Texas Tech University – Space Raiders

Flight Readiness Review 2017 – 2018

Space Raiders

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1. Summary

Team Name: Space Raiders
Team Address: 3710 Erskine St. Apt 336, Lubbock, TX 79415
Mentor/Certification Level: Bill Balash/TRA-L3
Educator/Certification Level: Barre Wheatley/TRA-L3
Director: Davis Hall

1.1 Team Summary

Vehicle Team:

- Edward Hieb: Vehicle Team Lead
- Reid Yentzen: Team Member
- Daniel Lee: Team Member
- Hans Teilmann: Team Member
- Hector Ruiz: Team Member

Recovery Team:

- Matt Rowe: Recovery Team Lead
- Jericho Rosas: Team Member
- Braden Nelson: Team Member

Payload Team:

- Jacob Hinojos: Payload Team Lead
- Tyler Eyre: Team Member
- David Hilbun: Team Member
- Hance Clark: Team Member
- Jacob Steckbeck: Team Member

Safety Team:

- Derrick Slatton: Safety Team Lead
- Brianna Mares: Team Member
- Zoe Smith: Team Member

Special Thanks:

- Fred Schneider
- Bill Balah
- Barre Wheatly

Fig 1-1 Fred helping us repair our airframe

1.2 Launch Vehicle Summary

- Size and Mass: 6 inch Diameter | 44lbs | 10.37 feet
- Launch Day Motor: Cesaroni L1395-BS
- Recovery System: 16 foot Main | 2 foot Drogue
- Rail Size: 1515 | 12 feet

1.3 Payload Summary

Payload Title: Rover R.I.C.K.

Payload Description

- Upon vehicle landing, a rover containing solar panels will be deployed from the separated nose cone. In order to ensure that our payload will exit the rocket in a correct orientation, the rover will be housed in a bearing housing that will allow the rover to exit in an upright position. The rover will use an ultrasonic guidance system to avoid obstacles.
- Nose separation charges will separate the nose cone from the rest of the rocket body.
- The pins holding the bearing housing fixed will release and the housing will rotate to orient the rover in an upright position.
- The rover will then deploy from the vehicle and travel a distance of at least 5 feet.

2. Changes Since PDR

2.1 Vehicle Changes

Reinforced Phenolic Airframe Payload and E-Bay

The airframe will be getting upgraded with a carbon fiber and kevlar composite wrapped phenolic tube to allow larger charges without allowing catastrophic failure during separation that occurred during testing. This change resulted in a slight increase in length.

Polycarbonate Nose Cone

The design of the nose cone is only going to change with respect to the material selection. Selecting polycarbonate for the replacement nose cone was decided based off the readily available filament material and it will provide higher impact and flexural strength compared to the originally proposed ABS filament.

2.2 Recovery Changes

Ejection Charge resizing

After testing the different sections we realized that our previous ejection charge estimations were off so these charge amounts have since been reduced to ensure the safety of the rocket.

Nose Cone Attachment

The full-scale test brought up the issue of how the nosecone was attached and we will be moving up to 6 nylon shear pins to 8-32.

Black Powder Charge Wiring

As requested we have revisited the wiring of our ejection charges and refrained from using a cluster of charges and will be using black powder packed into the finger of a Nitril glove.

Eyebolt Concerns

As per requested, we will be welding our eye bolts shut to ensure they do not open when the parachute is deployed. We will also be going with the next size up due to yielding during the full scale test.

Pilot Parachute

We have added a pilot parachute connected to the top of the main parachute to aid in successful deployment of the main parachute.

Higher Deployment Apogee

We will be deploying our main parachute at 1000 feet instead of 800 feet to help give the main parachute more time to fully deploy as it comes out of the deployment bag.

Shock Cord Revision

We will be using two separate shock cords spliced together with a quick link to achieve the 40 feet length that was decided on during the Critical Design Review.

Bundle Sizes

We are increasing the amount of material used to bundle the main shock cord to help reduce the amount of forcing traveling through the vehicle.

Bulkhead Material Selection

We are having to rebuild certain bulkheads due to damage during testing and will be making them thicker or out of G10 fiberglass were they will see substantially higher pressure.

2.3 Payload Changes

Axles changed from smooth pins to threaded screw design.

Motor mounting method reversed based on received parts

Radio transmissions now occur in series based on received parts

Decreased number of solar panels based on received parts

Bayonet joint changed to winch style wire to pull the bearing pin

Servo mounted on bayonet bearing instead of back plate

Used threaded fasteners for counterweight and housing to prevent failure of connections

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

As the project evolves, so does the complexity of problems at hand. The design has undergone continuous evolution, with optimization every step of the way. The goal is to develop a reusable, modular launch vehicle, that will allow integration of various mission-specific payloads and the TTU Space Raiders team has been working around the clock to make this goal into a reality.

3.1.1 Addressing the Changes

The design of the rocket stayed primarily the same except for a few key changes. We have made changes to the E-bay, nose cone, and also to a section of the rocket to address safety issues that arose during both ground and flight testing.

3.1.1.1 Nose Cone

Due to issues with the full-scale flight, there is a need to fabricate a replacement nose cone with a stronger polycarbonate additional details analyzing alternate materials and issue propagation are outlined below.

Why this change is necessary- During our test launch the shear pins failed when the main parachute deployed, opened, and the cord pulled tight. According to data, the vehicle in this moment pulled approximately 60 G's and the shear pins failed causing the nose cone to fall approximately 600 feet and subsequently causing the nose cone to crack along lamination lines in the 3D print. The print cracked in two places and separated into four pieces. Because of these cracks in the lamination we are sourcing a lab to print this material. We own the material and we are searching for a lab to assist us in printing the nose cone with the polycarbonate material. If we can not find a lab to assist with printing this material we will result back to ABS.

Materials comparison between ABS and Polycarbonate- Polycarbonate material compared to our current ABS material nose cone has about a three times higher impact strength than ABS (15.0ft-lbs/in compared to ABS' 5.51ft-lbs/in) and polycarbonate has a tensile strength of 8500psi compared to ABS tensile strength 6500psi. The ABS mechanical properties table from the data sheet and the polycarbonate mechanical properties table from the data sheet are both placed below. The ABS data sheet is the table directly below this and the polycarbonate data sheet is below that.

ABS Data Sheet:

Mechanical Properties		
Hardness, Rockwell R	103 - 112	103 - 112
Tensile Strength, Yield	42.5 - 44.8 MPa	6160 - 6500 psi
Elongation at Break	23 - 25 %	23 - 25 %
Flexural Modulus	2.25 - 2.28 GPa	326 - 331 ksi
Flexural Yield Strength	60.6 - 73.1 MPa	8790 - 10600 psi
Izod Impact, Notched	2.46 - 2.94 J/cm	4.61 - 5.51 ft-lb/in

Fig 3-1

Polycarbonate Data Sheet:

MECHANICAL		
Impact Strength, Izod		
notched 1/8 in (3.2 mm) section	15.0 ft-lbs/in	801 J/m
unnotched 1/8 in (3.2 mm) section	No Break	No Break
Tensile Strength	8500 psi	59 MPa
Tensile Elongation	> 10.0 %	> 10.0 %
Tensile Modulus	0.32 x 10^6 psi	2206 MPa
Flexural Strength	13500 psi	93 MPa
Flexural Modulus	0.34 x 10^6 psi	2344 MPa

Fig 3-2

3.1.1.2 Sections of Airframe

We replaced the section of airframe that is directly associated with the main parachute bay of the rocket due to the testing failure (explained in further depth in the Testing section) and are in the process of replacing the payload bay with the new airframe.

E-bay - We added six inches of length to the E-bay to increase the volume of the parachute bay. It is hypothesized that the reason of our black powder testing failure was due to the lack of space in the parachute bay, resulting in a failure in our blue tube. To avoid this problem in the future, we added six inches of airframe to the E-bay section. The CDR length of the E-bay was 24 inches and now it is currently 30 inches. This allows a level of convenience in space and safety to the vehicle and any team member with hands in this vicinity.

Why this change is necessary - Because of the testing failure resulting in the destruction of the parachute bay and the fact we didn't have a replacement Blue Tube we had to search and find a replacement tube very fast. We happened to find a six-inch tube on campus that we could use. It is a phenolic tube coated in a layer of carbon fiber and outside of that there is a Kevlar sock over resulting in a much stronger tube. A stronger airframe in this area of the rocket is necessary because we learned in the test launch that our shear pins failed in the payload area during main parachute ejection. We will need larger shear pins (and therefore more black powder in order to purposefully fail said shear pins) that will not fail when encountering the G forces of the main parachute opening but instead fail on the ground allowing the rover to exit the rocket. This new section of airframe will allow larger shear pins and a larger amount of black powder to be utilized without having to risk airframe failure upon black powder charge ignition. The new section of tube is shown below with a diagram explaining the layers of the tube. This new section of airframe is monumental to the success of our flight.

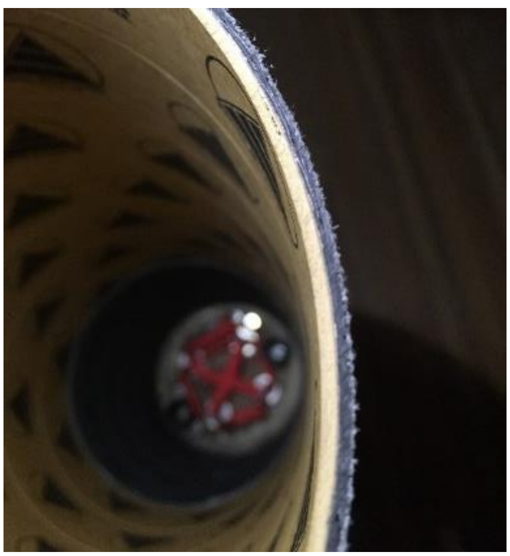
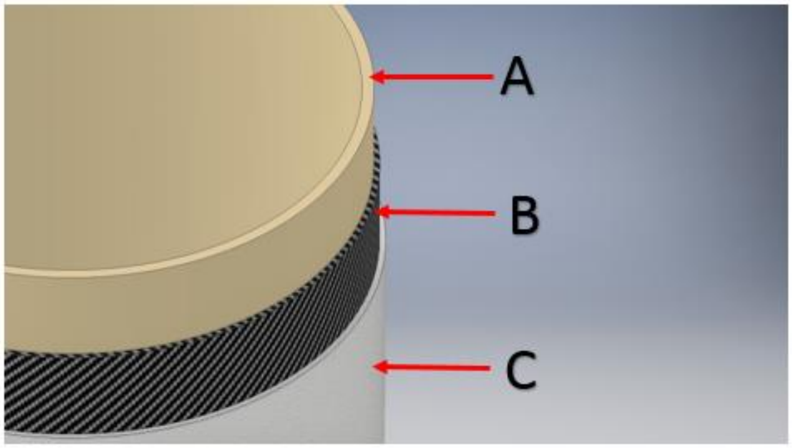


Fig 3-3 Top view picture of the wall of the new section of airframe.



A: Phenolic
B: Carbon Fiber
C: Kevlar

Fig 3-4

In this diagram of the new section of airframe, each- layer is imagined to be peeled back to see the underlying layer. The layer labeled, “A”, is the base phenolic tube that is a 6-inch diameter tube. The layer labeled, “B”, is a small layer of carbon fiber which is wrapped around the phenolic tubing, making it more resilient to shattering and cracking. The layer labeled, “C”, is a Kevlar sock wrap that goes over both layers, “A”, and “C”. All of these layers combined create a much stronger tube that is more resistant to shattering and cracking.

3.2 Key Elements for Launch and Recovery

The key elements for launch and recovery have been broken down into two different sections: Structural and Electrical elements. Components that play a contributing role in these topics are discussed in detail in the following section.

3.2.1 Structural Elements

Eyebolts: Eyebolts are one of the keys to the recovery of our rocket. They connect the drogue and main parachute to the main airframe via bulkheads. After our test launch we realized the eyebolts that the drogue parachute had attached to had yielded slightly and we realized we needed to increase the size of the eye bolts slightly. They were one-quarter inch eye bolts and we are increasing them to three-eight inch eye bolts to ensure that this doesn’t happen again. Even though the eye bolts didn’t fail we want full rocket reusability and we don’t want any yielding that could lead to failure. These eyebolts help to ensure a safe recovery of our rocket.

Bulkheads: Bulkheads are vital to the recovery of our rocket and the safety of the launch. Bulkheads are the attachment of the eyebolts, and parachutes to the airframe. We have several different bulkhead types listed in the section 3.2.2.

Motor Mount System: The motor mount system is integral to the safety of the launch, the people in the vicinity of the launch, and recovery of the vehicle. It allows the energy of the motor to be placed not inside of the rocket onto bulkheads but instead on the actual airframe of the rocket making it much more reliable and safe during the launching and recovering process. This motor mount system that we have also doesn't allow the motor to fall out of the rear of the rocket when parachutes deploy ensuring the safety of the people around the launch site, the recovery of the rocket and the reusability of the rocket. If you would like to see the diagram of the motor mounting system, look to section 3.2.2.

Centering Rings: The centering rings are crucial to the safety and success of the launch. The centering rings are present to ensure that there is no side to side movement of the motor. This is to ensure a flight that is completely vertical in terms of the motor (not factoring in wind).

3.2.2 Electrical Elements

All on-board electronic systems that contribute to the flight profile in a way that aids in descent, locating, or apogee correction are considered a part of the recovery system or the DACS alternate payload. The only other on-board electrical systems are discussed in depth in the payload section. External electrical elements are the electrically activated ignitor. The ignitor is an E-match that is coated in a highly combustible material that ignites the grain when the circuit is activated.

3.3 Drawings and Schematics of the built Launch Vehicle

Computer aided design was employed very heavily when designing the launch vehicle and its aspects. Everything from the nosecone to the fins have been modeled and detailed drawings were derived to gain additional understanding/ perspective of certain assemblies or providing instructions on machining parts. These drawings are displayed below.

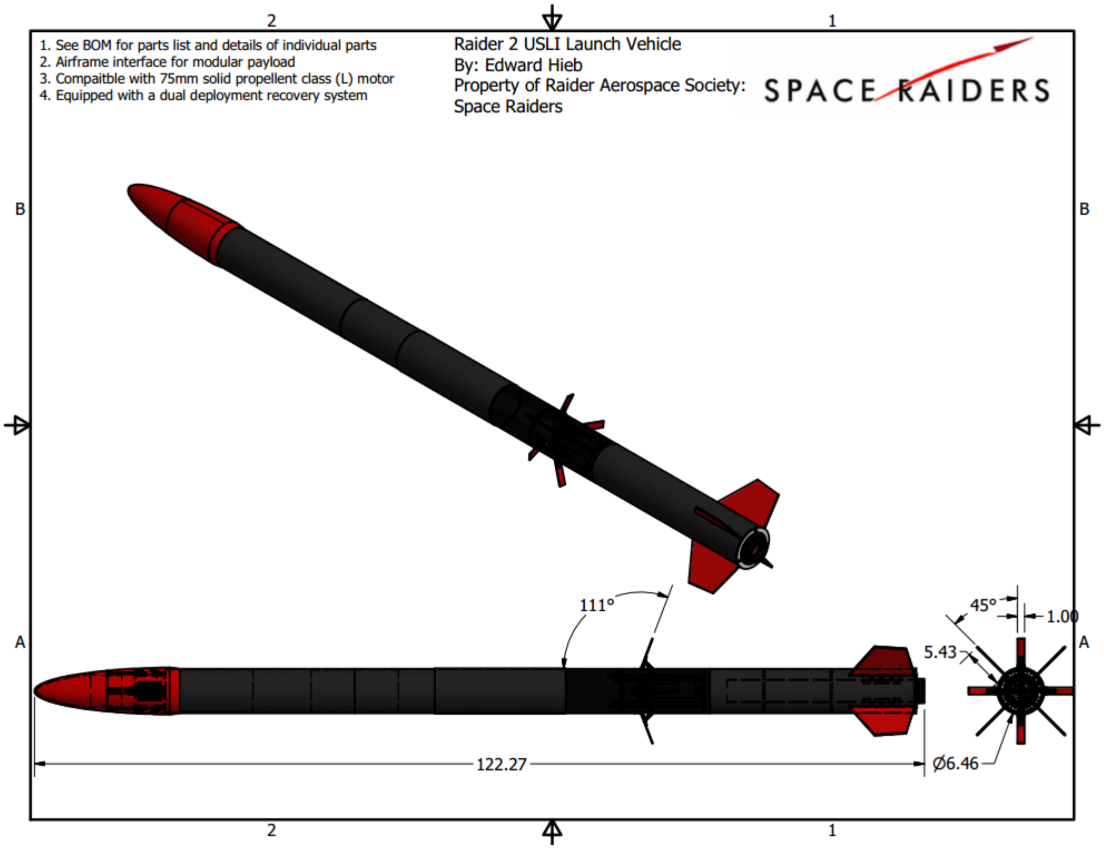
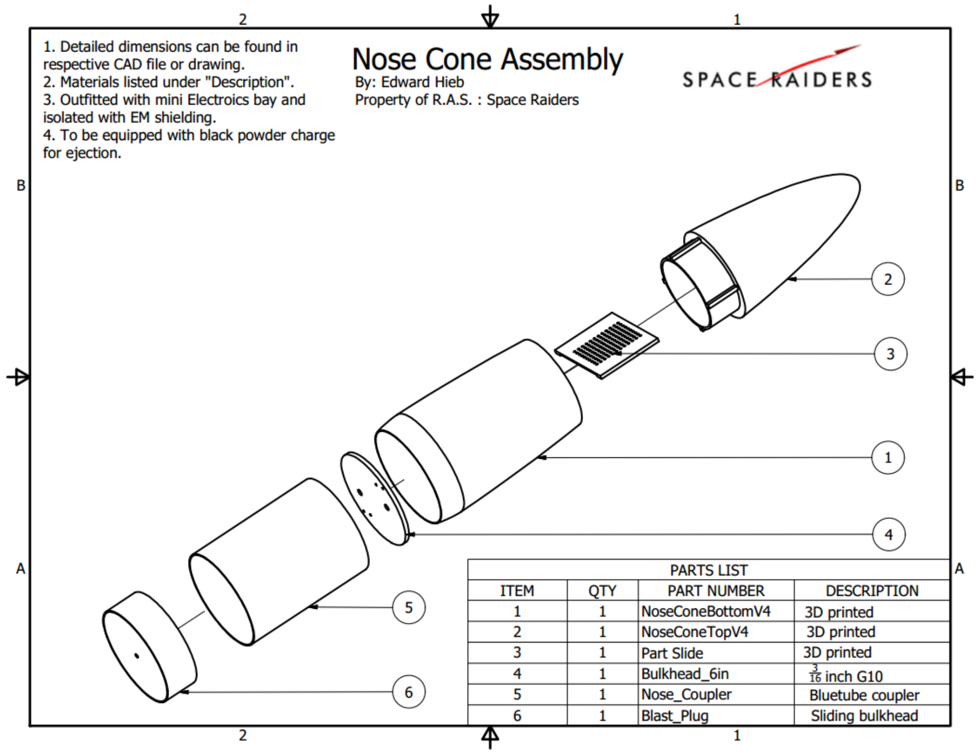
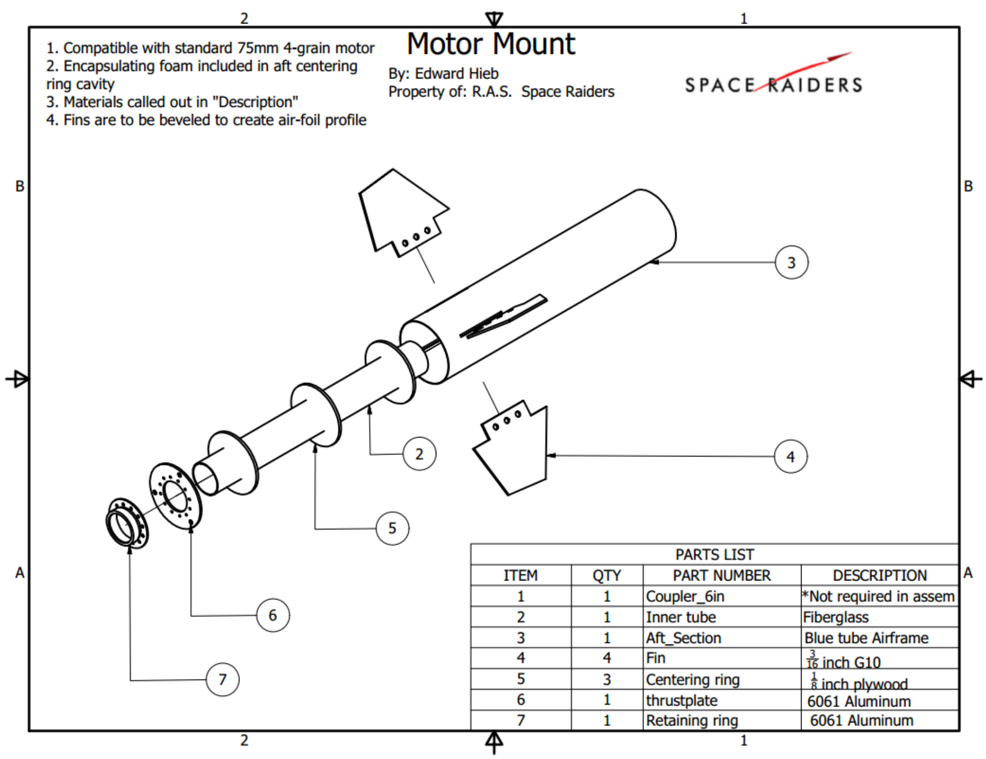


Fig 3-5



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	NoseConeBottomV4	3D printed
2	1	NoseConeTopV4	3D printed
3	1	Part Slide	3D printed
4	1	Bulkhead_6in	$\frac{3}{16}$ inch G10
5	1	Nose_Coupler	Bluetube coupler
6	1	Blast_Plug	Sliding bulkhead

Fig 3-6



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Coupler_6in	*Not required in assem
2	1	Inner tube	Fiberglass
3	1	Aft_Section	Blue tube Airframe
4	4	Fin	$\frac{3}{16}$ inch G10
5	3	Centering ring	$\frac{1}{8}$ inch plywood
6	1	thrustplate	6061 Aluminum
7	1	Retaining ring	6061 Aluminum

Fig 3-7

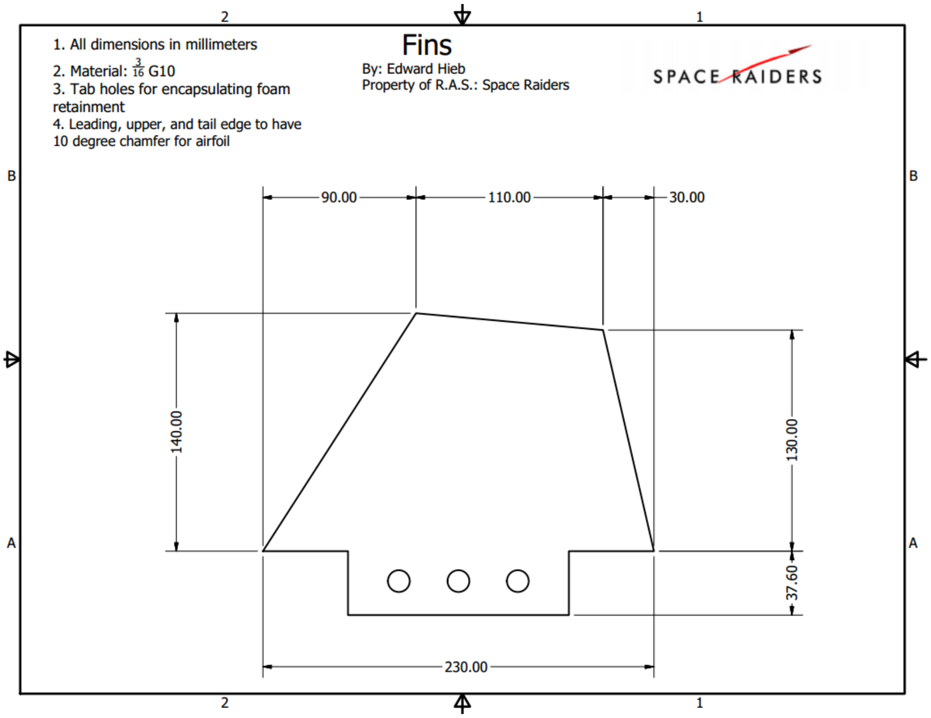

1. All dimensions in millimeters
2. Material: 3/16 G10
3. Tab holes for encapsulating foam retainment
4. Leading, upper, and tail edge to have 10 degree chamfer for airfoil
Fins
By: Edward Hieb
Property of R.A.S.: Space Raiders
SPACE RAIDERS
90.00
110.00
30.00
140.00
130.00
37.60
230.00

Fig 3-8

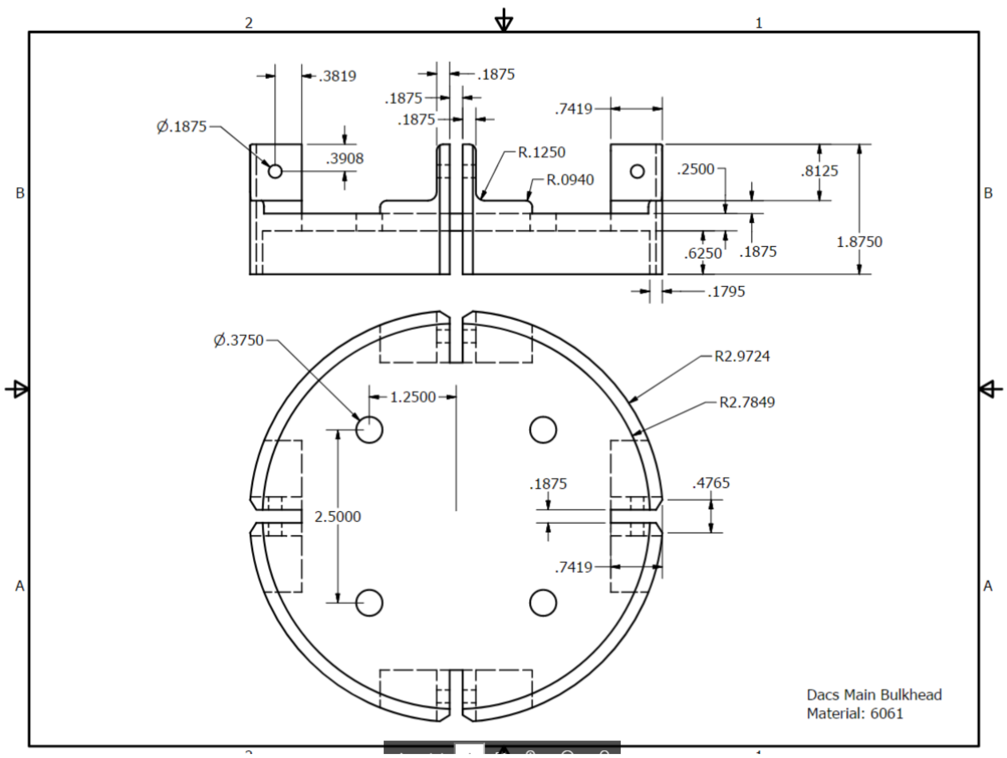

.3819
.1875
.1875
.1875
.7419
Ø.1875
.3908
R.1250
R.0940
.2500
.8125
1.8750
.6250
.1875
.1795
Ø.3750
1.2500
R2.9724
R2.7849
2.5000
.1875
.4765
.7419
Dacs Main Bulkhead
Material: 6061

Fig 3-9

3.4 Flight Reliability Confidence

Safely and successfully launch the rocket: We believe in our ability to successfully launch our rocket based on our simulations and build likeness to this simulation. We have a stability margin of 2.39 which makes it very difficult for our rocket to be affected by outside forces. Our OpenRocket file says that we are going 5944 feet at apogee and our test launch had an apogee of 6065 feet (shown in meters in the figure below). Even though this is an astounding difference in height from what we aim to achieve, we have still surpassed one mile in height and we have an altitude control system at our disposal (the DACS system). We also have estimated the amount of ballast weight needed to correct this error down to a 2% margin. We have full confidence that we can keep our rocket as close to a mile as possible with the DACS and an added ballast weight.

Recover the Rocket: We have confidence in our ability to recover our rocket in a reusable condition because of what we have learned from our test launch and its results. Because we are updating the shear pins on the payload bay to withstand the forces of our test launch recovery (about 60 G's, the increase in vertical acceleration is shown in the graph below) we are confident in the rockets ability to withstand these forces and be recovered in a reusable condition.

3.5 Fabrication and documentation of Raider II

Raider II embodies the teamwork, dedication, and pinnacle of engineering design that the Raider Aerospace Society has to offer. It is a physical example of creative problem solving and overcoming challenges as the outcome of countless hours of research into a new field of study; High Powered Rocketry. Dive into the fabrication with the construction manual below.

Facilities: The Raider aerospace is lucky to have facilities that utilize advanced fabrication machinery at our disposal. These facilities have played a pivotal role in sparking innovation and ensuring precision in the manufacturing of the custom parts that make up the Raider II.

The generosity, time, and mentorship that was provided by the technicians of these workspaces are beyond commendable and the launch vehicle could not have been built to the same caliber without them.

Fig 3-10

The Advanced Vehicle Engineering Facility was home base for the Raider II throughout the lengthy fabrication process. It is located at the Reese Technology Center for Research and is also the home of the TTU robotics club, Solar Car club, and Raider Aerospace Society. All precision machined parts were products of the Mechanical Engineering machine shop. This shop provided a place to employ advanced fabrication techniques such as DMLS 3D printing, FDM 3D printing, CNC mills, and manual tools. Under the guidance of senior technicians, members of the team gained firsthand experience with manufacturing processes and even sparked interest and opened up new possibilities that apply directly to the future careers of the respective members.

Fig 3-11

Nose cone: While the design for every part of the Raider II began on a whiteboard, most parts were transferred to CAD and then made by hand or some means of automation

3D Printing: The Nose cone is a prime example of additive manufacturing using DFM 3D printing. Additive manufacturing is excellent for providing means of rapidly producing the complicated part out of multiple types of filament if there is a desire for alternate material properties. Preparing the part for printing is a process that starts with converting the 3 CAD files (top, bottom, and part slide) to STL files, and then slicing them in a software called' "Catalyst" to generate support material placement and the tool paths that are in the form of GMZ files. The GMZ files were then sent to a Stratasys 3D printer to build the parts.

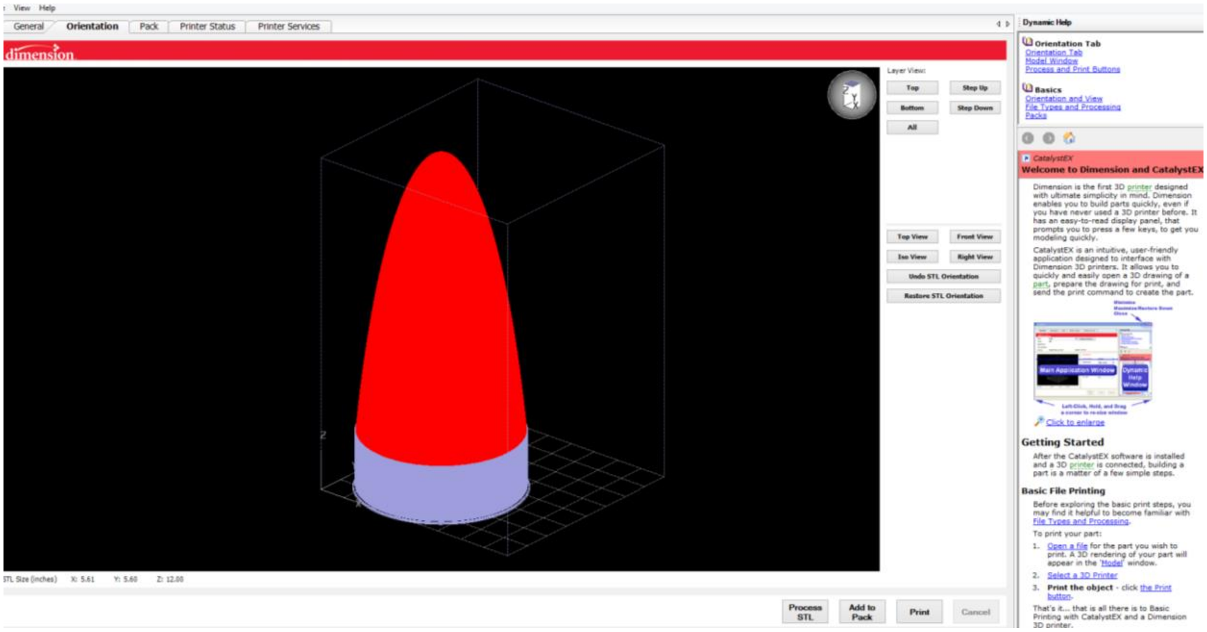


Fig 3-12

Nose Cone 3D print Statistics	
Model Material (in^3)	(22.3+31.87+1.97) = 57.14
Support Material (in^3)	(4.47+1.87+0) = 6.34
Build Time (Hours)	(27.5+36.33+3.18) = 67.01

Post Work: After the Nose cone was printed, the parts were then removed and placed into bath of solution for at least 12 hours to dissolve the residual support material that could not be removed by hand. After the parts had gone through the bath, they were manually sanded with P60-P500 grit sandpaper with steps of 60-100 in between each sanding. This sanding process was tested on the Raider 1 and implemented to remove the ridges left behind by the 3D printer and create a uniform rough surface to prep for painting.

Part Integration: The next step in assembling the nose cone is integrating the other components such as the coupler, bulkhead, electronics, blast isolator, and 8-40 hardware. Most of this part of the process was completed in Bill's workshop. Holes were marked and drilled in the bulkhead for posts and the eyebolt and both sections of the nose cone for the 8-40 nuts and bolts. Terminal connectors are being used to mount the wires to the posts with connectors attached to the other end to allow for the electronics slide to be removable from the nose cone . After applying G5000 epoxy to the bulkheads and coupler, the assembly was left in a small room with heaters to create an isolated environment that aided in the curing stage of the epoxy.

Paint Paint was then applied to the nose cone in layers using thin coats of conventional spray paint. First, three coats of gray primer were applied to cover up the color difference of the two main sections and establishing an ideal surface to paint on. Next, glossy red was applied over the primer in 2 coats. The Nose cone is shown in the paint booth in fig 3-13 below

Fig 3-13

Payload interface: The payload interface was designed to be modular and utilizes a standard six-inch diameter Blue Tube coupler as the housing. The coupler was then modified to suit the needs of the specific payload that was included in the flight profile.

Airframe Positioning/Mounting: First this coupler was cut to length, as specified in the design, and then positioned inside of the airframe where it will be mounted during flight. Once the housing is in position axially, it is secured, and 4 holes are drilled at 90 degrees apart from each other, around the airframe.

Payload Specific Modification: For this mission, the rover was selected as the payload, and thus the interface was heavily modified to suit the needs of storing a vehicle in flight, as well as ensuring correct orientation to allow for deployment at landing. Because nose cone ejection is necessary for rover deployment, an isolator plug is used to contain the explosion. For the blast plug to be pulled out, vent holes must be incorporated behind the plug to release the vacuum that resists the plug's ejection.

Airframe: The airframe that the launch vehicle is made of is Blue Tube 2.0, more details about this material can be found in the section that discusses the design and material justification of this document, as well as the CDR. While the material comes pre-fabricated, there are many steps that were taken to create a functional airframe. These steps include, cutting the blue tube to lengths for each section, filling the spiral grooves with epoxy, mounting bulkheads, mounting hardware for fixing sections together, and drilling holes for internal pressure stabilization.

Fig 3-14

Initial Modification: The lengths of the sections were measured, and masking tape was used to mark where each section was to be cut on a band saw. After the tube was cut, files were used to de-burr the edges of the tube the grooves were filled in with G5000 to create a smooth uniform surface along the airframe. The epoxy was initially applied and then the sections were placed in a warm room to cure. Once cured it was sanded down by hand to prepare for painting.

Slotting and Cutting: Before painting certain sections were cut, slotted, and modified with windows or pressure stabilization holes. The placement of the slots were determined by using custom tooling, that was a 3D printed jig with slits that are exactly 90 degrees apart and in the proper placement from the bottom of the airframe (seen in the background of fig 3-15) After the lines were transferred, a Dremel tool was used to cut the slot out very carefully and then a hand file to finish and de-burr the tube.

Fig 3-15

Furthermore, the DACS requires windows for the control arms to and hinges to control the external drag flaps. Airframe modification was also done to create the openings for the DACS by using a similar method of transferring a pattern using a 3D printed jig. After the jig was lined up 45 degrees from the fins, the window was transferred and a Dremel was used to cut the windows, following finish work with a hand file. The jig can be seen on the airframe in figure 3-16

Fig 3-16

Reinforcement: While reinforcing the airframe was planned on some sections of the launch, vehicle, some were not, and only determined necessary after testing. These sections that required reinforcement include; the DACS interface, E-Bay to Main chute section, and Payload section.

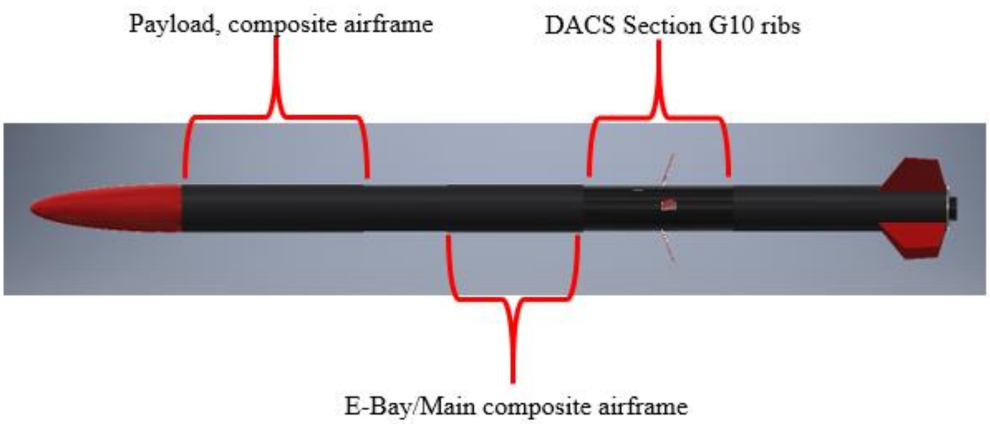


Fig 3-17

The DACS section ribs are made from 1/16th inch thick G10 with holes at the top for attaching to the main aluminum bulkhead. The four G10 fins are 90 degrees apart from each other, and 45 degrees from the cut-out windows. Because the orientation of these ribs is crucial and must be precise, we cut out a scaffolding with leftover-over 2.6mm plywood on the CNC router and then assembled an inserted as a unit before setting in epoxy. The assembled rib-scaffolding unit is shown in the figure below.

Fig 3-18

After insertion into the airframe, the ribs were epoxied with 1/8fillets to the internal wall of the blue tube. After the epoxy has set on all ribs, the thin wooden scaffolding was broken and removed, leaving the ribs in proper orientation for the finishing epoxy work. The inserted unit is shown in figure 3-19 below:

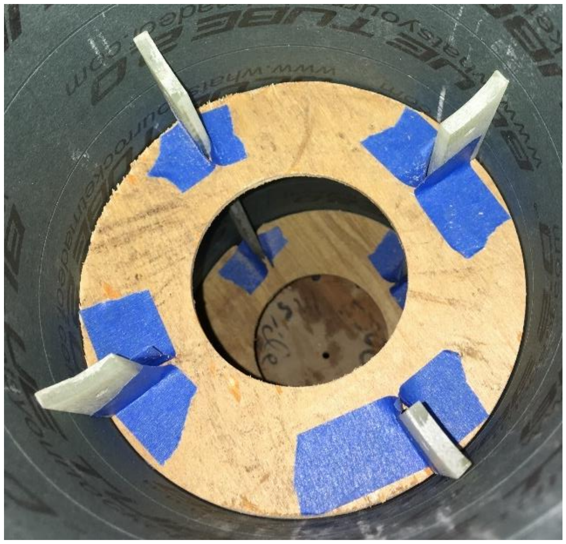


Fig 3-19

During ground testing, it was discovered that the blue tube airframe alone could not stand up to the larger black powder charges used in the recovery system. Because we had over pressurization, resulting in de-lamination, emergency re-design went on during the damage control response period. Implementing the upgraded airframe design was relatively simple, as the team had sourced a section of the pre-fabricated phenolic airframe that is reinforced with carbon fiber and Kevlar from our Tripoli Level 3 informal advisor, Fred Schneider.

For the first full-scale test flight we had only repaired the E-bay/Main chute section, due to the approaching deadline, and are in the process of reinforcing the payload section and will finish before the next test flight. The first step the repair was splicing the E-bay section, which entailed cutting off the dead wood, or the shredded section left over from testing. This was done with supervision by Fred on an industrial band saw in the Industrial Manufacturing and Systems Education machine shop on TTU campus. This process is shown in the figure below.

Fig 3-20

After the old tube has been cut, we cut a 6in longer section of the carbon and Kevlar tube and used a blue tube coupler that was originally intended for the payload integration housing as an internal splice. This piece was epoxied in and fastened with size 6-32 button head screws. After the coupler was installed, the newly cut piece of the composite tube was epoxied in and fastened in the same manner. The splice is shown in the figure below.

Fig 3-21

After the epoxy has set and the hardware was installed, holes for shear pins were drilled out and then counter-sunk into the new composite section of airframe.

Bulkheads: The bulkheads are vital components of the launch vehicle due to the shock chords connecting directly to them, transferring all the momentum of the falling rocket being stopped by the parachutes. Due to the strength that these bulkheads must have, they have been made from composite materials, or aluminum, depending on the application. The composite bulkheads are made from sheets of 2.6mm plywood and sheets of fiberglass. These were made by cutting 6-inch circles out of wood on the CNC router, and then 7-inch squares of fiberglass using a large paper shear. After the fiberglass sheets were cut, the thin-set epoxy was applied to both the bulkhead face and the cloth of each component that is to be bonded, and then clamped to harden. The clamped bulkheads are shown in fig 3-22.

Fig 3-22

The other bulkheads that are not the fiberglass composites, are either made out of aluminum or G10. The G10 bulkheads will be replacing the fiberglass wood nose cone bulkhead, and the blast plug bulkhead. The aluminum bulkhead was machined out of 6061 AL in the TTU machine shop and started from a piece of stock material. Next it was turned on an industrial lathe, moved to a CNC mill, and finished on a manual end mill. The aluminum bulkhead is shown getting slotted on the Bridgeport mill in figure 3-23.

