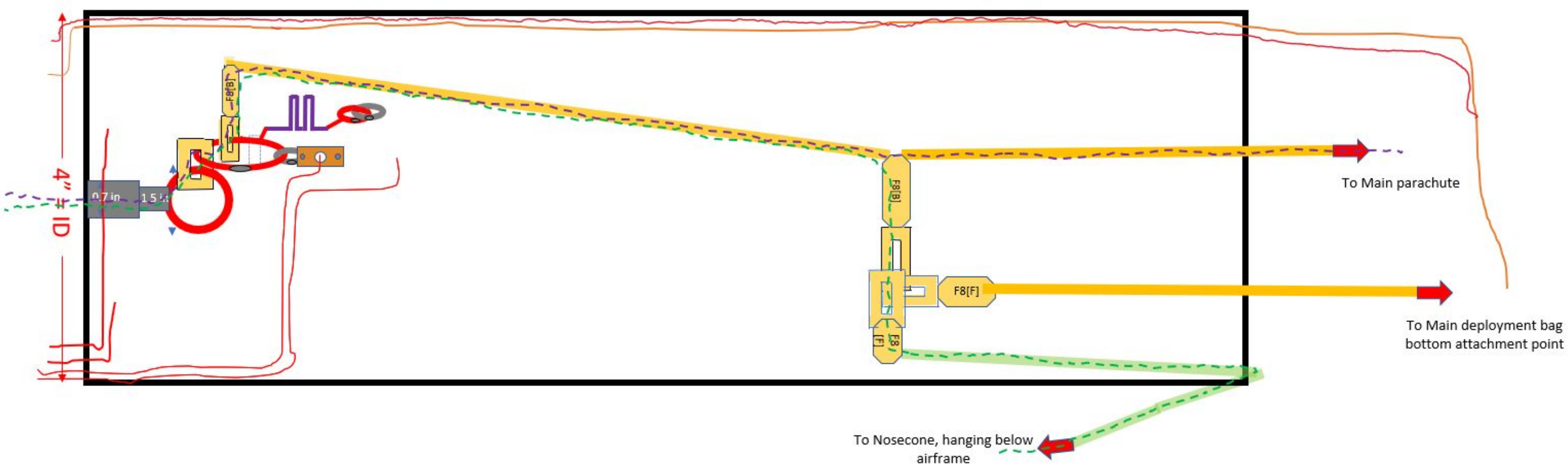
Showing main shock cord in tension(before full extension) for detail



SUSTAINER RECOVERY SEQUENCE PAGE 4

Recovery Steps

1. Main shock cord pulled to full extended length. Tension for nosecone and main parachute shown.
2. Outside the airframe, as the main shock cord extends to full length, a difference in length between the deployment bag tether and main shock cord pulls the main parachute from bag under tension of drogue parachute drag(not pictured).

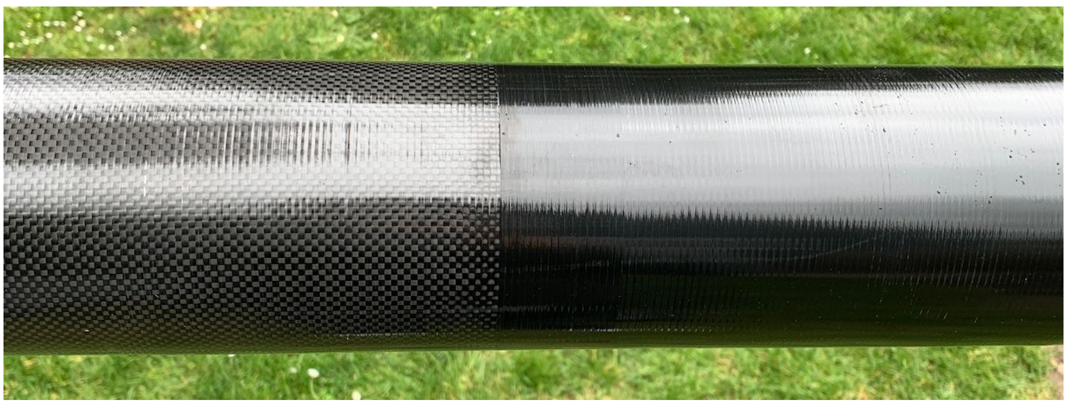


Structures

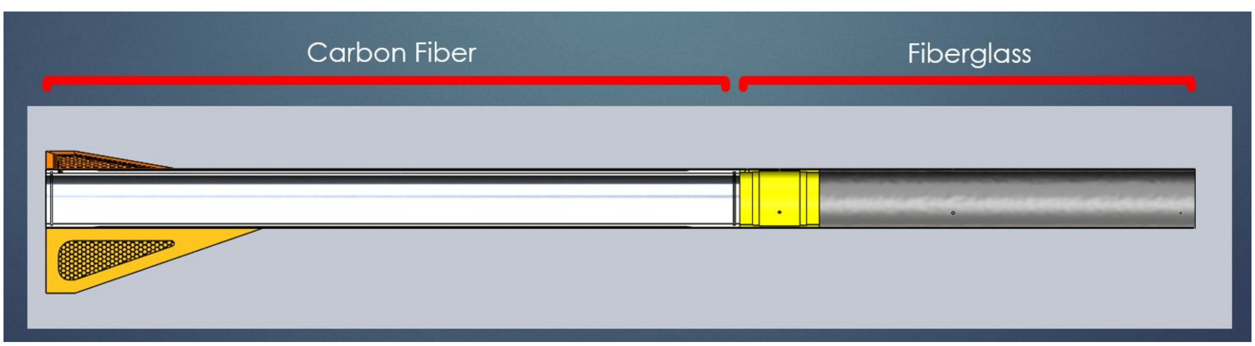
Airframe

The airframes for both stages are purchased from Innovative Composite Engineering. The booster is all fiberglass and the sustainer is fiberglass and carbon fiber. The inner diameter is 4.00” and has a layup schedule of 0 / -45 / 0 / +45 / 0. The ends are also tapered to increase thickness, decreasing the risk of zippering.

The booster airframe is 78” long and is all fiberglass. The sustainer airframe is 62” long, 42” of carbon fiber and 20” of fiberglass. The sustainer airframe is one continuous tube, there are no breaks or couplers, shown below. The fiberglass section begins at the bottom of the avionics bay for radio transparency.



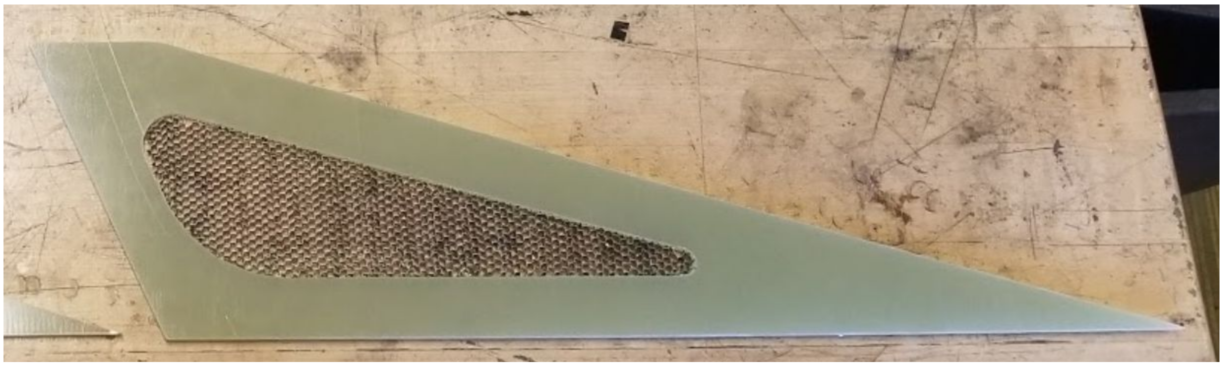
Sustainer airframe carbon fiber to fiberglass transition.



Note: this shows the booster stage, however the
transition is only relevant to the sustainer airframe.

Fins

Eash fin is made with a frame of 0.188” thick G10 fiberglass with a 0.188” thick aluminum honeycomb core bonded to the G10. The interface between materials is lined with core splice during the layup.



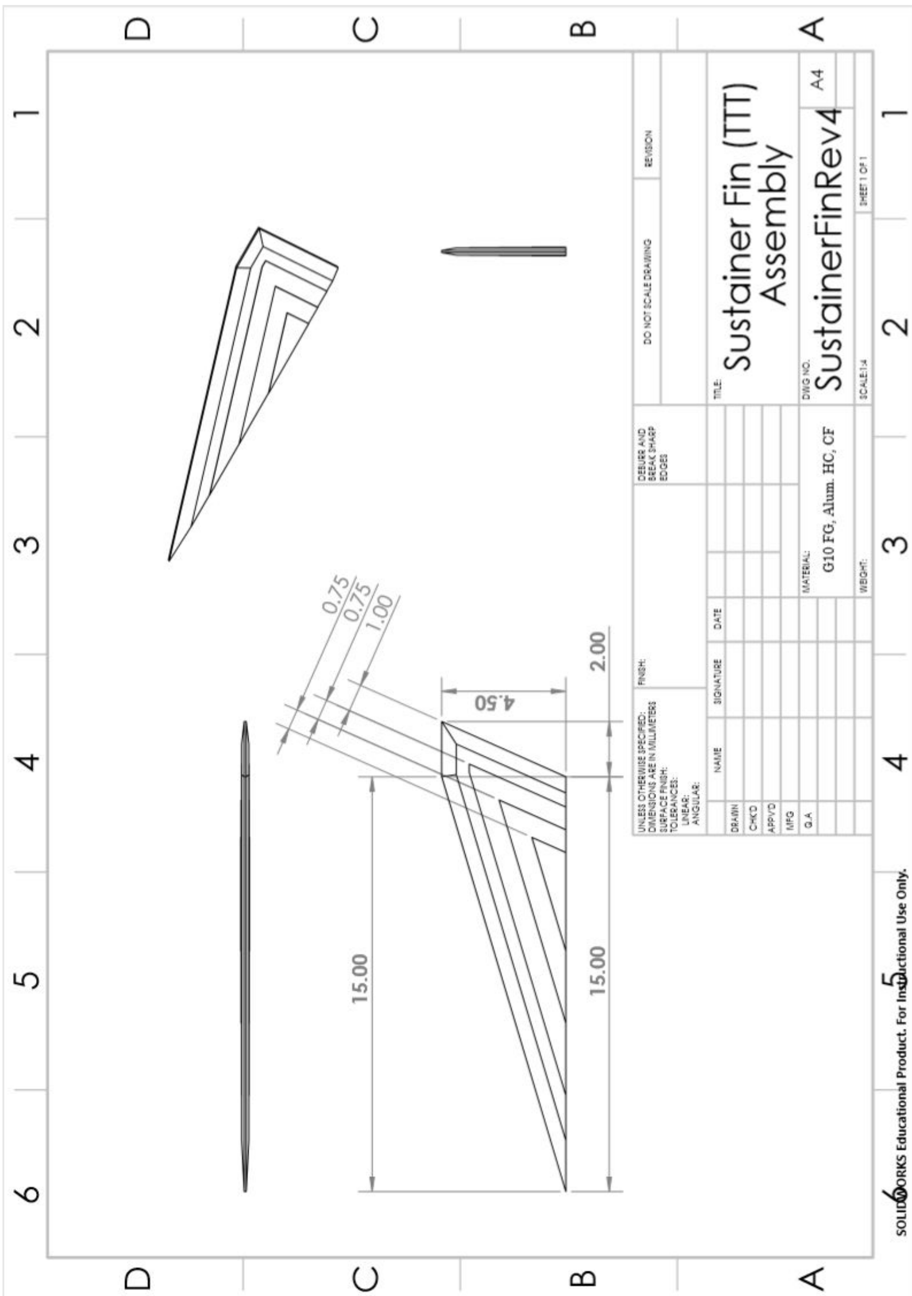
It is then sandwiched between 3 layers of 0/90 T800 carbon fiber weave on both sides (a total of 6 layers per fin). A 0.875” beveled edge (not shown) will be added to the leading and trailing edges. The fin is 0.258” thick after adding these first carbon layers.

This fin will be attached to the airframe with 1/2 inch rocketpoxy fillets. On top of those there will be 3 structural carbon fiber tip-to-tip layers with decreasing height relative to the tip of the fin to create a slight airfoil shape. There will also be a sacrificial fiberglass tip-to-tip layer that will be sanded to create a smooth, aerodynamic surface. The fins will have a final thickness of 0.340“ once attached to the airframe.

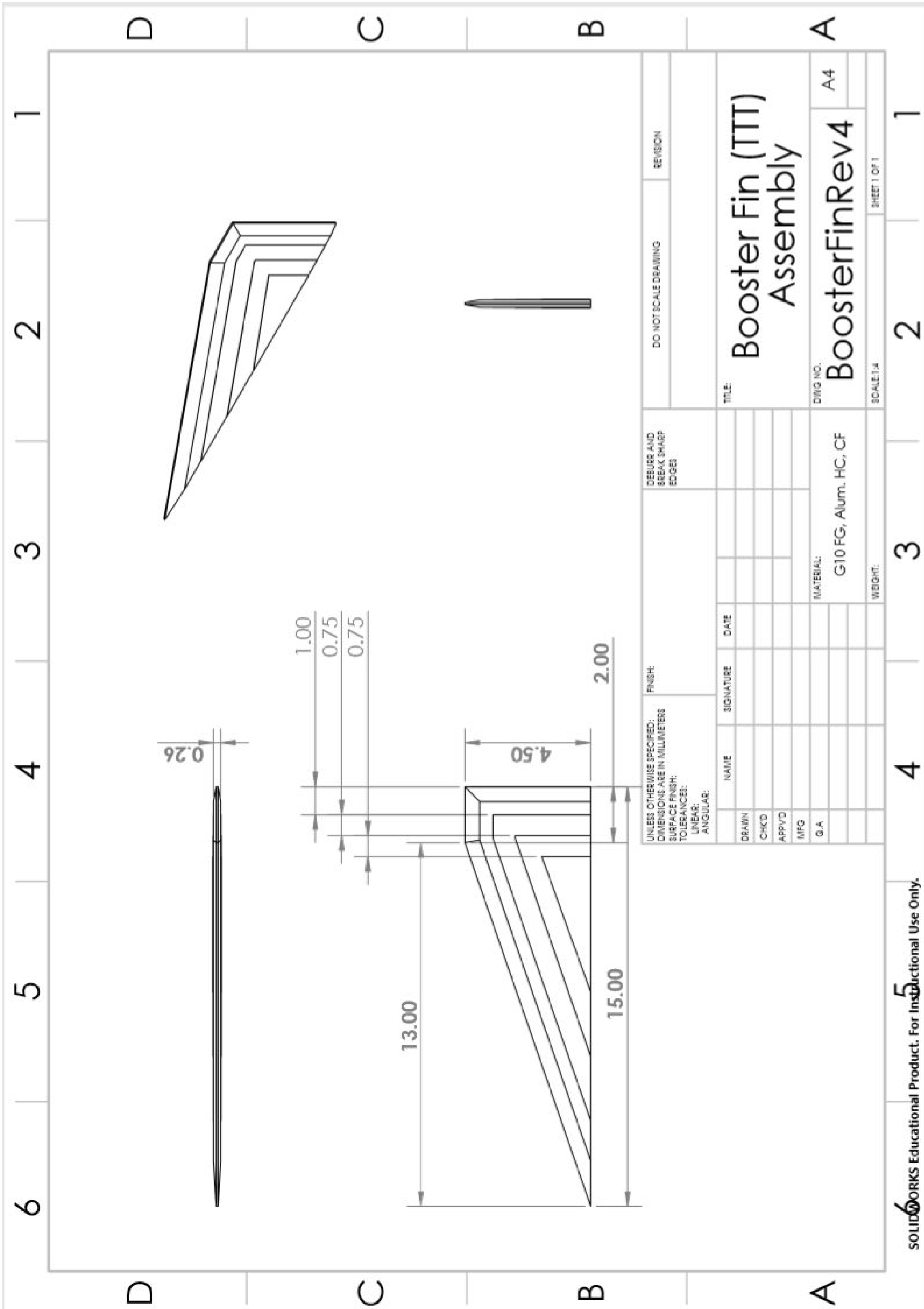
The composite layup schedule is as follows:
[0/45/0] tip-to-tip carbon fiber layers
[0/45/0] part of the fin
[Film Adhesive]
[G10 & Aluminum HC]
[Film Adhesive]
[0/45/0] part of the fin
[0/45/0] tip-to-tip carbon fiber layers

The combination of 4 different materials (with varying natural frequencies) and the varying cross sectional area will make our fins very resilient to flutter. We have completed both impact testing and instron 3-point bend testing to validate the structural integrity and the flutter velocity.

