NASA Student Launch

2016-2017 Critical Design Review

January 13th, 2017

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1 Summary of CDR Report

1.1 Team Summary

School Name:	University of Louisville
Organization:	River City Rocketry
Location:	J.B. Speed School of Engineering 132 Eastern Parkway Louisville, KY 40292
Project Title:	River City Rocketry 2016-2017
Name of Mentor:	Daryl Hankes
TRA Number:	130
Certification Level:	3

1.2 Launch Vehicle Summary

Using OpenRocket to model the flight characteristics of the launch vehicle, the vehicle parameters were established. These characteristics are defined below in Table 1.

Length (in)	140
Diameter (in)	6.1
Mass (lbm)	43.9
Motor Choice	AeroTech L2200-G
Recovery System	Cruciform Drogue/Toroidal Main

Table 1: Launch vehicle parameters.

The diameter of the launch vehicle was chosen to be 6 inches to allow adequate room for all payloads and recovery hardware. A length of 140 inches was determined to provide adequate space for all recovery systems, payload containment, and mission electronics. In order to safely launch the vehicle and provide a margin of error for mass assumptions of various components, an AeroTech L2200-G solid ammonium perchlorate motor was chosen. The VDS will allow the launch vehicle to reach 5,280 feet with accuracy within ±33 feet.

The recovery of the launch vehicle will have to be staged into two primary recoverable sections in order to accommodate deployment of the multirotor payload. At apogee, the launch vehicle will separate at its midsection, and the booster section will recover separately from the upper deployment bay. Both sections feature a dual deployment from a single recovery bay in which the drogue parachute will act like a pilot parachute to deploy the main parachute.

1.3 Payload Summary

This year's competition Payload is designed to accomplish the Target Detection and Upright Landing Challenge with the NASA Student Launch Competition. The Payload features a multirotor system which is capable of delivering a coupler section of the Launch Vehicle to an optimum viewing location where an onboard camera will identify and detect the targets. The Payload will incorporate an onboard backup recovery system of capable of deploying a parachute as a secondary recovery method.

2 Changes Made Since PDR

Changes to Vehicle

2.1.1 Vehicle Design Changes

Change	Justification
Wind tunnel testing will no longer be used to verify the coefficient of drag requirement. Instead the control and full-deploy test launches will be used to verify this requirement	The current launch/manufacture schedule does not allow for the extended time needed to conduct wind tunnel testing. Subscale results show that onboard accelerometers are sufficient for determining coefficient of drag.
Fin design change	The shape of each fin was adjusted to maintain a minimum off the rail stability of 2.2 due to component mass changes within the launch vehicle
GPS tracking system change	Every independent section of the full scale launch vehicle will contain a Eggfinder GPS tracking system instead of the selected Garmin DC Astro 40 in PDR. The GPS tracking system was changed due to the low weight and price of the Eggfinder GPS in relation to the Garmin Astro DC 40.
Motor retainer design change	Due to the recalculation of the parachute opening force from subscale flight data, the motor retainer design was changed to withstand the higher loads that it will be expected to experience during flight.
Altimeter sled design change	Due to the gemoetry of the previous altimeter sled design that was reported in PDR, the altimeter sled was redesigned to take up less space in the launch vehicle as well as reduce weight.

2.1.2 Recovery Design Changes

Change	Justification
General parachute diameter changes	Calculated drag coefficient from subscale testing was higher than expected – parachutes may now be smaller than initially designed.
ARRD connected in series to tender descender for both booster and deployment bay recovery systems	Redundancy requested during PDR presentation. Tender descender implemented to provide redundancy for ARRD.

2.1.3 Variable Drag System (VDS) Changes

Change	Justification
Component switch from the BMP180 pressure sensor to the BMP280 pressure sensor.	The BMP280 has better resolution on its measurements. See VDS electronic hardware.
All-Thread	The all thread that will be used to secure the VDS electronics, VDS mechanical system, and altimeter

2.1.4 Changes to Payload

Change	Justification
Removed torsion dampers from Propulsion Arm Assembly.	Torsion dampers with the necessary specifications were very hard to get ahold of.
RRS tube was changed from a carbon fiber to a phenolic material	The RRS tube will be bought. Finding a tube the team can afford for this application would be highly expensive and hard to find. Phenolic

	material provides sufficient strength and a much more cost effective alternative.
DCS nomenclature changed to DS (Deployment System)	The nomenclature of the system changes slightly due to the reason that this system is not specifically responsible for cutaway and would add clarity to the entire Payload System.
GSE (Ground Support Equipment) added as a Payload Subsystem	This change was made to provide more attention to the supporting equipment used to interface with the payload in real time.

Changes Made to Project Plan

Table 2: Major project plan changes since proposal.

2.1.5 Budget Changes

Changes since PDR			
Category	**PDR Budget**	**Revised CDR Budget**	**Fluctuation**
Variable Drag System	$888.33	$1,079.45	**$191.12**
Full-Scale Vehicle	$3,834.16	$5,301.13	**$1,466.97**
Sub-Scale Vehicle	$733.24	$1,000.34	**$267.10**
Recovery	$1,744.99	$1,874.27	**$129.28**
Payload	$1,696.37	$2,748.16	**$1,051.79**
Educational Engagement	$1,877.03	$1,877.03	**$0.00**
Equipment and Misc.	Addition to Budget	$741.95	**$0.00**
Travel Expenses	$4,118.40	$4,632.30	**$513.90**
Promotional Materials	$2,187.50	$2,187.50	**$0.00**
Overall Total	**$16,191.69**	**$21,442.13**	**$5,250.44**

2.1.6 Educational Outreach Changes

Educational Outreach Student Count			
Date	*Location of Event*	*Activity*	*# of students*
Tuesday, October 25, 2016	Ramsey Middle School	Construct Estes Rockets	27
Wednesday, October 26, 2016	Barrett Middle School	Construct Estes Rockets	20
Thursday, October 27, 2016	Carithers Middle School	Construct Estes Rockets	23
Saturday, October 29, 2016	J.B. Speed School (Raytheon)	Construct and Launch Rockets	20
Wednesday, November 2, 2016	Barrett Middle School	Further construction/launch	20
Thursday, November 3, 2016	Carithers Middle School	Further construction/launch	23
Saturday, November 5, 2016	Youth Science Summit	Build and launch	12
Wednesday, November 9, 2016	Barrett Middle School	Further construction/launch	23
Thursday, November 17, 2016	STEM Night	Booth Set up	70
Saturday, December 3, 2016	Oldham Country Middle School	First Lego League	500
Monday, December 19, 2016	Watkins United Methodist	STEM Lincoln Herritage Counc	36
		Current Total	**774**
	NASA Requirment	*Our Requirment*	
Requirment to Reach	200	2000	
Students yet to be reached	Complete	1226	
PDR Total	**96**	**Current Total**	**774**

2.2 PDR Action Items

2.2.1 Action items

No action items were provided to the team post PDR.

2.2.2 Response to feedback

2.2.2.1 **What is the redundancy plan for the ARRD in the booster? The ARRD in the final full scale design will now be linked in series with a tender descender to ensure main event still occurs if one or the other fails. This is discussed in depth in section 3.3.1.**

The redundancy plan for the ARRD is the use of a Tender Descender in series with the ARRD.

2.2.2.2 **Since the activation of the ARRD on the drone is not required for parachute deployment, there is no need for redundant ARRD's on the drone.**

The team has noted this feedback and will not implement the use of an ARRD within the Payload design.

2.2.2.3 **Currently if you detach a parachute the rocket will exceed four allowable sections.**

During a conference call held with NASA on January 05, 2017, it was established that releasing the Deployment Parachute from the Payload would not increase the allowable section of the Launch Vehicle from four to five sections.

3 Technical Design: Launch Vehicle

3.1 Launch Vehicle Design

The launch vehicle will be constructed primarily from carbon fiber, aluminum, plywood, Delrin, and ABS plastic. In order to maximize the braking power of the VDS and achieve an apogee altitude of 5280 feet, the launch vehicle will be optimized to minimize mass. The launch vehicle can be divided into seven distinct section, which are outlined below in Figure 1; nose cone section, payload recovery bay, deployment bay, payload bay, booster recovery bay, VDS bay, and propulsion bay.

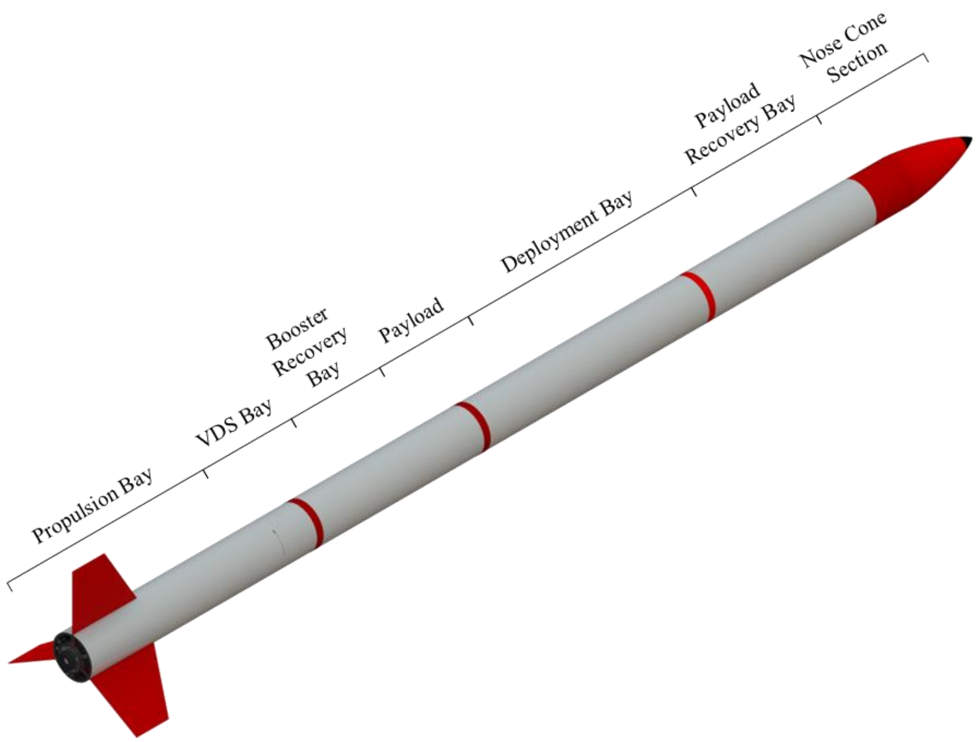


Figure 1: Full scale launch vehicle.

A rendering of the full scale launch vehicle with transparent airframe, which displays the location and orienation of all major sub-systems within the launch vehicle, is shown below in Figure 2.

Figure 2: Full scale launch vehicle (airframe transparent).

3.1.1 Mission Success Criteria

For the launch vehicle's flight to be considered a success, the launch vehicle must meet the following criteria:

1. The launch vehicle shall carry a payload up to an apogee altitude of 5280 [ft] ±33ft with zero anomalies.
2. All recovery events shall occur at the programmed altitudes.
3. The launch vehicle shall have a stable ascent.
4. The launch vehicle shall be completely reusable once it is recovered.
5. All vehicle sections shall land under kinetic energy requirements.

3.1.2 Variable Drag System (VDS)

In past years River City Rocketry has utilized a ballast system to achieve its target apogee altitude. While a ballast system is simple, it is subject to variability in motor impulse, rail friction, and weather conditions. As a result, ballasted vehicles often cannot achieve a level of precision in their apogee altitudes greater than $\pm$167 ft (51 m).[1] In order to improve the consistency with which the team can achieve its target apogee, River City Rocketry has begun the development of the Variable Drag System (VDS).

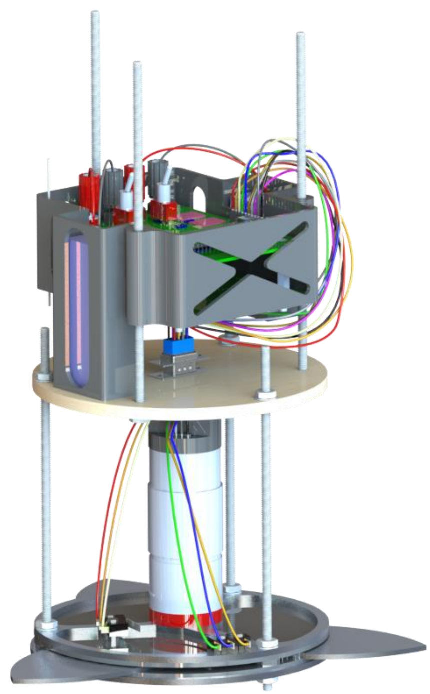


Figure 3: Variable Drag System (VDS) rendering.

The VDS is set to replace the ballast system as the system responsible for determining the vehicle's apogee altitude and will be able to achieve a target apogee with $\pm$10m accuracy. This will be achieved by

[1] 95% confidence interval based on 27 samples from the NSL 2015-2016 competition flights

dynamically changing the drag force of the vehicle during the coast phase, allowing the VDS to compensate for the variations in burn phase flight characteristics. The VDS varies the drag force on the vehicle by projecting three flat blades into the airstream surrounding the rocket. With the flat faces of the blades perpendicular to the airstream, the VDS is able to increase the projected area of the vehicle by a factor of 1.28 and the coefficient of drag by an estimated factor of 1.35.

Design Overview

The VDS uses three aluminum drag blades, actuated by a central gear. The central gear is driven by a single DC electric motor and can be actuated precisely to any position in its range with feedback provided by an encoder. The DC motor is controlled by a main electronic controller which is responsible for both actuation and the reading of sensor data. It uses this sensor data to determine the state of the vehicle and control the flight of the vehicle

3.1.2.1 **Software**

The objective of the VDS software is to respond to sensor data and actuate the drag blades. The program is written in C/C++ and runs on a Teensy 3.6 microcontroller. To accomplish this task, the VDS software controls everything from sensors and data acquisition to prediction and motor actuation of the VDS drag blades. A block diagram of this software can be seen below in Figure 4.

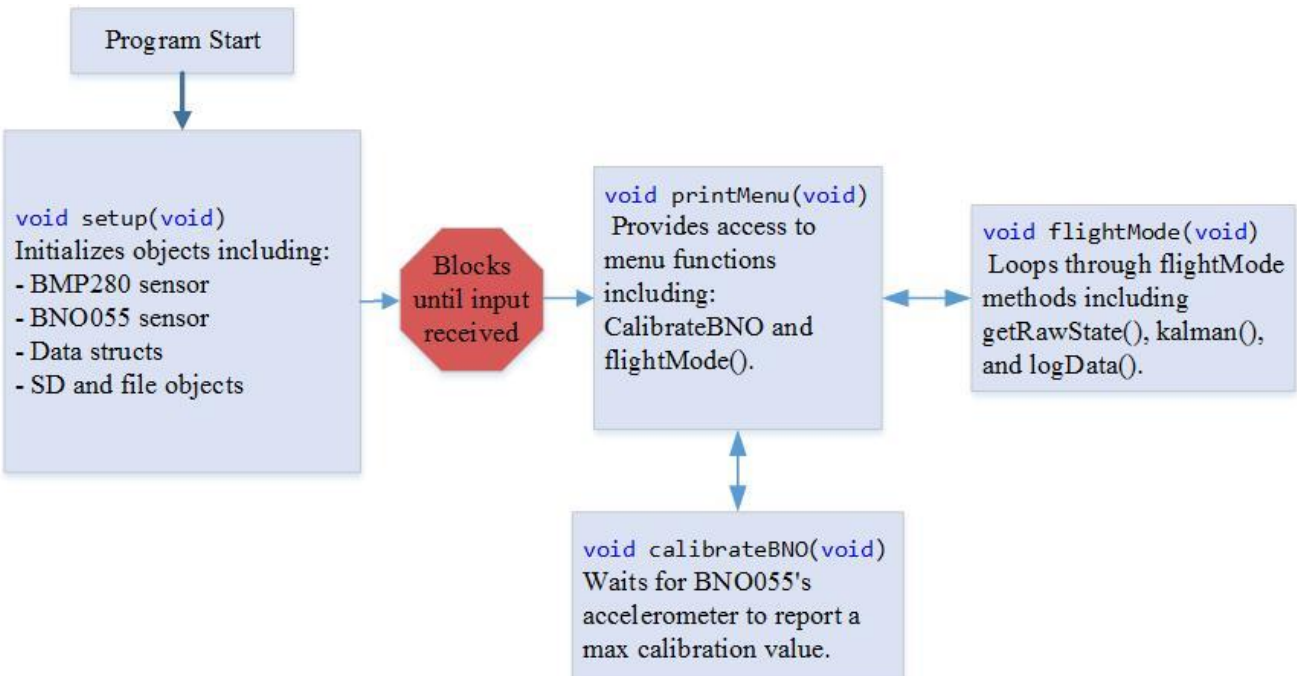


Figure 4: VDS software functional block diagram.

As displayed in the figure above, the VDS program begins by initializing data file locations, sensor objects, and data structures. It's data structures include a struct which holds all information for one moment of time in the flight including altitude, velocity, vertical acceleration, time, and time passed since the last reading, and an array of these structs which is used for velocity calculations.

After the program finishes setting up objects and data structures, it presents a menu across the serial port with notable options including calibrating the BNO055 sensor and entering flight mode. To receive the most precise acceleration values from the BNO055, it requires an "accel" calibration value of 3. To achieve the best results, this must be done before entering flight mode. See VDS launch procedures.

1.1.1.1.1 flightMode() Function

A diagram of the flightMode() function can be seen below in Figure 5.

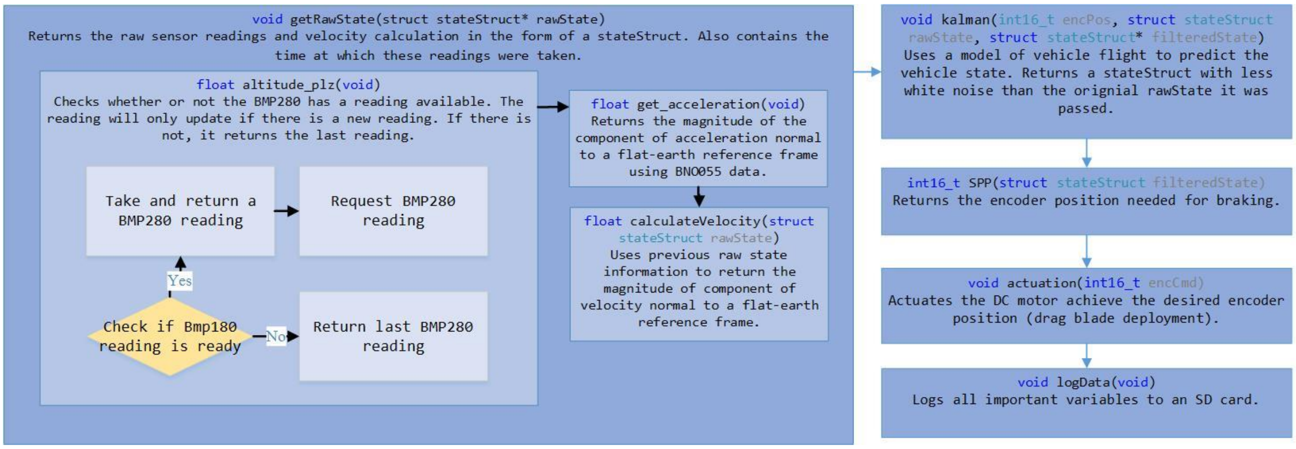


Figure 5: VDS software flightMode() block diagram.

When the VDS electronics are in flight mode, the program cycles through five methods: getRawState(), kalman(), SPP(), actuation(), and logData(). These methods read sensor data, reduce noise in that data, calculate an appropriate amount of braking, actuate the DC motor, and log info respectively.

3.1.2.1.1 Velocity Algorithm – calculateVelocity()

After the vertical acceleration and altitude is calculated, the program uses an array of past "raw state" structs to estimate the rocket's velocity. This is done by taking the sum of both the derivative of the last N altitude readings and the integral of the last N/2 acceleration readings. This is shown below as

$$v = \frac{(\sum_{i=1}^{N} t_i)(\sum_{i=1}^{N} h_i) - N\sum_{i=1}^{N} t_i h_i}{(\sum_{i=1}^{N} t_i)^2 - N\sum_{i=1}^{N} t_i^2} + \sum_{i=1}^{N/2} \frac{1}{2}(a_i + a_{i+1})(t_i - t_{i+1}) \qquad (1)$$

where N is an even integer, t_i is the time at moment i, h_i is the altitude at moment i, and a_i is the acceleration at moment i.

3.1.2.2 **Electronics Hardware**

3.1.2.2.1 Electronics Design

The VDS hardware design is in the final design and fabrication phase of the project cycle. The hardware components were chosen based on system requirements, ease of implementation, compatibility, and performance. The major system control components are listed below:

- Teensy 3.6 Microcontroller
- BNO055 9-axis absolute orientation sensor
- BMP280 absolute barometric pressure sensor
- BTN7960 high current half-bridge

The PCB design is split into two separate boards: one for power distribution and one for system control. The power distribution board will stack on top of the system control board. Power will route to the bottom board. Output signals will route back through the top board to actuate the system. The two boards create a more modular design overall. This makes the components easier to troubleshoot and replace. The hardware schematics for the power distribution board and the system control board are displayed in the figures below:

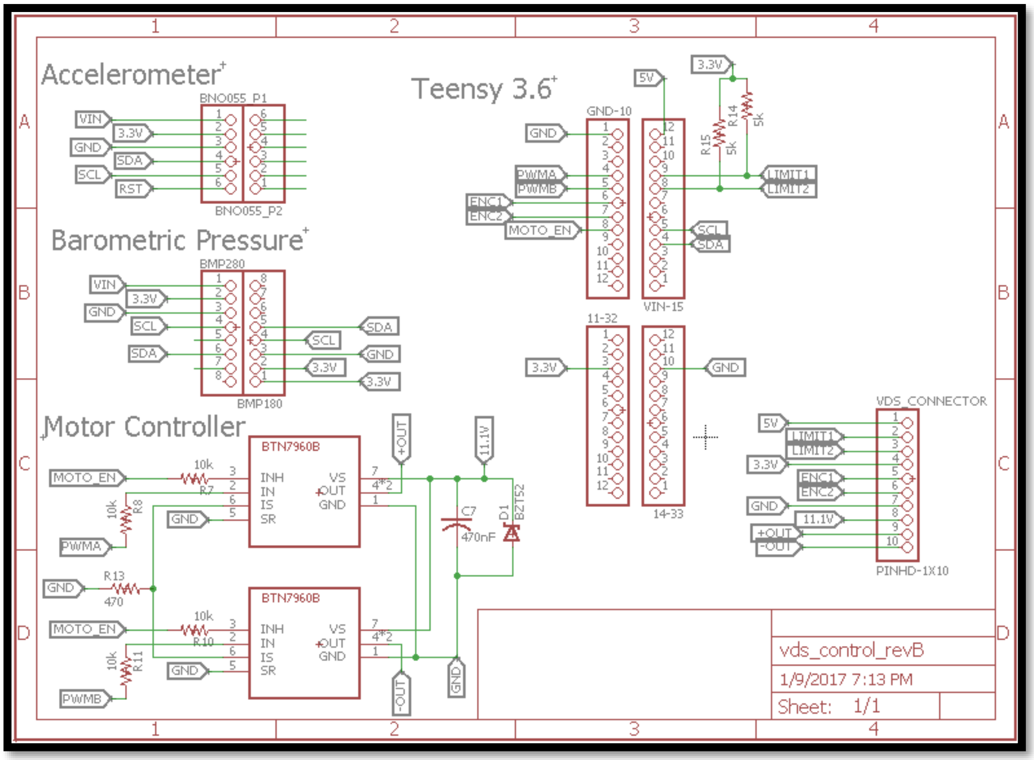


Figure 6: System control board revision B

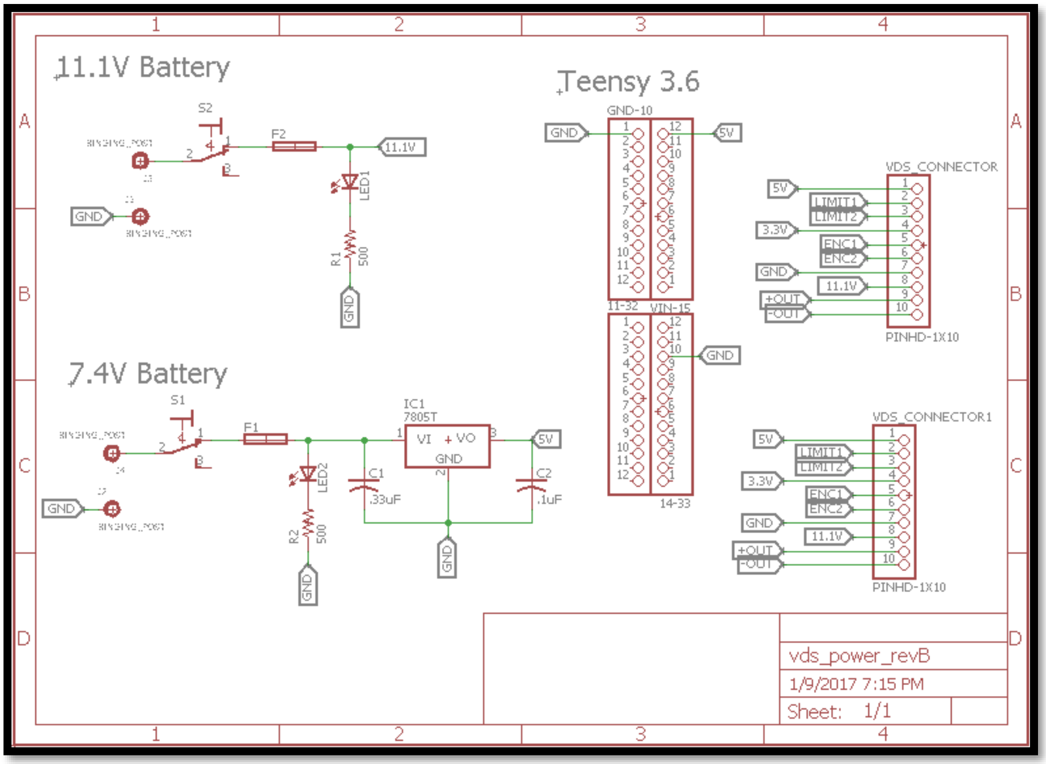


Figure 7: Power distribution board revision B.

The BNO055 sensor is used to collect acceleration data of the launch vehicle. This sensor is coupled with the BMP280 sensor that is used to calculate an acceleration value as well. The dual sensor combination allows the VDS system to have higher data accuracy. The BMP280 pressure sensor replaced the original BMP180 stated in the preliminary design review (PDR). The BMP280 sensor provides an improved pressure resolution of 0.16 Pa versus the BMP180 resolution of 1 Pa. The BTN7960 half bridge was selected because it is rated to handle high current draw from the motor. The BMP180 and the BNO055 were tested by collecting data on each sensor. The BTN7960 circuit and BMP280 still need to be tested. The BTN7960 circuit will be tested by actuating the motor through the PCB. The BMP280 will be tested by collected data from the sensor.

The current hardware has been verified to operate under an external power supply. An external power supply was connected to a 5 volt regulator that powered the Teensy 3.6 microcontroller. The microcontroller was then used to actuate the system motor.

Further testing is necessary to verify the battery life and the current draw requirements of the system. The test will consist of actuating the full hardware setup under an extended period of time. A full hardware setup is defined as all components connected on the printed circuit board (PCB). Data collection and motor actuation will verify that the components are functional and that the manufacturing process was successful. The current draw and voltage of both batteries will be monitored during extended operation to verify system requirements referenced in the launch vehicle requirements section.

3.1.2.2.2 Manufacturing

The hardware design is currently beginning the manufacturing phase. The first revision of the printed circuit board (PCB) design has been created. Revision A of the board design layout is displayed in the figures below:

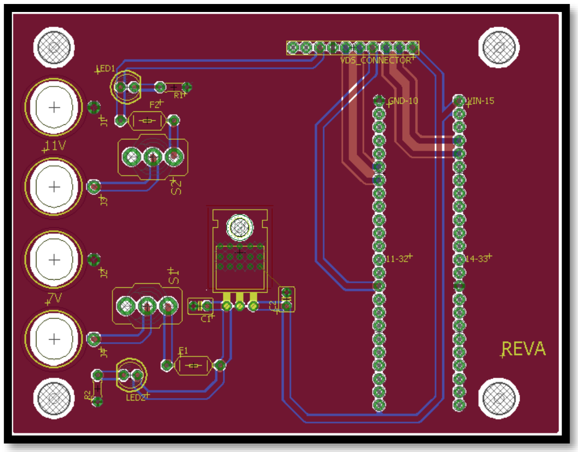


Figure 8: Power distribution board revision A.

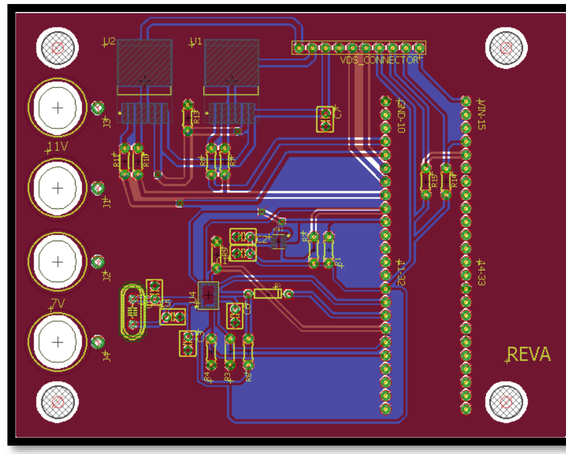


Figure 9: System control board revision A.

The manufacturing phase will help revise and finalize the circuit design. The stages below describe the plan of manufacturing:

1. Printed Circuit Board (PCB) prototyping
2. Refining circuit design
3. Finalize and outsource PCB

The prototyping stage will consist of soldering circuit components onto the PCB's and testing system functionality. Prototyping is used to verify system design and fabrication processes. The results from prototyping will lead into the next stage of refining the design. This cycle continues to iterate until the design is ready to outsource for manufacturing.

The first prototype printed circuit board (PCB) design has been constructed. The prototype was constructed with a local LPKF milling machine. The prototype board provides a mean to test hardware components and to find issues with the design. Some of the issues that occurred during prototyping include:

- Not enough insulation spacing
- Trace width adjustments
- Component spacing
- Difficulty in component installation
- Signal continuity between the top and bottom layers
- Loose connector connection

This information from the prototype board was used to adjust the PCB board layout. Fixing these issues decreased the chance of system failure and increased the reliability in the manufacturing process. Revision B of the PCB design is shown in the figures below.

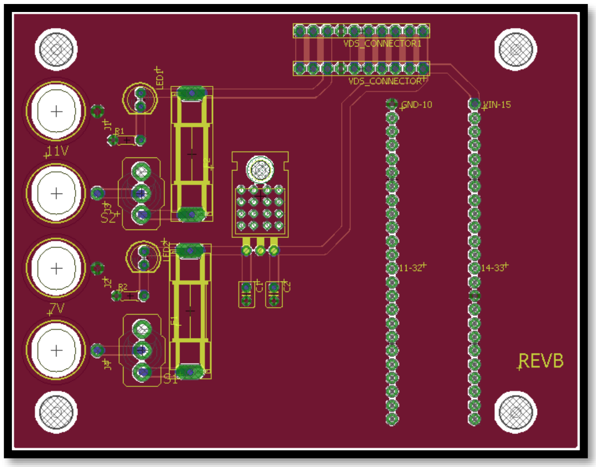


Figure 10: Power distribution board revision B.

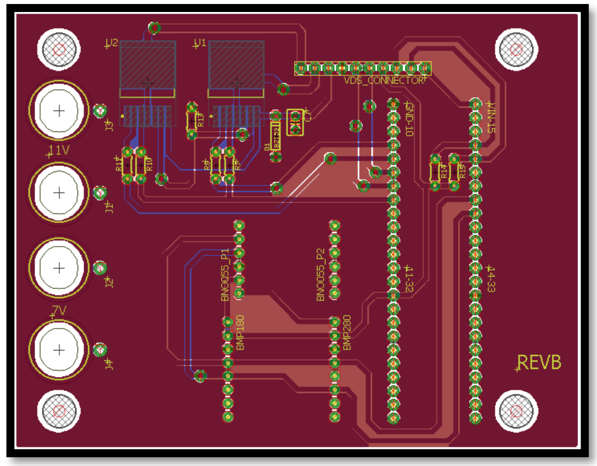


Figure 11: Sensor control board revision B.

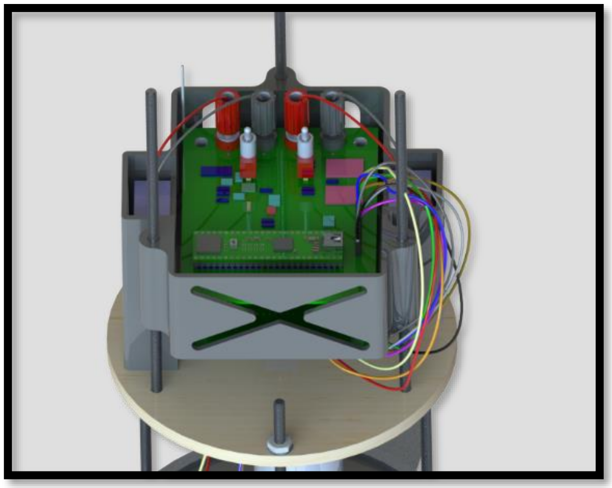
The major change made was the replacement of soldering the BNO055 and BMP280 chips individually. The new method is to solder the tested breakout boards of these chips onto the PCB. This change will improve the component installation process because the breakout boards are significantly easier to solder than the surface mount chips. The breakout boards are modular and can be easily tested. The new process will save time with installation. The breakout boards will also decrease the amount of failure points in the manufacturing process.

Another change to the design was the addition of a sturdier 10 pin connector at the top of the board. The previous connector posed a risk of disconnecting during operation. The new connector clips to the PCB. The new connector securely fastens the 10 pin connection on the board through a female and male snap connection.

The top layer traces in version 1 of the PCB designed created an issue in the component installation process. The header would block the soldering connection. This required the use of rivets to complete the header connections during prototyping. The solution was to move the header traces to the bottom layer of the board. This change allowed the solder joint to be directly connected to the signal trace without the use of rivets.

Other improvements included increasing the trace insulation. This reduced the risk of accidental shorts during manufacturing and system operation. The trace widths were also increased to improve the current capacity and trace strength. A removable fuse mount was installed to provide modular fuses based on the current and voltage results from testing.

The current prototype of the VDS electronics assembly is displayed in the figure 11. The prototype assembly displays the two PCBs, the 7.4V battery, and the 11.1V battery inserted in the 3D-printed sled. The battery terminals are routed through a banana plug cable that will attach to the banana plug mounts on the PCB. The 10-pin connector will route the signals for the encoder, limit switch, and motor output to the actuation bay.



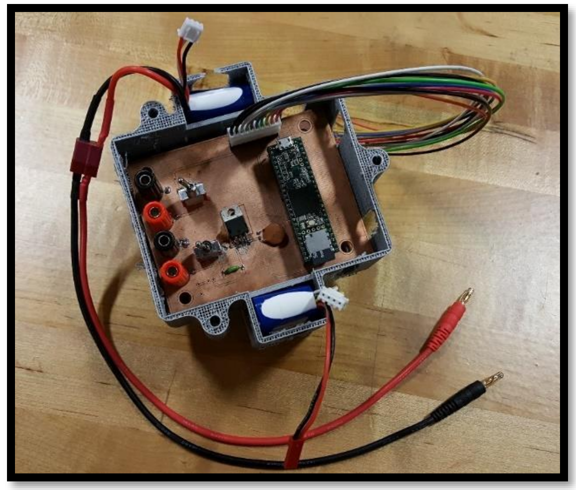


Figure 12: VDS electronics and sled rendering (attached to bulkplate).

Figure 13: VDS electronics PCB prototype and sled.

3.1.2.2.3 Success Criteria

The success criteria of the hardware design is to provide robust operation of the VDS under an extended amount of time. The success plan is projected with three key milestones. The milestones are listed below:

1. Design the PCB layout
2. Finalize the PCB manufacturing process
3. Operate the VDS under fully mounted PCBs

The PCB layout design drives how the hardware system progresses. The layout is currently being reviewed and finalized with PCB prototyping. The manufacturing process gives the design a standardized way to construct multiple iterations of the design. This is important for establishing a system of revising the design or producing new designs in the future. Operating the VDS under a completely fabricated PCB system is the end goal of the hardware design. The VDS will be actuated under extended operation to ensure a robust hardware design and to establish an operational safety margin in terms of battery life, current/voltage ratings, and harness stability.

3.1.2.2.4 Outlook

The electronics design has established the necessary hardware to complete the success criteria plan. The PCB layout is being finalized and the manufacturing phase has started. The next steps include: system operation on PCB's, establishing a manufacturing plan with an outside vendor, and assembling the harnessing between hardware components.

The primary success plan is to fully fabricate a custom designed PCB hardware design to operate the VDS. The next major components that require PCB testing is the full-bridge motor controller circuit and the BMP280. These components will be tested once the full hardware is installed on the PCB.

3.1.2.3 **Mechanical Design**

In order for the VDS to be the most mechanically efficient system possible, several factors were taken into consideration for the mechanical design of the VDS:

1. Volume
2. Actuation speed

3. Mass
4. Drag area

The VDS prototype and current assembly of the VDS is shown below in Figure 14 and Figure 15.

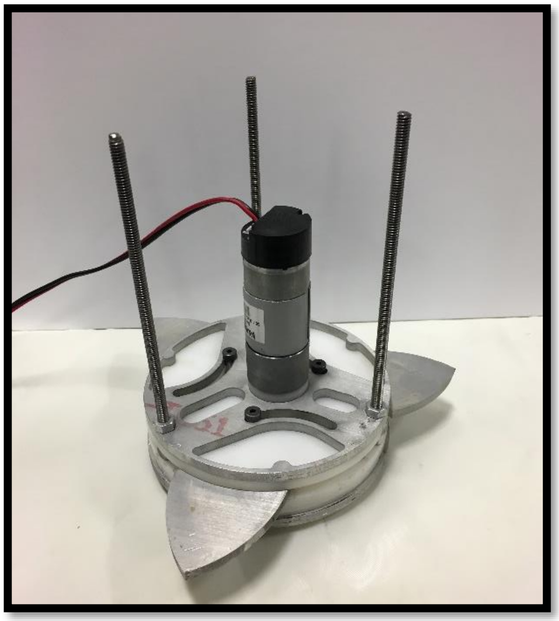


Figure 14: VDS prototype.

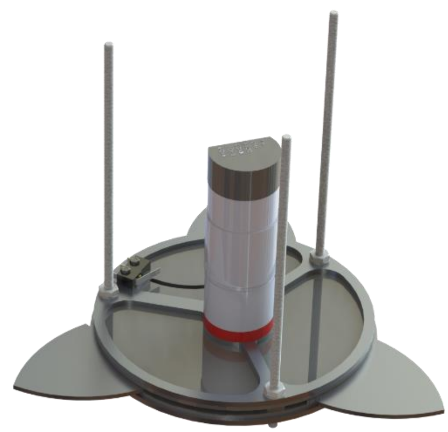


Figure 15: Rendering of current configuration of VDS.

3.1.2.3.1 Actuation

In order to optimize the actuation speed of the VDS, the drag blades radially extend perpendicular to the axial direction of the airframe of the launch vehicle. The load of the drag force exerted on the drag blades is transferred to the support plates of the VDS, rather than directly on the motor. Actuating the drag blades perpendicular to the drag force reduces the torque the motor will have to output to actuate the drag blades, which in turn allows the drag blades to extend faster. The three drag blades are controlled simultaneously by a central gear, which is attached to the motor via D shaft and set screw. The control of all three drag blades by a central gear reduces the risk of mechanical failure. Each drag blade contains a set of radial gear teeth that mesh with the central motor gear. Involute gear teeth were chosen for the central gear and drag blades due to their reliability and efficiency. The meshing between the central gear and drag blades can be seen below in Figure 16.