Fig 3-23

E-Bay: The electronics bay is made up of two plywood bulkheads, one on each end of a 1/8th-inch support rack. The support rack was epoxied to two threaded rods that connect the bulkheads. The electronic equipment consists of two altimeters, two batteries, and two switches accessible from the exterior of the airframe. Two of each component for redundancy and cross-referencing purposes. The batteries power the altimeters and the switches allow us to activate the devices at the launch pad. We chose the *StratologgerCF* altimeters from ©PerfectFlite for its versatile data collection methods. The devices record flight altitude, temperature, and velocity; As well as allows programming for parachute deployment. The devices output peak altitude and maximum velocity in a series of audible beeps and provide USB connections to download data.

Recovery System: The recovery system is comprised of three parachutes; a drogue, pilot, and main chute. The drogue chute has a 2ft diameter and was manufactured using 1.9 ripstop nylon. The drogue is connected to the rocket with a 15ft shock chord. The drogue chute is to be deployed at apogee to slow the freefall speed and minimize drift. The main and pilot chutes are 16ft and 4ft in diameter respectively. Manufactured with 1.1 Ripstop nylon and connected in tandem with a 40ft shock chord. The main chute sits within a NOMEX deployment bag to protect from the blast charges.

Motor Mount: The Motor Mount System is essential for housing the motor and providing structural support for the fins. The system is comprised of a fiberglass tube, three centering rings, two-part encapsulating foam, thrust plate, and retaining cap. The three centering rings were CNC routed. The forward two rings are 1/8th inch thick and the aft rings is comprised of three 1/8th rings laminated with G5000 epoxy. The aft centering ring includes three concentric nuts for securing the thrust plate with machine screws.

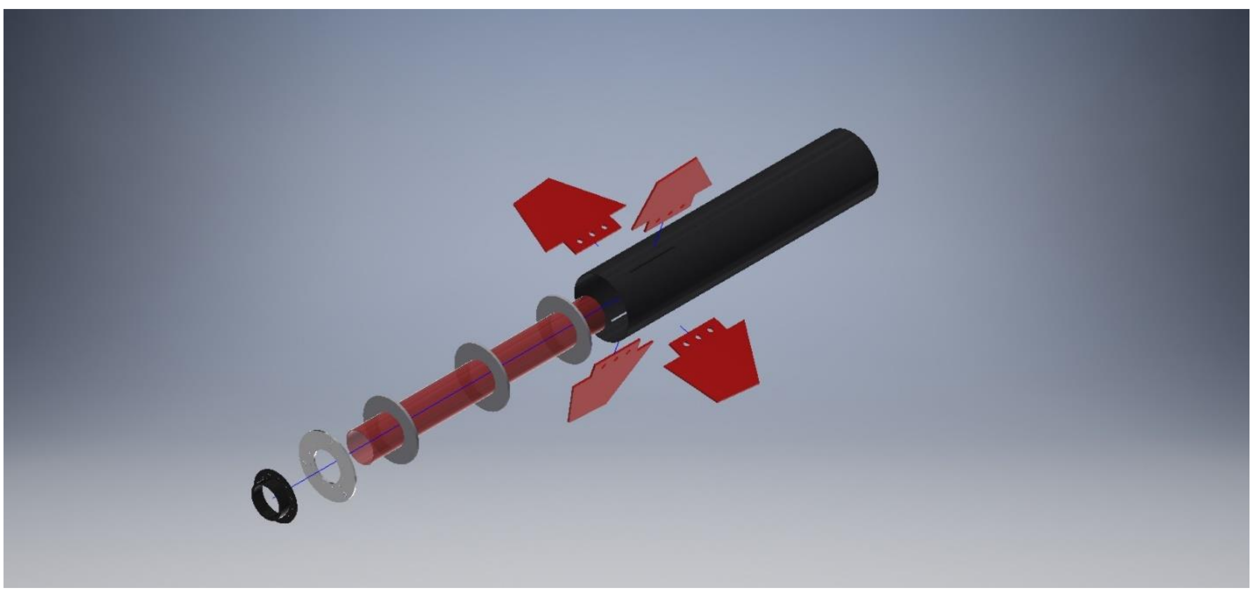


Fig 3-24

Fig 3-25

Two-part missile work encapsulating foam was filled between back and middle centering ring to form around the fins and create extra bonding to the motor mount. The 2-part epoxy is the same as was used on the sub-scale build and it was measured in equal parts by weight and then additional drops of water was added to lower the density. After the foam has set, the rear cavity had to be carved out to fit the aft-most centering ring and thrust plate shown in figure 3-26 and the centering ring can be seen inserted in figure 3-27.

Fig 3-26

Fig 3-27

Following centering fixation, the thrust plate was installed. A series small socket head screws fastens the retaining ring bracket to thrust plate and the ring itself is threaded onto the bracket. The thrust plate is shown in position in figure 3-28 below.

Fig 3-28

Fins: The fins are an integral part of a successful rocket system due to the stabilization and the effect on the center of pressure of the rocket. For the fabrication of our fins, we chose to use G10 fiberglass; a heat compressed fiberglass/resin composite material. We began with 3/16th inch sheets of G10 and cut them to shape with a CNC router. We added a 10-degree bevel to the fin edges with a table saw to enhance the aerodynamic properties by reducing the drag. After initial cutting, the edge was finished on a hand-held belt sander, with care taken to wear proper PPE such as respirators and gloves during the process. Routing and initial edge-forming is shown in figure 3-29 below.

Fig 3-29

After fin formation, they were inserted into the slotted airframe, and epoxied into place. To ensure a 90-degree offset of each fin, a wooden guide was routed out to hold them in position while setting the initial internal epoxy fillet. The wooden guides are shown during the curing process in figure 3-30 below:

Fig 3-30

After the initial internal fillets, placed on the tabs where there is direct contact with the motor mount tube, have dried, the external ¼ inch fillets were created by masking off parts of the airframe and fins and then applying the G5000 with large popsicle sticks. These fillets are shown in figure 3-31 below.

Fig 3-31

3.6 Recovery System

For this rocket the recovery system will contain both a main and a Drogue parachute along with two completely independent altimeters that will each be connected to a set of ejection charges to aid in the deployment of the main and drogue parachutes. The requirements of this competition have led us to go with a sixteen foot main parachute and a two foot drogue parachute.

Along with the main electronics bay there will be a GPS tracker in the nosecone along with a transmitter receiver combination that will aid in the deployment of the rover. Once the rover lands a remote signal will be sent to the nose cone jettisoning the nose cone and leaving a path for the rover to freely drive out of the rocket.

3.6.1 Design Justification and Defense

One of the biggest concerns for the rocket and overall in the project is the safety of not only the participants but also the safety of the launch vehicle itself. With recovery being one of the most important aspects of vehicle safety, that being returning the rocket safely to the ground after launch. With safety being such high precedence we will be utilizing 2 completely separate altimeters that will each control an ejection charge for the main and drogue parachute. These 2 altimeters will act as a main and backup recovery system with the back up being delayed by 1 second for drogue deployment and the main parachute deployment will be deployed 100 feet lower than the main recovery system. The backup recovery system will be NASA's dedicated altimeter while still functioning as part of the recovery system. These two recovery systems mirror each other in design and construction only differing in ejection charge size with the backup system holding 1.25 times as much black powder.

The fact that we will be using two complete separate systems just works to increase the likelihood of successful system deployment. With a single recovery system, or single altimeter, we could easily have a discontinuity from the ejection charges to the altimeter itself which would cause no separation at that respective stage in flight. By using two recovery systems there is a greater chance to have continuity through at least one of the ejection charges. With both ejection charges being large enough to separate the different sections this redundancy will help ensure deployment of the different parachute

3.6.2 Structural Elements

Most of the forces that act on the recovery system will be seen when the main parachute fully deploys as the entire system will experience 64g's once the parachute is fully open. With this massive deceleration all of the forces seen by the system will be greatly increased and hence the construction of each component will have to be ample enough to withstand these increased loads. The five main structural components for the recovery system are the bulkheads, shock cords, connection hardware, 550 Paracord, and Nosecone attachment.

3.6.2.1 Hardware Connections

Working from the top down, as soon as the parachute deploys the first structural component will be a 5/16th inch thick Stainless Steel quick link. These quick links are rated to withstand a total force of 2400 lbf. Now to prove that this is a sufficient and robust design we need to fully understand all the forces that are going to be acting on the quick link and how they will be acting on this specific component. When the main parachute deploys the quick link will essentially have two separate forces acting on it, the force of the parachute pulling straight up and then the force from deceleration of the entire rocket acting straight down. This can be seen in fig R-1below:

Figure R-1

Where the F_{main} and F_{rocket} are calculated below:

$$mass\ of\ rocket\ (M_{rocket}) = 17582\ g\ or\ 17.582\ kg$$

$$deccloration\ (a) = 631.19\ \frac{m}{s^2}$$

$$F = Ma$$

$$F = (17.582\ kg)(631.19\frac{m}{s^2})$$

$$F = 11097.6\, N\ or\ 2494.9\, lbf$$

Now that we have the total force acting on this component we can calculate the factor of safety as seen below:

$$Maximum\ Strength = 2400\ lbf$$

$$Force\ Applied = 2494.9\ lbf$$

$$n = \frac{Maximum\ Strength}{Force\ Applied}$$

$$n = \frac{2400\ lbf}{2494.9\ lbf}$$

$$n = 0.96$$

Here we can see that this component will not fail as the factor of safety is 0.96. Now this might be a little concerning seeing how it is below 1.00 that it might not seem like a robust design but we have to consider the fact that this is the worst case possible and the safe working load not the breaking strength when the main parachute deploys so in actuality the factor of safety would be greater than the above value. We will be upgrading this parachute quick link to a 3/8th inch thick one because the safe working load is 3900 lbf which will give us a factor of safety of 1.56 which is more than ample to withstand the impulse from parachute deployment.

Following the same logic we calculated the safety factor for each component for the main parachute connections. Before we dive into calculations we have to fully understand how the system is put together. The construction process and built design is talked about in detail later in the document. In summary the electronics bay has a cross woven on the bulkhead through four separate ¼ inch eye bolts where the shock cord is connected through a 3/8th inch quick link. The 30 foot shock cord is then spliced in the middle where the parachute is attached along with the 10 foot shock cord before it funs to the bulkhead directly above the D.A.C.S system. The 550 Paracord, being the weakest point, will be wrapped multiple times to increase the effective strength of this connection to have a safety factor above 2.00. The following tables, figure R-2 and fig R-3, calculate the force due to deceleration of each independent section and then the safety factor for each for each induvial component respectively:

Section	m (g)	a (m/s/s)	F = ma (N)	F (lbf)
Payload	2823.00	631.19	1781.85	400.58
E-Bay	5029.00	631.19	3174.25	713.60
Motor	8118.00	631.19	5124.00	1151.92
Total	15970.00		10080.10	2266.10

Figure R-2 (Independent Section Deceleration Force)

Component	Total Force Acting (lbf)	Component Strength (lbf)	Multiplier	Safety Factor
Main Parachute Connection Quick Link	2266.10	2400.00	1.00	1.06
Main Motor Connection Quick Link	1151.92	2400.00	1.00	2.08
Main E-Bay Connection Quick Link	1114.18	2400.00	1.00	2.15
Main Motor Shock Cord 1" Nylon	1151.92	4200.00	1.00	3.65
Main E-Bay Shock Cord 1" Nylon	1114.18	4200.00	1.00	3.77
8x Main Motor Paracord 550	1151.92	550.00	8.00	3.82
10x Main E-Bay Paracord 550	1114.18	550.00	10.00	4.94

Figure R-3 (Main Parachute Component Safety Factor)

Seeing how all of these calculations were done under assumptions that would make them the worst possible case and the fact that all the factors of safety are well above 1.00 I can confidently say that the constructed design is not only functional but it is quite robust. During the full scale test launch we further confirmed that each component of the vehicle recovery system functioned just as designed.

With the biggest concern being the amount of energy that is being transferred through the vehicle from main chute deployment we must strive to reduce this energy at every chance possible. To do this we are using the 550 Paracord that was looked at above along seeing how it’s decently elastic and will act as a shock absorber reducing the impulse past that point of connection. We will also be bundling the shock cord in one foot sections spaced six inches apart and securing each section with a warping of tape. For our full scale test we used a single wrapping of making tape that, when tested, absorbed 0.75 lbf on average for each bundle. With a total of 15 bundles we effectively reduced the force being applied to the forward section by 11.25 lbf. This is pretty much negligible when looking at the total forces as seen in figure R-3. For our next launch we will be increasing the amount of material used to bundle each one foot section and conduct further testing to further reduce the forces acting on the vehicle.

3.6.2.2 Bulkheads

The next thing we will be looking at is the structural integrity of the different bulkheads. There are a total of four bulkheads that are included as part of the recovery system and they are labeled and positioned as follows:

- Payload – Directly behind the payload housing and connected to the drogue parachute.
- Drogue E-Bay – The forward portion of the electronics bay and connected to the drogue parachute.
- Main E-Bay – The aft portion of the electronics bay and connected to the main parachute.
- DACS – Directly above the DACS system in the aft most section of the rocket and connected to the main parachute.

Both bulkheads that that are connected to the drogue parachute will be made from a in-house composite consisting of single ply plywood encasing double layered fiber glass sheets. The Main E-Bay bulkhead will be made of the same material as both drogue bulkheads but it will be almost double in thickness as both drogue bulkheads. The DACS bulkhead will machined out of aluminum and connected directly to the airframe from the inside of the rocket and the outside.

Looking at both drogue bulkheads they are made from a wood-fiberglass composite that is layered in an alternating fashion with the fiberglass sheets being doubled up for added strength. In total both bulkheads have three layers of single ply-wood and two layers of doubled up fiberglass sheet. These layers were secured together by epoxy and then clamped together for maximum strength when curing. The following drawings show the design of both drogue chute bulkheads, payload and drogue E-Bay, shown in figure R-4and figure R-5 respectively.

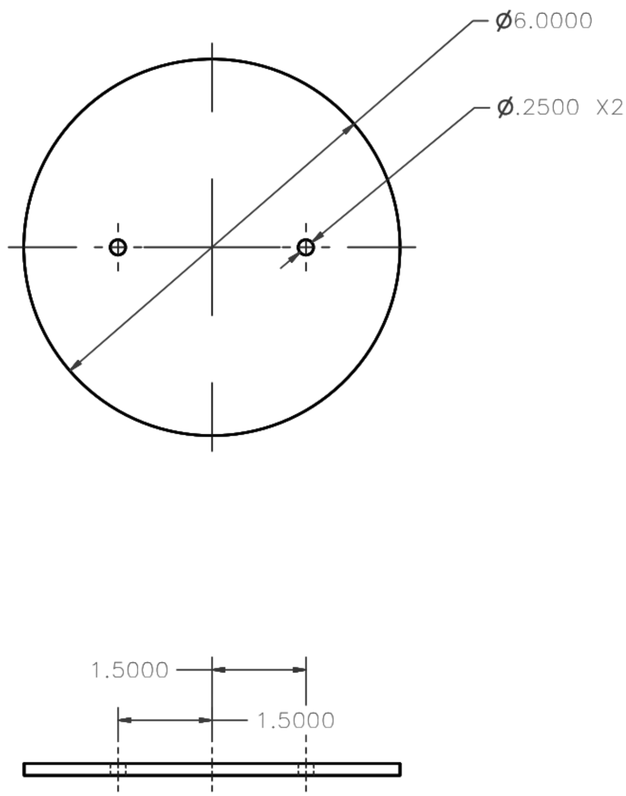
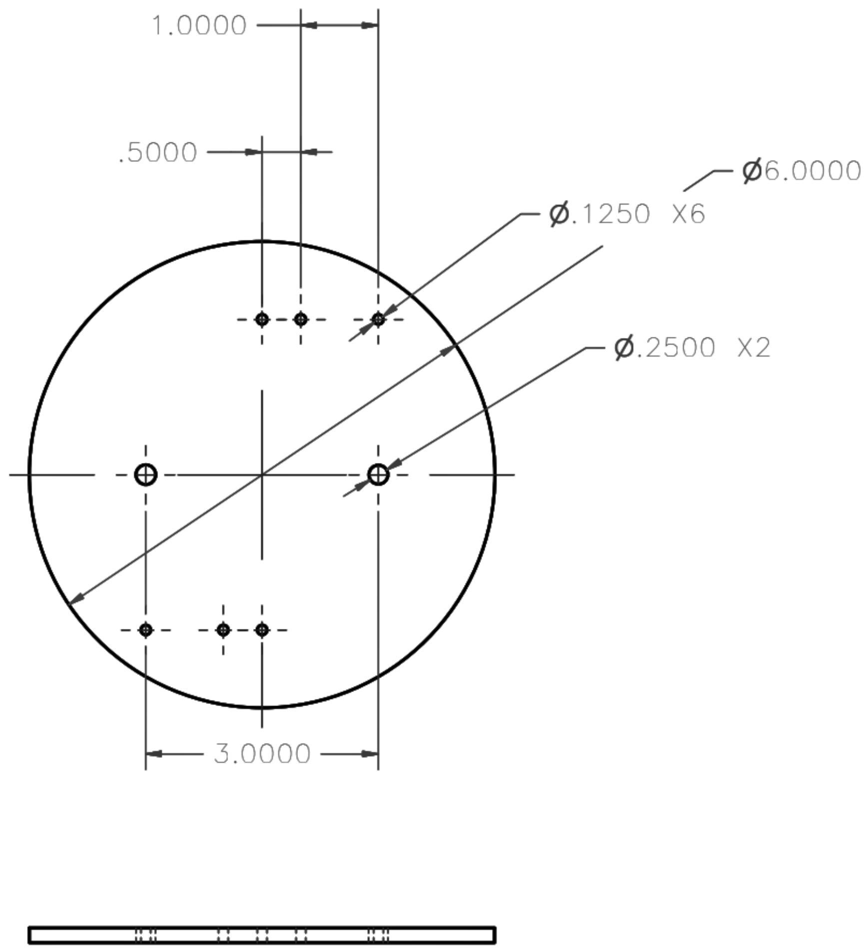


Fig R-4



Fig's R-6

The main E-Bay bulkhead was made out of the same composite material as both drogue bulkheads are and also made in the same fashion. With this bulkhead seeing much more force than the other two composite bulkheads it was made with five layers of ply-wood and three layers of fiber glass and again bonded together with epoxy before getting clamped together during the cuing process. In figure R-6 below the dimensions for this bulkhead can be seen.

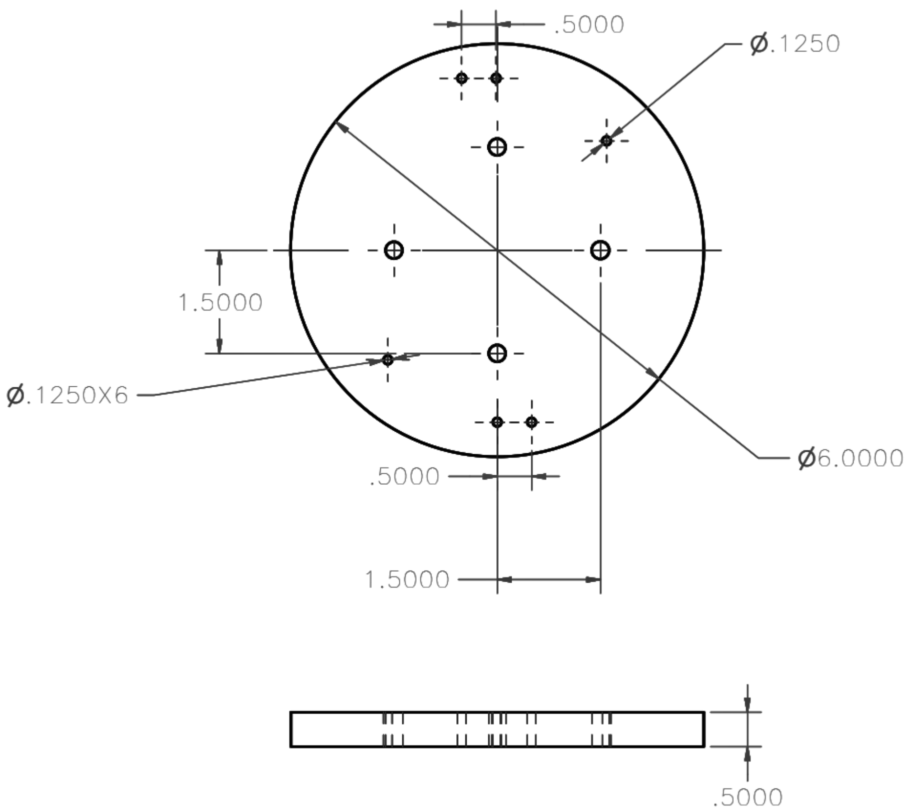


Fig R-7

With no efficient way of calculating the strength of this composite our biggest prove to its robustness was the full scale test. In the full scale test it held up well with no signs of deformation and or delamination. From this we can safely say that this bulkhead is robust enough to withstand multiple flights.

Last we have the DACS bulkhead which will be experiencing the most force in comparison to the other bulkheads. With this bulkhead see roughly 1200 lbf we needed to make sure there was little to no deformation along with assurance that I would not be ripped out of the airframe. In order to insure success of the recovery system we deiced to go with aluminum for our final design. Another concern we had was the fact that it could be removed so we wanted to make sure we could attach it on the inside of the airframe to the reinforcing ribs that run along the length of this section of airframe. The final design is shown in figure R-8 below:

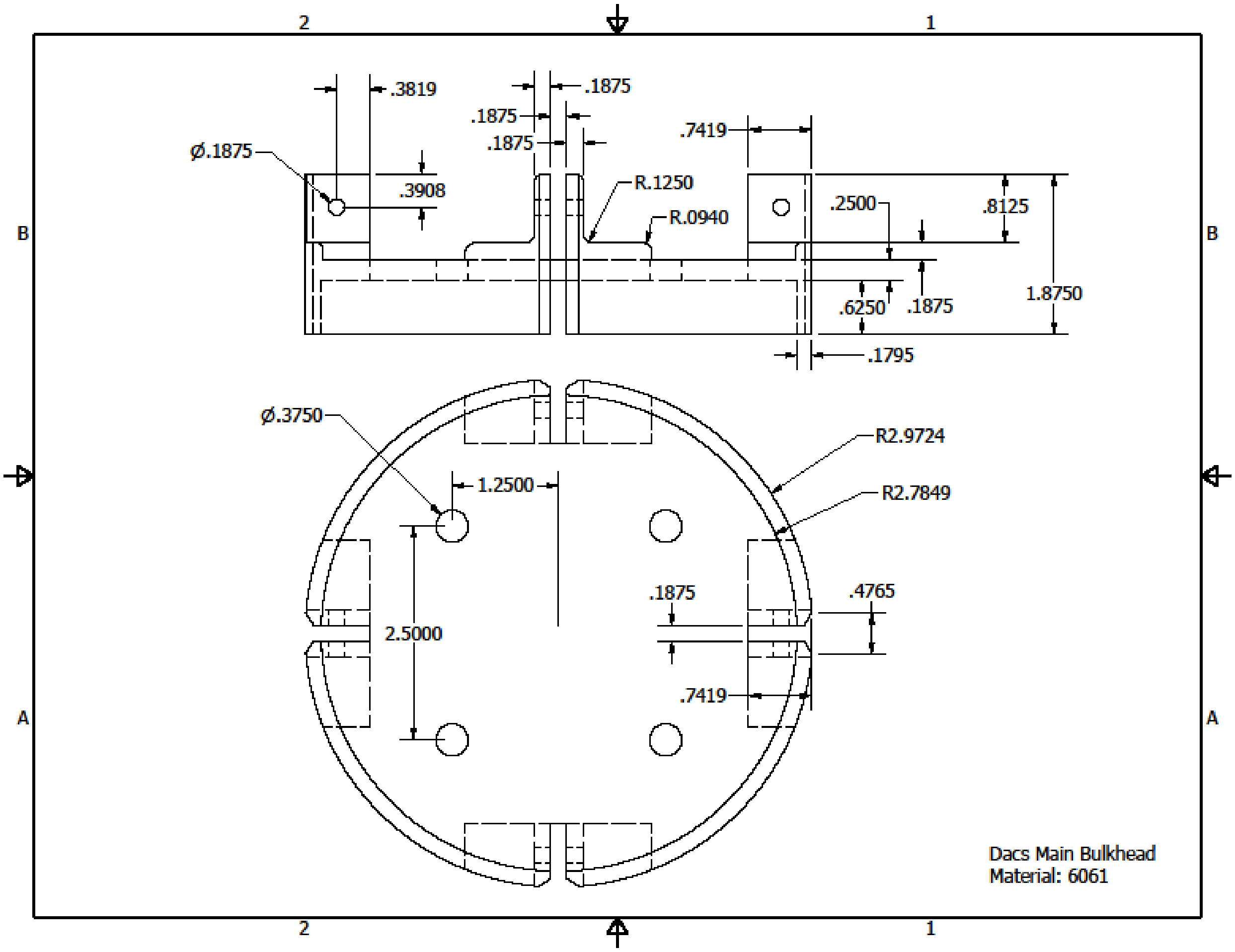


Figure R-8

As seen in the drawing above the upright flanges will work to mechanically fasten the bulkhead to the inside of the airframe by four 6-32 machine screws. To connect the bulkhead from the outside of the airframe we will use four 8-32 button head machine screws. The point of having 8 points of connection was to help reduce the overall stress from concentrating in a specific area and ultimately increase the likelihood of success upon main deployment.

Seeing how the design has not changed from the CDR the previous stress analysis still applied and we have a calculated factor of safety of 2.14. This is quite adequate for the current application in the rocket as it has little to no displacement under this loading.

With this bulkhead seeing the largest load along it is a good reflection of the system as a whole and seeing how it can safely handle the lading it is subject too I am comfortable saying he structural design of the recovery system is robust enough for this rocket and the successful recovery of the rocket.

3.6.2.3 Electrical Elements

Within the recovery system all of the vital electronics are housed within the electronics bay. There are two completely independent recovery system within the electronics bay; the primary recovery system which is our dedicated system and the backup recovery system which will be used as NASA's dedicated recovery system. These two systems will be a mirror copy of each other and each control and ejection charge for both main and drogue parachute deployment. They will be wired as seen in figure **** as seen below:

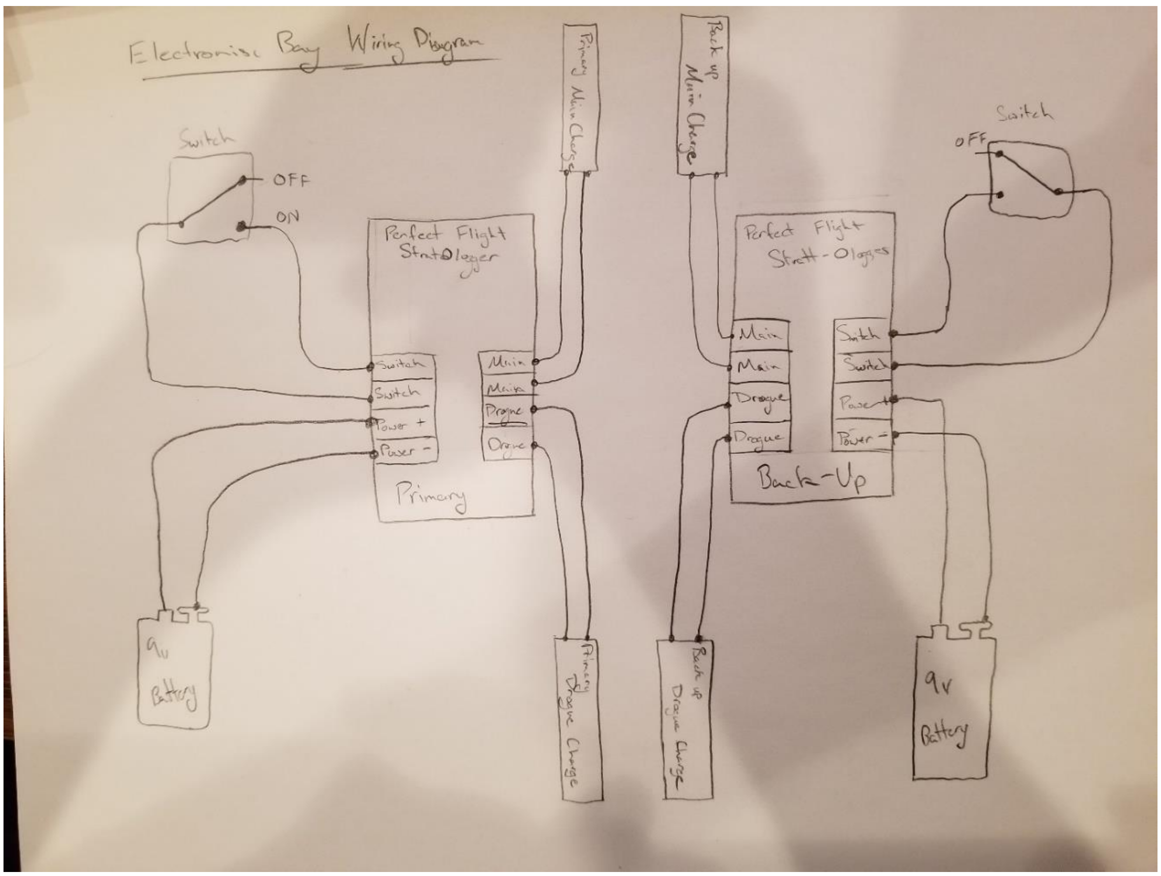


Figure R -9

The use of two independent recovery systems will help make sure that there is a successful recovery system deployment. By adding another recovery system we greatly reduce the risk of charges not going off properly and help add a safety net by have two sets of charges. All in all the dual system will aid in making the entire recovery system more robust by adding a safety net to separation and parachute deployment.

3.6.2.4 Transmitters and GPS

For our rocket we are using a both a GPS tracker and transmitter. The GPS tracker is a Missile Works T3 GPS Tracking System and our transmitter will be a SenMod Long Distance 2 Channel Transmitter. Both of these components will be housed on the part sled inside of the nose cone as they will only be activated after the rocket has landed. These two systems will be housed in the same compartment but they will be independent from on another due to the operational voltage required for each component. The SenMod transmitter has the following technical specifications as seen in figure R-10 below:

Remote Distance	1000 m
Operating Frequency	433 MHz
Wattage	< ½ watt
Code	Learning(Non-Latched)
Receiver Sensitivity	-105dBm
Operation Way	Inching, Self Locking
Number of Channels	2
Operation Voltage	12v

Figure R-10

For the GPS Tracker the technical specifications can be seen in figure R-11 below:

Range	Up to 9 miles
Operational Frequencies	902 to 928 MHz

Wattage	¼ watt
Weight	.68 oz / 19.5 g
GPS Operational Range Altitude	50,000 m / 160,042 ft
Velocity	500 m/sec / 1640 ft/sec
Operation Voltage	3.1 to 7.4 v

Fig R-11

3.6.2.5 EM Shielding

With the transmitter and the GPS tracker being in close proximity to two relatively large ejection charges it is important that both of these systems do not pick up stray signals that could cause the electric match to light. In order to prevent this from happening we will be shield the base of the bulkhead inside the nose cone with a layer of brass mesh. The main concern is the SenMod transmitter picking up stray signals seeing how it directly controls both the primary and backup ejection charge. In order to prevent this from happening the transmitter itself has a handshake with the receiver so it cannot be falsely activated. This with the EM shielding should prevent any premature ejection charge detonation and aid in successful deployment of the rover.

3.6.3 Testing Results

In addition to testing the compartments, we tested nitrile gloves tips as an alternative to the centrifuge and metal casing. The charge packets were packed and wired, as specified in the recovery section, and then tested by placing a plywood board on top of the charge in order to contain it. The charges were then manually detonated from a safe location. The test charge proved to provide a safer, omnidirectional, softer, low velocity explosion.

3.6.3.1 Nose Cone Ejection Charge Testing

Ground testing done for the nose cone ejection charge was done by packing a canister charge, laying the airframe down on its side with the nose cone’s aft half affixed via shear pins, and detonating the charge manually. The charge was wired and ran to a safe location where they were affixed to a switch which would allow for remote detonation. The test setup is pictured below.

The size of the charge tested was 2.5 grams. This charge size was a slightly energetic of a detonation, which separated the nose cone from the airframe with considerable distance between the ends. This can be easily attributed to the lack of shear pins during this test trial. The charge was safe in terms of explosive power and will not compromise either the airframe or the nose cone.

With the results from our full-scale test and our ground testing in mind, particularly with the nose cone issue, moving up the number of shear pins will not significantly change the required charge size.

3.6.3.2 Drogue Separation Testing

Ground testing done for the drogue parachute's ejection charge was done by packing the parachute and canister charge, laying the airframe down on its side and simply detonating the charge manually. The airframe was laid flat on the ground for this test. The charges were then wired to a switch and ran to a safe location where they were remotely detonated. The setup can be seen in the photo below.

The size of the initial charge tested was 1 gram. This proved to be an effectively sized charge, providing sufficient separation of the compartment. The second charge tested was the 1.5 gram secondary backup charge, which proved to be a safely sized charge which would not compromise the airframe.

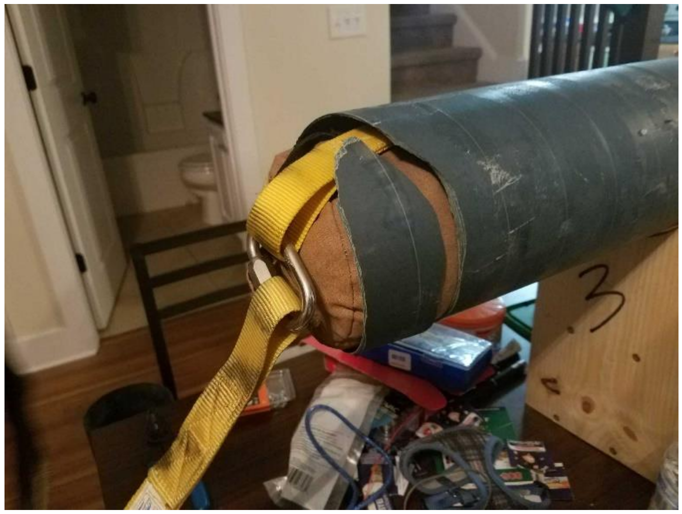
3.6.3.3 Initial Main Ejection Charge

Ground testing done for the main parachute's ejection charge was conducted by packing the parachute and charge, laying the airframe down on its side and manually detonating the charge, similar to the drogue testing method. The parachute was packed in a manner that a void rested forward of it, with a smaller cavity aft of the chute. A canister & centrifuge charge was placed in the forward void, above the parachute bag. The initial test setup is pictured below.

The charge was originally calculated using the entire volume of the section and to 15 psi (per our mentor's advice). The specified charge size in the CDR was 7.7559 grams, and after our prior ground tests, it was determined that charge size would be too large to safely detonate. We recalculated the charge size, using the same volume, for 7 psi and found our new charge size to be approximately 3.5 grams.

During our initial test, the charge size proved to be too large and caused our airframe to rupture, as seen in the photo below. After speaking with several experts and reaching out to our mentor and other high-powered rocketry specialists, we proceeded with analysis of the test.

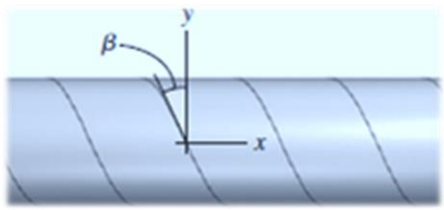
The damage from this test is pictured in the photos below.



Preliminary forensic analysis has been conducted on the failed piece of airframe, with the current working theory being that the parachute compressed, thus created a pressure seal which created significant back pressure. This compression and sealing reduced the volume of our pressurized compartment from 500.9222 in3, as previously calculated, to about 140 in3 and potentially even lower. With a reduction in volume of about 360 in3, this created a significantly higher pressure than expected.

In addition, we suspect that because of the charge’s metal housing and its lack of securing mechanisms, it acted as shape charge against the inner wall of our airframe. This effect is suspected of causing a weakening effect, which when coupled with the over pressurization of the vessel, caused a failure due to hoop and lateral stresses.

Back of the envelope calculations using thin-walled pressure vessel assumptions are conducted in the following lines to provide further insight, particularly as it relates to stress within the walls of the airframe, into the nature of the failure. Certain material properties could not be provided to us by the manufacturer, so material properties are estimated using similar materials and their corresponding properties. The airframe is represented as a spiral wound and welded cylinder as seen in the diagram below.



Given:

$$V_{eff} = 140 \text{ in}^3$$

$$mass_{BP}(grams) = \frac{P_{req}/* V_{eff}}{\left(266\frac{in * lbf}{lbm}\right) * (3307\ R)} * (454\frac{g}{lbf})$$

Rearranging to solve for pressure yields:

$$P_{actual} = \frac{mass_{BP}(grams) * \left(266\frac{in * lbf}{lbm}\right) * (3307\ R)}{\left(454\frac{g}{lbf}\right) * V_{forward\ void}}$$

$$P_{actual} = 48.5\ psi$$

Given:

$$Inner\ Diameter = I.D. = 5.973"$$

$$Outer\ Diameter = O.D = 6.097"$$

$$thickness\ of\ wall = t = O.D. - I.D. = .106"$$

$$angle\ of\ spiral = \beta \approx 15°$$

Substituting this pressure into thin-walled pressure vessel equations yields:

$$\sigma_{hoop} = \frac{pd}{4t} = \frac{48.5\ psi * 5.973"}{2 * .106"} = 1366.465\ psi = 9.42\ MPa = \sigma_y$$

$$\sigma_{long} = \frac{pd}{4t} = \frac{48.5\, psi * 5.973"}{4 * .106"} = 683.232\, psi = 4.71\, MPa = \sigma_x$$

Calculating for normal and shear stresses along the airframe seams:

$$\sigma_{weld,normal} = \sigma_x \cos^2 \beta + \sigma_y \sin^2 \beta = 728.887\, psi = 5.03\, MPa$$

$$\sigma_{weld,shear} = -(\sigma_x - \sigma_y) \sin \beta \cos \beta = 170.782\, psi = 1.18 MPa$$

While the specifics of our Blue Tube airframe’s material properties aren’t available, it is hypothesized that the airframe was compromised by the initial heat and expansion of the charge and then finally torn apart by the resulting pressure wave represented by the above calculations. The initial rupture, which started in between the seam lines which were reinforced with epoxy resin, then carried through the airframe, separating the body at the glued seams.

3.6.3.4 Second Main Ejection Test

After repairing and reinforcing our airframe as detailed in the launch vehicle section, we went back to testing the ejection charges. The methodology was the similar to the initial test, differing only in the implementation of a roller which angled the airframe upward and reduced friction during the test. We used our effective volume of 140 in3 for calculating the size of the charges. In order to ensure safe charge sizes, we started testing at 1 gram of black powder and tested up to 2 grams. The charges used during this test were the nitrile packet charges. The test setup is pictured below.

We observed little difference between the 2 gram and 1.5 gram charge in terms of the deployment of the shock cords and parachute bag. With that in mind, we determined that 1.5 grams was a safe and effective charge size for our main charge, pressurizing the compartment to about 20 psi. 20 psi proved to be reasonably effective in separating the 2 sections and providing sufficient deployment of the shock cord. 2 grams will be our larger secondary backup charge.

3.6.4 Kinetic Energy

Kinetic energy calculations were run again to ensure that our slight changes to airframe weight and chute deployment altitude would not adversely affect or put the airframe in danger. The drogue deployment section of the tables below represents the average kinetic energies that the airframe will experience after deployment of the drogue. The main deployment section represents the same quantities but for the main parachute deployment. Furthermore, these quantitates will represent the energy the airframe will experience at touch down.

Kinetic energy was calculated using

$$E_k = \frac{1}{2}mv^2$$

and was calculated for the average terminal velocities during drogue and main deployment. These values were taken from OpenRocket simulations.

The kinetic energy for the CDR was provided prior the FRR kinetic energy table for referencing purposes.

Kinetic Energy *CDR*		
Drogue Deployment		
	Section 1 (Forward)	Section 2 (Aft)
Mass (g)	4804.000 g	13483.700 g
Mass (lbm)	10.591 lb	29.726 lb
Velocity (m/s)	36.623 m/s	36.623 m/s
Velocity (ft/s)	120.154 ft/s	120.154 ft/s
Kinetic Energy (J)	3221.668 J	9042.467 J

Kinetic Energy *FRR*			
Drogue Deployment			
	Section 1 (Forward)	Section 2 (Aft)	
Mass (g)	4451 g	13129 g	
Mass (lbm)	9.813 lb	28.944 lb	
Velocity (m/s)	38.082 m/s	38.082 m/s	
Velocity (ft/s)	124.941 ft/s	124.941 ft/s	
Kinetic Energy (J)	3227.506 J	9520.092 J	
Kinetic Energy (ft·lb)	2380.462 ft·lb	7021.660 ft·lb	
Main Deployment & Touchdown			
	Section 1 (Forward)	Section 2 (E-Bay)	Section 3 (Middle)
Mass (g)	4451 g	3752 g	8100 g
Mass (lbm)	9.813 lb	8.272 lb	17.857 lb
Velocity (m/s)	4.532 m/s	4.532 m/s	4.532 m/s
Velocity (ft/s)	14.869 ft/s	14.869 ft/s	14.869 ft/s
Kinetic Energy (J)	45.710 J	38.531 J	83.183 J
Kinetic Energy (ft·lb)	33.714 ft·lb	28.419 ft·lb	61.353 ft·lb
Kinetic Energy (ft·lb)	2376.180 ft·lb	6669.380 ft·lb	
Main Deployment & Touchdown			
	Section 1 (Forward)	Section 2 (E-Bay)	Section 3 (Aft)
Mass (g)	4804 g	2385.700 g	9821 g
Mass (lbm)	10.591 lb	5.260 lb	21.652 lb
Velocity (m/s)	3.9627 m/s	3.9627 m/s	3.9627 m/s
Velocity (ft/s)	13 ft/s	13 ft/s	13 ft/s
Kinetic Energy (J)	37.719 J	18.731 J	77.110 J
Kinetic Energy (ft·lb)	27.820 ft·lb	13.816 ft·lb	56.873 ft·lb

Comparing the kinetic energy from the CDR to the FRR, the only section to see a significant increase was the E-bay section at touchdown. It saw an increase of about 100% increase in the kinetic energy going from 13.8 ft·lb to 28.4 ft·lb. While this is relatively large increase in KE, it does not constitute a worry and the airframe should remain within the maximum allowable kinetic energy at touchdown.

The increase in kinetic energy across the board can be attributed to a general increase in the vehicle's mass, particularly after the change made to the E-bay compartment after ground testing. The safety of these kinetic energies has been verified through full scale testing. The airframe has remained in airworthy shape after touchdown during testing.

One additional concern, apart from kinetic energy at touchdown, is the impulse experienced at main chute deployment. The acceleration felt during our full scale test was approximately 65 g's. Impulse is calculated through the following equation.

$$impulse = J_{main\ chute} = \int_{t_1}^{t_2} F\,dt = mv_2 - mv_1$$

The initial and final velocities were pulled from simulation data as well and can be approximated as the difference in descent velocities used above. The mass of concern, as determined from full scale testing, is that of the forward section containing the rover and nosecone.