There will be an additional fiberglass layer laid from the root of a fin, over the tip, and to the root on the other side of the fin. The leading edge will also be coated with a high temp epoxy to further prevent delamination. The manufacturing process and materials selection of the booster fins are identical to the sustainer fins.



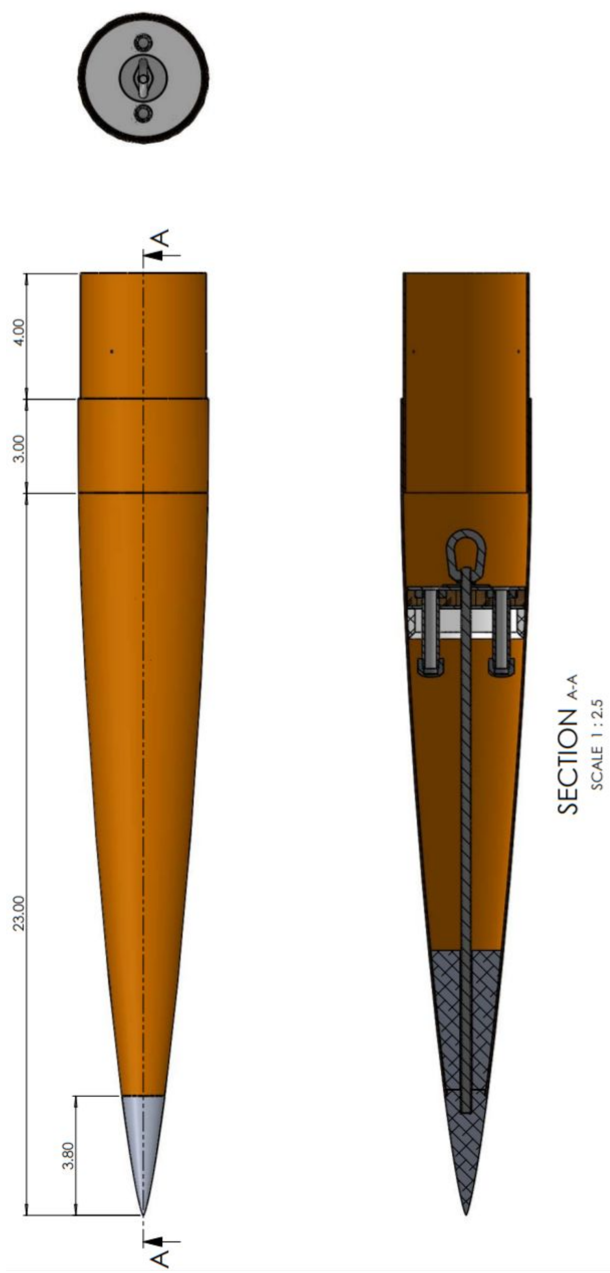
CAD drawing of sustainer fin with the tip-to-tip layup



CAD drawing of booster fin with tip-to-tip layup

Nosecone

The nose cone is primarily made of fiberglass, with the body taking on a von Karman profile, and being 23 inches long. The tip is made of metal to withstand the supersonic heating experienced during flight. The tip is secured via being epoxied to the fiberglass body and screwed onto a threaded rod attached to the high altitude charge bulkhead. The charge assembly is mounted to a ring that is epoxied to the inside of the nosecone and secured by an eye nut held in place by a lock washer. The nosecone eye nut is attached to the drogue shock cord.

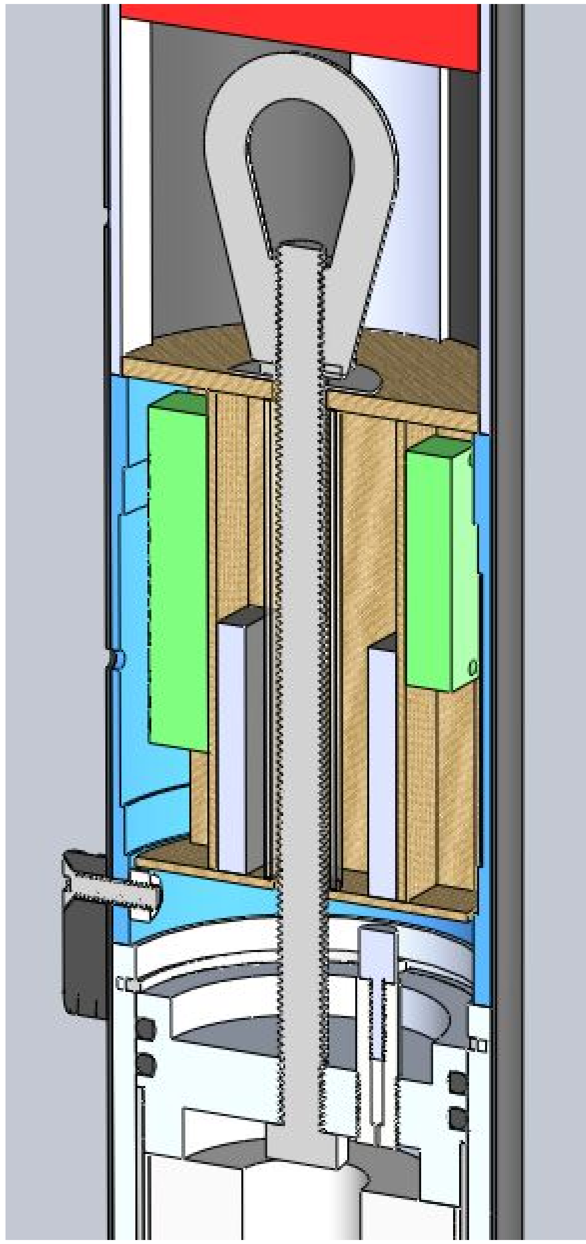


Nosecone assembly

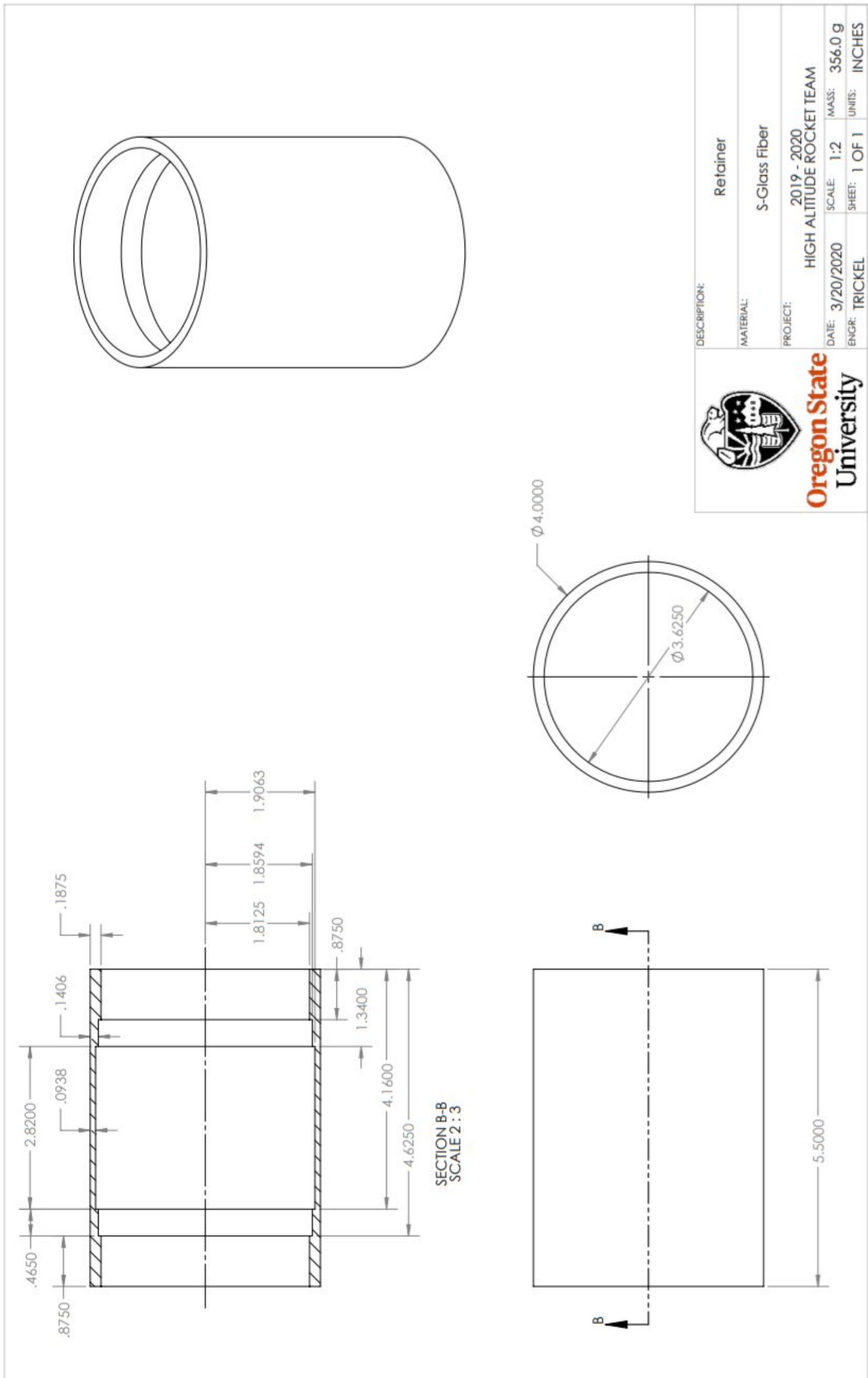
Retainer

The retainer assembly is composed of the forward bulkhead of the avionics bay and the forward enclosure of the motor casing. Together with a threaded steel rod, these two components clamp around a fiberglass cylinder that is epoxied into the airframe. The threaded rod is secured into the forward enclosure and also has an eye nut on the avionics bay's forward bulkhead. This eye nut serves as the attachment point for the rocket's recovery system. The design was validated in an Instron Universal Testing System to over twice the loads expected in flight. Additionally, the fiberglass retainer's epoxy joint with the airframe was tested to over 8 times the expected load.

The threaded eye nut has also been secured to the avionics bay forward bulkhead to prevent unthreading during flight. There is a lock washer between the top of the avionics bay bulkhead and the bottom of the eye nut. There is also an additional zip tie that loops through the top of the avionics bay bulkhead and through the eye nut to prevent unscrewing in the event the lock washer fails to prevent loosening. This method has been tested and verified. The shock cord will ravel up and lift the entire stage as the cord coils before the eye nut loosens, which realistically will never happen in a real flight. The zip tie did not break even at max loading, meaning loosening and unscrewing will not happen.



CAD model of the retainer assembly (retainer shown in blue)



Retainer engineering drawing.

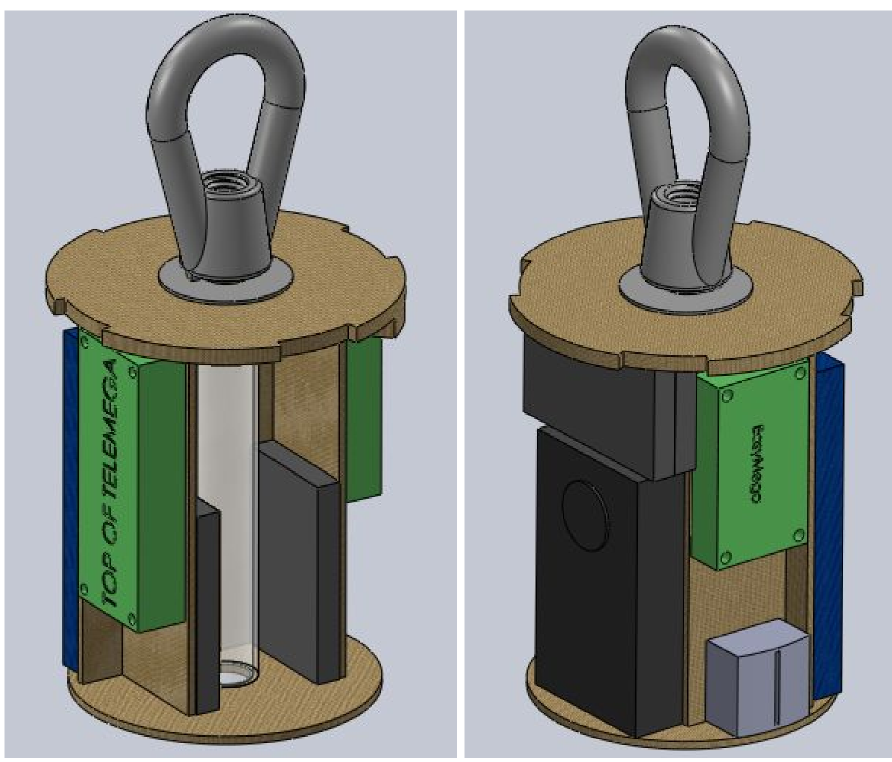
Avionics

AV Bay

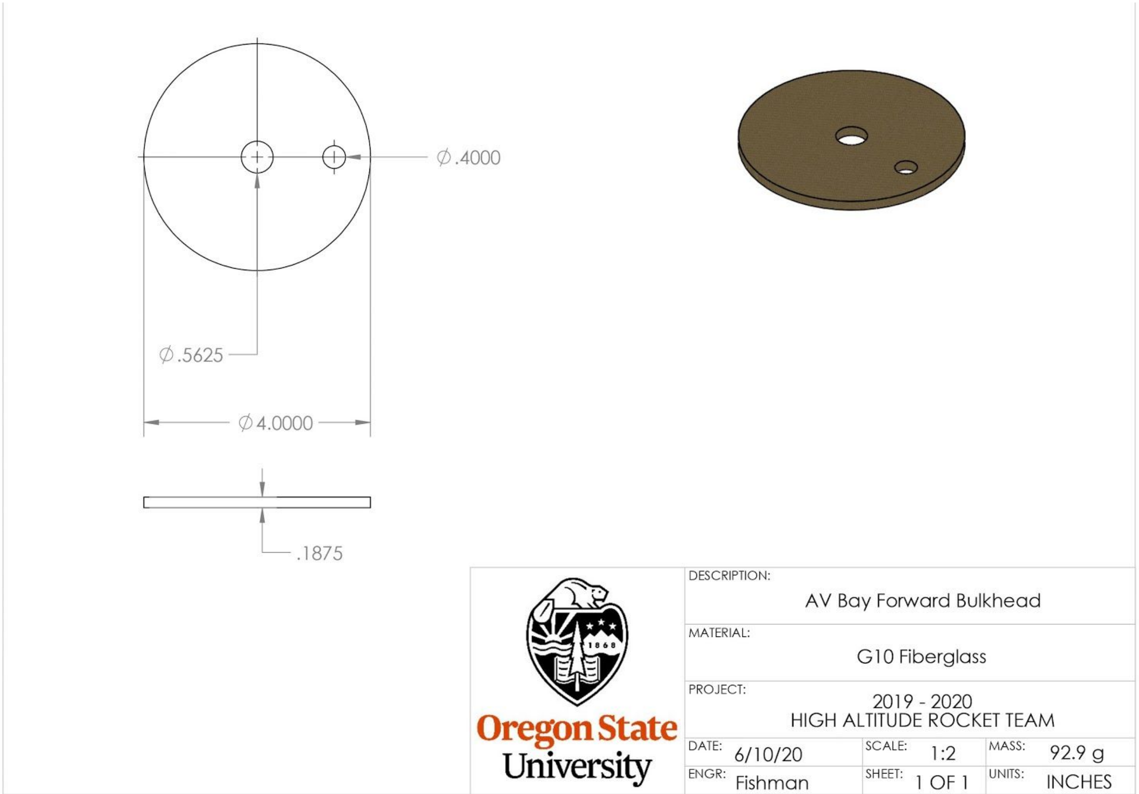
The material selected for the construction of the AV bay is a fiberglass G10. This fiberglass material allows for the transmission of radio frequency used by the electronics. G10 fiberglass is commercially available in a variety of sheet thickness.