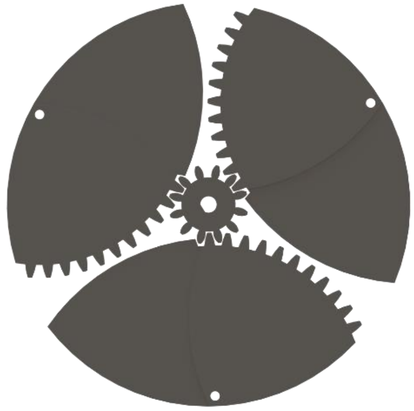


Figure 16: Gear Meshing of Drag Blades.

Each drag blade pivots around a $^1/_8$" Dowel Pin. After full actuation, approximately half of the drag blade is exposed to the exterior of the launch vehicle, and half of the drag blade is located within the VDS assembly. This configuration ensures the maximum amount of area each drag blade extends outside of the airframe of the launch vehicle, while allowing the central motor gear to simultaneously control the actuation of each drag blade. Controlling each drag blade through a central motor gear simplifies the mechanical design and control system of the VDS. Actuation of the blades can be seen in Figure 17 and Figure 18.

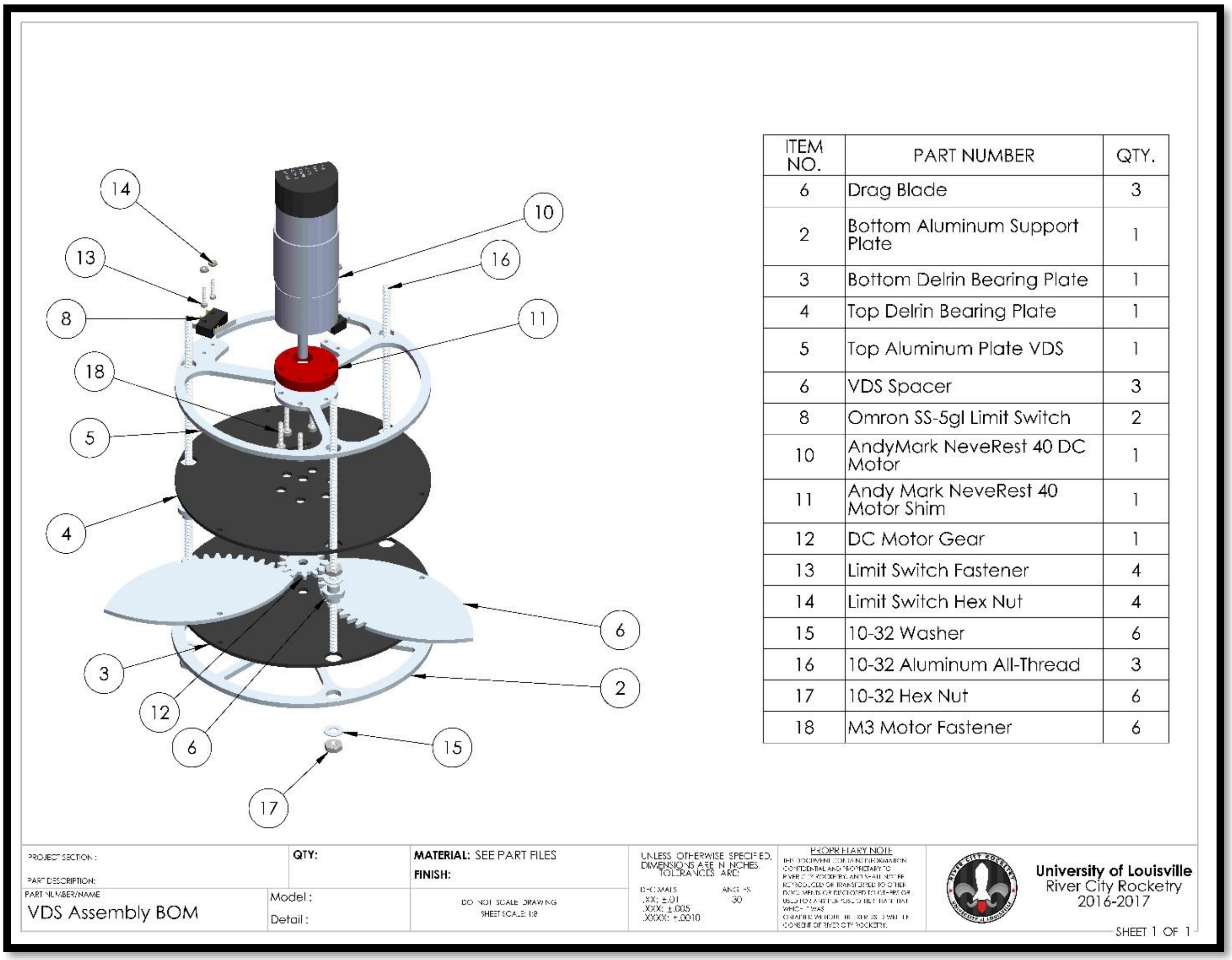
Figure 17: VDS top view with no actuation.

Figure 18: VDS top view with full actuation.

The drag blades are manufactured from $^1/_8$" 6061-T6 aluminum using a Maxiem 450 Water Jet. The drag blades will be manufactured from 6061-T6 aluminum due to its rigidity.

3.1.2.3.2 Components

The drag blades sit between two $^1/_8$" Delrin acetal resin plates, which will be laser cut. Delrin was chosen for the drag blades to slide across due to its low coefficient of friction with aluminum, which is rated at 0.3. Placing the drag blades between two plates made from a material with a low coefficient of friction allows for a precise actuation of the drag blades, while also allowing a slick surface for the drag blades to slide across when compared to aluminum, which is approximately 1.05. An additional Delrin plate was placed below the bottom Delrin plate to hold the dowel pins in place and add support for the drag blades. Three custom machined aluminum spacers are placed between the Delrin plates to ensure proper alignment of all of the plates of the assembly and prevent overtightening of plates on the drag blades to minimize the friction force of the Delrin plates on the drag blades during actuation. A bill of materials of the VDS assembly is shown below in Figure 19.



ITEM NO.	PART NUMBER	QTY.
6	Drag Blade	3
2	Bottom Aluminum Support Plate	1
3	Bottom Delrin Bearing Plate	1
4	Top Delrin Bearing Plate	1
5	Top Aluminum Plate VDS	1
6	VDS Spacer	3
8	Omron SS-5gl Limit Switch	2
10	AndyMark NeveRest 40 DC Motor	1
11	Andy Mark NeveRest 40 Motor Shim	1
12	DC Motor Gear	1
13	Limit Switch Fastener	4
14	Limit Switch Hex Nut	4
15	10-32 Washer	6
16	10-32 Aluminum All-Thread	3
17	10-32 Hex Nut	6
18	M3 Motor Fastener	6

Figure 19: VDS assembly BOM.

Two aluminum support plates are placed above and below the Derlin bearing plates, which transfer the load from the drag blades during the flight to the rest of the launch vehicle.

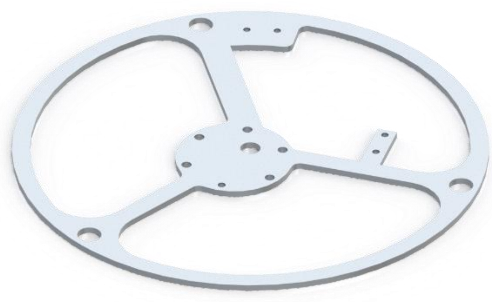


Figure 20: Rendering of top support plate.

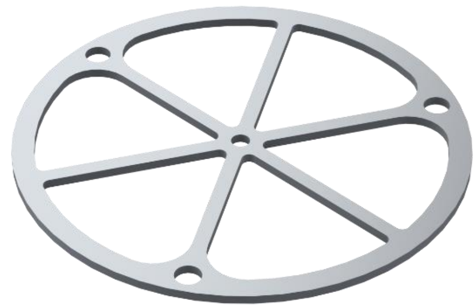


Figure 21: Rendering of bottom support plate.

A prototype of the VDS was manufactured and extensively tested via four full scale test launches. Due to correct tolerances between the gear teeth of the drag blades and the gear teeth of the central gear, the VDS actuated without any anomalies. Gear binding was not found to be an issue.

One issue the team faced during the prototype phase of the VDS early in the season was over-actuation of the drag blades. During one of the test flights of the test vehicle with the VDS prototype on board, the motor tried to actuate the drag blades past their mechanical limit, thus causing the gearbox of the DC motor to fail. In order to prevent this problem in the future, limit switches have been selected to detect the actuation of the drag blades. The limit switches selected for the VDS is the Omron SS-5GL.

An 1/8” dowel will be press fitted into the designated hole in one of the drag blades, which will trigger either of the limit switches upon full actuation and retraction. Radial slots have been cut out of the top and bottom Delrin bearing plates to allow for the Dowel pin to free move during actuation, and will be stopped by the end of the radial slots if the motor were to actuate the drag blades past the maximum actuation.

3.1.2.3.3 *Mechanical Analysis*

By analyzing past failure modes of other teams’ air braking designs, the team decided to design a robust system that would be able to withstand all of the drag forces during flight. The thickness of the drag blades was optimized to minimize mass while maintaining an acceptable factor of safety. Through experimental test launches with a prototype of the VDS, it was determined that maximum drag force exerted on the drag blades was approximately 20 pounds. Due to changes in maximum velocity in the launch vehicle and uncertainties in the calculation of drag, each drag blade was designed to be able withstand the full drag force that was experimentally determined with a factor of two. A Finite Element Analysis was performed on the drag blade to ensure the structural integrity of the drag blade design. A minimum factor of safety of 2.2 within each drag blade was determined from the FEA simulations when subjected to conservative estimates of the load each drag blades would experience, which is 45 pounds. The results from the FEA simulation is shown below in Figure 22.

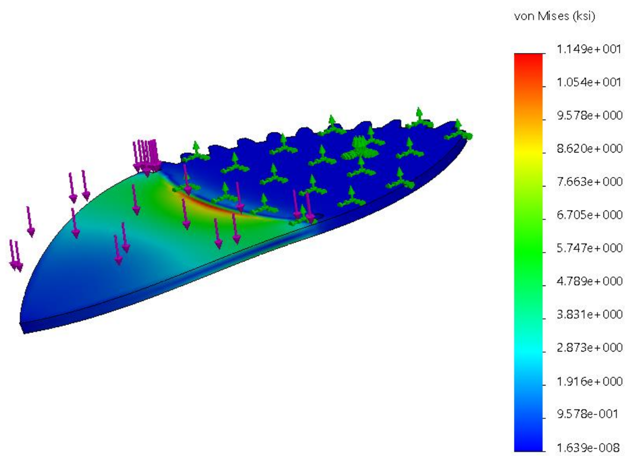


Figure 22: Drag blade FEA stress plot.

The structural integrity of the gear teeth was also verified through FEA simulations. Under worst case scenario, the teeth on the central gear and drag blades will be required to withstand the forces exerted under the stall torque induced by the DC motor. A minimum factor of safety of 1.9 within the central gear was determined from the FEA simulation. The stress plot from the FEA simulation of the central gear teeth when subjected to the stall torque of the motor is shown below in Figure 23.

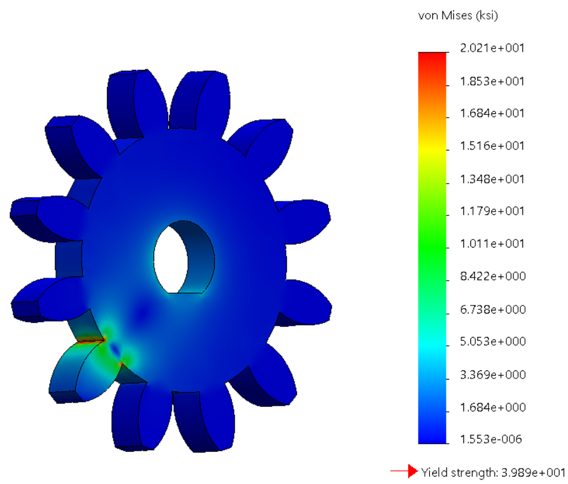


Figure 23: Central gear teeth FEA stress plot.

An FEA simulation was performed on the entire VDS assembly to ensure the minimum factor of safety throughout the assembly was greater than two. With expected loads applied to each drag blade, the minimum factor of safety throughout the VDS assembly was determined to be 3.4 from the FEA simulation. A stress plot from the FEA simulation of the VDS assembly is shown below in Figure 24.

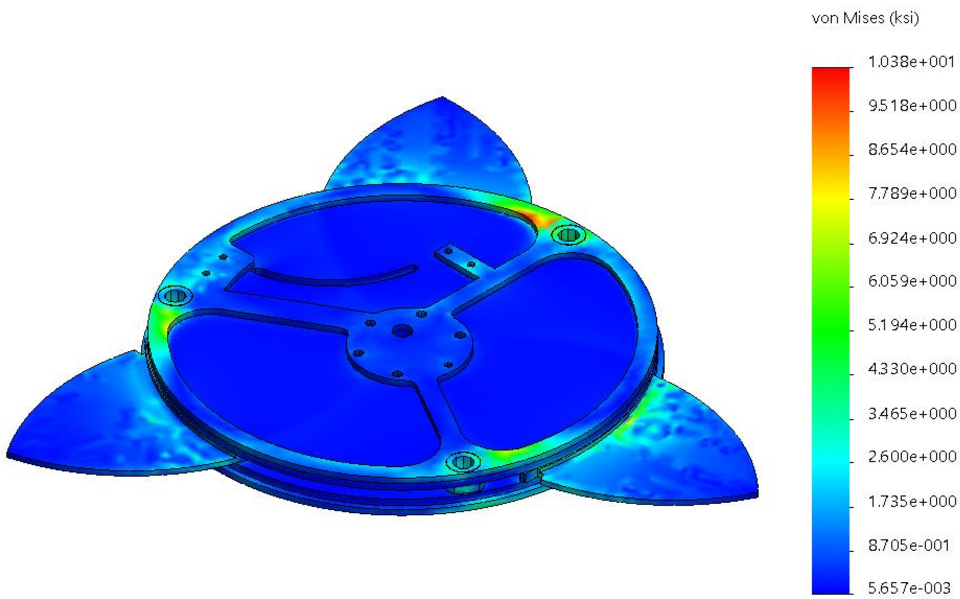


Figure 24: VDS assembly FEA stress plot.

3.1.2.4 Integration

A custom 3D printed has been designed to house the electronics for the VDS. The PCB boards will be secured to the 3D printed sled using M4 hexagonal standoffs. The sled will be secured to the rest of the launch vehicle via three 10-32 aluminum all thread rods. The cover for the sled is secured using 10-32 hex nuts, and has cutouts in the geometry to allow for access to power switches, diodes, and battery harnessing. A rendering of the VDS electronics sled is shown below in Figure 25.

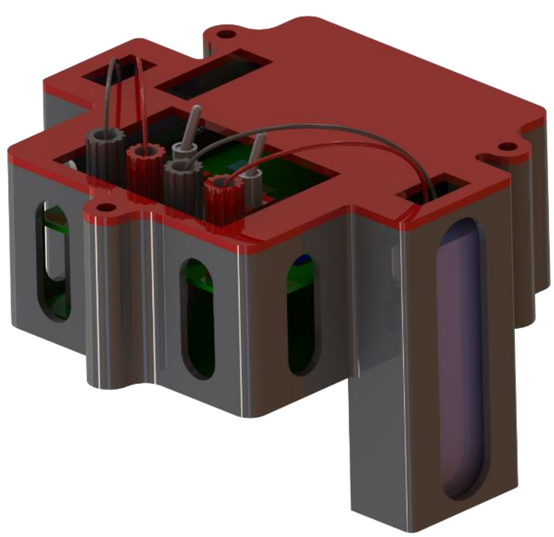


Figure 25: VDS electronics 3D printed sled.

A wooden plate will be mounted in the middle of the coupler of the VDS bay using Glenmarc G5000 epoxy. This will act as an attachment point for the VDS, recovery harnessing equipment, and the VDS electronics.

3.1.3 Propulsion Bay

The two primary goals achieved with the propulsion bay are to serve as the attachment point for the removable fin system and house the motor and motor casing to propel the launch vehicle. The propulsion bay airframe will be constructed from 6.0 inch diameter filament wound carbon fiber tubing. In order to ensure that the fin slots are cut at the specified location, a jig has been created to mark where the slots would be placed using a Universal Laser Systems laser cutter. The jig is seen below in Figure 26.

Figure 26: Fin slot alignment jig.

Once drawn, the fin slots will be cut using a rotary Dremel tool with an abrasive cut off tool attachment. The thickness of the stencil, 0.125 inch, used in the jig is identical to that of the fins used in the launch vehicle, ensuring a near perfect fit with the fins.

3.1.3.1 **Motor Mount**

The motor mount tube will be constructed from 3.0 inch diameter filament wound carbon fiber tubing. The motor tube will be cut to a length of 16 inches, which is the length of the motor. This ensures proper axial alignment of the motor within the launch vehicle.

3.1.3.2 **Removable Fin System**

In order to reduce weight, and remove epoxy joints, a precision fin mounting system has been designed for the launch vehicle. This system eliminates the possibility of damaging fins or epoxy joints during transportation of the launch vehicle or during the landing of the launch vehicle. Additional fins will be readily available at launch, allowing for any damaged fin to immediately be replaced. Along with having the ability to replace damaged fins before a launch, the removable fin system also allows different fin designs to be utilized during test launches to account for mass changes throughout the year.


Figure 27: Propulsion bay assembly.

Figure 27 shows an assembled rendering of the removable fin system as it appears in the propulsion bay. The assembly consists of three centering rings, a rear fin retainer, and a motor casing retainer. The centering rings are the only components epoxied to the motor mount tube and airframe. Proper alignment of the centering rings is critical to the success of the removable fin system. To ensure proper alignment, the fins will be placed in the centering rings during the curing process of the epoxy.

With the motor installed in the casing and motor tube, the motor retainer mounts to the fin retainer via three #10-32 UNF-3A shoulder screws 1 inch in length. All fasteners in the system are made from 18-8 stainless steel. An exploded propulsion bay assembly and BOM is shown below in Figure 28.

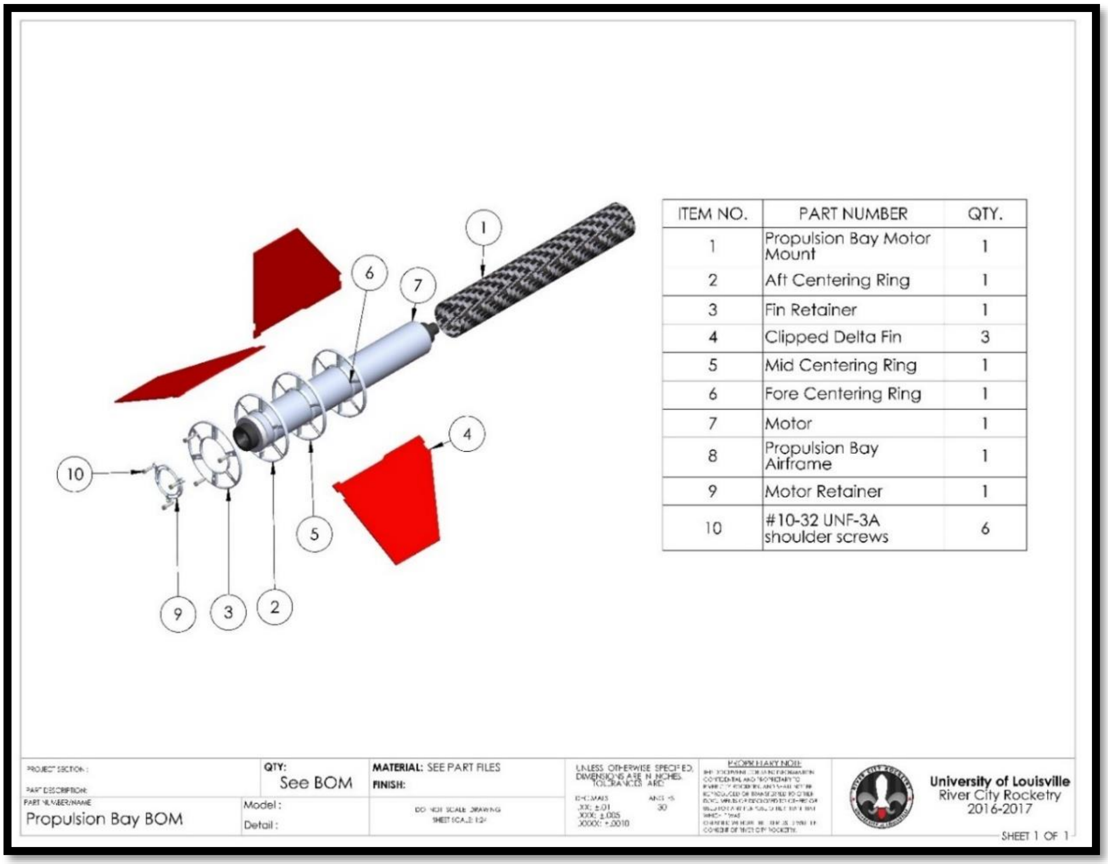


Figure 28: Propulsion Bay BOM.

The fins are held in place in the propulsion bay by placing the fin tab into their proper slots in each centering ring. The fins are inserted into the centering rings and each fin is secured into the propulsion to the launch vehicle by four connection points. Each forward fin tab is pushed forward into the slot located in the fore centering. The slot in the mid centering ring and aft centering ring provides proper alignment for each fin with the motor mount. The fin is locked into place by sliding the aft fin tab into the alocated fin slot in the fin retainer. The fin retainer is mounted to the aft centering ring via three #10-32 UNF-3A socket head cap screws 1 inch in length. A schematic showing the fin tabs and connection points of the fins into the centering rings is show below in Figure 29.

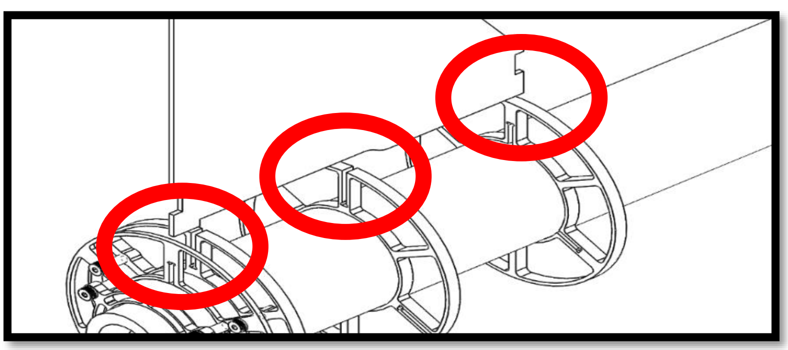


Figure 29: Removable fin system connection points.

3.1.3.3 Centering Ring Design

The centering rings will be custom manufactured from a Maxiem Water Jet from 6061 – T6 aluminum. All of the centering rings have specifically sized slots radially separated 120° to insert the three fins into the propulsion bay. A detailed drawing of the fore centering ring can be seen below in Figure 30.

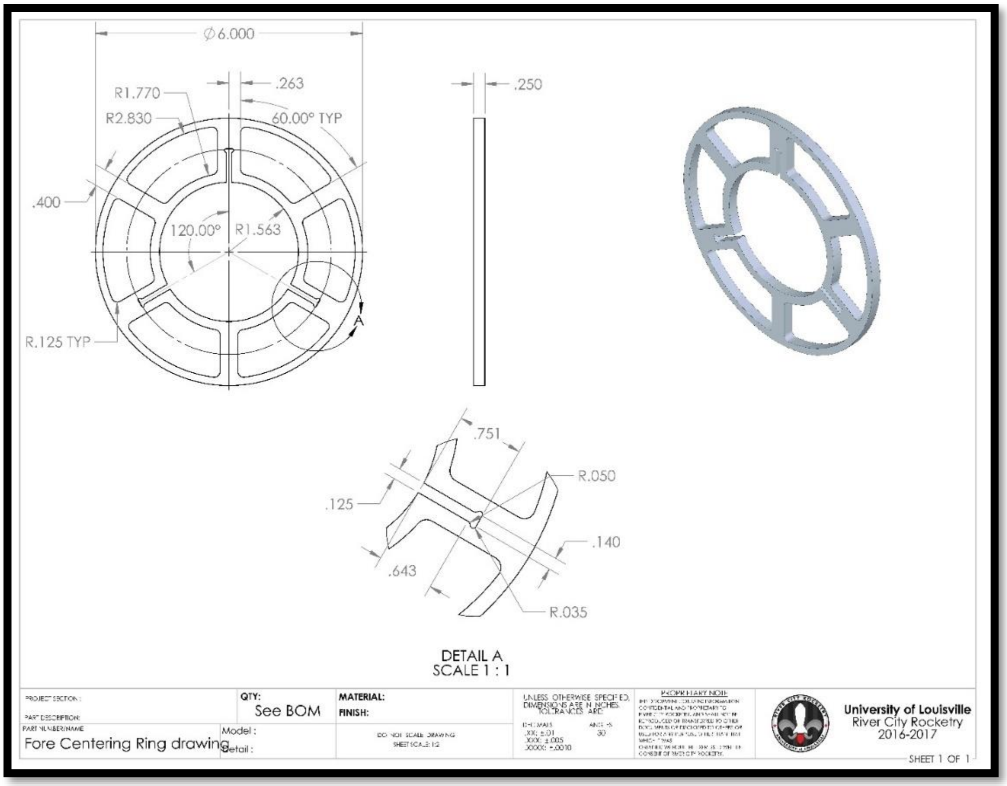


Figure 30: Detailed drawing of fore centering ring

Each centering ring has a set of three equally spaced weight reduction slots. While reducing weight, the weight reduction slots will also effect the strength of the section. To combat this issue, Finite Element Analyses (FEA) were performed for each centering ring with the following parameters conditions shown blow in Table 3.

Component	Simulated Load (N)	% of Maximum Motor Thrust
Fore centering ring	1550.9	50
Mid Centering Ring	1550.9	50
Aft Centering Ring	1550.9	50

Table 3: FEA simulation parameters.

The stress and displacement results can be seen below in Figure 31 and Figure 32.

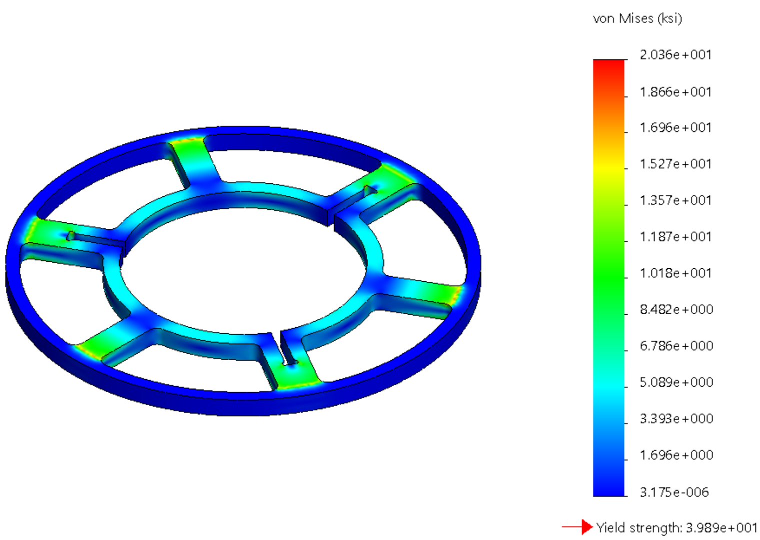


Figure 31: Finite element analysis stress plot.

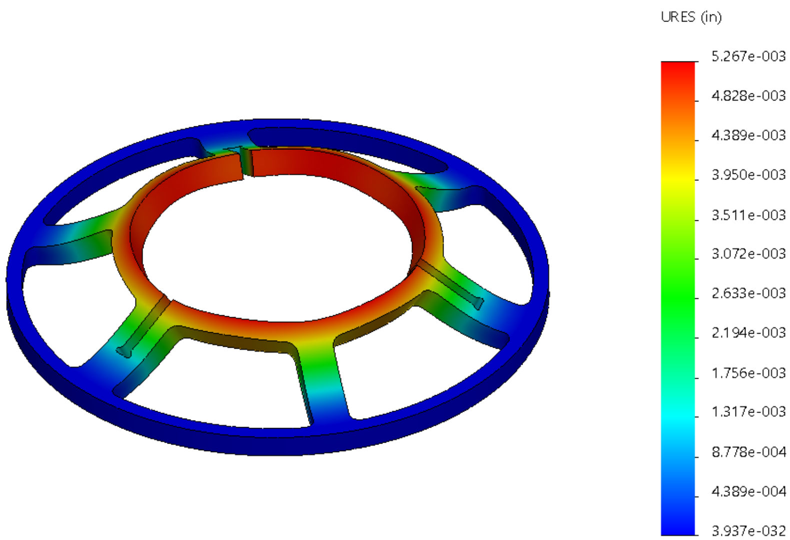


Figure 32: Finite element analysis displacement plot.

The minimum factor of safety throughout each centering ring with the simulated load and maximum displacement is shown below in Table 4.

Component	Minimum Factor of Safety	Maximum Displacement (in)
Fore centering ring	2.0	0.0053
Mid Centering Ring	2.0	0.0058

Aft Centering Ring	2.0	0.0054

Table 4: FEA centering ring results.

3.1.3.4 Motor Retention System

To properly secure the motor casing to the propulsion bay, a custom motor retainer has been designed. Since drogue recovery will not be facilitated by motor ejection, the motor retainer will be subjected to the following loads:

1. Supporting the weight of the motor casing with motor installed.
2. Withstand impact force of parachute deployment.

A rendering of the motor retainer design is shown below in Figure 34.

Figure 33: Motor retainer rendering.

The force that the motor retainer will have to withstand during flight, F_m, was calculated using

$$F_m = m_m a_m \qquad (2)$$

where m_m is the mass of the empty motor casing and a_m is the acceleration of the motor casing under maximum opening force of the parachute. The expected opening force of the motor casing due to the deployment of the main parachute for the VDS bay and Propulsion bay is 439 pounds. The acceleration of the booster was calculated by first subtracting the weight of the booster from the opening force and then dividing that force by the mass of the entire vehicle section. Once the acceleration was found, the force required to retain the motor casing during recovery deployment was calculated using equation (2).
The force required to hold the empty motor during recovery equipment was calculated to be 132.81 pounds. A FEA simulation was set up to verify that the motor was able to withstand the maximum expected forces during flight. Results from the simulation are shown below in Figure 343.

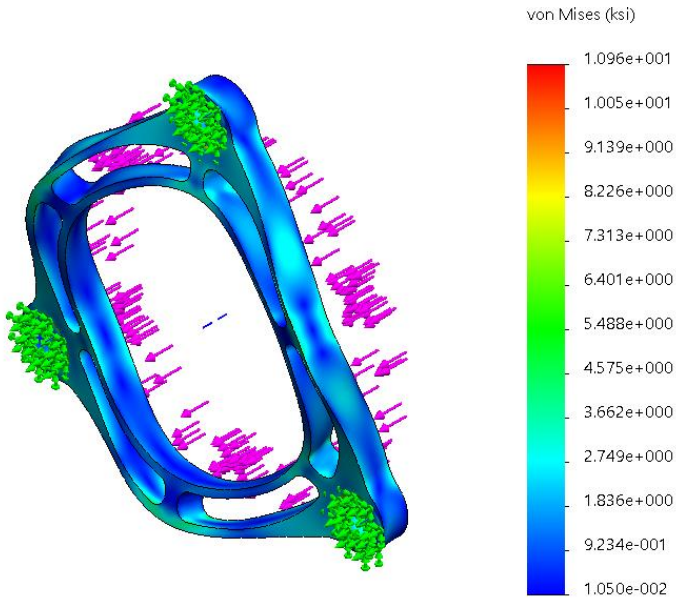


Figure 34: Motor retainer FEA simulation stress plot.

The factor of safety of the motor retainer assuming an opening force of 439 pounds was determined to be 3.6.

Prior to motor installation, the launch vehicle fins and fin retainer must be installed. With the casing installed, the motor retainer will be attached to fin retainer via three #10-32 UNF-3A shoulder screws 1 inch in length. The motor retainer will be machined from 6061- T6 aluminum, using an OMAX Abrasive Waterjet.

3.1.3.5 Fin Design

In order to reduce drag and better compensate for the VDS, vehicle will utilize three fins. The fins will be constructed from carbon fiber. A material thickness of 1/8" was chosen for the fins as the launch vehicle will travel below supersonic speeds. A further analysis of the required thickness of the fins is shown in the Fin Flutter Analysis section. The fins will be cut using an OMAX Abrasive Waterjet. This manufacturing method has been proven to be faster and more precise than traditional manufacturing methods. A detailed drawing of the selected fin shape is shown below in Figure 35.

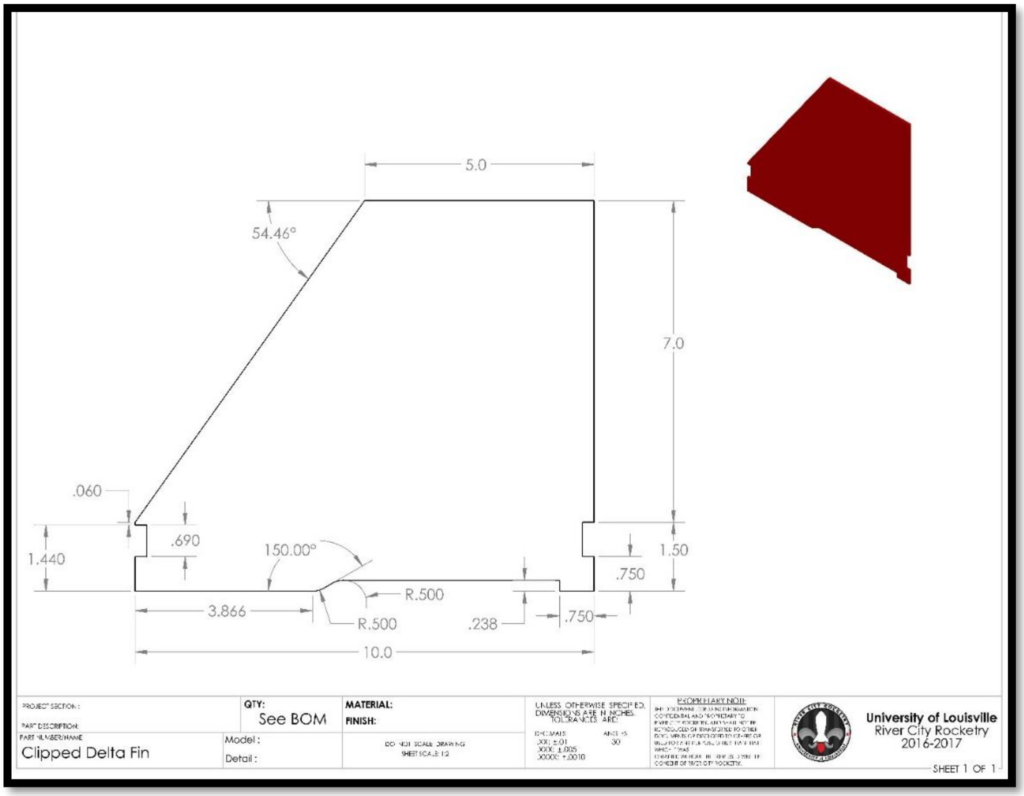


Figure 35: Detailed drawing of fin shape.

3.1.4 Nose Cone Design

The nose cone shape selected for the full scale launch vehicle is the 2:1 fineness ration LD Haack nose cone. Several different nose cone shapes were considered for the launch vehicle, however the LD Haack nose cone provided the best combination of low mass and low coefficient of drag. A further analysis comparing all of the considered nose cone shapes for the launch vehicle can be found in Section 5.4.1 of the Preliminary Design Review. The nose cone will be secured to the launch vehicle via three 4-40 SHCS nylon shear pins. The nose cone will attach to the forward end of the deployment bay. A rendering of the 2:1 fineness ratio LD Haack series nose cone is shown below in Figure 30.

Figure 36: LD Haack nose cone rendering.

Originally, the nose cone was going to be manufactured by making a mandrel out of polystyrene using a ShopBot and winding 6K carbon fiber filament around the mandrel using a 4-Axis X Winder. However, the surface finished created by the X-Winder on a contoured surface is not ideal, and would increase the overall coefficient of drag of the vehicle, thus making the launch vehicle less efficient. To solve this, the manufacturing technique of the nose cone has been adjusted to ensure a smooth exterior finish. A positive mold will be manufactured from ABS plastic using a 3DP1000 Classic 3D Printer. This positive mold will facilitate the construction of a fiberglass negative mold, which will provide a molding surface for the carbon fiber layup to form to while curing. The exterior of the 3D print will be sanded using 2000 grit sand paper to reduce the surface roughness of the print and then spray painted to provide a slick surface. PVA mold release and Partall Paste will then be applied to the 3D printed mold to provide a method to release the fiberglass negative mold from the positive mold once the curing has completed. The fiberglass sheet will then be laid up onto the positive mold using US Composites 435 Polyester Resin. Peel ply, breather cloth, and nylon bagging will then be laid over the fiberglass to allow for a vacuum seal. The peel ply allows any excess resin to exit away from the fiberglass and the breather cloth layer absorbs excess resin as well as allows the vacuum pump to a create constant pressure within the vacuum bagging. After the fiberglass mold is cured and released, Bondo body filler will be applied to any areas with rough surface finishes and sanded down. Carbon fiber fabric will then be laid onto the fiberglass mold and the process will be repeated in order to a create a finished part.

3.1.5 Vehicle Structure

3.1.5.1 Airframe

The launch vehicle will be constructed by strictly adhering to proven manufacturing processes. The vehicle airframe will consist of four 6 inch diameter sections, two 25 inch and two 35 inch sections. The four sections of launch vehicle airframe will be manufactured in house using a 4-axis X-winder composite winder, 6k carbon fiber tow and epoxy vinyl ester resin. All separating sections of the launch vehicle shall be joined to their respective coupler with 4-40 nylon shear pins. Similarly, sections which will not be separating through the course of the flight will be joined with 6-32 UNC-2A BHSCS. Different threads have been selected for the separating and non-separating sections in order to prevent accidental installation of metal screws into separating joints and vice versa. Due to the very thin wall thickness of the carbon fiber coupler tube and carbon fiber airframe of the launch vehicle, the shear pins will be prone to the falling out the designated hole. This will result in premature separation of the vehicle, thus resulting in unexpected deployment of recovery equipment. In order to solve this, a shear pin brace has been designed to secure the shear pins to the vehicle for the entirety of the flight.

The shear pin brace will be epoxied to the interior of its respective coupler tube, and each designated hole for the 4-40 shear pin will be threaded to ensure that the shear pins are attached to the vehicle throughout the flight.

All bulk plates, centering rings, and permanently secured sections of the rocket will be epoxied using Glenmarc's G5000 two component filled epoxy. This epoxy was chosen for its superior strength, as seen in Table 5.

Tensile Strength	7,600psi
Compression Strength	14,800 psi
Elongation	6.30%
Shore “D” Hardness	85

Table 5: Glenmarc's G5000 epoxy mechanical properties.

The airframe for the launch vehicle will be constructed using a 4-axis X-Winder, which is shown below in Figure 37.

Figure 37: 4-Axis X-Winder

The current research on the effects of different winding angles on the strength and deformation of filament wound composite tubes has shown a direct relationship between decreased filament winding angle relative to the mandrel axis and resistance to axial tension and compression, as well as resistance to longitudinal bending. Research has also shown a direct relationship between increased filament winding angle relative to the mandrel axis and resistance to circumferential tension and compression. A quasi-isotropic layup with 50% of fibers running in the direction of the load, 40% running 45˚ to the load and 10% running transverse to the load has been determined to have ideal properties. However, decreasing winding angle causes a decrease in winding filament consolidation on the mandrel during each pass of the X-Winder and an increased likelihood of filament slippage and bunching. This can negatively affect the volumetric fiber to resin ratio on a microscopic level, not perceivable with the naked eye during manufacturing. Without the results of the Carbon Fiber Test Campaign it has been decided that for the 2016/2017 season winding angles well within the manufacturing capabilities of the X-Winder will be used in place of the extreme 0˚ and 90˚ angles suggested in the previously mentioned layup. Instead the airframe will be wound with 50% of fibers at 5˚, 40% of fibers at 45˚ and 10% of fibers at 85˚.