This yield:

$$J_{main\ chute} = m_{forward\ section}\left(v_{main} - v_{drogue}\right) = 149.331\ N \cdot \mathrm{s}$$

It therefore follows that the nosecone and payload section should be able to sustain an impulse energy of at least 150 N·s or 33.57 lbf·s.

3.6.5 Drift

Drift was calculated again to ensure that changes made since the critical design review, and to verify that expected drift has remained within 2500 ft of the launch site. Drift was calculated using the same equations as in the preliminary design review and critical design review, given below.

$$h = change\ in\ altitude\ after\ chute\ deployment$$
$$v = descent\ rate$$
$$W = velocity\ of\ wind\ acting\ horizontally$$
$$Drift = \frac{h}{v} * W$$

Using simulation data from OpenRocket, the change in altitude and descent rates were found. Wind speed was calculated across the gamut of potential wind speeds on launch day, with the maximum wind speed being 20 mph, the maximum windspeed for which Tripoli Rocket Association recommends for safe launch conditions. Expected wind speed is within the range 9-12 mph.

For the sake of calculating drift in nominal flight conditions, average descent velocity, given by vavg,drogue and vavg,main, is used to calculate nominal drift, assuming nominal deployment of the chutes. The descent distance found from simulation data is denoted by hdrogue and hmain

$$v_{avg,drogue} = 31.9317 \frac{m}{s}$$

$$v_{avg,main} = 10.1386 \frac{m}{s}$$

$$h_{drogue} = 1514.58 \text{ m}$$

$$h_{,main} = 287.31 \text{ m}$$

The values for drift were then calculated for these descent rates and descent distances and then tabulated below.

Nominal Drift (2 ft drogue and 16 ft main)					
Wind Speeds					
Wind Speed (mph)	0 mph	5 mph	10 mph	15 mph	20 mph
Wind Speed (ft/s)	0 ft/s	7.33333 ft/s	14.6667 ft/s	22 ft/s	29.3333 ft/s
Wind Speed (m/s)	0 ft/s	2.2352 m/s	4.4704 m/s	6.7056 m/s	8.9408 m/s
Drogue Drift					
Drift (ft)	0 ft	347.8360 ft	695.6719 ft	1043.5079 ft	1391.3438 ft
Drift (m)	0 m	106.0204 m	212.0408 m	318.0612 m	424.0816 m
Main Drift					
Drift (ft)	0 ft	207.8137 ft	415.6274 ft	623.4411 ft	831.2548 ft
Drift (m)	0 m	63.3416 m	126.6832 m	190.0248 m	253.3665 m
Total Drift (ft)	0 ft	555.6496 ft	1111.2992 ft	1666.9488 ft	2222.5988 ft
Total Drift (m)	0 m	169.3620 m	338.7240 m	508.086 m	677.4481 m

These calculations neglect potential crosswinds at altitude and provide rough approximations. Whilst rough, these approximations do a reasonable job at estimating actual drift.

Provided below is a satellite image of the test launch area, with a line denoting the distance between the Launchpad and touchdown. The drift distance according to the satellite image is approximately 920 feet.

With an approximate wind speed of about 7 mph at our test launch, we were able to linearly interpolate from our table and estimate a nominal drift of about 780 ft. Find the difference between the two values and dividing by the actual drift distance yields a percent error of about 15%. After considering the potential error in meteorological data, it proves to be a reasonable estimate of drift. Assuming an error of +15%, our maximum drift remains under 2500 ft, which occurs at the maximum allowable wind speeds, which we do not expect to be actual launch conditions in Huntsville.

3.6.6 Parachute Size and Decent Rate

Parachute sizes are detailed in the table below. No changes have been to parachute sizes since the

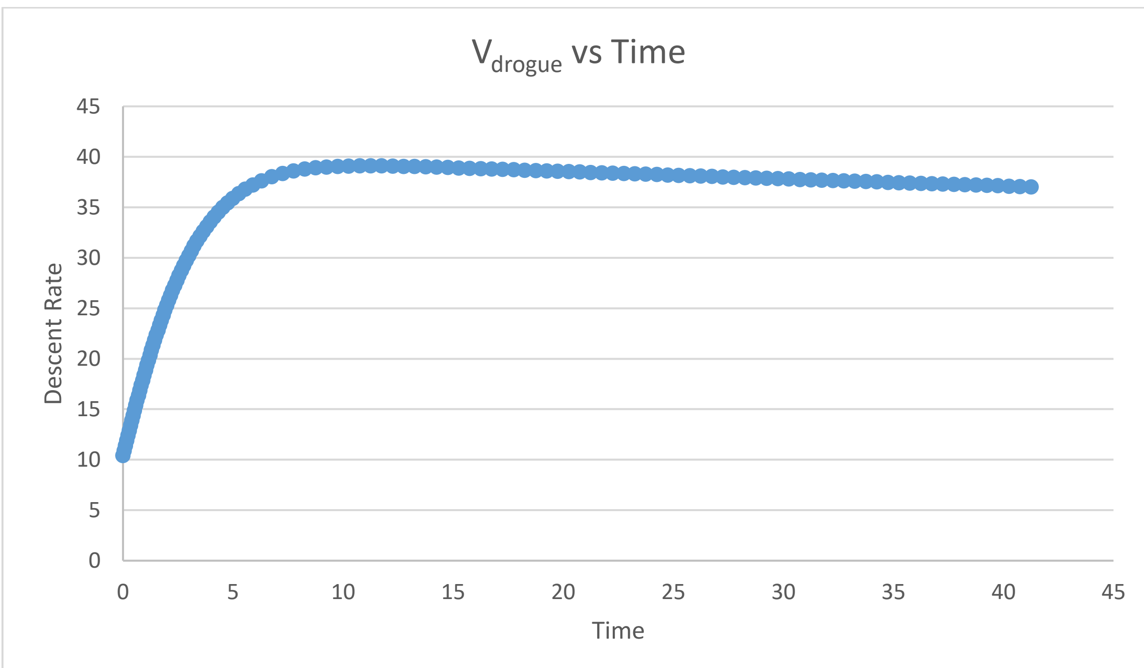
Parachute Sizes			
Drogue Deployment			
	Pilot Parachute	Drogue Parachute	Main Parachute
Size (ft)	2 ft	4 ft	16 ft

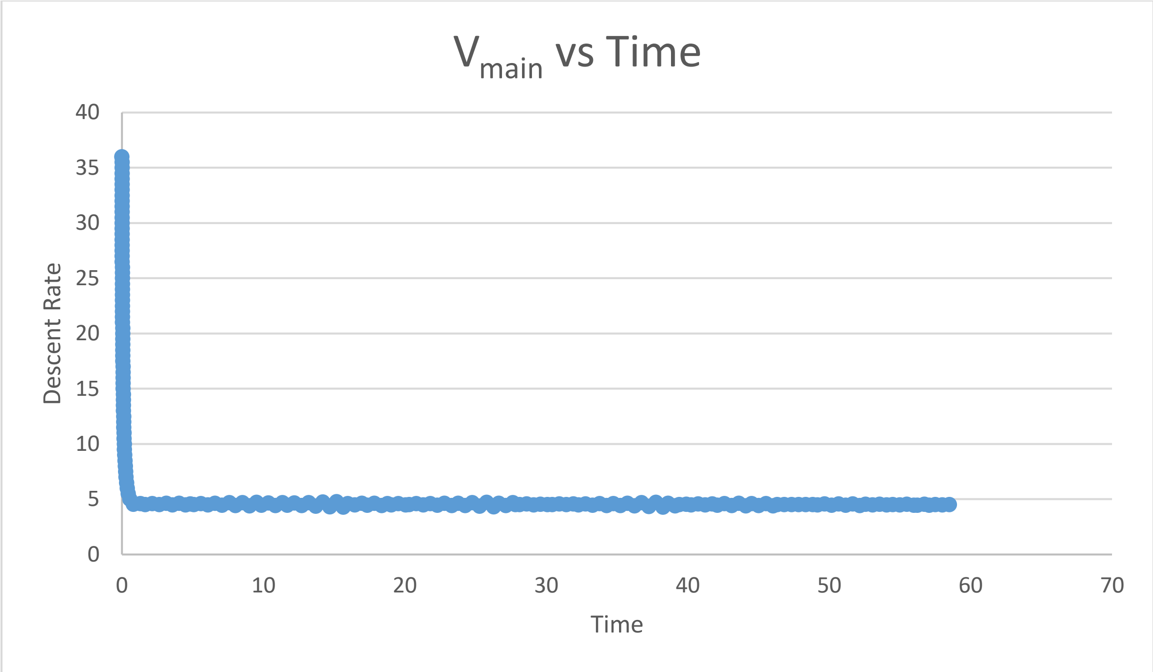
Descent rates have been extracted from simulation data from OpenRocket. Average descent rate was calculated by averaging the decent velocity during the drogue stage and main parachute stage and are denoted below as vavg,drogue and vavg,main.

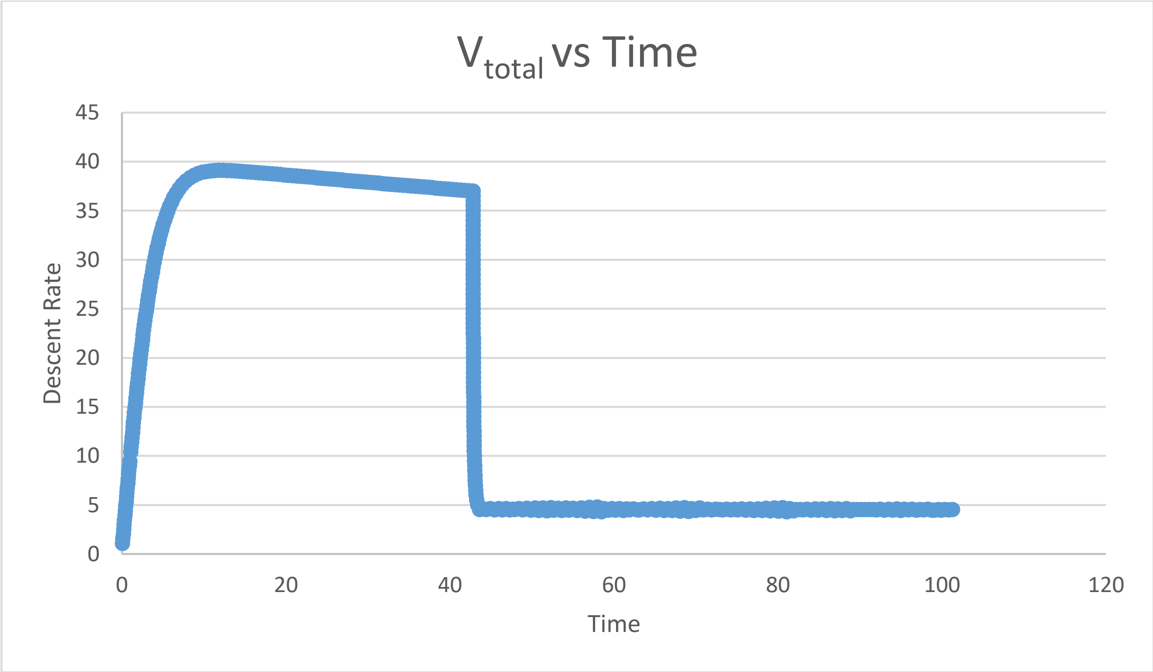
$$v_{\text{avg,drogue}} = 31.9317\frac{m}{s}$$

$$v_{\text{avg,main}} = 10.1386\frac{m}{s}$$

Descent rates for the drogue stage, main parachute stage, and both stages vs time is plotted below. The plotted data was simulated in OpenRocket.







Descent rates for the drogue stage involves the acceleration from roughly 0 ft/s to, at apogee, to the terminal velocity of the system with the chute deployed. Descent rates for the main stage involves the deceleration from that terminal velocity to the final velocity. Note the immediate change in velocity, or rapid deceleration, that occurs at main deployment. This acceleration is addressed in the kinetic energy calculations.

3.7 Mission Performance Predictions

Throughout the course of this project, Open Rocket has been our main source of accurate simulation data for Raider I and Raider II. As in the PDR and CDR, our team had to validate the results of our Open Rocket simulation in the following section of the FRR. Though changes to Raider II were made in the days leading up to the actual launch, simulation data was continually updated as modifications were made.

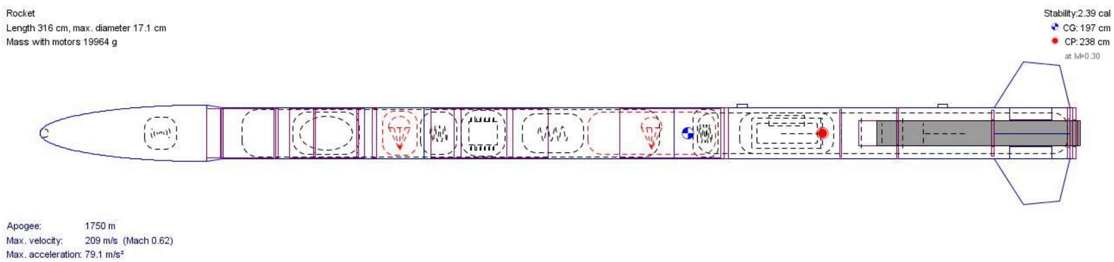


Fig 3-32

3.7.1 Flight Profile

The desired flight profile of the Raider 2 follows a flight profile that is very typical for high powered rockets, with an added stage for apogee correction. This is laid out in the bullets below:

- Safe motor ignition
- Motor burnout
- Dynamic apogee control
- Apogee and drogue deployment (5280 feet AGL)
- Main deployment (1000 feet AGL)
- Touchdown
- Nose cone separation
- Rover deployment

3.7.2 Drag Characteristics

From data received in Open Rocket, the drag coefficient for Raider II came out to be 0.41 after the updates made to the rocket in the days leading up to the FRR. Each component of Raider II was simulated to find the total drag coefficient of the full rocket. From this we were able to make the table listed below from Open Rocket of each section and the rocket as a whole. The equation that the program used was:

$$C_{D_0} = \left(\frac{A_{component}}{A_{ref}}\right) * C_{D_i}$$

Stability | Drag characteristics | Roll dynamics

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose cone	0.02 (5%)	0.00 (0%)	0.03 (8%)	**0.05 (13%)**
Transition	0.00 (0%)	0.00 (0%)	0.00 (1%)	**0.00 (1%)**
Payload Section	0.00 (0%)	0.00 (0%)	0.05 (11%)	**0.05 (11%)**
E-Bay Section	0.00 (0%)	0.00 (0%)	0.06 (14%)	**0.06 (14%)**
Aft Section	0.00 (0%)	0.11 (26%)	0.09 (23%)	**0.20 (49%)**
Freeform fin set	0.01 (3%)	0.00 (0%)	0.03 (7%)	**0.04 (10%)**
Launch lug	0.00 (1%)	0.00 (0%)	0.00 (0%)	**0.00 (1%)**
Launch lug	0.00 (1%)	0.00 (0%)	0.00 (0%)	**0.00 (1%)**
Total	**0.04 (9%)**	**0.11 (26%)**	**0.27 (65%)**	**0.41 (100%)**

Fig 3-33

When looking deeper into the methods Open Rocket used to calculate the coefficient of drag, a problem was noticed that could affect our mission predictions if not addressed or acknowledged. The software does not allow for the different material properties affecting drag to be included. Knowing our surfaces were not the idealized versions that Open Rocket had assumed, our team ran simulations of for the coefficient of drag using our full assembly AutoDesk Inventor file with the material properties used in each section included.

A supplemental program titled AutoDesk Flow Design allowed the Raider II model to be placed directly into a simulated wind tunnel where plots of the coefficient of drag were plotted over time. The settings in the program did not allow for a fluid speed over 150 $\frac{m}{s}$ the be modeled. To confirm that our coefficient of drag at 200 $\frac{m}{s}$ would be similar to the one at 150 $\frac{m}{s}$, multiple plots of drag were done at different speeds to test for convergence with respect to the Reynolds number. The plots at 100 $\frac{m}{s}$, 125 $\frac{m}{s}$, and 150 $\frac{m}{s}$ are shown below.

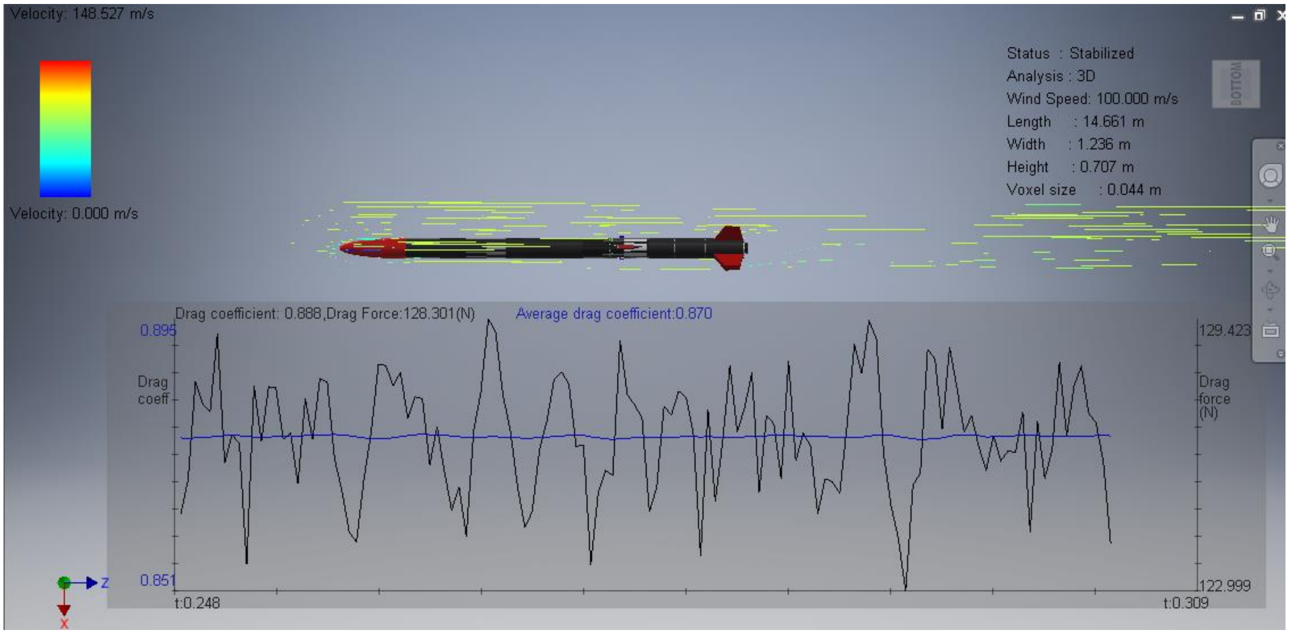


Fig 3-34

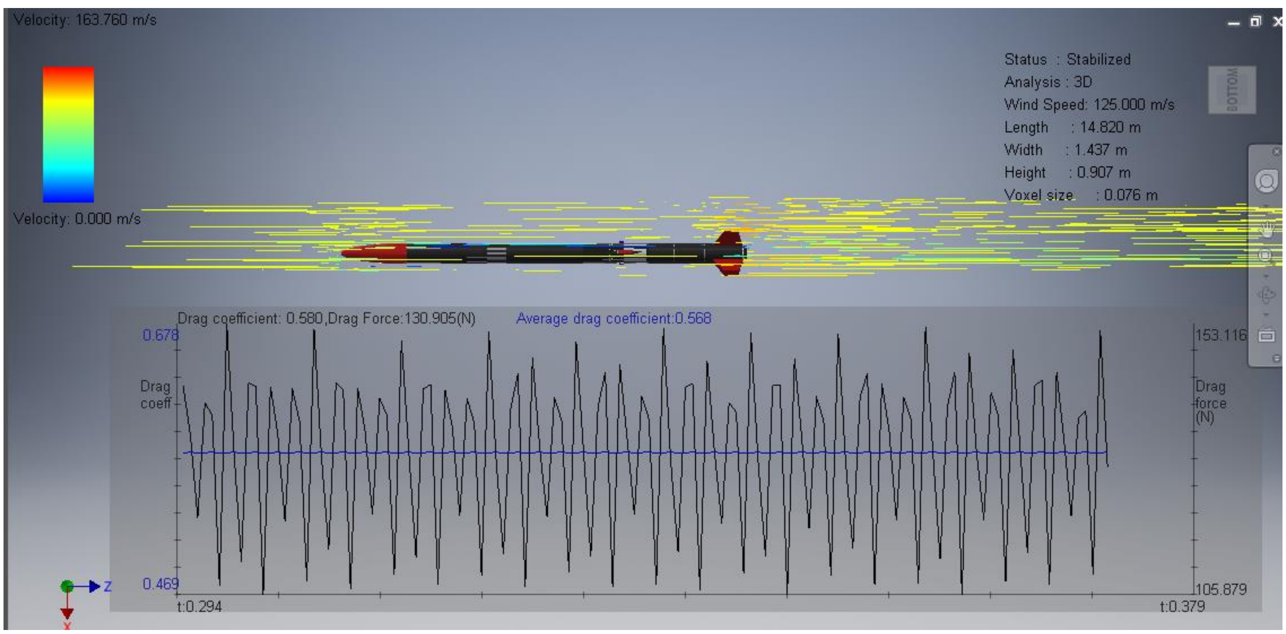


Fig 3-35

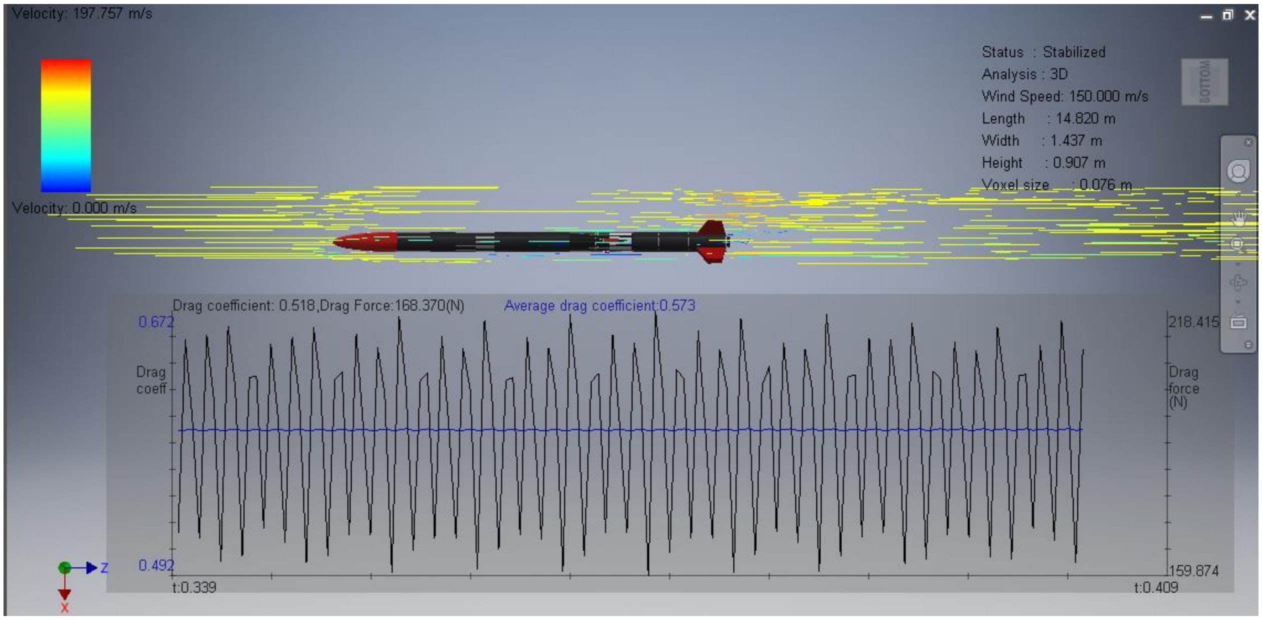


Fig 3-36

From the results of these plots, it can be inferred that the coefficient drag does indeed coverage at speeds over 125 $\frac{m}{s}$. At 100 $\frac{m}{s}$ the coefficients of drag came out to be 0.87, but at both 125 $\frac{m}{s}$ and 150$\frac{m}{s}$ the coefficients of drag came out to be 0.57. After more simulations, our team felt comfortable in inferring a linear relationship after reaching a speed of 125 $\frac{m}{s}$. So, at 200 $\frac{m}{s}$, our coefficient of drag predicted in AutoDesk Inventor comes out to be 0.57.

There are other methods such as altitude backtracking that could have been used to confirm the results above. Since tools to do these other methods were not available to our team at the current moment, the most accurate prediction of what our coefficient of drag will actually be is an average of Open Rocket and AutoDesk Inventor. Our final estimate of the actual drag is:

$$C_D = \frac{Open\ Rocket + AutoDesk}{2}$$

$$C_D = \frac{0.41 + 0.57}{2} = 0.49$$

3.7.3 Simulation Data

The Open Rocket simulation data for Raider II was plotted on the graph in figure ***** below. The predicted apogee shown came out to be 1806 m without the Dynamic Apogee Control System activated. Maximum acceleration comes out to be 79.1$\frac{m}{s^2}$ and the maximum velocity achieved will be Mach 0.62 (195 $\frac{m}{s}$). This velocity falls under the maximum allowable given the mission profile of Mach 1.

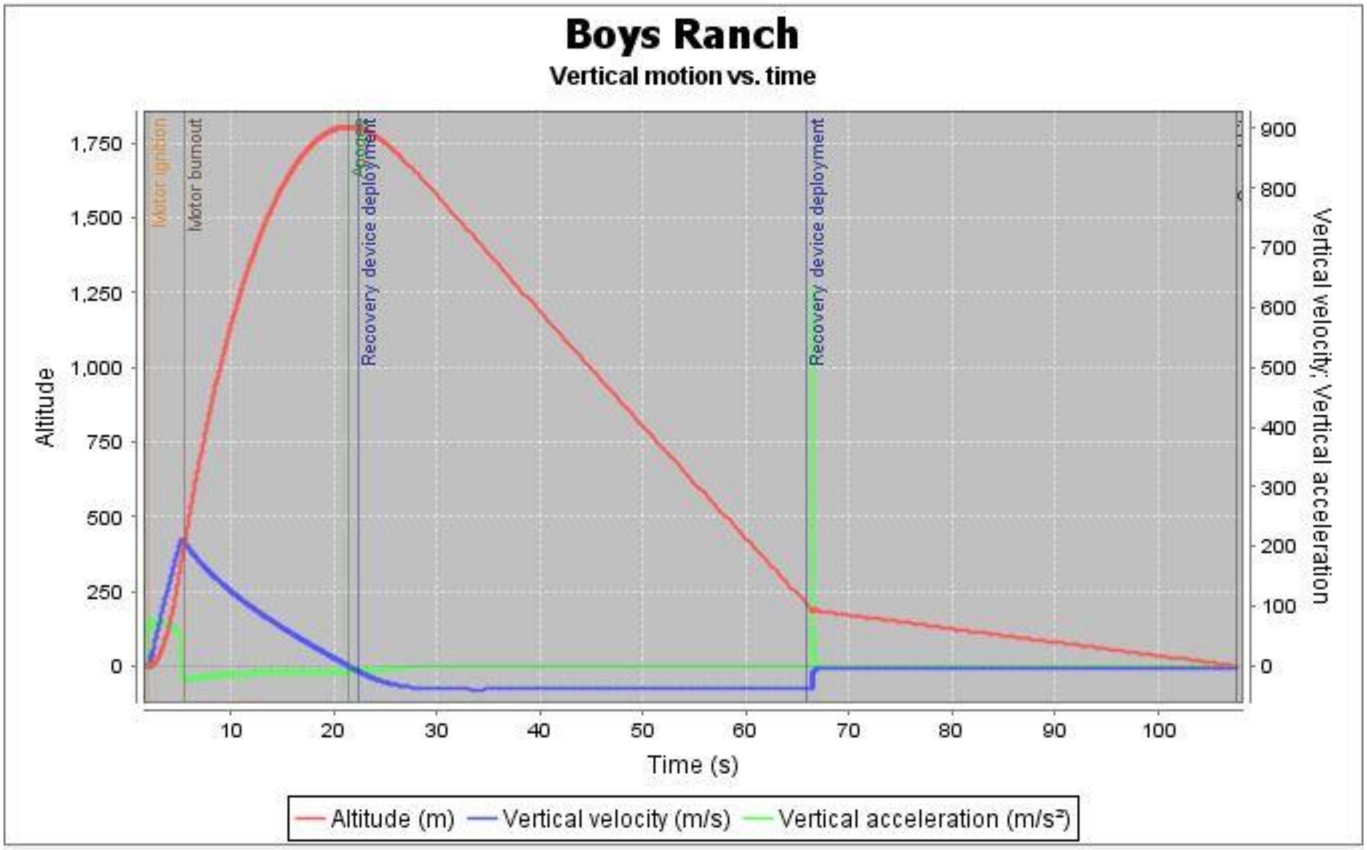


Fig 3-37

The Center of Pressure (C_p) and the Center of Gravity (C_G) were also predicted in Open Rocket. Utilizing the Barrowmen Equations shown below, our team was able to find that Raider II will be stable even with the changes done since CDR.

$$d = diameter$$

$$Stability\ Factor = \frac{C_P - C_G}{d}$$

$$Stability\ Factor = \frac{238\ cm - 197\ cm}{15.24\ cm} = 2.69$$

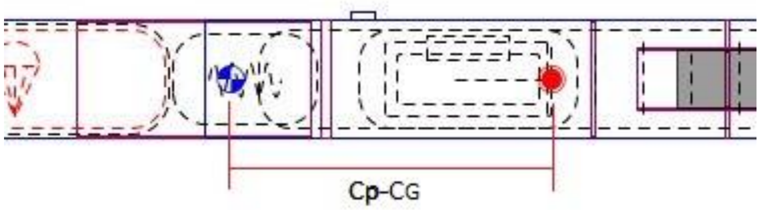


Fig 3-38

The thrust to weight ratio was calculated for Raider II by the equation listed below. The previous calculation done for this in the CDR of 7.66 was updated due to the changes made for the FRR. The new thrust to weight ratio is calculated below.

$$Thrust\ to\ Weight\ Ratio = \frac{Average\ Thrust}{Weight}$$

$$Thrust\ to\ Weight\ Ratio = \frac{1395\ N}{19.96\ kg * 9.81\frac{m}{s^2}} = 7.12$$

To meet all the mission requirements, rail exit velocity as well was calculated in Open Rocket. Our shown rail exit velocity came out to be 63.65 fps which is above our needed 52 fps. All together our simulations show that all of mission requirements will be reached by Raider II.

Additional simulations have been run using weather data modelling Huntsville AL to compare the flight characteristics to that of the local Boy's Ranch launch site and determine the amount of ballast weight that is required to bring the apogee down to 1650 meters, or, 5,400 feet in Huntsville. The predicted apogee of the launch vehicle in the same configuration that was launched for the first test, is 1754m, 5754 feet, in Huntsville AL. Updating this Huntsville specific simulation file to 5,400 feet at apogee predicts a necessary ballast weight of 2.67 lbf which puts overall weight on the pad at 46.76 pounds. 5,400 feet is the desired apogee because it is below the FAA waiver ceiling of 5,600 feet, and still above the 1-mile target. This leaves the on dynamic apogee control system (DACS) room to correct the actual apogee and ensures the rocket does not exceed the limit. The simulated data for 2.67 pounds of ballast weight in AL is shown in the graph figure 3-39 below:

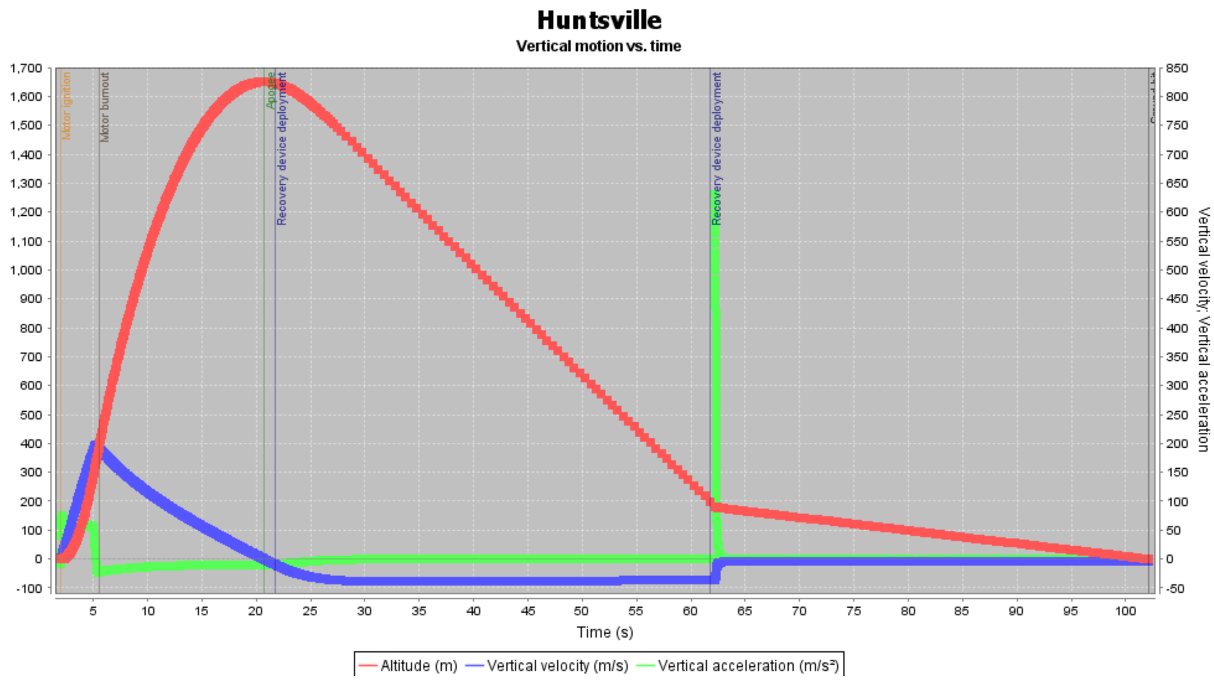


Fig 3-39

3.7.4 Modeling and Scaling Factors:

As shown in the CDR, comparing our subscale and full-scale rockets already assumes a distorted model. This means that not every variable will be accounted for or scaled when predicting the flight outcomes of our full-scale rocket. For example, our team could not scale the density of air or gravitational acceleration. Acknowledging that this is a distorted model simply means that we should expect some level of error in our similitude equation's results. Even with this build in error, the predicted outcomes for the full-scale were in shockingly close to our simulation in open rocket. These results will be shown after a quick refresher on how these similitude equations were written.

In transforming all the geometries form the full scale to the subscale, each length was transformed by a factor of three. This translated to having a scaling factor of:

$$k = \frac{1}{3}$$

For the powered flight portion of our rocket launch, the equation generally used for acceleration is:

$$a = \frac{T - D}{m} - g$$

With T being the thrust of the engine, D being the drag force, m being the mass of the rocket, and g being acceleration due to gravity. Both our subscale and full scale use this acceleration equation with the thrust and drag force equations listed below.

$$T = [\rho_e V_e^2]A_c$$

$$D = \frac{1}{2}C_D \rho V^2 A$$

If the density and velocity at the exit of our engines comes out to be similar, it can be inferred that our area is proportional to thrust. This same principle can be applied to the drag force too as it is also proportional to area. Both k factors in the previous two equations come from the fact that area is just a length squared. Since k is a length relation, it would have to be squared for similitude to translate. The equations of similitude for thrust and drag force comes out to be:

$$T_{ss} = k^2 T_{fs}$$

$$D_{ss} = k^2 T_{fs}$$

For the mass relation between the full and sub scales, it was important to realize that mass is dependent on volume and not area. Placing this principle into math, the equation of similitude for the mass come out to be:

Now we are left with three equations for the variables in our previous acceleration equation. It is now possible to relate the acceleration during the powered portion of our flight between our subscale and our full scale.

$$a_{ss} = \frac{k^2\left(T_{fs} - D_{fs}\right)}{k^3 m_{fs}} - g$$

Performing a bit of algebra, we are left with the following similitude equation:

$$a_{ss} = \frac{1}{k}\frac{\left(T_{fs} - D_{fs}\right)}{m_{fs}} - g$$

The next step of our analysis is extremely interesting but is entirely dependent on our subscale and full-scale rockets both having the same fuel chemistry. The first equation listed below is the similitude equation for the mass of the fuel for each engine. This is the same equation which was used for total mass above, but for the next step in the analysis this mass will be referring to total fuel mass. Moving forward with the assumption that the motors do have the same or a negligible difference in chemistry, the mass flow rate for the full scale would come out to be the second equation listed below.

$$m_{ss} = k^3 m_{fs} \ (total\ fuel\ mass)$$

$$\dot{m}_{fs} = \rho_e V_e A_{fs}$$

A similitude equation for the subscale can also be derived from the logic used in the thrust similitude equation above. Since the velocity and fuel density of the two engines is assumed to be similar, the equation can again be seen to depend only on area and a k squared similitude equation for the mass flow rate can be derived as seen below.

$$\dot{m}_{ss} = k^2 \rho_e V_e A_{fs}$$

$$\dot{m}_{ss} = k^2 \dot{m}_{fs}$$

The final step in this analysis is using the similitude equations for total fuel mass and mass flow rate to create a similitude equation for the time of engine burnout. By dividing the total mass by the mass flow rate, our time of burn of can be calculated for the large scale and by similitude to the subscale model.

$$(t_{burnout})_{fs} = \frac{m_{fs}}{\dot{m}_{fs}}$$

$$(t_{burnout})_{ss} = \frac{k^3 m_{fs}}{k^2 \dot{m}_{fs}}$$

$$(t_{burnout})_{ss} = k(t_{burnout})_{fs}$$

The final phase of this analysis comes in the coasting phase. The velocity at the time of burn out for the both scales should come out to be the same in this idealized model. This conclusion derives itself in the fact that the acceleration due to thrust of each engine is so much greater than the acceleration due to gravity that the gravity term can be neglected. After the gravity term is canceled out, multiplying the acceleration of the rocket and the time of burn out cancels out the scaling factor thus the velocity of the subscale and full-scale should be the same at time of burnout.

$$\frac{T_{fs} - D_{fs}}{m_{fs}} \gg g$$

$$a_{ss} = \frac{1}{k} a_{fs}$$

$$V_{ss} = a_{ss} t_{ss} = \left(\frac{1}{k} a_{fs}\right)\left(k t_{fs}\right) = V_{fs}$$

$$(V_{ss})_{bo} = \left(V_{fs}\right)_{bo}$$

The heights at burnout are very different for the subscale and the large scale. From the first equation below, the initial velocity of zero for both the full and sub scale. This causes the equation to become just the acceleration part and transforms it into the following equation.

$$\Delta h = V_i t + \frac{1}{2} a t^2$$

$$(h_{bo})_{fs} = \frac{1}{2} a_{fs} (t_{bo})_{fs}^2$$

$$(h_{bo})_{ss} = \frac{1}{2}\left(\frac{1}{k} a_{fs}\right)(kt_{bo})_{fs}^2$$

$$(h_{bo})_{ss} = k\frac{1}{2}(a_{fs})(t_{bo})_{fs}^2$$

The last two steps of this the analysis comes from the combining the terminal velocity of the rocket body during the coasting phase with an equation for the apogee of the full scale and the subscale. This final equation gives a way in which height and engine data from the scale model test can be used to determine the coefficient of drag for the full scale.

$$V_{term} = \sqrt{\frac{2mg}{\rho A C_d}}$$

$$h_{apogee} = h_{bo} + \frac{V_{term}^2}{2g} \ln\left(1 + \left(\frac{V_{bo}}{V_{term}}\right)^2\right)$$

$$\left(h_{apogee}\right)_{ss} = k\frac{1}{2}(a_{fs})(t_{bo})_{fs}^2 + \frac{2m_{fs}}{k\rho A_{fs}(C_d)_{fs}} \ln\left(1 + \frac{V_{bo}^2 \rho (C_d)_{fs} A_{fs} k}{2m_{fs} g}\right)$$

This final equation had to be transformed in order to switch the input data from full scale to small scale. Allowing for the recorded data from our small-scale test to be plugged into the equation to predict our full-scale performance. After transformation, the resulting equation came out to be:

$$\left(h_{apogee}\right)_{fs} = \frac{1}{2k}(a_{ss})(t_{bo})_{ss}^2 + \frac{2m_{ss}k}{\rho A_{ss}(C_d)_{ss}} \ln\left(1 + \frac{(V_{bo})_{ss}^2 \rho (C_d)_{ss} A_{ss}}{2m_{ss} g k}\right)$$

Utilizing a simple Matlab code listing the recorded data from the sub-scale launch and the equation shown above, the predicted apogee of the full-scale rocket is shown in figure 3-40 below.

```
Command Window
  The Predicted Height of Raider 2 will be 1619.32 meters.
  The Predicted Height of Raider 2 will be 1.0062 miles.
  The Predicted Height of Raider 2 will be 5312.7 feet.
fx >>
```

Fig 3-40

Error between the similitude equations and the predicted results in Open Rocket was small considering how idealized the similitude equations had to be. With an open rocket predicted apogee of 1806 m, the percent error came out to be:

$$\%\ Error = \left|\frac{Open\ Rocket\ Value - Similitude\ Value}{Open\ Rocket\ Value}\right| * 100\%$$

$$\%\ Error = \left|\frac{1806\ m - 1619.32\ m}{1806\ m}\right| * 100\% = 10.34\%$$

Before the events which lead to changes in our body tube and nose cone, the percent error was just over 1%. If the rocket hadn't had these changes, our similitude equation would have been spot on for predicting our real-world apogee. Due to the fact that final geometry of Raider II had differed from the simulated geometry of Raider I the similitude equation was not able to as accurately predict the apogee of Raider II. All-in-all the percent error was in an exciting range for our team to see. It is low enough that our team can trust the results of this equation and our Open Rocket apogee.

3.8 Full Scale Flight

The Launch Raider II was carried out on March 3rd, 2018 roughly forty-eight hours after recovering from a catastrophic failure during ground testing. The test was ran in the last possible launch window after being delayed a week and two days due to high winds and unforeseen adversities. The primary motive of the test launch was to gather flight data, ensure stability, and determine the overall altitude cap possible of the launch vehicle as-constructed to optimize the design and determine the amount of additional weight to add as ballast.