The AV bay is constructed with two 0.188” bulkheads and 0.09375” struts to connect them. Through the center of the bulkheads is a hole to allow the threaded rod to pass through so the entire AV bay can be clamped onto the retainer. Along with the hole for the threaded rod there is a second hole to allow the wires for the black powder charges to pass through to the electronics. On the bottom of the forward bulkhead there is a small key also manufactured out of G10 to allow the avionics bay to be oriented in the proper direction at all times by fitting into a cutout in the retainer. The electronics will be mounted on the upright struts with standoffs to give the chips space.

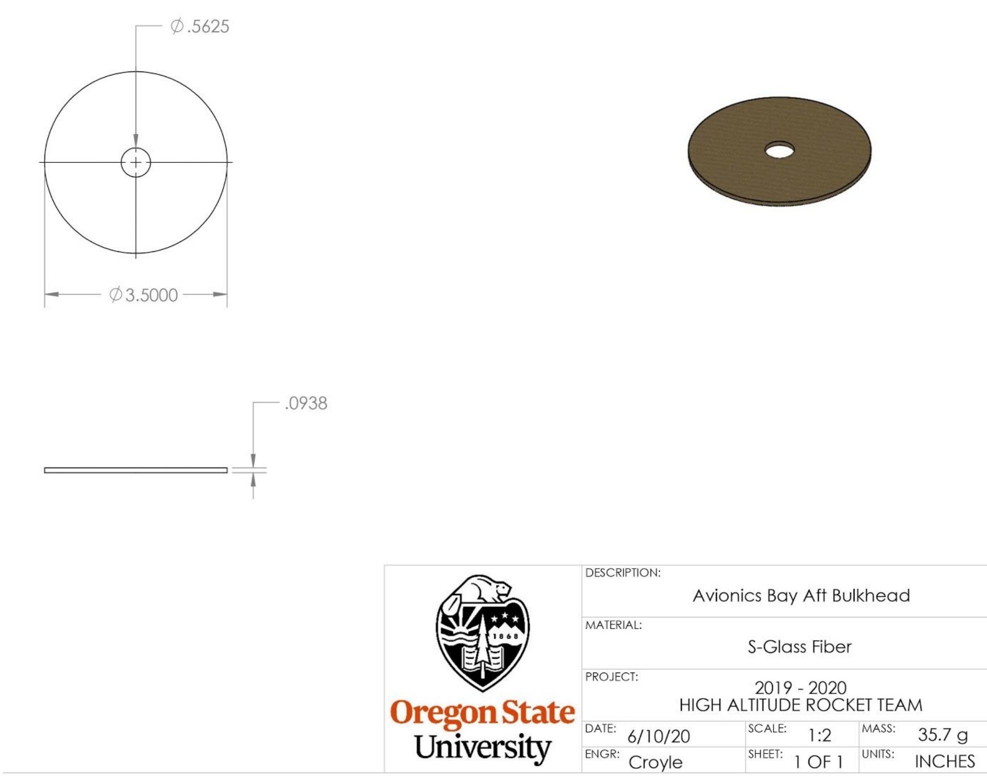
There are 2 independent flight computers on each AV Bay. An Altus Metrum TeleMega acts as the main flight computer and the Altus Metrum EasyMega acts as the backup computer. There is also an independent student developed chip for recording pressure data from the motor during flight. It is not used to control anything flight critical.



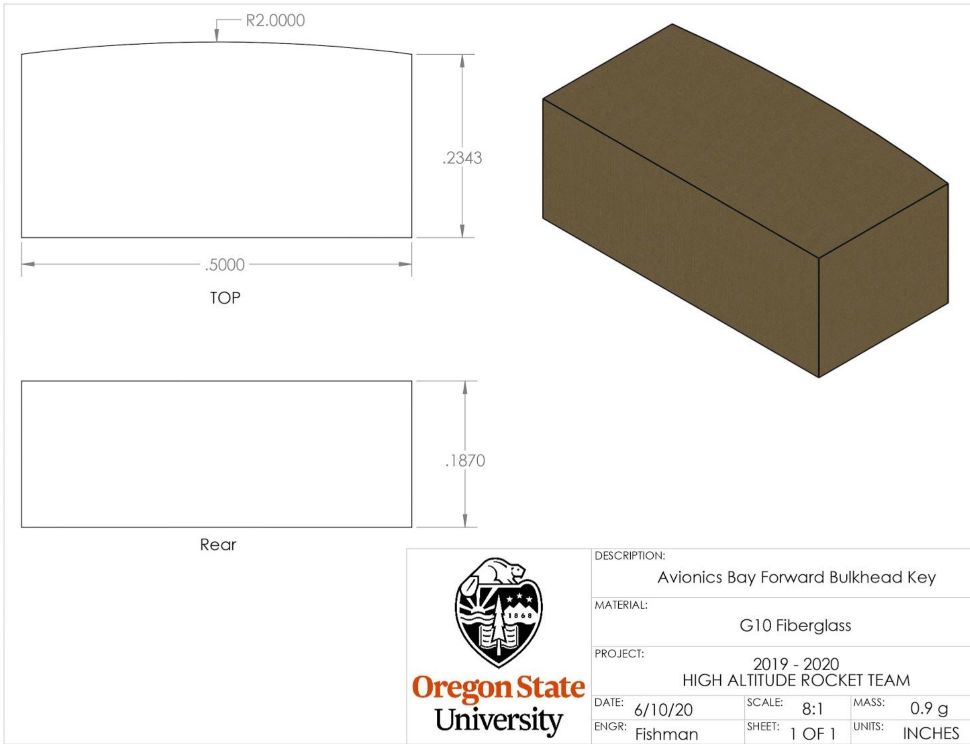
Booster (left) and sustainer (right) avionics bays



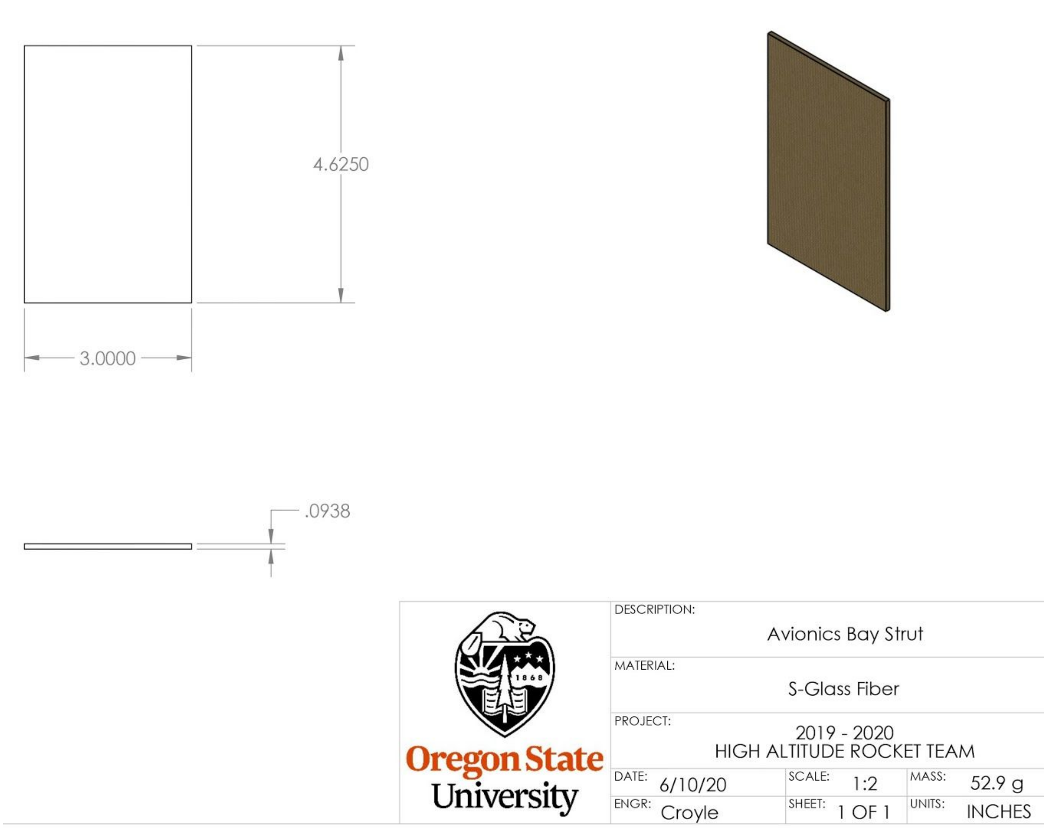
Forward Bulkhead for Avionics Bay



Aft Bulkhead for Avionics Bay



Key for Forward Bulkhead

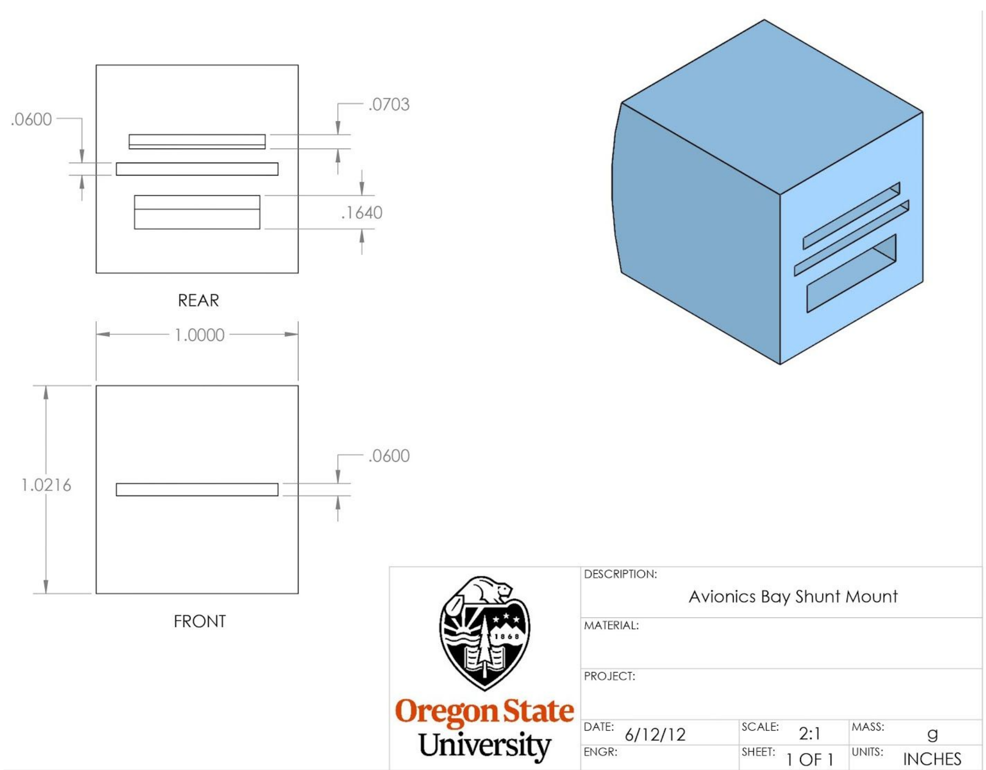


Vertical Struts for Avionics Bays

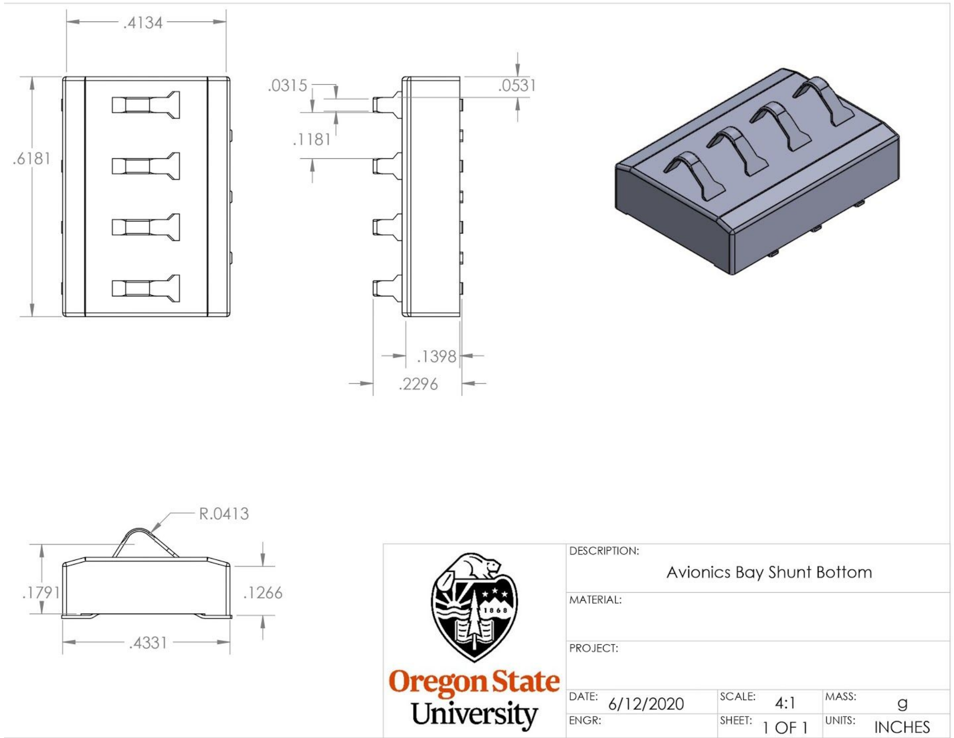
Ignition Shunt

The design chosen uses commercially available battery connector terminals, where one end of the connector has a spring loaded and push retractable connector and the other is a flat metallic plate. The spring loaded ends that have a range of motion of 5mm and are lined up with flat plate connectors with a gap of 3mm. The gap between the connectors allows for a 1.5mm, credit card thick, shunt card to be inserted between the connectors. The shunt card has thin metallics strips on one side that short the ignitor end of the system while simultaneously disconnecting it from the electronics as the sprung prongs are retracted and make contact only across the metallic strip on the card.This allows for a single, vertical slot in the airframe of 2mm by 2cm. While the shunt card is inserted there is a measured resistance of 0.2 ohms across the short and zero load, or infinite resistance across the disconnect. Once the card is removed there is a resistance of 2 ohms across the connectors, which is well below the max resistance that the telemegas can provide sufficient current across and still ignite the motor.