Carbon fiber has been selected as the filament of choice for its high tensile and compressive strength, resistance to harsh environmental factors, strong adhesive properties and low weight. One of carbon fiber's greatest advantage is the wide range of filament properties that are available, making it ideal for custom applications with specific material property requirements. Without the results of the Carbon Fiber Test Campaign it has been decided that for the 2016/2017 season the same carbon fiber filament from the 2015/2016 season will continue to be used. The mechanical properties are shown below in Table 6.

Number of Filaments	6000
Approximate Yield	3728 ft/lb
Tensile Strength	608,000 psi
Elongation	1.80%

Table 6: Carbon fiber 6K filament mechanical properties.

EVERs combine many of the advantages of epoxy, vinyl ester and polyester resins without many of the disadvantages. EVERs have similar mechanical properties, similar heat resistance, better performance in harsh environments and better chemical resistance than epoxy resins. EVERs, like polyester resins, are also easier to work with due to their viscosity, shelf life and cure times, but are more forgiving to changes in environmental temperatures during curing. EVER will be used because of its tensile strength, resistance to fatigue, high adhesiveness, resistance to environmental factors and low volumetric shrinkage. Specifically, Derakane 8084 has been selected for its increased toughness and impact resistance imparted by the elastomer modification. These properties will help prevent airframe damage that could ground the vehicle during competition in the event of a hard landing. The mechanical properties for Derakane 8084 are shown below in Table 7.

Tensile Strength	11,000 psi
Flexural Strength	19,000 psi
Tensile Elongation	8-10%
Heat Distortion	180˚F
IZOD Impact (unnotched)	8.9 ft.lbf/inch

Table 7: Derakane 8084 mechanical properties.

3.1.5.2 Bulkplates

In order to verify the structural integrity of the bulkplates that will be connecting the recovery equipment to each respective launch vehicle section, a FEA simulation was performed to optimize the thickness of the bulkplates. Two bulkplate assemblies were analyzed to verify the structural integrity of them under expected loading conditions. The first bulkplate analyzed was the one that attaches to the VDS Bay and Propulsion Bay to its respective recovery equipment. The expected load the bulkplate will experience during a flight is 399 pounds, which is the expected opening force of the main parachute for that section. The expected load of the bulkplate assembly in the payload recovery bay is 222pounds. An FEA simulation of two eighth inch thick 0/90 carbon fiber plates epoxied together using the calculated opening force as the applied load was performed to estimate the maximum stress within the plate under the maximum. The load was applied to the region of the bulkplate assembly where the U-bolt washers are expected to sit. The bulkplate assembly was fixed where the all thread washers that connect the plate to the rest of the vehicle section are expected to be. The results from the simulation are shown below in Figure 38.

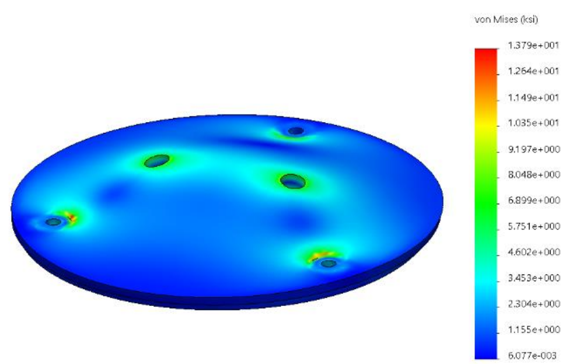


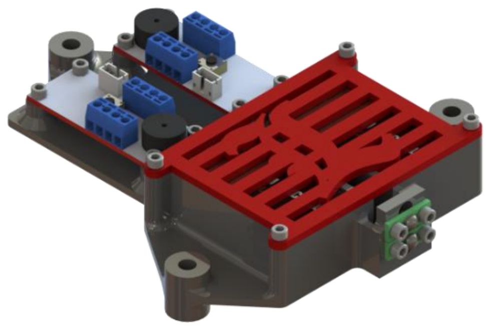
Figure 38: Bulkplate FEA simulation stress plot.

The maximum tensile stress in the plate was determined to be 13.79 ksi. Based on this data, eighth inch thick Dragon Plate EconomyPlate carbon fiber sheet was chosen for the material for the booster recovery bay bulkplate.

3.1.6 Avionics

3.1.6.1 Overview

In order to facilitate separation of the launch vehicle throughout the flight, PerfectFlite Stratologger CF altimeters have been selected to detonate pyrotechnic charges within each separation section of the launch vehicle. Custom altimeter sleds have been designed to house the altimeters inside the launch vehicle. There will be two altimeter sleds located within the launch vehicle. One altimeter sled will be located in the coupler connecting the deployment bay to the payload recovery bay and the other altimeter sled will be in the VDS bay. Each altimeter sled houses two PerfectFlite Stratologger CF altimeters, two Duracell 9 volt batteries, and two Featherweight screw switches. The screw switches will be utilized to arm each altimeter through the respective vent hole in the avionics bay. There will be two altimeter sleds located in the launch vehicle. The altimeter sleds will be 3D printed from PLA plastic using a MakerBot Replicator 3D printer. A rendering of the altimeter sled assembly is shown below in Figure 32.



3.1.6.2 **Vent Hole Sizing**

The diameter of each vent hole, Dn, and the number of vent holes, Dt, was calculated using

$$D_N = D_T \sqrt{\frac{L * A_{ref}}{N * V_{ref}}} \quad (3)$$

where L is the length of the avionics bay, A_{ref} is the reference area of the static vent hole, V_{ref} is the reference volume of the avionics bay in relation to the reference area of the vent hole, D_T is the interior diameter of the avionics bay, and N is the number of desired vent holes. According to Vern's Rocketry, it is recommended that a one fourth of an inch vent hole be created for every 100 cubic inches of avionics coupler. Therefore, one fourth of an inch was used for A_{ref} and 100 cubic inches was used for V_{ref}. Due to the fact that the vent holes in the avionics bays will also be used as an access hole for arming the altimeters of the launch vehicle, a vent hole quantity of one was selected for each avionics bay. Dimensions of each avionics bay is shown below in Table 8

Dimension	Payload Recovery Avionics Bay	Booster Recovery Avionics Bay
Length (in)	5.75	6.375
Interior Diameter (in)	5.85	5.85

Table 8: Dimensions of each avionics bay.

The calculated vent hole diameter assuming only one vent hole is shown below in Table 9.

Payload Recovery Avionics Vent Hole Diameter (in)	Booster Recovery Avionics Bay (in)
0.31	0.33

Table 9: Calculated vent hole diameters for each avionics bay.

3.1.6.3 **GPS Tracking**

To satisfy the GPS requirement for each independent section other than the payload, the Eggfinder GPS tracking system will be located in each independently recovery section of the launch vehicle. The Eggfinder is only 20 grams and has a range of 8000 feet from the tracking receiver. The Eggfinder operates at a frequency of 900 MHz at 100mW. The Eggfinder GPS tracking system is shown below in Figure 39.

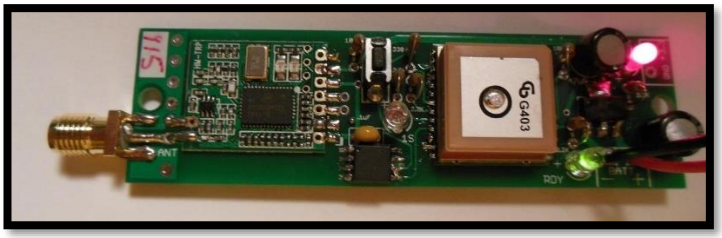


Figure 39: Eggfinder GPS tracking device.

Due to the fact that all of the airframe, bulkplates, couplers, and nose cone will be manufactured using carbon fiber, the antenna of each Eggfinder will be secured to the exterior of the launch vehicle through a vent hole in the airframe of each independent section other than the payload. Placing the antenna on the exterior of the launch vehicle reduces the risk of signal attenuation from the carbon fiber airframe.

3.2 Subscale Flight Results

3.2.1 Design Overview

In order to test the design and aerodynamic characteristics of the launch vehicle, a one half-scale model was designed, manufactured, and tested. To facilitate a single recovery bay configuration, the payload and deployment bays featured in the full scale model were replaced with a recovery bay and the VDS bay was replaced with an avionics bay. Additionally, recovery bay sizes were adjusted to allow adequate room for all recovery equipment. The subscale vehicle utilized an Cesaroni I150-BS motor. The final subscale launch configuration is shown in Figure 40.

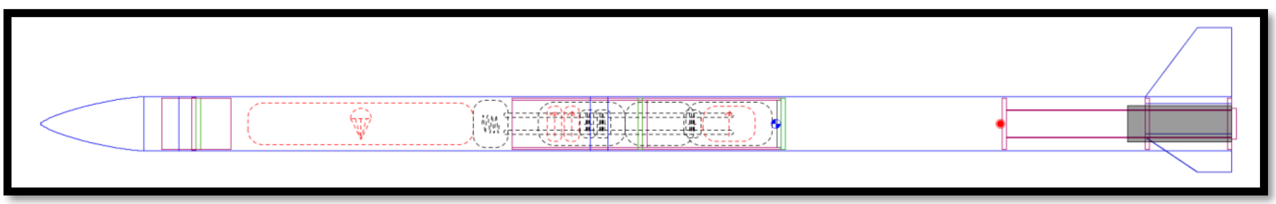


Figure 40: Subscale OpenRocket configuration.

A scaling factor of one-half for the subscale vehicle was chosen due to the integration of the flight electronics and recovery equipment as well as the availability of airframe sizes. A three-inch diameter airframe was the minimum size required to house all flight electronics and recovery equipment. The nose cone, altimeter sled, and flight computer sled of the subscale vehicle were constructed from PLA plastic using a MakerBot Replicator 3D. The airframe, coupler, and motor mount were constructed from phenolic tubing. The fins were constructed from G10 fiberglass using a Maxiem abrasive water jet. The fully assembled subscale vehicle is shown below in Figure 41.

Figure 41: Fully assembled subscale vehicle.

A comparison of the properties between the full scale launch vehicle and subscale vehicle is shown below in Table 10.

Property	Full Scale	Sub Scale (Dec 3rd)	Error (%)
Diameter (in)	6	3	50
Length (in)	140	70	50
Burnout Weight (lbs)	45.9	6.656	86
Static stability margin (at rail exit)	2.71	2.65	0.84

Table 10: Comparison of properties between the full scale and subscale vehicles.

In order to accurately estimate the drag coefficient of the full scale launch vehicle from the sub scale flight data, the team designed the subscale so that the dimensions of the subscale vehicle's exterior profile were kept proportional to the full scale launch vehicle. The coefficient of drag varies with surface roughness, airflow speed, and air density, however, an estimate of the full scale launch vehicle coefficient of drag can be computed from subscale vehicle flight data.

Another parameter of the subscale vehicle that was kept constant with respect to the full scale launch vehicle was the overall mass distribution of the vehicle, which resulted in a nearly identical off the rail stability to the full scale launch vehicle. The flight trajectories of the subscale and full scale launch vehicles were designed to be as similar as possible by designing the subscale vehicle to have the same off the rail stability as the full scale launch vehicle.

Parameters of the subscale vehicle that were not kept constant with respect to the full scale launch vehicle include longitudinal rotational inertia, overall weight, and surface roughness. While it is desirable that the longitudinal rotational inertia of the subscale vehicle be the same as the full scale launch vehicle in order to reproduce similar flight characteristics, the permissible overall weight of the subscale vehicle in order to achieve a safe rail exit velocity limited the team's ability to replicate the rotational inertia of the full scale vehicle. The overall weight of the subscale was not kept constant relative to the full scale because the coefficient of drag does not vary with respect to mass. While the surface roughness does contribute to the value of the coefficient of drag, the team did not have the ability to keep the surface roughness identical between the subscale and full scale launch vehicles due to varying material selection. The nose cone of the full scale launch vehicle will be constructed by custom winding carbon fiber filament around a mandrel, whereas the nose cone of the sub scale was 3D printed from PLA plastic. Differences in manufacturing techniques resulted in varying surface roughness throughout the exterior of the subscale and full scale vehicles, which will propagate errors between estimations of the coefficient of drag of the subscale vehicle and full scale launch vehicle.

3.2.2 Recovery Subsystem Design Overview

The design of the subscale included a single recovery system that was designed to be representative of the primary recovery systems for both the booster and payload bay as they were designed in PDR. The subscale recovery system consisted of a cruciform drogue and a toroidal main parachute stowed in the upper section of the rocket to serve as proof of concept of the functionality of main deployment via ARRD release. This is shown below in Figure 42 with the main deployment bag in white, main and drogue shock cords in red, and the deployment bag tether in blue.

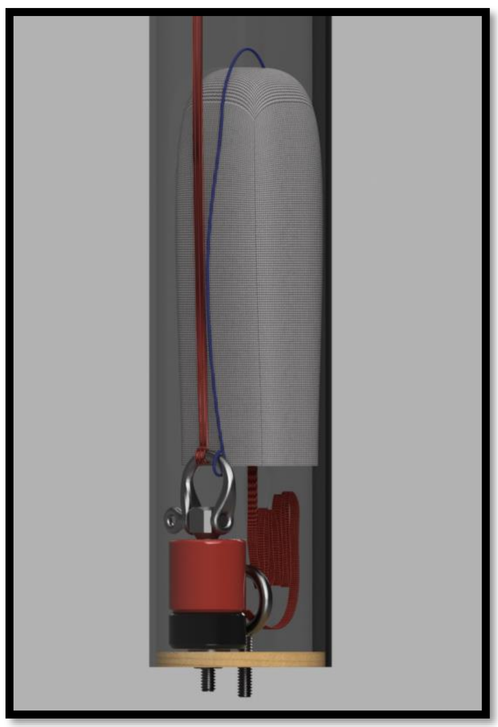


Figure 42: Subscale recovery layout

The recovery gear was sized based on the design criteria outlined in section 3.3 The subscale recovery gear does not follow the ½ scaling factor due to the nature the equation for drag coefficient where parachute diameter varies with the weight of the recoverable sections, which was not held to the ½ scale parameter. C_d was kept constant, as it varies with parachute geometry and not the diameter of the parachute. All rigging and shroud lines were kept constant with respect to parachute diameter. The specifications for the subscale recovery system are shown below in Table 11**.**

Recovery Gear Specifications			
Drogue		**Main**	
Panel width (in)	7	**D_O (in)**	33
Panel length (in)	27	**S_O (ft^2)**	5.94
S_O (ft^2)	2.04	**Vent hole size (in)**	6.5
Shroud Line Length (in)	20	**Outer Shroud Line Length (in)**	48
Shock Cord Length (ft)	9	**Inner Shroud Line Length (in)**	13
		Centerline Length (in)	37.5
		Shock Cord Length (ft)	9

Table 11: Subscale recovery gear specifications

The subscale vehicle was launched in Elizabethtown, Kentucky and in Bowling Green, Kentucky. Simulations of the subscale vehicle's flight trajectory were created based on the predicted weather conditions for December 3rd in Elizabethtown, Kentucky and for December 18th in Bowling Green, Kentucky. The launch day conditions for December 3rd and December 18th are shown below in Table 12.

Property	December 3rd at Elizabethtown, Kentucky	December 18th at Bowling Green, Kentucky
Average Wind Speed (mph)	3	17
Wind Direction	North	South
Temperature (°F)	40	27
Pressure at Ground Level (inHg)	30.32	30.26
Air Density at Ground Level (kg/m^3)	1.2836	1.3153

Table 12: Launch Day conditions for the subscale vehicle.

Based on these conditions, two simulations were conducted using the OpenRocket configuration of the subscale vehicle. Predicted flight characteristics of the December 3rd launch and December 18th launch are shown below in Table 13.

Property	December 3rd Launch Simulation	December 18th Launch Simulation
Apogee (ft)	1,980	1,746
Maximum Acceleration (ft/s^2)	150	132
Maximum Velocity (ft/s)	359	319
Rail Exit Velocity (ft/s)	54.4	55.6
Motor Burnout Altitude (ft)	677.54	605.32
Rail Exit Stability Margin	2.65	2.81

Table 13: Predicted subscale vehicle flight characteristics.

3.2.3 Flight Data

VDS test electronics were housed within the avionics coupler of the subscale vehicle along with the altimeters. The VDS Test Electronics installed on-board during the December 3rd and December 18th subscale launch returned the following results found below in Figure 43.

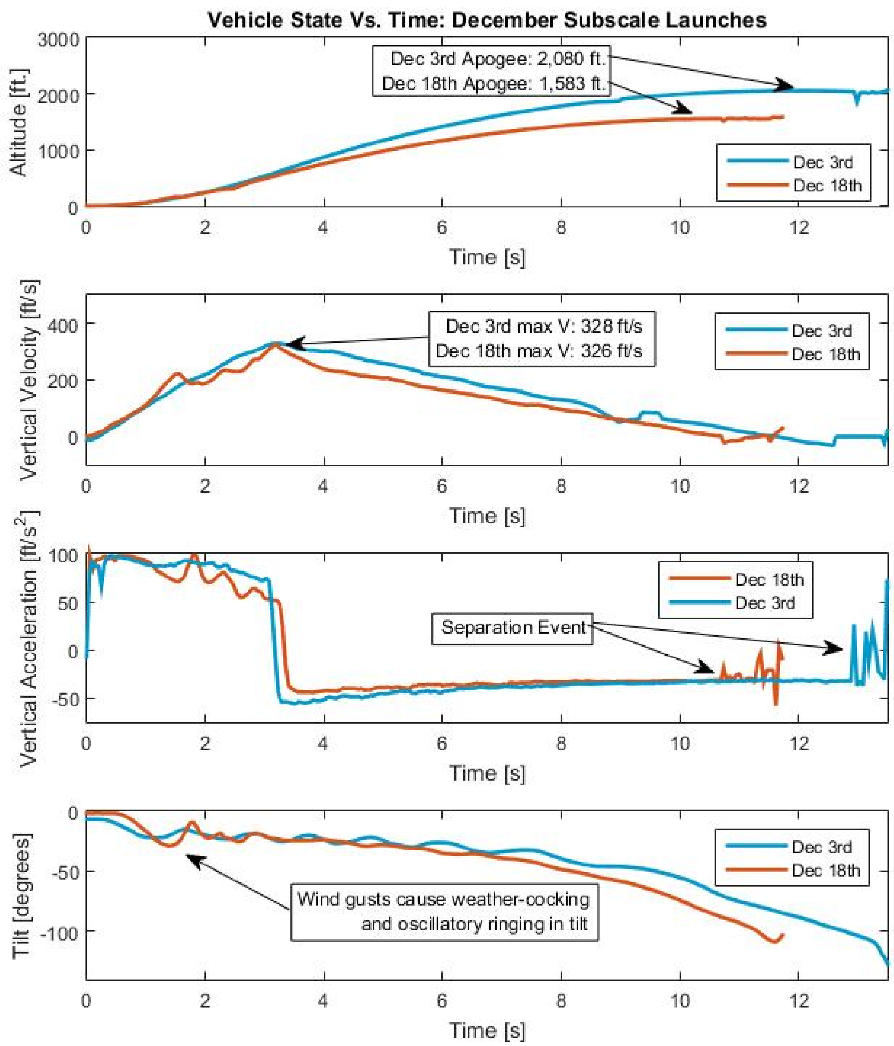


Figure 43: Vehicle State Vs. Time: December subscale launches.

The most notable difference of the two flights was the oscillation of the vehicle throughout the flight. During the December 3rd launch, the subscale vehicle experienced continuous oscillation about the center of gravity throughout the entirety of the flight, as evidenced by the tilt vs time graph shown in Figure 43

The PerfectFlight Stratologger CF altimeters housed on the subscale vehicle during the December 3rd and December 18th launches returned the results shown below in Figure 44 and Figure 45.

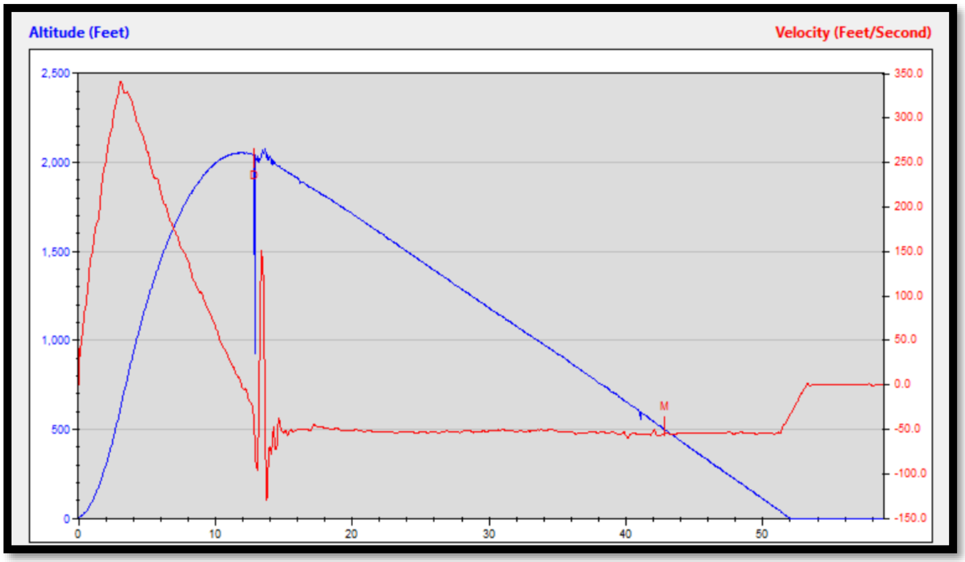


Figure 44: December 3rd Launch Results

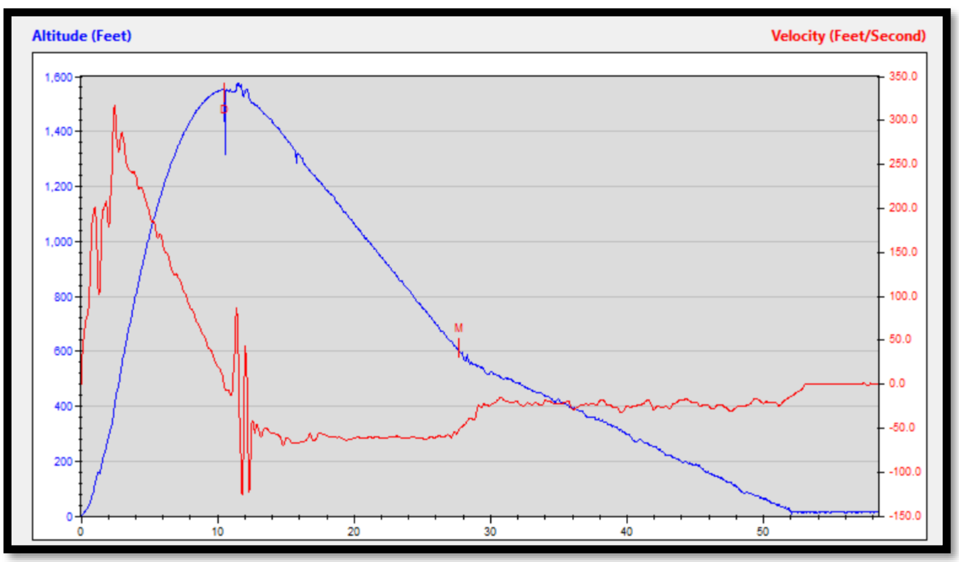


Figure 45: December 18th Launch Results

A summary of the results from the PerfectFlite Statologger CF altimeters is shown below in Table 14.

Property	December 3rd Launch Data	December 18th Launch Data
Apogee (ft)	2,054	1,559
Maximum Vertical Velocity (ft/s)	340	320
Drogue Descent Vertical Velocity (ft/s)	53.1	61.7
Main Descent Vertical Velocity (ft/s)	N/A	23.6

Table 14: Subscale vehicle altimeter flight data.

VDS test electronics were also housed within the avionics coupler of the subscale vehicle along with the altimeters. The VDS test electronics board assembly consisted of the BNO055 accelerometer and the BMP180 pressure sensor. The test electronics assembly is displayed in Figure 46 below.

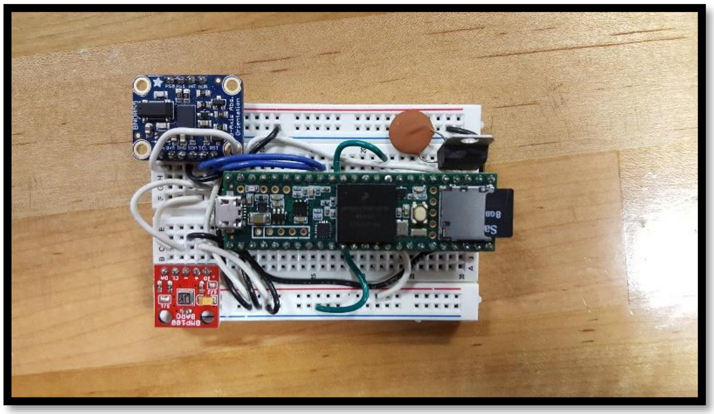


Figure 46: VDS Test Electronics

During the December 18th flight, the subscale vehicle initially started to oscillate, but the oscillation was completely dampened by approximately 3 seconds after motor ignition. This indicates that the configuration of the subscale vehicle during the December 3rd launch had a higher damping moment coefficient than the configuration of the subscale vehicle during the December 18th launch. The damping moment coefficient of the subscale vehicle, C_2, was calculated for each launch using

$$C_2 = C_{2A} + C_{2R} \tag{4}$$

where C_{2A} is the aerodynamic damping moment coefficient of the subscale vehicle and C_{2R} is the propulsive damping moment coefficient of the subscale vehicle. The aerodynamic damping moment coefficient of the subscale vehicle was calculated using

$$C_{2A} = \frac{\rho V A_r}{2} \sum \left(C_{N\alpha_{component}} \left[Z_{component} - W \right]^2 \right) \tag{5}$$

where ρ is air density, V is the velocity of the vehicle, A_r is the reference area, $C_{N\alpha_{component}}$ is the normal force coefficient of each exterior component, $Z_{component}$ is the distance from the nose tip to the CP of each exterior component, and W is the distance from the nose tip to the center of gravity of the vehicle. The propulsive damping moment coefficient of the subscale vehicle was calculated using

$$C_{2R} = \dot{m}[L_{ne} - W]^2 \tag{6}$$

where $\dot{m}$ is the mass flow rate of the motor, and L_{ne} is the distance from the motor nozzle to the nose cone tip. The calculated damping moment coefficient of the subscale during the December 3rd and December 18th launches is shown below Figure 47.

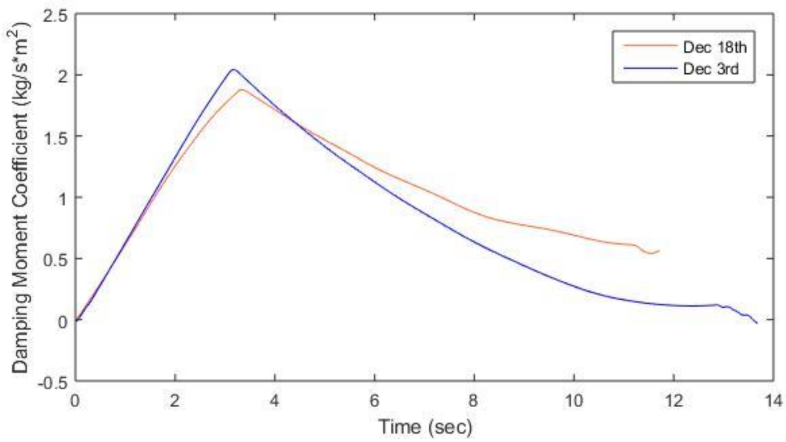


Figure 47: Damping moment coefficient of the subscale vehicle launches.

As seen above, the damping moment coefficient of the subscale vehicle was higher after motor burn during the December 18th launch than during the December 3rd launch. This caused the amplitude of the oscillation of the vehicle during the December 18th launch to decrease at a faster rate when compared to the December 18th launch. The immediate tilt angle of the subscale vehicle after rail exit of each flight is attributed to the high corrective moment coefficient of the vehicle. The corrective moment coefficient of the subscale vehicle, C_1, for the December 3rd launch and for the December 18th launch was calculated using

$$C_1 = \frac{\rho V^2 A_r C_{na}[Z - W]}{2} \tag{7}$$

Variables $\rho, V, A_r, C_{na}, Z,$ and W have already been introduced. The calculated corrective moment coefficient of the subscale vehicle for each launch is shown below in Figure 48.

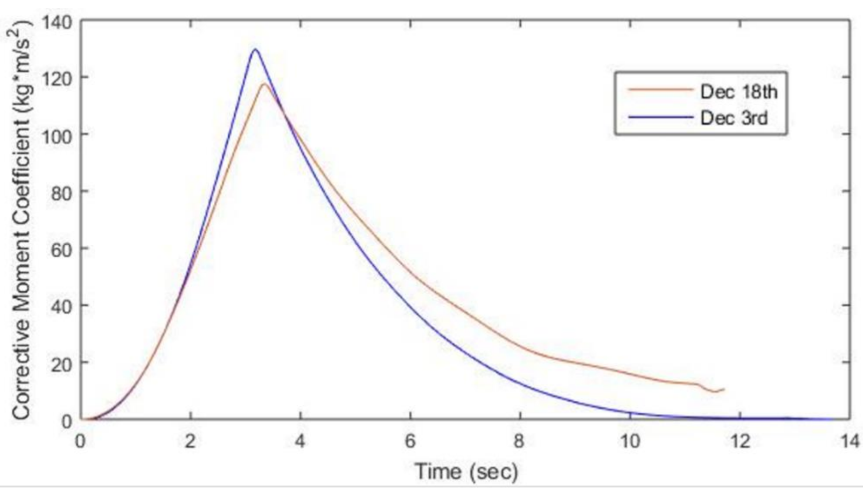


Figure 48: Corrective Moment Coefficient of the subscale vehicle for each launch.

On December 18th, the average wind speed during the time of launch was 14mph greater than the average wind speed on December 3rd during the time of launch. The higher wind speed during December 18th launch caused the subscale vehicle to weathercock after rail exit more so than on December 3rd. As shown in the tilt vs time graph in Figure 43, the amplitude of the initial oscillation of the subscale vehicle of the December 18th launch was greater than the amplitude of the initial oscillation of the December 3rd launch. This can be attributed to the drastically different wind conditions that the two subscale launches were performed in. The exit rail velocity of the subscale vehicle was also greater on the December 18th launch when compared to the December 3rd launch, which contributed to the higher peak oscillation amplitude.

The damping ratio of the subscale vehicle, δ, was calculated using

$$\delta = \frac{C_2}{2\sqrt{I_L C_1}} \quad (8)$$

where I_L is the longitudinal moment of inertia of the subscale vehicle. Variables C_2 and C_1 have already been introduced. The calculated damping ratio values of the subscale vehicle in the December 3rd configuration and December 18th configuration is shown below in Table 15.

December 3rd Configuration Damping Ratio	December 18th Configuration Damping Ratio
0.2372	0.2054

Table 15: Calculated subscale vehicle damping ratios.

Indication of varying wind turbulence intensity between the December 3rd launch and the December 18th launch results from the difference in calculated values of damping ratios. During the December 18th launch, a wind disturbance caused the subscale vehicle to have a large angle of tilt after rail exit. However, the oscillation of the subscale was quickly dampened. This signifies that the subscale vehicle experienced a gust of wind during the initial motor burn, but the wind intensity was reduced after motor burn and throughout the ascent. In contrast, the oscillation of the subscale vehicle during the December 3rd launch continued throughout the entirety of the ascent. This suggests that the subscale vehicle was subjected to continual wind disturbances during the ascent of the vehicle.

The higher oscillation amplitudes of the subscale vehicle during the motor burn resulted in a large decrease in apogee altitude. The first large angle of tilt of the subscale vehicle during the December 18th launch is shown below in Figure 49.

Figure 49: Initial peak angle of tilt during December 18th launch.

The large initial angles of tilt of the subscale vehicle during the December 18th and December 3rd launch caused the motor to spend a majority of the burn in directions offset from vertical relative to gravity, which propagated error from the actual and simulated apogee altitude of the vehicle. The component of the motor's thrust in the direction of the positive vertical direction relative to gravity from motor ignition to motor burnout is shown below in Figure 50.

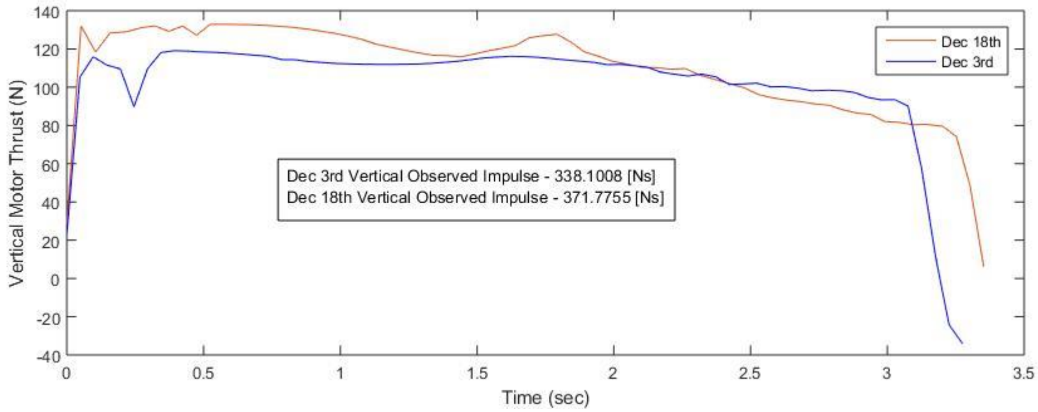


Figure 50: Observed vertical motor thrust of the Cesaroni I150 for both subscale launch.

A comparison of the apogee altitude read by the PerfectFlite Stratologger CF altimeters and the simulated apogee altitudes from the OpenRocket simulations of the subscale vehicle is shown below in Table 16.

Launch Date	OpenRocket simulated Apogee Altitude (ft)	Achieved Apogee Altitude (ft)	Error (%)
December 3rd	1,980	2,054	3.60%
December 18th	1,746	1,559	12.01%

Table 16: Simulated and actual apogee altitude comparison.

Another cause of the difference between the simulated and achieved apogee altitude was the difference in launch rail length. The subscale launched off an eight-foot rail during the December 3rd launch and launched off a twelve-foot rail during the December 18th launch. The longer launch rail used during the December 18th subscale vehicle launch could have induced more rail friction than during the December 3rd launch, thus performing more work on the subscale vehicle and reducing the change in kinetic energy of the vehicle.

For the recovery of the subscale vehicle, the nosecone was tethered to the launch vehicle instead of recovering separately under the drogue to evaluate the possibility of recovering the launch vehicle as one tethered unit. This caused a failure in the December 3rd flight in which the nosecone was tethered to the bulkplate at the bottom of the recovery bay. This produced tangling between the tether to the nose cone and the drogue shock cord, which prevented the drogue from deploying main, causing failure of the main parachute as shown below in Figure 51.

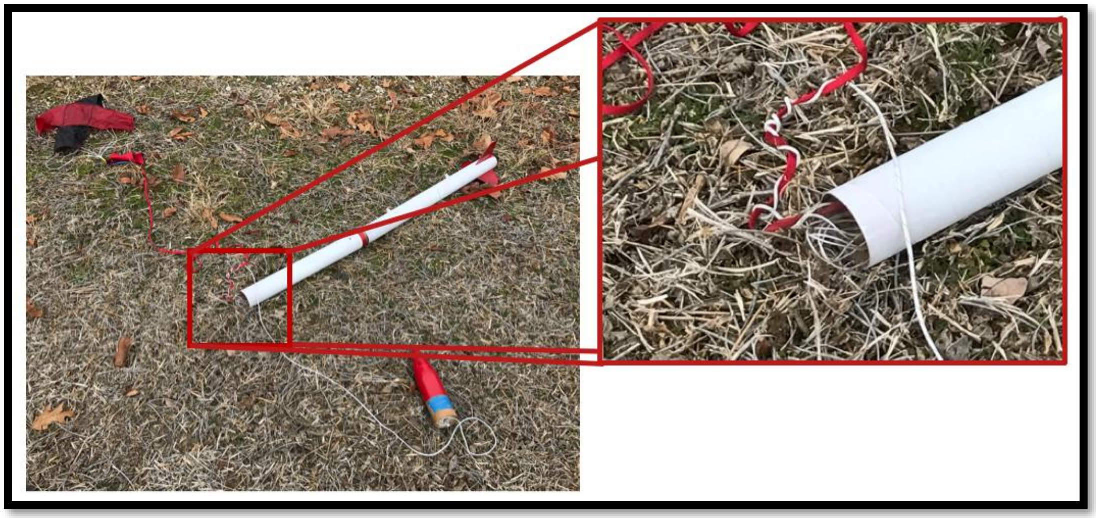


Figure 51: Failure of main on December 3rd

This issue was addressed in a redesign in which the nosecone was attached to the drogue parachute by a short tether to ensure that it would not interfere with main deployment. This was an effective redesign and enabled an orderly main deployment.

Figure 52: Successfully recovered subscale from December 18th flight

During the December 18th flight, the drogue shock cord was kept tethered to the top of the main parachute. This modification, while functional, produced significant instability under main in windy conditions. The drogue and nose cone assembly tended to be more sensitive to changes in wind direction and speed. As a result, the assembly would drift away from the launch vehicle and impart force to the top of the main parachute, causing severe instability as shown below in Figure 53.

Figure 53: Severe instability caused by drogue and nosecone

As addressed in PDR, the primary test items for the subscale recovery were drag coefficient of the drogue and main parachute, and opening force of the main parachute. Using the drogue descent velocity from Table 14, and the recovery gear specifications from Table 11, the drag coefficient of the drogue and parachute were calculated using the following equation

$$C_d = \frac{2mg}{v_e^2 S_o \rho} \tag{9}$$

Where m is the mass of the vehicle, g is gravitational acceleration, v_e is the equilibrium velocity, s_o is the surface area of the parachute, and ρ is the air density at sea level at the time of launch. The calculated drag coefficient is shown below in Table 17.

Drogue C_d			
December 3rd	December 18th	Average	Expected
0.83	0.66	0.75	0.6 – 0.85

Table 17: Calculated drag coefficient of drogue parachute

The discrepancy of the two calculated drag coefficients is possibly due to the differing wind speeds detailed in Table 12. Since the drogue is a relatively small parachute and the cruciform geometry is sensitive to wind factors, it is plausible that the higher wind speeds on December 18th affected the angle or nominal diameter of the drogue, causing it to appear less effective. However, the calculated drag coefficients for both launches fall within the acceptable expected range.

For the calculation of the main parachute drag coefficient, it is crucial to include the drag force of the deployed cruciform drogue in the calculation. The drag force of the cruciform was calculated to using the following equation

$$D = \frac{C_d S_o \rho v^2}{2} \tag{10}$$

Where D is drag force, and v is velocity. C_d, S_o, and ρ have already been introduced.

Using descent velocity under main, the drag force of the cruciform was calculated to be 1.08 lbs. We subtract the drag force from the force component in equation 9 to form the following modified equation

$$C_d = \frac{2(mg - D)}{v_e^2 S_o \rho} \tag{11}$$

With this equation, the updated C_d was calculated and is shown in the table below.

Main C_d		
December 3rd	**December 18th**	**Expected**
N/A	1.48	1.2- 1.3

During descent, the VDS electronics continued to record the acceleration acting axially on the vehicle. This data was used to generate the opening force curve of the main parachute as shown below in Figure 54.