Fig 3-41 Pretty Picture

3.8.1 Launch Day Conditions

Weather condition table	
Temperature (F)	39
Altitude (ft)	3400
Wind (mph)	6
Wind Direction	SW
Condition	Clear
Visibility (mi)	10

3.8.2 Preform an Analysis of the Full Scale Flight

The flight profile of this test flight was simpler than the final test, and thus there are plans for a second test launch in the coming month before final launch in Alabama to test on-board systems and payload integration. Overall, all events; Ignition, liftoff, burnout, drogue deployment, main deployment, and touchdown were carried out successfully. There was only one issue that is being addressed, concerning the mounting of the nose cone to the airframe. Due to payload simulation mass sliding against the cone coupler during main deployment, the shear pins were pre-maturely broken. More information on this testing issue can be found in the Testing section of the document. Nevertheless, the vehicle was successfully recovered and is being upgraded with systems and reinforcements in preparation for the next flight.

3.8.2.1 Compare the Predicted Flight Model to Actual Data

The results of the full-scale flight and the simulation data are very similar, with 2% margin of error, which was shown in the sub-scale launch as well. This was determined by comparing the achieved altitude of 6065 feet, and the estimated 5944 feet. The data and plotted altitude given from the simulation can be found in the mission predictions section, while the plotted graph with altitude data was extracted from the Strato-logger on-board altimeter is found in figure 3-42.

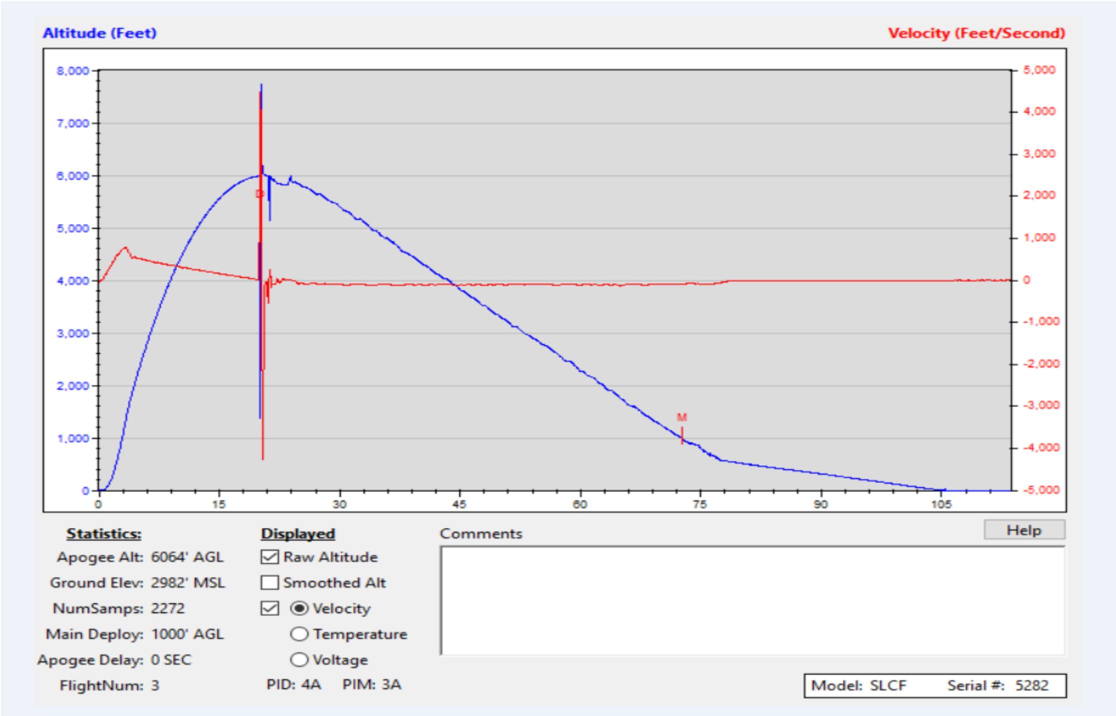


Fig 3-43

3.8.2.2 Comparison between Full-Scale and Sub-Scale

The two launches showed relationships in more ways than just one. While the most obvious similarity is the 1/3 geometric scaling of the fins, nose cone, and airframe diameter, there was also correlations that are reflected in the recovery system, test procedures, and flight plan. The non-conventional recovery system orientation of having the drogue chute in the front and main in the rear was tested in the sub-scale and proven to work and thus implemented in the large scale. The flight plan was identical as well, with only greater altitudes at events to account for in the large-scale flight. Everything from the building process to data acquisition has been done before with the sub-scale and it has been a great benefit to have that experience going into the full-scale phase of the project.

4. Payload Criteria

4.1 Changes Since CDR

Axles changed from smooth pins to threaded screw design.

- After discovering the difficulty of tolerancing 3D printed plastic, a threaded insert was placed in the axle-holes in the chassis, where the axle was screwed into. This provided the ability to remove axles and wheels for adjustments.

Motor mounting method reversed based on received parts

- Upon receiving the wheel motors, it was discovered that they rotated in an unexpected way. The entire shell of the motor rotates instead of just the shaft. As a result, the mounting plates to the rover chassis were redesigned.

Radio transmissions now occur in series based on received parts

- Upon receiving the radio receivers and transmitters from CDR, the dimensions were twice those provided in documentation, resulting in a receiver that was effectively four times the footprint of what was expected. As a result, the original radio receiver would not fit on the rover. The Arduino now powers a short range transmitter between the rear payload and the rover.

Decreased number of solar panels based on received parts

- Solar panels received were significantly thicker than anticipated. To fit other required electrical components, the rotating plates that hold the solar panels were decreased to one solar panel each.

Bayonet joint changed to winch style wire to pull the bearing pin

- Tolerances on 3D printing made rigid connections of the type for the bearing pin release assembly extremely ineffective. Instead, the bayonet rotates and "winds up" a plastic wire, similar to a winch. This wire then pulls down the bearing pin to release the bearing.

Servo mounted on bayonet bearing instead of back plate.

- The decision to mount the bayonet servo on the centering weight rather than the rotating portion of the back bearing was an oversight in the design process, which was revealed during fabrication. If the bayonet was mounted to the centering weight, the bearing would rotate in relation to the bayonet after release, possibly relocking the rover within the housing. By mounting the bayonet and servo to the bearing, these parts rotate with the bearing, allowing the rover to release.

Used threaded fasteners for counterweight and housing to prevent failure of connections

- Counterweight is now mounted to the housing platform with screws to prevent any motion and increase safety. In addition, the housing is mounted to the coupler and airframe via screws because it will be experiencing thrust loads.

4.2 Unique Features of Payload

4.2.1 Rover Housing

The payload team constructed the rotating bearing housing with a cross-section exit. The rotating bearing housing provides a way for the rover to deploy in any orientation. The rover is constrained to the inside of the rotating bearing by a bayonet pin as well as the ramp, which is flush with the blast plug, and the back plate of the bearing. After landing, the inner races of the bearings will be released from the bayonet pins and will be free to rotate. A counterweight underneath the rover provides the torque required to rotate the bearings to the correct orientation. The rover will rotate with the inner races of the bearings and drive out of the cross-sectional exit after landing.

4.2.2 Rover Chassis

The rover chassis will consist of seven different pieces that will be secured together by utilizing a system of "tabs" which allow the use of 2-56 screws and threaded inserts to join the pieces. Each piece of the chassis will be 3-D printed and will be made off ABS plastic. This method of joining the pieces can be visualized in figure 4-1, which shows the chassis put together (not including the top or back panel of the chassis). This chassis will be driven by four brushless motors that will be attached to the left and right side walls respectively (C1 and C2), and will use an ultrasonic sensor, attached to the front plate (C6), in order to efficiently detect and avoid obstacles as the rover comes upon them. The top panel (C3) will act as a cover for all of the electronics, as well as support the solar panel deployment system and the receiver small holes will be drilled into the top panel to allow for wiring. The Arduino microcontroller will also be on the top of the rover, connected between the left and right side walls (C1 and C2). The ESC is constrained within the body of the chassis. The battery for the electronics and motors is constrained by the bottom panel. Electronic components are secured to the chassis either by the shape of the chassis itself, or by screws that were provided by manufacturers. The back plate of the chassis (C7) will be used to secure the bayonet fitting, which will be explained in detail in later sections, preventing the rover and bearings from rotating during flight to avoid destabilization. The axles of the rover extend past the wheels and will slide along the rails of the housing that will act as constraints during flight and guiderails after landing.

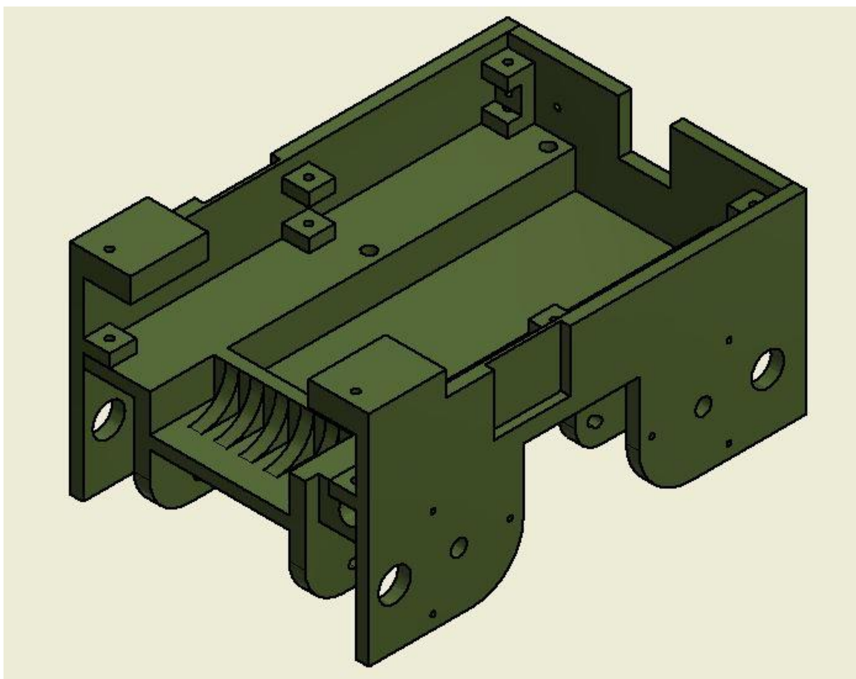


Figure 4-1: Rover Chassis

4.2.3 Rover Drivetrain Method

The drivetrain system is required to have control over the rover velocity and be able to climb over small dirt hills. The use of brushless motors requires an alternating current to be supplied. Since Arduino microcontrollers can only output DC, an electronic speed controller is used. The electronic speed controller allows a great deal of control over the throttle and response of the motors. Specifically, properties such as start-up power, maximum and minimum throttle, and motor direction were edited through the ESC. After the ESC provides power to the motor, the motors transmit power through a 4:1 gear reduction to the wheels. The motors are attached to the undercarriage of the rover. Each wheel contains a large spur gear inside of it and acts as a cover, protecting the gears from interference from dirt and dust as shown by Figure 4-2. Each wheel contains a bearing allowing it to rotate freely around the axle pin. The axles are screwed into the chassis of the rover, and do not rotate with the wheels.

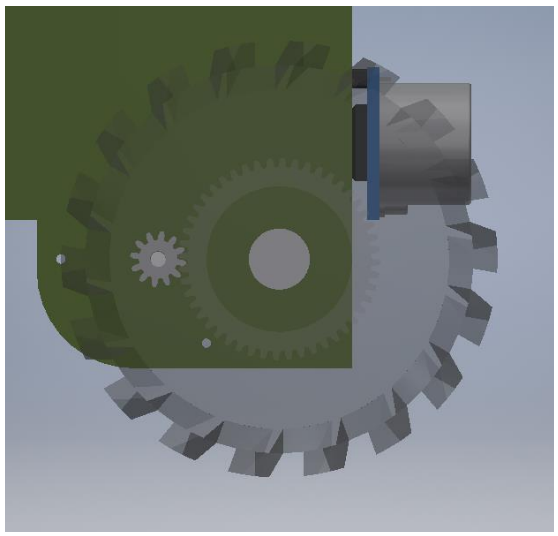


Fig 4-2: The drivetrain for the front right wheel is show inside of the wheel

4.2.4 Rover Steering Methods

The limited space inside the rocket limited the options for a steering system. The motors can only turn in one direction, so the rover steers by alternately powering both left motors or both right motors. The rover cannot make a zero-point turn with this method, but still has a sufficiently small turning radius to be able to avoid obstacles.

4.2.5 Wheel Design

The wheels (C10) for the rover serve two purposes, to provide the rover with traction and house the drive train. The wheels are designed to rotate around a stationary axel pin (C8) by using two ball bearings placed in the center of the wheel. The 2.25 in diameter of the wheels adds to the rover's power to transverse uneven terrain. The elevated chevron tread pattern yielded the best results in tests by giving the rover the most traction in loose soil. The team added a slight chamfer to allow the wheel to be able to fit inside the rover housing.

The wheels each house an individual drive train connected to its own motor. The spur gear (C11) attached to the inside of the wheel seen on the right of Figure 4-3. Each wheel was 3-D printed out of high-density ABS plastic with dissolvable supports. Two different versions of the wheel were created (C9 and C10) to account for tread pattern on the left and right sides of the rover.

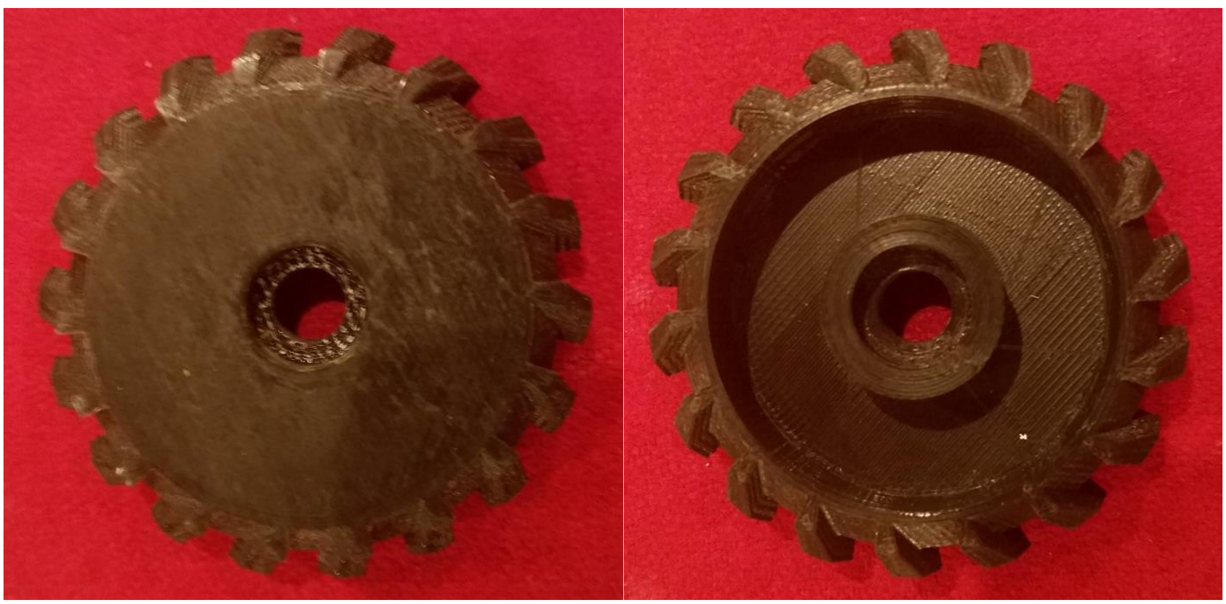


Figure 4-3: Front and back surfaces of the wheels.

4.2.6 Solar Panel Deployment

The solar panel deployment takes place using two servos. Each servo controls one solar panel, which are mounted on hinges. Since servos are low speed and high torque, they are ideal for this style of solar panel deployment. The chosen servos (GoolRC Micro 3.7g servo) have 0.65 kg*cm torque capacity, which is more than enough to deploy an individual solar panel. This has been confirmed in both analysis and testing. The solar panels attached to the rover can be seen in Figure 4-4, which shows one deployed solar panel and one undeployed solar panel.

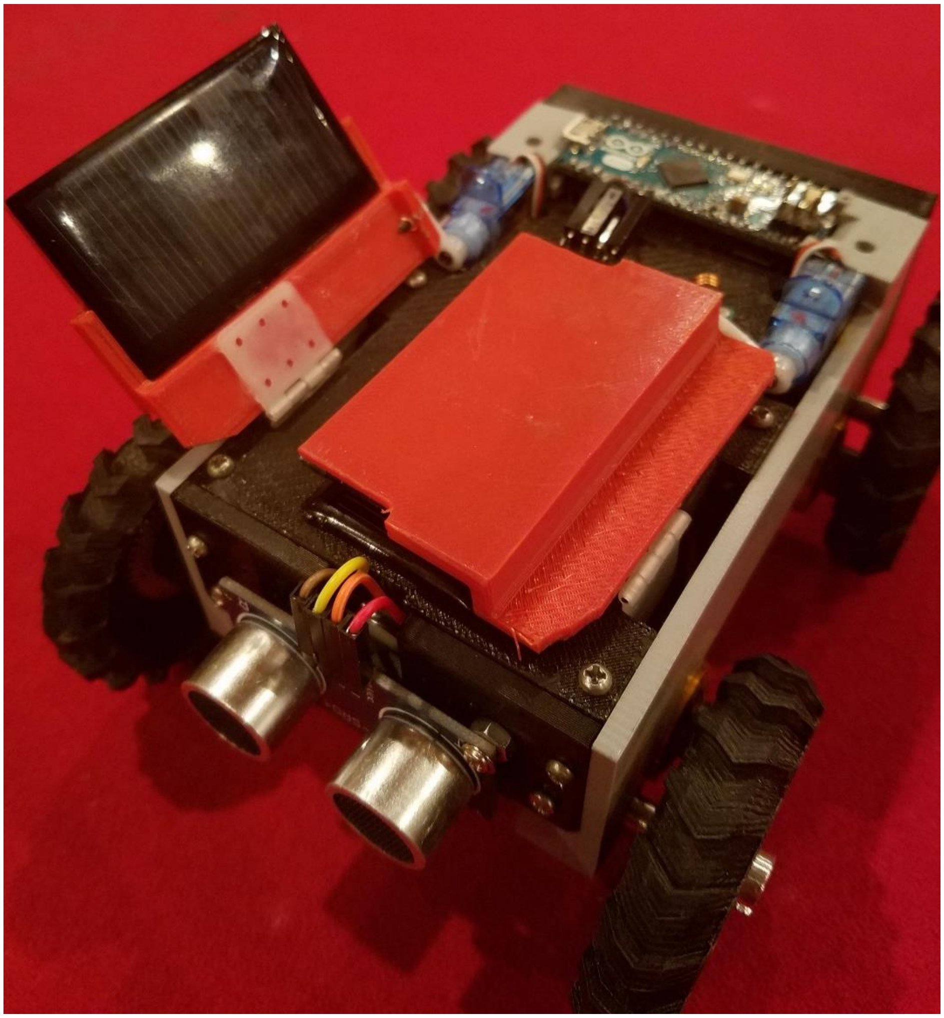


Figure 4-4: Rover Solar Panels

4.2.7 Bayonet Fitting

The bayonet fitting was mounted to the Bayonet Bearing, and can be seen in Figure 4-5 Its purpose is to hold the inner and outer races of the Bayonet Bearing (and by extension, the Exit Bearing) in the same orientation during launch. After the rocket has landed, a signal from an Arduino on the Rear Payload Assembly will command the Bayonet Servo to pull the pins from the outer race. At this point, the counterweight will cause the inner races of the bearings to rotate towards the correct orientation for rover deployment. The Bayonet Servo rotates with the inner race, and the extra slack in the wires prevents the servo from impeding the motion of the bearings.

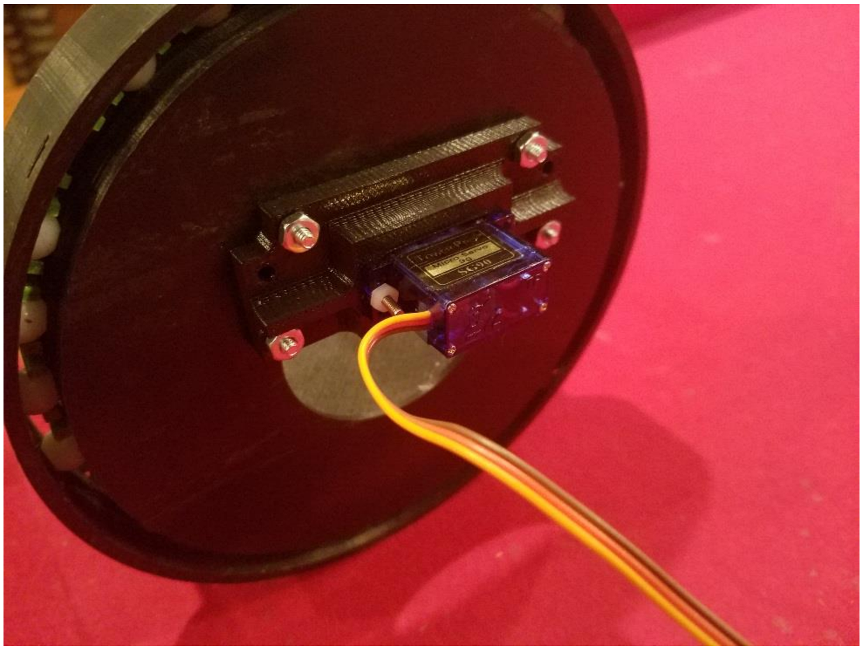


Figure 4-5: Bayonet Fitting Rear View

4.2.8 Rear Payload Assembly

The rear payload assembly contains many of the electronic components required for the transmission of a remote signal from the spectator zone to the landing zone. This assembly can be seen in Figure 4-6. A wiring diagram can be seen in Figure 4-7. The team will send a 433MHz long-range radio transmission from a remote control. This radio transmission is linked to a long-range receiver in the rear payload assembly. The radio receiver will only pick up transmissions from the specific remote control that it is linked to. The radio receiver is powered by a 12V battery, and a resistor circuit that provides a location for the Arduino to read a voltage from. When the radio receiver sends a signal, the Arduino picks it up and sends a password transmission to the 315MHz transmitter. The password is transmitted to a short-range radio receiver on the rover, which compares the password to its stored value. If they are the same, the rover pauses for a four second delay before it begins driving. During this pause, the Arduino in the rear payload assembly provides a signal for the Bayonet Servo to disengage from the outer race of the Bayonet Bearing. The housing bearings take less than one second to rotate to the correct orientation, so the rover will not begin driving until it is in the correct orientation.

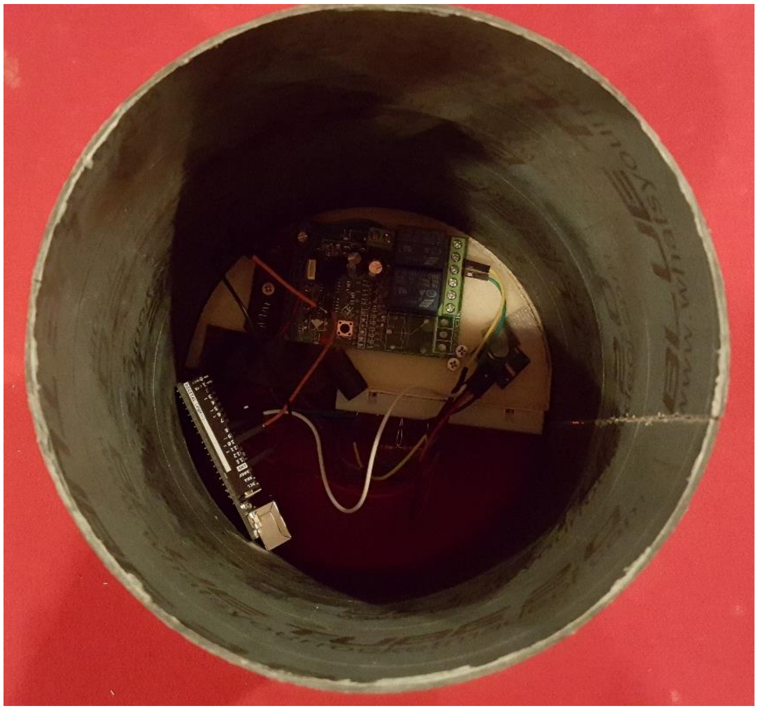


Figure 4-6: Rear Payload Assembly

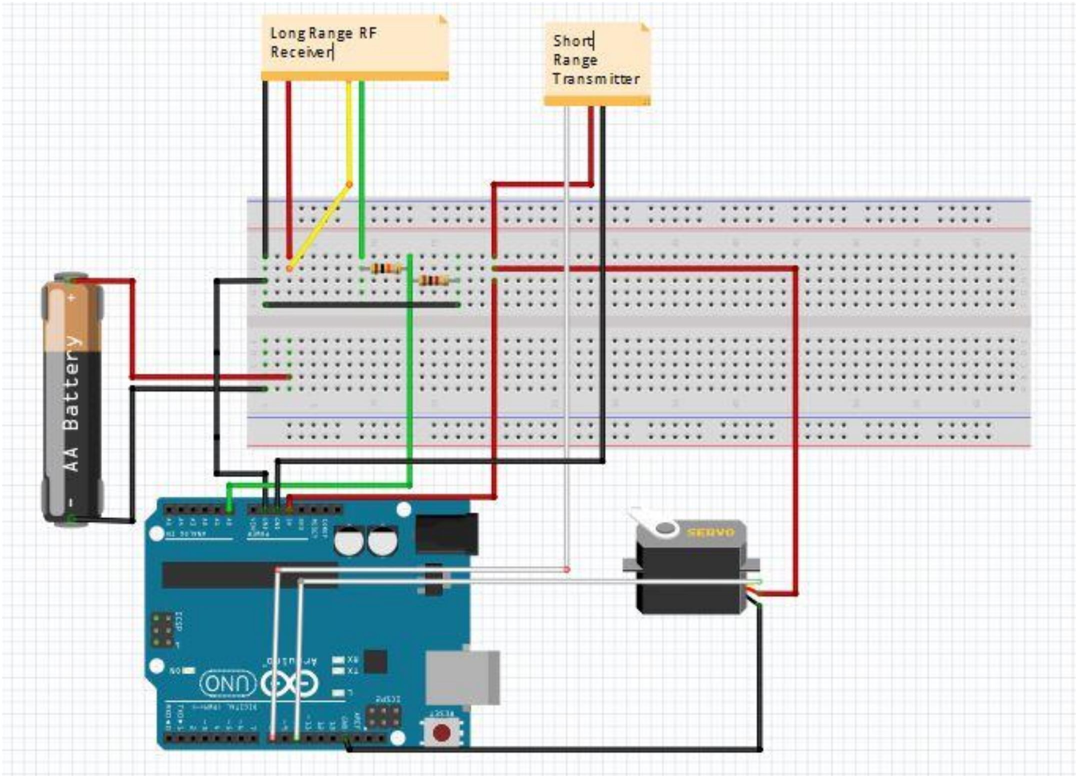


Figure 4-7: Rear Payload Assembly Schematic

4.3 Payload Construction Documentation

Construction of the payload consisted of three main assemblies: the rover, the housing, and the back assembly. Construction of the rover required mechanical assembly of the body and wheel assemblies, mounting of electronics, and electrical wiring. The housing was an almost entirely mechanical assembly and required 3D printing of the components and mechanical assembly. The back assembly consisted of primarily electrical components, with only one structural part, and therefore its construction was mostly wiring and mounting those components.

4.3.1 Rover Construction

Most of the parts on the rover, including the 7 body components and the four wheels, were 3D printed out of ABS plastic. After printing the body components, brass threaded inserts were pressed into the connection holes to provide threads for the #2-56 connecting screws. Figure 4-8 below shows the side panel of the rover body with several threaded inserts pressed into the plastic holes.

Figure 4-8 - #2-56 brass threaded inserts pressed into the plastic of a rover side panel

The axles were machined on a manual lathe and consisted of a shaft with one threaded end and a shoulder on the other end. The threaded end screws into larger threaded inserts on the rover body, and the shoulder holds the wheels in place laterally. After pressing the bearings into the 3D printed wheels, the wheel assemblies could be assembled with the integrated spur gear within the wheel housing.

To assemble the rover, the four drive motors were attached to the central chassis. The top and side panels of the body were attached, as well as the servos for the solar panels. The solar panel servos were attached to the solar panel plates, which are located on hinges on the top panel. This forms a "body" of the rover, similar to that of a motor vehicle, which drops down over the chassis. The inner geometry of this "body" is shown in an upside-down configuration in Figure 4-9 below.

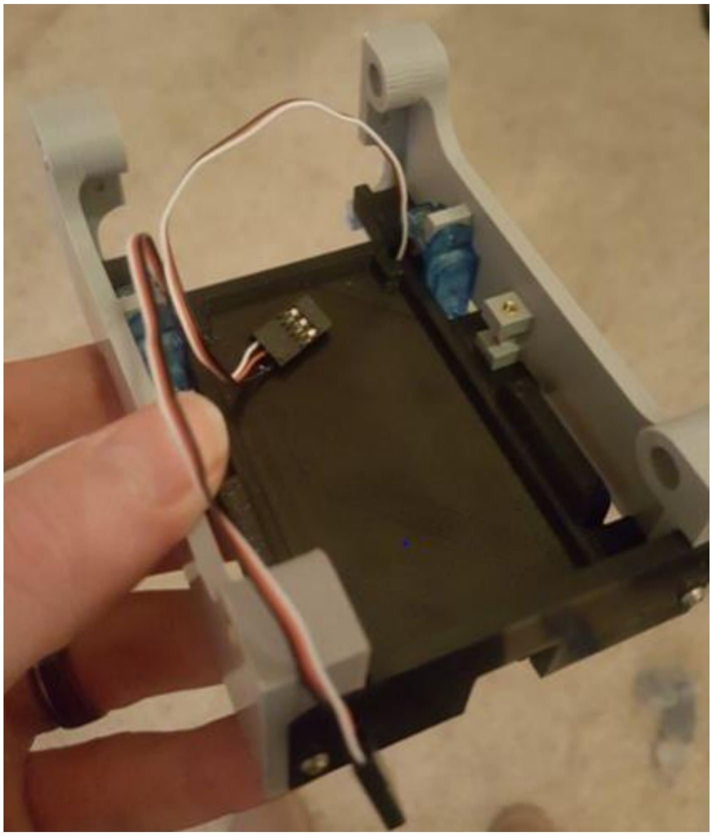


Figure 4-9 – Upside-down view of the "body" of the rover, which drops down over the rover chassis

After assembling the rover body, the wheel assemblies were screwed into the body, meshing with the gears on the drive motors. Wires were run from the various electrical components, including the front ultrasonic sensor, the two panel servos, the short-range receiver, and the Arduino Micro at the rear of the rover. The front and back plates were the last components attached to the rover, and completed the assembly of this portion of the payload. The wiring diagram and the fully assembled rover are shown in Figures 4-10 and 4-12.

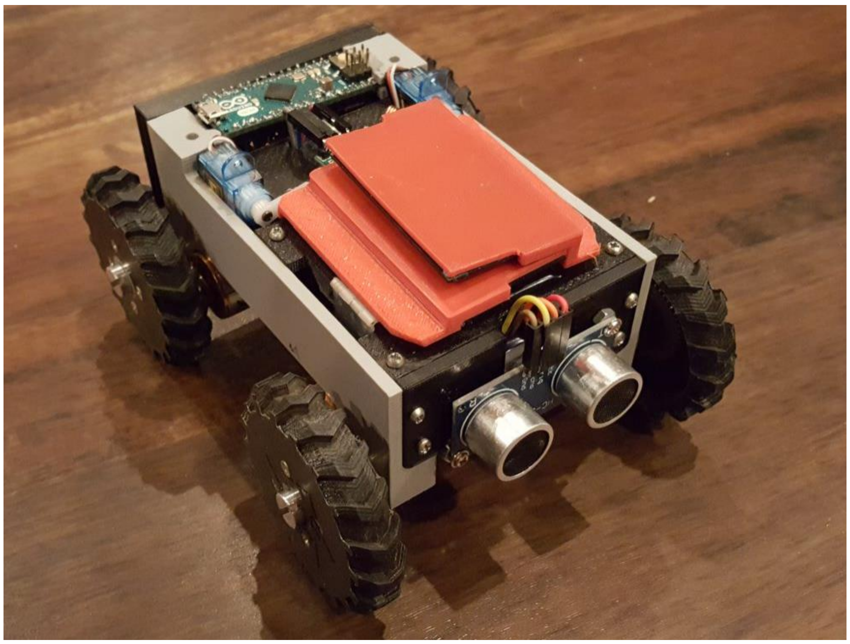


Figure 4-10 – Fully constructed and assembled rover

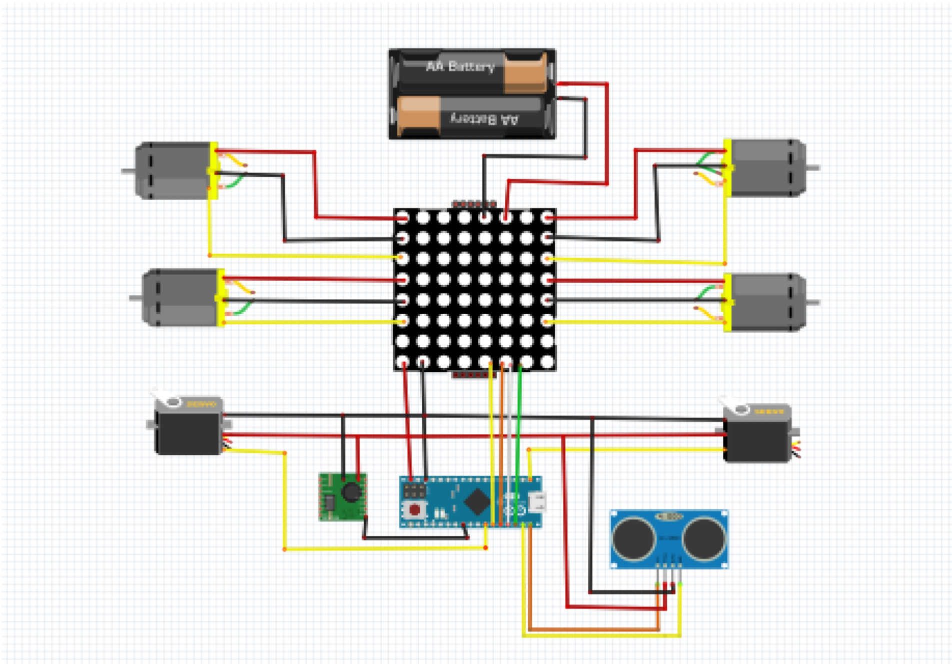


Figure 4-11 – Wiring diagram of the fully constructed rover

4.3.2 Housing Construction

The critical components of the payload housing are the front and back bearings. These bearings are what allow for the rover to orient itself upright after landing. The four rings of these two bearings were 3D printed, then manually sanded both two fine-tune the size of the bearing races and to remove the rough surfaces from the inaccuracies of the 3D printer. After sanding, the bearings could be assembled with the Delrin balls and the bearing cages. Figure 4-12 shows a fully constructed front bearing with the balls and cage.

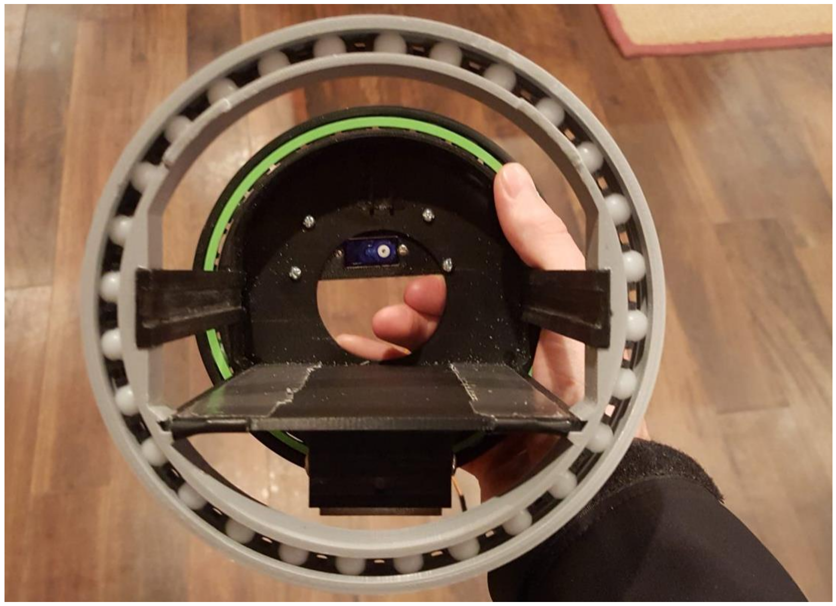


Figure 4-12 – Fully constructed front bearing with Delrin balls and 3D printed ABS cage

The other parts of the housing, which consisted of rails for the rover axles, and a bottom panel for the rover wheels to rest on during flight, were also 3D printed. After printing, these parts were adhered together using ABS Acetone welding, in which acetone partially dissolves the ABS on both parts, and the parts are pressed together.

The counterweight, which is attached below the bottom platform of the housing and provides the torque to orient the rover upright upon landing, was machined using a manual mill, and was tapped with four holes to be screwed into the bottom platform. Figure 4-13 below shows the counterweight attached to the bottom platform with the four #8-32 screws.

Figure 4-13 – Counterweight attached via #8-32 screws to the bottom platform of the payload housing

After attaching the 3D printed locking pin and bayonet to the back of the payload housing, the final payload housing, shown in Figure 4-14 below, was completed.

Figure 4-14 – Completed payload housing with front and back bearings, bottom panel, and axle rails

4.3.3 Back Assembly Construction

The purpose of the back assembly is to drive the bayonet servo, which releases the rover after landing, and to house the long-range receiver and short range transmitter, which receive the signal from the operators and transmit the activation signal to the rover. Assembly and construction of the back assembly started with test wiring the various electrical components. After testing, these components were permanently soldered or attached via a breadboard. The centering weight, which pulls the offset center of mass back to nearly-concentric with the rocket's centerline, was 3D printed after construction of the rest of the payload, when accurate mass and center of mass measurements could be taken. Most of the electrical components were mounted to this centering mass, which is shown within the vehicle integration coupler in Figure 4-15.

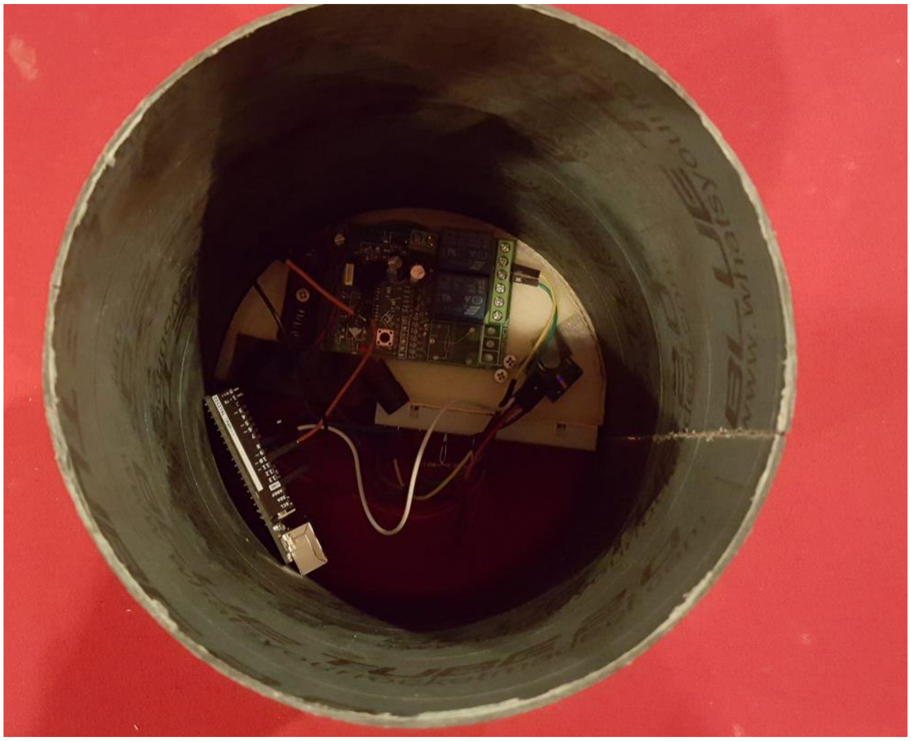


Figure 4-15 – Back payload assembly within the vehicle integration coupler

The complete construction integrates the rover, housing and rear assembly. However, these three components cannot be seen together within the coupler. Figure 4-16 below shows the rover integrated with the housing, with the rear assembly omitted.

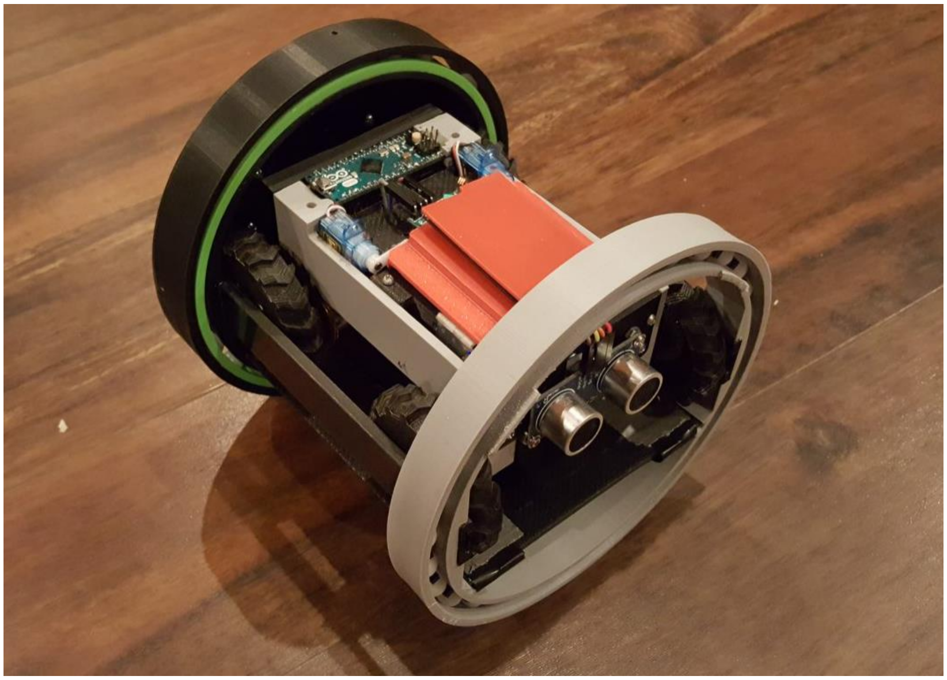


Figure 4-16 – Final integration of the fully constructed rover and payload housing

4.4 Testing

4.4.1 Rover Egress Testing

	Test Description	Result
1	No platform surface modification	Rover spins out from lack of friction. Rover doesn't exit the housing
2	One strip of duct type under each wheel	Motor experienced a gear jam. Slow forward movement till exiting the housing after 3 reputations of 1100 rpms at 1 second.
3	Two strips of duct tape under each wheel	No wheel movement due to friction with rails. Rover does not exit the housing
4	One strip of electrical tape	No wheel movement due to friction with rails. Rover does not exit the housing
5	One strip of duct tape without motor jam.	Rover Successfully exits the rover. Repeatability fails with increasing difficulty
6	One strip of duct tape with sanded rails	Success. Repeatability is achieved

4.4.2 Radio Transmission Test

	Test Description	Result
1	Only password transmission system.	Success. Passphrase is transmitted from one Arduino to another
2	Long range Receiver connected to Arduino with short range transmitter all components to 12v battery	Failure. A capacitor reduced the voltage across the regulator preventing it from functioning.
3	Removed voltage, power Arduino independently	Success. no time-variation on voltage arcos the receive and all functions are proper
4	Password transmission from long range receiver to short range transmitter to Arduino	Success. Passphrase was transmitted by each system.