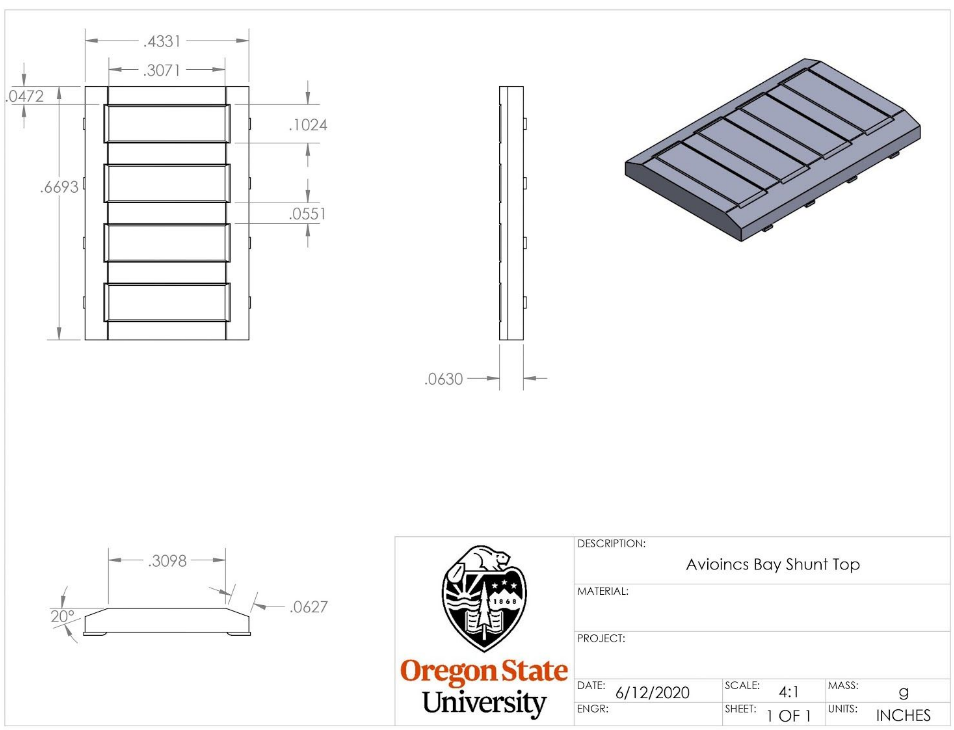
This system is designed so that the card can have a thin string attached which is fed through the airframe slot and the shunt card is inserted as the first step in integration and assembly of the avionics bay. Once the avionics bay has been fully assembled and inserted into the airframe the only protruding piece of the shunt is the string attached to the card. Once on the launch rail, and as the final step before retreating to the launch control area, the cord will be used to pull the shunt card from the airframe and complete the circuit between the electronics and the forward ignition system.



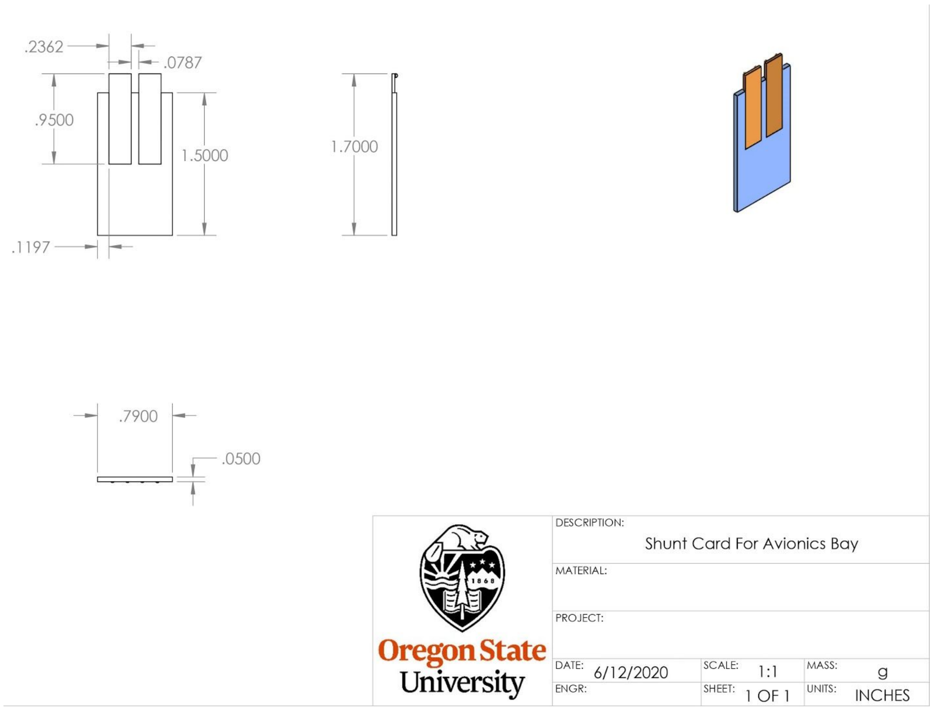
Shunt mount installed into the AV bay



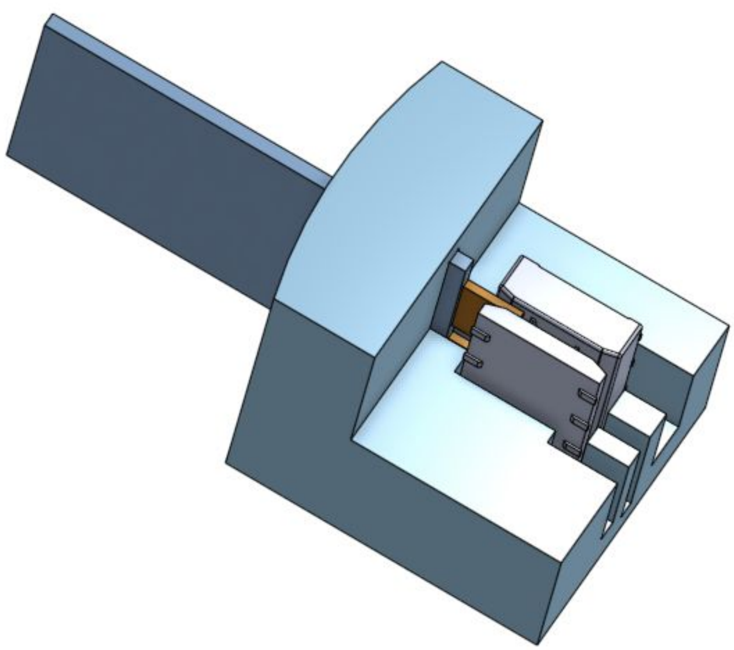
Protruding side of the shunt battery connector

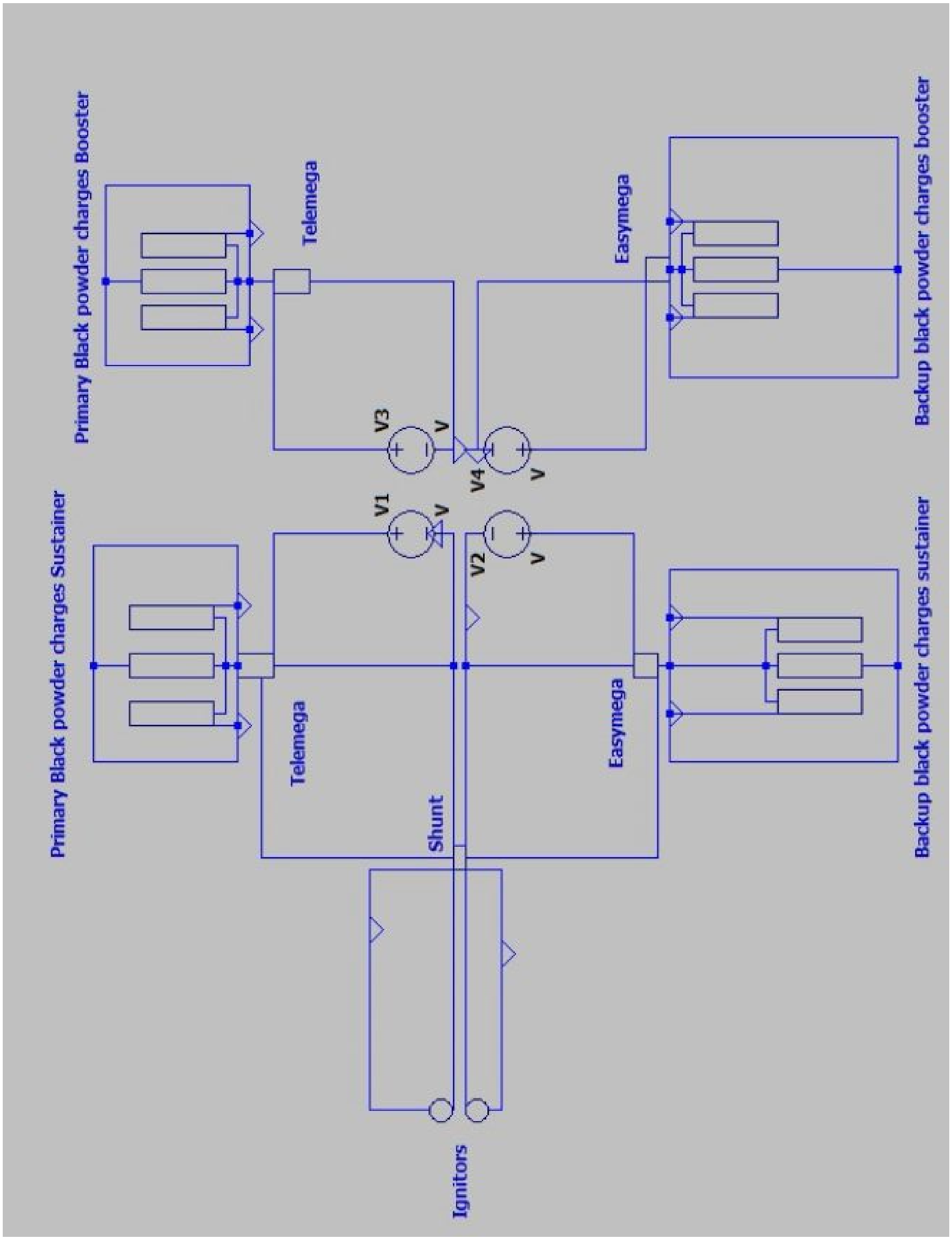


Receiving side of the shunt battery connector



The shunt card


Section view of the shunt assembly with the shunt card

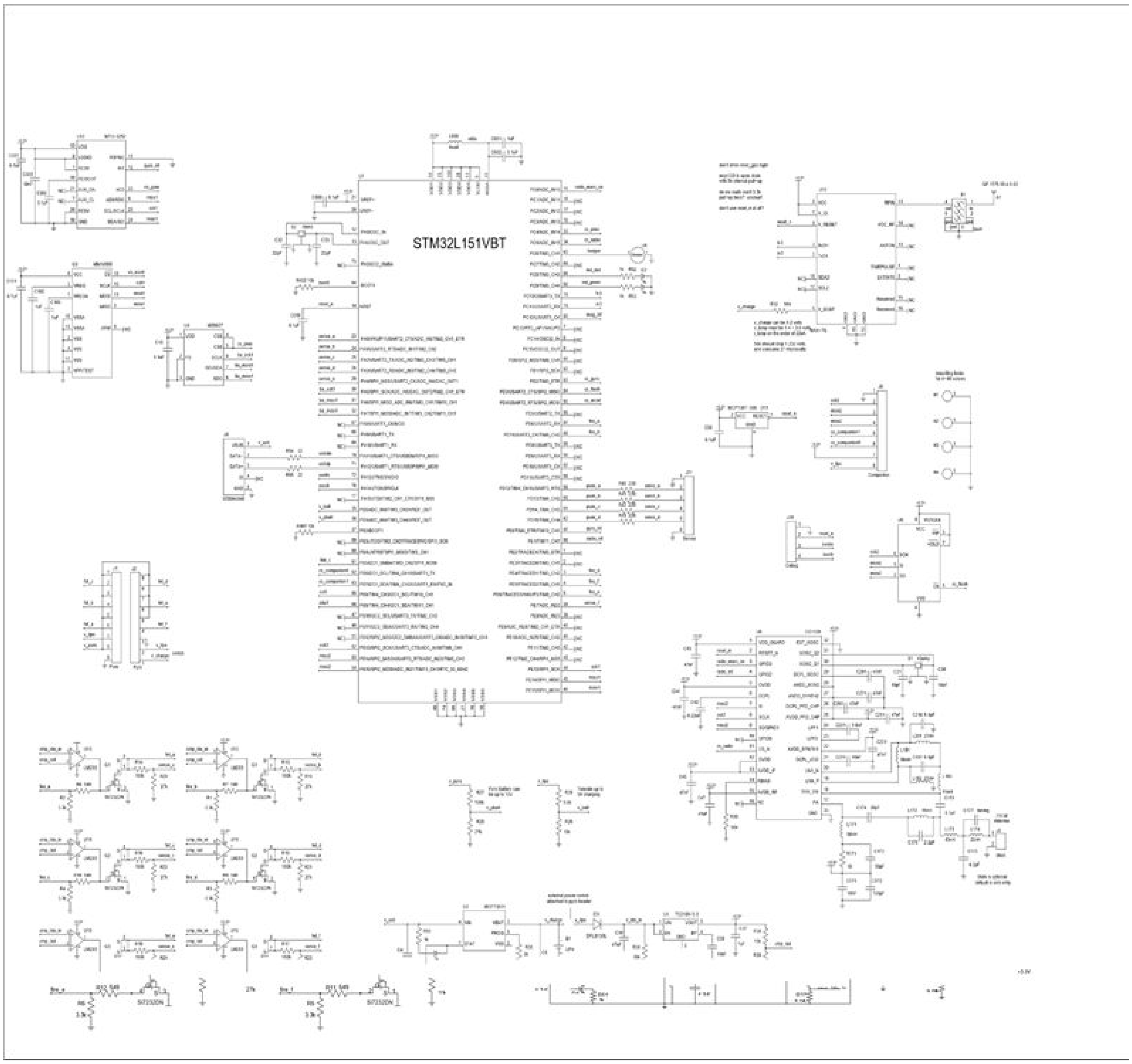


Wiring diagram

Batteries

The batteries used are manufactured by SparkFun Electronics. They are 1000 mAh, 3.7 V batteries composed of Lithium, cobalt/nickel, and have a container composed of a composite [4]. They include built-in protection against over voltage, over current, and minimum voltage.

TeleMega and EasyMega Specifications



The telemega is composed of many different electrical components so due to the complexity of it we will say it is composed of aluminum, glass fiber reinforced epoxy resin, and plastic. This is the same for the Easymega, albeit having a slightly simpler schematic without GPS capabilities [1].