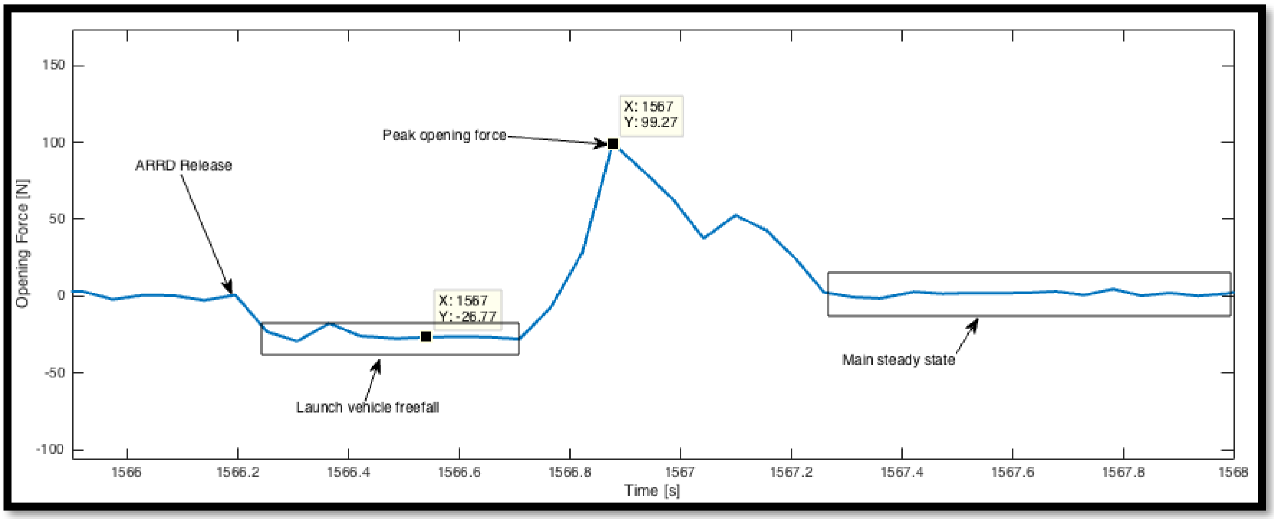


Figure 54: Force curve during main opening.

Figure 54 shows the peak opening force to be 99.27 Newtons, or 22.34 lb_f.

3.2.3.1 **Motor Thrust Characteristics**

The subscale launch data was used to determine the thrust curve of the I150 motor as an exploration of the tolerances on commercial high-power rocket motors. Accelerometer flight data was used to determine the forces acting axially on the vehicle. Gravity and drag forces were then subtracted from this data to find the thrust of the motor. The equation for the forces acting axially on the vehicle during motor burn is given as

$$F_a = T - mg - \frac{C_d \rho A_r v_a^2}{2} \qquad (12)$$

where F_a is the force acting axially on the vehicle, T is the motor thrust, g is the component of gravitational acceleration in the direction of the vehicle's roll axis, C_d is the coefficient of drag, ρ is the air density, A_r is the cross-sectional area of the rocket, v_a is the axial velocity of the vehicle, and m is the mass. The thrust term T can be found by subtracting out the drag and gravity terms from the logged force data. Doing so results in the following observed thrust curve found below in Figure 55.

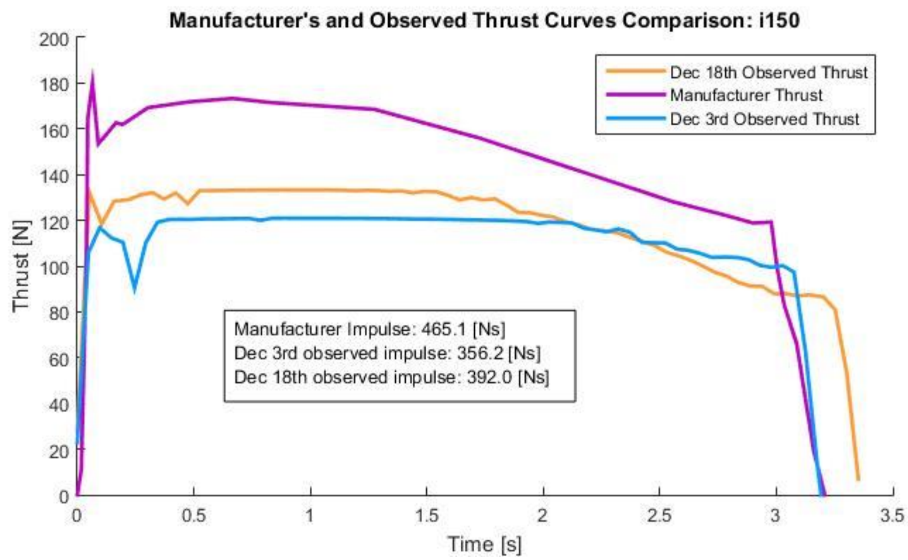


Figure 55: Observed and Manufacturer's thrust curves for I150 motor: December 18th subscale.

The percent error of the total impulse between the observed and manufacturer's curves found above was found to be 15.7% (23.6% December 3rd). This error could be due to several things including measurement error and/or motor tolerance error. Possible measurement errors include the possibility that the VDS Electronics 9DOF sensor (accelerometer) not being mounted perfectly axially, resulting in a measurement of smaller magnitude in the axial direction. Another possibility for discrepancies between the manufacturer's curve and the observed curve are tolerance errors.

Evidence for tolerance error is found in the difference in burn times between the manufacturer's curve and the observed one. The manufacturer curve has a burn time of 3.208 seconds and the observed curve has a burn time of 3.352 seconds. Because measurement error is unlikely in determining the duration of burn time, discrepancies for burn time can be reasonably attributed to tolerance errors.

3.2.4 Flight Analysis

3.2.4.1 Coefficient of Drag Estimation

The average coefficient of drag for the subscale vehicle was found to be 0.4781. This number was found by using on-board accelerometer data from the VDS Test Electronics and fitting a curve to the following equation:

$$a_a = -g - \frac{C_d \rho A_r v_a^2}{2m} \tag{13}$$

Where a_a is the axial acceleration of the vehicle, g is the component of gravitational acceleration in the direction of the vehicle's roll axis, C_d is the coefficient of drag, ρ is the air density, A_r is the cross-sectional area of the rocket, v_a is the axial velocity of the vehicle, and m is the mass. The curve fitting session for this equation with the December 18th subscale launch data can be seen below in Figure 56.

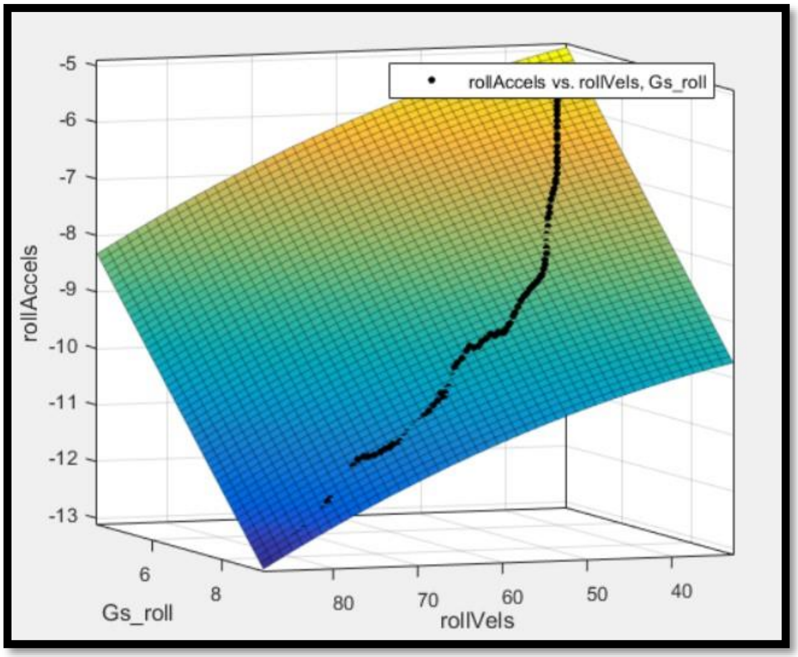


Figure 56: Subscale coefficient of drag curve-fitting results.

This curve fitting session used the ascent portion of the flight and excludes the burn phase so that drag and gravity are the only significant forces acting on the vehicle. This data also only includes the components of acceleration and velocity in the axial direction of the vehicle. The curve-fitting tool was used to solve for the average coefficient of drag that fit this data with the least error-squared. The resulting curve fit the data model with an R-square value of 0.9981 and had a sum-squared-error value of 0.8942, indicating a good fit.

The average coefficient of drag was also calculated for the subscale launch that occurred on December 3rd but gave invalid results. The December 3rd subscale coefficient of drag curve-fitting session gave a coefficient of drag of 0.9782. This value is being thrown out due to the sum-squared-error for this session being 62.53, much higher than the December 18th session which returned a sum-squared-error value of 0.8942. This large amount of error in the curve-fitting indicates that the model of the flight does not fit the data. This is most likely due to the fact that the December 3rd launch experienced un-damped oscillation on ascent while the December 18th launch was relatively straight with very little oscillation. These behaviors can be seen in Figure 43.

3.2.5 Conclusion

Overall, the team has gained knowledge from the subscale launches and the team will use the knowledge gained to improve the design of the full scale competition launch vehicle.

3.2.5.1 Launch Vehicle Design Changes

Flight results from the two subscale vehicle launches have demonstrated differences between flight profile simulations and the actual flight that can be mitigated. Due to the exterior geometry and mass distribution of the subscale vehicle, unexpected oscillation of the vehicle about the center of gravity occurred. Further research has indicated methods to mitigate oscillation and large angles of tilt of the vehicle, which in turn will lead to apogee altitude optimizations. By analyzing the dynamic stability of the vehicle throughout the flight, the flight characteristics of the subscale vehicle, as well as the full scale launch vehicle, can be more accurately determined. As a result, changes to the full scale launch vehicle design have been made. First, requirements have been created to ensure that the oscillation damping of the full scale launch vehicle will designed to be an acceptable amount in order to achieve an apogee altitude of 5,500 feet. More specifically, the maximum angle of tilt of the full scale vehicle will be required to be below 10 degrees, which can be found in Requirement Vehicle.1.1.3.5.

3.2.5.2 Recovery Design Changes

The primary recovery design changes involve the resizing of all parachutes based on the new drag coefficient found from the subscale data and the new X_1 force reduction factor. Both parachutes were found to be more efficient than expected, which will allow the overall recovery system to be much lighter. The X_1 factor was much larger than expected, largely due to the incorrect assumption made during PDR, the neglected factor being the incorrect mass loading term of the opening force equation that will be corrected with the new X_1 factor. Additionally, due to the instability of main phase caused by the nosecone and drogue assembly, the nosecone will be separated from the main vehicle as originally planned and detailed in PDR.

3.3 Recovery Subsystem

3.3.1 Design Overview

As discussed in PDR, the recovery of the launch vehicle will have to be staged into two primary recoverable sections in order to accommodate deployment of the multirotor payload. At apogee, the launch vehicle will separate at its midsection, and the booster section will recover separately from the upper deployment bay. Both sections feature a dual deployment from a single recovery bay in which the drogue parachute will act like a pilot parachute to deploy the main parachute. This sequence is illustrated pictorially in Figure 57.

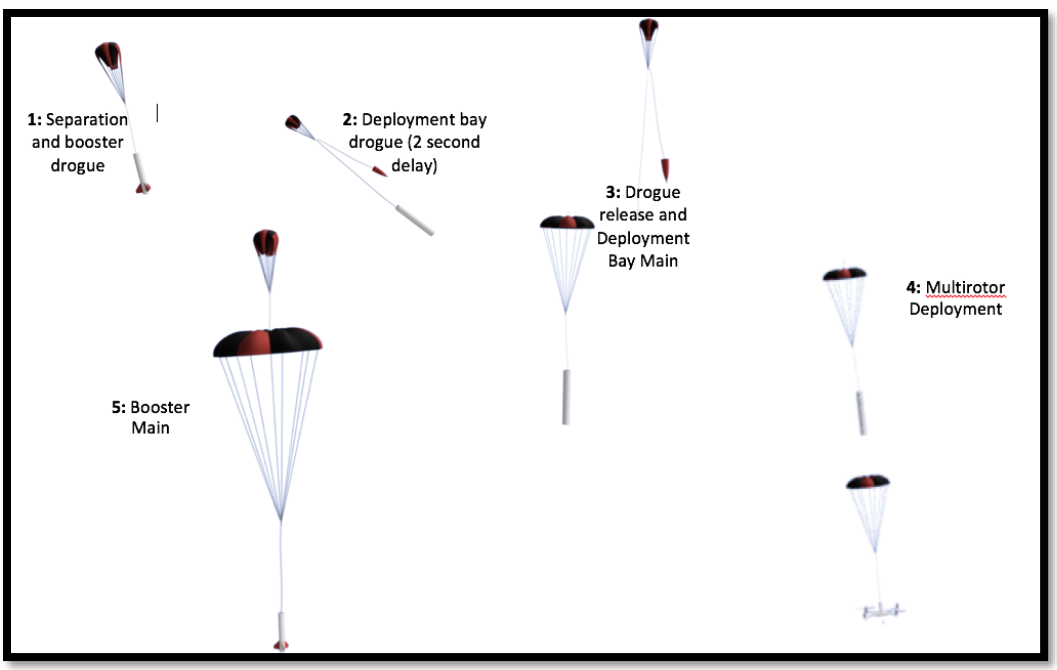


Figure 57: Illustration of recovery sequence.

The altitudes of each event are shown below in Table 18.

Event	Altitude	Phase	Description
1	5,280 ft.	Booster Drogue Event	Launch vehicle separates at the midsection of the vehicle via black powder charge and shear pin configuration. Booster section begins drogue descent.
2	5,280 ft. +2 sec. delay	Deployment Bay Drogue Event	Upper section of launch vehicle containing deployment bay separates at nose cone, beginning its drogue descent.
3	~1230 ft.	Deployment Bay Main Event	ARRD disengages deployment bay drogue shock cord, and causes main deployment.
4	~710 ft.	Multirotor Deployment	Multirotor is ejected from deployment bay via black powder charges, bringing the deployment bay under the kinetic energy requirement, and initiating deployment of the MDP
5	~600 ft	Booster Main Event	ARRD disengages booster drogue shock cord, and causes main deployment.
6*	N/A	Multirotor Abort Event	If multirotor kinetic energy exceeds 75 ft-lb during autonomous flight, multirotor reserve parachute (MRP) will deploy.

Table 18: Deployment Sequence

The pilot chute functionality of the drogue parachutes will be enabled through the utilization of Advanced Retention Release Devices (AARDs), which will release the drogue shock cord from the bulkplate via a black powder actuated piston, which ejects the metal shackle to pull the main deployment bag out of the recovery bay. The layouts for the booster and deployment bay recovery bays are shown in Figure 58.

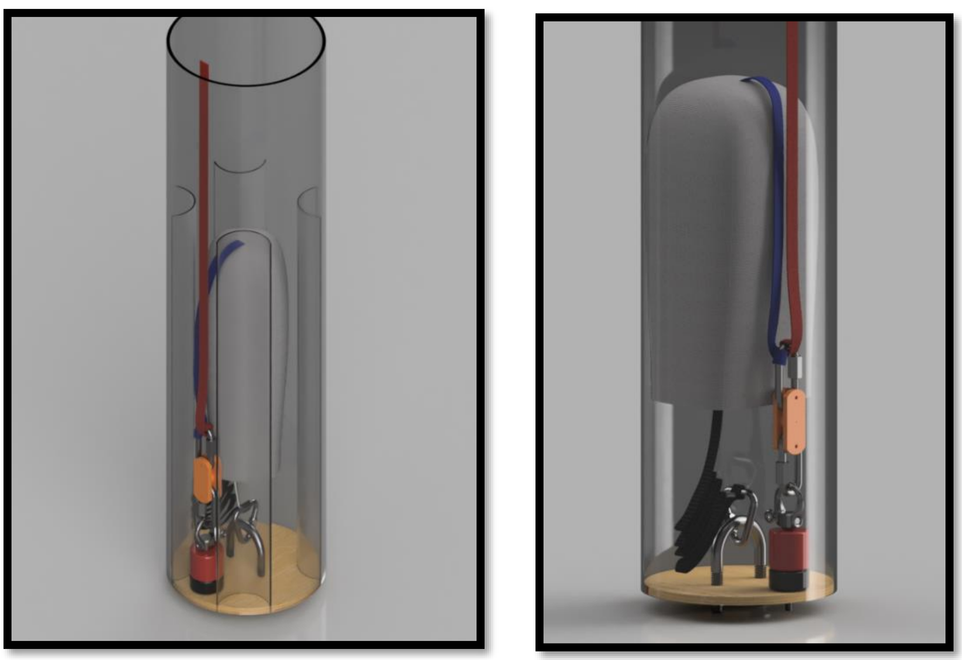


Figure 58: Transparency of booster recovery layout with payload leg sheaths (left) and deployment bay recovery layout (right) with drogue shock cord (red), deployment bag tether (blue), main shock cord (black), and ARRD and tender descender devices.

As PDR section 6.3 discusses, both primary sections will utilize a cruciform drogue and a toroidal main parachute, primarily due to their simplicity, and notably the high drag coefficient of the toroidal parachute combined with the simplicity and reliability of its geometry. For redundancy, both sections will utilize a tender descender and ARRD linked in series as seen above in Figure 58, allowing main deployment if either devices fail. Exploded views of the devices are shown below in Figure 59.

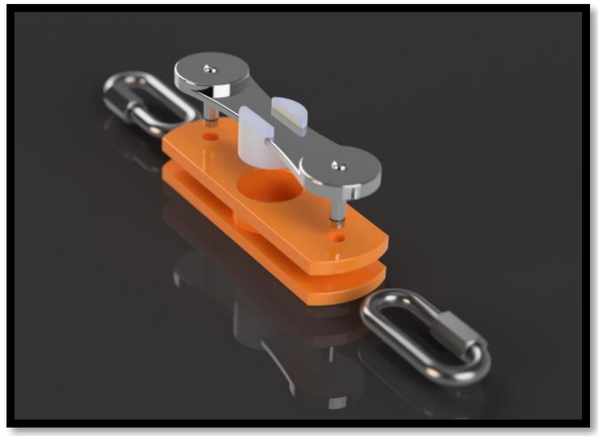



Figure 59: Exploded view of ARRD and Tender Descender

Each system will be triggered at each deployment event by a redundant set of PerfectFlite StratologgerCF's. The PerfectFlite StratologgerCF's altimeter records its altitude at a rate of 20Hz with a 0.1% accuracy. In previous testing, the altimeter was found to be accurate to ±1 foot. The StratoLogger can be configured to provide a constant serial (UART) stream (9600 baud rate ASCII characters) of the device's current altitude over ground. Each StratoLogger will be powered by an individual Duracell 9V battery. Duracell batteries have been selected due to their reliability and the feature that their leads are internally soldered.

3.3.2 Drogue

The design of the cruciform drogue parachutes has been advised by the calculated drag coefficient from the subscale flight data. The cruciform drogue for the deployment bay was sized with the constraint that after ARRD release, the retired drogue would become the nosecone main once separated, and would need to be properly sized to ensure that the nosecone's kinetic energy satisfies SOW 2.3. The nominal diameter was calculated using

$$D_o = \sqrt{\frac{4m_v m_s g}{\pi E C_d \rho}} \tag{14}$$

Where D_o is the nominal diameter of the parachute, mv is the total mass of the vehicle (or all tethered sections being recovered), m_s is the mass of the most massive section, g is gravitational acceleration, E is kinetic energy, C_d is the drag coefficient of the parachute, and ρ is the air density at sea level. In the recovery case of this specific rocket, the rocket is being recovered in 4 individual sections, ($m_v = m_s$) so this equation for each section reduces to

$$D_o = \sqrt{\frac{4m^2 g}{\pi E C_d \rho}} \tag{15}$$

This drogue size ensures that deployment bay drogue descent speed is maximized (provided that main opening forces are reasonable and the safety of the system can be guaranteed), and thus minimize drift during drogue state and maximize the deployment altitude for the multirotor. The cruciform parachute dimensions for both the booster and the deployment bay adjusted from PDR are shown below in Table 19.

Section	Section Weight (lb)	Drogue Diameter (in)
Booster	18.75	19.5
Deployment Bay (with payload)	19.624	14.0

Table 19: Section weights and drogue diameters

3.3.2.1 **Panel Geometry**

The panels of the drogue parachutes are designed with a 1:4 width to length ratio. This ratio was selected since width to length ratios greater than 1:3 for cruciform parachutes provide additional stability for high speed drogue descent. Assuming approximately spherical inflation, the necessary panel lengths can be calculated using

$$l = \pi r \tag{16}$$

Where L is the length of the panel, and r is the radius of the inflated cruciform. Dimensions of the cruciform panel geometry are shown below in Figure 60.

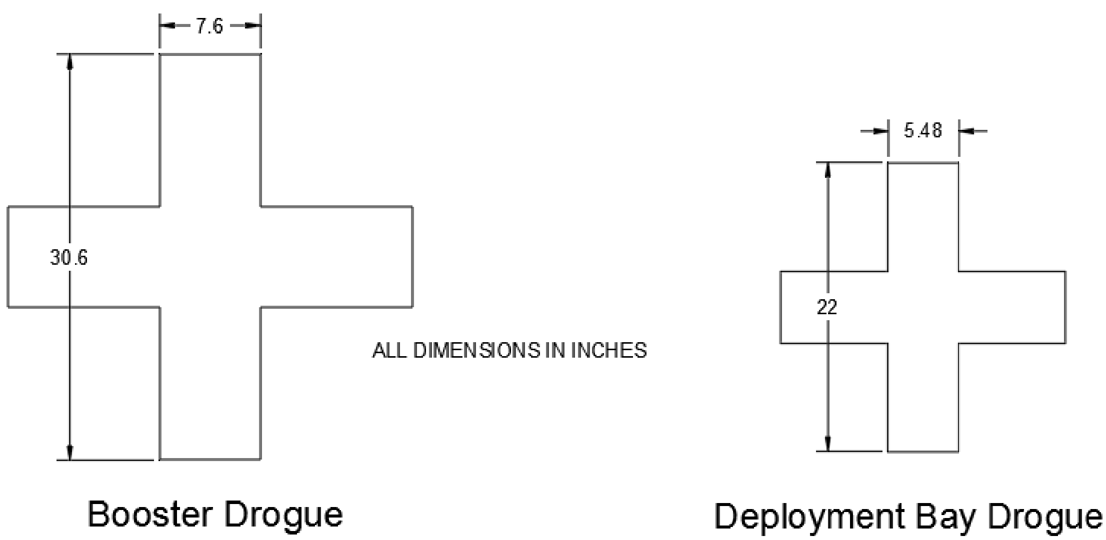


Figure 60: Drogue dimensions

The drogue will utilize 400 lb Spectra line for the shroud lines instead of the paracord used in previous years due to its similar break strength and dramatic volume savings. For these dimensions, the following rule of thumb equation was used

$$l = 1.5D_O \tag{17}$$

Where l is shroud line length, and D_o is nominal diameter. The lengths of all rigging are shown below in Table 20

Rigging	Booster Drogue	Deployment Bay Drogue
Shroud Line Length (in)	29.2	21.0
Shock Cord Length (ft)	9	9

Table 20: Drogue rigging lengths.

1 ½” length zinc plated steel quick links will be used for all drogue tethering points, and are rated for 600lbs.

3.3.3 Main

For main parachute, both sections will utilize toroidal parachutes. The toroidal parachute is a modified elliptical parachute, in which the vent is pulled down by a centerline to increase the drag coefficient of the parachute without significantly increasing material or weight. The toroidal parachute is designed to be constructed from a 0.707 ratio ellipsoid parachute, with a centerline vent pull down to increase the overall drag of the parachute. The drag profile of this parachute can be seen in Figure 61.

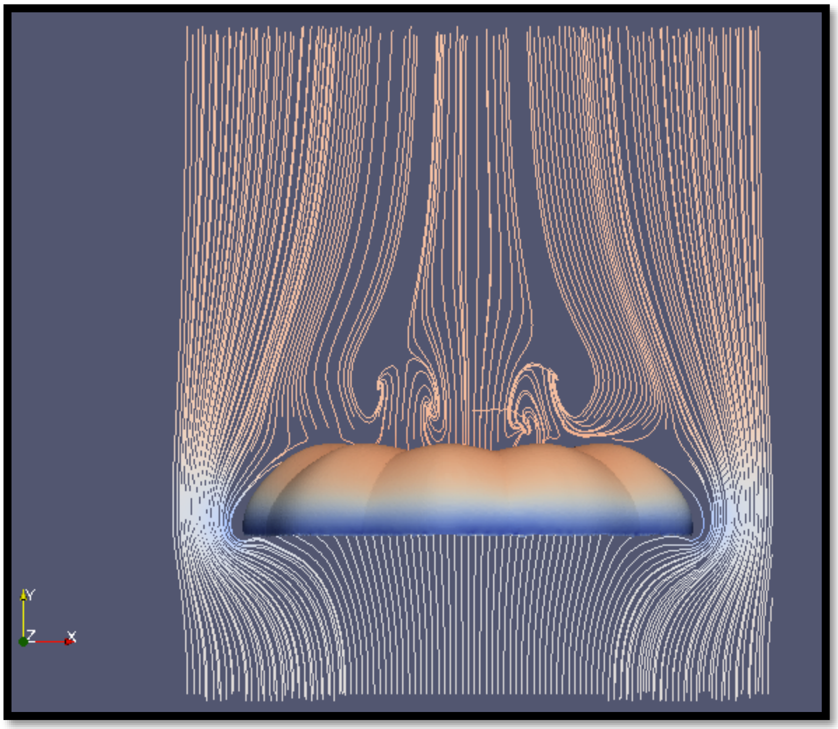


Figure 61: Drag profile of toroidal parachute.

The 0.707 ellipsoid parachute is very geometrically similar to a hemispherical parachute, but reduces canopy material without reducing effective drag area by using a minor/major axis ratio of 0.707, shown in Figure 62 below.

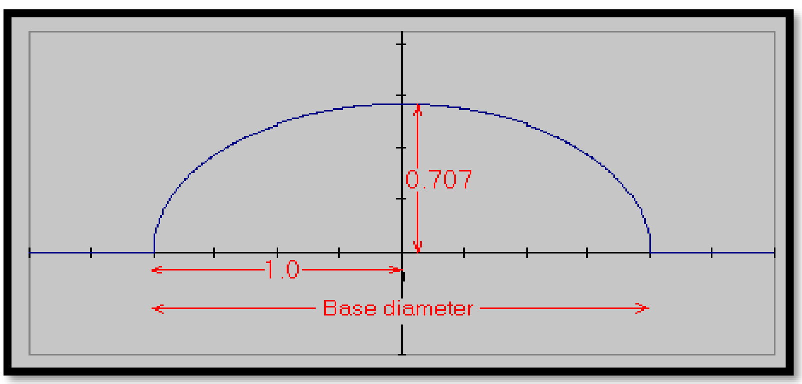


Figure 62: Ellipsoid parachute side profile

In order to solve for parachute sizes such that the empty deployment bay descends slower than the multirotor and avoids collision, we can use the following equation for steady state velocity under canopy

$$v_e = \sqrt{\frac{2m_v g}{C_d S_o \rho}} \tag{18}$$

Where v_e is terminal velocity under parachute. In order to solve for parachute sizes such that the empty deployment bay descends slower than the multirotor and avoids collision, we can use this equation to form the following inequality

$$\sqrt{\frac{2m_1 g}{C_{d1} S_{o1} \rho}} < \sqrt{\frac{2m_2 g}{C_{d2} S_{o2} \rho}} \tag{19}$$

Where the subscripts 1 and 2 denote the empty deployment bay and deployed multirotor, respectively.

From the new computed drag coefficient from the subscale flight results in section 3.2.2 the diameter for all main parachutes have been also been calculated using equation 14 and is shown below in Table 21.

Section	Section Weight (lb)	Main Diameter (inches)
Booster	18.75	89
Deployment Bay (without payload)	8.94	45

Table 21: Section weights and main parachute diameters.

The shroud lines for main were also sized using equation 16, including the smaller additional set of shroud lines used for the vent pull down. The dimensions of the main parachutes are shown below.

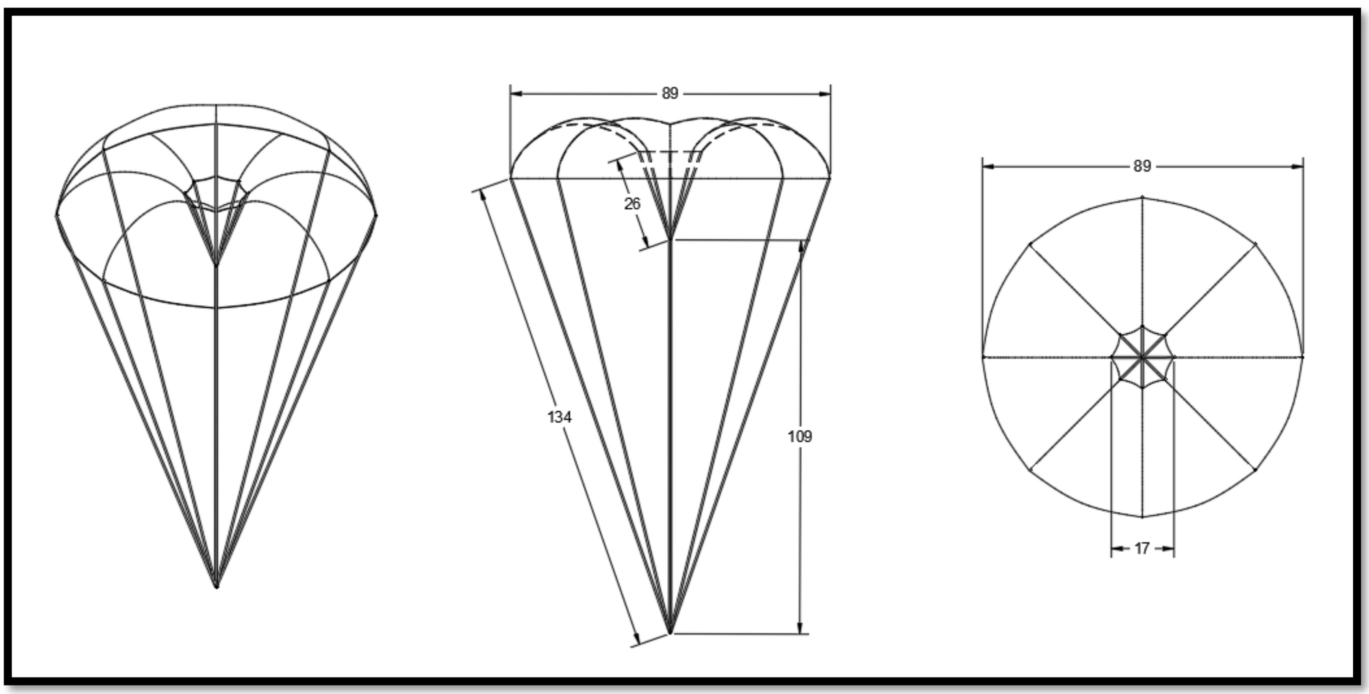


Figure 63: Booster main parachute dimensions

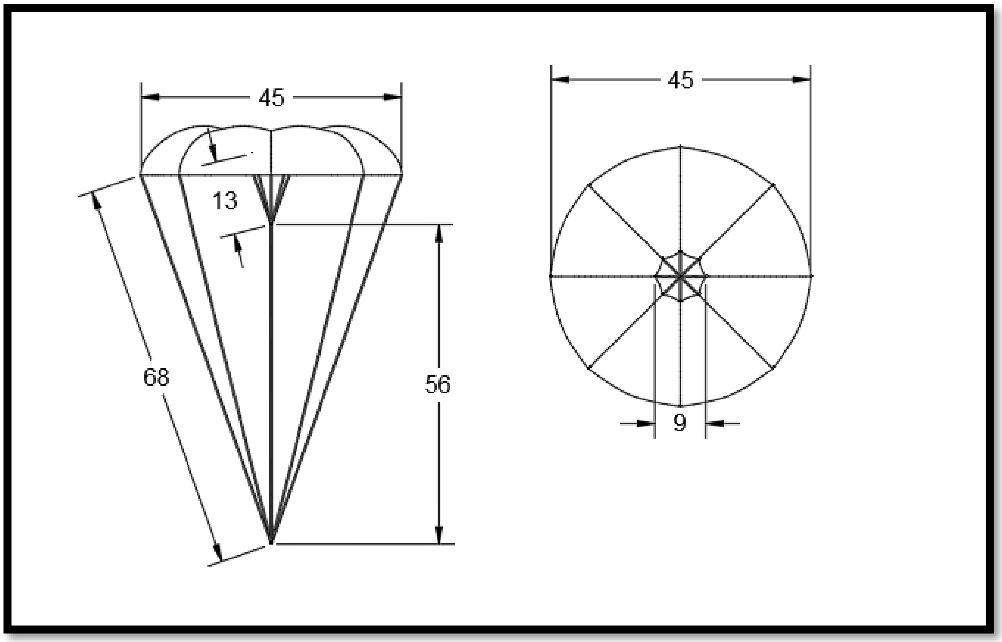


Figure 64: Dimensions of deployment bay main

The rigging for the main parachutes is detailed below in Table 22.

Component	Rigging	Break Strength (lb)	Booster Main Length	Deployment Bay Main Length
Outer Shroud Lines	Spectra Lines	400	134 in	68 in
Inner Shroud Lines	Spectra Lines	400	26 in	13 in
Centerline	Paracord	400	109 in	56 in
Shock Cord	3/8" Nylon	1400	18 ft	18 ft

Table 22: Rigging for main parachutes.

5/16" zinc plated steel quick links, rated for 1200lbs, will be used to tether main to the bulkplates to provide a wide attachment point for the 3/8" flat nylon shock cord.

3.3.3.1 **Panel Geometry**

The canopies themselves will be constructed from 8 individual ripstop nylon panels. These panels are similar to polyconical panels for a hemispherical canopy, but are shaped to fit the .707 width to height ratio elliptical parachute. The geometry for both main parachutes are shown below in Figure 65.

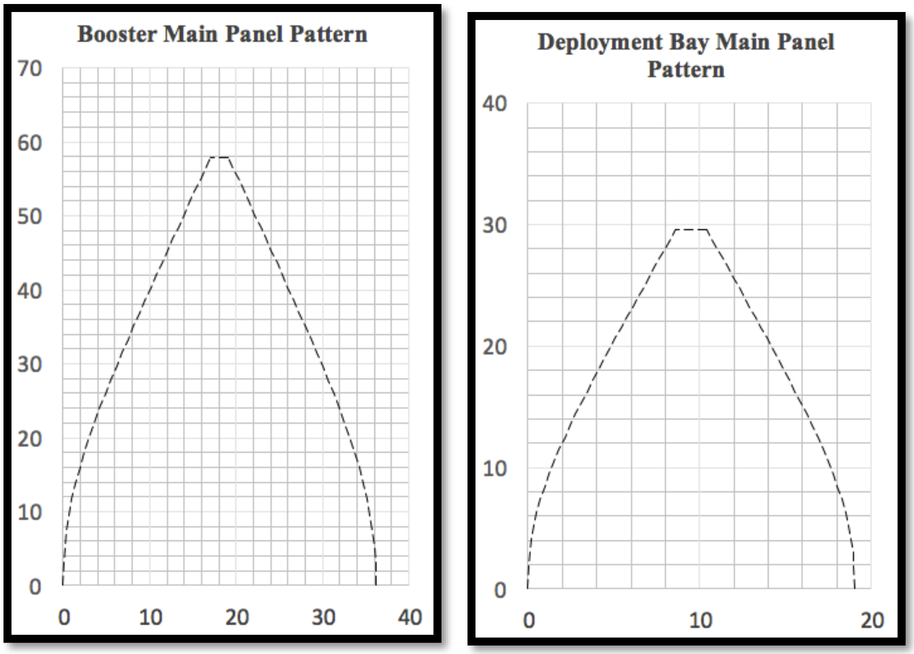


Figure 65: Main parachute panel geometries. Axes in inches. (Note: Not to scale)

Parachute Materials

The canopy of the parachutes will be made of 1.1 oz. rip stop nylon. The team has a history of using rip stop due its high strength-to-weight ratio, derived from the crosshatching of reinforcing fiber, which prevents tears from propagating through the fabric.

Each panel hem will be constructed by folding over the material two times. This will help prevent the material from fraying. The hem fold and stitch pattern are shown in Figure 66.

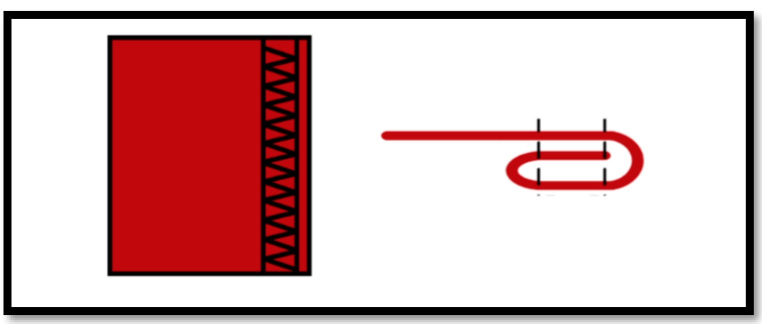


Figure 66: Hemming pattern

At the eight connection points between panels on the inner and outer diameter of the parachute, each shroud line will be connected by folding the shroud line into the hem and stitching over it twice.

Custom deployment bags for each main parachute, shown below, will be constructed out of canvas with integrated line stow loops to ensure that deployment is clean.

Figure 67: Deployment bag and line stows from 2015-2016 season.

3.4 Mission Performance Predictions

3.4.1 Applicable Formulations

Three core values must be calculated to assess the stability and success of the rocket: peak altitude, center of gravity, and center of pressure. The peak altitude is found through a precise sequence of equations. The average mass, m_a, is first calculated using

$$m_a = m_r + m_e - \frac{m_p}{2} \tag{20}$$

where m_r is the rocket mass, m_e is the motor mass, and m_p is the propellant mass. The aerodynamic drag coefficient (kg/m) is then computed by

$$k = \frac{1}{2}\rho C_D A \tag{21}$$

where ρ is the air density (1.22 kg/m^3), C_D is the drag coefficient, and A is the rocket cross-sectional area (m^2). Equations 20 and 21 are utilized to calculate the burnout velocity coefficient (m/s) using

$$q_1 = \sqrt{\frac{T - m_a g}{k}} \tag{22}$$

where T is the motor thrust, and g is the gravitational constant (9.81 m/s^2). Equations 20, 21, and 21 are then used to compute the burnout velocity decay coefficient (1/s) using

$$x_1 = \frac{2kq_1}{m_a} \tag{23}$$

Equations 22 and 23 are used to calculate the burnout velocity (m/s) using

$$v_1 = q_1 \frac{1 - e^{-x_1 t}}{1 + e^{-x_1 t}} \tag{24}$$

where t is motor burnout time (s). The altitude at burnout can then be computed by

$$y_1 = \frac{-m_a}{2k} \ln\left(\frac{T - m_a g - k v_1^2}{T - m_a g}\right) \quad (25)$$

Once the burnout altitude is calculated, the coasting distance must be determined beginning with the calculation of the coasting mass using

$$m_c = m_r + m_e - m_p \quad (26)$$

The coasting mass replaces the average mass in equations 22 and 23; this results in equations 27 and 28 for the coasting velocity coefficient and coasting velocity decay coefficient, respectively:

$$q_c = \sqrt{\frac{T - m_c g}{k}} \quad (27)$$

$$x_c = \frac{2 k q_c}{m_c} \quad (28)$$

Equations 27 and 28 can then be utilized to determine the coasting velocity (m/s) using

$$v_c = q_c \frac{1 - e^{-x_c t}}{1 + e^{-x_c t}} \quad (29)$$

The coasting distance can then be computed using

$$y_c = \frac{m_c}{2k} \ln\left(\frac{m_c g + k v^2}{T - m_c g}\right) \quad (30)$$

The peak altitude is then determined using

$$PA = y_1 + y_c \quad (31)$$

The center of gravity location is calculated using

$$cg = \frac{d_n w_n + d_r w_r + d_b w_b + d_e w_e + d_f w_f}{W} \quad (32)$$

where W is the total weight, d is the distance between the denoted rocket section center of gravity (nose, rocket, body, engine, and fins, respectively) and the aft end. The center of pressure measured from the nose tip is calculated using

$$X = \frac{(C_N)_N X_N + (C_N)_F X_F}{(C_N)_N + (C_N)_F} \quad (33)$$

where C_{NN} is the nose cone center of pressure coefficient (2 for conical nose cones), X_N is the computed by

$$X_N = \frac{2}{3} L_N \quad (34)$$

where L_N is the nose cone length. C_{NF} in equation 33 is the fin center of pressure coefficient calculated using

$$(C_N)_F = \left[1 + \frac{R}{S + R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}}\right] \quad (35)$$

where R is the radius of the body at the aft end, S is the fin semispan, N is the number of fins, L_F is the length of the fin mid-chord line, C_R is the fin root chord length, and C_T is the fin tip chord length. X_F in equation 33 is calculated using

$$X_F = X_B + \frac{X_R(C_R + 2C_T)}{3(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right] \quad (36)$$

where X_B is the distance from the nose tip to the fin root chord leading edge. X_R is the distance between the fin root leading edge and the fin tip leading edge measured parallel to body. Equations 33 through 36 are also known as the Barrowman Equations (The Theoretical Prediction of the Center of Pressure, 1966). Note that Equation 33 is a simplified form because the rocket has no transition in diameter in the body; thus, the transitional terms have been omitted. These equations are used to verify the OpenRocket simulation conducted of the full scale launch vehicle.