4.4.3 Environment Tests

Tests 1 -12 were conducted in a dry fine-grained sandy environment used to simulate worst-case environmental conditions. All test after 12 were conducted in an area that simulated tilled farm land.

	Test Description	Result
1	Two wheels turning using throttle between 10% and 50%	At low throttle wheels don't spin. At medium throttle the two power wheels loose traction with the dirt.
2	Forward test. Four wheels turning at 1100 microseconds 1.2 seconds .	Successful forward motion, wheel lock ups are common.
3	Forward test. 4 wheels turn at 1200 microseconds for 1.2 seconds delay 1.2 seconds	Success forward motion without wheel lock ups. Approximately 4ft of forward motion
4	Right turn. Both left wheels at 1200 microseconds for 2 seconds delay repeat .	Front left and back right turn. No forward movement
5	Right turn. Both left wheels at 1200 microseconds for 2 seconds delay repeat .	At low throttle wheels don't spin. At medium throttle the two power wheels loose traction with the dirt.
6	Right turn. Both left wheels at 1300 microseconds both right wheel at	Successful turn. Approximately 1 ft diameter.

	1100 microseconds for 2 seconds delay repeat.	
7	Attempted forward motion 4 wheels turn at 1200 microseconds for 1.2 seconds delay 1.2 seconds. Shift terrain to thick grass	Spun out. Tearing up grass.
8	Attempted forward motion 4 wheels turn at 1200 microseconds for 1.2 seconds 1.2 seconds. Shift terrain to thin grass	Lack of delay results in rover exiting testing area at high speeds. Pursuit and capture of rover after short chase.
9	Attempted forward motion 4 wheels turn at 1200 microseconds for 1.2 seconds delay 1.2 seconds.	Successful forward motion. Approximately 5 feet.
10	Burst to 1500 microseconds for .3 seconds, return to 1200 microsecond for 1 sec	Successful movement on first iteration. Failure on the second.
11	1200 microseconds for 2.5 seconds	One wheel movement. Other 3 wheels no movement
12	Burst to 1700 microseconds for .3 seconds retain to 1200 microseconds for 2.5	One wheel movement. Other 3 wheels no movement
13	Start up power 0.5 from .25, all wheels at 1200 microseconds for 2 seconds	Successful forward movement. All four wheels turning.

4.4.4 Non Loaded Motor Testing

	Test description	Result
1	No modification	Front right wheel running and Back Right wheel running inconsistently.
2	Tightened Front right motor	Front right wheel running and back right wheel running inconsistently
3	Removed Material from Front left wheel	Front wheels running and back right wheel running inconsistently
4	Tightened Front left motor	Front wheels running and Back Right wheel running
5	Removed material from Back right wheel	Front wheels running and Back Right wheel running
6	Removed material from back left wheel	Front wheels running and Back Right wheel running

4.5 Schematics of as Built Payload

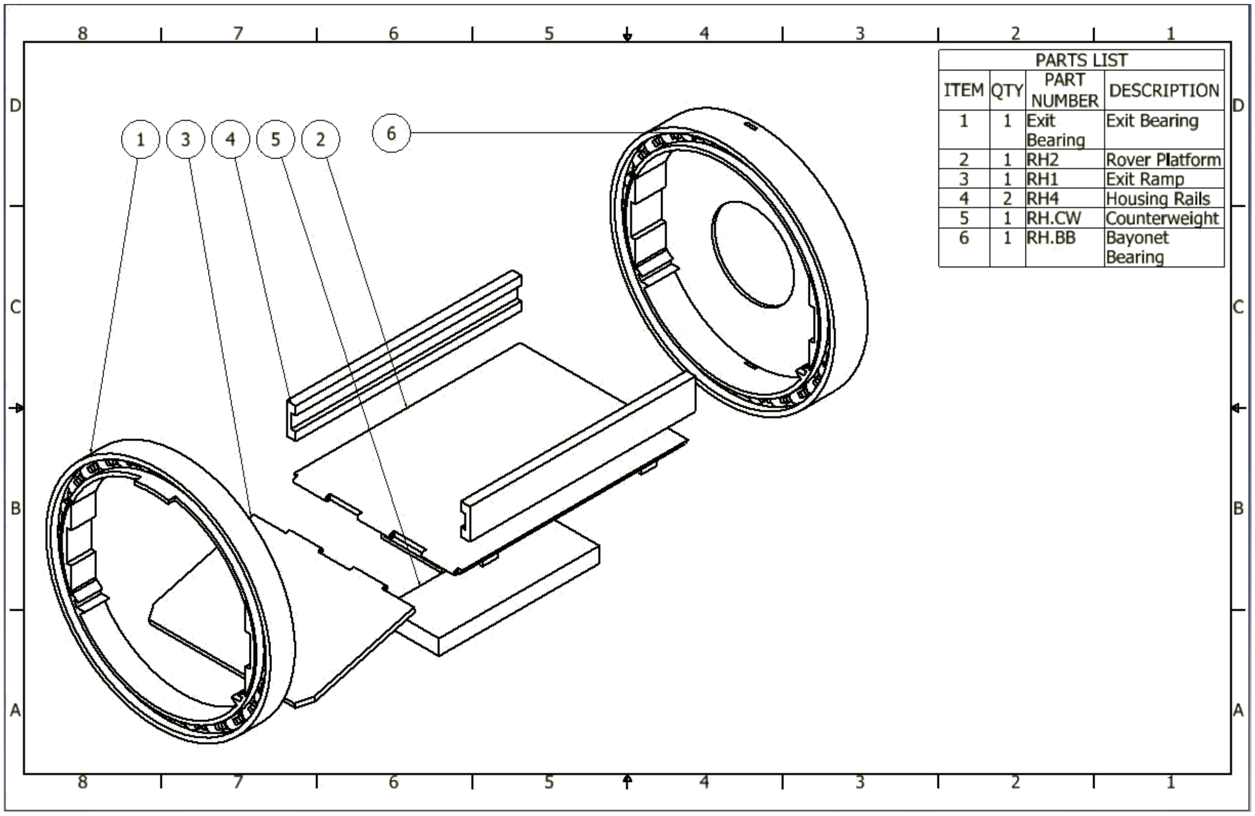


Figure 4-17

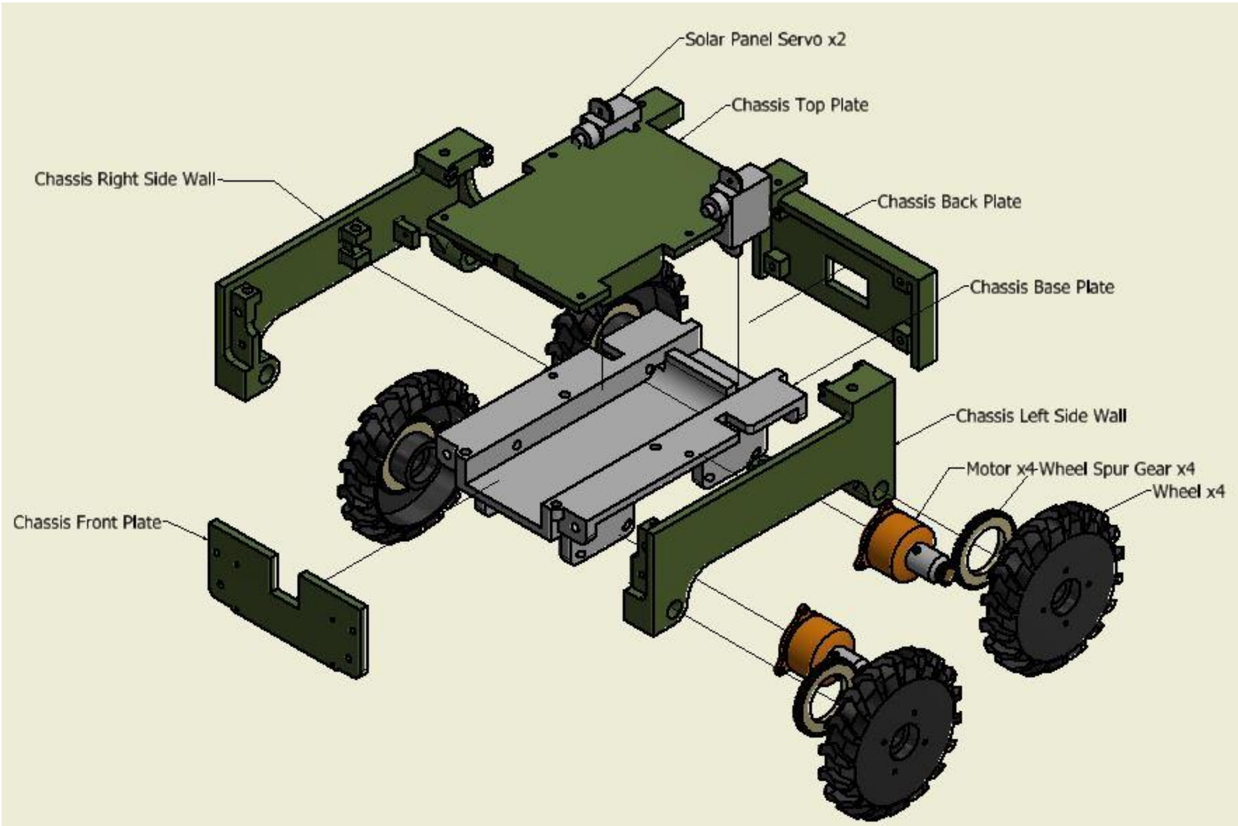
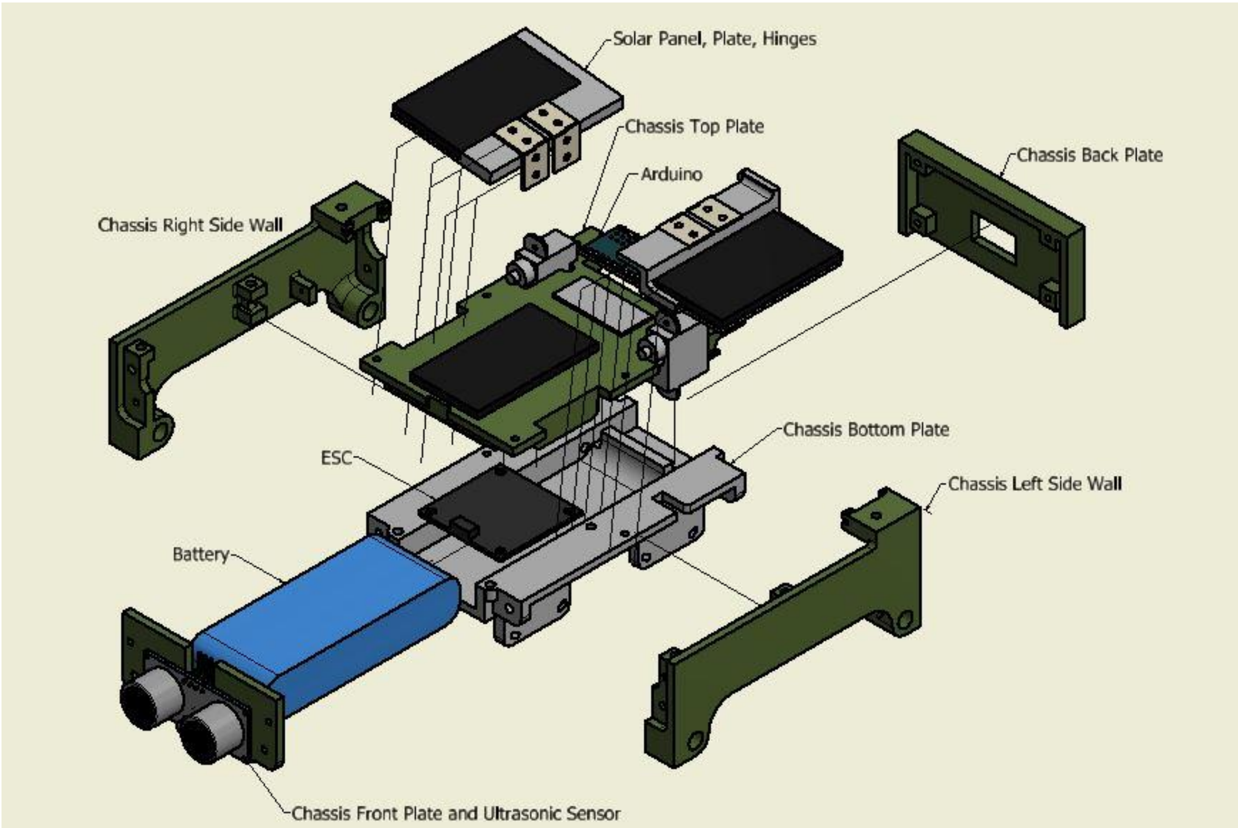
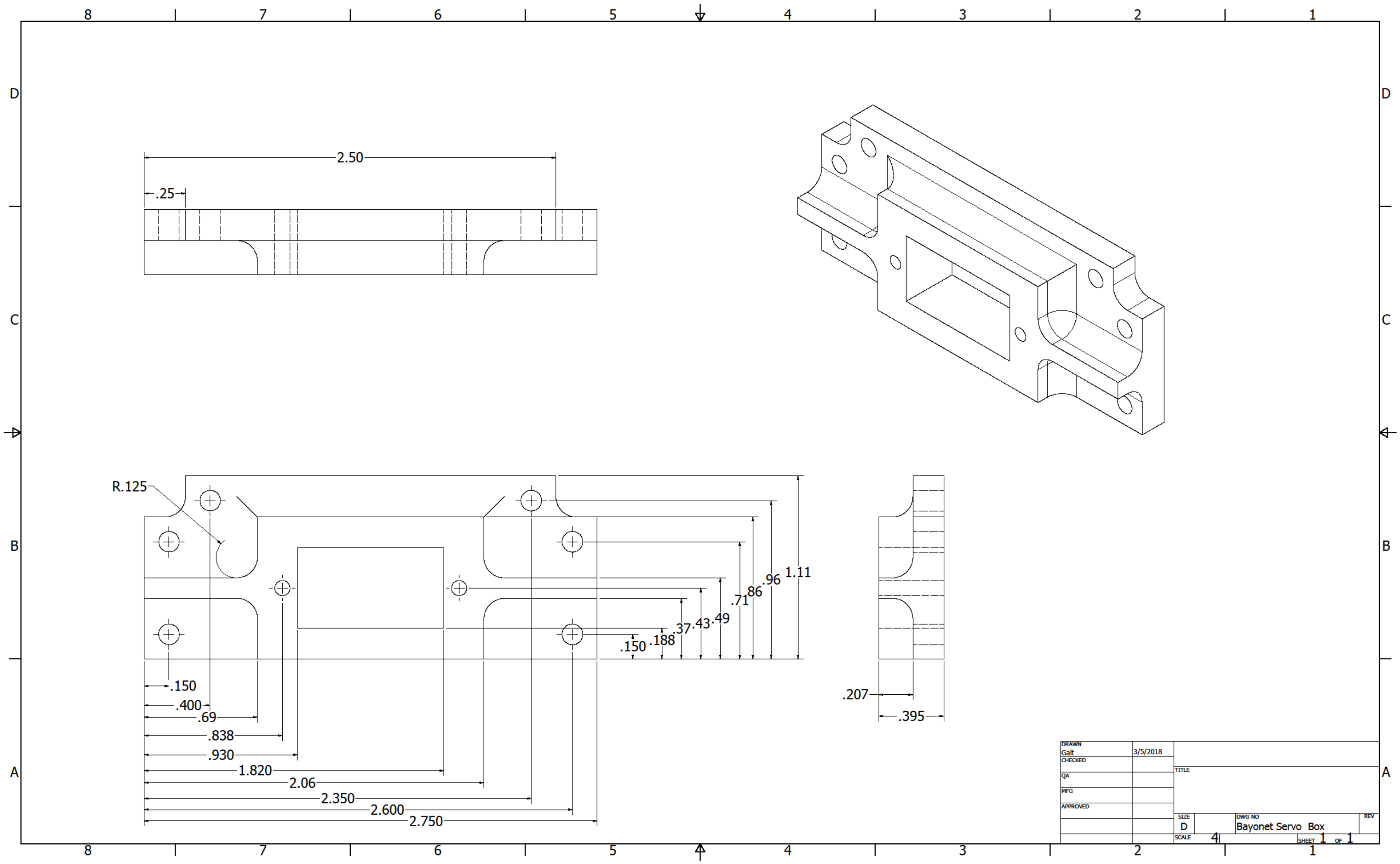

Solar Panel Servo x2
Chassis Top Plate
Chassis Right Side Wall
Chassis Back Plate
Chassis Base Plate
Chassis Left Side Wall
Motor x4
Wheel Spur Gear x4
Wheel x4
Chassis Front Plate

Figure 4-18



Solar Panel, Plate, Hinges
Chassis Top Plate
Chassis Back Plate
Arduino
Chassis Right Side Wall
Chassis Bottom Plate
ESC
Chassis Left Side Wall
Battery
Chassis Front Plate and Ultrasonic Sensor

Figure 4-19


2.50
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R.125
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.43
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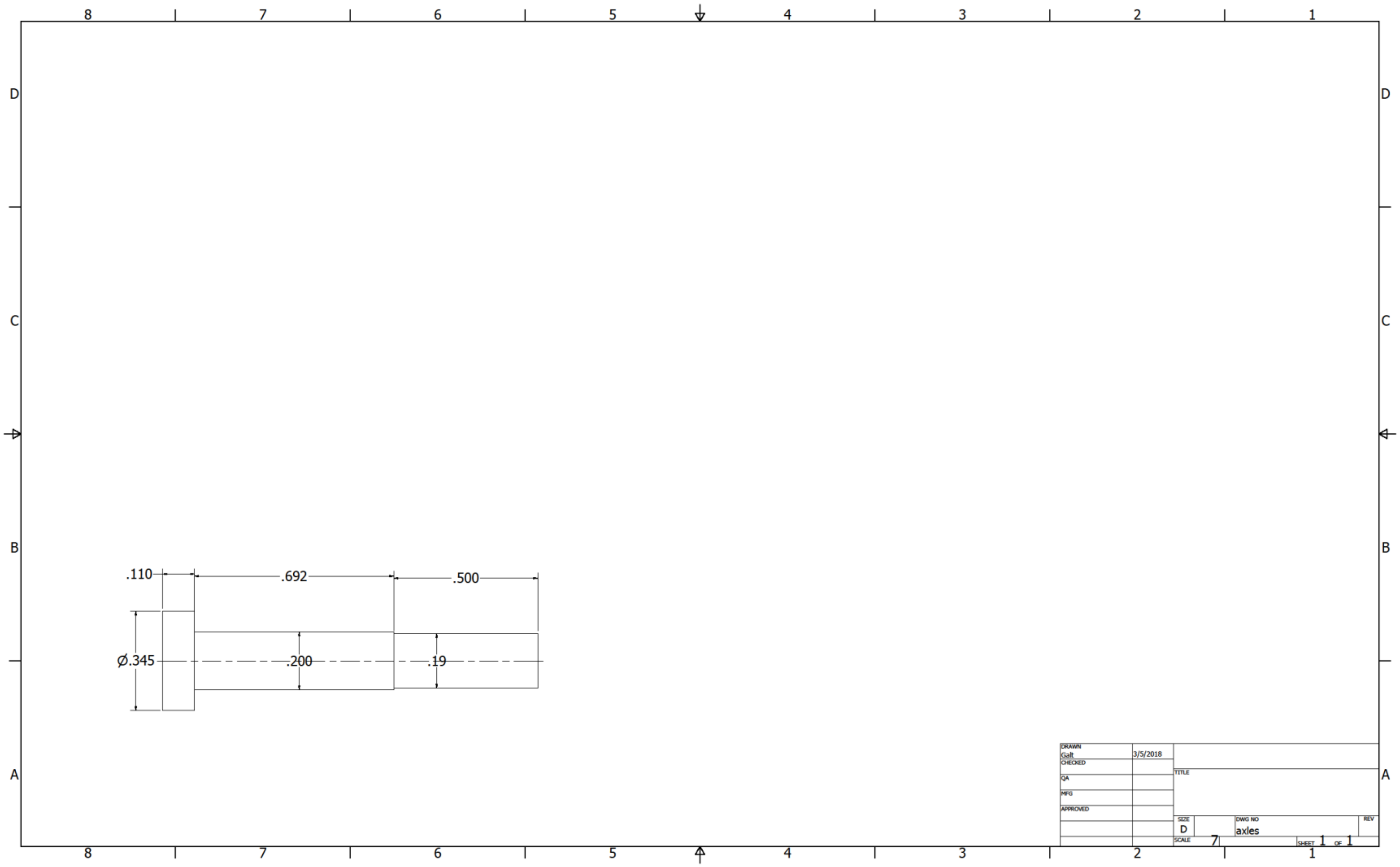
Fig 4-20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SHEET 1 OF 1

Figure 4-21

5. Safety

5.1 General Team Safety

5.1.1 Vehicle

G10 Fiberglass will be utilized for the fins and the Dynamic Apogee Control System (DACS) flaps. When cutting, or shaving down this material certain safety precautions will be taken since it is deadly when shavings are inhaled. Everyone in the proximity MUST wear the proper PPE: disposable coveralls, respirators, gloves, and safety goggles. The area will be removed of any shavings before removing PPE and continuing any other work.

Blue Tube 2.0 will be utilized for airframe with G10 reinforcement ribs if needed with holes drill for inserts and screws for alignment and securing of couplers and E-bay. When drilling into or cutting this material certain safety precautions will be taken similarly to the G10 fiberglass. Everyone in the proximity MUST wear the proper PPE of disposable coveralls, respirators, gloves, and safety goggles to avoid any possible shavings being inhaled or cutting oneself on a sharp un-sanded edge of the newly cut blue tube. The couplers will also be from Blue Tube 2.0 material.

When handling any adhesives such as Epoxy, proper PPE will be provided on site and worn by those within a 6-foot radius. Epoxy will be used only for bonding parts together for the USLI rocket and will be given the appropriate time to dry. Epoxy will be stored on the bottom shelf of the flammable cabinet to compensate for any falling damage. Proper PPE consists of but not limited to: disposable coveralls and gloves.

Regarding rocket motors, they will be stored in the appropriate container and locked away in the flammable cabinet. These motors will only be used for our USLI rocket scaled down model and full-scale model. Lastly, these motors will be disposed of in the proper fashion.

E-matches will be used for ignition to ensure appropriate distance of personnel from the launch pad. They will be secured and locked away in the appropriate container in the flammable cabinet. E-match's will be tested and properly fixed into the rocket motor.

5.1.2 Recovery

E-bay: The E-bay is comprised of a battery, altimeter, and wires leading to the pyro charge. When handling the altimeter, failure to use an anti-static band could result in grounding the electronics of the altimeter resulting in electrostatic discharge and short circuiting. If the solder is loose, it could result in interruptions in the connection and complete disconnection and therefore, failure to deploy ejection charges and parachutes. Properly securing the Altimeter will prevent the solder from failing and vibrations from damaging or disrupting the altimeter. Failure to store or operate electronics of the altimeter from water could result in short circuiting and permanent damage.

Shock cord: The shock cord will be attached to an eye bolt on a bulkhead with a secured and tight knot. When attaching the eye bolt to bulkhead, the proper PPE is required when drilling into bulkhead such as disposable coveralls, respirators, gloves, and safety goggles to avoid any possible shavings being inhaled.

Black powder: Will be utilized for the separation stages and the following safety measure will be followed by Space Raiders personnel. The flammable cabinet will be used for all black powder products of which will be ensured are sealed tightly. The cabinet will be securely locked inspected daily to upkeep cleanliness. When handling the black powder, the proper PPE will be provided and worn by all those within a 6-foot radius: disposable coveralls, gloves, safety glasses, fire hydrant, fire-blanket, and a first aid kit. Quantities will be tested before implementing into the rocket itself. Tests will be executed safely by following these procedures: e-match ignition, all personnel at least 30 yards away, notified fire marshal and appropriate remote testing location.

Packing procedures: Only the safety officer and the Recovery Team Lead are permitted to pack the black powder discharging stages of the rocket. Appropriate PPE will be provided and worn. All other personnel will remain at least 30 yards away.

5.1.3 Payload

Battery use and storage – Among the batteries we're considering, all of them are Lipo-batteries. Lipo-batteries must always be stored at a storage charge and never completely discharged during use. For this reason, we will check our batteries at the beginning of every design period to ensure the battery condition is maintained. A battery voltage checker will always be on site, which confirms the voltage across each cell and if they are balanced.

ESC use – The Electronic Speed Control is dependent upon what current the motors require to function at a given voltage. Otherwise, the ESC would shut off at a given value pre-programmed or overheat causing an electrical fire. Clearly, to avoid overheating is desired, so many cross referencing and testing our connections will be executed to guarantee proper implementations. The ESC will be stored away from any exposure to water to avoid short circuiting.

Electric Motor – Our motor is the control when considering purchasing electronics. When selecting a motor, we concern ourselves with the kv value and required current to perform at certain voltages. This current is then cross referenced with other electronics to avoid any overheating resulting in electrical fires. Electric Motors will always be stored in its provided casing in order to avoid dust collection and exposure to water.

Wiring: When wiring any electronics together, it is important that you do not cause the circuit to short circuit or fry. When stripping wires, make sure that any exposed wires do not become interfered with due to being loosely secured could short circuit the connection. Adhesive: When handling any adhesives such as Epoxy, proper PPE will be provided on site and worn by those within a 6-foot radius. Epoxy will be used only for bonding parts together for the USLI rocket and will be given the appropriate time to dry.

Epoxy will be stored on the bottom shelf of the flammable cabinet to compensate for any falling damage. Proper PPE consists of but not limited to: disposable coveralls and gloves.

5.1.4 All PPE Necessary

- Eye Goggles
- Safety Glasses
- Wool/Nylon Fire Blanket
- Disposable Coveralls
- ABC Class Fire Extinguisher
- Disposable Gloves
- Leather Gloves
- First Aid Kit
- Plastic Tarp
- Breathing Mask
- Anti-Static Band

5.2 General Assembly Safety

When assembling the launch vehicle together, the following safety from construction still applies:

Blue Tube 2.0 will be utilized for airframe with G10 reinforcement ribs if needed with holes drill for inserts and screws for alignment and securing of couplers and E-bay. When drilling into or cutting this material certain safety precautions will be taken similarly to the G10 fiberglass. Everyone in the proximity MUST wear the proper PPE of disposable coveralls, respirators, gloves, and safety goggles to avoid any possible shavings being inhaled or cutting oneself on a sharp un-sanded edge of the newly cut blue tube. The couplers will also be from Blue Tube 2.0 material.

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Regarding rocket motors, they will be stored in the appropriate container and locked away in the flammable cabinet. These motors will only be used for our USLI rocket scaled down model and full-scale model. Lastly, these motors will be disposed of in the proper fashion.

E-matches will be used for ignition to ensure appropriate distance of personnel from the launch pad. They will be secured and locked away in the appropriate container in the flammable cabinet. E-match's will be tested and properly fixed into the rocket motor.

E-bay: The E-bay is comprised of a battery, altimeter, and wires leading to the pyro charge. When handling the altimeter, failure to use an anti-static band could result in grounding the electronics of the altimeter resulting in electrostatic discharge and short circuiting. If the solder is loose, it could result in interruptions in the connection and complete disconnection and therefore, failure to deploy ejection charges and parachutes. Properly securing the Altimeter will prevent the solder from failing and vibrations from damaging or disrupting the altimeter. Failure to store or operate electronics of the altimeter from water could result in short circuiting and permanent damage. Also it is important to shield the altimeter from any pyro charge.

Shock cord: The shock cord will be attached to an eye bolt on a bulkhead with a secured and tight knot. When attaching the eye bolt to bulkhead, the proper PPE is required when drilling into bulkhead such as disposable coveralls, respirators, gloves, and safety goggles to avoid any possible shavings being inhaled.

Parachutes: When packing the parachutes, it is important that they are placed away from any pyro charge.

Battery use and storage – Among the batteries we're considering, all of them are Lipo-batteries. Lipo-batteries must always be stored at a storage charge and never completely discharged during use. For this reason, we will check our batteries at the beginning of every design period to ensure the battery condition is maintained. A battery voltage checker will always be on site, which confirms the voltage across each cell and if they are balanced.

ESC use – The Electronic Speed Control is dependent upon what current the motors require to function at a given voltage. Otherwise, the ESC would shut off at a given value pre-programmed or overheat causing an electrical fire. Clearly, to avoid overheating is desired, so many cross referencing and testing our connections will be executed to guarantee proper implementations. The ESC will be stored away from any exposure to water to avoid short circuiting.

Electric Motor – Our motor is the control when considering purchasing electronics. When selecting a motor, we concern ourselves with the kv value and required current to perform at certain voltages. This current is then cross referenced with other electronics to avoid any overheating resulting in electrical fires. Electric Motors will always be stored in its provided casing in order to avoid dust collection and exposure to water.

Wiring: When wiring any electronics together, it is important that you do not cause the circuit to short circuit or fry. When stripping wires, make sure that any exposed wires do not become interfered with due to being loosely secured could short circuit the connection. Adhesive: When handling any adhesives such as Epoxy, proper PPE will be provided on site and worn by those within a 6-foot radius. Epoxy will be used only for bonding parts together for the USLI rocket and will be given the appropriate time to dry. Epoxy will be stored on the bottom shelf of the flammable cabinet to compensate for any falling damage. Proper PPE consists of but not limited to: disposable coveralls and gloves.

Screws: With inserting screws into any material to evenly distribute the screws. Also when inserting a screw into a surface like Blue Tube or plywood, it is important that when you drill the hole that you wear the proper PPE required of disposable coveralls, respirators, gloves, and safety goggles to avoid any possible shavings being inhaled .

5.3 Environmental Concerns

Fire Marshall is always notified of testing or launching and on the site with our area currently in a fire ban

• All waste materials will be disposed of using proper trash receptacles

• Biodegradable and flame resistant recovery wadding will be used

• Flame resistant/explosive storage containers will be used

• Solid rocket motor manufacturers' instructions will be followed when disposing of any rocket motor parts

• Consideration of environmental ramifications will be made regarding applicable activities

• Proper blast shields on the launch pad will be used to prevent direct infringement of rocket motor exhaust on the ground

• Waste receptacles (trash bags) will be available for use around the prep area to encourage proper disposal of waste from rocket prep activities

• The following list of materials have been identified as potentially hazardous:

a. G5000 Rocket Epoxy

b. Expanding density foam

c. FFFFG Black Powder

See Appendix A for complete MSDS specifications on these materials.

5.4 Hazards Recognitions

5.4.1 General Hazards

5.4.1.1 Always ask and Knowledgeable Member

- Equipment
- Tools
- Procedures
- Materials Handling
- Other concerns

5.4.2 Chemical Hazards

- The following are risks of chemical handling:
  - Irritation of skin, eyes, and respiratory system from contact and/or inhalation of hazardous fumes.
  - Secondary exposure from chemical spills

  - Destruction of lab space
- Ways to mitigate these risks:
  - Whenever using chemicals, refer to MSDS sheets for proper handling
  - Always wear appropriate safety gear
  - Keep work stations clean
  - Keep ventilation pathways clear
  - Always wear appropriate clothing
  - Always label containers
  - Immediately return equipment and clear workspace before leaving

5.4.3 Hazardous Equipment and Tools

- The following are risks of equipment and tool handling:
  - Cuts
  - Burning
  - General injury
- Ways to mitigate these risks:
  - Always wear appropriate clothing, such as closed-toed shoes.
  - Always wear appropriate safety equipment
  - Always ask if unsure
  - Always unplug electronics when not in use

5.4.4 Hazardous Composite Safety

- Carbon fiber, fiberglass, epoxy, and other composite materials require special care when handling.
- The following are risks composites handling:
  - Respiratory irritation
  - Skin irritation
  - Eye irritation
  - Splinters
  - Secondary exposure
- Ways to mitigate these risks:
  - Always wear face masks/respirators when sanding, cutting, or grinding
  - Always wear gloves when handling pre-cured composites
  - Always wear puncture-resistant gloves when handling potentially sharp composites
  - Immediately clean area after handling to prevent further exposure
- No carbon fiber will be handled

5.4.5 Hazardous Motor Handling and Inspection

- What to look for when inspecting motor
  - Any air bubbles such as pictured in the figure below. Where there is one defect, more may follow

Vehicle Hazards

- ❑ Centering Rings: If poorly secured and bonded, the centering rings could result in failure anytime during combustion allowing the center of thrust to fall out of alignment with the center axis line through the center of the rocket.
- ❑ Encapsulating Foam: If too much foam is used during the expansion process, it could result in overflow into the area for motor and centering ring placement. Also if applied while coupler is not centered, the center of thrust would be stuck in a position offset from the alignment with the center axis line through the center of the rocket.
- ❑ Thrust Plate and Retaining Ring: Since both are secured by screws and both are responsible for securing the rocket motor from moving, if the tension of these screws are axially symmetric placement, it could result in an unstable rocket motor and center of thrust.
- ❑ Motor: If motor is stored in the incorrect environment could result in hazardous motor performance. If motor is assembled incorrectly,
- ❑ Motor Mount: If there is no snug fit between the casing and inner tube during construction, it could result in undesired vibration and variation from a constant center of thrust. Also, if motor is improperly installed into the motor mount, it could prove extremely hazardous. Finally, if improperly installed closures and retaining rings, it would alter the ability to contain the static position of the motor during ignition.
- ❑ Fins: If fins are improperly expoxied to the airframe, it would result in potential fin flutter and the separation of a fin from the airframe. Also if fins are not separated by an equal distance from one another, the flight of the rocket would be very erratic.
- ❑ Screws: Failure to evenly distribute the screws, which prevent undesired separation, could result in material failure under stress. With the holes in the vehicle in such a close proximity, failure analysis proves this could be an area of weakness. Incorrectly placing the screws could result in completely defeating the purpose of the screws if it secured the wrong or no two sections of the rocket together. In the event screws of an inadequately small diameter were used, this could prove to be a problem if the ejection charges provided a force that exceeded that of the screws. The process in which the screws are

secured along the walls of the rocket is done with placing threads for the screws to hold on to. Failure to provide these screws would result in the screws simply falling out during flight and prematurely separating during ascension.

4.4.7 Recovery Hazards

- ❑ Parachute: If parachute is folded improperly or entanglement of cords occurs, it can result in delayed or no deployment at all. Also, incomplete coverage of parachute with Kevlar fire cloth could result in minor to major burn damage to parachute or cords. Finally, if the cords during construction or packing become frayed, it could affect the performance of the drogue or main parachutes causing the rocket to fall at an undesired accelerated rate.
- ❑ Bulkheads: If there is an improper tolerance between inner dimension wall of airframe and the bulkhead, it will result in loss in pressure and potentially failure to separate. If there is an improper application of adhesives of bulkhead to the airframe, it could result in loss of pressure and potentially failure to separate.
- ❑ Nylon Recovery Harness: If the harness is tied incorrectly or too loose, the knot could come undone under the heavy weight resulting in disconnection between the main parachute and bulkhead. If frayed during storage or packing, the nylon rope would possess a location of weakness promoting failure to withstand high tension forces
- ❑ Eye Bolts and Washers: In the event the nut has become loose and was not included in the checklist, heavy vibrations could further loosen the seal between the nut and I bolt and potentially disconnect. Any washer other than a fender washer could provide a less than adequate area to distribute stress. Not including the washer completely would ensure the pre-load is applied to a smaller area and totally on the airframe which could result in damaging the airframe.
- ❑ Altimeter: When handling the altimeter, failure to use an anti-static band could result in grounding the electronics of the altimeter resulting in electrostatic discharge and short circuiting. If the solder is loose, it could result in interruptions in the connection and complete disconnection and therefore, failure to deploy ejection charges and parachutes. Properly securing the Altimeter will prevent the solder from failing and vibrations from damaging or disrupting the altimeter. Failure to store or operate electronics of the altimeter from water could result in short circuiting and permanent damage.
- ❑ Battery: Failure to store batteries within the recommended range of temperature and prevent impact damage could result in hazardous battery performance. Failure to secure the battery to the sled of E-bay could cause disconnection to the altimeter and possibly battery damage. Loose soldering to the battery and incorrect polarity would prevent proper connections and failure to complete electronic circuit.
- ❑ E-Bay: With the corrosive by-products of FFFFG ejection charges, allowing these gases to flow into the low-pressure chamber of the E-bay could potentially damage any electronics. Failure to follow the specified directions for required quantity and hole diameters for the given altimeter performance could result in poor data produced and improper trigger of ejection charges. Failure to create complete seal and bond of bulkheads to the ends of the E-bay to the coupler could not only allow corrosive gases to enter the E-bay, but could distribute the pressure of the ejection charges improperly and damage the electronics. Any damage to the sled prior or during flight will result in heavy vibrations to electronics and potentially disconnected seal along soldered points.
- ❑ Wires: When stripping wires, inability to ensure any exposed wires doesn’t become interfered with due to being loosely secured could short circuit the connection. Inability

to securely tighten any connections between wires and conductive materials would cause a disruption in the performance of the altimeter during flight and potentially failure to deploy ejection charges or parachutes.

- ❑ Soldering: If the solder is loose, it could result in interruptions in the connection and complete disconnection and therefore, failure to deploy ejection charges and parachutes.
- ❑ Shear Pins: Shear pins that aren't secured tightly could come loose during flight and result in the portions of the rocket partially deploying earlier than intended ending in many complications during flight. Shear pins that fail to shear due to too thick of a gauge would prevent separation forcing the rocket to go ballistic and damage the internal components with trapped heat. In the event the shear pins are not evenly distributed, the combined resistance to any shear force could prevent the pins from shearing and allowing the vehicle to separate. Incorrect placement of the shear pins along the body of the rocket could bypass the whole purpose of the shear pins to prevent the rocket from separating pre-maturely.

4.5 Procedures

4.5.1Construction Procedures and Checklist

- ❑ When cutting or shaving a material, you MUST wear disposable coveralls, respirators, gloves, and safety goggles to prevent inhaling shavings or getting in your eye. Also clean up area BEFORE continuing work
- ❑ When handling adhesives such as Epoxy, you MUST wear gloves. Make sure the Epoxy does not get on any unwanted surface.
- ❑ Regarding the rocket motors, they MUST be stored in the appropriate container and locked away from sight until ready to be placed inside rocket and for launches.
- ❑ Regarding E-matches, they MUST be stored in the appropriate container and locked away from sight until ready to be placed inside motor for launches.
- ❑ When working on any electronics, you MUST have anti-static band on and ground yourself BEFORE touching any electronic such as altimeter.
- ❑ Regarding the Reese Technology Center, you MUST follow all rules provided to you and wear proper PPE when needed.

4.5.2 Assembly Procedures and Checklist

- ❑ When cutting or shaving a material, you MUST wear disposable coveralls, respirators, gloves, and safety goggles to prevent inhaling shavings or getting in your eye. Also clean up area BEFORE continuing work
- ❑ When handling adhesives such as Epoxy, you MUST wear gloves. Make sure the Epoxy does not get on any unwanted surface.
- ❑ Regarding the rocket motors, they MUST be stored in the appropriate container and locked away from sight until ready to be placed inside rocket and for launches.
- ❑ Regarding E-matches, they MUST be stored in the appropriate container and locked away from sight until ready to be placed inside motor for launches.
- ❑ When working on any electronics, you MUST have anti-static band on and ground yourself BEFORE touching any electronic such as altimeter.
- ❑ Regarding the Wind Tunnel and Reese Technology Center, you MUST follow all rules provided to you and wear proper PPE when needed

- ❑ When launch vehicle is fully assembled and being transported, be aware of your surroundings
- ❑ When going to a launch, you MUST bring the following PPE: Wool/Nylon fire blanket, ABC Class fire extinguisher, first aid kit, anti-static band, safety glasses, plastic tarp, and gloves in case of repairs needed at launch site

4.6 Testing of systems

4.6.1 DACS system

We will be doing wind tunnel testing on our sub and full scale Dynamic Apogee Control System (DACS) at the National Wind Institute at Reese Air Park. We will be gathering data on drag forces varying with wind speed using the load cells that the facility has. We will test how different angles of DACS flap deployment will affect the amount of drag on the launch vehicle. We will then use this data to determine how DACS deployment angle effects the launch vehicles drag coefficient. This will allow us to accurately regulate our desired apogee.

4.6.2 Drag Testing

We complete aerodynamic drag testing on both sub and full scale using the wind tunnel at the National Wind Institute located in Reese Airpark. Using load cells, we will conduct tests on the drag forces created by out launch vehicles to then extrapolate drag coefficients

4.6.3 DACS Control Arms

The control arms used to extend the flaps as a part of the Dynamic Apogee Control System will have to withstand large compressive forces. To be able to handle the large stresses that these four control arms will undergo, we have decided to make them out stainless steel. In order to ensure they can handle such stresses we will perform an ultimate failure analysis in the Texas Tech Mechanical Engineering Department’s machine shop. The results from this test will show us the maximum strength of these control arms

4.6.4 Separation Charge

Before large-scale testing, we did two separate tests to ensure that our separation charges were adequate to separate the sections of the launch vehicle. We tested the main parachute ejection charge and the drogue parachute ejection charge as well as nose cone separation for rover deployment. In this case both main and drogue chute charges successfully separated with 1.5g of 4F black powder and the nose cone successfully separated from body with 2g of 4F black powder.

4.6.5 Shock Cord Bundle

Part of our procedure for packing the shock cord is to fold it every 5.5 inches until 15 bundles is achieved. Each bundle will then be taped in the center with one layer of electrical tape. We will do this continually throughout the length of the shock cord. This will allow for greater energy absorption. While the shock cord is unraveling. We will test this principle by dropping a weight connected to this bundle while connected to a fish scale to record the force experienced during the drop. This could shed some light onto how much force it takes to pop the tape on each bundle and whether or not it provides adequate shock absorption.

4.6.6 Rover Payload

Testing the bearing housing system

The test and analysis for the bearing housing system will be conducted with full size models and computer simulations. The bearing system full-size models will be stress tested with mock rovers with similar weights. All possible landing orientations will be tested with mock rovers to ensure functionality. These tests must be conducted prior to any test launches aboard the vehicle.