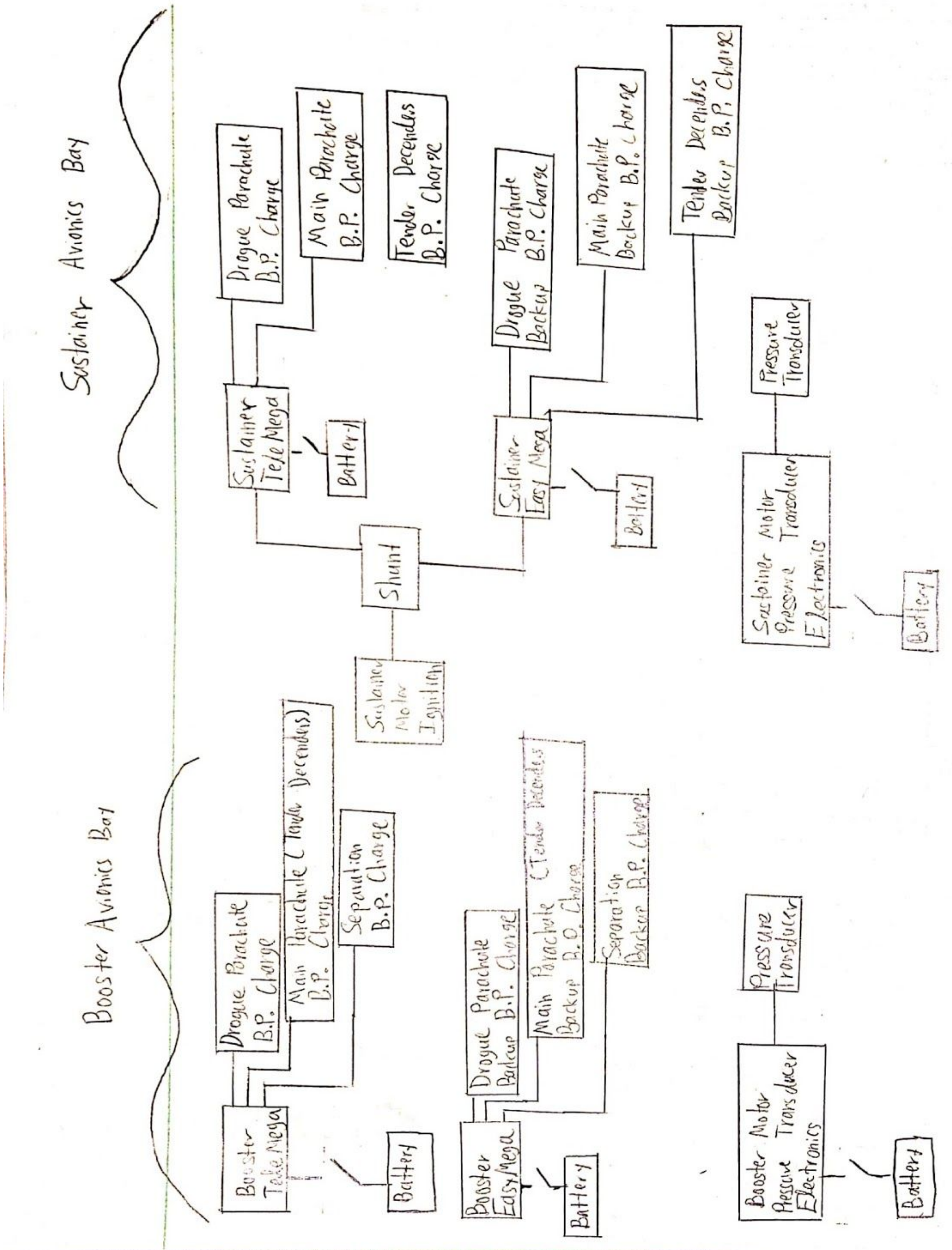
EasyMega specifications [2]:

- Recording altimeter for high power model rocketry
- Supports dual deployment and 4 additional pyro events.
  Pyro events are configurable and can be based on time and various flight events and status, including angle from vertical (for safety in staging and air start flights).
- Barometric pressure sensor good to 100k feet MSL
- 1-axis 105-g accelerometer for motor characterization
- 3-axis 16-g accelerometer for gyro calibration
- 3-axis 2000 deg/sec gyros
- 3-axis magnetic sensor
- On-board non-volatile memory for flight data storage

Telemega specifications [3]:

- Recording altimeter for high power model rocketry
- Supports dual deployment and 4 additional pyro events.
  Pyro events are configurable and can be based on time and various flight events and status, including angle from vertical (for safety in staging and air start flights).
- 70cm ham-band transceiver for telemetry downlink
- Barometric pressure sensor good to 100k feet MSL
- 1-axis 105-g accelerometer for motor characterization
- 3-axis 16-g accelerometer for gyro calibration
- 3-axis 2000 deg/sec gyros
- 3-axis magnetic sensor
- On-board, integrated GPS receiver
- On-board non-volatile memory for flight data storage

Wiring Box Diagram



Testing and Analysis

Propulsion

Testing Procedure: Snap Ring Groove Instron Test

Purpose: Ensures that the snap rings and snap ring grooves on the motor casing will be able to withstand the pressures and forces during flight

Test Equipment:

- 1 foot section of full scale sized aluminum tube with a snap ring groove machined into it.
- Round plate with a diameter equal to that of a forward enclosure.
- Flat steel plate
- Snap ring
- Instron Machine
- Safety glasses

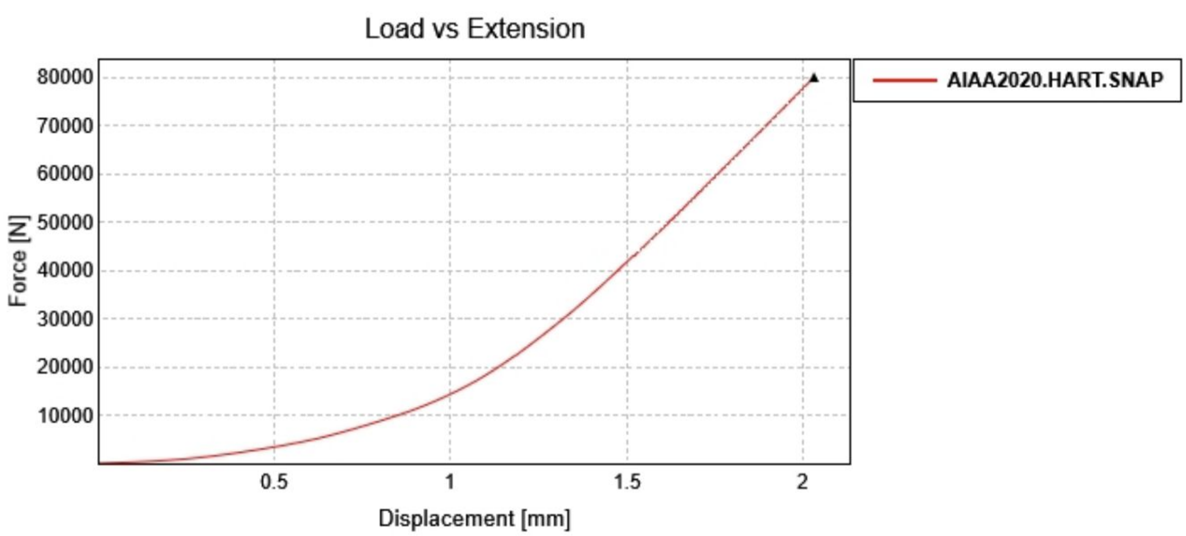
Testing Procedure:

1. Insert the snap ring into the section of aluminum tubing.
2. Insert the plate into the top side of the tubing so that the plate is flush with the snap ring.
3. Use the Instron machine to push the disc against the snap ring.
4. Increase the load and record the data until the part fails or a load of 1.5 times the expected force is reached.

Passing condition: The part successfully holds 1.5 times the expected load (10 kN) without deforming the snap-ring-groove.

Testing Result: PASS. The snap-ring-groove held a load of 80 kN without deforming or breaking.

Test Validation: The graph below shows the load vs. displacement data from the instron test. The groove did not fail nor did it show any signs of deformation.



Testing Procedure: Motor Casing Hydrostatic Testing

Purpose: Ensure the motor casing can withstand the expected pressure from the operating pressure.

Test Equipment:

- Full-scale motor casing
- Full-scale forward enclosure
- Full-scale forward enclosure with no holes in it
- Four O-rings
- Two snap rings
- Grease gun
- Water
- Dry bucket
- Safety glasses

Testing Procedure:

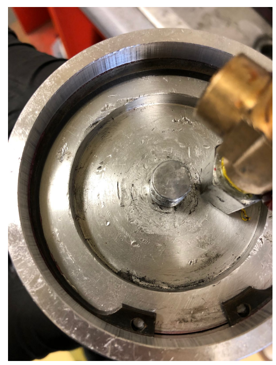
1. Ensure everyone is wearing safety glasses.
2. Place O-rings in the O-ring grooves on both forward enclosures and rub grease on the outsides of them.
3. Assemble the motor casing, using the two snap rings to hold in the two forward enclosures.
4. Fill the motor casing with water up to the threads on the actual forward enclosure.
5. Ensure that the grease gun has at least half of a container of grease.
6. Attach the grease gun to the forward enclosure.
7. Place the motor casing in the dry bucket so it is easier to observe leaks
8. Pump the grease gun until the pressure gage reads at least 1.5 times the max expected pressure.
9. Leave pressurized for 2 minutes.
10. Look over casing for any water that leaked out or any other signs of damage
11. Remove pressure valve bolt from grease gun to release pressure.
12. Remove snap-ring on one end, remove that forward enclosure, dump out grease and water, and clean up

Passing condition: The part successfully holds at least 1.5 times the needed pressure for two minutes without leaking.

Test Result: PASS. With an expected pressure of 900 psi, the casings need to withstand 1350 psi for a safety factor of 1.5. The test showed that both the booster and sustainer casings can successfully hold a pressure greater than 1350 psi for 2 minutes.

Test Validation: The first image below shows the pressure gage reading 1500 psi and the second image shows that there were no leaks after the 2 minutes were reached. These first two images are for the booster motor casing.


The next two images are for the sustainer motor casing. The first image shows the pressure gage reading 1350 psi and the second images show that there were no leaks after two minutes under pressure.



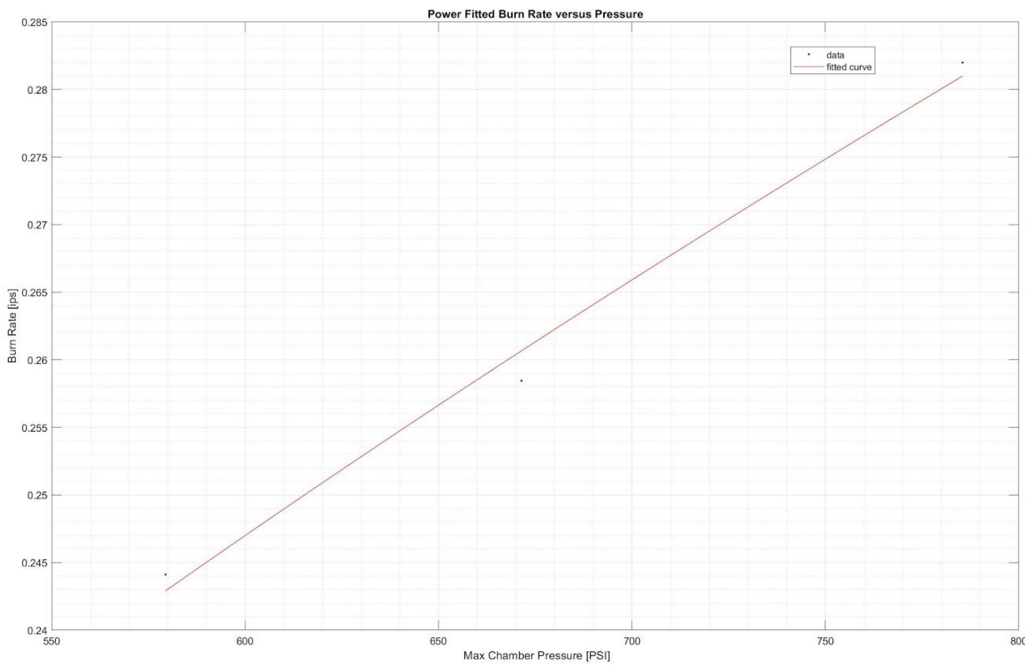
Booster Propellant Characterization

In order to characterize the booster propellant, three subscale tests were conducted. The test characteristics can be seen below.

	Throat diameter [in]	Avg.Pressure [psi]	Burn time [s]
1	0.375	579.43	1.92
2	0.368	671.44	1.81
3	0.358	785.45	1.66

The above data was used to plot a power fit curve with the following results.

a	n
0.01155	0.4788

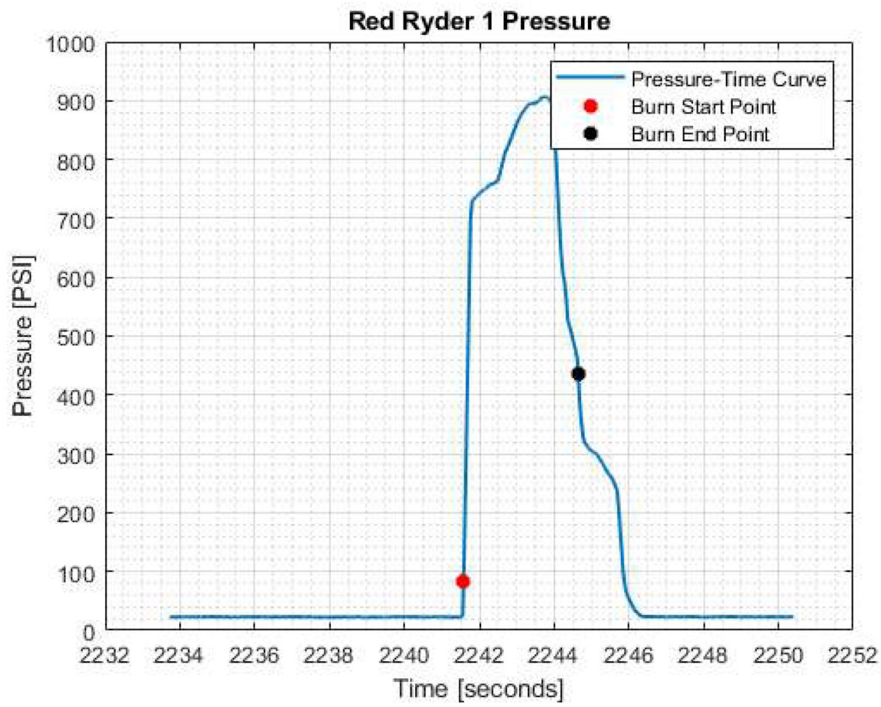


Power fit curve of Chamber Pressure vs Burn Rate

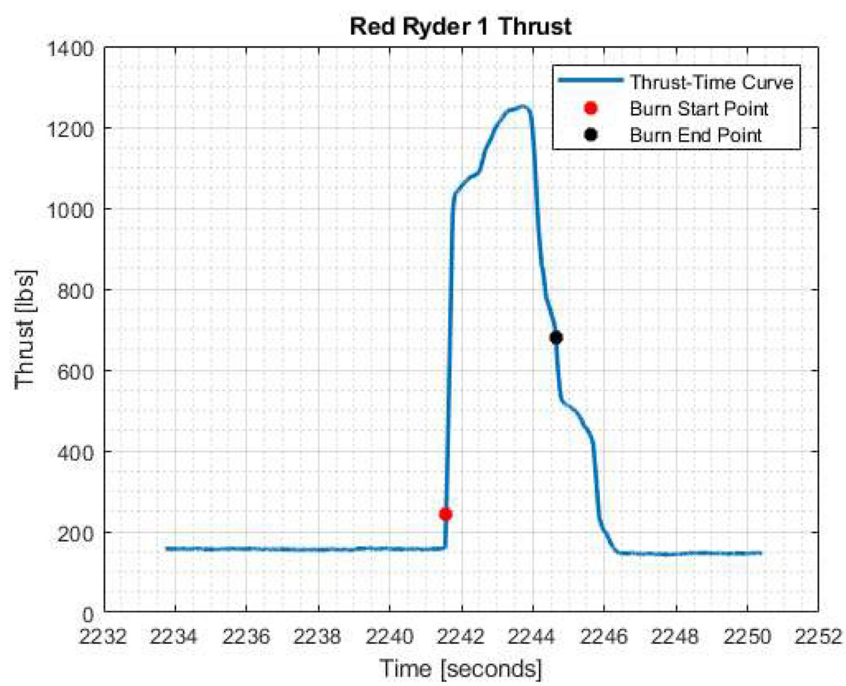
Full Scale Booster Static Fire

The data from the full scale booster motor static fire is shown in the table and graphs below.