The calculated center of gravity and center of pressure location measured from the tip of the nose cone is shown below in Table 23.

Center of Gravity (in)	Center of Pressure (in)
94.1	114.9

Table 23: Center of gravity and center of pressure locations.

3.4.2 Flight Simulations

Flight simulations for the 2016-2017 launch vehicle have been performed in both the OpenRocket software and a custom Simulink simulation to account for the VDS. OpenRocket was used to predict how well the vehicle would be able to reach its 'no-brakes-target' of 5,500 ft. AGL. The VDS simulation was used to predict how well the VDS would be able to reduce the apogee of the vehicle from 5,500 ft. to 5,280 ft.

3.4.2.1 OpenRocket Simulation

Using the OpenRocket software, mass measurements from previous years and component material densities were using to calculate the overall mass of the launch vehicle. An OpenRocket model of the full scale launch vehicle was created to verify Equations 20 through 36 as well as determine the overall flight characteristics. The specifications of the Open Rocket Simulation of the launch vehicle are shown in Table 24.

Average Center of Gravity Location (in from nose)	94.15
Average Center of Pressure Location (in from nose)	114.029
Rail exit velocity with 12 foot rail (ft/s)	97.6
Max. acceleration (ft/s2)	469
Predicted apogee altitude (ft)	5561
Thrust to weight ratio	14.65

Table 24: Launch vehicle flight specifications.

The launch vehicle will include three clipped delta fins. The clipped delta fin shape was chosen due to its efficiency and durability. Three fins were chosen rather than four to accommodate the VDS system to allow even airflow over all three fins. The drag blades of the VDS are offset by 60 degrees relative to the fins. One concern the team faced during the integration of the launch vehicle with the VDS was disruption of airflow around the fins during flight. At 700 ft/s, which is an approximation for the burnout velocity of the launch vehicle, a CFD and validates that the turbulent air flow from the drag blades do not interfere with the air flow over the fins, as shown in Figure 68 below.

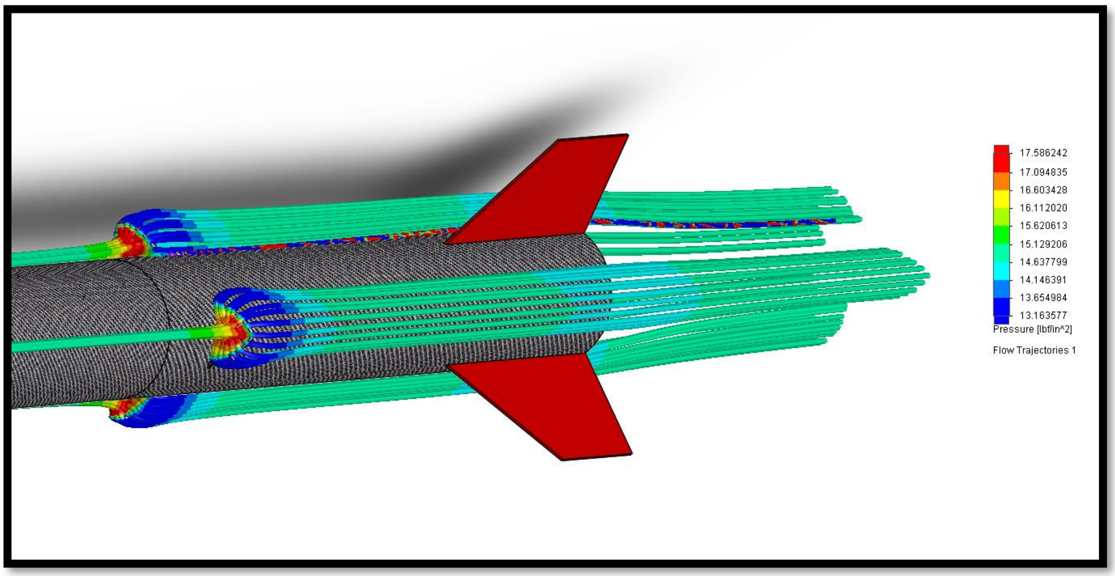


Figure 68: VDS air flow CFD simulation results.

As eluded to in the VDS Section, the launch vehicle will aim for an apogee altitude higher than 5280 ft in order to account for variances in launch condition. The launch vehicle will be designed to reach an apogee altitude of approximately 5,500 ft to provide a 100 ft buffer for the penalty associated with an apogee altitude of 5,600 ft in case the VDS does not deploy.

An OpenRocket model, which is shown below in Figure 69, was created to verify Equations 1 through 17, which calculate the location of the center of gravity, location of the center of pressure, and apogee altitude of the launch vehicle.

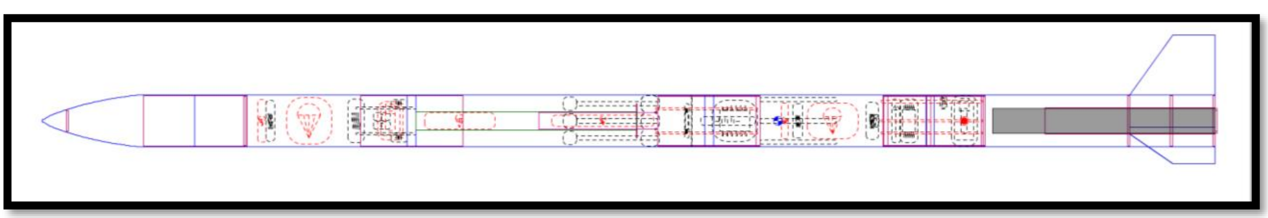


Figure 69: OpenRocket full scale launch vehicle configuration.

The following plots shown in Figure 70 through Figure 73 display various simulation results without any VDS involvement, indicating proper motor selection and vehicle stability.

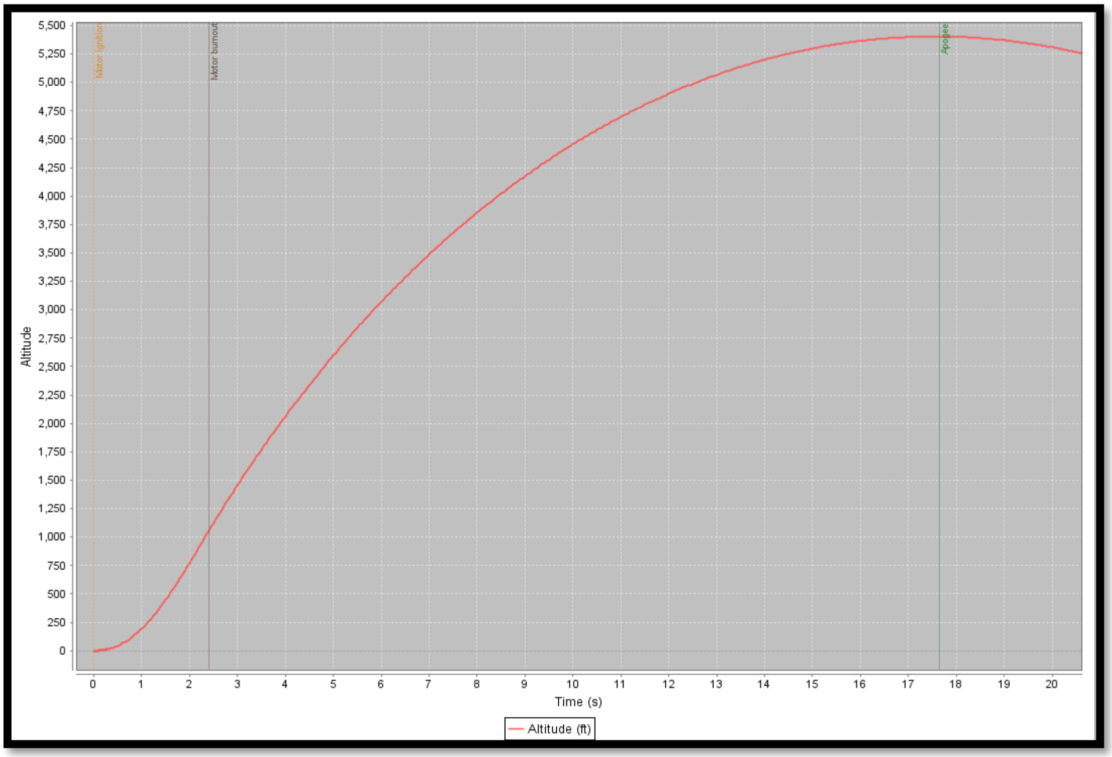


Figure 70: Altitude vs time without VDS.

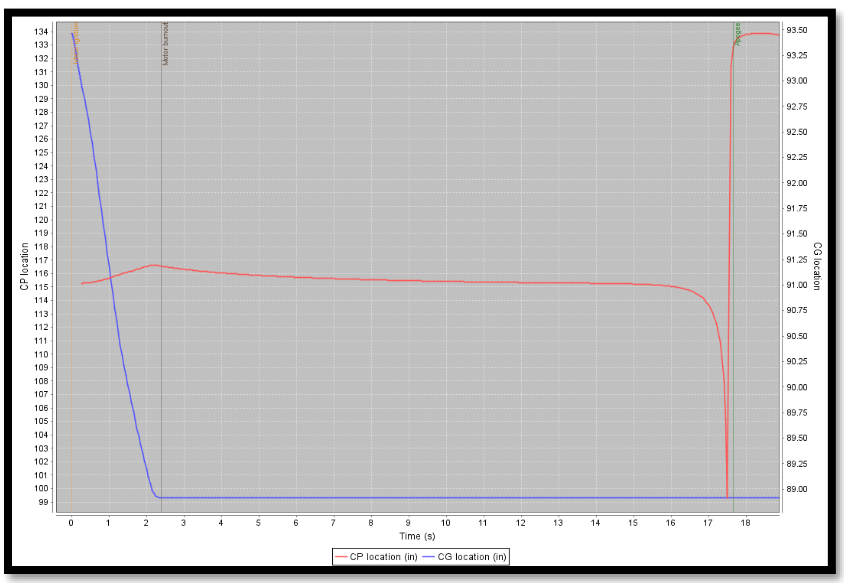


Figure 71: A plot of CG and CP locations versus time.

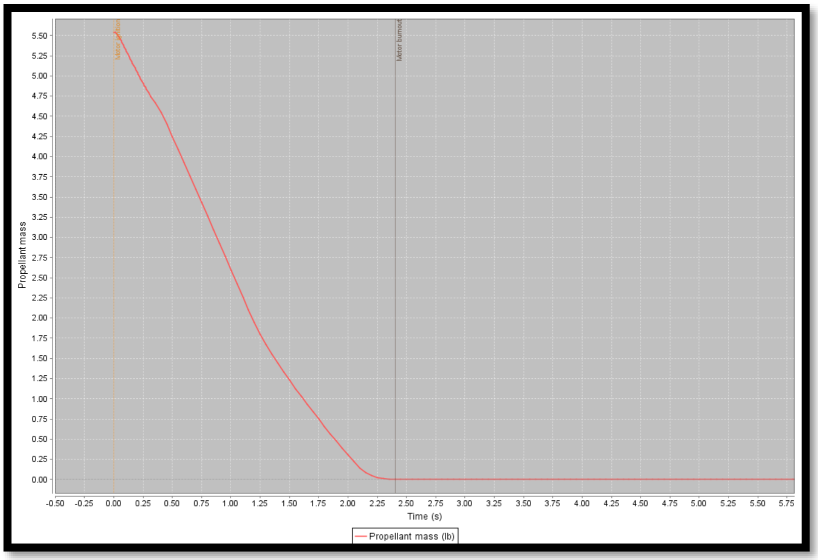


Figure 72: Propellant mass versus time.

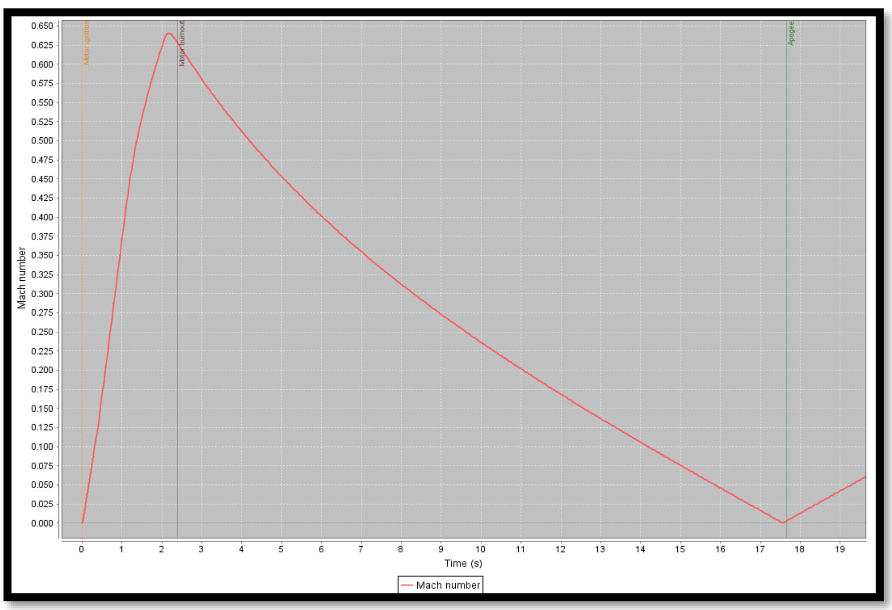


Figure 73 Mach number versus time.

3.4.2.2 **VDS Simulation**

Because OpenRocket is only capable of simulating the flights of standard rockets, the team has developed its own simulation to provide mission performance predictions for the vehicle with the VDS system. This simulation incorporates the kinematics of vehicle ascent, the responses of the control scheme, and the mechanics of the VDS's actuators. This simulation has been used to predict flight performance, tune controls parameters, and derive performance requirements. The Mathworks Simulink blocks for the simulation are shown below in Figure 74.

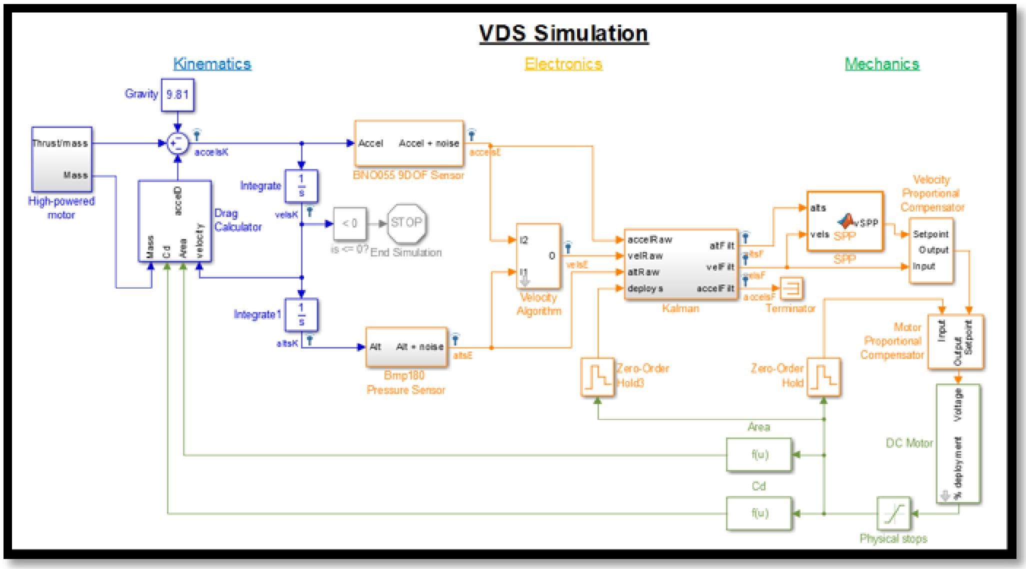


Figure 74: VDS simulation Simulink blocks.

The simulated flight for the full scale vehicle with the VDS installed is shown below in Figure 75.

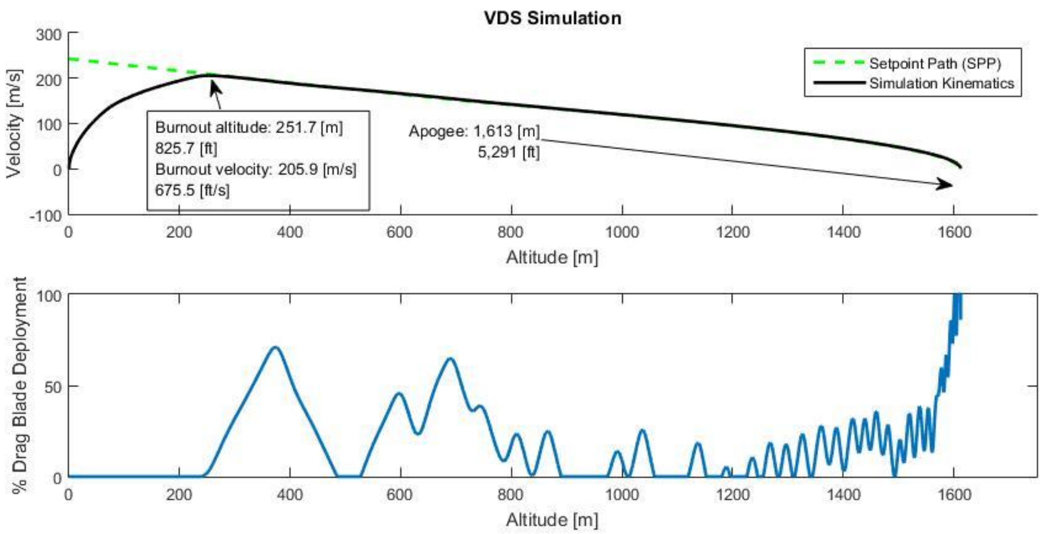


Figure 75: VDS simulation of full scale vehicle.

The VDS simulation returned an apogee value of 5,291 ft. which is within the +/- 33 ft. stipulation.

3.4.2.2.1 Simulation of Kalman Filter

The VDS simulation incorporates an exact model of the VDS Electronics and its software. This includes the Kalman Filter that is used to reduce the noise of incoming signals from the sensors. An exact model of this Kalman Filter has been developed and has been used to tune its parameters and gauge its effectiveness. The Simulink blocks for the Kalman Filter model are shown below in Figure 76.

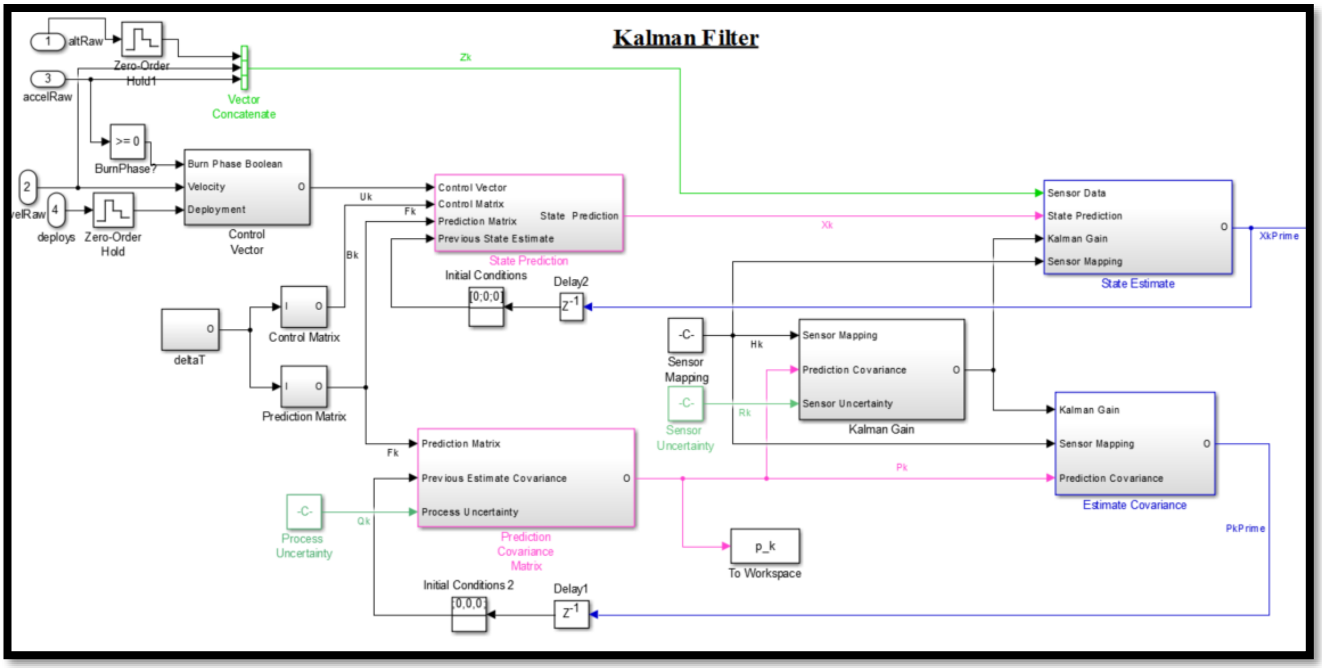


Figure 76: VDS simulation model of Kalman Filter.

This model is an exact replica of the logic in the VDS Electronics software and has been used to predict its effectiveness and tune its parameters. A sample output of the Kalman Filter reducing noise on the acceleration signal can be seen below in Figure 77.

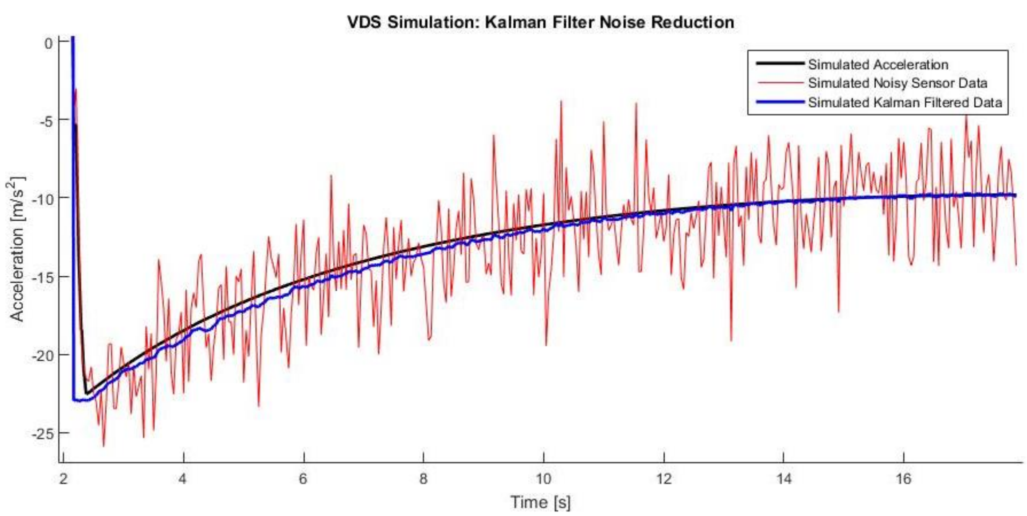


Figure 77: VDS simulation Kalman Filter noise reduction example.

The Kalman filter in the simulation can be seen to greatly reduce the noise on the simulated accelerometer. While this simulation does demonstrate the potential for the Kalman filter to reduce noise on signals, demonstrating the Kalman filter in simulation is limited in that the Kalman filter uses a similar flight model to the simulation to predict flight behavior. The Kalman filter will have to be tested in flight to determine its true effectiveness. See Sensor Fidelity Test.

3.4.3 Center of Pressure Analysis

While the Barrowman Equations were able to determine the average center of pressure location of the launch vehicle during the entire flight, the specific location of the center of pressure of the launch vehicle at the point of rail exit could not be determined by hand calculations. In order to verify the center of pressure location of the full scale launch vehicle at the point of rail exit from the OpenRocket simulation, a CFD simulation was set up. The exact location of the center of pressure of the launch vehicle at rail exit is imperative to the stability and safety of the ascent of the launch vehicle.

The first CFD simulation was performed to verify the center of pressure location of the launch vehicle at rail exit in order to verify that the rail exit stability of the launch vehicle was higher than 2.2. Input parameters of the CFD simulation are shown below in Table 25.

Airflow Velocity (ft/s)	96.8
Angle of Attack (degrees)	0
Fluid Density (kg/m^3)	1.27
Fluid Temperature (°F)	68

Table 25: CFD simulation input parameters.

The location of the center of pressure was determined by establishing a coordinate system at the tip of the nose of the launch vehicle so that the z direction was in the forward axial direction of the launch vehicle. The coordinate system location relative to the launch vehicle is shown below in Figure 78.

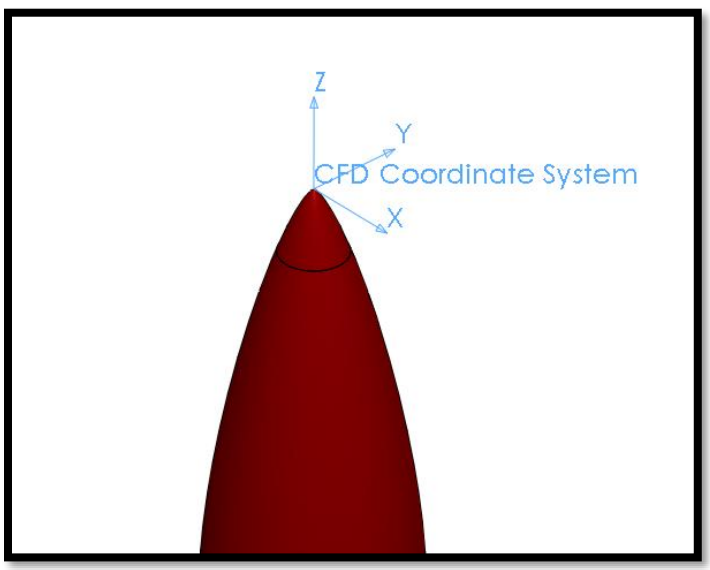


Figure 78: CFD simulation coordinate system.

The CFD simulation was created so that the airflow was in the z direction relative to the coordinate system, which assumes an angle attack value of zero. 185 iterations were completed with the simulation goals of calculating the force in the y direction and the moment about the x axis at the point location of the coordinate system. The center of pressure location relative to the aft end of the launch vehicle was computed by dividing the moment about the x axis and force in the z direction for each iteration of the simulation. The surface pressure results from the simulation are shown below in Figure 79.

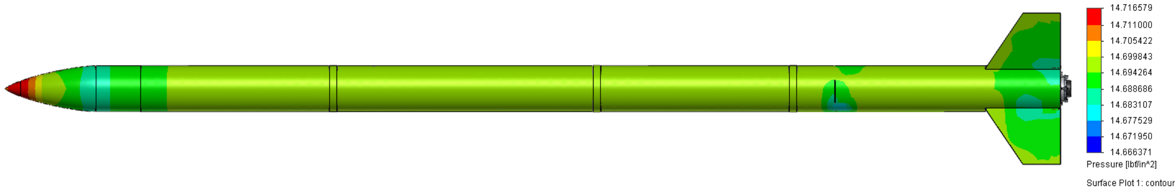


Figure 79: CFD simulation surface pressure results.

The average center of pressure location of the launch vehicle was computed for every completed iteration. The center of pressure location results from the CFD simulation compared to the OpenRocket simulation is shown below in Table 26.

Center of Pressure Location at Rail Exit Measured from Nose Cone Tip (in)	
OpenRocket Simulation	CFD Simulation
115.3	117.6

Table 26: OpenRocket and CFD simulation results comparison.

A percent error of 1.87% between the center of pressure locations of the launch vehicle of the OpenRocket and CFD simulations was found. The center of pressure location of the launch vehicle for the CFD simulation provided a higher stability value than the OpenRocket Simulation, indicating that the actual exit rail stability of the launch vehicle will be higher than the minimum of 2.2 that the team requires.

3.4.4 Fin Flutter Analysis

The velocity at which the fins will flutter, V_f, was estimated using

$$V_f = 1.223 C_s \sqrt{\frac{G(2+\frac{b^2}{S})}{P(1+\frac{c_t}{c_r})}\left(\frac{St}{b^2 c_r}\right)^3} \tag{35}$$

where C_s is the speed of sound considering changes in altitude, G is the shear modulus of the material of the fins, b is the height of each fin, b is the area of fin shape, P is the air pressure considering changes in altitude, c_t is the tip chord of the fin shape, c_r is the root chord of the fin shape, and t is the thickness of the fin. The flutter boundary velocity was calculated at motor burnout assuming a ground level temperature of 90 degrees Fahrenheit and a pressure of 14.7 psi. A graph of fin flutter boundary velocity vs fin thickness is shown below in Figure 80.

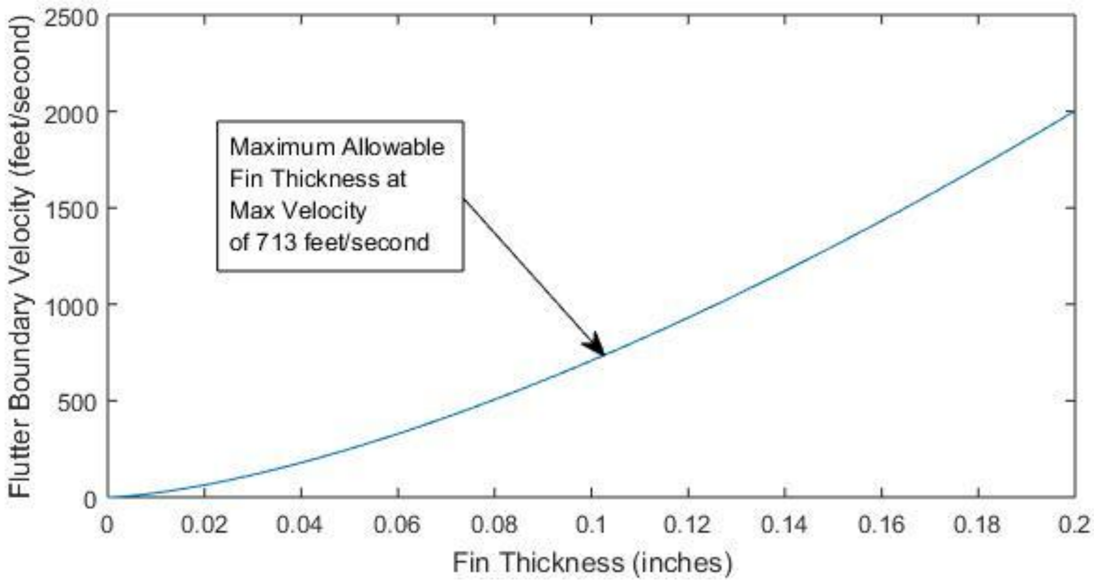


Figure 80: Fin Flutter Velocity vs Fin Thickness

The fin thickness at which fin flutter would start to occur at 713 ft/s assuming a fin material of a 0/90 degree carbon fiber layup was determined to be .1005 inches. In order to add an additional safety factor as well as comply with available carbon fiber sheet thicknesses, the team decided to utilize a thickness of 0.125 inch. In order to verify the fin flutter calculation and determine the velocity of aero-elastic divergence failure of the fins, AeroRocket FinSim was utilized. The results from the FinSim simulation using 0.125 inch carbon fiber material for the fins is shown below in Figure 81.

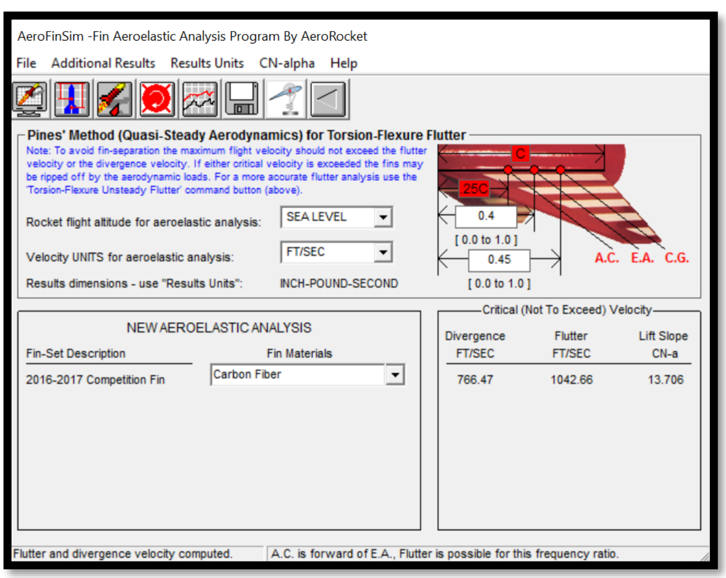


Figure 81: FinSim simulation results

The results from the FinSim[2] simulation showed that the divergence and flutter velocity were both above the maximum velocity of the launch vehicle, indicating that the fins will not fail.

3.4.5 Component Weights

In order to accurately predict the flight characteristics of the launch vehicle, the masses of every component on the launch vehicle must be known. By using CAD modeling of components and knowledge gained from the past years, every sub-system has been assigned a predicted mass within the launch vehicle. A breakdown of the weight of every sub system on the full scale launch vehicle is shown below in Figure 82.

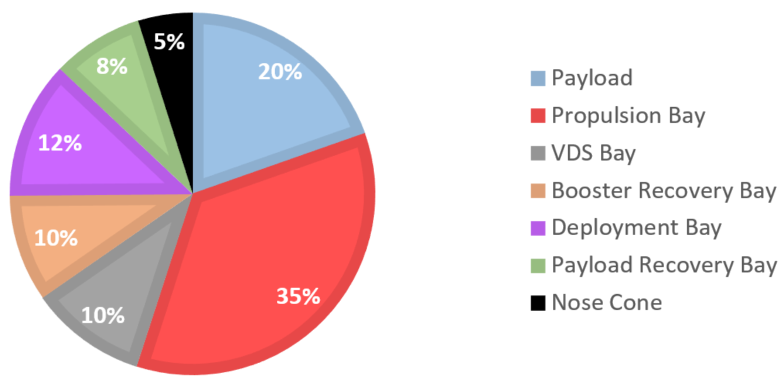


Figure 82: Launch vehicle sub-system weight breakdown.

A detailed list of the weight of every sub system along with the length of each subsystem is shown below in Figure 83.

Section of launch vehicle	Length of section (in)	Weight (lbs)
Nose Cone Section	12	2.106
Payload Recovery Bay	25	3.57
Deployment Bay	34	5.37
Payload Section	12	8.61
Booster Recovery Bay	25	4.21
VDS Bay	12	4.543
Propulsion Bay with Motor	34	15.545
Total	**140**	**43.954**

Figure 83: Length and weight per section of launch vehicle.

[2] reference: https://www.apogeerockets.com/education/downloads/Newsletter411.pdf

A more detailed list of all major components and their corresponding masses within each major sub-system of the full scale launch vehicle is shown below in Table 27 through Table 32.

Component	**Mass (lbm)**
Centering Rings	0.656
Fin Retainer	0.219
Motor Retainer	0.054
Motor (loaded)	10.5
10-32 Shoulder Bolts (x6)	0.102
Motor Mount	0.461
Epoxy	0.547
Airframe	1.557
Fins (x3)	1.447
Total Mass	15.545

Table 27: Propulsion bay component masses.

Component	**Weight (lbm)**
Drag Blades (x3)	0.2283
Central Gear	0.00621
AndyMark NeveRest 40 Motor	0.750
Delrin Acetal Resin Bearing Plates (x2)	0.25049
Aluminum Support Plates (x2)	0.20443
10-32 All Thread (x6)	0.0932376
10-32 Hex Nuts (x21)	0.02495
10-32 Washers (x21)	0.005799
VDS Electronics Sled	0.265
Altimeter Sled	0.11804
PerfectFlite Stratologger CF altimeters (x2)	0.0475
Duracell 9 Volt Batteries (x2)	0.099208
Eggfinder GPS Tracking Device	0.0440925
VDS electronics	0.90
Bulkplate	0.3534
U-Bolt	0.2336875
3/8” Hex Nuts (x2)	0.038
Terminal Blocks	0.0998694
4-40 Shear Pins (x3)	0.0003
6-32 SCHS (x3)	0.0100
Coupler Tube	0.460
Epoxy	0.310
Shear Pin Brace	0.050
Limit Switches (x2)	0.0044
GoPro Hero4 Silver Camera	0.335103
Camera Mount	0.123
Sealing Bulkplate	0.3343
VDS Sled Lid	0.05340
Total Mass	4.543

Table 28: VDS bay component masses.

Component	**Mass (lbm)**
Airframe	0.9503

Shock Cord	0.4
ARRD	0.25
Tender Descender	.11
Quick Links	1.45
Main Parachute	0.82
Drogue Parachute	0.05
Shroud Lines	0.32
Total Mass	4.32

Table 29: Booster recovery bay component masses.

Component	Mass (lbm)
Airframe	0.9503
Shock Cord	0.4
ARRD	0.25
Tender Descender	.11
Quick Links	1.45
Main Parachute	0.27
Drogue Parachute	0.05
Shroud Lines	0.2
Total Mass	3.68

Table 30: Payload recovery bay component masses.

Component	Mass (lbm)
Coupler Tube	0.46
Bulkplate	0.3534
U-Bolt	0.2336875
Baffel Bulkplate	0.332
Baffels (x4)	1.505
Deployment Bay Airframe	1.292
Payload Deployment Tube	0.36
Altimeter Sled	0.11804
PerfectFlite Stratologger CF Altimeters (x2)	0.0475
Duracell 9 Volt Batteries (x2)	0.099208
Sealing Bulkplate	0.44
¼ - 20 SCHS 1 inch (x4)	0.134
Total Mass	5.375

Table 31: Deployment bay component masses.

Component	Mass (lbm)
Nose Cone Tip	0.2059
Nose Cone Base	0.6592
Coupler Tube	0.46
U-bolt	0.2336875
Bulkplate	0.3532
Epoxy	0.15
Eggfinder	0.0440925
Total Mass	2.106

Table 32: Nose cone component masses.

Component	Mass (lbm)

MRS	4.70
RRS	1.05
PSS	0.75
LLS	0.50
Epoxy	0.50
Flight Electronics Sled	0.61
Fasteners	0.50
Total Mass	8.61

Table 33: Payload component masses.

3.4.6 Motor Selection

Several OpenRocket simulations were conducted with different motor configurations in order to choose the motor that produced an appropriate apogee altitude. Simulations were conducted for motors ranging from 4600 Newton-seconds to 5120 Newton-seconds, which is the maximum total impulse for a motor set forth by the Statement of Work. Table 34 below shows the combination of every available motor and the corresponding loaded launch vehicle weight that results in an apogee altitude of 5,500 feet.