4.6.7 Payload Interface

The payload interface system includes the bayonet fitting and the axles and tracks. The axles and tracks will be tested with full sized models of both the rover and payload housing. Stress simulations will be run on the bayonet fitting prior to creating full scale models. All the tests for scale models will be run in cognition with the testing of the payload housing.

4.6.8 Electrical Systems

The electrical systems include all electrical components outside of pre-fabricated sensors and motors. The heart of the Electrical system and the rover itself, the control board will be inspected for any faults before installation and after any test of the rover. All sensors will undergo calibration testing in controlled environments to ensure accuracy. Voltage and amperage will be measured across the system to ensure all levels are within a safe range specified in our safety sheets.

4.6.9 Drivetrain and Steering

Drivetrain and steering systems are defined as systems responsible for the movement and the automated steering of the rover. All motors will be tested prior to installation to ensure all they are able to meet the required minimum forces. The steering system will undergo testing in controlled environments to ensure all sensors are accurate and the system will respond to obstacles as planned. The team will conduct a full-scale test in corn or cotton fields to simulate the expected performance environment.

4.6.10 Solar Panel Deployment

Solar panel deployment system consists of the panel housing, the deployment gear assembly, and the deployment motor. The entire system will undergo computer simulated stress testing prior before any scale models are constructed. The motor output will be tested and measured to ensure it meets projected forces

4.7 Pre-launch procedures:

4.7.1 Recovery prep

- ❑ Parachute packed correctly
- ❑ Drogue chute packed correctly
- ❑ Shock cords are secured to bulkheads by a strong and sturdy knot
- ❑ Parachute and drogue chute secured inside the rocket correctly and protected against pyro charges
- ❑ Shock cords are not tangled when packed inside the rocket
- ❑ Inspect wiring of E-bays to make sure there is no exposed wire or break
- ❑ Check program of both altimeters
- ❑ Altimeters are set to deploy drogue chute when the launch vehicle reaches apogee
- ❑ Altimeters are set to deploy main chute when the launch vehicle reaches 700 ft during descent
- ❑ E-bays are secured and protected against pyro charges
- ❑ Each altimeter is properly armed by an on/off switch which is accessed from outside the rocket
- ❑ Inspect to make sure the altimeter goes through the beeping sequence when the switch is flipped on repeating 3 beeps different pitches
- ❑ Rail buttons are secured to bulkheads by screw and tightened

- ❑ Rail buttons are lined up with each other vertically
- ❑ Securely tighten all screws as final check of rail buttons

4.7.2 Motor Assembly

- ❑ Apply Axle grease to threads on casing and closures (To be able to remove after burn
- ❑ Inspect compartments (Tracking smoke module and ignitor kit for smoke liner)
- ❑ Line forward closure cavity with highest temp axle grease and insert smoke grain, cover smoke grain face with grease (forward face unexposed)
- ❑ Wipe grease from open face
- ❑ Remove nozzle from liner and inspect for chamfer and deburring of liner
- ❑ Locate smaller O-ring in bas and insert into the inner groove of nozzle holder/rear closure
- ❑ Push nozzle holder over the nozzle with O-ring side in the rear. Use grease to help fitment
- ❑ Inspect grains for cracks and bubbles. (If possible, weigh for consistent mass)
- ❑ Fit one grain from the top and follow with grain O-ring
- ❑ Install dry grains with spacer O-rings (End with one spacer O-ring on top)
- ❑ Install O-ring onto forward closure and nozzle carrier exteriors
- ❑ Insert loaded liner into motor casing. (Push in via nozzle holder all the way in)
- ❑ Insert the rear closure and screw in until flush with back of cases, then back out a half turn
- ❑ Apply O-ring lube (or axle grease) to top of O-ring/spacer (Ensure the area is clean)
- ❑ Insert black plastic ring above grain
- ❑ Insert forward retaining ring with <u>exactly flush or slightly inlaid</u> (If not flush, back out nozzle end and re-tighten)

4.7.3 Vehicle prep

- ❑ Inspect configuration of launch vehicle
- ❑ Nose cone fits secure
- ❑ Inspect airframe for any structural failures
- ❑ Inspect to make sure there is no epoxy drying
- ❑ Inspect to make sure everything is secured both inside and outside the launch vehicle
- ❑ DACS is properly secured and working functionally
- ❑ Rectangular flaps move on DACS
- ❑ Recognize readiness alarm/light for launch

4.7.4 Rover payload prep

- ❑ Rover is assembled correctly
- ❑ The motors on the rover are working properly to move the rover
- ❑ The motor on the rover is working properly to deploy the solar panels
- ❑ Rover is ready for deployment
- ❑ Recognize readiness light/beeping for payload ejection charges
- ❑ Recognize readiness light/beeping for solar panel deployment
- ❑ Rover is stored securely in launch vehicle away from pyro charges

4.7.5 Pre-Launch Safety Checklist

- ❑ Ensure there is no exposed wire of the electrical systems
- ❑ Ensure that the drogue parachute is protected from the pyro charge
- ❑ Ensure that the main parachute is protected from the pyro charge
- ❑ Ensure that the E-bay is protected from the pyro charge
- ❑ Ensure that the rover is protected from the pyro charge

- ❑ Ensure that BEFORE you check the arming of the altimeters that there is no black powder inside the rocket
- ❑ Ensure that the shock cord and parachute is folded and placed inside the launch vehicle correctly so that no tangling occurs when recovery system is deployed
- ❑ Ensure that it is safe and cleared by the RSO to go onto launch pad
- ❑ Ensure that before launch, everyone is a safe distance away and only certified people are allowed on the launch pad.
- ❑ Ensure that before launch, the sky is clear from wildlife, clouds, or planes.
- ❑ Ensure that everyone has full attention on the rocket during its full flight (launch to landing)

4.8 Launch Procedures and Checklist

- O Wait for approval from RSO and event staff to walk to pad with rocket
- O Turn on rover to run program and wait for landing command
- O Pack rover back in rocket and secure rover
- O Nose cone is fitted snug and screws tightened
- O Set up launch pad
- O The launch pad will be notified when lowering or raising the launch rail. Launch pad will be notified when doing any of the following:
    - Connecting ejection charges
    - Turning altimeters on
    - Loading shear pins
    - Sealing any section with screws
    - Loading rocket motor
    - Loading motor igniter
    - Connecting motor igniter to electrical leads
    - Activating rover
    - Running through all electrical light and beeping signals.
- O Tip pad over to lower rail.
- O Check rail and rail buttons to make sure everything is in perfect condition
- O Slide the rocket all the way onto the rail
- O Tip pad up to raise rail and rocket
- O Arm first altimeter
- O Listen for the correct series of beeps
- O Arm second altimeter
- O Listen for the correct series of beeps
- O Connect ELS to battery
- O Clear the launch area
- O Wait for approval from the event administration for launch
- O Do final check for range being clear and clear sky Do not launch with wildlife in sky, airplanes, or into clouds
- O Insert key into ELS
- O Start countdown from 5
- O Launch
- O Remove key from ELS

- Disconnect ELS from battery
- Recover rocket and the rover

4.9Recovery Procedure/Post flight inspection:

4.9.1 Recovery Procedures

- ❑ The Director, Safety Officer, and all three team leads (vehicle, recovery, and payload) will be approaching rocket for recovery
- ❑ Wait for all clear from RSO to retrieve rocket
- ❑ Approach the rocket. We will be bringing a magnetic platform and necessary storage compartments for smaller parts.
- ❑ Upon reaching rocket, inspect to make sure no pyro charges are live
- ❑ Collect data from altimeters through series of beeps
- ❑ In event of a contingency occurring such as parachute failing to deploy or no sign of separation charge for rover, we will adjust plans in regards to the safety of our team members with pyrotechnic safety.

4.9.2 Payload deployment checklist

- ❑ Activate 1st channel via transmitter to activate payload ejection charge
- ❑ In the event of failed ejection, immediately activate the 2nd channel via transmitter and activate the backup ejection charge
- ❑ Activate the 3rd channel via transmitter to activate removing the pin to release the bearing for correct orientation
- ❑ Activate the 4th channel to engage the rover to drive out of the Rocket

4.9.3 Post flight inspection

- ❑ Did it leave launch pad:
- ❑ Altitude:
- ❑ How far high/below was the altitude from 5280 ft:
- ❑ Drogue parachute deployment successful:
- ❑ Main parachute deployment successful:
- ❑ Velocity at landing:
- ❑ Separation charge successful:
- ❑ Rover exited launch vehicle:
- ❑ Rover travelled 5 ft minimum away from launch vehicle:
- ❑ Rover deploy solar panels:
- ❑ Airframe in tact:
- ❑ Motor damaged:
- ❑ Any sign of damage on launch vehicle:
- ❑ Can it be launched again if required:

❑ 4.10 Failure Mode Assessment Chart

Item	Identification	Description	Failure Modes	Cause of Failure Mode	Effect On The Mission	Safeguard and Mitigation	Risk, 1-10
1	Shock Cord	Absorbs the shock from vehicle	• Shock Cord	• Main Parachute Fails to	• Failure to fully deploy	• Mentor inspection	1

		separation and secures sections	Entanglement • Shock Cord Twisting	Deploy properly or at all	parachute and land within the safe velocity range	before launching	
2	Deployment Bag	Flame retardant bag which protects the parachute from harmful ejection charge flames	• Deployment Bag Failure	• Parachute Damaged in stage separation	• Failure to deploy main parachute and safely recover flight vehicle	• Correct orientation of deployment bag • Correct packing	1
3	Quick Link	Connects shock cord to the paracord with quick removability	• Section is no longer connected and fails to decelerate upon landing	• Vibrations during flight • Loose fitting regarding threaded end	• Failure to connect the shock cord and paracord resulting in freefalling damaged sections	• Inspects and torque down before flight	1
4	Paracord	Shock absorbing cord member	•Weak paracord wraps causing the system to unwrap and come apart	•Thermal Fatigue• Improper knot	• Failure to fully deploy parachute and land within the safe velocity range	• Inspection for compromised portion and correct knot	5
5	Eyebolt	Creates connection between the bulkhead	• Eye bolts threaded end could get severed from bulkhead	• Vibrations during flight	• Failure to recover undamage	• Inspect for yielding and	8

		and shock cord	and lose the parachute or vehicle section upon deployment	• Loose Fitting with bulkhead	d vehicle sections	proper welds	
6	E-Match	Receives electrical signal to ignite ejection charges	• Prevention to ignite ejection charges	• Connection to the wrong leads ejecting unintended charges	• Failure to separate sections and deploy recovery systems	• Continuity check before flight • Safe Placement within vehicle	3
7	Nose Cone	Creates efficient drag coefficient and secures Payload experiment equipment	• Failure to deploy and separate • Nose Cone Damage	•Complication with the shear pins installed • Adjacent section premature deployment would cause unpredicted damage	• Failure to detach will prevent successful deployment of the rover • Damage to nosecone would affect the nosecone performance or payload continuity.	• In the event the nosecone is separated from the vehicle recovery system, a backup parachute has been installed • Larger shear pins installed and will be tested	9
8	Shear Pin	Prevents premature separation due to low force engine shutoff and high force	• Premature shear and separation • Failure to shear and separate	• The shear pins would already be sheared prior to launch of the rocket	• Premature separation would allow undesired forces on separated	• Larger shear pins in nose cone area to be tested	2

		parachute deployment		• Incorrect number or gauge of shear pins	sections causing functionality complications		
9	Electronic Wires	Transmits electric signals to ejection charge, receiver, ESC, and electric motors.	• Failure to send/receive signals	• Improper securement of Electronics • Electronics could be damaged on launch or parachute deployment which would not allow them to operate or their data be recovered	• No ejection, altimeter, and payload would lose connection and would no longer function	• Placement • Verification of solder connections	1
10	Battery	Stores voltage for mobile electric supply to deploy payload, record data, and operate altimeter	• Battery Failure	• Water damage • Voltage discharge • Impact damage	• Would cause the altimeters to not turn on or function at all.	• Replace and secure battery before flight with pull test	1
11	Pilot Chute	Deployment chute that assists in the deployment	• Failure to deploy	• Damage during ejection charge • Poorly packed and	• Would cause the main parachute to not deploy	• Tightly wrapped fire blanket • Ensure Mentor	4

		of the main chute		failure to deploy		packs pilot chute	
12	Bulkhead	Creates fixed volume for ejection charge deployment	• Failure to deploy	• Impulse from parachute deployment	• Causing a different section of the rocket to become separated.	• Inspection before installation to determine any defects	1
13	EM Shielding	Prevents any early ejection by blocking unpredicted electronic signals	• Failure to block undesired electronic signals	• Failure to properly shield the ejection charges from the transmitter signal	• Nosecone could deploy either in the air or on the launch pad	• Properly install EM shielding	3
14	Altimeters	Verifies continuity for all ejection charges, records flight data, and initiates ejection charge ignition	• Poor connection • Poorly secured to rigid surface	• A short circuit or buildup of static charge • Flight vibrations and disconnections	• Stage deployment when arming the rocket on the launch pad	• Test verified functionality	1
15	Centering Rings	Ensures axial thrust vector	• Motor thrust line deviates from axial line	• Poorly secured when bonded to the airframe	•Unaligned thrust vector, sending the vehicle off course	• Minor forces experienced	1

16	Encapsulating Foam	Seals an airtight and structural bond between the motor mount and airframe	• Failure to install motor and centering rings	• During filling process, foam could expand uncontrollably into undesired areas	• Presents complications during construction costing the team a necessary replacement	• Minor forces experienced	1
17	Thrust Place and Retaining Ring	Secures the rocket motor from moving out of a static position	• Material failure and improper installment	• Thrust plate or retaining ring could allow rocket motor to fall out	• Unstable rocket motor and center of thrust	• 66 aluminum thickness offers high factor of safety	2
18	Motor	Creates thrust and propels the vehicle and payload off of the ground	• Improper storage and installment • Explosive fuel grain	• Failure to follow Reese storage and Motor Assembly Procedures • Air bubbles in fuel grain accelerates ignition past a burn and into an explosion	• Could result in failure to propel vehicle or improper ignition	• Inspect fuel grain for air bubbles and take the appropriate measures	4
19	Fins	Creates a center of pressure at the cost of drag in order to	• Fin flutter and poor guidance	• Poor Epoxy application and unbalanced placement distance	• Unpredictable flight path and even erratic	• Fins are secured via fillets centered on the motor mount, G10	1

		guide the vehicle			flight behaviors	material has been custom CNC'ed	
20	Setup on Launcher	Point at which ignition connections are made and vehicle is armed	• Personnel or vehicle injury	• Failure to follow checklist directions directed to avoid such scenarios	• Inability to launch vehicle or immediate disqualification	• Limited personnel will be on site and Safety officer executing the checklist procedures	2
21	Black Powder Charge	Creates a small ejection force to deploy separation regarding the recovery process	• Premature ignition	• Insecure connections allowing voltage to flow freely from the battery to the e-match	• Ejection charge deployment on the launch pad causing injury to vehicle and personnel	• Verify connections and ensure safe placement within vehicle	1
22	Electrical Tape	Adds strength to solders and prevents any short circuiting	• Failed adhesive seal	• Loose application or expired tape used	• Cause early ejection charge deployment or electronic short circuit	• Recovery Team lead and Mentor verification of adhesive seals	1
23	ESC	Converts voltage from the battery to	• Overheating	• Improper current sent through electronics causing the	• Inability to send correct voltage to electric	• Payload team lead verification for correct	1

		the electric motor		ESC to be overloaded	motors and failure for payload to operate	electronic testing before launch	

6. Launch Operations Procedures

6.1 Testing

Ground Charge Testing

In addition to testing the compartments, we tested nitrile gloves tips as an alternative to the centrifuge and metal casing. The charge packets were packed and wired, as specified in the recovery section, and then tested by placing a plywood board on top of the charge in order to contain it. The charges were then manually detonated from a safe location. The test charge proved to provide a safer, omnidirectional, softer, low velocity explosion.

Initial and Second Nose Cone Ejection Charge Test

Ground testing done for the nose cone ejection charge was done by packing a canister charge, laying the airframe down on its side with the nose cone’s aft half affixed via shear pins, and detonating the charge manually. The charge was wired and ran to a safe location where they were affixed to a switch which would allow for remote detonation. The test setup is pictured below.

The size of the charge tested was 2.5 grams. This charge size was a slightly energetic of a detonation, which separated the nose cone from the airframe with considerable distance between the ends. This can be easily attributed to the lack of shear pins during this test trial. The charge was safe in terms of explosive power and will not compromise either the airframe or the nose cone.

With the results from our full-scale test and our ground testing in mind, particularly with the nose cone issue, moving up the number of shear pins will not significantly change the required charge size.

Initial and Second Drogue Chute Ejection Charge Test

Ground testing done for the drogue parachute's ejection charge was done by packing the parachute and canister charge, laying the airframe down on its side and simply detonating the charge manually. The airframe was laid flat on the ground for this test. The charges were then wired to a switch and ran to a safe location where they were remotely detonated. The setup can be seen in the photo below.


n

The size of the initial charge tested was 1 gram. This proved to be an effectively sized charge, providing sufficient separation of the compartment. The second charge tested was the 1.5 gram secondary backup charge, which proved to be a safely sized charge which would not compromise the airframe.

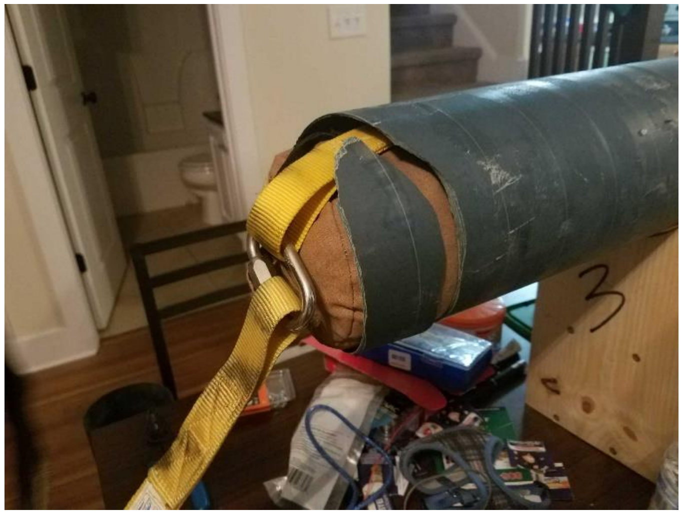
Initial Main Chute Ejection Charge Test

Ground testing done for the main parachute's ejection charge was conducted by packing the parachute and charge, laying the airframe down on its side and manually detonating the charge, similar to the drogue testing method. The parachute was packed in a manner that a void rested forward of it, with a smaller cavity aft of the chute. A canister & centrifuge charge was placed in the forward void, above the parachute bag. The initial test setup is pictured below.

The charge was originally calculated using the entire volume of the section and to 15 psi (per our mentor's advice). The specified charge size in the CDR was 7.7559 grams, and after our prior ground tests, it was determined that charge size would be too large to safely detonate. We recalculated the charge size, using the same volume, for 7 psi and found our new charge size to be approximately 3.5 grams.

During our initial test, the charge size proved to be too large and caused our airframe to rupture, as seen in the photo below. After speaking with several experts and reaching out to our mentor and other high-powered rocketry specialists, we proceeded with analysis of the test.

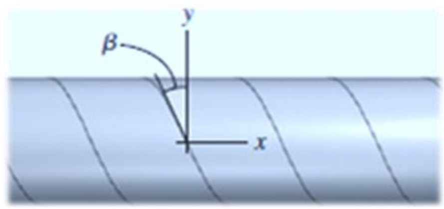
The damage from this test is pictured in the photos below.



Preliminary forensic analysis has been conducted on the failed piece of airframe, with the current working theory being that the parachute compressed, thus created a pressure seal which created significant back pressure. This compression and sealing reduced the volume of our pressurized compartment from 500.9222 in^3, as previously calculated, to about 140 in^3 and potentially even lower. With a reduction in volume of about 360 in^3, this created a significantly higher pressure than expected.

In addition, we suspect that because of the charge's metal housing and its lack of securing mechanisms, it acted as shape charge against the inner wall of our airframe. This effect is suspected of causing a weakening effect, which when coupled with the over pressurization of the vessel, caused a failure due to hoop and lateral stresses.

Back of the envelope calculations using thin-walled pressure vessel assumptions are conducted in the following lines to provide further insight, particularly as it relates to stress within the walls of the airframe, into the nature of the failure. Certain material properties could not be provided to us by the manufacturer, so material properties are estimated using similar materials and their corresponding properties. The airframe is represented as a spiral wound and welded cylinder as seen in the diagram below.



Given:

$$V_{eff} = 140 \text{ in}^3$$

$$mass_{BP}(grams) = \frac{P_{req}/* V_{eff}}{\left(266 \frac{in * lbf}{lbm}\right) * (3307\ R)} * (454 \frac{g}{lbf})$$

Rearranging to solve for pressure yields:

$$P_{actual} = \frac{mass_{BP}(grams) * \left(266 \frac{in * lbf}{lbm}\right) * (3307\ R)}{\left(454 \frac{g}{lbf}\right) * V_{forward\ void}}$$

$$P_{actual} = 48.5\ psi$$

Given:

$$Inner\ Diameter = I.D. = 5.973"$$

$$Outer\ Diameter = O.D = 6.097"$$

$$thickness\ of\ wall = t = O.D. - I.D. = \ .106"$$

$$angle\ of\ spiral = \beta \approx 15°$$

Substituting this pressure into thin-walled pressure vessel equations yields:

$$\sigma_{hoop} = \frac{pd}{4t} = \frac{48.5\ psi * 5.973"}{2 * .106"} = 1366.465\ psi = 9.42\ MPa = \sigma_y$$

$$\sigma_{long} = \frac{pd}{4t} = \frac{48.5\ psi * 5.973"}{4 * .106"} = 683.232\ psi = \ 4.71\ MPa = \sigma_x$$

Calculating for normal and shear stresses along the airframe seams:

$$\sigma_{weld,normal\ =} = \sigma_x \cos^2\beta + \sigma_y \sin^2\beta = 728.887\ psi = 5.03\ MPa$$

$$\sigma_{weld,shear} = -\left(\sigma_x - \sigma_y\right) \sin\beta \cos\beta = 170.782\ psi = 1.18 MPa$$

While the specifics of our Blue Tube airframe's material properties aren't available, it is hypothesized that the airframe was compromised by the initial heat and expansion of the charge and then finally torn apart by the resulting pressure wave represented by the above calculations. The initial rupture, which started in between the seam lines which were reinforced with epoxy resin, then carried through the airframe, separating the body at the glued seams.

Second Main Chute Ejection Charge Test

After repairing and reinforcing our airframe as detailed in the launch vehicle section, we went back to testing the ejection charges. The methodology was the similar to the initial test, differing only in the implementation of a roller which angled the airframe upward and reduced friction during the testF. We used our effective volume of 140 in^3 for calculating the size of the charges. In order to ensure safe charge sizes, we started testing at 1 gram of black powder and tested up to 2 grams. The charges used during this test were the nitrile packet charges. The test setup is pictured below.

We observed little difference between the 2 gram and 1.5 gram charge in terms of the deployment of the shock cords and parachute bag. With that in mind, we determined that 1.5 grams was a safe and effective charge size for our main charge, pressurizing the compartment to about 20 psi. 20 psi proved to be reasonably effective in separating the 2 sections and providing sufficient deployment of the shock cord. 2 grams will be our larger secondary backup charge.

6.1.1 Post-Flight Inspection

7. Project Plan

7.1 Budget

Budgeting

Raider Aerospace Society (RAS) within Texas Tech University will acquire all funding. Space Raiders, functioning as a subsidiary of Raider Aerospace Society will be funded by the parent company (RAS). The society's treasurer, Russell Curlee, will continue seeking funding and budgeting for RAS. Space Raiders funding will be spearheaded by Hector Ruiz. A line item budget with parts and prices are detailed below. All prices are subject to an 8.25% sales tax unless otherwise noted. Furthermore, income will be separated into three categories: Funding, Material acquisition, and Facilities/services.

Expenses			Income	
Recovery Parts	$740.00		RAS	$2,250.00
Vehicle Parts	$1,320.00		Top Tier	$1,200.00
DACS Parts	$130.00		Sponsor 1	$750.00
Payload Parts	$310.00		ME Dept.	$1,000.00
Travel	$2,650.00		Eng. College	$1,200.00
Freight	$350.00		Sponsor 2	$500.00
Sponsor investment	$1,001.00		Sponsor 3	$250.00
Miscellaneous	$500.00		Sponsor 4	$250.00
Safety	$269.00		Sponsor 5	$250.00
Scale Model	$550		Sponsor 6	$500.00
	$7,820.00			$8,150.00

All values rounded to highest dollar
10% + accounted for spare parts
Taxes and Shipping accounted for

Fig. 6.1
*See figure 6.3, 6.4, 6.5, and 6.6 for Recovery, Vehicle, DACS, and Payload parts respectively.

Funding:

Top Tier- Texas Tech University uses Top Tier catering services. Each member will participate in a 10-hour shift which will incur $100 per shift to the organization. The organization has not had available slots for the team to work; however, the situation is still developing.

The Texas Tech Mechanical Engineering department has had a history of matching funds, dollar-dollar, an organization can fundraise on its own. The organization must demonstrate the funds are to be used for goals aligning with the department's mission, ethics, and standards.

Rush Enterprises has demonstrated interest in sponsoring the project to support the caliber of engineering students graduating from the university. Approval is pending.

Chik-fil-a and Amazon have also expressed interest in sponsoring the project. Approval from management is still pending and negotiations are underway.

Raider Aerospace Society has allocated $2000 towards Space Raider's mission in NASA's university student launch initiative.

Local businesses popular with the university will be offered a presence in the organization's literature as well as potential company logos on the rocket's body which will appear in local news channels. Further negotiations with local businesses will seek a mutually beneficial relationship. All businesses who contribute to the organization's mission will also receive tax exemption credits. See figure 6.2.

A Gofundme account has been created to further acquire funds as the organization grows and gains supporters. This has raised over $500 so far. The organization received approval to function as a non-profit from the Internal Revenue Service. With the EIN of a non-profit the organization can now guarantee tax break vouchers for sponsor companies. This is detailed in the contract created for sponsorship agreements between the sponsor and the organization.

Additionally, the team had some unexpected complications and was forced to buy new parts. Thankfully, faculty donated a few parts and our budget was set back no more than $200 in new parts.

Sample Fundraising Portfolio:

Material Acquisition:

The following institutions would serve as sources for materials taken as donations. Some might require purchasing and will later on be refunded once materials are demonstrated to be used for collegiate project purposes.

-Texas Tech Industrial, Manufacturing, & Systems Engineering Department
-Home Depot
-Progressive automotive
-MarkForged

Facilities:

The following institutions will serve as facilities for either manufacturing, testing, or modeling

-CB&I Advanced manufacturing and prototyping facility

-Texas Tech IE machine shop
-National Wind Institute
-Reese Technology Center

Recovery Parts List

##	Name	Quanity	Price	Total Price	Store
1	16 ft 1.1 Ripstope Nylon	1	$170.00	$170.00	http://www.the-rocketmar
2	2 ft 1.9 Ripstop Nylon	1	$33.00	$33.00	http://www.the-rocketmar
3	15 ft Kevlar Covered Tubular Nylon Webbing	1	$40.00	$40.00	http://www.the-rocketmar
4	40 ft Kevlar Covered Tubular Nylon Webbing	1	$65.00	$65.00	http://www.the-rocketmar
5	9in NOMEX Blankets	1	$7.00	$7.00	http://cart.amwprox.com/i
6	30in NOMEX Blankets	1	$18.00	$18.00	http://cart.amwprox.com/i
7	3/8in Eyebolt	14	$0.85	$11.90	Hardware Store
8	^^ Nuts	14	$0.85	$11.90	Hardware Store
9	Paracord 100ft	1	$8.29	$8.29	https://paracord.com/colle
10	T3 GPS Tracking System	1	$149.45	$149.45	https://www.missileworks.
11	9 volt Bttery 4 pack	1	$14.95	$14.95	Hardware Store
12	Perfect Flight StratologerCF	2	$54.95	$109.90	http://www.perfectflite.co
13	Switch	3	$2.95	$8.85	Hardware Store
14	Long Distance RF Switch Transmitters & Receivers	2	$11.99	$23.98	https://www.amazon.com /dp/B01G8B9PR8/ref=asc
15	E-Match	6	$0.05	$0.30	Mentor
16	Centerfuge Tube	20	$0.01	$0.20	Mentor
17	Black Powder	50	$0.02	$1.00	Mentor
			Total	$673.72	

Fig. 6.3

Vehicle Parts List

Part	Material	Size	Qty	Cost (ind)	Source	Total
Fins	G10	3ftx1ft 3/16in	1	53.000	http://www.eplastics.	53.00
Motor Retainer ring	AL	75mm	1	53.000	https://www.apogeer	53.00
Body Tube	Blue Tube	6in diam 4 ft	2	66.000	https://www.apogeer	132.00
Nose Cone	ABS	6.25inx20in	1	0.000	Mechanical Engineerin	0.00
Mounting Screws	Steel	1/8in	24	0.100	Hardware Store	2.40
Mounting Nuts	Steel	1/8in	24	0.100	Hardware Store	2.40
Thrust Plate	AL	6in	1	65.000	https://www.apogeer	65.00
Inner Tube	Fiberglass	75mm	1	0.000	Bill's surplus	0.00
Epoxy	G5000	2pints	1	0.000	Previous expense	0.00
Foam	2 Part mix	Pub Missles	1	0.000	Bill's surplus	0.00
Fuel Grain	AP	75m 4 grain	2	247.000	https://csrocketry.com	494.00
Motor Casing	Aluminum	75mm	1	331.000	https://www.apogeer	331.00
Rail Buttons	Delrin	1515	2	0.000	Surplus	0.00
Coupler	Blue Tube	4 feet	1	66.000	https://www.apogeer	66.00
					Total	$1,199

Fig. 6.4

DACS Parts List

Part	Cost	P/N	Source	Total
Pressure sensor	$15	SparkFun Altitude/Pressure S	https://www.sparkfun.com/products/11084	
Accelerometer	$10.49	SparkFun Triple Axis Accelerometer Breakout - MMA8452Q (with Headers)	https://www.sparkfun.com/products/13926	
Linear Actuator	$75	PA-14P	https://www.progressiveautomations.com/linear-actuato	
Control Arms	$0	Custom DMLS	ME shop	
G10 Flaps	$0	G10 Fiberglass	Surplus	
G10 Ribs	$0	G10 Fiberglass	Surplus	
Removable Bulkhead	$0	Aluminum (milled)	ME shop	
Fixed Bulkhead	$0	Plywood	Surplus	
Hinges	$0	Aluminum (milled)	ME shop	
Crown	$0	Aluminum (milled)	ME shop	
Battery	$?	Lithium		
Pins	$0	Stainless steel (milled)	ME shop	
Arduino UNO	$0	Microcontroller	Surplus	
			Total	$100.49

Fig. 6.5

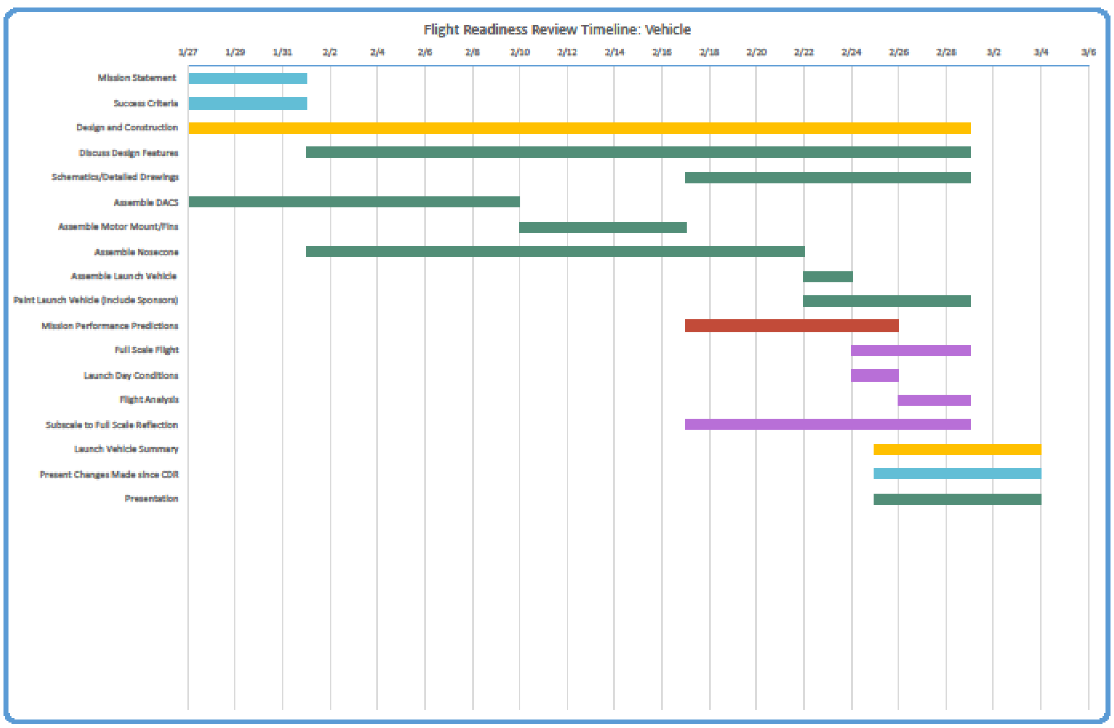
Payload Parts List

Item	Descriptions	Price	Qty	Total Price	Part No	Link
General						
.125" Plastic Stock	12" x 12"	$4.23	1	$4.23	8619K441	https://www.mcmaster.c
.25" Plastic Stock	6" x 12"	$4.62	1	$4.62	8619K751	https://www.mcmaster.c
.5" Plastic Stock	12" x 12"	$7.46	1	$7.46	8619K461	https://www.mcmaster.c
1" Plastic Stock	6" x 6"	$13.23	1	$13.23	8619K614	https://www.mcmaster.c
3D Printing Materials	-	$0.00	1	$0.00		https://www.depts.ttu.ed
3D Printing Machine Time	-	$0.00	1	$0.00		https://www.depts.ttu.ed
Bearing Housing						
Motor for Bayonet	Servo	$13.99	1	$13.99	900-00008	https://www.alliedelec.c
Spring for Bayonet	.2 OD, .36" CL, .49 LB	$0.61	1	$0.61	965K46	https://www.mcmaster.c
Rover						
Raspberry Pi	3 Model B	$34.90	1	$34.90		https://www.amazon.com
Pressure/Altitude/Temp.	MPL3115A2 - I2C	$9.95	1	$9.95	MPL3115A2	https://www.adafruit.con
Temp & Humidity Sensor	Adafruit Si7021	$6.95	1	$6.95	Si7021	https://www.adafruit.con
ZIPPY Compact Battery		$10.56	2	$21.12	9067000018-(	https://hobbyking.com/er
~~Step Down Regulator~~		$3.95	1	$3.95	2098	https://www.pololu.com/
Wires	80 pc set	$5.99	1	$5.99	4330587431	https://www.amazon.com
Breadboard	Solderable Breadboard	$4.95	1	$4.95	PRT-12070	https://www.sparkfun.co
Ultrasonic sensor		$3.95	2	$7.90	474-SEN-1395	https://www.mouser.com
Solar Panel	53X30mm	$0.59	3	$1.77		https://www.aliexpress.c
Panel Deployment Servo	1.3"x1.2"x0.5" servo	$7.50	2	$15.00	2442	https://www.adafruit.con
Torsion Springs	1 in-lb torque, 6 pk.	$6.41	1	$6.41	9271K31	https://www.mcmaster.c
Wheel Bracket Pins	1/16" x 3" Shaft	$2.70	1	$2.70	1327K83	https://www.mcmaster.c
Wheel Extension Motor	Brushed motor 256:1 r	$4.96	2	$9.92	225000049-0	https://hobbyking.com/er
Wheel Extension Screw	ASTM A193 Steel ACM	$8.98	2	$17.96	93420A881	https://www.mcmaster.c
Drive Motor	4 pk	$13.99	4	$55.96	RV2306	https://www.hobby-wing
ESC	BLHeli Series, 30Amp	$13.00	2	$26.00	XT60	https://store.flitetest.com
			Total	$275.57		

Fig. 6.6
Safety Parts List

Equipment	Qty	Price	Total	Vendor Link
Eye Goggles	14	$1.20	$16.80	rds&id=294712
Safety Glasses	12	$1.85	$22.20	rds&id=40789
Disposable Gloves	200	$0.06	$12.00	https://www.
Disposable Coveralls	25	$1.24	$31.00	id=CjwKCAjwh
Breathing Mask	20	$0.60	$12.00	ype=pla&id=S-
Wool/Nylon Fire Blanket	1	$55.50	$55.50	VUMO3AAAAG
Poly Plastic Tarp	4	$2.80	$11.20	iwAx2nhLovM
First Aid Kit	1	$25.00	$25.00	293&gclid=Cjw
ABC Class Fire Extinguisher	1	$60.00	$60.00	=S-9873&gclid
			$245.70	

Fig. 6.7



7.2 Requirement Compliance

7.2.1 Section 1

Requirement	Verification
Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Verify the students on the team have done 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).
The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Verify the has maintained and will provide a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.
Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	Verify all Foreign National (FN) team members have been identified in the Preliminary Design Review (PDR) and are aware they may be separated from their team during launch week activities.
The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: Students actively engaged in the project throughout the entire year; One mentor (see requirement 1.14); No more than two adult educators.	Verify all team members have been identified in the Critical Design Review (CDR). Team members will include: Students actively engaged in the project throughout the entire year; One mentor (see requirement 1.14); No more than two adult educators.

The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.	Verify the team has engaged at least 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. Verify an educational engagement activity report will be completed and submitted within two weeks after completion of an event
The team will develop and host a Web site for project documentation.	Verify the team has developed and is hosting a Web site for project documentation.
Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	Verify all required deliverables have been uploaded to the team Web site by the due dates specified in the project timeline.
All deliverables must be in PDF format.	Verify all deliverables are in PDF format.
In every report, teams will provide a table of contents including major sections and their respective sub-section.	Verify a table of contents, including major sections and their respective sub-section, has been included in every report.
The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone	Verify the team has any computer equipment necessary to perform a video teleconference with the review panel. Verify the team has at least one cell phone as a last resort.

capability only as a last resort.	
All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	Verify the rocket design will be able to use the launch pads provided by Student Launch's launch service provider.
Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Verify the team has implemented the Accessibility Standards of 36 CFR Part 1194.
Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the	Verify the team has identified a mentor, who has supported the team throughout the project year in the reports. Verify said mentor maintains a current certification, and is in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR.

number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.	

7.2.2 Section 2

Requirement	Verify
The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	Verify the vehicle traveled 5,280 feet above ground level with the onboard barometric altimeter.
The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.	Verify the commercially available, barometric altimeter is secured within the vehicle.
Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Verify the mechanism is present to arm the altimeter through the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
Each altimeter will have a dedicated power supply.	Verify the dedicated power supply is present within the vehicle for the altimeter.
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Verify the arming switch is capable of being locked in the ON position for launch.
The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications	Verify visually and within the reports, the launch vehicle has been designed to be recoverable and reusable.

The launch vehicle will be limited to a single stage.	Verify visually and in the reports the launch vehicle is only using a single stage.
The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.	Verify the launch vehicle has been designed to be completely assembled and ready for launch within a 3-hour time frame.
The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.	Verify in the reports the launch vehicle has been designed to stay in launch-ready configuration at the pad for a minimum of 1 hour, this includes all batteries having the capacity to hold enough energy for launch after sitting for 1 hour.
The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	Verify within the calculations the launch vehicle has been designed to be launched by a standard 12-volt direct current firing system.
The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	Verify the launch vehicle can be launched without any external circuitry or special ground support equipment.
The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Verify through the motor’s manufacturer it uses ammonium perchlorate composite propellant (APCP).
Final motor choices must be made	Verify the motor in the launch vehicle is the same one chosen in the CDR.

by the Critical Design Review (CDR).	
Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.	If the motor is different from the one chosen in the CDR verify it has been approved by the NASA Range Safety Officer (RSO).
The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Verify the calculations show the impulse will be no greater than 5,120 Newton-seconds.
The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail	Verify with calculations the launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit.
The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Verify with calculation the launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	Verify the team has launched a subscale rocket before CDR.
The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full -scale will not be used as the subscale	Verify the subscale model resembles and performs as similarly as possible to the full-scale model using dimensional analysis.
The subscale model will carry an altimeter capable of reporting the model's apogee altitude.	Verify the subscale model has an altimeter on board.
All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight	Verify the team has successfully launched and recovered the full-scale rocket prior to the FRR in its final flight configuration. This full-scale rocket must be the same one used on launch day.

is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight.	
If the payload is not flown, mass simulators will be used to simulate the payload mass	Verify the mass simulator was used to simulate the payload mass at the full-scale launch.
The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Verify visually the mass simulator was housed in the same approximate location as the missing payload mass.
If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.	Verify if any part of the payload changes the external surfaces of the rocket they are present for the full-scale launch.
The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full- scale motor is not flown during The full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted	Verify the full-scale launch is either the same one intended for launch day or closely simulates the motor to be used on launch day.

maximum velocity and maximum acceleration of the launch day flight.	
The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	Verify at the full-scale launch test flight the vehicle is in its fully ballasted configuration for launch day.
After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Verify the vehicle used during full-scale launch is designed to not be modified and will not be modified before launch day without the concurrence of the NASA Range Safety Officer (RSO).
Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018will be granted. This extension is only valid for re-flights; not first-time flights	Verify the full-scale launch is completed before March 6^{th}, 2018.
Any structural protuberance on the rocket will be located aft of the burnout center of gravity	Verify any structural protuberance on the rocket is designed to be located aft of the burnout center of gravity.
The launch vehicle will not utilize forward canards.	Verify the launch vehicle will not utilize forward canards.
The launch vehicle will not utilize forward firing motors.	Verify the launch vehicle will not utilize forward firing motors.
The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.).	Verify the launch vehicle will not utilize motors that expel titanium sponges.
The launch vehicle will not utilize hybrid motors.	Verify the launch vehicle will not utilize hybrid motors.

The launch vehicle will not utilize a cluster of motors.	Verify the launch vehicle will not utilize a cluster of motors.
The launch vehicle will not utilize friction fitting for motors.	Verify the launch vehicle will not utilize friction fitting for motors.
The launch vehicle will not exceed Mach 1 at any point during flight.	Verify the launch vehicle will not exceed Mach 1 at any point during flight.
Vehicle ballast will not exceed 10% of the total weight of the rock.	Verify the vehicle ballast will not exceed 10% of the total weight of the rock.