	Booster
Max pressure	907 psi
Burn time	4.6 seconds
Nozzle throat diameter	1.05 in
Total impulse	14,027 N-s
Motor class	37% N-3262



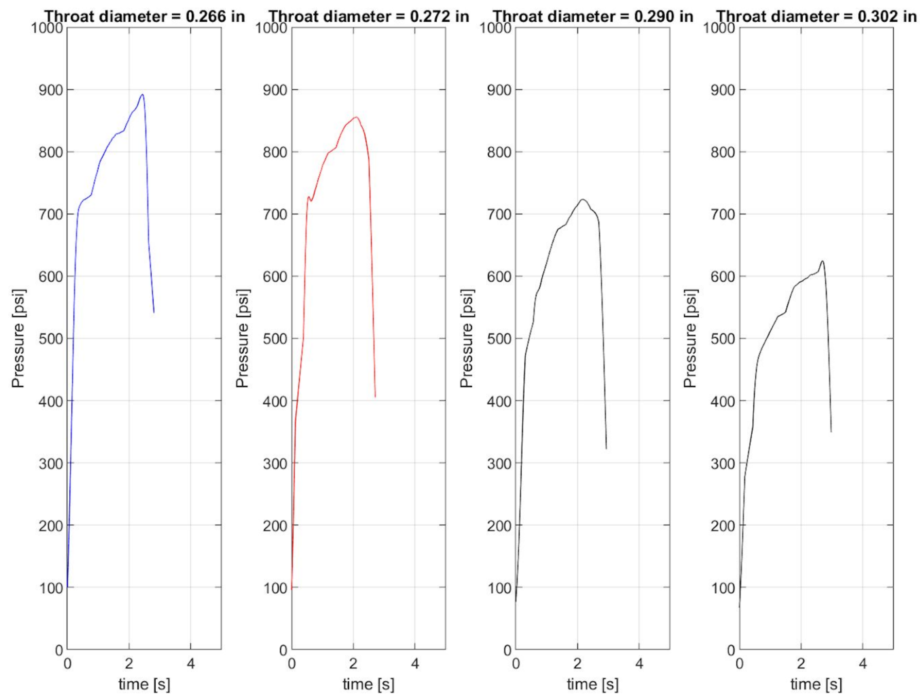
Red Ryder 1 Pressure
Pressure-Time Curve
Burn Start Point
Burn End Point
Pressure [PSI]
1000
900
800
700
600
500
400
300
200
100
0
2232
2234
2236
2238
2240
2242
2244
2246
2248
2250
2252
Time [seconds]



Red Ryder 1 Thrust
Thrust-Time Curve
Burn Start Point
Burn End Point
Thrust [lbs]
1400
1200
1000
800
600
400
200
0
2232
2234
2236
2238
2240
2242
2244
2246
2248
2250
2252
Time [seconds]

Sustainer Propellant Characterization

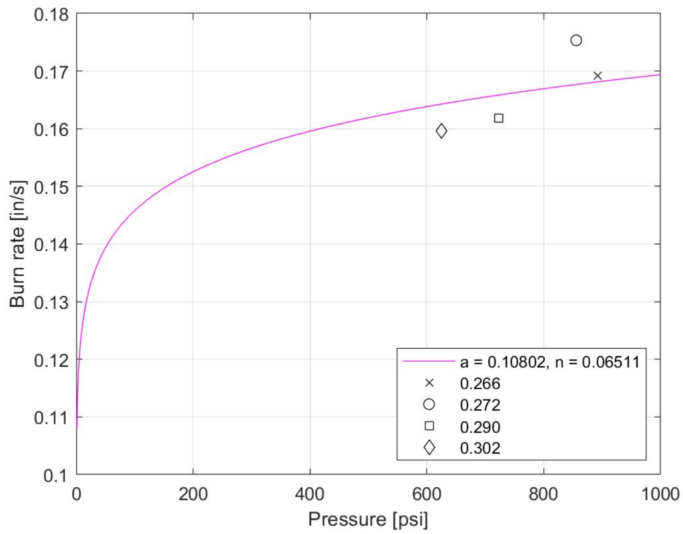
To characterize the sustainer propellant, four sub-scale static tests were conducted. The nozzle throat size of each test was different to vary pressures and burn times. The following is the static fire testing results:



	Throat diameter [in]	Max Pressure [psi]	Burn time [s]
1	0.266	892	2.81
2	0.272	865	2.71
3	0.290	723	2.93
4	0.302	624	2.98

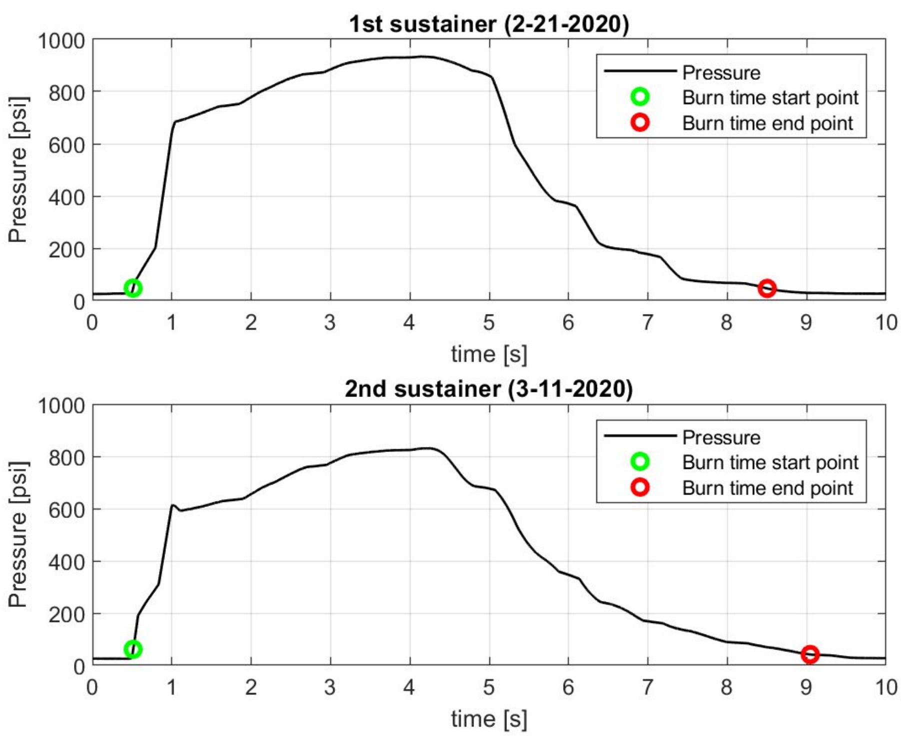
The collected pressure and burn time gave the following characteristics for the propellant:

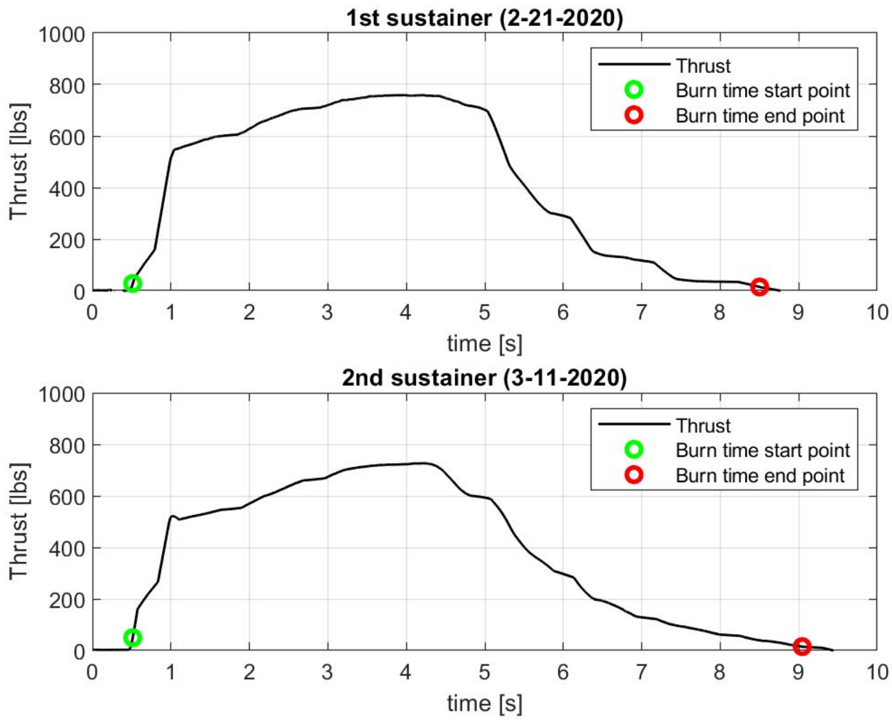
a	n
0.10802	0.06511



Full Scale Sustainer Static Fires

The following represent the results of two full-scale static fire tests for the sustainer motor. All the parameters of the motor were the same for both tests except for the nozzle throat diameter. The nozzle throat diameter was slightly increased to test how it would affect the pressure and burn rate.





	1st sustainer	2nd sustainer
Max pressure	934 psi	831 psi
Burn time	7.8 seconds	8.3 seconds
Nozzle throat diameter	0.8594 in	0.8906 in
Total impulse	15,700 N-s	15,388 N-s
Motor class	53% N-2050	49% N-1850

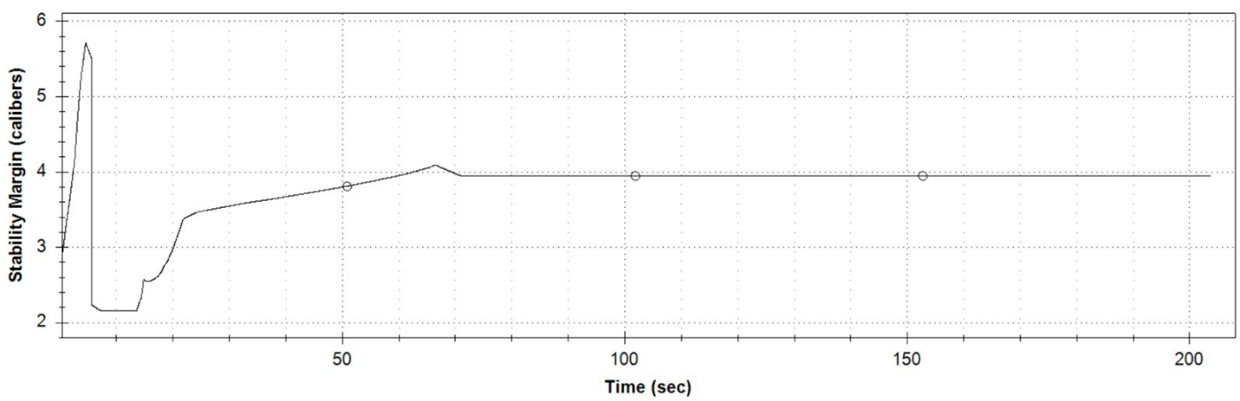
Aerodynamics and Recovery

Stability

Testing Procedure: The CP at least 2 calibers below the CG.
Purpose: Test if the rocket will be stable during flight.
Test Equipment: Laptop, calculator
Testing Procedure:

1. Use OpenRocket and RasAero II to analyze the stability.
2. Measure and weight every component on the rocket, record the data .
3. Input all measurements into the software.

Passing condition: The stability should be no less than 2.0 at any point during flight.
Testing Result: PASS. The minimum stability margin is 2.14.
Testing Validation:



Parachute Deployment

Testing Procedure: Number of parachutes successfully deployed during ground tests.
Purpose: Deploy all 4 parachutes from the rocket.
Test Equipment: Airframes, 2 main parachutes, 2 drogue parachutes, nosecone, shear pins, black powder charges
Testing Procedure:

1. Set-up fully integrated rocket in deployment test configuration.
2. Ignite nosecone separation/sustainer drogue deployment charge.
3. Verify the nosecone has separated and sustainer drogue is free of the airframe.
4. Ignite primary and backup tender descender charges.
5. Ignite sustainer main parachute deployment charge.
6. Verify the sustainer main parachute is free of the airframe.
7. Ignite booster drogue deployment charges
8. Verify booster drogue parachute is free of the airframe
9. Ignite the primary and backup tender descender charges.
10. Ignite the booster main parachute deployment charges.
11. Verify the booster main parachute is free of the airframe

Passing condition: All parachutes are pushed fully out of the airframe.

Testing Result: PASS. All 4 parachutes were ejected from the airframe.
Testing Validation:

Booster stage before deployment

Booster drogue parachute after deployment

Booster main parachute before deployment

Booster main parachute after deployment

Sustainer stage before deployment

Sustainer drogue parachute after deployment

Sustainer main parachute before deployment

Sustainer main parachute after deployment

Drogue Parachute Sizing

Testing Procedure: Terminal velocity of the booster and sustainer under the drogue parachute.
Purpose: Verify drogue parachute descent speed matches target range.
Test Equipment: Air density table, computer, Microsoft Excel
Testing Procedure:

1. Get the most up to date rocket weight
2. Look up parachute manufacturer specifications
3. Calculate the descent rate

Passing condition:

1. Booster:
    a. Maximum: 100 ft/s
2. Sustainer:
    a. Target: 100 ft/s
    b. Maximum: 125 ft/s

Testing Result: PASS.

1. Booster:
    a. 59.2 ft/s
2. Sustainer:
    a. Without propellant: 92.7 ft/s
    b. With propellant: 118.7 ft/s

Testing Validation:

Descent Rate Calculator		
term	value	unit
m =	10.65	kg
g =	9.81	m/s^2
rho =	1.007	kg/m^3
A =	0.657	m^2
Cd =	0.97	
velocity =	18.05	m/s
velocity =	59.21	ft/s

1a: Booster stage

Descent Rate Calculator		
term	value	unit
m =	11.60	kg
g =	9.81	m/s^2
rho =	1.007	kg/m^3
A =	0.292	m^2
Cd =	0.97	
velocity =	28.25	m/s
velocity =	92.69	ft/s

2a: Sustainer stage without propellant

Descent Rate Calculator		
term	value	unit
m =	19.03	kg
g =	9.81	m/s^2
rho =	1.007	kg/m^3
A =	0.292	m^2
Cd =	0.97	
velocity =	36.19	m/s
velocity =	118.73	ft/s

2b: Sustainer stage with propellant

Main Parachute Sizing

Testing Procedure: Terminal velocity of the booster and sustainer under the main parachute.
Purpose: Verify main parachute descent speed matches target range.
Test Equipment: Air density table, computer, Microsoft Excel
Testing Procedure:

1. Get the most up to date rocket weight
2. Look up parachute manufacturer specifications
3. Calculate the descent rate

Passing condition:

Booster:

1. Target: 20 ft/s
2. Maximum: 30 ft/s

Testing Result: PASS.