Motor	Overall Launch Vehicle Weight (lbs)
Aerotech L1420	37.9
AeroTech L952	42.8
AeroTch 2500	38.4
AeroTech L1365	40.0
Cesaroni L3150	40.3
Cesaroni L1410	40.6
Cesaroni L610	39.9
Cesaroni L2375	41.6
Cesaroni L1395	41.3
Cesaroni L1115	42.8
Cesaroni L1685	44.7
AeroTech L1500	43.2
AeroTech L2200	44.5

Table 34: Motor and weight combination required to achieve apogee altitude of 5,500 feet.

The motor choice has been made with consideration of motor availability and the maximum allowable weight to reach approximately 5,500 feet. Due to the mass of the payload and desired apogee altitude of the VDS, the full scale launch vehicle will utilize the Aerotech L2200 Mojave Green motor. This motor was chosen due to its desired total impulse, brand reliability, and availability. With this motor, the launch vehicle will reach an estimated apogee altitude of 5561 feet. This apogee altitude was chosen to utilize the VDS, which will deploy the drag blades to decrease the apogee altitude to 5280 feet. The thrust vs time curve and the specifications of the Aerotech L2200 Mojave Green motor can be seen blow in Figure 84 and Table 35, respectively.

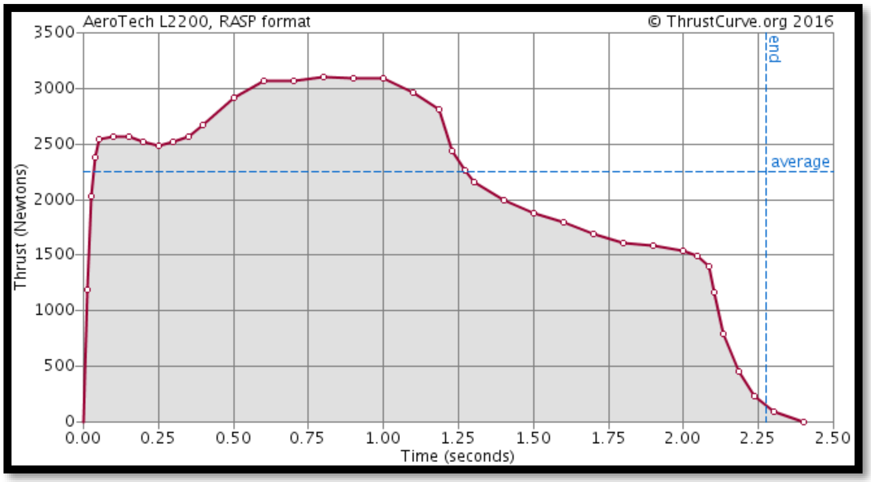


Figure 84: Aerotech 2200G Thrust Curve.

Diameter	75.0 mm
Total Weight	167.59 oz
Propellant Weight	88.75 oz
Average Thrust	2200.0 N
Maximum Thrust	3101.8 N
Total Impulse	5104.1 N-sec
Burn Time	2.3 sec

Table 35: Aerotech L2200 Mojave Green Specifications.

3.4.7 Recovery

3.4.7.1 Drift

Drift values from the launch point can be easily calculated for each section via simple vector addition, provided the simplifying assumptions are made that each section moves at nearly the speed of the influencing crosswind, and that the vehicle follows a perfectly vertical ascent path. These values are detailed in the table below. Gray boxes represent items tethered or otherwise coupled in drogue phase. Termination of the gray box represents main event.

Predicted Drift Values						
Crosswind Velocity (mph)	Section	Descent Duration (s)		Drift (ft)		Total Drift (ft)
		Drogue	Main	Drogue	Main	
0	Booster	47.1	38.7	0		0
	Nose Cone	28.5	27.0			
	Deployment Bay	28.5	61.0			
	Multirotor (off-nominal descent)	28.5	31.6			
5	Booster			345	284	629
	Nose Cone			209	198	407
	Deployment Bay				447	656
	Multirotor (off-nominal descent)				232	441
10	Booster			691	568	1258
	Nose Cone			418	395	814
	Deployment Bay				894	1313
	Multirotor (off-nominal descent)				463	881
15	Booster			1036	851	1887
	Nose Cone			628	593	1221
	Deployment Bay				1342	1969
	Multirotor (off-nominal descent)				695	1322
20	Booster			1381	1135	2517
	Nose Cone			837	791	1627
	Deployment Bay				1789	2626
	Multirotor (off-nominal descent)				926	1763

Table 36: Drift values

3.4.7.2 **Kinetic Energy**

Using equation 18 for terminal velocity and the following equation for kinetic energy

$$KE = \frac{1}{2}mv^2 \quad (36)$$

The terminal velocities of each section and their kinetic energies at landing were calculated and are shown along with parachute diameter D_O and v_e in Table 37.

Main Descent Phase				
Section of Rocket	Mass (lb_m)	D_o (ft)	V_e (ft/s)	E (ft·lb)
Nose Cone	2.1	1.2	45.7	69.9
Booster	18.7	7.4	15.3	69.9
Deployment Bay (loaded)	17.5	3.8	28.2	223.4
Deployment Bay (unloaded)	8.9		20.1	58.1
Multirotor	8.6	3.4	22.5	69.9

Table 37: Kinetic energy of sections upon landing

3.4.7.3 **Opening Force**

From the subscale flight data in section 3.2.2, a more accurate opening force for main can be found. Opening force is described in the equation below

$$F_x = \frac{(C_D S)_o \rho v^2 C_x X_1}{2} \quad (37)$$

Where C_dS_o is the drag area of the fully open parachute, v is the velocity at parachute deployment, C_x is the opening force coefficient (dimensionless), and X1 is the force reduction factor (dimensionless).

The new X_1 force reduction factor can be calculated by rearranging the equation to form the following equation

$$X_1 = \frac{2F_x}{(C_D S)_o \rho v^2 C_x} \tag{38}$$

The new X_1 was calculated to be 0.289 from the subscale test data and has been used to recalculate all opening forces shown below in Table 38.

Opening Forces						
Event	Velocity At Opening (ft/s)	C_x	X_1	F_x (lb_f)	Affected Linkage Component	Linkage Component Break Strength (lb_f)
Booster Drogue	24.9	1.2	1.0	1.4	Drogue Quick Link	600
Deployment Bay Drogue	72.6			6.4	Drogue Quick Link	600
Deployment Bay Main	139.6	1.8	0.289	222.2	Main Triangular Quick Link	1200
Deployment Bay Unloading	28.3			8.6	Main Triangular Quick Link	1200
Multirotor Main	13.9			13.9	ARRD	2000
Booster Main	98.1			399.8	Main Triangular Quick Link	1200
Reserve Deployment	23.4			4.8	Quick Link	600

Table 38: Opening forces.

4 Safety

The overall safety of the team is constantly being monitored throughout the season and ensuring that each member is aware of the safety precautions throughout the course of the season. The team enforces the overall safety of the team by creating team derived safety requirements that illustrate the criteria needed for the team to maintain an acceptable level of safety.

By creating safety requirements we were able to cover all aspects of safety that is necessary for NASA Student Launch by separating our requirements into three categories. Those three categories consist of Human Safety, Environmental Safety, and Asset Safety.

- Human Safety involves all items that will injure personnel and affect the human body throughout the season. This category is broken up into five (5) separate sections; Vehicle, Payload, Recovery, VDS, and Launch Day.
- Environmental Safety are all items that deal with Mother Nature and how the team influences the environment or vice versa. This category consists of two (2) separate sections; Team Effecting the Environment and Environmental Concerns
- Asset Safety are all tangible items that deal with hardware that will be implemented on the launch vehicle. This category is filled with an assortment of sections anywhere from 3D Printed Component Check to ESD Safe Storage. This category protects not only the hardware the team is using on the vehicle but the personnel handling the hardware throughout the course of the season.

4.1 Launch Concerns and Operations Procedures

Launch Concerns and Operations Procedures facilitate the team by addressing the concerns with the prep of the rocket and the overall safety during a launch. The use of cause and effect analysis is utilized by the team to help mitigate any hazards that might arise during the prep or launching of the vehicle. The team uses both the launch operations procedures and assembly of the vehicle before a launch to address all causes of hazards during the prior for leaving for launch and at launch site steps.

A lot of the launch concerns are directly correlated to the individual technical designs and how the overall vehicle is assembled. By looking at each sub-system within the vehicle they all are correlated to a Failure Mode Effect Analysis (FMEA) table that addresses the cause and effect criteria. Each individual section is outlined below with a link to an FMEA table that best represents the safety hazards that occur during the prep and/or launching of the vehicle.

Launch Vehicle
The launch vehicle incorporates the launching aspect of the cause and effect analysis where most of the hazards start to become relevant as soon as the rocket is set on the rail. A greater breakdown of what hazards are incorporated into this section are located in the Launch Vehicle FMEA table.

Recovery System
The recovery system is tied into the launching aspect of the cause and effect analysis where a majority of the hazards can occur during the descent of the vehicle. Those items can be further addressed in both the Booster Recovery FMEA and Deployment Bay Recovery FMEA tables. Prepping recovery also implements hazards but are easily mitigated with the teams launch procedures checklist by having a minimum of two engineers sign off on all checklist items.

Variable Drag System
The variable drag system involves solely in the launching aspect of cause and effect analysis due to the concept behind the VDS. This systems has the ability to fluctuate the overall performance of the launch vehicle which generate hazards that are showcased in the VDS FMEA table.

Payload System
The payload system incorporates hazards during assembly, especially when the arms and legs of the payload are being assembled into either end of the deployment bay and booster recovery bay. With the complexity of the payload system, hazards associated with launching were broken up into individual FMEA tables based on sub-system. The FMEA tables cover the MRS, GSE, RRS, TDS, PSS, LLS, and DS.

As the team developed the payload for this year's competition it became clearer that when the team tested the MRS there needed to be a safety document that authorized flight of the MRS. This would ensure the safety of the team and personnel operating the MRS during the test flights.

4.1.1.1 Multirotor Flight Safety Document

In order to ensure the safety of all River City Rocketry team members associated with flight tests of the Multirotor Recovery System (MRS), a strict pre-flight safety checklist has been established along with startup and shutdown procedures that should be used to initiate every flight.

NOTE: FLIGHT OF THE MULTIROTOR REQUIRES TWO (2) OPERATORS.

4.1.1.1.1 Preflight Checklist

1. _____ All participants are equipped with safety glasses

   ⚠**CAUTION** Failure to comply with this requirement can result in damage to eye sight in an extreme scenario.

2. _____ At least 30 feet between participants and multirotor for its entire planned flight path

   ⚠ DANGER Collision between the multirotor and a participant can result in severe lacerations. Extreme attention should be paid to the multirotor at all times by all participants.

   In the event that the multirotor performs an off-nominal movement in the direction of a participant, this distance will allow them time to move and avoid collision.

3. _____ Multirotor flight path is clear of obstacles
4. _____ Wind speeds are below 10 mph
5. _____ No inclement weather expected
6. _____ Multirotor battery fully charged
7. _____ Battery is equipped with voltage monitor
8. _____ RC transmitter battery fully charged
9. _____ RC transmitter connected
10. _____ Transmitter switch positions set
11. _____ Ground station telemetry connected
12. _____ Home point set via ground station
13. _____ Appropriate flight mode set
14. _____ Propellers are clear of defects

⚠**CAUTION** Undetected defects in the propellers could lead to unintended flight characteristics and potential crashes of the multirotor. Care should be taken to ensure that all propellers are properly maintained.

4.1.1.1.2 Startup Procedure

The startup procedure that shall be followed when flying the multirotor is outlined below.

1. Operator #2: Place multirotor in a safe takeoff location clear of any obstacles
2. Operator #1: Keep both hands on transmitter at all times during preflight and flight and be prepared to take control of the multirotor in the event of an emergency
3. Operator #2: Plug in battery and allow adequate time for the system to initialize
4. Operator #2: If necessary, run sensor calibration procedure
5. Operator #2: Lock propellers onto motors
6. Operator #2: Hold safety switch to arm motors while keeping hands free of potential collision with the propellers

   ⚠**WARNING** Spin-up of the motors during this step could cause injury to the operator. Extreme caution should be taken.

7. Operator #2: Return to the ground station to initiate launch

4.1.1.1.3 Shutdown Procedure

Upon completion of a flight, this procedure shall be followed to ensure the safe shutdown of the multirotor.

1. Operator #1: Maintain both hands on transmitter at all until complete shutdown and be prepared to take control of the multirotor in the event of an emergency
2. Operator #2: Disarm multirotor via ground station
3. Operator #2: Approach multirotor with caution and verify that it's disarmed by monitoring the LED backlit safety switch

   Note: Slow pulsing of the red LED in the safety switch signifies that the system is disarmed. Fast pulsing of the same LED signifies that the system is armed for flight.

4. Operator #2: Immediately disconnect battery
5. Operator #1: At this point it is safe to remove hands from RC transmitter
6. Operator #2: Remove all propellers from motors

4.2 Safety and Environment

4.2.1 Analysis of Failure Modes

4.2.1.1 Overview of Analysis Guidelines

For the failure mode analysis of the mission, guidelines were established to standardize analytic methods between all systems. Reliability block charts were constructed for each major subsystem to highlight potential points of failure of the system and were used to advise subsequent FMEA charts. These FMEA charts outline potential hazards in the team's designs, their causes, effects, and how they can be mitigated or controlled.

Possible failure modes for each item are listed in the FMEA tables along with their potential effects. Each failure mode is ranked on a 4-point scale in terms of **severity (S)**, **likelihood of occurrence (O)**, and **detectability (D)**. The scales for each category are shown below in **Figure 85**.

Severity	
1	Loss of redundancy
2	Degraded mission
3	Mission failure
4	Catastrophic Failure/injury

Likelihood of Occurrence	
1	Highly unlikely
2	Improbable
3	Somewhat probable
4	Extremely Likely

Detectability	
1	Easily detectable
2	Moderately detectable
3	Somewhat detectable
4	Extremely difficult to detect

Figure 85: Severity, Occurrence, and Detectability scales.

These numbers are multiplied to obtain a **Risk Probability Number (RPN),** which is a numerical representation of the risk associated with each failure. RPN values rank from 1 to 64. The team opted for an RPN factor of safety of 4 and determined that any RPN greater than 16 required a recommended method to mitigate potential risk, which is noted in an additional column.

4.2.1.2 Launch Vehicle

Figure 86 below shows the overall launch vehicle reliability block diagram. The block diagram represents all the steps and components that must not fail in order for the mission to succeed. The block diagram is broken down into the high level categories where failure of the mission can occur; liftoff, ascent, and decent of the launch vehicle.

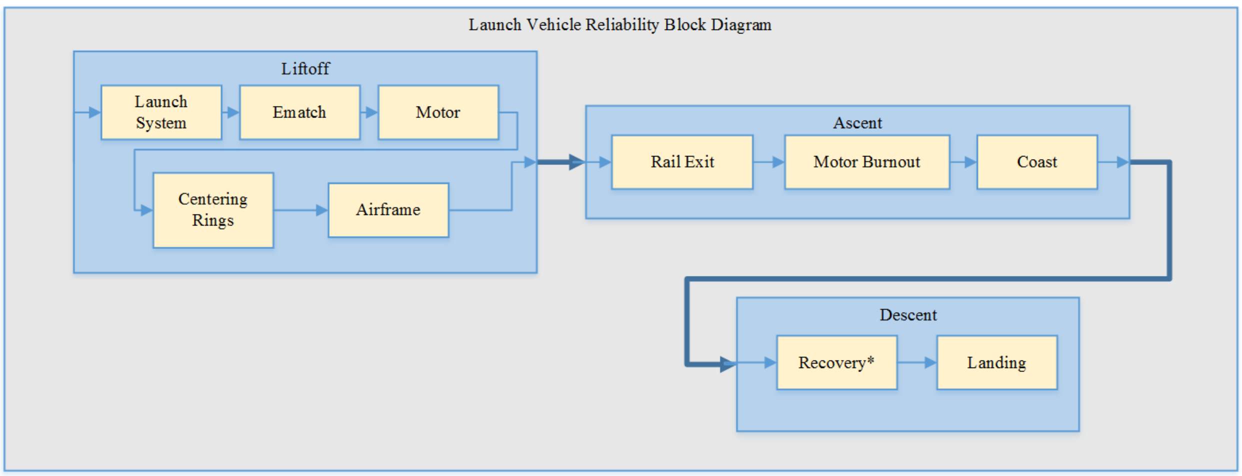


Figure 86: Launch vehicle reliability block diagram.

The recovery block of the launch vehicle reliability block diagram is discussed in detail in Section 4.2.1.3. The resultant FMEA charts advised by the potential failure points outlined in the block diagrams are shown below in Figure 87.

Launch Vehicle FMEA							
Possible Failure	**Failure Mode**	**Effect**	**S**	**O**	**D**	**RPN**	**Recommended Mitigation**
Liftoff							
Launch System	Launch system malfunction	None - redundant item	1	1	1	1	Ensure proper storage and regular testing of launch system prior to flight.
Ingniter	Defective igniter	Motor does not ignite and flight of the launch vehicle will be delayed	1	2	4	8	Usage ofproper storage and inspection of igniters prior to flight.
	Loose Connection	Motor does not ignite and flight of the launch vehicle will be delayed	1	3	2	6	Ensure that an experienced team member connects the igniter to the motor.
Motor	Igniter inserted improperly	Motor does not ignite and flight of the launch vehicle will be delayed	1	1	1	1	Ensure that only an experienced team member inserts the igniter.
	Faulty motor	Catastrophic motor failure and launch vehicle will fail mission	4	1	4	16	Usage of inspection of motors before flight and proper motor packing technique.
Centering Rings	Epoxy is not properly applied to centering rings	Motor will continue to move through launch vehicle and destroy internals of launch vehicle	4	2	1	8	Ensure that only an experienced team member applies the epoxy while following all instructions for mixing the epoxy exactly.
	Centering rings fail	Motor will continue to move through launch vehicle and destroy internals of launch vehicle	4	1	1	4	Run FEA simulations on models of the centering rings at higher than expected stress levels.
Airframe	Airframe experiences higher stress than the material can support	Airframe ruptures during flight, causing failure of mission	4	1	1	4	Ensure that the expoy resin used in the airframe is mixed correctly and is given the correct amount of time to cure to ensure maximum strength.
Ascent							
Rail Exit	Rail buttons on launch vehicle shear during liftoff	Velocity at the point of rail departure is lower than what is acceptible, resulting in a large angle of tilt of the vehicle	3	2	2	12	Run FEA simulations on models of the rail buttons at higher stress levels than expected. Use strong materials for rail buttons.
	Rail buttons on launch vehicle are not properly aligned	Launch Vehicle exits the launch rail with an angle of tilt, which will decrease the apogee altitude of the vehicle	2	1	1	2	Ensure that an experieced team member aligns and installs the rail buttons.
	Impulse of motor is not high enough	Exit rail velocity of launch vehicle is not high enough, causing instability and susceptibility of a high angle of tilt.	2	1	1	2	Conduct thorough research on available motors and do calculations to ensure the impulse is high enough for the launch vehicle.
	Fins are not properly aligned	Launch vehicle will be unstable and susceptible to spinning	2	1	2	4	Ensure that an experieced team member aligns and installs the fins.
	High friction coefficient between the launch vehicle and launch rail	Exit rail velocity of launch vehicle is not high enough, causing instability and susceptibility of a high angle of tilt.	2	3	2	12	Use low friction materials for rail buttons and lubricate the launch rail.
Motor Burnout	Vehicle experiences higher aerodynamic forces than exptected	Exterior launch vehicle features could experience higher stress and fail during ascent, resulting a mission failure.	4	1	2	8	Ensure that proper calculations are made and simulations are done to accuratley predict the forces experienced by the airframe during flight.
	Fin flutter causes fins to shear off of vehicle	Stability of launch vehicle would be drastically decreased and launch vehicle in an unpredictable flight trajectory	4	1	1	4	Ensure that proper calculations are made and simulations are done to accuratley predict the forces experienced by the fins during flight and secure them accordingly to the airframe.
Coast	Black Powder Charges go off prematurely	Vehicle separate on ascent causing catastrophic failure and possible injury to personel.	4	1	4	16	Each altimeter will be demonstrated to have the ability to accurately detect apogee in a vaccuum chamber prior to flight.
Descent							
Motor Retention	Motor retainer did not have proper preload	Motor casing falls out of launch vehicle, resulting in mission failure and possible injury to personnel	4	1	1	4	Ensure that an experienced team member installs the motor retainer.
	Motor retainer did not have proper thread engagment	Motor casing falls out of launch vehicle, resulting in mission failure and possible injury to personnel	4	1	1	4	Ensure that an experienced team member designs and oversees fabrication and installation of motor retainer.
	Motor retainer was not sized correctly for expected loads.	Motor casing falls out of launch vehicle, resulting in mission failure and possible injury to personnel	4	1	2	8	Ensure that an experienced team member designs the motor retainer and conducts proper simulations with the expected loads applied.
Landing	Descent Velocity is higher than expected	Vehicle components break upon landing, resulting in a mission failure.	1	2	1	2	Conduct test launches and computer simulations to ensure a reasonable descent speed will be attained.

Figure 87: Launch vehicle FMEA chart.

4.2.1.3 Recovery

The failure modes analysis for the recovery system has been done in two main segments – one for the booster recovery subsystem and one for the deployment bay recovery subsystem, as they are separated at apogee and become two distinctly different subsystems thereafter. An overview of the system is shown below in Figure 88.

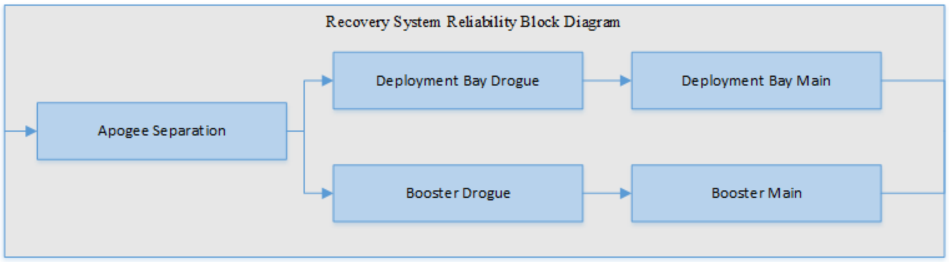


Figure 88: Reliability block diagram showing overview of recovery system.

The reliability block diagrams for the two sections and their subsidiary components are shown below in Figure 89 and Figure 90. Due to the many large scale single failure points (such as between power supply & sensors and apogee separation, as well as between apogee separation and booster, many of the components exhibit some form of redundancy to ensure that no single point of the recovery system fails.

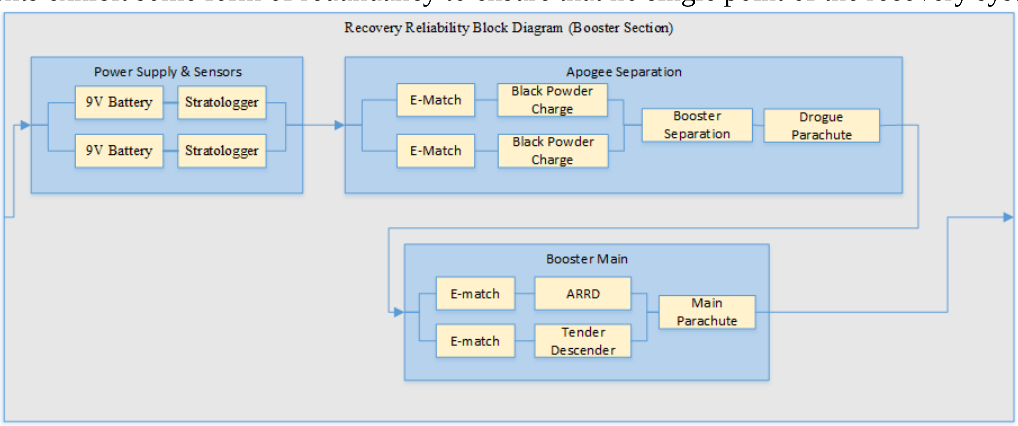


Figure 89: Reliability block diagram for booster section.

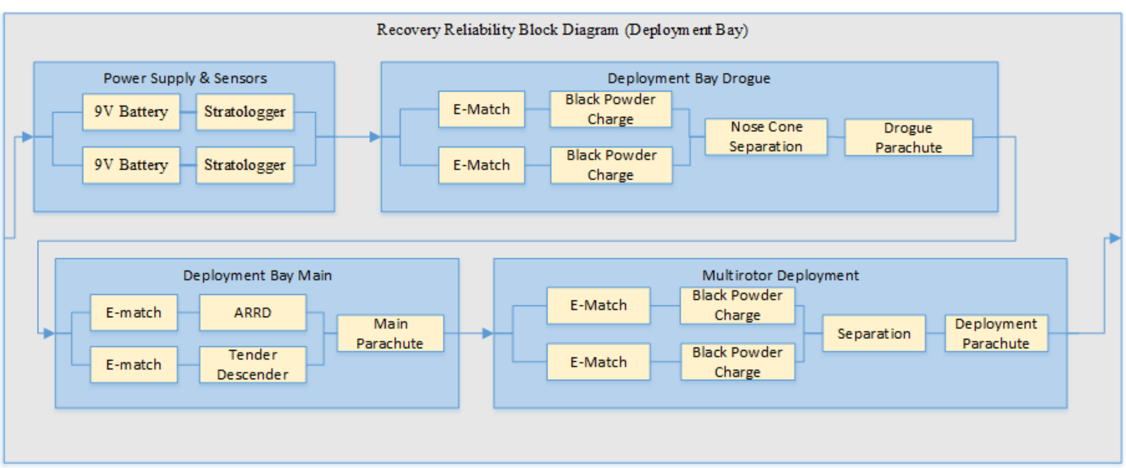


Figure 90: Reliability block diagram for deployment bay.

The resultant FMEA charts advised by the potential failure points outlined in the block diagrams are shown below in Table 39 and Table 40.

Booster Recovery System FMEA							
Possible Failure	**Failure Mode**	**Effect**	**S**	**O**	**D**	**RPN**	**Recommended Mitigation**
Power Supply & Sensors							
9V Battery	Dead battery	None - redundant item	1	1	1	1	Fresh batteries will be used for every launch
Stratologger	Loss of continuity	None - redundant item	1	2	1	2	Continuity checked before launch aand on pad
	Loose wire		1	2	2	4	Continuity checked before launch aand on pad
Booster Drogue							
E-Match	Loss of continuity	None - redundant item	1	2	1	2	Visual inspection of e-match before installation
	Defective e-match		1	2	3	6	Visual inspection of e-match before installation
Black Powder Charge	Insufficient black powder	None - redundant item	1	2	4	8	Black powder tests conducted before each launch
Booster Separation	Shear pins do not break	Loss of vehicle	4	1	1	4	Black powder tests conducted before each launch
Drogue Parachute	Inversion	Drogue descent faster than expected/Main opening force higher than expected	2	2	4	16	Ejection tests conducted before each launch
	Line tangle		2	2	3	12	Ejection tests conducted before each launch
Booster Main							
E-Match	Loss of continuity	None - redundant item	1	2	1	2	Visual inspection of e-match before installation
	Defective e-match		1	2	3	6	Visual inspection of e-match before installation
ARRD	Improperly assembled ARRD	ARRD release at apogee. Booster main at apogee.	3	2	2	12	Test ARRD by pulling on shackle after assembly
Tender Descender	Insufficient black powder	None - redundancy provided by ARRD	1	3	3	9	Tender descender black powder tests conducted before each launch
	Improperly assembled tender descender		1	2	4	8	Tender descender black powder tests conducted before each launch
Main Parachute	Inversion	Damage and potential loss of booster	4	2	4	32	Usage of deployment bag and precise packing techniques to manage proper main deployment
	Line tangle		4	2	3	24	Usage of line stow loops on deployment bag to retain organization of lines during deployment

Table 39: Booster recovery system FMEA chart

Deployment Bay Recovery System FMEA							
Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
Power Supply & Sensors							
9V Battery	Dead battery	None - redundant item	1	1	1	1	Fresh batteries will be used for every launch
Stratologger	Loss of continuity	None - redundant item	1	2	1	2	Continuity checked before launch aand on pad
	Loose wire		1	2	2	4	Continuity checked before launch aand on pad
Deployment Bay Drogue							
E-Match	Loss of continuity	None - redundant item	1	2	1	2	Visual inspection of e-match before installation
	Defective e-match		1	2	3	6	Visual inspection of e-match before installation
Black Powder Charge	Insufficient black powder	None - redundant item	1	2	4	8	Black powder tests conducted before each launch
Nose Cone Separation	Shear pins do not break	Deployment bay becomes ballistic. Main event does not occur. Payload and deployment bay are destroyed.	4	1	1	4	Black powder tests conducted before each launch
Drogue Parachute	Inversion	Drogue descent faster than expected/Main opening force higher than expected	2	2	4	16	Ejection tests conducted before each launch
	Line tangle		2	2	3	12	Ejection tests conducted before each launch
Deployment Bay Main							
E-Match	Loss of continuity	None - redundant item	1	2	1	2	Visual inspection of e-match before installation
	Defective e-match		1	2	3	6	Visual inspection of e-match before installation
ARRD	Improperly assembled ARRD	ARRD release at apogee. Main at apogee.	3	2	2	12	Test ARRD by pulling on shackle after assembly
Tender Descender	Insufficient black powder	None - redundancy provided by ARRD	1	3	3	9	Tender descender black powder tests conducted before each launch
	Improperly assembled tender descender		1	2	4	8	Tender descender black powder tests conducted before each launch
Main Parachute	Inversion	Damage and potential loss of deployment bay and payload	4	2	4	32	Usage of deployment bag and precise packing techniques to manage proper main deployment
	Line tangle		4	2	3	24	Usage of line stow loops on deployment bag to retain organization of lines during deployment
Multirotor Deployment							
E-Match	Loss of continuity	None - redundant item	1	2	1	2	Visual inspection of e-match before installation
	Defective e-match		1	2	3	6	Visual inspection of e-match before installation
Black Powder Charge	Insufficient black powder	None - redundant item	1	2	4	8	Black powder tests conducted before each launch
Separation	Shear pins do not break	Damage and potential loss of payload and deployment bay	4	1	1	4	Black powder tests conducted before each launch
Deployment Parachute	Inversion	Damage and potential loss of payload	4	2	4	32	Usage of deployment bag and precise packing techniques to manage proper main deployment
	Line tangle		4	2	2	16	Ejection tests conducted before each launch

Table 40: Deployment bay recovery system FMEA

4.2.1.4 VDS

Figure 91 below shows the VDS reliability block diagram. The block diagram represents all the steps and components that must not fail in order for the VDS mission to succeed. The block diagram is broken down into three high level categories where failure of the mission can occur; main controller, power and sensors, software, motor power & driver, and mechanical hardware.

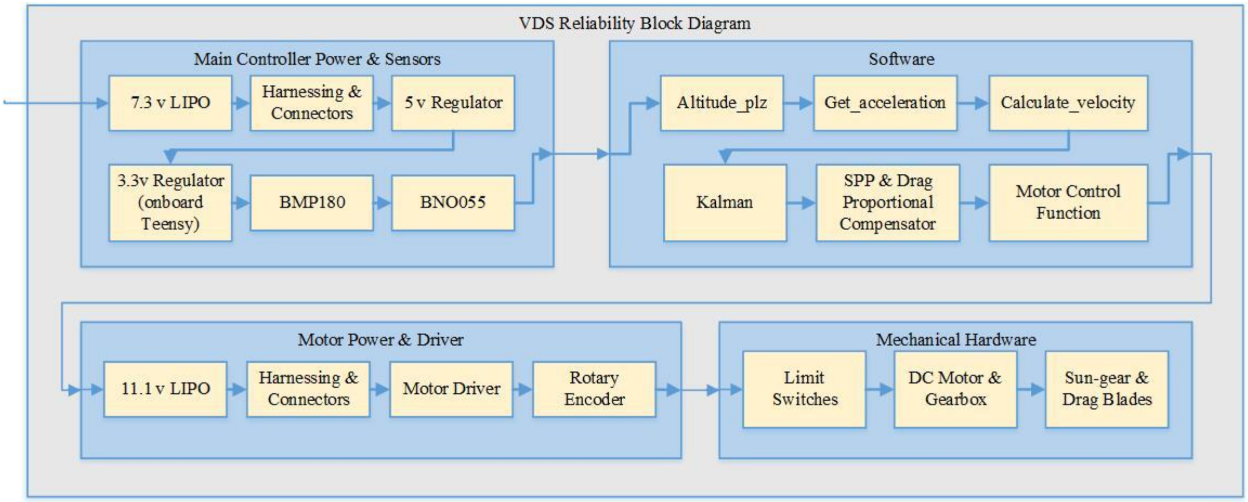


Figure 91: Reliability block diagram for VDS.

VDS FMEA							
Possible Failure	**Failure Mode**	**Effect**	**S**	**O**	**D**	**RPN**	**Recommended Mitigation**
Main Controller Power and Sensors							
7.4V LIPO	Dead battery	Power loss to all electronics	3	1	1	3	Include step in launch procedures for checking 7.4V LIPO
Harnessing and Connectors	Loose connector	Power loss to all electronics	3	2	2	12	Include step in launch procedures for checking that all connectors are secured and for checking continuity.
5V Regulator	Overheating	Power loss to all electronics	3	1	2	6	A regulator with a factor of safety of 2 on power output will be chosen
3.3V Regulator (onboard Teensy)	Overheating	Power loss to sensors	3	1	2	6	Sensor power with a factor of safety of 2 will be chosen
BMP280	Becomes unresponsive	Loss of altitude data	3	1	1	3	The launch procedures checklist includes a step for checking the validity of altitude data pre-launch
BNO055	Becomes unresponsive	Loss of accelerometer data	3	1	1	3	The launch procedures checklist includes a step for checking the validity of acceleration data pre-launch
Software							
altitude_plz Function	Variable overflow	False altitude data & false velocity data	3	1	2	6	The expected range of all variables will be calculated and variale types chosen accordingly
get_acceleration Function	Variable overflow	False acceleration data & false velocity data	3	1	2	6	The expected range of all variables will be calculated and variale types chosen accordingly
calculate_velocity Function	Loss of precision to high-valued floats	Erroneous velocity data	2	2	2	8	Time variables will be stored as unsigned longs in units of microseconds to avoid high-valued floats
	Variable overflow	False velocity data	3	2	2	12	The expected range of all variables will be calculated and variale types chosen accordingly
kalman Function	Variable overflow	All data false	3	2	2	12	The expected range of all variables will be calculated and variale types chosen accordingly
	Incorrect flight model	Small errors in all flight data	2	2	2	8	Further testing will be completed to verify flight model
SPP & Drag Proportional Compensator Functions	Incorrect flight model	VDS performs insufficient amount of braking	2	2	2	8	Further testing will be completed to verify flight model
Motor Control Function	Incorrect flight model	VDS performs insufficient amount of braking	2	2	2	8	Further testing will be completed to verify flight model
Motor Power and Driver							
11.1V LIPO	Dead battery	Power loss to DC motor	3	1	1	3	Include step in launch procedures for checking 11.1V LIPO
Harnessing and Connectors	Loose connector	Power loss to DC motor	3	2	2	12	Include step in launch procedures for checking that all connectors are secured
Motor Driver	Overheats	Power loss to DC motor	3	2	2	12	Analysis shows that motor driver overheating is unlikely
Rotary Encoder	Becomes disconnected	Loss of DC motor feedback	3	2	2	12	Usage of deployment bag and precise packing techniques to manage proper main deployment. Include step in launch procedures for checking continuity.
Mechanical Hardware							
Limit Switches	Loss of connection	Reduced motor feedback quality	2	2	2	8	Testing will ensure the integrity of limit switch connection by checking continuity.
DC Motor and Gearbox	Broken gearbox	VDS drag blades stuck in position	3	1	1	3	Testing will ensure the integrity of DC motor and gearbox
Sun-gear and Drag Blades	Gear binding	VDS drag blades stuck in position	3	1	1	3	Testing will ensure the integrity of the sun-gear and drag blades

Table 41: VDS FMEA chart.

The top safety concerns ranking highest in the above FMEA are largely associated with harnessing issues and software variable overflows.

4.2.1.5 Payload

. The block diagrams below represent all the steps and components that must not fail for the Payload mission to succeed. The block diagram is broken down into individual sections of the payload, providing details on where failure of the mission can occur.

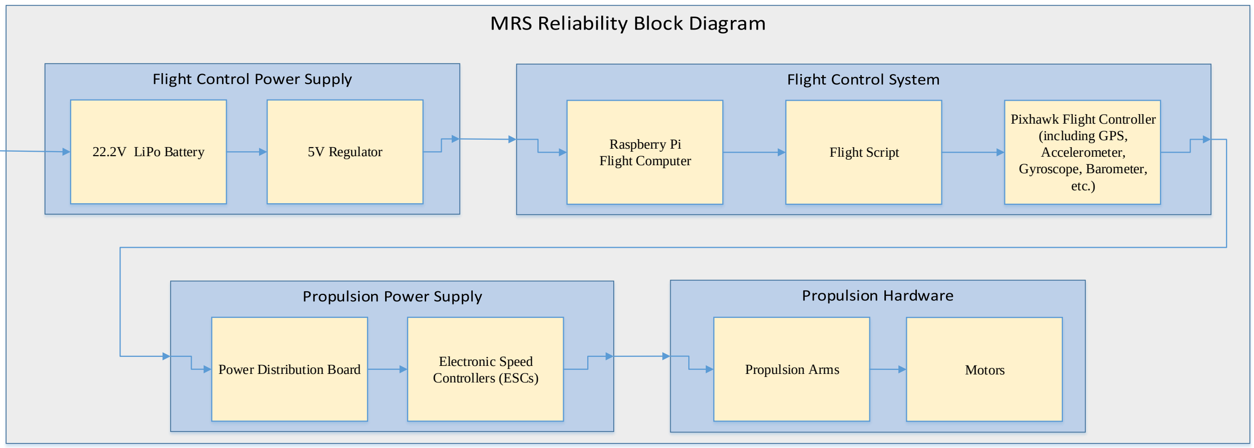


Figure 92: Reliability block diagram for MRS

MRS FMEA

Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
Flight Control Power Supply							
22.2V LiPo Battery	Low battery charge	Loss of MRS flight capability	3	1	1	3	Verify charge of battery prior to leaving for flight.
	Loose wiring harness connections		2	1	3	6	Inspect wiring harness connections prior to launch.
5V Regulator	Overheating due to power draw		3	1	3	9	Verify proper connection of the regulator within the circuit prior to launch.
Flight Control System							
Raspberry Pi Flight Computer	Raspberry Pi loses power and reboots	Degradation of MRS Flight Capability	3	3	3	27	Raspberry Pi will be capable of running the flight script from boot. Failsafes within the flight script will also make sure all variables necessary for flight are present before issuing commands.
Flight Script	Bug in autonomous flight script	Loss of MRS flight capability	3	3	2	18	Manual Overrides on RC transmitters to allow GSE to override flight script at any moment. Verify proper communication of transmitter to reciever prior to launch.
Pixhawk Flight Controller	Accelerometer/gyroscope/barometer sensor failure		1	1	1	1	Verify reliability of sensors prior to rocket assembly.
	Loss of GPS signal		2	2	1	4	Verify GPS lock prior to launch.
Propulsion Power Supply							
Power Distribution Board	Short in wiring system	Loss of MRS flight capability	3	2	1	6	Inspection of MRS electronics prior to launch.
Electronic Speed Controllers (ESCs)	Not enough airflow provided to the ESC's during flight	Degradation of MRS Flight Capability	2	2	3	12	ESC will be mounted underneath rotors to allow airflow from rotor to cool the ESC.
Propulsion Hardware							
Propulsion Arms	Torsion spring fails to actuate Arm Pivot	Loss of MRS flight capability	3	2	1	6	Individual Propulsion Arm Assemblies will be inspected pre-flight
	Propulsion Arm components structurally fail		3	1	1	3	Structural test and Analysis have been performed to verify the integrity of the Propulsion Arm design
	Any limit switch on Arm Pivot Assembly or Land Leg Assembly fails		3	2	2	12	Verify operation of limit switches prior to assembly of rocket before launch.
Motors	Shock load from arm deployment		3	1	1	3	Deployment tests will be accomplished to verify actuation mechanisms
	Entanglement of blades during arm deployment		3	2	3	18	Ensure proper assembly of payload and packing of parachute prior to assembly of full scale rocket.
	Interference between propulsion arm and blades		3	1	1	3	Deployment tests will be accomplished to verify actuation mechanisms

Table 42: MRS FMEA chart.