7.2.3 Section 3

The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	**Verify the launch vehicle is staged where drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Or the RSO has allowed for tumble or streamer recovery.**
Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launch.	Verify a successful ground ejection test has been performed prior to the initial subscale and full-scale launch.
At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Verify through calculations the maximum kinetic energy will be 75 ft-lbf at landing.
The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Verify all the circuits for recovery are independent of the circuits used in payload.

All recovery electronics will be powered by commercially available batteries.	Verify all the electronic components are running off of commercially available batteries.
The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Visually verify the recovery system contains redundant, commercially available altimeters.
Motor ejection is not a permissible form of primary or secondary deployment.	Verify the motor's not designed to eject as primary or secondary deployment.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Verify removeable shear pins are being used for both the main parachute compartment and the drogue parachute compartment.
Recovery area will be limited to a 2500 ft. radius from the launch pads.	Verify the recovery section is designed to land within a 2500ft radius from the launch pads.
An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Verify the electronic tracking device is installed in the launch vehicle.
Any rocket section, or payload component, which lands untethered to the launch vehicle, Will also carry an active electronic tracking device.	Verify the recovery is designed where any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.
The electronic tracking device will be fully functional during the official flight on launch day.	Verify the electronic tracking device will be fully functional during the official flight on launch day.
The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Verify visually the recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.

The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	Verify the recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.
The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Verify the recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.

7.2.4 Section 4

Requirement	Verification
Each team will choose one design experiment option from the following list.	Verify in the reports we have chosen Option 3, the deployable rover.
Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	Read through the reports we have not added any experiments beyond the deployable rover.
If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety.	Read through all the reports and verify no additional experiment is present in the payload section
Teams will design a custom rover that will deploy from the internal structure of the launch Vehicle.	Visually verify the rover is custom and the housing will allow it to deploy.
At landing, the team will remotely activate a trigger to deploy the rover from the rocket.	Visually verify the equipment is present for the rover to be remotely activated from the maximum distance possible.
After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	Visually verify the rover has driven at least 5ft from the landing autonomously.

Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	Visually verify the servos have deployed the solar panels once the rover stops.

7.2.5 Section 5

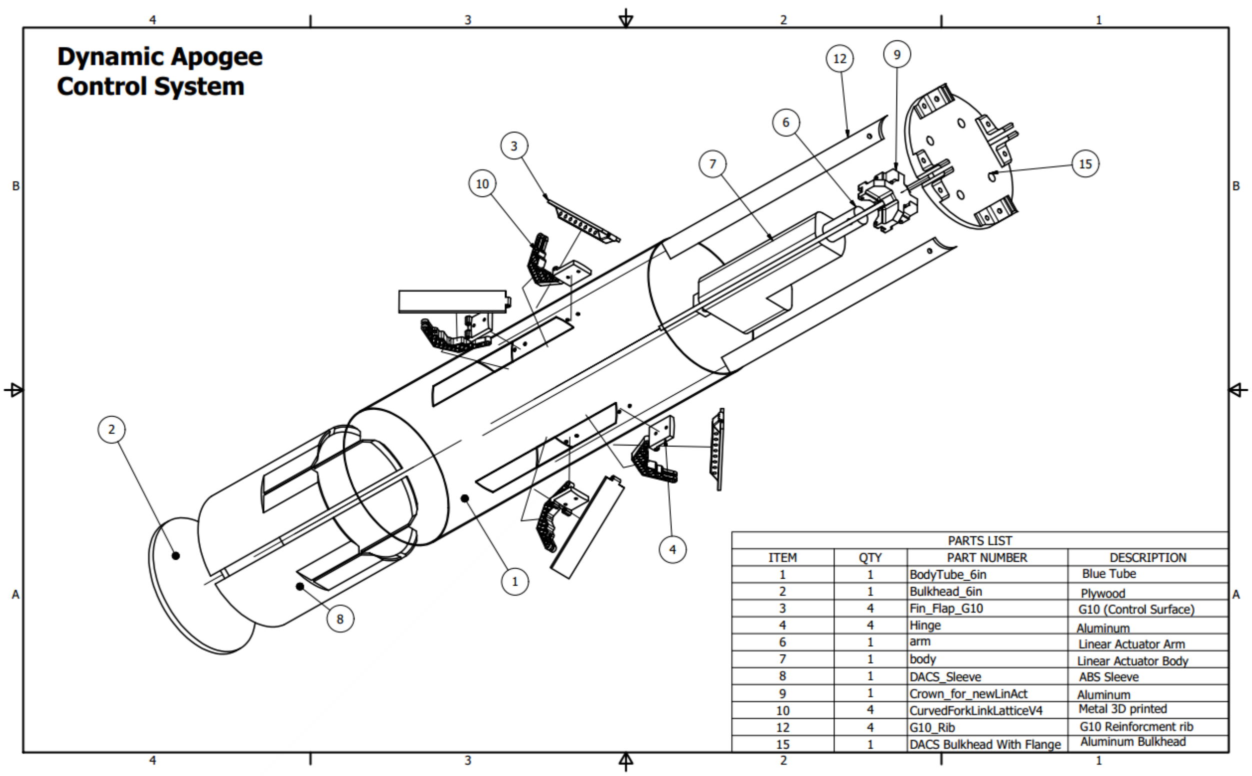
Requirement	Verification
Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	Verify the final checklist is included and completed in the FRR report.
Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Verify we have chosen a student safety officer on our team roster.
Safety officer will monitor team activities with an emphasis on Safety during the design of vehicle and payload.	Verify the safety officer has been involved and has complete knowledge of the payload and vehicle designs.
Safety officer will monitor team activities with an emphasis on Safety during the construction of vehicle and payload.	Verify the safety officer has been involved and has complete knowledge on the construction process of vehicle and payload.
Safety officer will monitor team activities with an emphasis on Safety during the assembly of vehicle and payload.	Verify the safety officer has been involved and has complete knowledge on the assembling of vehicle and payload.
Safety officer will monitor team activities with an emphasis on Safety during the ground testing of vehicle and payload.	Verify the safety officer has been involved and has complete knowledge in the ground testing of vehicle and payload.
Safety officer will monitor team activities with an emphasis on Safety during the sub-scale launch test(s).	Verify the safety officer has been involved and has complete knowledge on the sub-scale launch test.
Safety officer will monitor team activities with an emphasis on Safety during the full-scale launch test.	Verify the safety officer has been involved and has complete knowledge on the full-scale launch test.

Safety officer will monitor team activities with an emphasis on Safety during the launch day.	Verify the safety officer is going to be involved and will have complete knowledge over all activities on launch day.
Safety officer will monitor team activities with an emphasis on Safety during the recovery activities.	Verify the safety officer has been involved and has complete knowledge over the recovery activities.
Safety officer will monitor team activities with an emphasis on Safety during the educational engagement activities.	Verify the safety officer has been involved and has complete knowledge over the educational engagement activities.
Safety officer will implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Verify all procedures have been created by the safety officer for construction, assembly, launch, and recovery activities.
Safety officer will manage and maintain current revisions of the team’s hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	Verify the safety officer has all current revisions organized for the team’s hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.
Safety officer will assist in the writing and development of the team’s hazard analyses, failure modes analyses, and procedures.	Verify the safety officer has helped develop and write the team’s hazard analyses, failure modes analyses, and procedures.
During test flights, teams will abide by the rules and guidance of the local rocketry club’s RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club’s President or Prefect and RSO before attending any NAR or TRA launch.	Verify the team is abiding by the rules and guidance of the local rocketry club’s RSO. Verify the team will receive authority to fly the vehicle at any club launches outside of the NASA Student Launch Initiative, from the local club’s President or Prefect and RSO before attending any NAR or TRA launch.
Teams will abide by all rules set forth by the FAA.	Verify the team’s activities follow all rules set forth by the FAA.

8. Dynamic Apogee Control System

8.1 Design outline and functionality

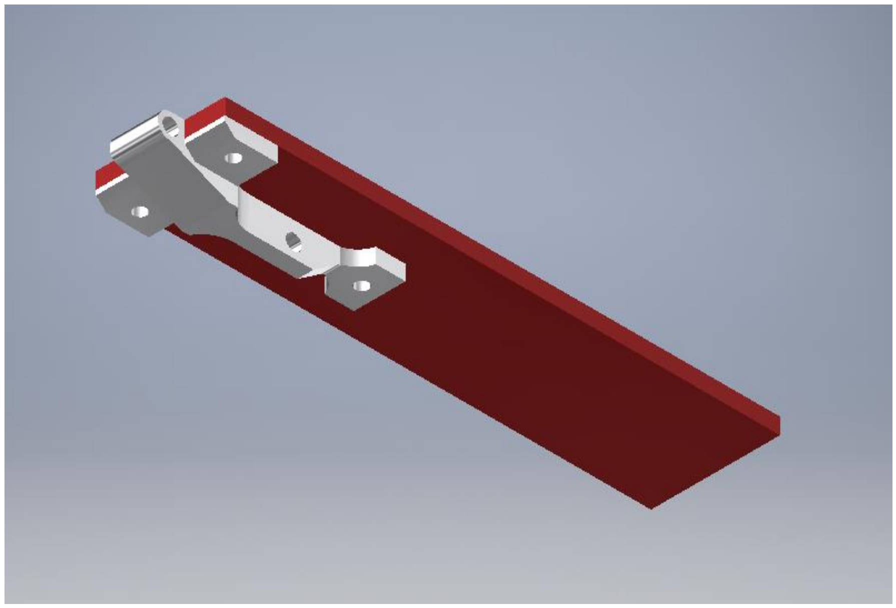
The DACS is a second experimental payload that will be incorporated in this project. The interface of the DACS will be directly mounted to the airframe of the launch vehicle, directly above the motor. This system will serve the purpose of adjusting the flight path by influencing the total drag that is acting upon the Raider 2. It will be programmed with a predictive code that will be able to determine the angle of flap opening to reach a target apogee, granted the rocket will overshoot the target.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	BodyTube_6in	Blue Tube
2	1	Bulkhead_6in	Plywood
3	4	Fin_Flap_G10	G10 (Control Surface)
4	4	Hinge	Aluminum
6	1	arm	Linear Actuator Arm
7	1	body	Linear Actuator Body
8	1	DACS_Sleeve	ABS Sleeve
9	1	Crown_for_newLinAct	Aluminum
10	4	CurvedForkLinkLatticeV4	Metal 3D printed
12	4	G10_Rib	G10 Reinforcment rib
15	1	DACS Bulkhead With Flange	Aluminum Bulkhead

8.1.1 Changes made since CDR

The drag flap construction has changed by the addition of a new component as the hinge. The previously selected material for the flap was G10 itself and due to the nature of the hinge, the thin wall surrounding the pin hole is a trouble spot and would be subject to breakage and flap separation from the airframe. Because this is a situation that would destabilize the rocket, it directly jeopardizes safety of the launch vehicle, and environment, thus is a change that must be made. The solution is to use an aluminum hinge piece that is directly mounted to the flap. This part is shown in the rendering below.



8.1.2 Fabrication and installation

The DACS is a complex system, requiring many custom machined parts and specialty hardware and electronics. Members of the group have shop experience and are becoming more familiar with precision machining instruments such as the Bridgeport and CNC end mill, as well as the Lathe in order to fabricate parts such as the control arms, central crowns and hinges. These parts have undergone critical design reviews with consideration towards geometry, material selection, cost, and complexity of the mechanism/design. Fabrication of the DACS was an on-going process, as the goal was to create and install all mechanical components by the first full-scale launch. After logging countless hours in the ME shop learning how to use precision machinery and fine tune components it was installed and launched in the full-scale flight test, as a simulation mass, and was intended to not actively correct the apogee.

The section below is a collection of images with brief descriptions following the parts fabrication in the Mechanical Engineering Machine Shop.

Direct metal laser sintering powder sifter

Direct Metal Laser Sintering the control arms

Post work grinding on the control arms

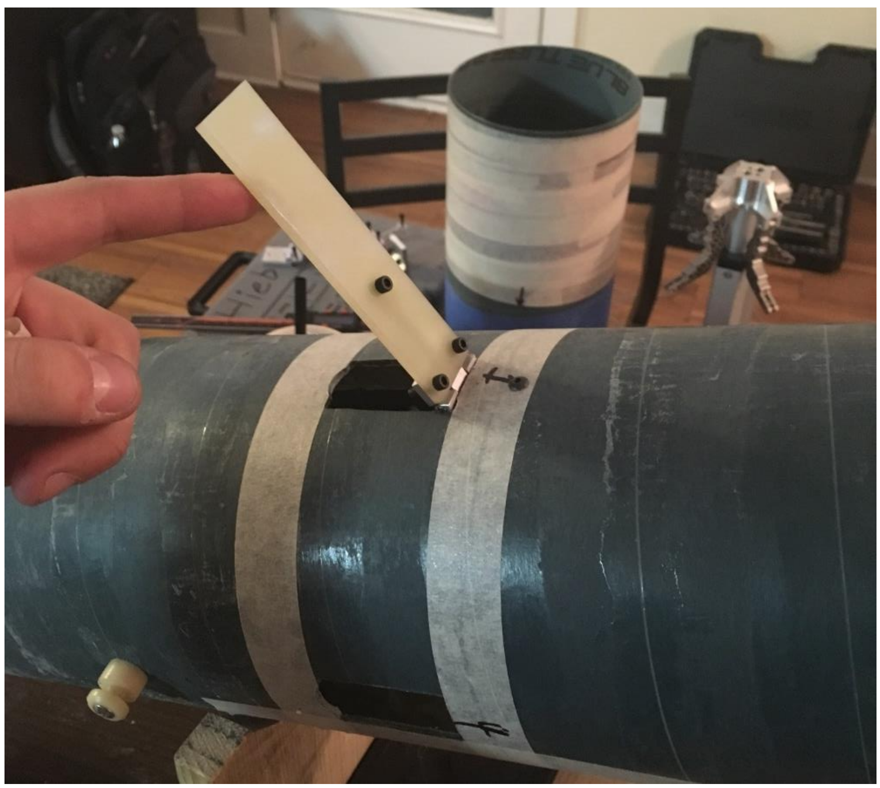
Post work, drilling out holes to be tapped

Tapping 5-40 threads

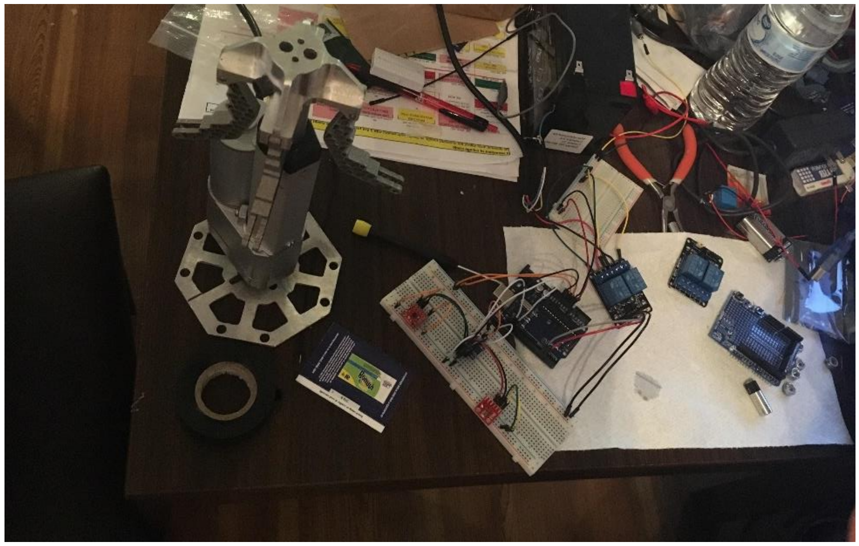
CNC milled crown piece

Finished crown

Manually milling hinges



Installation of hinges and flaps



Wiring DACS sensors for microcontroller testing

Installed system

Electrical Design

Introduction to DACS:

The main goal of the Dynamic Apogee Control System is to increase the precision of the projected apogee by using real-time flight data collected by an accelerometer and pressure sensor. The communication protocol, physical circuitry, and control logic are vital components to the execution of the system. Each aspect is described below in depth.

Communication protocol:

An Inter-Integrated Circuit (I2C) communication interface will be used for DACS between the Arduino and each sensor. Using multiple devices to one serial port has the potential for trouble when communicating data simultaneously. The main advantage of using I2C protocol lies in what is referred to as a two-wire bus. Numerous devices, or slaves, are connected to shared serial data and serial clock lines leading to a master device. An Arduino Uno is used as the master for the braking system. This method drastically reduces the concern of bus contention when data is transmitted from multiple sensor data lines to one port. Each device is assigned a unique address that the Arduino utilizes to communicate and transmit data that is collected during flight.

Physical Control System Circuitry:

An accelerometer and pressure sensor will be used to collect data as system inputs. Each sensor operates on 3.3 Volts while the microcontroller, an Arduino Uno, acts as a source of 5 Volts. A logic level converter will be used to safely relay connection from the Arduino to each device. The level shifter eliminates the need for using physical resistors in the circuitry. This is implemented to prevent damage to either sensor during testing or a full-scale launch. Serial data and clock lines are run from each sensor, to the level shifter, and then to the Arduino to form a complete connection of the system inputs.

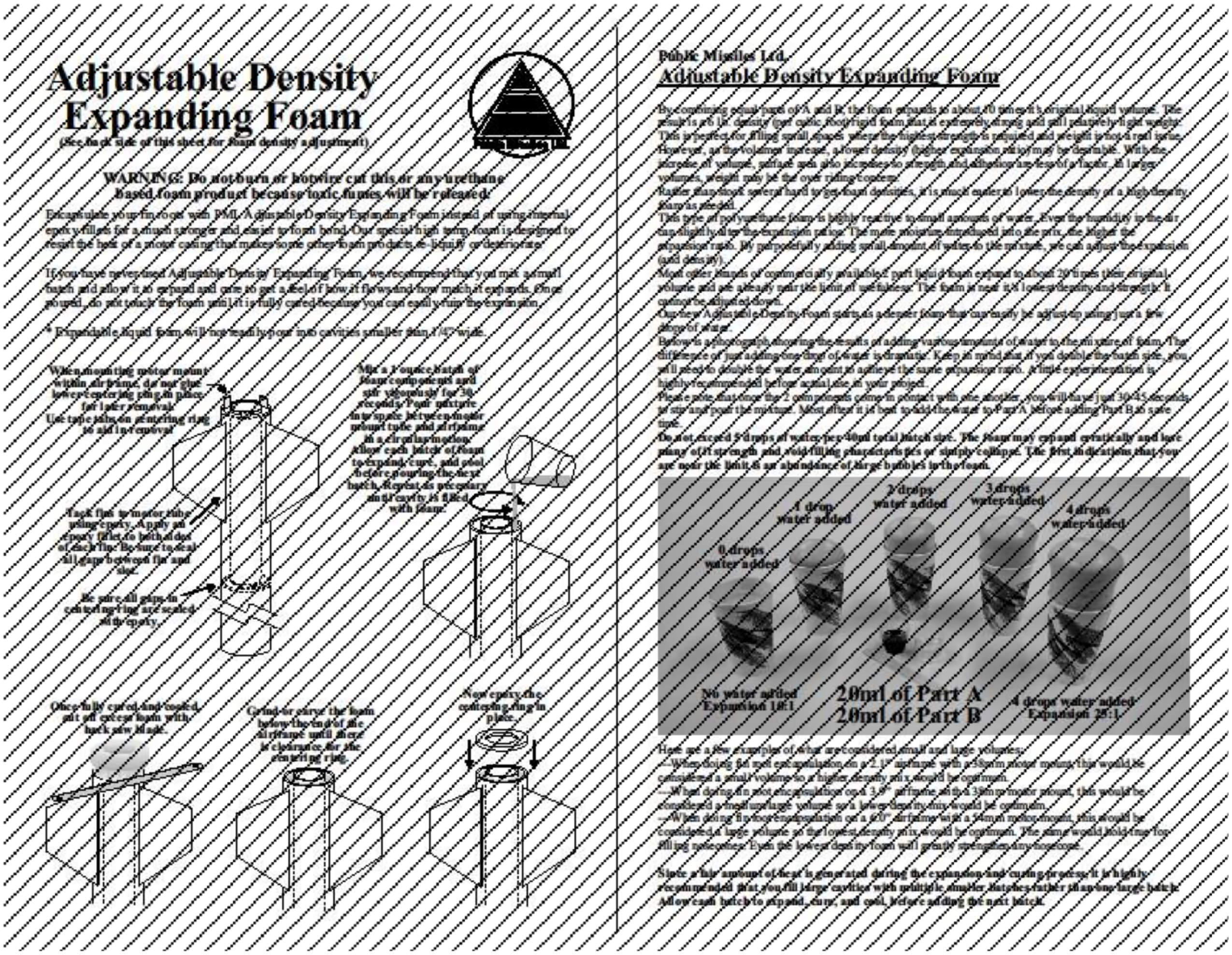
Once data is processed, a linear actuator is used as the system's output. A two-way relay is wired between the Arduino and the actuator. This allows for the vehicle's brake panels to be adjusted in either direction; decreasing or increasing the vehicle's overall drag coefficient. The linear actuator requires a 12 Volt power source that will be provided by an external battery directly connected to the actuator. The diagram below depicts the complete circuit created to control the system.

Control logic:

During a full-scale launch, data will be collected in real-time by each sensor and transmitted to the Arduino. Flight criteria programmed into Arduino software will process the input and predict if the vehicle will overshoot an apogee of a mile. If it is determined the vehicle will overshoot, an output signal is communicated to a two-way relay controlling the positioning of the linear actuator and the external brake panels. The output signal will be based on aerodynamic calculations to correct the vehicle's projected apogee. Brake panels will be rotated outward at a specific angle with respect to the airframe's vertical alignment increasing the overall coefficient of drag. This slows the vehicle therefore increasing the precision of the projected apogee.

If it is determined that the vehicle will undershoot due to any external variables such as wind resistance, then no action will be taken. An emergency protocol will be programmed to fully open if a percent overshoot is detected and cannot be corrected dynamically. At such a high velocity vertically, a fully open feature will still provide an increase in precision of the predicted apogee without exerting an extreme impulse due to the drastic slowing of the vehicle.

9. Appendix A



Adjustable Density Expanding Foam

(See back side of this sheet for foam density adjustment)

WARNING: Do not burn or hotwire cut this or any urethane based foam product because toxic fumes will be released.

Encapsulate your fin roots with PML Adjustable Density Expanding Foam instead of using internal epoxy fillets for a much stronger and easier to form bond. Our special high temp. foam is designed to resist the heat of a motor casing that makes some other foam products re-liquify or deteriorate.

If you have never used Adjustable Density Expanding Foam, we recommend that you mix a small batch and allow it to expand and cure to get a feel of how it flows and how much it expands. Once poured, do not touch the foam until it is fully cured because you can easily ruin the expansion.

* Expandable liquid foam will not readily pour into cavities smaller than 1/4" wide.

Public Missiles Ltd.

Adjustable Density Expanding Foam

By combining equal parts of A and B, the foam expands to about 10 times it's original liquid volume. The result is a 6 lb. density (per cubic foot) rigid foam that is extremely strong and still relatively light weight. This is perfect for filling small spaces where the highest strength is required and weight is not a real issue. However, as the volumes increase, a lower density (higher expansion ratio) may be desirable. With the increase of volume, surface area also increases so strength and adhesion are less of a factor. In larger volumes, weight may be the over riding concern.

Rather than stock several hard to get foam densities, it is much easier to lower the density of a high density foam as needed.

This type of polyurethane foam is highly reactive to small amounts of water. Even the humidity in the air can slightly alter the expansion ratios. The more moisture introduced into the mix, the higher the expansion ratio. By purposefully adding small amount of water to the mixture, we can adjust the expansion (and density).

Most other brands of commercially available 2 part liquid foam expand to about 20 times their original volume and are already near the limit of usefulness. The foam is near it's lowest density and strength. It cannot be adjusted down.

Our new Adjustable Density foam starts as a denser foam that can easily be adjust up using just a few drops of water.

Below is a photograph showing the results of adding various amounts of water to the mixture of foam. The difference of just adding one drop of water is dramatic. Keep in mind that if you double the batch size, you will need to double the water amount to achieve the same expansion ratio. A little experimentation is highly recommended before actual use in your project.

Please note that once the 2 components come in contact with one another, you will have just 30-45 seconds to stir and pour the mixture. Most often it is best to add the water to Part A before adding Part B to save time.

Do not exceed 5 drops of water per 40ml total batch size. The foam may expand erratically and lose many of it's strength and void filling characteristics or simply collapse. The first indications that you are near the limit is an abundance of large bubbles in the foam.

Here are a few examples of what are considered small and large volumes:

---When doing fin root encapsulation on a 2.1" airframe with a 38mm motor mount, this would be considered a small volume so a higher density mix would be optimum.

---When doing fin root encapsulation on a 3.9" airframe with a 38mm motor mount, this would be considered a medium/large volume so a lower density mix would be optimum.

---When doing fin root encapsulation on a 6.0" airframe with a 54mm motor mount, this would be considered a large volume so the lowest density mix would be optimum. The same would hold true for filling nosecones. Even the lowest density foam will greatly strengthen any nosecone.

Since a fair amount of heat is generated during the expansion and curing process, it is highly recommended that you fill large cavities with multiple smaller batches rather than one large batch. Allow each batch to expand, cure, and cool, before adding the next batch.

AeroTech Division, RCS Rocket Motor Components, Inc.

Safety Data Sheet

Prepared in accordance with 29 CFR § 1910.1200 (g)

Section 1. Identification

Product identifier: AeroTech-branded Model rocket motor, high power rocket motor, hobby rocket motor, composite rocket motor, rocket motor kit, rocket motor reloading kit with the trade names White Lightning™, Blue Thunder™, Black Jack™, Black Max™, Redline™, Warp-9™, Mojave Green™, Metalstorm™, Metalstorm DM™ or Propellant X™.

Manufacturer: RCS Rocket Motor Components, Inc., 2113 W 850 N, Cedar City, UT 84721, 435-865-7100, emergency response number: Infotrac (352) 323-3500

Recommended use: Propulsion for hobby rockets.

Section 2. Hazard Identification

Hazard classification: Explosive 1.4S (under 30 grams per motor or propellant grain) and explosive 1.4C (30 to 62.5 grams per motor or propellant grain).

Signal word: Flammable

Hazard statement: Caution: Rocket motors and reload kits are flammable; rocket motors may become propulsive in a fire. All propellants give off varying amounts of Hydrogen Chloride and Carbon Monoxide gas when burned, Mojave Green propellant also produces Barium Chloride.

Pictograms: 

Precautionary Statement: Do not smoke near rocket motors and reload kits and keep away from open flames and other heat sources.

Description of any hazards not otherwise classified: N/A

Unknown toxicity statement: N/A

1

OWEN COMPLIANCE SERVICES, INC.

Material Safety Data Sheet
(MSDS-BP)

PRODUCT IDENTIFICATION	
Product Name	BLACK POWDER
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX, Inc. (Doyline, LA) & various international sources
Transportation Emergency	800-255-3924 (24 hrs — *CHEM - TEL*)

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully handled and used following approved safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, or ordinances. If you have any questions or doubts as to how to use any explosive product, DO NOT USE IT before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

CESARONI TECHNOLOGY INCORPORATED

Pro150 Rocket Motor Reload Kit
SAFETY DATA SHEET

1.0 PRODUCT / COMPANY IDENTIFICATION

1.1 Product Identifier

Product Name: Pro150 Rocket Motor Reload Kit

Synonyms: Rocket Motor, Hobby Rocket Motor, HPR Reload Kit, Solid Rocket Fuel

Part Numbers: Reload kit: P150R-Y-#G-XX
Where: Y = reload type (A = adjustable delay, C = C-slot)
\# = number of grains, &
XX = propellant type

1.2 Relevant Identified Uses

Product Use: Solid fuel motor for propelling rockets

1.3 Details of the Supplier of the SDS

Manufacturer / Supplier:
Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, Ont.
Canada L0H 1G0
E-mail: regulatory@cesaroni.net

1.4 Emergency Telephone Numbers

Telephone Numbers:
Product Information: Tel: +1-905-887-2370 Fax: +1-905-887-2375
24 Hour Emergency Telephone Number: Tel: +1-613-996-6666 (CANUTEC)

2.0 HAZARDS IDENTIFICATION

2.1 Classification

Classification: Explosive Article – Division 1.3 (UN GHS – ST-SG-AC10-30-Rev5e)
(WHMIS 2015 – Canada, HazCom 2012 – USA, Regulation (EC) No. 1272/2008 [CLP] – EU, 67/548/EEC or 1999/45/EC – EU)

2.2 Label Elements

Signal Word: Danger **GHS Pictogram:**

Hazard Statement: H203 Explosive; Fire, Blast or Projection Hazard

Precautionary Statements

P210	**Keep away from heat/sparks/open flames/hot surfaces. No smoking**
P250	**Do not subject to grinding/shock/friction.**
P370+P380	**In case of fire: Evacuate Area.**
P372	**Explosion risk in case of fire.**
P373	**DO NOT fight fire when fire reaches explosives.**
P401	**Store in accordance with local/regional/national regulations.**
P501	**Dispose of in accordance with local/regional/national regulations.**

2.3 Other Hazards

Emergency Overview:
These articles contain cylinders of ammonium perchlorate composite propellant, encased in inert plastic parts. The SRM 3.0 rocket motors are classified as explosives, and may cause serious injury, including death if used improperly. All explosives are dangerous and must be handled carefully and used following approved safety

MATERIAL SAFETY DATA SHEET

Acculam™ Epoxyglas

You Know It's Right... When It's Accurate PLASTICS, INC

Accurate Plastics, Inc.
18 Morris Place
Yonkers, New York 10705-1929
Phone (914) 476-0700
FAX (914) 476-0527
www.acculam.com

Section 1. Chemical Product and Company Identification

Product name **Acculam™ Epoxyglas**	*Trade Name* **NEMA Grades G10, G11, FR4, FR 5**
Manufacturer Accurate Plastics, Inc. 18 Morris Place Yonkers, NY 10705-1929	*IN CASE OF EMERGENCY:* Tel: 914-476-0700 Chemtrec:
Date of Preparation: 11/29/07	Replaces: 10/20/04
Preparers Name KJ Soltys	

Section 2. Composition, Information on Ingredients

Component Information		*Exposure Limits*	
Chemical Name	*CAS #*	*TLV, TWA ACGIH*	*OSHA PEL, TWA*
Fiberglass	65997-17-3	10 mg/m^3 (dust)	15 mg/m^3 (total dust) 5 mg/m^3 (respirable)
Epoxy Resin	25036-25-3	N/A	N/A
Dust generated during grinding, cutting, or drilling fiber glass reinforced plastic contains respirable fiber shaped plastic (organic) particles which has an OSHA PEL of 5 mg/m^3 and nonrespirable fibrous glass dust regulated by OSHA as noted above. Bromine may be an integral part of the polymer matrices of some laminate grades.			

N/A = Not Applicable

Section 3. Hazards Identification

Dust generated during machining and grinding operations may cause skin or eye irritation. Fumes from thermal decomposition or burning may irritate eyes, nose, and throat. Minimize operator exposure to dust and fumes.

Routes of Exposure	Symptoms
Inhalation	Inhalation of dust during machining and grinding operations may cause moderate irritation to mucous membranes and coughing.
Skin	Contact with dust may cause moderate irritation.
Eyes	Contact with dust may cause moderate eye irritation, itching and redness.
Ingestion	Not determined
Cancer	OSHA: N/A IARC: N/A NTP: N/A
Chronic	Dust generated during grinding, cutting, or drilling fiber glass reinforced plastic produces respirable fiber shaped plastic (organic) particles whose concentration increases proportionally with dust concentration. These particles are not classified as carcinogenic by IARC or NTP. However, prolonged inhalation of dust can produce lung disease.

CARBON COMPOSITES, INC.

MATERIAL SAFETY DATA SHEET

SECTION 1 - PRODUCT IDENTIFICATION

Manufacture's Name
Carbon Composites, Inc.

Address
12 Jytek Park
Leominster, MA 01453-5932

Product Name
Rigidized Carbon Felt Insulation
Carbon Fiber Composite

Synonyms
Carbon/Graphite Felt Insulation
Graphite Foil Laminate
Carbon Fiber Composite Laminate, CFC, Carbon/Carbon

Emergency Telephone No.
(978) 840-0707

Telephone No. for Information
(978) 840-0707

Date Prepared
January, 2002
Updated December 4, 2009

SECTION 2 - INGREDIENTS (INERT & HAZARDOUS)

Composition	%	CAS #	OSHA PEL	ACGIH TLV
Carbon/Synthetic Graphite	99.9+	7440-44-0 7782-42-5	15 mg/m³	10 mg/m³

SECTION 3 – PHYSICAL / CHEMICAL DATA

Boiling Point	N/A	**Melting Point**	N/A
Evaporation Rate (Butyl Acetate = 1)	N/A	**Solubility in Water**	Negligible
Vapor Pressure (mm Hg)	N/A	**Vapor Density (Air = 1)**	N/A
Specific Gravity (H_2O = 1)	0.13 – 0.25	**Volatiles by Weight**	Negligible @ RT
Carbon Fiber Composite	1.3 – 1.5 g/cc		

Appearance and Odor
Gray solid laminate, Gray-black fibrous felt; negligible odor

SECTION 4 - FIRE AND EXPLOSION HAZARD DATA

Flash Point	N/A	**Flammable Limits**	LEL – N/A; UEL – N/A
Extinguishing Media	Water, CO_2, Sand	**Extinguishing Media to Avoid**	N/A

Special Fire Fighting Procedures N/A, Difficult to Ignite

Unusual Fire and Explosion Data
Graphite and carbon dusts are normally not explosive, but these may weakly contribute if the event is initiated by another explosive dust or gas. Graphite and carbon dusts are electrically conductive; dust accumulations may cause electrical short circuits or other electrical malfunctions.

Innofil3D make anything!

MATERIAL SAFETY DATA SHEET
according to Regulation (EU) No. 1907/2006

Innofil3D ABS

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY / UNDERTAKING

Product information

Trade name	:	Innofil3D ABS
Chemical name	:	Acrylonitrile Butadiene Styrene
Chemical family	:	Thermoplastic Copolymers
Use	:	Monofilament for 3D printing
Company	:	Innofil3D BV. Eerste Bokslootweg 17 7821 AT Emmen
Telephone	:	+31 (0)591 69 2117
Telefax	:	+31 (0)591 69 3456

2. HAZARDS IDENTIFICATION

a. Classification of substance or mixture
Classification – REGULATION (EC) No 1272/2008
This product is not classified as dangerous according to EC criteria.
Classification according to EU Directive 67/548/EEC or 1999/45/EC
This product is not classified as dangerous according to EC criteria.

b. Label elements
Labelling – REGULATION (EC) No 1272/2008
This product is not classified as dangerous according to EC criteria.

c. Other hazards
No information available

GLENMARC
INDUSTRIES INC.
2001 S. BLUE ISLAND AVE.
CHICAGO, IL 60608
PHONE 312-243-0800
FAX 312 243 4670
TOLL FREE 800-323-5350
www.glenmarc.com

DATA SHEET: G5000 HIGH STRENGTH EPOXY

Description: G5000 is a two component filled epoxy with high strength bonds for joining fiberglass and carbon fiber composites with extremely high shear strengths. It also has excellent adhesion to metals, plastics, woods, and ceramics as well. Cures to a very high strength bond that is also non-brittle to eliminate flexing cracks. Easy to mix 1 to 1 ratio by weight and volume. Mixes to a smooth creamy paste that when applied eliminates drips, sagging, or runoff. Does not require any thickening or strength additives as epoxy is ready to use as supplied. The adhesive cures relatively quickly and can be handled within a few hours. Cures to an easy to paint off white color but pigment can be easily added to provide almost any color desired.

It has excellent mechanical properties, high shear and peel strength, great adhesion, good chemical and environmental resistance, good thermal shock resistance and very low shrinkage. It has low exotherm during cure for filling large mass voids.

Uses: Joining and bonded fiberglass, carbon fiber, composites, any where a high strength non-brittle bond is needed. Great for attaching composite rocket fins, bulk plates, nose cone hardware and especially for professional grade fin fillets.

Mixing and Cure Instructions:

Ratio by weight:	Resin 100	Hardener 100
Ratio by volume:	Resin 100	Hardener 100
Pot life (100 gram mass at 72°F) =	30 to 40 minutes	ASTM D2471
Handling time =	3 to 4 hours	
Full cure =	6 to 8 hours	

Physical Properties (@ 72°F/ 22°C):

Color	Off white but can be pigmented to black or any color.	
Shore "D" hardness	85	ASTM D2240
Viscosity Resin	Paste	
Viscosity Hardener	Paste	
Viscosity Mixed	Paste	
Specific gravity, Resin	1.52	
Specific gravity, Hardener	1.48	
Specific gravity mixed	1.50	
Tensile strength	7,600 psi	ASTM D638
Compression strength	14,800 psi	ASTM D695
Elongation at break %	6.3%	ASTM D638
Typical operating temperature	-50°F to 175°F	
Maximum use temperature	225°F (107°C)	
Deflection temperature	150°F (66°C)	ASTM D648
Shelf Life	1-1/2 Years	

Notice: This information is presented to assist the user in determining whether our products are suitable for his intended use. The user assumes all risks and liability in connection therewith. No warranty or representation express or implied shall apply to these products. Seller's only obligation shall be to replace quantity of this product which has proven to not substantially comply with the data presented. Seller shall not be responsible for property loss or damage direct or consequential arising out of use of this product(s) or inability to use this product(s). See material safety data sheet before using.

Safety Data Sheet

Section 1: Identification

Product Name: **Electric Match (ALL)**

including but not limited to; BGZD, Flash, Shock Tube igniter, igniters

Recommended use: Electric ignition

Professional Use only by a qualified Pyrotechnician in a Theatrical Entertainment Application or in Professional Training Applications.

Manufacturer and Distributor's Name and Address:

Ultratec Special Effects, Inc.
148 Moon drive
Owens Cross Roads, AL 35763
United States
Telephone Number: (256) 725-4224
www.ultratecfx.com

Emergency Telephone Number: 800-255-3924 - ChemTel

Section 2: Hazard Identification

Chemicals have been withheld for trade secret and proprietary information purposes.

WARNING

Burn, eye, skin, respiratory irritation, ingestion, acute or chronic exposure
BURN: Wash affected area.
EYE: Flush eyes with water for several minutes.
SKIN: Wash with soap and water
RESPIRATORY: Move to fresh air and consult physician.
INGESTION: DO NOT INDUCE VOMITING, Contact poison control
ACUTE OR CHRONIC EXPOSURE: Seek medical attention immediately
SEEK MEDICAL ATTENTION IF YOU FEEL UNWELL
Keep away from heat, sparks and open flame, hot surfaces-
NO SMOKING
Store in a cool dry approved area
Dispose of content/container in accordance with local/regional/national

Lithium Polymer Battery

Safety Data Sheet

Version: 2.0

VENOM-GROUP.COM

SECTION 1. Product and Company identification

Product Name	:	Li-Polymer Battery
Synonyms	:	LiPo – [See APPENDIX A]
Use of the substance/preparation	:	Lithium polymer rechargeable cells
Company identification	:	Vertical Partners West 14028 North Ohio Street Rathdrum, ID 83858
Telephone number for information	:	1-800-705-0620 (USA)
24 hour emegency contact	:	Chemtrec 1-800-424-9300

SECTION 2. Hazards identification

2.1. OSHA Regulatory Status

The batteries are hermitically sealed articles under normal conditions of use. The products referenced herein are exempt articles and are not subject to OSHA's Hazard Communication Standard requirements for preparation of safety data sheets. This information is provided as a service to our customers.

2.2. Potential health effects

Lithium cobalt oxide: Odorless blue-black powder - cobalt and cobalt compounds are considered to be possible human carcinogens. By International Agency for Research on Cancer (IARC): May irritate eyes, skin, nose, throat and respiratory system and may cause allergic skin sensitization.

Carbon: Odorless black powder - no cases of carbon being harmful to humans have been reported. World Health Organization (WHO), and International Labour Organization (ILO) have never verified that carbon causes irritation of the skin and mucous membrane, etc.

Electric agent: Black powder (Garlic-Like), Toxicity (Am. Conf. Of Gov. Ind. Hygienists ACGIH 2000 Edition) - Simple Asphyxiant, Flammability limits in air (STP conditions): 2.4-83vol% (The upper limit could reach 100%)

Bond: Odorless white powder - inhalation and skin contact are expected to be the primary routes of occupational exposure to this material. As a finished product, it is a synthetic, high molecular weight polymer. Due to its chemical and physical properties, this material does not require special handing other than the good industrial hygiene and safety practices employed with any industrial material of this type. Under normal processing conditions this material releases fume or vapor. Components of these releases may vary with processing time and temperature. Process releases may produce eye, skin and/respiratory tract irritation and with repeated or prolonged exposures, nausea, drowsiness, headache and weakness. Although unlikely under normal handling conditions, if this material is heated in excess of 600°F (315°C), hazardous, decomposition products will be produced. Hazardous decomposition products include hydrogen fluoride and oxides of carbon, the concentrations of which vary with temperature and heating regimens.

Electrolyte: Colorless liquid - may cause moderate to severe irritation, burning, and dryness of the skin. May cause eye irritation or burning. Breathing of the mists, vapors or fumes may irritate the nose, throat and lungs. Exposure of material with areas which contain water may generate hydrofluoric acid which can cause immediate burns on skin, severe eye burns to the mouth and gastrointestinal tract if inhaled. Direct exposure to areas of the body needs to be treated immediately to prevent injury.

2.3. Potential environmental effects

No additional information available.

MATERIAL SAFETY DATA SHEET

SECTION 1
CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Name: Carbon Fiber

Product Codes: Carbon Fiber Fabric, 12K

Manufacturer's/Distributor's Name: Hi Temp Products of Canada, Inc.

Manufacturer's/Distributor's Address:

Hi Temp Products of Canada, Inc.
16810 – 129 Avenue, NW
Edmonton, AB T5V 1L2
780-424-1829 (Tel. No.)
780-423-4717 (Fax No.)

Emergency Telephone Number: **780-424-1829**

SECTION 2
COMPOSITION AND INFORMATION ON INGREDIENTS

Ingredient	CAS Registry No.	Weight %	Exposure Limits
Carbon fiber	7440-44-0	$\geq$ 99%	See Note 1 below
Respirable fibrous carbon dust	not assigned	not known*	not known*

Notes on *Composition and Information on Ingredients*

*AMOUNT WILL BE DEPENDENT UPON METHOD OF HANDLING
NE = Not established

German RepRap

Material Safety Data Sheet

Polymaker PC-Max

SECTION 1: Hazards identification

A. GHS classification of the substance/mixture

- Not classified

B. GHS label elements, including precautionary statements

Pictogram and symbol: Not applicable

Signal word: Not applicable

Hazard statements: Not applicable

Precautionary statements

Precaution: Not applicable

Treatment: Not applicable

Storage: Not applicable

Disposal: Not applicable

C. Other hazard information not included in hazard classification (NFPA)

Health: Not available

Flammability: Not available

Reactivity: Not available

German RepRap

SECTION 2: Composition / information on ingredients

Chemical Name	Common Name (Synonyms)	CAS number	Content (%)
Polycarbonate	PC	25037-45-0	>70%

SECTION 3: First aid measures

A. Eye contact

- Seek medical attention if eye symptoms occur.
- In case of contact with molten substance, immediately flush eyes with water for at least 15 minutes. Seek medical attention immediately.