1. Booster:
    a. 19.2 ft/s
2. Sustainer:
    a. Without propellant: 20.0 ft/s
    b. With propellant: 25.7 ft/s

Testing Validation:

Descent Rate Calculator		
term	value	unit
m =	10.65	kg
g =	9.81	m/s^2
rho =	1.056	kg/m^3
A =	2.627	m^2
Cd =	2.2	
velocity =	5.85	m/s
velocity =	19.20	ft/s

1a: Booster stage

Descent Rate Calculator		
term	value	unit
m =	11.60	kg
g =	9.81	m/s^2
rho =	1.056	kg/m^3
A =	2.627	m^2
Cd =	2.2	
velocity =	6.11	m/s
velocity =	20.04	ft/s

2a: Sustainer stage without propellant

Descent Rate Calculator		
term	value	unit
m =	19.03	kg
g =	9.81	m/s^2
rho =	1.056	kg/m^3
A =	2.627	m^2
Cd =	2.2	
velocity =	7.82	m/s
velocity =	25.66	ft/s

2b: Sustainer stage with propellant

Structures

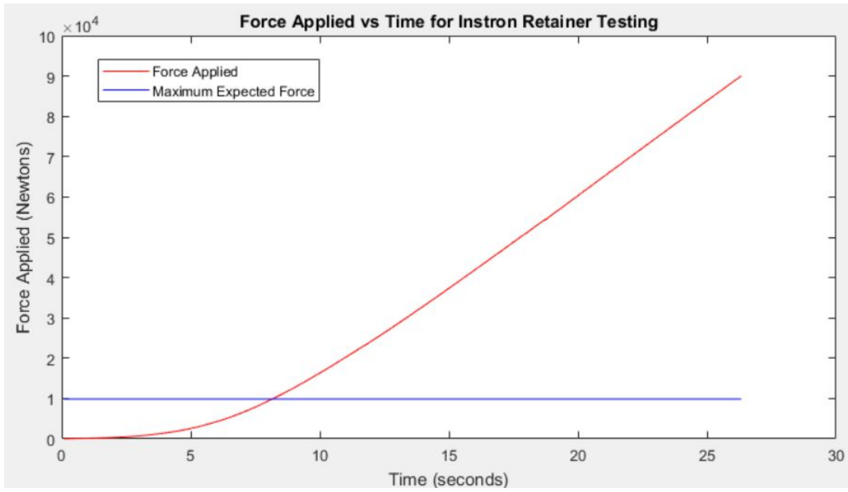
Retainer

Testing Procedure: Factor of safety of retainer under axial loading.
Purpose: Ensure the integrity of the vehicle under launch conditions.
Test Equipment: Instron
Testing Procedure:

1. Epoxy a prototype retaining ring into a fiberglass test-section of airframe.
    a. Leave a few inches of room on either side of retainer (i.e. not flush with fiberglass airframe surface)
4. Prepare an aluminum motor casing section (representative of full scale rocket motor) to press against the retainer.
    a. Motor casing section should slide easily into the airframe, up against the retainer
5. Begin Instron compression test
    a. Stop Instron test when a reduction in force is noticed in the Force vs. Displacement display of machine, or machine is maxed out to 90 kN.
6. Visually inspect retainer for damage

Passing condition: The retainer survives three times the expected loading during flight and recovery without damage to the assembly.
Testing Result: The retainer successfully met the required safety factor.
Testing Validation:

Retainer during Instron testing.



Plot showing results of the Instron test.

Fin Flutter Analysis

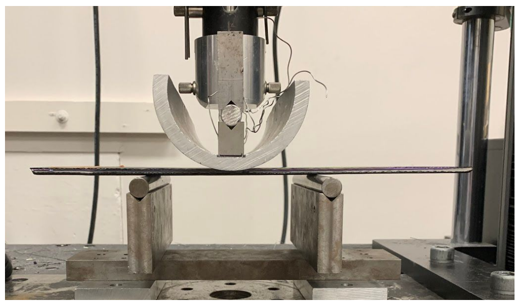
Testing Procedure: Ratio of critical flutter velocity to max flight velocity.
Purpose: Ensure the structural integrity of the vehicle under flight conditions.
Test Equipment: Matlab flutter script (based off of *Peak of Flight Newsletter, Issue: 291*, flutter boundary equation). Isentropic shear modulus of composite fin (Based off of ASTM D7250). Excel/csv output from A&R RasAero.
Testing Procedure:

1. Prepare two individual prototype fins for each fin type (i.e. booster and sustainer).
2. Perform testing called for in ASTM D7250
    a. Beginning with booster fin design, perform a mid-span loading (three point bend) test for a certain span distance (e.g. 300mm, if fin geometry is large enough).
    b. Repeat step a above, but change the span distance (e.g. 150mm).
    c. Follow the standard in selecting a variety of points in the elastic region of the Force/Displacement for both span distances.
        i. Apply the equations in the ASTM standard to find an average Shear Modulus (G) for the selected points -- take the average.
    d. Repeat steps a - c for the sustainer fin design
3. Assume both fins have their respective shear modulus yielded from steps 1 and 2.
4. Utilize the fluter boundary equation from the peak of flight newsletter, having collected an approximate shear modulus, fin geometry, and fin thickness.
    a. Iterate the flutter velocity for each data point from RasAero output.
5. For each data point, evaluate the simulated velocity divided by the approximated flutter velocity (step 4).
    a. The smallest safety factor is the one used for this analysis.

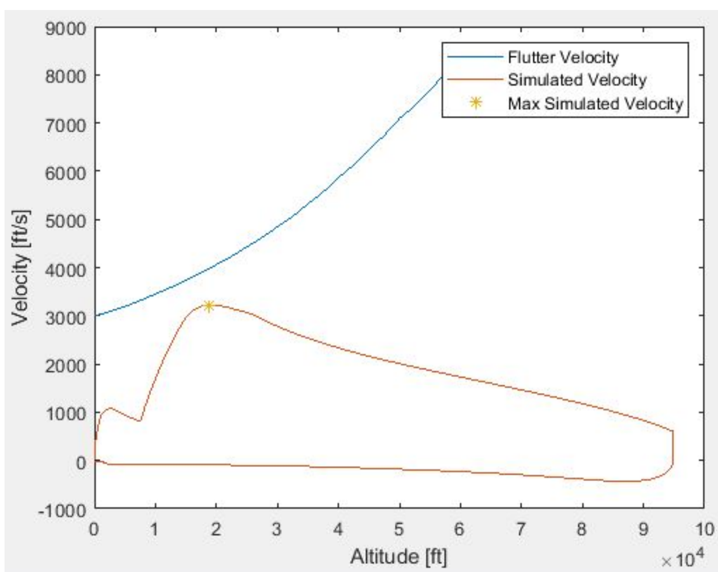
Passing condition: The estimated flutter velocity is at least 1.2 times the maximum simulated flight velocity.
Testing Result: The fin prototypes met the passing criterion. This test validated the fin designs

as being resistant to flutter. Important note: the tested carbon fiber sandwich layers were T800. The GFR composites team has made available a T700 carbon fiber weave with a higher in plane shear modulus. While the current design is validated against flutter, it is safe to assume the 'upgrade' in carbon fiber is going to effectively increase the velocity at which flutter will occur (therefore increasing the safety factor against flutter). Furthermore, with tip-to-tip layers joining the fins to the airframes, an increase in strength and rigidity not accounted for in the aforementioned fin testing, the safety factor against flutter will further be increased. Fin flutter and Instron analysis code can be found in the Appendix. Safety protocol, primarily utilizing PPE like safety glasses and only permitting a graduate student trained on the Instron to operate the machine, ensured the testing was completed in a safe manner.

Testing Validation:



Testing fixture for fin 3-point bending test.



Plot from MATLAB showing flutter velocity and maximum flight velocity.

```
The maximum dynamic pressure of a fin is 49.00 [psi] or 337.79 [kPa]
The altitude of maximum dynamic pressure is 17089.16 [feet] or 5208.78 [m]
The velocity at which max dynamic pressure occurs is 3174.18 [feet/s] or 967.49 [m/s]
The Safety Factor to Flutter is 1.2358
```

MATLAB printout showing a safety factor of approximately 1.23 for the sustainer fin design.

Booster Fin Structural Analysis

Testing Procedure: Structural factor of safety of booster fins.

Purpose: Demonstrate that the rocket's booster fins will survive the launch and recovery conditions.

Test Equipment: Impact test fixture, large rocks (representative of New Mexico launch conditions, Solidworks FEA software, isotropic material properties of booster fin, approximate maximum dynamic pressure.

Testing Procedure (A):

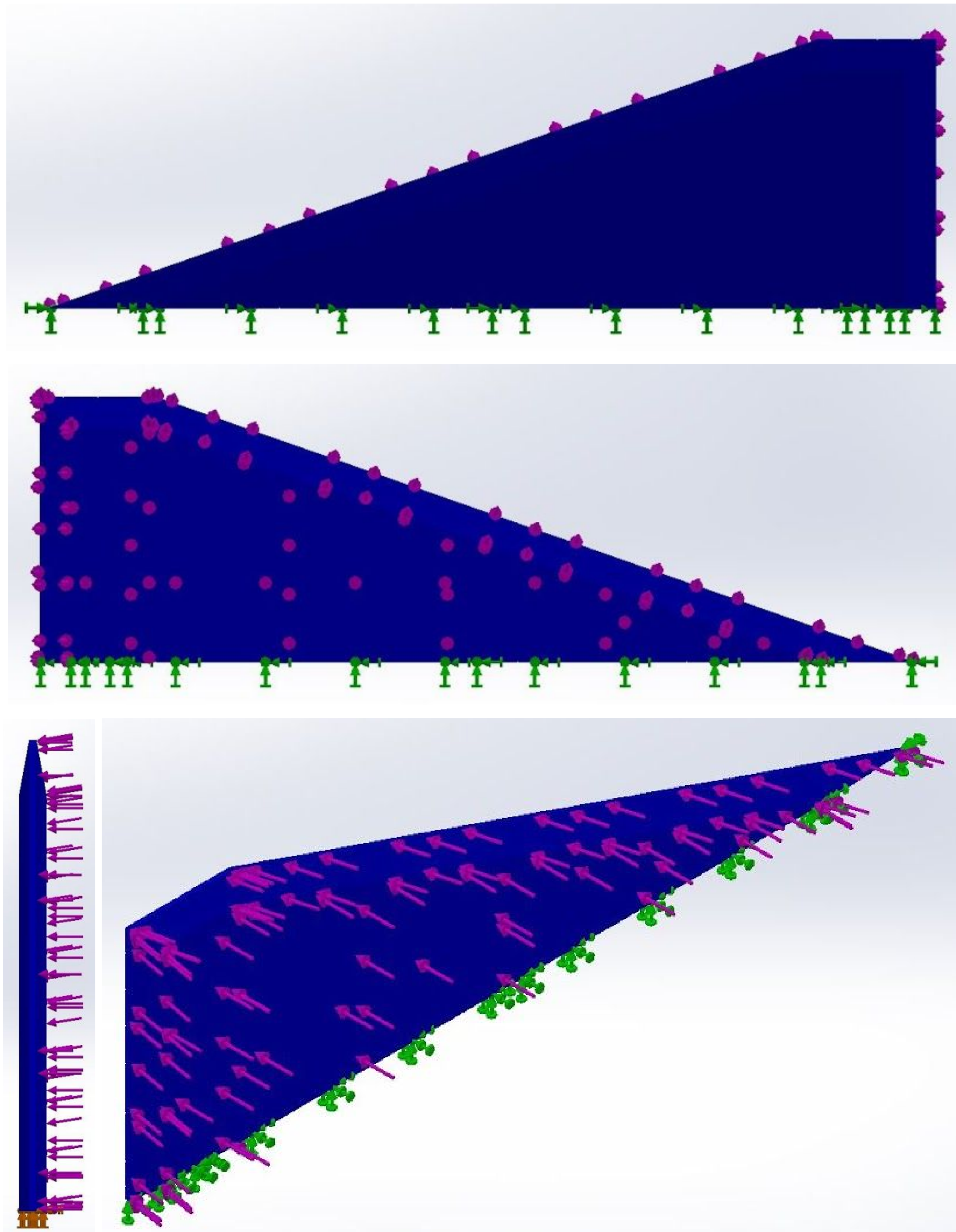
1. Generate booster fin model in Solidworks
    a. This includes the outer composite layers, core, and frame all as one component
    b. Include beveled edges (all but root cord)
    c. Assign the model the approximated shear modulus evaluated from the three-point bending testing (ASTM 7250)
2. In FEA analysis
    a. Cantilever the fin's root cord
    b. Apply a dynamic pressure or net force to one side of the fin
        i. Find this number with an estimated maximum angle of attack, and approximation for maximum dynamic pressure ($q = \frac{1}{2}(\rho)(velocity^2)$).

Passing condition (A): The booster fin will maintain a safety factor above 2 throughout the entirety of the fin.

Testing Result (A): A shear modulus of G = 433507 psi was applied to the fin model. The booster fin design maintained a factor of safety of 19 throughout the entirety of the solid model. <u>Note:</u> The booster fin FEA was simulated using the estimated maximum normal dynamic pressure against the sustainer fin. While the booster fin will not experience forces anywhere near the sustainer fin, validating it against the maximum dynamic pressure of the sustainer fin will serve as extra assurance of the structural integrity of the rocket fins. Safety protocol did not apply to this test as much as it did to the initial Instron testing.

Testing Validation (A): The booster fins maintained a minimum safety factor of 19 throughout the solid model.

Model name:BoosterFinRev4
Study name:SimulationXpress Study[-Default-]
Plot type: Factor of Safety Factor of Safety
Criterion : Max von Mises Stress
Red < FOS = 19 < Blue



Results of Solidworks stress analysis showing a
safety factor of 19 in the booster fins.

Testing Procedure (B):

1. Fill impact area with large rocks
2. Connect booster fin to the drop test rig
3. Calculate the height and mass necessary to create a scenario of 20 ft/s at impact
4. Add necessary weight and raise to necessary height
5. Release the rig and allow the fin to fall directly onto the impact area
6. Inspect the fin for damage

Passing condition (B): The booster fin will handle the anticipated kinetic energy upon landing.

Testing Result (B): The maximum anticipated landing velocity of the booster is 18.84 ft/s with a weight of 25.45 lb; this results in a kinetic energy of 190 J. To simulate this kinetic energy, a weight of 60 lb was added to the drop fixture and the fin was raised 7’ 1.5” off the ground and dropped; the minimum drop height required was 2’ 3”. The fin fell directly onto a mixture of gravel and medium sized rocks and showed only small scrapes and no structural damage. The booster fin passed this testing procedure.

Testing Validation (B):

Impact test fixture and fin landing area conditions.

Booster fin drop height and results after landing.

Sustainer Fin Structural Analysis

Testing Procedure: Structural factor of safety of sustainer fins.

Purpose: Demonstrate that the rocket's sustainer fins will survive the launch and recovery conditions.

Test Equipment: Solidworks FEA software, isotropic material properties of sustainer fin, approximate maximum dynamic pressure.