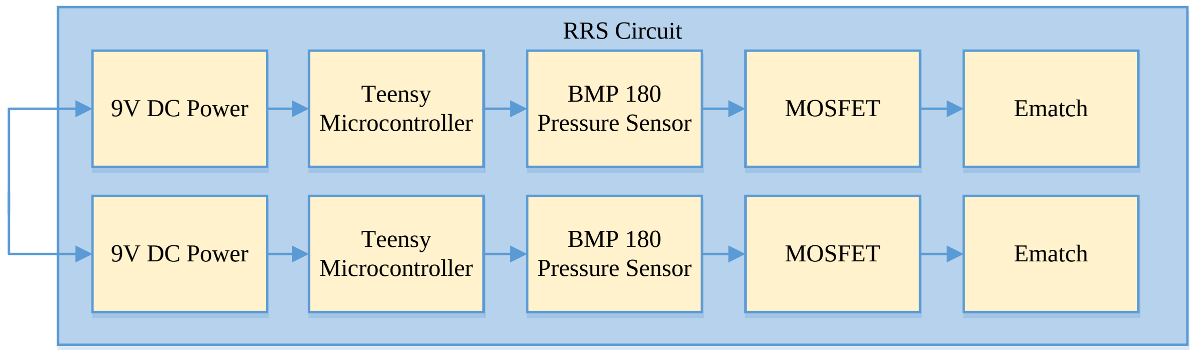


Figure 93: Reliability block diagram for RRS circuit.

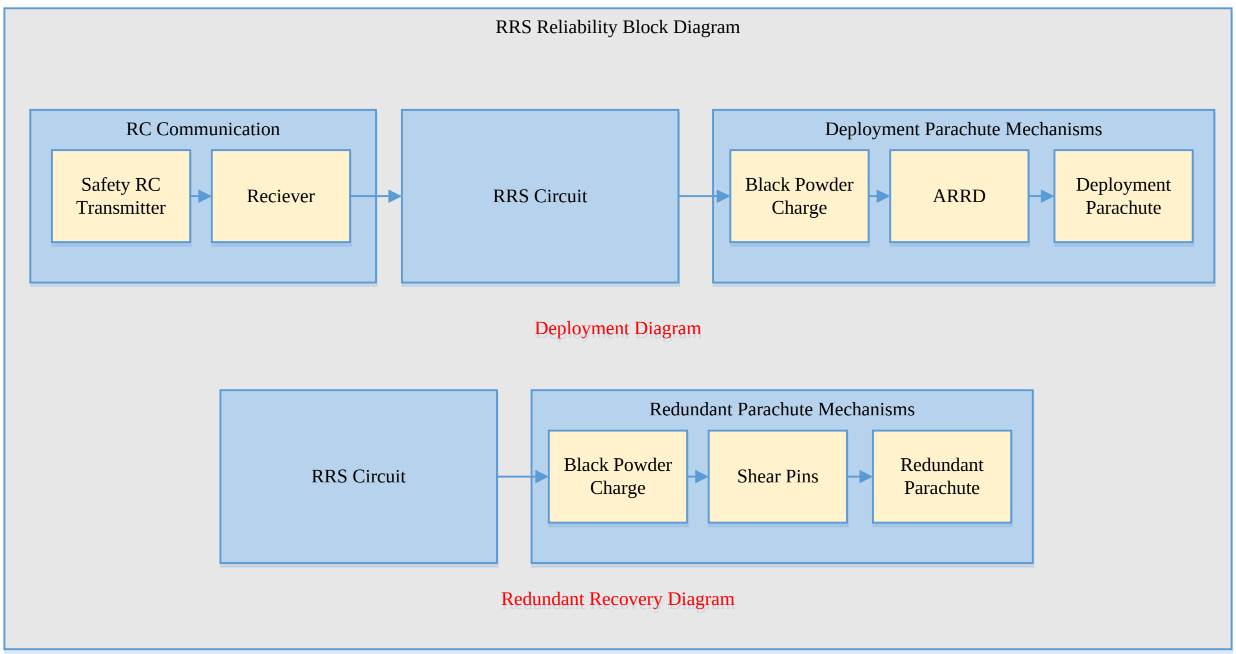


Figure 94: Reliability block diagram for the RRS functions.

RRS FMEA

Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
RRS Circuit							
9V DC Power	Bad battery	Loss or RRS Redundancy, RRS fail safe activated	1	2	1	2	Install new battery for each launch
	Short/open in circuit		1	2	3	6	Verify initialization prior to launch
Teensy Microcontroller	Short in Teensy circuit		1	1	1	1	Verify initialization prior to launch
	Bug in code		3	3	2	18	Extensive testing
	No continuity between teensy and BP charge	Loss of RRS Redundancy	1	2	1	2	Measure continuity prior to installation
BMP 180	Short in BMP circuit		1	2	2	4	Verify communication
	Thermometer component broken		1	2	2	4	Verify altitude measurements on site
	Uncalibrated altitude readings		1	3	3	9	Verify altitude measurements in testing
	Pressure hole drilled too small/large		2	2	3	12	Determine largest hole size in testing
MOSFET	MOSFET not strong enough to cut power to motors		4	1	1	4	Extensive testing
	PCB breaks due to accelerative loading		3	2	3	18	Analysis of forces expected during flight
	Short in MOSFET Circuit		3	1	1	3	Verify continuity of circuit
E-match fails	Lack of continuity		3	2	1	6	Verify continuity prior to installation
	Not installed into the terminal block properly		3	1	1	3	Inspect terminal block
RC Communication							
Safety RC Transmitter	Out of range	Payload doesn't begin mission	3	2	2	12	Extensive range testing
	Weather degrades signal		3	2	3	18	Perform mission below cloud cover
	Battery dies		1	2	3	6	Testing of battery life
	Continuity of transmitter switch fails		3	2	2	12	Verify signal recognition prior to launch
	User fails to send signal		3	2	1	6	Document when signal should be sent
RC Reciever	Out of range		3	2	2	12	Extensive range testing
	Weather degrades signal		3	2	3	18	Perform mission below cloud cover
	Continuity of to RRS fails		3	2	2	12	Verify signal recognition prior to launch
	Carbon Fiber Coupler Degrades Signal		3	2	1	6	Effects of Carbon Fiber signal atenuation will be tested
Deployment Parachute Mechanisms							
Black Powder Charge	Incorrect amount of black powder	Deployment Parachute remains attached while MRS begins flight	4	1	1	4	Verify required black power charge
	E-match not properly installed		3	1	1	3	Inspect terminal block
ARRD fails to deploy	Failure in RRS circuit	Payload fall under Deployment Parachute to ground	1	2	2	4	Extensive testing
	No continuity to BP charge	Deployment Parachute remains attached while MRS begins flight	1	2	1	2	Verify continuity prior to installation
	Improper assembly of ARRD		2	2	1	4	Inspection of ARRD
	BP charge fails to ignite		3	2	2	12	Verify ignition capability prior to launch
Deployment Parachute	Inversion	Deployment parachute faster than expected	4	1	1	4	Precise packing techniques to managage proper parachute deployment
	Line tangle		4	1	1	4	
Redundant Parachute Mechanisms							
Black Powder Charge	Incorrect amount of black powder	Deployment Parachute remains attached while MRS begins flight	4	1	1	4	Verify required black power charge
	E-match not properly installed		3	1	1	3	Inspect terminal block
Shear Pins	Shear Pins don't break	Redundant parachute Fails to deploy	4	1	1	4	Black Powder test will be performed prior to launches
Redundant Parachute	Inversion	Redundant parachute faster than expected	4	1	1	4	Precise packing techniques to managage proper parachute deployment
	Line tangle		4	1	1	4	

Table 43: RRS FMEA chart.

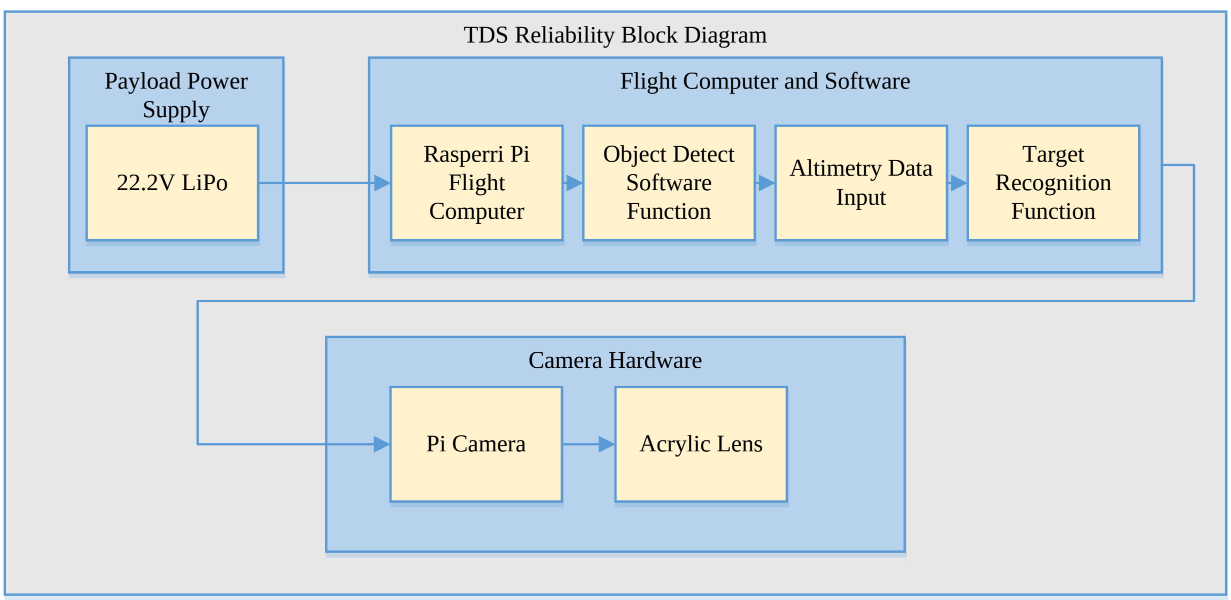


Figure 95: Reliability block diagram for TDS.

TDS FMEA							
Possible Failure	**Failure Mode**	**Effect**	**S**	**O**	**D**	**RPN**	**Mitigation**
Payload Power Supply							
22.2V LiPo	Battery Dead	Loss of ability to detect targets	3	1	1	3	Battery will be inpsected prior to flight
	Loose connetion		3	1	1	3	Battery will be inpsected prior to flight
Flight Computer and Software							
Rasperry Pi Flight Computer	Loss of Power	Loss of ability to detect targets	3	1	1	3	Pi will be securely fasented to electronics mount
	Software does not initialize	Loss of TDS	3	1	2	6	TDS shall undergo significant integration testing
Object Detection Software	Does not execute correctly/as expected	Loss of detection capabilities	3	1	2	6	TDS shall be tested exstensively to minimize change of unexpected behavior
	Bug	Potential loss of functionality or subsystem	3	2	2	12	Testing and code reviews shall take place to cut down on potential bugs
	Payload not in vicinity of targets	No targets shall be returned as detected	2	2	3	12	TDS detection software will be tested to find errors
	Accelrative loads fail camera system and electronics	Connections/components do not operate correctly	2	1	3	6	TDS detection software will be tested to find errors
	Enviormental lighting effects	Algorithm does not detect targets, targets invalid targets	2	2	1	4	TDS detection software will be tested to find errors
Altimetry Data Input	Invalid/Null input	Incorrect size approximation	2	2	1	4	Flight & subscale testing will be conducted to verify no such values are sent. Additionally code change could be made to circumvent this issue
Target Recognition Function	Failure to detect target	Loss of ability to complete challenge	3	2	2	12	Algorithm shall undergo significant vetting to ensure targets are detected correctly
	Detects invalid targets	Incorrect targets/false-positives selected	3	2	2	12	Algorithm shall undergo significant vetting to ensure targets are detected correctly
Camera Hardware							
Pi Camera	Failure to initiliaze	Loss of ability to capture images	2	1	1	2	TDS detection software will be tested to find errors
	Loose connection to RPi		3	1	1	3	Potential risk shall be taken into account during construction of camera circuit
	blur from ejection charge		2	3	4	24	A Nomax sheet will be applied to the camera to protect the lens from durtying due to the black powder charge. Testing will be conducted to gaurantee acceptible levels of blurr
Acrylic Lens	Smudged/Damaged from decoupling	Potential loss of image quality	2	3	1	6	Tests shall be conducted to find acceptable working conditions and constraints for lens

Table 44: TDS FMEA chart.

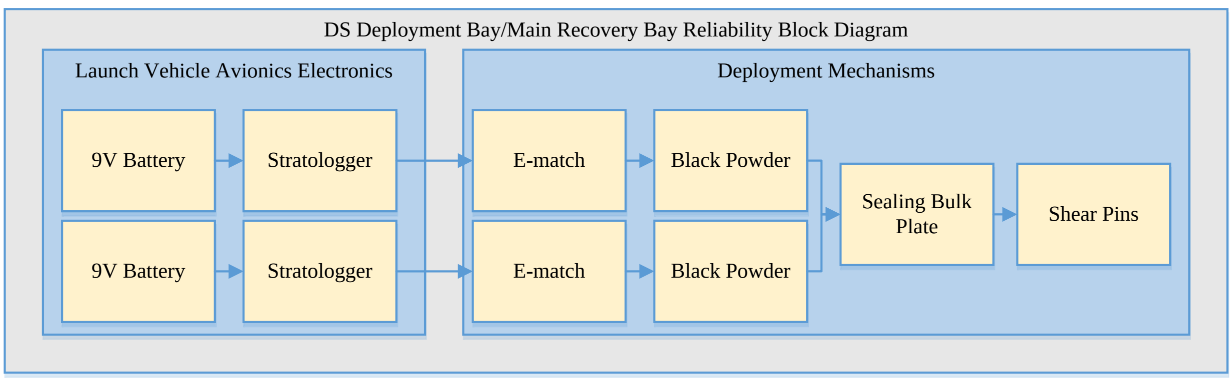


Figure 96: Reliability block diagram for DS.

DS FMEA							
Possible Failure	**Failure Mode**	**Effect**	**S**	**O**	**D**	**RPN**	**Recommended Mitigation**
Launch Vehicle Avionics Electronics							
9V Battery	Dead battery	None - redundant item	1	1	1	1	None
Stratologger	Loss of continuity	None - redundant item	1	2	1	2	None
	Loose wire		1	2	2	4	None
Deployment Mechanisms							
E-match fails	Lack of continuity	None - redundant item	3	2	1	6	Verify continuity prior to installation
	Not installed into the terminal block properly		3	1	1	3	Inspect terminal block
Black Powder Charge	Insufficient black powder	None - redundant item	1	2	4	8	None
Sealing Bulk Plate	Lack of a sufficient Seal	Payload fails to seperate from Launch vehicle	4	2	2	16	Black Powder test will be accomplished prior to launch
Shear Pins	Shear Pins don't break		4	1	1	4	Black Powder test will be performed prior to launches

Table 45: DS FMEA table.

GSE FMEA							
Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
Primary RC transmitter fails to control payload	Payload travels out of range of transmitter	MRS loses redundancy of manual override	3	2	2	12	Restrict flight area of MRS to within the range of the primary RC transmitter.
	Transmitter fails to bind to reciever on initialization	MRS loses redundancy of manual override	3	1	1	3	Preflight check to verify stable bind between transmitter and receiver.
	Interference of transmitter to receiver signal	Potential loss of redundancy of manual override	3	1	1	3	Ground testing on the day of launch to assess likelyhood of signal interference.
	RC transmitter battery dies	MRS loses redundancy of manual override	3	1	1	3	Ensure that the RC transmitter batteries are fully charged prior to launch.
Secondary RC transmitter fails to communicate with RRS	Payload travels out of range of transmitter	RRS loses redundancy of manual override	3	2	2	12	Restrict flight area of MRS to within the range of the secondary RC transmitter.
	Transmitter fails to bind to reciever on initialization	RRS loses redundancy of manual override	3	1	1	3	Preflight check to verify stable bind between transmitter and receiver.
	Interference of transmitter to receiver signal	Potential loss of redundancy of manual override	3	1	1	3	Ground testing on the day of launch to assess likelyhood of signal interference.
	RC transmitter battery dies	RRS loses redundancy of manual override	3	1	1	3	Ensure that the RC transmitter batteries are fully charged prior to launch.
Telemetry module loses communication with payload	Payload travels out of range of telemetry module	Loss of GPS tracking abilities and status messages from payload	1	3	1	3	Appropriate mounting of telemetry antennas.
	Ground station laptop battery dies	Loss of GPS tracking abilities and status messages from payload	2	3	1	6	Ensure battery of laptop is charged prior to launch. Also have backup laptop capable of acting as the ground station.

Table 46: GSE FMEA chart.

LLS FMEA							
Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
Landing Legs fail to deploy	Torsion spring fails to actuate legs	Loss of upright landing capability	3	2	2	12	Leg Actuation Tests must be performed prior to flight
	Vibrations cause bolts to loosen	Loss of upright landing capability	3	2	3	18	Locktite must be applied to all threading surfaces
	Vibrations cause lock pin to loosen	Loss of upright landing capability	3	1	3	9	Locktite must be applied to all threading surfaces
Landing Legs structurally fail	High speed landing loads experienced	Loss of upright landing capability	3	2	2	12	Testing will mitigate worst case landing scenarios
	BP seperation charge from main recovery bay damages leg components	Loss of upright landing capability	3	1	2	6	Testing will verify leg components are capable of recieving black powder charge

Table 47: LLS FMEA chart.

PSS FMEA							
Possible Failure	Failure Mode	Effect	S	O	D	RPN	Recommended Mitigation
Paylaod coupler	Acclerative compressive loads from launch fail coupler	Catastrophic Failure	4	1	1	4	Full Scale Test Flights
	Shear pins zipper coupler airframe, causing crack propogation		4	1	1	4	Full Scale Test Flights
Payload upper bulk plate	Loads from the Arm Pivot Assembly fails upper bulk plate	Payload Mission Failure	3	1	2	6	Full Scale Test Flights
	RRS deployment loads fail uppper bulk plate		3	3	3	27	Full Scale Test Flights
	Punch load from deployment bay BP charge fails upper bulk plate		3	1	1	3	Full Scale Test Flights
Payload bottom bulk plate	Punch load from main recovery bay BP charge fails lower bulk plate		3	1	1	3	Full Scale Test Flights
	High speed landing loads experienced		3	3	5	45	Payload deployment drop test
Payload battery container	Acclerative compressive loads from launch fail battery container	Degraded Mission/Potential Mission Failure	2	1	1	2	Full Scale Test Flights
	Heat from battery during operation weaken plastic		4	1	1	4	Full Scale Test Flights
RRS tube	Excessive bending loads introduced to the RRS tube during deployment	Catastrophic Failure	4	1	1	4	Black Powder Tests
	Pressure from BP charge overexpands tube and causes explosion		4	1	1	4	Black Powder Tests
Electronics Sleds	Acclerative compressive loads from launch fail electronics sled	Degraded Mission/Potential Mission Failure	2.5	1	1	2.5	Full Scale Test Flights
	Heat from battery during operation weaken plastic		2.5	1	1	2.5	Full Scale Test Flights
Camera Housing	Acclerative loads from launch fail housing	Payload Mission Failure	3	1	1	3	Full Scale Test Flights
	Punch load from main recovery bay BP charge fails lower bulk plate		3	2	2	12	Full Scale Test Flights

Table 48: PSS FMEA chart.

4.2.2 Personal Hazard Analysis

The Personal Hazard Analysis showcases the teams understanding of personal safety while focusing on the best procedures that will facilitate the team's safety when dealing with specific tasks. The main purpose of Personal Hazard Analysis is to allow the team to identify all risks that pertain to the human body, set a requirement for those risks, and then mitigate those risks accordingly.

After the team derived the main purpose of Personal Hazard Analysis a set of team derived requirements encompassing Human Safety were created to help mitigate personal risks throughout the season. These requirements can be seen in further detail in the Safety Requirements sections as well as Personal Protective Equipment (PPE) tables that are outlined below.

4.2.2.1 **Overview of Analysis Guidelines for PPE tables.**

The team has implemented Personal Protective Equipment Tables to ensure that the team addresses all hazards that are associated with tasks that occur in the manufacturing process. Throughout the 2016-2017 competition season each sub-team lead will address all tasks and hazards that are applicable to the manufacturing process.

When developing the PPE tables the team must follow the following process:

- A task must be selected that will result in potential harm to the individual performing that task or personal that may be around that task at the time of performing such task.
    - Note: This task must be identified as a potential hazard that can inflict potential harm to the public or a River City Rocketry member throughout the 2016-2017 competition season.
- When a task is selected, one of the following departments must be assigned; Vehicle, Payload, VDS, and or Recovery sub-team.
    - Note: Multiple departments can be associated to one specific task as numerous manufacturing practices are used by the same department throughout the season.
- After a task is selected, the associated Hazards must be called out for that particular task. These can be found either on MSDS sheets or are common Hazards that are applicable to the task called out.
- When a Hazard is selected three items must be addressed:
    - A control that can mitigate the hazard.
    - PPE available for team members to use while performing that task.
    - PPE selected that will help protect members when performing that specific task.

After a department is assigned the members assessing

4.2.2.1.1 Personal Protective Equipment (PPE) Tables

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Applying epoxy	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Skin Irritation	Always wash any epoxy off of exposed skin areas after working.	Nitrile Gloves, Long-Sleeved Clothing	Nitrile Gloves, Long-Sleeved Clothing
Eye Irritatation	N/A	Safety Goggles	Safety Goggles
Skin Sensitivy	N/A	Nitrile Gloves, Long-Sleeved Clothing	Nitrile Gloves, Long-Sleeved Clothing

To reduce skin and eye irritation during the application of epoxy, the vehicle and payload teams have identified several PPE items to be used. Nitrile gloves, safety goggles, and long-sleeved clothing will reduce the likelihood that epoxy can cause skin and eye irritation.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Using power drill	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Damage	N/A	Safety Goggles	Safety Goggles
Electrocution	Don't use power drill in wet environments, never use a power rill with loose or exposed wires,	Insulated Gloves	Insulated Gloves
Face Injuries	Ensure drill is clean of rust, ensure proper drill speed, use proper power drill technique, ensure proper training before power drill use, use vices and clamps on material being drilled into,	Face Mask	Face Mask
Hand Injuries	Ensure drill is clean of rust, ensure proper drill speed, use proper power drill technique, ensure proper training before power drill use, use vices and clamps on material being drilled into,	Gloves	Gloves
Resportory Injury	N/A	Face Mask	Face Mask
Fire	Ensure proper battery connection, search for loose wires and connections, take breaks to prevenet overheating of drill	N/A	N/A

All members planning on using the power drill be briefed on the safety risks associated with it during use. Also, members will be required to use gloves, face mask, and safety goggles during use of the power drill.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload/Recovery	Creating black powder ejection charges	Justin Johnson/ Wil Johnson/Evan Schurr	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Accidental ignition/ Burn Injuries	Stow ignition equipment and black powder in separate compartments, keep black powder isolated from any potential fire source	Long Sleeved Clothing, Insulated Gloves	Long Sleeved Clothing, Insulated Gloves
Eye Contact	Carefully handle black powder when creating ejection charges	Safety Goggles	Safety Goggles
Inhalation	Carefully handle black powder when creating ejection charges	Respiratory Mask	Respiroraty Mask

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	CNC Mill	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Hand Injury	Never reach inside of CNC mill during operation, use a shop towel to handle when installing and removing sharp cutting tools. **(NOTE: NEVER WEAR GLOVES DURING THE OPERATION OF THE MACHINE. GLOVES MAY GET CAUGHT IN MACHINE AND CREATE HAZARDOUS ENVIORNMENT)**	N/A	N/A
Skin Irritation	Always wash any coolant or particulates off of exposed skin areas after working with machine.	N/A	N/A
Eye Injury	Always operate CNC mill while door guards are closed	Safety Goggles	Safety Goggles
Toxic Inhalation	Always check MSDS sheets of materials being cut by the machine to verify no toxic fumes will be created during operation.	Respiratory Mask	Respiratory Mask

Figure 97: CNC Milling PPE table.

The use of CNC milling can pose many risks to the member operating the machine. The CNC milling machine the team has access too is owned by the Engineering Garage Facility. The Facility mandates all members go through a training and safety course before being able to use any of the equipment. This program ensures that all members who use the machine are trained to use the machine safely and properly.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Laser Cutter	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Damage	Always use laser cutter when lid is closed, never directly look at laser when cutting.	Safety Goggles	Safety Goggles
Skin Burn	Always use laser cutter when lid is closed, never have hands inside the cutting unit while the machine is operating.	Insulated Gloves	Insulated Gloves
Fire	Clean the cutting area free of debris after each cut, pay close attention when cutting flammable materials such as wood, use of fire extinguisher in case of fire	N/A	N/A
Air Contaminants	Use of exhaust filtration system, cutting of materials that don't emit toxic contaminents	Respirator Mask	Respirator Mask

Figure 98: Laser Cutter PPE

There are various hazards which can be mitigated through the use of PPE while using a Laser Cutter. Members who use this machine will be trained to always check the MSDS sheet of a work piece before operating the machine.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Abrasive Water Jet	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Hand Injury	Never reach inside cutting pool without proper hand protection **OR** while the machine is operational.	Protective Gloves	Protective Gloves
Eye Injury	N/A	Safety Goggles	Safety Goggles
Foot Injury	Pay close attention to tripping hazards around machine while setting the work up.	Closed-Toe Shoes	Closed-Toe Shoes

Table 49: Waterjet PPE table.

The abrasive water jet has some dangerous safety hazards associated with its use. Team member who will be using the water jet will only use it under close supervision from a certified water jet user. All members who plan to use the water jet will have to go through a certification process to ensure a thorough understanding of the associated safety risks and how to mitigate them.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Dremel rotary tool	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Injury	N/A	Safety Goggles	Safety Goggles
Skin Damage/Irritation	Always wash particulates off of exposed skin areas after working with tool, alert all workers near the work area of the potential particulate hazard.	Protective Gloves, Long-Sleeved Clothing	Protective Gloves, Long-Sleeved Clothing
Hearing Damage	Alert all workers near the work area of the potential hearing hazard.	Ear Plugs	Ear Plugs
Toxic Inhalation	Always check MSDS sheets of materials being cut by tool to verify no toxic fumes will be created during operation.	Respiratory Mask	Respiratory Mask

Table 50: Dremel PPE table.

A Dremel rotary tool has many safety concerns associated with it, due to the nature of the tool. Before using the Dremel, all users will be briefed on how to use the tool as well as supervised during the first uses to ensure proper and safe technique.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Sand Blaster	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Damage	Ensure the sand blaster doors are completetly closed	Safety Goggles	Safety Goggles
Hearing Damage	Alert all workers near the work area of the potential hearing hazard.	Ear Plugs	Ear Plugs
Skin Damage	Be cautious of any sharp edges while preparing work, never operate machine unless using the built in operating gloves.	Protective Gloves, Long-Sleeved Clothing	Protective Gloves, Long-Sleeved Clothing

Table 51: Sand blaster PPE table.

The most predominant safety risks associated with the sand blaster include eye damage and skin damage, which can be mitigated by using proper PPE such as safety goggle and protective clothing.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Manual Lathe	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Damage	N/A	Safety Goggles	Safety Goggles
Laseration/ Dismemberment	Don't wear long-sleeved clothing, don't wear any form of gloves, be highly conciencious of all moving components when operating machine and keep at a safe distance.	N/A	N/A
Skin Irritation	Always wash any coolant or particulates off of exposed skin areas after working with machine.	N/A	N/A
Toxic Inhalation	Always check MSDS sheets of materials being cut by the machine to verify no toxic fumes will be created during operation.	Respiratory Mask	Respiratory Mask

Figure 99: Manual Lathe PPE table.

A Manual Lathe poses many safety concerns to its many large powerful rotating components which the user is exposed to. All users must prove that they can use the machine effectively and safely before gaining access to the machine.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	Band Saw	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Eye Damage	N/A	Safety Goggles	Safety Goggles
Laseration/ Dismemberment	Don't wear long-sleeved clothing, don't wear any form of gloves, be highly conciencious of all moving components when operating machine and keep at a safe distance.	N/A	N/A
Skin Irritation	Always wash any coolant or particulates off of exposed skin areas after working with machine.	N/A	N/A
Toxic Inhalation	Always check MSDS sheets of materials being cut by the machine to verify no toxic fumes will be created during operation.	Respiratory Mask	Respiratory Mask

Table 52:Band saw PPE table.

The band saw can cause serious injury to the user, the most common of which is a laseration. All team member planning on using the Band Saw will go through a certification process to ensure proper technique and use. Also, since the team's carbon fiber airframe is cut using the Band Saw, face mask usage will be enforced to prevent toxic inhalation to the user.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
Vehicle/Payload	X-Winder	Justin Johnson/ Wil Johnson	12/23/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Skin Irritation	Always wash any epoxy off of exposed skin areas after working with machine.	Nitrile Gloves, Long-Sleeved Clothing	Nitrile Gloves, Long-Sleeved Clothing
Eye Irritatation	N/A	Safety Goggles	Safety Goggles
Skin Sensitivy	N/A	Nitrile Gloves, Long-Sleeved Clothing	Nitrile Gloves, Long-Sleeved Clothing

Table 53: X-winder PPE table.

X-winder can pose certain risks to the user during its use. Every member of the team who uses the X-Winder will be properly trained beforehand, especially on how to properly handle epoxy.

Personal Protective Equipment Hazard Assessment (PPE)			
Department	**Task**	**Assessed By**	**Date**
VDS	Soldering	Ben Stringer	12/21/2016
Hazard	**A control that can mitigate the hazard?**	**PPE Available**	**PPE Selected**
Inhalation of Lead-based Solder	Working in a well-ventilated area	Smoke Absorber	Well-ventialted area; Smoke Absorber
Eye Sensitivity	Frequent breaks from soldering	Protective Glasses	Protective Glasses

Table 54: Soldering PPE table.

Soldering can be a dangerous activity if proper training and PPE are not applied. To mitigate risks caused by inexperience, new members first learning to solder must be overseen by an experienced member. This is a mitigation for such risks as burns.

4.2.3 Environmental Hazards Analysis

The Environmental Hazard Analysis is a way for River City Rocketry to address all of the hazards that the team inflicts on the environment as well as the hazards that the environment will inflict on River City Rocketry.

As each hazard arises the team assigns a risk level through the risk assessment matrix shown below in Table 56, which evaluates the severity of the hazard and the probability that the hazard will occur.

For each hazard a severity value between 1 and 4 has been assigned with 1 being the most severe. To determine the severity of a hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, and damage to the rocket and/or equipment. The criteria is outlined below in Table 55.

Severity		
Description	**Value**	**Criteria**
Catastrophic	1	Failure to an extreme where injury to personnel or team members occur.
Critical	2	Failure to the mission statement where zero requirements are met.
Marginal	3	Degraded the mission to where only some requirements are met but the overall mission still fails.
Negligible	4	Little to no mishap occurs to the overall mission and only a loss of redundancy can occur.

Table 55: Severity value criteria.

A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being the most likely. The probability value was determined for each hazard based on the estimated percentage chance that the mishap will occur given the following criteria:

- All team members involved have undergone proper training on all procedures during construction of the rocket, testing, pre-launch operations, and at the launch site.
- All team members have read and acknowledged that they have a clear understanding of all rules and regulations set forth by the latest version of the Safety Manual.

- Personal Protective Equipment (PPE) is used as indicated in the Personal Hazard Analysis section.
- All components were thoroughly inspected for damage or fatigue prior to any test or launch.

The criteria set for the probability value is shown below in Table 56.

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.
Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 56: Probability value criteria.

By the combination of both the severity table and the probability table the risk assessment matrix was developed as shown below in Table 57. The matrix identifies each combination of a severity vs. probability that have hazards result in a high, moderate, or low risk. If a hazard is not at a low risk then the team must take action in the redesign, an update in safety restrictions, or an update of requirements to reduce the overall risk of any particular hazard.

Risk Assessment Matrix				
Probability Value	**Severity Value**			
	Catastrophic-(1)	Critical-(2)	Marginal-(3)	Negligible-(4)
Almost Certain- (1)	2-High	3-High	4-High	5-Moderate
Likely-(2)	3-High	4-High	5-Moderate	6-Moderate
Moderate-(3)	4-High	5-Moderate	6-Moderate	7-Low
Unlikely-(4)	5-Moderate	6-Moderate	7-Low	8-Low
Improbable-(5)	6-Moderate	7-Low	8-Low	9-Low

Table 57: Risk assessment matrix.

With the development of the risk assessment matrix several risk assessment tables can be created that identify hazards in directly correlated between the team and Mother Nature. The following risk assessment tables directly correlate to the Environmental impact the team imposes throughout the course of the season, they are indicated below:

Environmental Hazards to Rocket Risk Assessment

The hazards outlined in Table 101 are risks from the environment that could affect the rocket or a component of the rocket. Several of these hazards resulted in a moderate risk level and will remain that way for the remainder of the season. These hazards are the exception for needing to achieve a low risk level. This is because several of these hazards are out of the team's control, such as the weather. In the case that environmental hazards present themselves on launch day, putting the team at a moderate risk, the launch will be delayed until a low risk level can be achieved. The hazards that the team can control will be mitigated to attain a low risk level.

Hazards to Environmental Risk Assessment

The hazards outlined in Table 102 are risks that construction, testing or launching of the rocket can pose to the environment.

4.2.3.1 Environmental Hazard Requirements

The team has developed some team derived environmental requirements due to its critical function to identify the external and internal environments for 2016-2017 NASA Student Launch competition. The Safety Officer broke up the environmental requirements into two major categories; Team Affecting the Environment and Environmental Concerns. When placing requirements into one of these two categories the following decision tree was created.

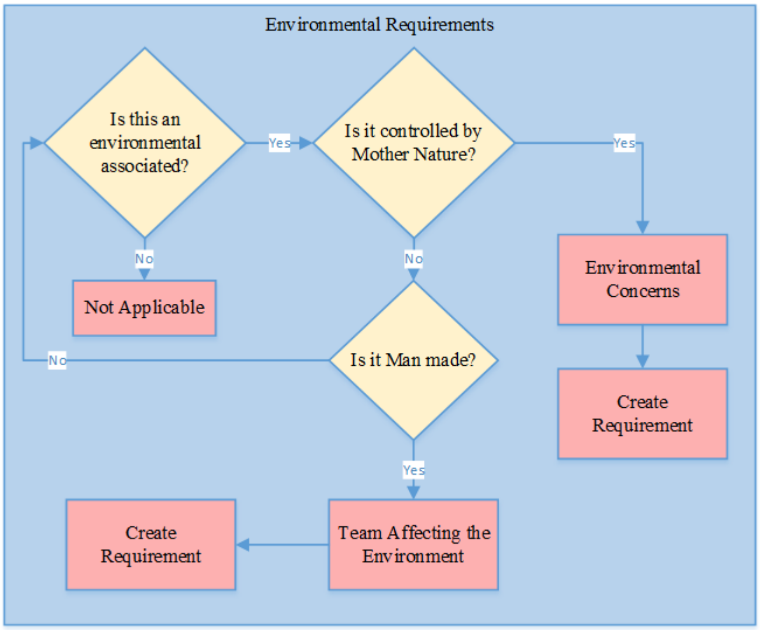


Figure 100: Environmental requirements decision tree.

By placing requirements into the one of the following categories outlined by the decision tree in Figure 100 the team was able to derive the following requirements outlined in the Safety Requirements section.

5 Technical Design: Payload

The Target Detection and Upright Landing challenge was selected for this year's competition experimental payload. As stated in prior documents, in order to accomplish the Statement of Work Requirements set forth by NASA, a multirotor platform integrated into the Launch Vehicle will deploy, transport a custom designed camera system an optimum viewing location to detect the randomly placed targets, and will upright land.

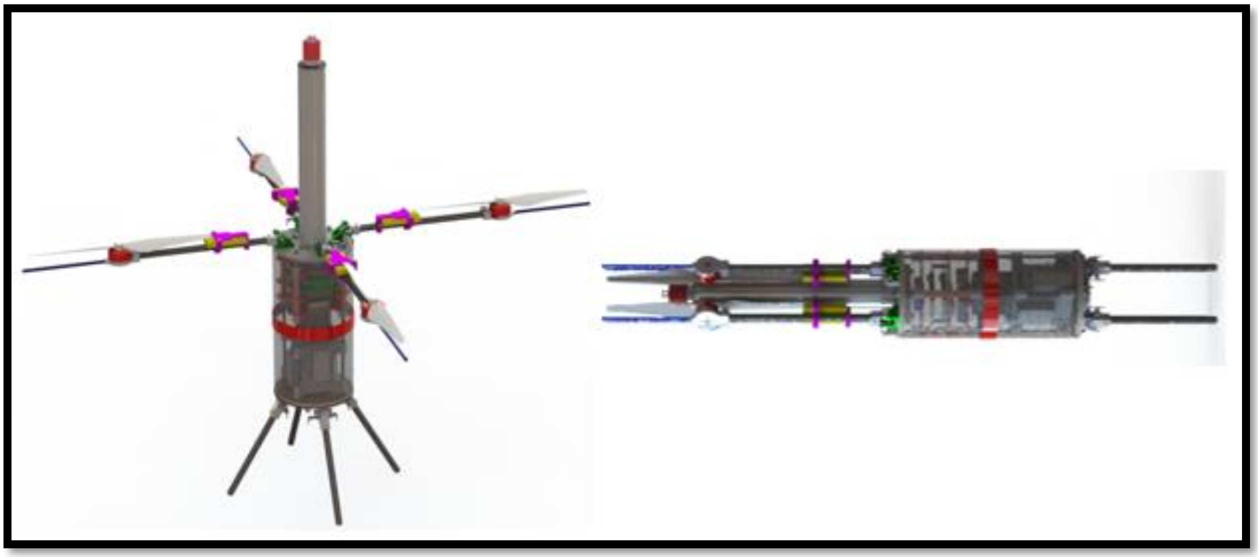


Figure 101: Rendering of the Experimental Payload (left; deployed, right; stowed).

5.1 Overview

The Payload is constructed out of a coupler section of the Launch Vehicle. The overall dimensions of the Payload can be seen below in Table 58: General Dimensions of the Payload..

Payload Characteristic Dimension	Value
Overall height stowed configuration	40.8 in
Overall height deployed configuration	36.0 in
Motor to Motor distance	29.0 in
Overall Payload Mass	8.50 lb

Table 58: General Dimensions of the Payload.

5.1.1 Mission Overview

Table 59 shown below lists the Mission Overview for the Payload.

Mission Step	Mission Item Description
1.	The Launch Vehicle will ascend to its intended apogee and begin its recovery scheme.
2.	At approximately 1300ft the launch vehicle will deploy the multirotor payload under a parachute.
3.	Once deployed, the Payload will run through preflight system checks to determine airworthiness.