B. Skin contact

- Remove and isolate contaminated clothing and shoes.
- Seek medical attention if skin syptoms occur.
- If burned by contact with hot material, cool molten material adhering to skin as quickly as possible with water, and see a physician for removal of adhering material and treatment of burn.
- Wash contaminated clothing and shoes before reuse.

C. Inhalation:

- Not available

D. Ingestion:

- Get medical attention if substance is ingested.

E. Indication of immediate medical attention and notes for physician

- Call emergency medical service. Get medical advice/attention if you needed.
- Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves.
- If burned by contact with molten material, cool as quickly as possible with water, and then see a physician for treatment.

SAFETY DATA SHEET

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT IDENTIFIER:..................................WEST SYSTEM® 105 Epoxy Resin
APPLICABLE PRODUCT CODES: 105, 105-A, 105-B, 105-C, 105-E, C-105-A, C-105-B, C-105-C, C-105-E
CHEMICAL FAMILY:...Epoxy resin mixture.
INTENDED PRODUCT USES:............................Resin for coatings or adhesives.
PRODUCT USE RESTRICTIONS:......................None identified.
SDS VERSION: 105-2016a

MANUFACTURER:
Gougeon Brothers, Inc.
100 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS (24 HRS):
Transportation
CHEMTREC:.................... 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation
Poison Hotline: 800-222-1222

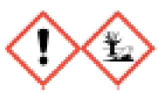
2. HAZARDS IDENTIFICATION

Classification of Substance or Mixture

Skin corrosion/irritation, Category 2
Skin sensitizer, Category 1
Eye damage/irritation, Category 2A
Chronic aquatic toxicity, Category 2

Label Elements

Hazard Pictogram(s):



Signal Word
WARNING

Hazard Statements
H315 Causes skin irritation.
H317 May cause an allergic skin reaction.
H319 Causes serious eye irritation.
H411 Toxic to aquatic life with long lasting effects.

Precautionary Statements
Prevention
P261 Avoid breathing dust/fume/gas/mist/vapors/spray.
P264 Wash hands thoroughly after handling.
P272 Contaminated work clothing should not be allowed out of the workplace.
P273 Avoid release to the environment.
P 280 Wear protective gloves/protective clothing/eye protection.
Response
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P333 + P313 If skin irritation or rash occurs: Get medical attention/advice.
P337 + P313 If eye irritation persists: Get medical attention/advice.
P362 + P364 Take off contaminated clothing and wash it before re-use.
P391 Collect spillage.
Disposal
P501 Dispose of contents/container in accordance with local, regional and international regulations.

Other Hazards Not Resulting in Classification
None known.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

INGREDIENT NAME	CAS #	CONCENTRATION (%)
Propane, 2,2-bis[p-(2,3-epoxypropoxy)phenyl]-, polymers	25085-99-8	60-100
Benzyl alcohol	100-51-6	10-30

Last Revised: 15AUG16

Phenol-formaldehyde polymer glycidyl ether	28064-14-4	1-10

The exact chemical identity and/or exact percentage (concentration) of each ingredient has been held as confidential business information (CBI). Refer to Section 15 for additional information regarding this CBI claim.

4. FIRST AID MEASURES

FIRST AID FOR EYES.. SYMPTOMS: Causes serious irritation and redness. RESPONSE: Flush immediately with water for at least 15 minutes. Remove contact lenses if present and easy to do. Consult a physician as precautionary measure.

FIRST AID FOR SKIN.. SYMPTOMS: Causes skin irritation. May cause allergic skin reaction and sensitization. RESPONSE: Remove contaminated clothing. Wipe excess from skin. Apply waterless skin cleaner and then wash with soap and water. Consult a physician if effects occur.

FIRST AID FOR INHALATION.. SYMPTOMS: Not a likely route of exposure under normal conditions of use. RESPONSE: Remove to fresh air if respiratory irritation occurs and keep comfortable for breathing.

FIRST AID FOR INGESTION.. SYMPTOMS: No acute adverse health effects expected from amounts ingested under normal conditions of use. RESPONSE: Seek medical attention if a significant amount is ingested.

5. FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA: .... SUITABLE: Foam, carbon dioxide (CO_2), dry chemical. NON-SUITABLE: Direct water stream.

FIRE AND EXPLOSION HAZARDS: .... During a fire, smoke may contain the original materials in addition to combustion products of varying composition which may be toxic and/or irritating. Combustion products may include, but are not limited to: phenolics, carbon monoxide, and carbon dioxide.

SPECIAL FIRE FIGHTING PROCEDURES: .... Wear a self-contained breathing apparatus and complete full-body personal protective equipment. Closed containers may rupture (due to buildup of pressure) when exposed to extreme heat.

6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS AND PROTECTIVE EQUIPMENT: .... Keep unnecessary and unprotected personnel from entering area. Use appropriate safety and personal protective equipment as indicated in Section 8.

MITIGATION AND CLEAN UP PROCEDURES:.. Stop leak without additional risk. Isolate area. Dike and absorb with inert material (*e.g.*, sand) and collect in a suitable, closed container. Warm, soapy water or non-flammable, safe solvent may be used to clean residual.

ENVIRONMENTAL PRECAUTIONS:.. Prevent from entering into soil, ditches, sewers, waterways and groundwater. See Section 12 for environmental impact information.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 120°F (49°C)

STORAGE:.. Store in cool, dry place. Store in tightly sealed containers to prevent moisture absorption and loss of volatiles. Excessive heat over long periods of time will degrade the resin.

HANDLING PRECAUTIONS: .... Avoid all skin and eye contact. Wash thoroughly after handling. Launder contaminated clothing before reuse. Avoid inhalation of vapors from heated product. Precautionary steps should be taken when curing product in large quantities. When mixed with epoxy curing agents this product causes an exothermic, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Safety glasses with side shields or chemical splash goggles.

SKIN PROTECTION GUIDELINES:.. Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES:.. Use with adequate general ventilation and/or local ventilation to keep exposures below established limits. When ventilation cannot be made adequate enough to keep exposures below established limits, use a NIOSH approved respirator with an organic vapor cartridge, or organic vapor cartridge + P100 particulate filter, depending on specific workplace conditions. Consult with your respirator and cartridge supplier to ensure proper selection of respirator and cartridge based on ingredients listed in Section 3 and specific workplace conditions. Use and select a respirator according the guidelines established in OSHA 1910.134 or other applicable respiratory protection standard.

ADDITIONAL PROTECTIVE MEASURES: .... Practice good caution and personal cleanliness to avoid skin and eye contact. Avoid skin contact when removing gloves and other protective equipment. Wash thoroughly after handling. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Exposure limits may not be established for this product as a whole. For established exposure limits of specific ingredients in this product, or other available exposure limit information, refer to the table below.

Ingredient Name	CAS#	Exposure Limit Information
Propane, 2,2-bis[p-(2,3-epoxypropoxy)phenyl]-, polymers	25085-99-8	No data available
Benzyl alcohol	100-51-6	10 ppm (AIHA-WEEL)
Phenol-formaldehyde polymer glycidyl ether	28064-14-4	No data available

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL FORM: .... Viscous liquid.
COLOR: .... Colorless.
ODOR: .... Mild.
ODOR THRESHOLD: .... No data available
pH .... No data available
MELTING POINT / FREEZING POINT .... No data available
BOILING POINT (760mmHg): .... > 400°F (204°C).
FLASH POINT: .... >200°F (93°C). Estimated based on ingredient data.
FLAMMABILITY (solids or gasses) .... No data available
AUTO IGNITION TEMPERATURE .... No data available
LOWER EXPLOSIVE LIMIT (LEL) .... No data available
UPPER EXPLOSIVE LIMIT (UEL) .... No data available
VAPOR PRESSURE .... No data available
SPECIFIC GRAVITY/DENSITY (water = 1) 1.15
BULK DENSITY .... 9.6 lb./gal. (1.15 kg/L)
VAPOR DENSITY (air = 1) .... Heavier than air. Estimated based on ingredient data.
EVAPORATIOIN RATE (Butyl Acetate = 1) .... No data available
WATER SOLUBILITY (% BY WT.) .... No data available
PARTITION COEFFICIENT, n-OCTANOL/WATER (log Pow) .... No data available
KINEMATIC VISCOSITY: .... 869.5 mm^2/s @ 20°C
DECOMPOSITION TEMPERATURE: .... No data available.
% VOLATILE BY WEIGHT: .... ASTM D 2369-07 was used to determine the Volatile Content of mixed epoxy resin and hardener. Refer to the hardener SDS for information about the total volatile content of the resin/hardener system.

10. STABILITY AND REACTIVITY

STABILITY: .... Product is stable at normal temperatures and pressures.

REACTIVITY/HAZARDOUS REACTIONS: .... Product will not react by itself. A mass of more than one pound of product mixed with an aliphatic amine will cause irreversible polymerization with significant heat buildup. Strong acids, bases, amines and mercaptans can cause polymerization.

INCOMPATIBILITIES: .... Strong acids, bases, amines and mercaptans can cause polymerization. External heating or self-heating could result in rapid temperature increase and pressure build up. If such a condition were to occur in a drum, the drum could expand and rupture violently.

CONDITIONS TO AVOID: .... Avoid excessive heat.

DECOMPOSITION PRODUCTS: .... Carbon monoxide, carbon dioxide and phenolics may be produced during uncontrolled exothermic reactions or when otherwise heated to decomposition.

11. TOXICOLOGICAL AND HAZARD ENDPOINT INFORMATION

Component Name	CAS#	LD_{50} Oral	LD_{50} Dermal	LC_{50} Inhalation
Propane, 2,2-bis[p-(2,3-epoxypropoxy)phenyl]-, polymers	25085-99-8	>15,000 mg/kg (rat)	>23,000 mg/kg (rabbit)	No data
Benzyl alcohol	100-51-6	1620 mg/kg	No data	>4.18 mg/l 4 h aerosol
Phenol-formaldehyde polymer glycidyl ether	28064-14-4	>2,000 mg/kg (rat)	2,000 mg/kg (rat)	No data

ACUTE TOXICITY: .... No specific toxicity data exists for this mixture. Classification is based on acute toxicity estimation methods using ingredient data.
Oral: .... Not classified. Does not meet acute oral toxicity criteria.
Dermal: .... Not classified. Does not meet acute dermal toxicity criteria.
Inhalation: .... Not classified. Does not meet acute inhalation toxicity criteria. If product is heated, vapors generated can cause headache, nausea, dizziness and possible respiratory irritation if inhaled in high concentrations.

WEST SYSTEM® 105 Resin

SKIN CORROSION / IRRITATION:.. Causes skin irritation – Category 2.

SERIOUS EYE DAMAGE / IRRITATION:.. Causes serious eye irritation. Category 2A.

RESPIRATORY SENSITIZATION:... Not classified. Does not meet criteria for respiratory sensitizer. Repeated exposure to high vapor concentrations may cause irritation of pre-existing lung allergies and increase the chance of developing allergy symptoms to this product.

SKIN SENSITIZATION:.. May cause allergic skin reaction. Category 1.

REPRODUCTIVE TOXICITY:... Not classified. Diglycidyl ether bisphenol-A, in animal studies, has been shown not to interfere with reproduction. Diglycidyl ether bisphenol-A did not cause birth defects or other adverse effects on the fetus when pregnant rabbits were exposed by skin contact, the most likely route of exposure, or when pregnant rats or rabbits were exposed orally.

MUTAGENICITY:.. Not classified. Diglycidyl ether bisphenol-A. In animal mutagenicity studies were negative. In vitro mutagenicity tests were negative in some cases and positive in others.

CARCINOGENICITY:.. Not classified. No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

Many studies have been conducted to assess the potential carcinogenicity of diglycidyl ether of bisphenol-A. Although some weak evidence of carcinogenicity has been reported in animals, when all of the data are considered, the weight of evidence does not show that Diglycidyl ether bisphenol-A is carcinogenic. Indeed, the most recent review of the available data by the International Agency for Research on Cancer (IARC) has concluded that Diglycidyl ether bisphenol-A is not classified as a carcinogen.

Epichlorohydrin, an impurity in this product (<5 ppm) has been reported to produce cancer in laboratory animals and to produce mutagenic changes in bacteria and cultured human cells. It has been established by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (Group 2A) based on the following conclusions: human evidence – inadequate; animal evidence – sufficient. It has been classified as an anticipated human carcinogen by the National Toxicology Program (NTP). Note: It is unlikely that normal use of this product would result in measurable exposure concentrations to this substance.

STOT (Single Exposure): .... Not classified. Does not meet STOT SE criteria.

STOT (Repeated Exposure): .... Not classified. Does not meet STOT RE criteria.

ASPIRATION HAZARD: .... Not classified. Does not meet aspiration toxicity criteria.

OTHER HEALTH HAZARD INFORMATION:.................................... None known.

12. ECOLOGICAL INFORMATION

ACUTE AQUATIC TOXICITY:.. No specific test data available for the mixture. Calculated Estimate: Not classified. Does not meet acute aquatic classification criteria.

CHRONIC AQUATIC TOXICITY: .... No specific test data available for the mixture. Calculated Estimate: Aquatic Chronic Category 2.

PERSISTANCE AND BIODEGRADABILITY:....................................... No specific test data available for the mixture.

MOBILITY IN SOIL: .... No specific test data available for the mixture.

ADDITIONAL ECOTOXICITY INFORMATION:................................. In the liquid, uncured state, this product may be harmful to aquatic life long lasting effects. Prevent release to the environment, sewers and natural waters.

Ingredient	CAS#	Ecotoxicity Classification Information
Propane, 2,2-bis[p-(2,3-epoxypropoxy)phenyl]-, polymers	25085-99-8	Aquatic Chronic Cat. 2
Benzyl alcohol	100-51-6	Not Classified
Phenol-formaldehyde polymer glycidyl ether	28064-14-4	Aquatic Chronic Cat. 2

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD:... Evaluation of this product using RCRA criteria shows that it is not a hazardous waste, either by listing or characteristics, in its purchased form. It is the responsibility of the user to determine proper disposal methods.

Incinerate, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

US DOT
U.N./N.A. NUMBER:.. Not regulated.
SHIPPING NAME:.. Not applicable.

TECHNICAL SHIPPING NAME:.. Not applicable.
HAZARD CLASS:.. Not applicable.
PACKING GROUP:.. Not applicable.

CANADA TDG
U.N./N.A. NUMBER:.. Not regulated.
SHIPPING NAME:.. Not applicable.
TECHNICAL SHIPPING NAME:.. Not applicable.
HAZARD CLASS:.. Not applicable.
PACKING GROUP:.. Not applicable.

IMDG
U.N. NUMBER: .... UN3082.
SHIPPING NAME:.. Environmentally hazardous substance, liquid, n.o.s.
TECHNICAL SHIPPING NAME:.. Epoxy Resin.
HAZARD CLASS:.. Class 9.
PACKING GROUP:.. PG III.
EmS Number: .... F-A, S-F
MARINE POLLUTANT .... Yes

ICAO/IATA
U.N. NUMBER: .... UN3082.
SHIPPING NAME:.. Environmentally hazardous substance, liquid, n.o.s.
TECHNICAL SHIPPING NAME:.. Epoxy Resin.
HAZARD CLASS:.. Class 9.
PACKING GROUP:.. PG III.
MARINE POLLUTANT: .... Yes

15. REGULATORY INFORMATION

COUNTRY	INVENTORY LIST	STATUS
United States	TSCA	All ingredients are listed or otherwise compliant.
Europe	EINECS or ELINCS	All ingredients are listed or otherwise compliant.
Canada	CEPA (DSL/NDSL)	All ingredients are listed or otherwise compliant.
Australia	AICS	All ingredients are listed or otherwise compliant.
Japan	ENCS	All ingredients are listed or otherwise compliant.
South Korea	KECI	All ingredients are listed or otherwise compliant.
China	IECSC	All ingredients are listed or otherwise compliant.
Philippines	PICCS	All ingredients are listed or otherwise compliant.

US EPA SARA TITLE III Reporting and Notification Requirements:
Subject to Section 302 (TPQ) .... No data available.
Subject to Section 304 (RQ).. No data available.
Subject to Section 311 or 312 .... Immediate.
Subject to Section 313 .... No data available.

Canada WHMIS Confidential Business Information (CBI):............. The HMIRA number issued for this CBI claim is #9455. The date of filing is 2015-04-09.

STATE REGULATORY INFORMATION:
Chemicals listed below may be specifically regulated by individual states. For details on state regulatory requirements you should contact the appropriate state agency.

COMPONENT NAME /CAS NUMBER		STATE CODE
Epichlorohydrin 106-89-8	< 5ppm	[1]CA

[1] These substances are known to the state of California to cause cancer or reproductive harm, or both.

16. OTHER INFORMATION

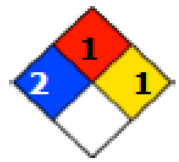
REASON FOR ISSUE:.. SDS prepared according to the requirements of the US OSHA 1910.1200 HazCom 2012 and Canada Hazardous Products Regulation WHMIS 2015.
PREPARED BY:.. G. M. House
APPROVED BY:.. G. M. House
SDS CONTACT:.. safety@gougeon.com
TITLE: .... Health, Safety & Environmental Manager
APPROVAL DATE: .... August 15, 2016
SUPERSEDES DATE:.. June 1, 2015
SDS VERSION: 105-2016a

OTHER HAZARD INFORMATION AND RATING SYSTEMS:

HMIS® RATING

HEALTH:	2
FLAMMABILITY:	1
PHYSICAL HAZARD:	1
PERSONAL PROTECTION:	

NFPA® 704 CODES



Approximate HMIS and NFPA Risk Ratings Legend:
0 = Low or None; 1 = Slight; 2 = Moderate; 3 = Serious; 4 = Severe

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SAFETY DATA SHEET

Trade Name: FIBERGLASS CLOTH

Chemical Family: N/A
Formula: N/A
Manufacturer: BGF Industries
3802 Robert Porcher Way
Greensboro, MC 27410
Emergency Phone #'s: (800)476-4845
Transportation EMG. Phone # CANUTEC (613) 996-6666
(604) 930-0650

Supplier: COAST FIBER-TEK
1306 Boundary Road
Burnaby, BC V5K 4T6
Tel.# (604) 294-8116

HAZARDOUS INGREDIENTS:

FIBROUS GLASS:	CAS # 65997-17-3	99.94%
FIBROUS GLASS DUST:		% not known *

* Amount will be dependent upon method of handling.

Exposure Limits: ACGH TLV (Source): 5mg/m³, OSHA PEL (Source): 5mg/m³

PHYSICAL DATA:

Appearance & Odour:	Solid, White no odor
Vapour Pressure:	2.00 hPa
Vapour Density:	N/A
Solubility in Water:	Negligible
Specific Gravity:	Approximately 2.5
Evaporation Rate:	N/A
Softening Point:	Approximately 835°C
Density:	2.560 g/cm3 @ 77°F / 25°C
pH:	N/A

FIRE & EXPLOSION DATA:

Flashpoint & Method:	N/A
Flammable Limits:	N/A
Extinguishing Methods:	Water, foam, carbon dioxide, dry chemical
Special Equipment & Procedures:	Self contained breathing apparatus and complete protective clothing.

REACTIVITY DATA:

Conditions Contributing to Instability:	Stable
Incompatible Substances:	None
Hazardous Decomposition Products:	Carbon dioxide, carbon monoxide, hydrocarbons, water.
Hazardous Polymerization:	Will not occur.

HEALTH HAZARDS DATA:

NOTE: Health studies have shown that exposure to chemicals pose potential risks which may vary from person to person. Exposure to liquids, vapours, mists or fumes should be minimised.

SAFETY DATA SHEET

Fiberglass Cloth - Pg 2

PRINCIPAL HEALTH HAZARDS:

Skin Contact:	Minor irritation
Eye Contact:	Minor irritation
Ingestion:	Minor irritation
Inhalation:	Minor irritation

FIRST AID PROCEDURES:

Skin:	Wash with soap & water. If irritation persists see physician
Eyes:	Flush with water for 15 minutes. If irritation persists see physician.
Ingestion:	Give 2 glasses of water. If irritation persists see physician.
Inhalation:	Remove to fresh air.

PREVENTIVE MEASURES:

Skin:	Always apply appropriate barrier cream to exposed skin. Wear impervious gloves (butyl rubber), coveralls and safety footwear.
Eyes:	Chemical proof goggles or full face respirator if vapours cause eye irritation.
Ingestion:	Wash thoroughly before consuming food stuffs.
Inhalation:	Use only in well ventilated areas or use NIOSH approved respiratory protection with organic vapour cartridges.

CONTROL MEASURES & PRECAUTIONS

Keep container tightly closed. Do not consume food, drink or tobacco in work area or material storage areas. Use caution and personal cleanliness to avoid skin and eye contact. Avoid breathing vapours of heated materials. Use paper covering absorbent wipes and suitable disposable containers in work area.

SPILL, LEAK & DISPOSAL METHODS

Review fire and explosion hazards and safety precautions before proceeding with clean up. Restrict access to area. Contain spill to prevent dust from entering sewers or waterways. Place in suitable container for disposal.

DISPOSAL METHOD

Dispose only in a facility permitted to dispose of hazardous waste by Federal, Provincial and Municipal regulations.

SHIPPING INFORMATION

Shipping Name:	
Hazard Class:	Non Regulated
UN/PIN #:	
Flashpoint:	
WHMIS:	D2B

The information contained herein is based on data that we believe to be accurate. No warranty either expressed or implied is made. This information is offered solely for your consideration interpretation and information.

Preparation Date:	September 1, 2000
Prepared by:	Nigel Poore, 1306 Boundary Road, Burnaby, BC V5K 4T6
Telephone #:	(604) 294-8116
Revised Date:	April 28, 2017

N/A = Not Available

I. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product/Trade Name:	LaserForm™ A6
Chemical Family:	Metal Powder
Product Use:	Material for SLS® (selective laser sintering) systems

Hazardous Materials Identification System (HMIS):
(Degree of hazard: 0 = low, 4 = extreme):

Health	0
Flammability	1
Physical Hazards	0

Personal Protection:
Dust mask, skin, eye protection

Manufacturer:

3D SYSTEMS

Manufacturer Contact	3D Systems GmbH Guerickeweg 9 Darmstadt, Germany
For Information	Phone: +49 (0) 6151 357-357 Fax: +49 (0) 6151 357-111
Emergency	703.527.3887 - Chemtrec (U.S.)

II. COMPOSITION INFORMATION

EC #	Component	Classification	Percent
231-157-5	Chromium (CAS# 7440-47-3)	Xi R36/37/38	<1.81
231-111-4	Nickel (CAS# 7440-02-0)	Xn R40 R43	<0.905
231-158-0	Cobalt (CAS# 7440-48-4)	Xn R42/43 R53	<0.905
231-105-1	Manganese (CAS# 7439-96-5)		<1.81

General Product Information
This preparation is classified as hazardous according to European Union Directives 67/548/EEC and 99/45/EC.
Xn R43

III. HAZARDS IDENTIFICATION

Emergency Overview

This preparation can cause an allergic skin reaction. Prolonged or multiple exposures can cause skin sensitisation. Can cause eye, skin, and respiratory tract irritation. Dusts or fume can cause respiratory system damage. The metal alloy contains a substance that can cause nervous system effects.

Potential Health Effects:

Eyes: This product can cause eye irritation. Symptoms include discomfort, itching and redness after contact.

Skin: This product can cause skin irritation. Symptoms include reversible redness, itching and/or pain.

Ingestion: Ingestion of large amounts can cause gastrointestinal irritation, vomiting, diarrhea and/or nausea.

Inhalation: This product can irritate the respiratory system. Symptoms include mild nasal and respiratory irritation, coughing, and difficulty breathing. Inhalation of fumes when the product is heated can cause metal fume fever with resulting flu-like symptoms.

Chronic: Prolonged or repeated inhalation of powder, dust or fumes can cause more severe irritation and possibly lung damage. Prolonged or repeated exposures to chromium dusts or fumes may cause perforation of the nasal septum, bloody nose and other symptoms of severe nasal irritation. Chronic exposure to very high concentrations of manganese dust has caused nervous system effects including muscle weakness, tremors, and behavioral changes. Epidemiological studies in humans have shown an association between lung and nasal cancers and prolonged occupational exposures to high concentrations of metallic nickel. While metallic nickel has been identified as a possible health hazard under extended exposure to large concentrations, the nickel in this product is in low concentration and is alloyed with other metals. The particles are also coated with a binder, further reducing the risk of exposure to nickel.

Medical Conditions Aggravated by Exposure
Could aggravate existing asthma, neurological conditions, emphysema, or other respiratory disease.

IV. FIRST AID MEASURES

Eyes: Immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention immediately.

Skin: Brush off powder using paper or textile towels. Wash affected area with mild soap and water. In case of dermatitis or if irritation persists, remove contaminated clothing and get medial attention. Wash contaminated clothing before reuse.

Ingestion: Not an expected route of entry. If large quantities of this material are ingested, affected person should drink 500 - 800 ml water, if possible with suspended activated carbon for medical use. Give water repeatedly. Get medical attention immediately. Artificial induction of vomiting should be restricted to first aid staff. Never give anything by mouth to an unconscious person.

Inhalation: If a problem develops, move affected person to fresh air, give artificial respiration if not breathing, and get medical attention immediately.

V. FIRE FIGHTING MEASURES

Flash Point: NA
Method Used: NA
Upper Flammable Limit (UFL): NA
Lower Flammable Limit (LFL): NA
Auto Ignition: NA
Rate of Burning: NA

General Fire Hazards: Dusts can form an explosive mixture with air.

Hazardous Combustion Products: Thermal decomposition products can include CO_2, CO, NOx, metal fumes, organo-metallic compounds, and smoke.

Extinguishing Media: Dry sand or an extinguisher approved for metal powder fires. Without disturbing the burning mass, smother the fire and allow the fire to burn itself out. DO NOT USE CO_2 extinguishers or water on metal powder fires.

Fire Fighting Equipment/Instructions: Wear full protective clothing, including helmet, self-contained positive-pressure or pressure-demand breathing apparatus, protective clothing and facemask. Move container from area if it can be done without risk. Do not use high-volume water jet or high-pressure inert gas. Avoid inhalation of material or combustion by-products. Dust accumulation from this product can present an explosion hazard in the presence of an ignition source.

VI. ACCIDENTAL RELEASE MEASURES

Containment Procedures: Stop the flow of material, if this is without risk. Ventilate contaminated area. Eliminate sources of ignition. Avoid the generation of dusts during clean up.

Clean-Up Procedures: Wear appropriate protective equipment and clothing, including a ground strap or conductive-soled shoes, during clean up. Vacuum the dry powder into a closed container with internally and externally explosion-proof vacuum equipment or use non-sparking tools to collect the material. Avoid the generation of dusts during clean-up. Avoid contact with water. Place material in an appropriate container for disposal.

Evacuation Procedures: Keep unnecessary personnel away.

Special Precautions: A substantial slipping hazard exists when these small spherical particles are spilled.

VII. HANDLING AND STORAGE

Handling Procedures: Avoid dust accumulation of this material to reduce potential explosion hazard. Use non-sparking tools when opening or closing containers. Use spark-proof, bonded, and grounded conveying and processing equipment to prevent static charge build-up. Keep this product from heat, sparks, or open flame.

Storage Procedures: Keep this material in a cool, dry, well-ventilated place. Avoid dust accumulation of this material. Eliminate all sources of ignition. Keep separate from incompatible materials.

VIII. EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure Guidelines

A: General Product Information: Follow all applicable exposure limits.

B: Substance Exposure Limits:

Substance	International OELs
Chromium	Finland: 0.01 mg/m^3 Australia: 0.05 mg/m^3 Belgium, Denmark, France, Netherlands, Norway, Poland, Sweden, Japan, U.K (MEL).: 0.5 mg/m^3 Philippines: 1 mg/m^3
Manganese	Canada Alberta (TWA): 1 mg/m^3 (fume); Ceiling: 5 mg/m^3 Manitoba (TWA): 1 mg/m^3 (fume); STEL: 3 mg/m^3 (fume); Ceiling: 5 mg/m^3 (dust) New Brunswick, Ontario (TWA): 1 mg/m^3 (fume), 5 mg/m^3 (dust); STEL: 3 mg/m^3 (fume) Quebec (TWAEV): 1 mg/m^3 (fume), 5 mg/m^3 (dust) Saskatchewan (TWA): 5 mg/m^3 (as Mn); 1 mg/m3 (TWA); STEL: 5 mg/m^3 (elemental), 3 mg/m^3 (fume) Yukon: Ceiling 5 mg/m^3 Belgium, Denmark, Finland, France, Switzerland, U.K. – 1 mg/m^3 Sweden – 2.5 mg/m^3 Germany (MAK) – 0.5 mg/m^3
Nickel	Canada: Alberta (TWA): 1 mg/m^3 STEL: 1 mg/m^3 Manitoba, New Brunswick, Ontario (TWA): 1 mg/m^3 Quebec (TWAEV): 1 mg/m^3 British Columbia (TWA): 0.05 mg/m^3; K1 (confirmed human carcinogen); sensitizer – reduce exposure to minimum possible level

Engineering Controls

Use explosion-proof local exhaust ventilation. Ventilation should effectively remove and prevent buildup of any dust generated from the handling of this product.

PERSONAL PROTECTIVE EQUIPMENT

Eyes/Face: Wear goggles.

Skin: Use impervious gloves and apron.

Respiratory: If ventilation cannot effectively keep dust concentrations below established limits, appropriate certified respiratory protection must be provided.

General: An eye wash fountain is recommended.

IX. PHYSICAL AND CHEMICAL PROPERTIES

Appearance .... Silver/Gray Powder
Physical State .... Powder
Vapour Pressure .... NA
Boiling Point .... NA
Solubility (H_2O) .... Insoluble @ 20 °C
Percent Volatile .... <1%

Odor .... Metallic
PH .... NA
Vapour Density .... NA
Melting/Freezing Point .... NA
Specific Gravity .... NA
Molecular Weight .... NA

X. CHEMICAL STABILITY AND REACTIVITY

Chemical Stability:	Stable under normal conditions of handling, use and transportation.
Conditions to Avoid:	Avoid dispersion of dust in air. Avoid ignition sources where dust is produced. Avoid contact with moist air or humid conditions.
Incompatibility:	Oxidizing materials, strong acids and strong bases.
Hazardous Decomposition:	Thermal decomposition products can include CO_2, CO, NOx, metal fumes, organo-metallic compounds, and smoke.
Hazardous Polymerization:	Will not occur.

XI. TOXICOLOGICAL INFORMATION

Acute and Chronic Toxicity

A: General Product Information: NA.

B: Component Analysis

Component	LD_{50} Oral	LC_{50} Inhalation
Chromium	27.5 mg/Kg (rats)	86 mg/m^3 (rats)
Manganese	9 g/Kg (rats)	no data

Chromium: In some workers, chromium compounds act as allergens and may cause dermatitis and/or pulmonary sensitisation. Chromic acid and chromates have a direct corrosive effect on the skin and the mucous membranes of the upper respiratory tract. Although rare, there may be the possibility of skin and pulmonary sensitisation.

Cobalt: Cobalt has been reported as causing hyper-sensitisation type dermatitis in individuals who are susceptible. Animal studies have shown that particulate cobalt is an acutely irritating substance and industrial exposures, possibly combined with small amounts of silica, are reported capable of producing serious pneumoconiosis.

Nickel: The most common ailment arising from contact with nickel or its compounds is an allergic dermatitis known as "nickel itch" which usually occurs when the skin is moist.

Since these substances are all part of a metal alloy, exposure to elemental metals is highly unlikely, and they are not expected to pose the afore mentioned health-hazards in this product.

Carcinogenicity

A: General Product Information: This product is not listed by IARC.

B: Component Analysis

Nickel: In laboratory animal studies, chronic exposure to high concentrations of metallic nickel has caused an increase in lung and nasal tumors. IARC has classified nickel as possibly carcinogenic to humans, group 2B. The National Toxicology Program (NTP) classifies metallic nickel as "Reasonably Anticipated to be a Human Carcinogen." Nickel-containing alloys have not been listed by NTP as carcinogenic due to inadequacy of the data. The form of this product and the alloy structure make it highly unlikely that exposure to metallic nickel will occur.

Chromium: IARC has determined that there is sufficient evidence of increased lung cancer among workers in the chromate-producing industry and possible chromium alloy workers. This determination is supported by sufficient evidence for carcinogenicity to animals and possible mutagenicity testing of Cr VI compounds. The form of this product and the alloy structure make it highly unlikely that exposure to elemental chromium or Cr VI compounds will occur.

Neurological Effects

A: General Product Information: This product is not known or reported to cause neurological effects.

B: Component Analysis

Manganese: Chronic exposure to very high concentrations of manganese dust has caused nervous system effects including muscle weakness, tremors, and behavioral changes in humans. The form of this product and the alloy structure make it highly unlikely that exposure to metallic manganese will occur.

Safety Data Sheet
Material Name: LaserForm A6

XII. ECOLOGICAL INFORMATION

Ecotoxicity

A: General Product Information: This product is not classified as dangerous to the environment.

B: Component Analysis - Ecotoxicity - Aquatic Toxicity: No ecotoxicity data are available for this product.

Mobility – No information available for product.

Persistence & Degradation – No information available for product.

Bioaccumulation – No information available for product.

Other Adverse Effects – No information available for product.

Environmental Fate: No information available for product.

XIII. DISPOSAL CONSIDERATIONS

Waste Disposal Instructions

Avoid disposal. Attempt to utilize preparation completely. Prior to disposal of unused preparation, consult an approved waste disposal operative to ensure regulatory compliance.

XIV.TRANSPORT INFORMATION

	US DOT	RID/ADR	IMDG	IATA	IMO	Canada TDG
Shipping Name	Not Regulated					
Hazard Class:						
UN Number:						
Packing Group:						

XV. REGULATORY INFORMATION

European Union Regulatory Information

General Product Information: This substance is not classified according to European Union Directive 67/548/EEC

Xn Harmful

R43 May cause sensitisation by skin contact.

S22 Do not breathe dust.

S23 Do not breathe fumes.

S24/25 Avoid contact with skin and eyes.

S36/37 Wear suitable protective clothing and gloves.

Component Analysis - Inventory

Component/CAS	EC #	EEC	CAN	TSCA	NLP
Chromium (CAS# 7440-47-3)	231-157-5	EINECS	DSL	Yes	No
Nickel (CAS# 7440-02-0)	231-111-4	EINECS	DSL	Yes	No
Cobalt (CAS# 7440-48-4)	231-158-0	EINECS	DSL	Yes	No
Manganese (CAS# 7439-96-5)	231-105-1	EINECS	DSL	Yes	No

XVI. ADDITIONAL INFORMATION

Full text of all Risk Phrases in Sections 2 & 3

EC#	Component/CAS	Classification	
231-157-5	Chromium (CAS# 7440-47-3)	Xi R36/37/38	Irritant Irritating to eyes, respiratory system and skin.
231-111-4	Nickel (CAS# 7440-02-0)	Xn R40 R43	Harmful Limited evidence of a carcinogenic effect. May cause sensitisation by skin contact.
231-158-0	Cobalt (CAS# 7440-48-4)	Xn R42/43 R53	Harmful May cause sensitisation by inhalation and skin contact. May cause long-term adverse effects in the aquatic environment.

MSDS Creation Date: 25.01.06
MSDS Revision #: .... n/a
MSDS Revision Date: .... n/a
Reason for Revision: ..... n/a
For more information: www.3dsystems.com
+49 (0) 6151 357-357 (Europe GMT+01:00; Mon – Fri, 08:00 a.m. - 17:00 p.m. MEZ)
800.793.3669 (Toll-free in the US GMT-07:00; N. America, Mon – Fri, 6:00 a.m. to 6 p.m.)
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Key/Legend

ACGIH = American Conference of Governmental Industrial Hygienists
CAS = Chemical Abstracts Service
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulations
CPR = Controlled Products Regulations
DOT = Department of Transportation
DSL = Domestic Substances List
EINECS = European Inventory of Existing Commercial Chemical Substances
EPA = Environmental Protection Agency
IARC = International Agency for Research on Cancer
IATA = International Air Transport Association
IDL = Ingredients Disclosure List
mg/Kg = milligrams per Kilogram
mg/L = milligrams per Liter
mg/m3 = milligrams per Cubic Meter
MSHA = Mine Safety and Health Administration
NA = Not Applicable or Not Available
NIOSH = National Institute for Occupational Safety and Health
NJTSR = New Jersey Trade Secret Registry
NTP = National Toxicology Program
OSHA = Occupational Safety and Health Administration
SARA = Superfund Amendments and Reauthorization Act
STEL = Short Term Exposure Limit
TDG = Transport Dangerous Goods
TSCA = Toxic Substances Control Act
WHMIS = Workplace Hazardous Materials Information System.

RAIDER AEROSPACE SOCIETY
REESE AIR FORCE PARK
SAFTEY PROTOCOL

Document Disclosure: This document has been drafted per request of Texas Tech professor, Dr. Gale, in order to appropriately ensure efficiency and safety during the use of this facility.

Tool Disclosure: For specific procedures and regulations, refer to the RoboRaider's Safety Exam: https://docs.google.com/forms/d/e/1FAIpQLSeplfB0_4bH5-M5h1R-F5xtqwybu_13TJ_llAHWV1XxpgKnpQ/viewform

Equipment is used at your own risk and neither the Raider Aerospace Society nor Reese Technology Center accepts any responsibility

Members of R.A.S. will adhere to the following:

Behavior and Conduct

- Horseplay or aggressive actions towards any and all persons at the facility will not be tolerated
- The consumption, possession, and the presence of alcohol will not be tolerated on the facility property
- Members will be limited to a maximum of two guests to avoid overcrowding
- All food and drinks must be kept out of construction zones
- Access to equipment other than that owned by R.A.S. must be approved by a credible representative of ownership
- Members should NEVER run inside of the workspace building
- NEVER use equipment you are not familiar with and haven't been introduced to by an authorized officer
- Never work in poor lit areas
- Keep yourself well balanced and never overreach.
- Never work with material that is broken or unclean.
- Always consult a RAS officer before using any special equipment or setups.

- Never stand near danger zones or close to anyone operating equipment.

General Equipment Behavior

- Always keep hands, arms, or legs out of the cutting path of equipment.
- Position your body out of harms way while operating any equipment
- NEVER use faulty equipment that is subject to replacement.
- NEVER test the sharpness or temperature of a tool with an appendage of a body.
- Equipment will be used solely for its functions and are not to be considered toys
- The appropriate use of tools for a given action must be considered in order to avoid error in equipment performance and protection.
- Only authorized members may use both the given equipment of the facility and equipment purchased by the organization.
- Equipment is not to be removed from the premises unless for club events or repairs
- Properly use secure support surfaces while operating any equipment in order to ensure safety to both equipment and adjacent people.
- Always store or secure tools away from potential harm to yourself, other person(s), or the equipment itself.
- Cutting edges must be sharp and within operating conditions.
- Equipment should always be adjusted and calibrated before attempting a given task.
- Always consult a RAS officer before making adjustments or performing maintenance to equipment.
- Never force or apply uneven pressure while performing any tasks with equipment.

Cleanup and Awareness

- Keep workspaces clear and organized
- Keep isles clear of loose materials
- Never use your hand or body parts to remove scraps or shavings away from equipment operating area.
- Remove any special attachments from equipment as well as reset both safety guards and standard settings to equipment.
- Don't leave spills or hazardous materials unattended.
- All equipment and tools will be returned to their designated storage area(s)/container(s)
- Maintain cleanliness of equipment to insure equipment functions properly

Clothing Standards and PPE (Personal Protective Equipment)

- Always use personal protective equipment while operating any equipment.
- Complete coverage of feet must be worn
- Hair should be secured with proper hair accessories
- Jewelry must be removed before using any equipment
- No baggy clothing will be worn while using equipment
- Pants must be worn while using equipment.
- Shirts should be tucked in and long sleeves neatly rolled up
- Do not wear gloves while operating equipment unless handling rough materials
- Wear ear protection while around working around loud equipment
- Use proper ventilation and wear masks to avoid breathing in harmful material debris.

Shop Maintenance

- If you are not certain on cleaning procedures or cannot identify spilled substances, notify a RAS officer immediately.

- Always know where and how to use fire extinguishers.
- Always keep cabinet doors and drawers closed
- If you disconnect power to a machine at the circuit breaker, use a lock out system or put up a sign: "Don't Connect."

Chemical Use and Storage

- Chemicals include but are not limited to:
    - Potassium nitrate, ammonium nitrate and potassium chloride, liquid oxygen, oxidizers, lithium, fluorine, methane, water, etc.
- All chemicals must be properly secured and stored when not in use
- Any chemicals with noxious and flammable fumes must remain in airtight containers until directly in use.
- All flammable materials must be properly stored within given fire cabinets
- While handling any dangerous fumes proper use of the fume hood, masks, goggles, lab coat, and gloves must be enforced.
- Chemical expiration's must be documented and properly disposed of.
- Disposal of chemicals must be done properly and safely
- Chemicals must be properly and eligibly labeled

Materials:

- Materials include but are not limited to:
    - PVC pipe, wood, aluminum, steel, carbon fiber, polyethylene, polyurethane, polystyrene, various plastics and foams, etc.

Hand Tools

- Tools include but are not limited to:
    - Non-powered equipment such as: screwdrivers, pliers, hammers, etc.

- Hand tools are to be used in a safe manner at all times and should never be used outside of their designed purpose.
- Proper maintenance and replacement of hand tools should be exercised by all RAS members

Power Tools

- Tools include but are not limited to:
  - Table saw, Band saw, power drill, drill press, routing tools, sander, jig saw, circular saw, lathe, etc.
- Electric Power tools must be grounded or double insulated to prevent electric shock. If equipment does not meet that standard, it will not be used.
- Re-assure power tool as been turned off before connecting to a power source to avoid any unscripted equipment actions.
- Always make sure equipment has been turned off and unplugged before any adjustments or maintenance is performed.
- Always wait for machine to reach operating position/speed before use.
- Unplug or turnoff any equipment not being used

Specialized Machine and Equipment

- Policies and procedures for any heavy equipment not listed above will be added under this given section as the need arises.

Failure to adhere to the policies listed above will result in being given a warning appropriate to the offense. Repeated offenses will encourage suspension from construction activities