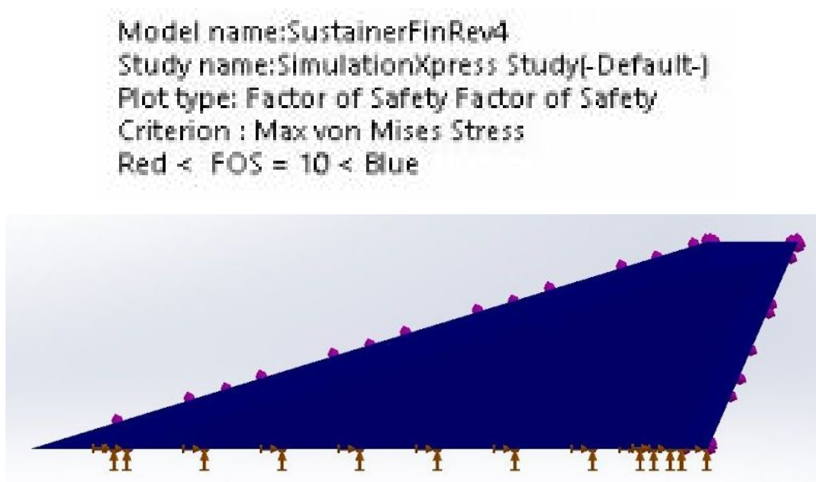
Testing Procedure (A):

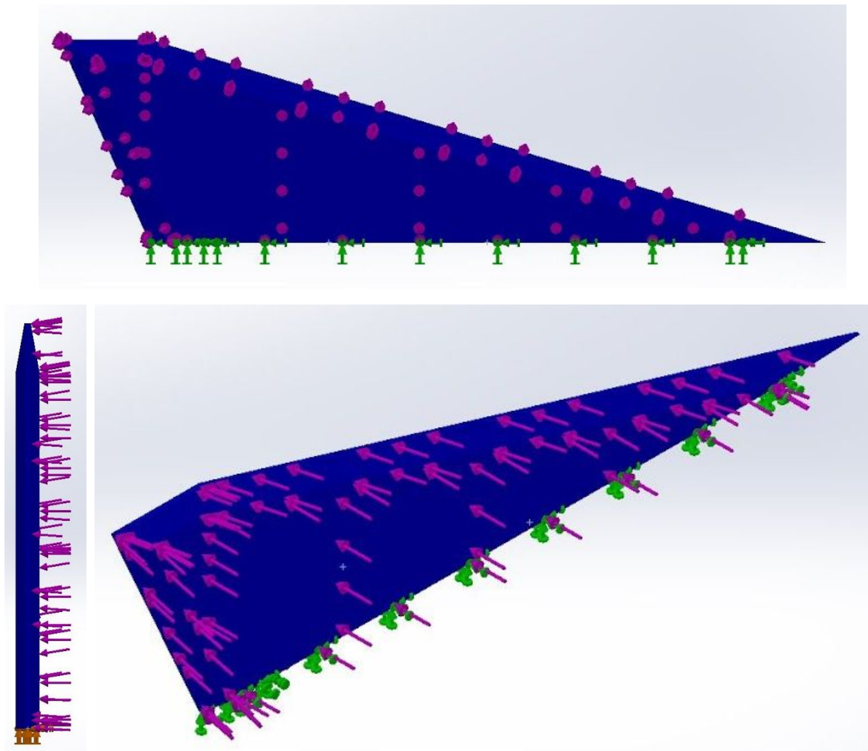
1. Generate sustainer fin model in Solidworks
    a. This includes the outer composite layers, core, and frame all as one component
    b. Include beveled edges (all but root cord)
    c. Assign the model the approximated shear modulus evaluated from the three-point bending testing (ASTM 7250)
2. In FEA analysis
    a. Cantilever the fin's root cord
    b. Apply a dynamic pressure or net force to one side of the fin
        i. Find this number with an estimated maximum angle of attack, and approximation for maximum dynamic pressure (q = ½(rho)(velocity^2)).

Passing condition (A): The sustainer fin will maintain a safety factor above 2 throughout the entirety of the fin.

Testing Result (A): A shear modulus of G = 433507 psi was applied to the fin model. The fin maintained a minimum factor of safety of 10 throughout its body. Safety protocol did not apply to this test as much as it did to the initial Instron testing.

Testing Validation (A): The sustainer fin maintained a safety factor of 10 throughout the entirety of its solid model.





Results of Solidworks stress analysis showing a safety factor of 19 in the sustainer fins.

Testing Procedure (B):

7. Fill impact area with large rocks
8. Connect booster fin to the drop test rig
9. Calculate the height and mass necessary to create a scenario of 20 ft/s at impact
10. Add necessary weight and raise to necessary height
11. Release the rig and allow the fin to fall directly onto the impact area
12. Inspect the fin for damage

Passing condition (B): The booster fin will handle the anticipated kinetic energy upon landing.

Testing Result (B): The maximum anticipated landing velocity of the sustainer is 24.84 ft/s with a weight of 44.26 lb; this results in a kinetic energy of 575 J. To simulate this kinetic energy, a weight of 62 lb was added to the drop fixture and the fin was raised 6’ 10” off the ground and dropped. The fin fell directly onto a mixture of gravel and medium sized rocks and showed only small scrapes and no structural damage. The sustainer fin passed this testing procedure.

Testing Validation (B): This test used the same fixture setup shown in Figure 5.2.13.4.

Sustainer fin drop height and results after landing.

Nosecone

Testing Procedure: Factor of safety of nosecone to aerodynamic loading scenario
Purpose: Demonstrate the rocket's nose cone to withstand max flight conditions, deployment events, and landing.
Test Equipment: Instron Machine, Solidworks FEA, Autodesk Helius Composite
Testing Procedures:

Tensile test ASTM Standard

1. Generate a rectangular coupon section of the nosecone laminate (follow composite manufacturing procedure)
2. Cure coupon in the oven following carbon fiber curing methods
3. Instron tensile test to determine yield stress, ultimate tensile strength, elastic modulus, and strain. Pull to failure or 30 kN

Compression test ASTM Standard

1. Generate a square coupon section of the nosecone laminate (follow composite manufacturing procedure)
2. Sandwich ends of coupon between 2 aluminum tabs, held in with adhesive
3. Cure adhesive in the oven (follow oven curing specifications)
4. Instron compressive test to determine critical buckling load or delamination.

Passing condition: Instron Data compared to FEA and Helius Composite generates a F.o.S. greater than 1.5.
Testing results: Three samples were tested in the instron machine under tensile loading. Each tensile sample withstood loads up to 15 kN of force. The tensile data revealed an average yield stress around 150 MPa and an ultimate tensile strength of around 450 MPa. The fiberglass has an average Elastic modulus of around 77 GPa and the carbon fiber is up at 140 GPa. This was determined through the average and the maximum values of elastic modulus. Three samples were tested in the instron machine for compression. Unfortunately, the samples were warped when the coupons were cut to size. It was also determined that a different compression test could be implemented

where the compressive sample is a tube rather than a coupon shape. The compression test is not necessary for engineering specification pass or fail justification.

Testing validation: Through analysis of the testing data, the nose cone maintained a F.o.S around 15 as determined from Solidworks FEA. Analysis through Autodesk Helius Composite determined the F.o.S to be a valid system to measure the strength of the nose cone. Through tensile testing, it can be determined that the nose cone will PASS the predefined engineering specification.

Instron tensile test of nose cone coupon

Airframe

Testing Procedure: Factor of safety of airframes to aerodynamic loading scenario

Purpose: Ensure the airframe will not buckle or fail due to the compressive axial loads experienced during flight.

ES Addressed: 13 (Components must be designed to tolerate launch conditions and recovery.)

Test Equipment: Instron, Dremel

Testing Procedure:

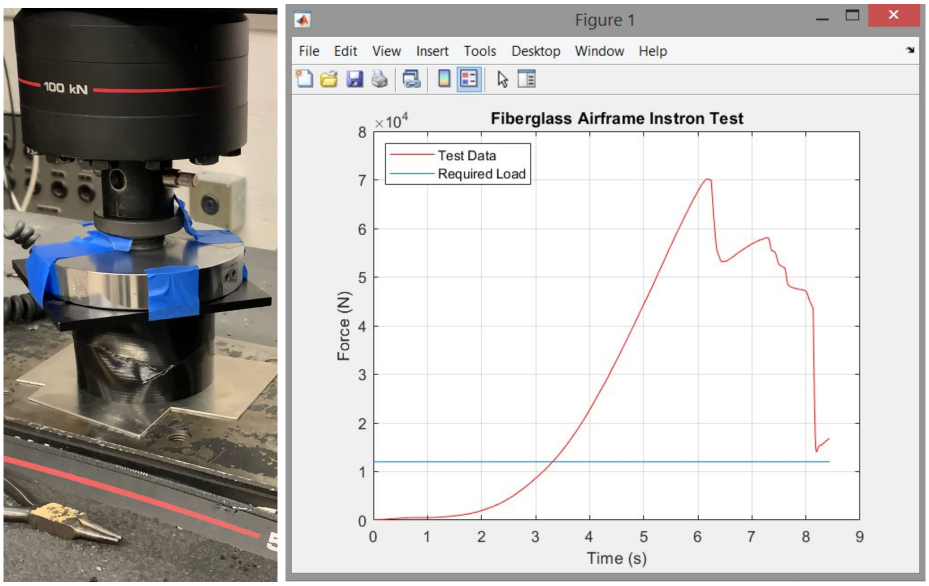
1. Cut a 3” long section of fiberglass airframe.
2. Only run the instron with a qualified individual present.

3. Position the section of fiberglass airframe between the two flat plates on the instron.
4. Activate the Instron and apply an increasing compressive load until failure.

Passing condition: The airframe sample does not fail until the compressive load applied is at least 2 times greater than the expected loads during flight (6000 N).

Recorded Condition: PASS. Factor of safety of 11.70 (70,213 N)

Testing Evidence: Instron compressive testing showed the sample will survive flight.



Instron compression data of the fiberglass airframe section.

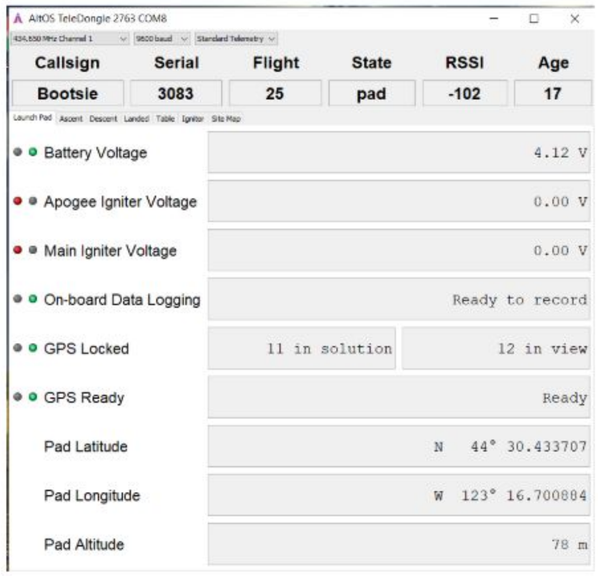
Avionics

Telemetry

Testing Procedure: The number of different data points the vehicle can transmit will be 6.
Passing condition: At least six data points are received.
Recorded Condition: PASS. 8
Testing Evidence: Software readout showing data points transmitted.

Data points (**8**):

- *Global position*
- *Pad Altitude*
- *Continuity*
- *Voltage Connections*
- *GPS status*
- *State*
- *RSSI*
- *Pressure*



Testing Procedure: The frequency of data transmission will be 5/sec.
Passing condition: The rate of data transmissions is greater than or equal to 5 per second
Recorded Condition: PASS. 6.25/sec
Testing Evidence: Software readouts and calculations of the data transmission rate.

Knowns:

- *Baud rate of data transmission for telemega = 9600 baud*
- *Size of each data point = 32 bytes*
- *Bytes/s = Baud rate * n (n=8)*
- *Frequency = (bytes/s)/(6*size)*

Equations:

- *1200(Bytes/s)=9600 Baud / 8 (Baud*s/(Bytes))*
- *Frequency = (1200 bytes/s)/(6*32 bytes) =* ***6.25/s***

Table 10. Data Storage on Altus Metrum altimeters

Device	Bytes per Sample	Total Storage	Minutes at Full Rate
TeleMetrum v1.0	8	1MB	20
TeleMetrum v1.1 v1.2	8	2MB	40
TeleMetrum v2.0	16	8MB	80
TeleMetrum v3.0	16	8MB	80
TeleMini v1.0	2	5kB	4
TeleMini v3.0	16	512kB	5
EasyMini	16	1MB	10
TeleMega	32	8MB	40
EasyMega	32	8MB	40

AV Bay Structure

Testing Procedure: The avionics bay will be able to withstand a pressure of 30 psi.
Purpose: Ensure that avionics bays can withstand the pressure generated by separation and deployment charges.
Test Equipment: 2 X 4 in diameter by 0.188 in thick G10 fiberglass
Testing Procedure:

1. Integrate the forward bulkhead into the testing airframe.
2. Place a 4 gram black powder charge on top of the bulkhead (4 grams of black powder creates more than 30 psi (as discovered by the aerodynamics and recovery sub-team)
3. Integrate the rest of the recovery system above the black powder charge
4. Detonate black powder charge and document damage done to bulkhead

Passing condition: No visible damage or deformation to the forward bulkhead.
Alternate Testing Procedure:

1. Integrate rocket as normal
2. Detonate surgical tubing black powder charge to generate at least 44.7 psi

Alternate Passing condition: No visible damage
Recorded Condition: PASS. No deformation or damage to the forward bulkhead, as seen from photos below
Testing Evidence:

Ignition Shunt

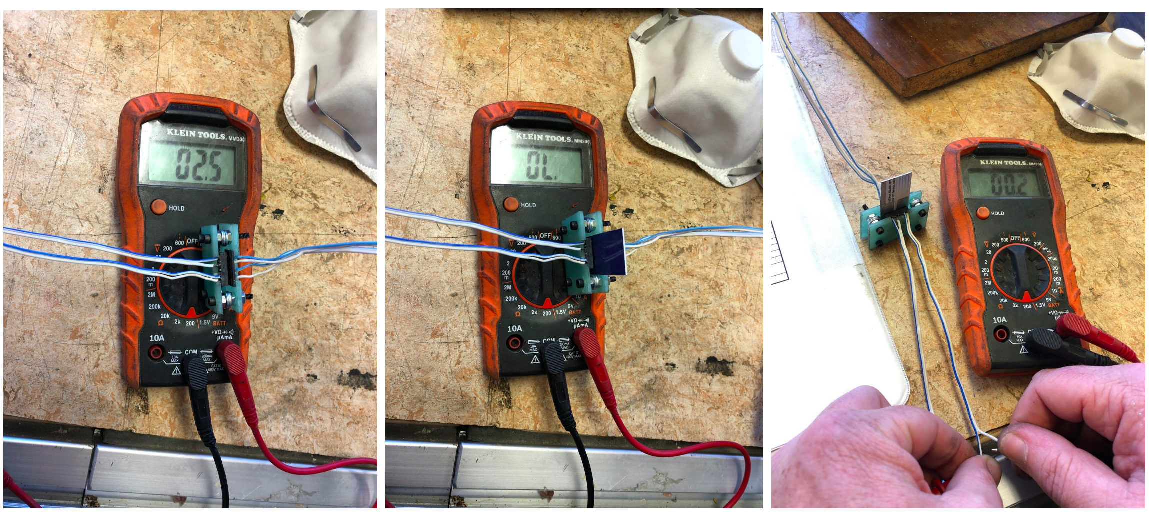
Testing Procedure: The measured current flowing to the upper stage e-match with shunt installed.
Purpose: Ensure the shunt reduces current flow to the ignitor below the current required for ignition
Test Equipment: Avionics bay with shunt assembly, 3.4 V Li-Po battery, multimeter, e-match, Telemega, tele-dongle, laptop with Alt OS installed.
Testing Procedure:

1. Turn on Telemega and connect any pyro channel to the shunt assembly with shunt installed.
2. Connect multimeter to shunted side of shunt assembly
3. Using Alt OS on the laptop, fire the channel that is attached to the shunt.
4. Record the maximum current reading while channel is being fired
5. Connect e-match to the shunted side of assembly.
6. Place e-match behind a barrier and at a safe distance from any people of flammable materials.
7. Using Alt OS on the laptop, fire the channel that is attached to the shunt.
8. Check to see if the e-match ignited.

Passing condition: measured current is no more than 75% of the listed current to fire the e-match and the e-match did not ignite.

Recorded Condition: PASS. Zero load across shunt with card inserted

Testing Evidence: Pictures below (First: resistance with shunt card removed; Second: zero load with shunt card inserted; Third: resistance across short created by shunt)



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[1] B. Garbee, K. Packard, B. Finch, and A. Towns, “The Altus Metrum System: An Owner’s Manual f2or Altus Metrum Rocketry Electronics,” Altus Metrum.

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