4.	Once all of the preflight checks have been accomplished the payload will alert the ground station that the payload is ready to take flight. To proceed to the next step, approval by the RSO must be acquired in order to continue.
5.	Upon approval via the RSO, the payload will jettison the deployment parachute through the use of the ARRD mechanism for which it was attached to and continue in completing the flight mission via the multirotor system.
6.	Once the payload has taken flight the RSO will have the ability to deploy the backup parachute for any reason he/she sees fit in the event of a safety concern.
7.	Once the payload is 500ft above the launch pad that the launch vehicle originally ascended from, the payload will begin the target differentiation and identification process.
8.	The payload will position hold as the onboard camera system identifies and differentiates between the targets.
9.	The payload will maneuver to a position of 300ft forward of the launch rail and will then position hold.
10.	The payload will then alert the ground station it is ready to land.
11.	The RSO will decide whether they want the payload to autonomously land or whether they would prefer for the payload to land via it backup onboard parachute due to safety concerns. If a decision is not made within 1 minute, the Payload will land via backup parachute.

Table 59: Mission Overview Table.

5.1.2 System Overview

In order to complete the Payload's mission and fulfill all of the Statement of Work Requirements set by NASA as well as all of the team derived requirements, the Payload was separated into several specific subsystems. Figure 102 displays a rendering of the Payload with highlighted subsystems. Table 60 lists the Payload subsystems along with their descriptions which are color-coded with accordance to Figure 103.

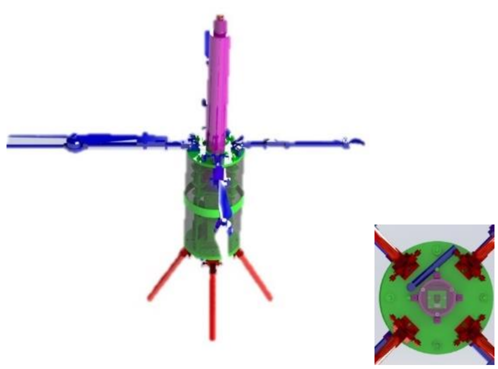


Figure 102: Payload Subsystem breakdown by color.

Payload Subsystem	Description
Multirotor Recovery System (MRS)	The Multirotor Recovery System is the main system responsible for maneuvering the Payload to a clear line of sight over the targets and for performing a controlled upright landing.
Redundant Recovery System (RRS)	The Redundant Recovery System is a backup system which monitors the state of the payload during deployment from the Launch Vehicle and during the MRS's flight.

Target Detection System (TDS)	The Target Detection System is the camera system responsible for identifying and detecting the three randomly placed targets.
Landing Leg System (LLS)	The Landing Leg System is the system responsible for providing structure for the Payload to land upright upon.
Payload Structural System (PSS)	The Payload Structural System is the system which provides support and reacts flight loads induced by various operations of the Launch Vehicle and the Payload.
Deployment System (DS)	The Deployment System is the system which integrates and deploys the Payload from the Launch Vehicle.
Ground Support Equipment (GSE)	Ground Support Equipment serves as the system which the team will utilize to receive real time telemetry data of the Payload.

Table 60: Payload Subsystems and their descriptions.

5.2 MRS (Multirotor Recovery System)

5.2.1 Overview of System

As stated in section 7.4 of the PDR, the Multirotor Recovery System (MRS) is the primary system responsible for maneuvering the Payload to an appropriate point of view for the Target Detection System (TDS) and for safe recovery and upright landing of a section of the rocket. The MRS encompasses all of the components necessary for the flight of the Payload.

5.2.1.1 Guidance, Navigation and Control (GNC)

5.2.1.1.1 Updates to Flight Logic

Changes to the MRS GNC logic flowchart are outlined in Figure 103 below.

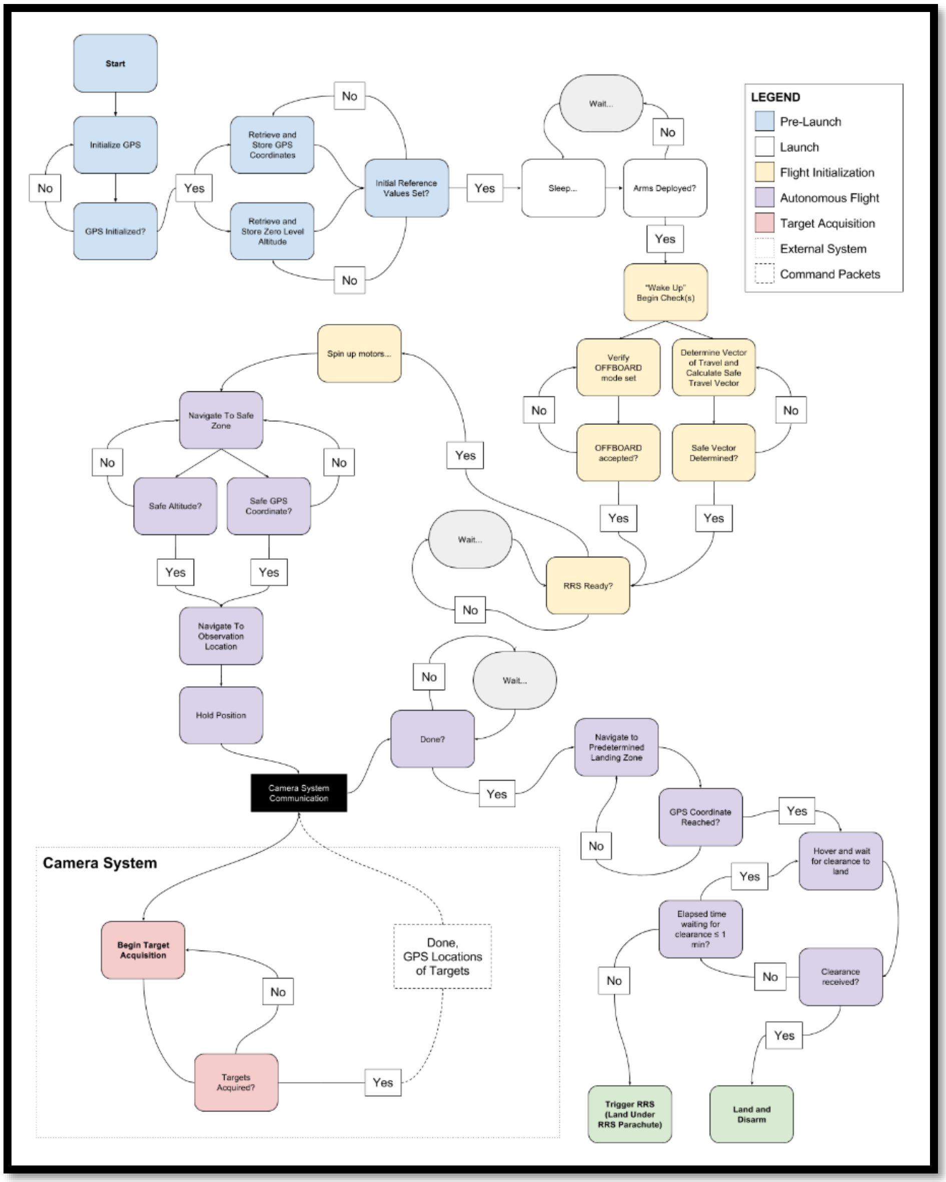


Figure 103: MRS GNC flight logic.

The changes to the flight logic originally presented in PDR are mostly related to the simplification of several steps in the recovery flight.

Within the Flight Initialization stage, the MRS will send a signal to the GSE through telemetry that will alert the RSO that the flight system is ready to be released from the Payload Deployment Parachute. After the RSO verified that the Payload can begin autonomous flight, the GSE will be send a signal to the RRS, triggering the cutaway of the Payload Deployment Parachute. Other changes revolve around the simplification of the flight for safety concerns related to maneuvering the Payload close to the launch site. These changes include eliminating the ability of the TDS to direct flight as well as removing the goal of landing on the targets. Rather than automatic autonomous landing, the MRS will now move to a predetermined landing location and wait for RSO clearance to land via rotor power. If no clearance is received after 1 minute, the RRS will fire and the Payload will land under the RRS Parachute. This is summarized in requirement MRS.1.5.

5.2.2 Software

The autonomous flight software of the MRS is written in C++ and Python 2.7 and runs on a Raspberry Pi 3 flight computer, as originally chosen in section 7.4.8.1 in PDR. Within the flight computer, a software framework called the Robot Operating System (ROS) is utilized to handle control of the flight controller via the flight computer's onboard universal asynchronous receiver/transmitter (UART) peripheral. Section 5.2.2.1 below details the functionality and concepts behind ROS.

The MRS software is summed up in Figure 104 below.

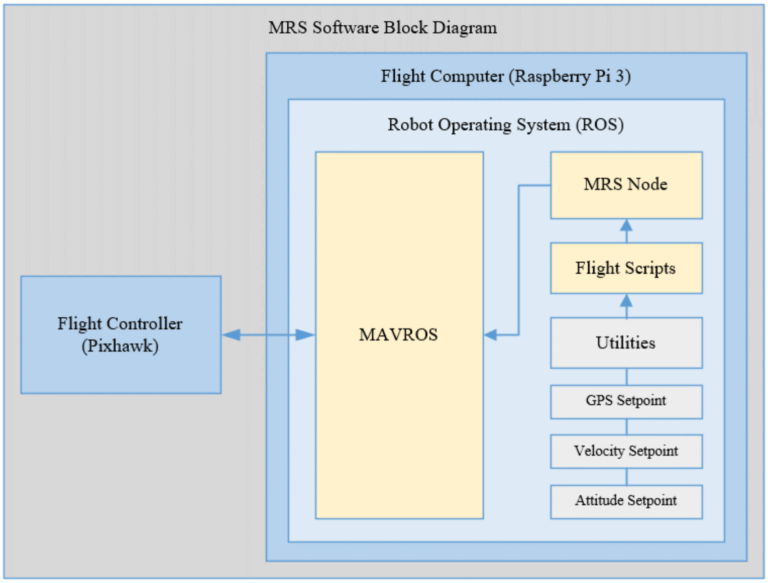


Figure 104: Block diagram of the MRS software.

5.2.2.1 Flight Controller Software

The Pixhawk flight controller handles all low-level communication with the array of sensors necessary to achieve flight of the multirotor. It runs a software package called PX4 which is an open-source autopilot solution for aerial robotic systems and allows for rapid development of autonomous behavior.

5.2.2.2 Robot Operating System

The Robot Operating System is widely used in the robotics industry as a means of interfacing several individual systems containing a potentially complex network of sensors into one cohesive robotic system that can be used to achieve a desired end-goal. Software written to run on ROS is referred to as a *node* and runs concurrently with all other active nodes. ROS also includes middleware meant to allow communication and collaboration between nodes. This system, coupled with the tools made available for use by the ROS framework, make it a perfect solution for the programming of the Payload.

5.2.2.2.1 MAVROS

On the Payload, ROS is configured to run constantly on the flight computer and maintain an active connection to the flight controller through a node called MAVROS which is available online from the developers of the PX4 software package. MAVROS is an implementation of the Micro Aerial Vehicle Link (MAVLink) protocol. The PX4 software package is designed to provide full control of the flight controller through the MAVLink connection, therefore the combination of these two systems allows for constant tracking and manipulation of the state of the Payload using ROS. This ultimately provides the capability to perform fully autonomous control.

The flight scripts controlling the Payload run in their own node within ROS. Commanding of the flight controller is achieved via internal communication from the flight script node to the aforementioned MAVROS node and ultimately to the flight controller.

5.2.2.2.2 Simulations

An integral piece of the design process of the Payload is the ability to simulate flight behavior. This allows for the mitigation of risking flight hardware damage during the development process.

Simulation capability is provided by a ROS-compatible robotic simulation software package called Gazebo. On the flight computer, ROS can be triggered to run in software-in-the-loop (SITL) mode in order to simulate a connection to the flight controller without requiring actual flight. In this mode, the SITL instance will accurately simulate nominal conditions of the flight controller including sensor inputs, occasional input anomalies, and physical interactions with its simulated environment. The SITL simulation startup is shown below in Figure 105.

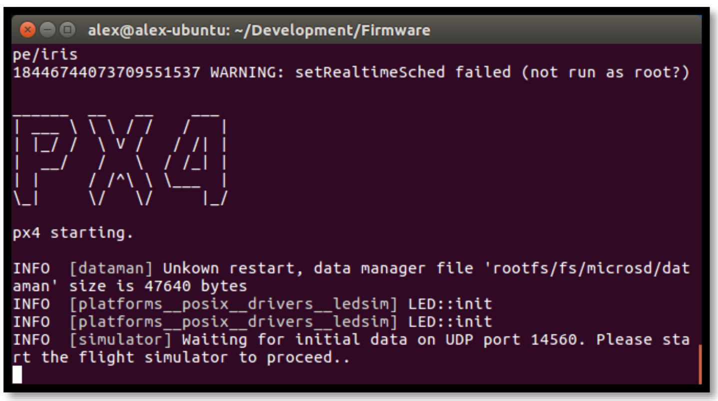


Figure 105: Gazebo simulator startup.

Figure 106 below shows the GUI of Gazebo after initialization of the SITL simulations is complete.

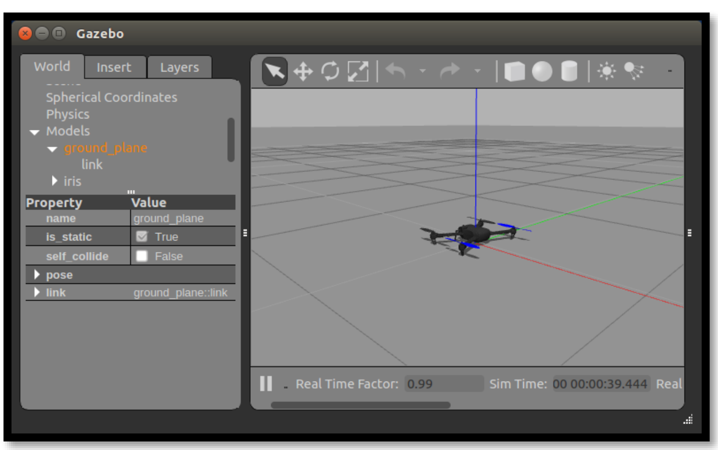


Figure 106: Gazebo simulator GUI.

With the simulator running, development and testing of the flight scripts can proceed rapidly without concern for damage to equipment. Moving from a simulated flight to an actual flight requires only that ROS be restarted and the SITL simulation not to be entered. This will connect to the actual flight controller normally.

5.2.3 Hardware

Figure 107 shows a high level block diagram of how the electronic hardware of the MRS is connected.

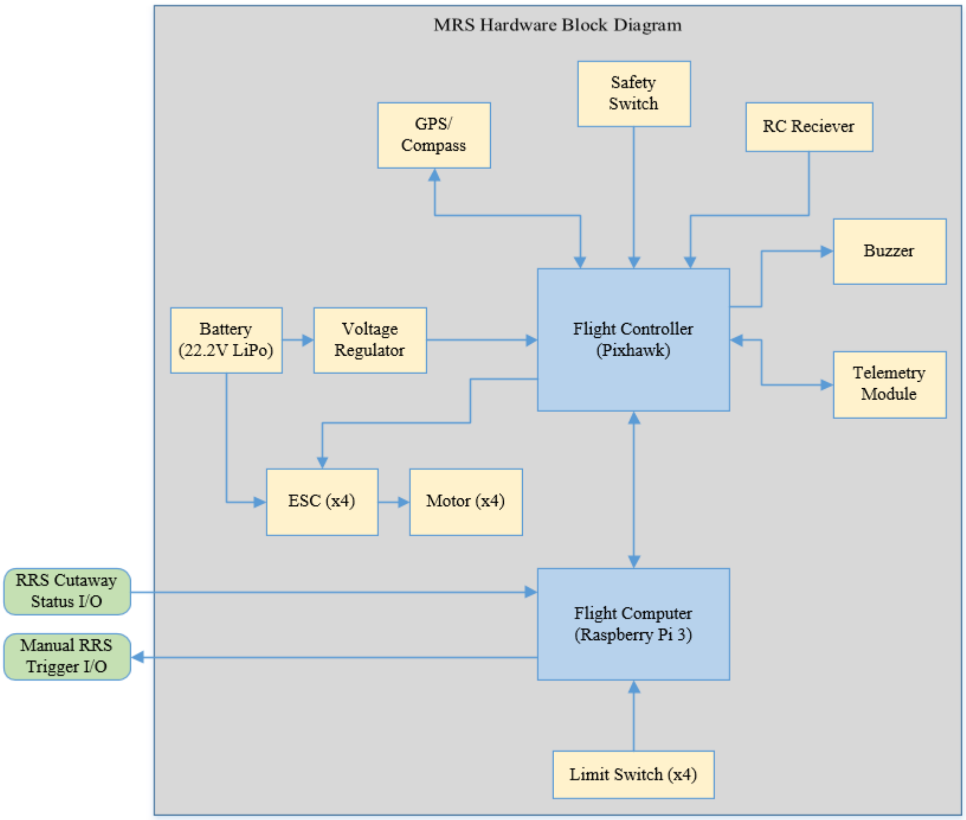


Figure 107: MRS Hardware Block Diagram

The MRS has been assembled for real-world flight testing on a Tarot Iron Man 650mm quadcopter and is shown in Figure 108 below. Refer to the MRS Test Campaign for details about the usage of this test platform.

Figure 108: The MRS test platform.

5.2.4 Mechanical Design

5.2.4.1 Propulsion System

The Propulsion System selected is the DJI E800 motor set. The motor configuration and hardware remains the same from the selection made during PDR. See the PDR document for more details regarding trade studies and specifics of the system. See Test Document for thrust verification testing. Table 61 depicts the specifications of the selected propulsion system.

Propulsion System Specification	Value
Multirotor Configuration	Quadcopter X4
Motor	DJI E800
ESC	DJI 620S
Rated Max Thrust	2.1 kg
KV	350 Rev/Volt

Table 61: Propulsion system specifications.

5.2.4.2 Propulsion Arm

The Propulsion Arm is a structural system which is used to deploy the multirotor motors from the vehicle and react the thrust loads induced by the motor during flight. Figure 109 displays the Propulsion Arm.

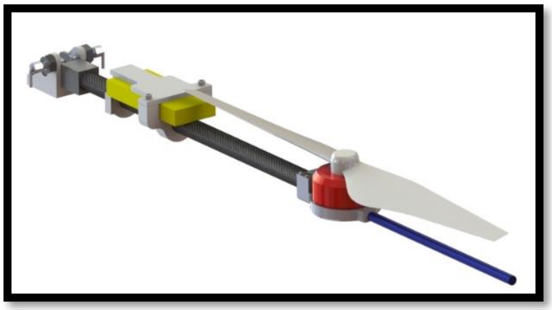


Figure 109: Rendering of the Propulsion Arm in the deployed configuration.

The Arm Deployment Mechanism is broken down into two primary subsystems shown below in Table 62.

Subsystem	Description	Function
Arm Pivot Assembly	Assembly which contains the arm clevis, arm pivot, lock pins, and torsion spring.	The Arm Pivot Assembly actuates the Motor Mount Assembly from the stowed position into the deployed position and rigidly locks the assembly into place.
Motor Assembly	The Motor Assembly consists of the Carbon Fiber Arm, the Motor Mount, the propeller guard, and the E800 Motor	The Motor Assembly generates lift necessary to maneuver the Payload in the air.

Table 62: Arm Deployment Mechanism Subsystems.

5.2.4.2.1 *Arm Pivot Assembly*

The Arm Pivot Assembly is pictured below in the stowed and locked configurations. Figure 110 display the detailed drawing of the Arm Pivot Assembly with its exploded view.

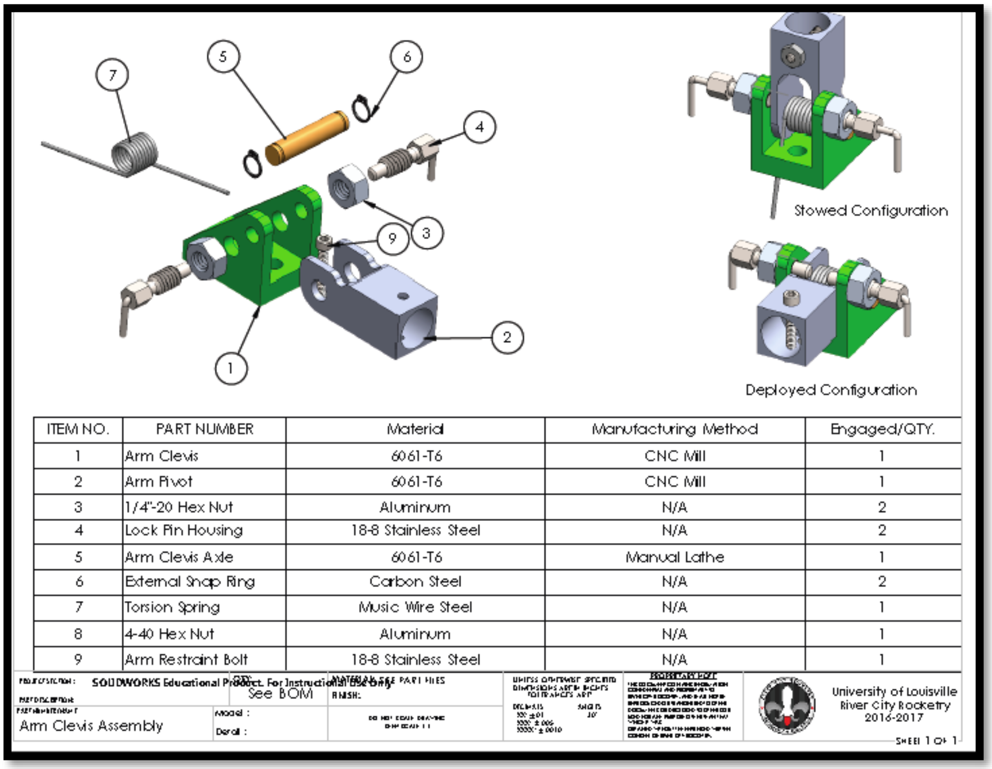


Figure 110: Detailed drawing and exploded view of the Arm Pivot Assembly.

The Arm Pivot Assembly was designed to serve as a simple mechanism to deploy the Motor Assembly into the deployed flight configuration. The actuation of the Arm Pivot Assembly is centered around the Arm Pivot, Arm Clevis, Pivot Axel, and torsion spring.

5.2.4.2.1.1 Arm Pivot

The Arm Pivot is a component CNC machined out of 6061-T6. Key design features of the Arm Pivot are the arm mounting hole located in the front of the component, a through hole and concentric 4-40 threaded hole which the arm restraint bolt mounts into, lock pin contours, and the contoured rear forks.

The threaded through hole allows for a 4-40 bolt to pass through the Arm Pivot and the carbon fiber arm which axially and rotationally restrains the Motor Assembly in place. Figure 111 displays a rending of a detailed section view of the interaction between the Arm Pivot, Restraint Bolt, Jam nut, and the Carbon Fiber Arm.

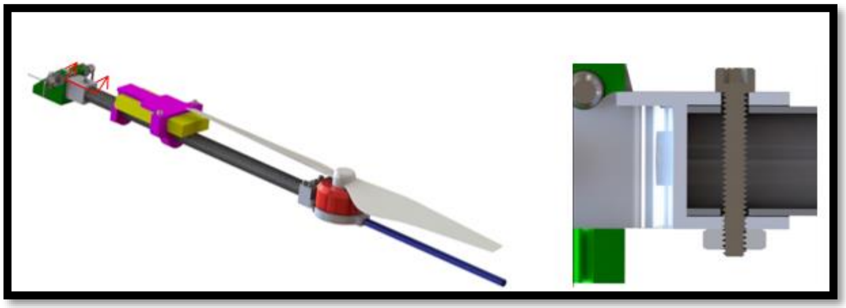


Figure 111: Detailed section view of the interaction between the Arm Pivot, Restraint bolt, Jam nut, and Carbon Fiber Arm.

The Arm Pivot utilizes geometry which allows for the Lock Pin Mechanism to engage only once the Arm Pivot is fully actuated. Once the Arm Pivot has actuated into the fully deployed state, the lock pin is allowed to engage past the lock pin contour feature of the Arm Pivot. Figure 112 displays a detailed view of the Lock Pin, Arm Clevis, and Arm Pivot interaction.

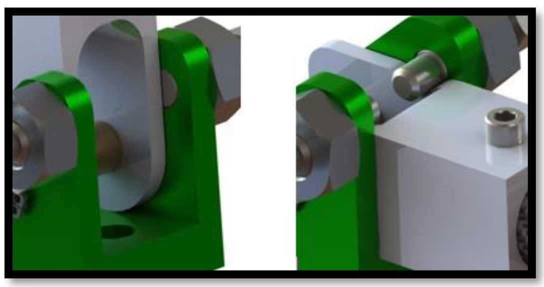


Figure 112: Detailed view of the Lock Pin being restrained in the stowed configuration (Left) and being engaged into the lock pin contour feature in the Arm Pivot (Right).

The Arm Pivot utilizes a contoured fork geometry which allows for only actuation in the deployment configuration. This is accomplished through a built in flat on the back of the component which acts as a stop in stowed configuration. Figure 113 displays the interaction between the fork stop geometry of the Arm Pivot and the Arm Clevis.

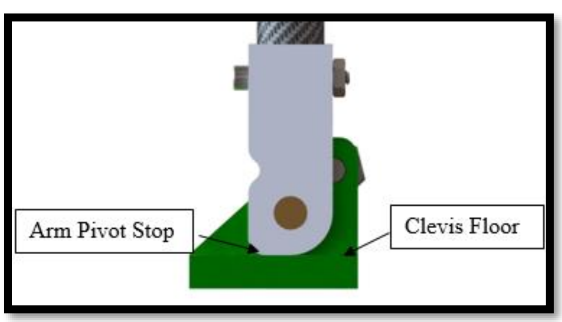


Figure 113: Section view displaying Arm Pivot mechanical stop contour against Arm Clevis floor.

5.2.4.2.1.2 Torsion Spring

The Arm Pivot Assembly actuates through the implementation of a torsion spring. The torsion spring is constrained axially by the Arm Clevis Axel, the Arm Pivot. The Arm Pivot Assembly is designed to actuate 90 degrees about the Arm Clevis Axel. In order to maintain a torque on the Arm pivot at all actuation angles, a McMaster-Carr torsion spring with a 0 degree deflection angle was selected. Table 63 displays the specifications of the selected torsion spring.

Torsion Spring Specification	Value
McMaster part no.	9271K182
Un-deflected angle	0 deg
Deployed deflection angle	12 deg
Stowed deflection angle	101 deg
Torsion spring rate	.015 in*lb/deg

Table 63: Selected torsion spring specifications

Using the information shown in Table 63, a motion analysis was conducted using SolidWorks to determine deployment time of the Propulsion Arm. The deployment time of the Propulsion Arm was analyzed to be 0.52 sec.

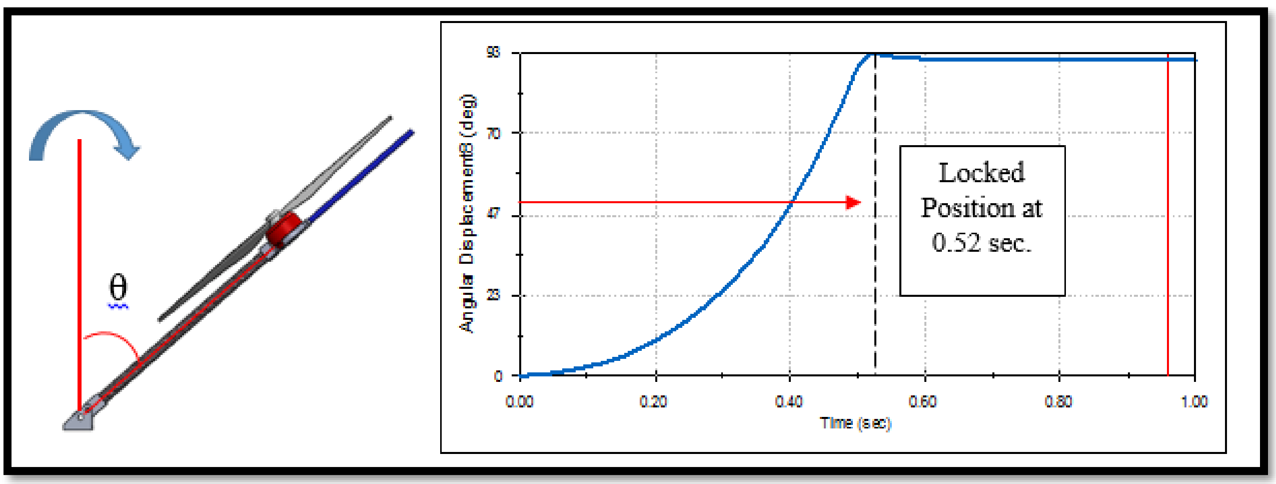
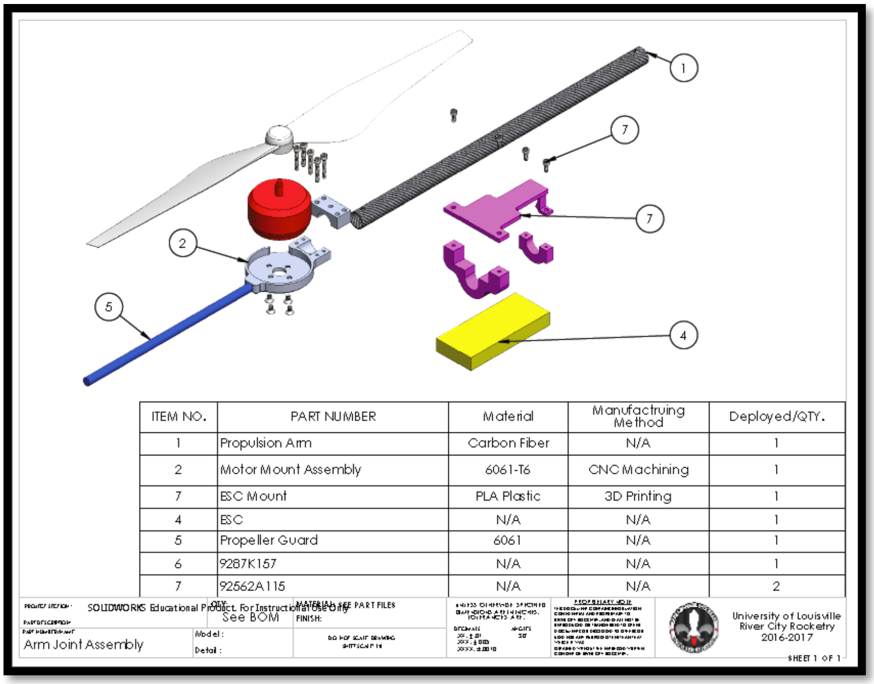


Figure 114: Results from the motion study analysis.

5.2.4.2.2 Motor Assembly

The Motor assembly consists of the carbon fiber arm and the motor mount which supports the DJI E800 motor. This assembly serves to transfer the thrust loads produced by the motor into the Arm Pivot Assembly.



ITEM NO.	PART NUMBER	Material	Manufactruing Method	Deployed/QTY.
1	Propulsion Arm	Carbon Fiber	N/A	1
2	Motor Mount Assembly	6061-T6	CNC Machining	1
7	ESC Mount	PLA Plastic	3D Printing	1
4	ESC	N/A	N/A	1
5	Propeller Guard	6061	N/A	1
6	9287K157	N/A	N/A	1
7	92562A115	N/A	N/A	2

Figure 115: Detailed drawing and exploded view of the Motor Assembly.

5.2.4.2.2.1 Motor Mount Sub-Assembly

The Motor Mount Sub-Assembly is a set of 6061-T6 CNC machined components which allows for the mounting of the E800 motor into the Propulsion Arm. The Motor Mount Sub-Assembly also incorporates the 0.25 inch propeller guard rod. This rod is used to protect the propellers from breaking upon deployment from the Deployment bay of the Launch Vehicle. Carbon Fiber Arm

5.2.4.2.2.2 Carbon Fiber Arm

The Carbon Fiber Arm was selected to be made from the Rock West Composites 45551-HM tube. This tube was selected for its extreme rigidity, strength, and light weight.

Carbon Fiber Arm Specification	Value
Outer Diameter	0.508 inch
Wall thickness	0.036
Density	.057 lb/in^3
Elastic Modulus	18 Mpsi

Table 64: 45551-HM Carbon Fiber Tube Properties.

5.2.4.2.3 Propulsion Arm Stress Analysis

All stress cases where based off the Max thrust conditions. The following equations were used to develop the thrust and torque.

$$P = VI \tag{39}$$

where V is voltage, I is current. The KV motor characteristic is defined by

$$KV = \frac{\omega}{V} \tag{40}$$

where ω is angular velocity. Additionally, rotational power output is defined by

$$P = T\omega \tag{41}$$

where T is motor torque. Combining the above equations yields the following equation.

$$T = \frac{I}{KV} \tag{42}$$

E800 Parameter	Value
Max Thrust (at Sea Level)	2.1 kg
Calculated Max Motor Torque	0.546 N*m

Table 65: DJI E800 Motor Performance Parameters.

Using this information Finite Element Analysis models were derived based of these loading configurations. Figure 116 displays the FEA model setup and results performed on the Arm Pivot Assembly.

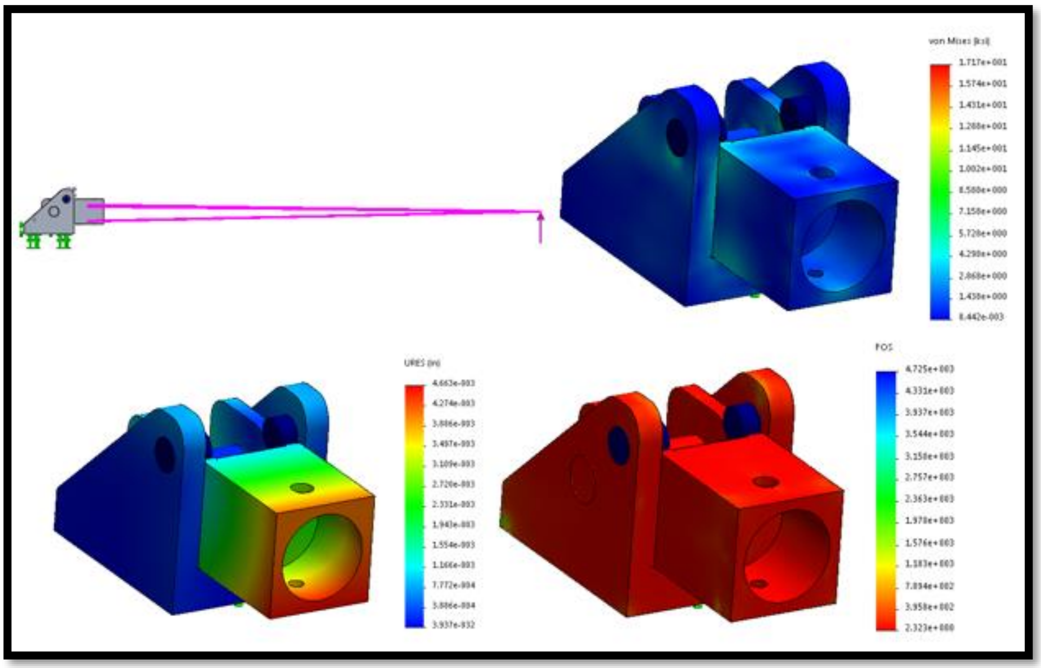


Figure 116: FEA model setup, Von Mises Stress, Deflection, and FOS on the Arm Pivot Assembly.

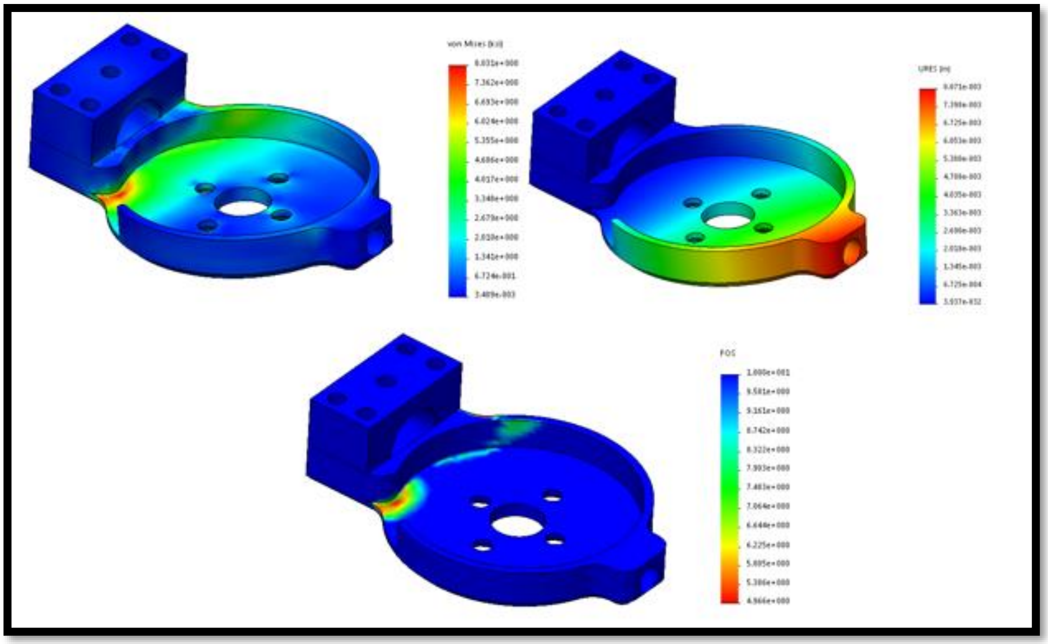


Figure 117: FEA model setup, Von Mises Stress, Deflection, and FOS on the Motor Mount Assembly.

5.3 GSE (Ground Station Equipment)

5.3.1 Overview of System

The Ground Station Equipment (GSE) is designed to receive telemetry data from the payload, specifically the MRS and the RRS. This system also provides ground crew controlled emergency override capabilities of the electrical systems in the payload.

5.3.2 Software

The GSE laptop will display telemetry data from the MRS. This data includes GPS and altitude as well as battery levels, mode information, estimated ground speeds and the general attitude of the payload. All of this data is provided via QGroundControl (shown below in Figure 118), a free ground control software designed for use with commercially available multirotors and other RC aircraft.

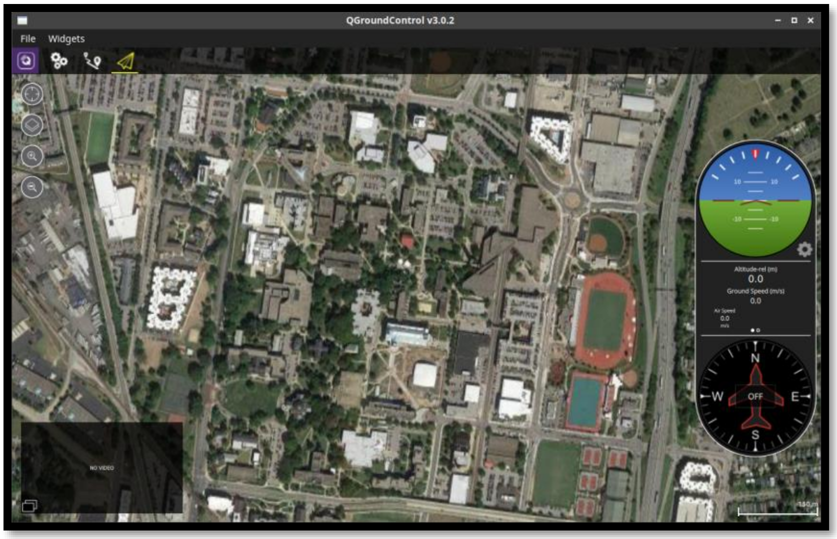


Figure 118: The QGroundControl GUI.

5.3.3 Hardware

The GSE hardware consists of two radio transmitters and a laptop connected to a telemetry module for communication with the Payload. This hardware can be seen below in Figure 119.

Figure 119: The GSE Hardware.

5.3.3.1 Primary RC Transmitter

The Primary RC transmitter is for communication with the MRS. This transmitter is a Turnigy 9XR handheld radio with a FrSky transmitter module. This transmitter has the ability to place the payload in hold, land, and return to launch modes as well as stabilized flight mode where the operator will have full flight control over the Payload.

5.3.3.2 Secondary RC Transmitter

The Secondary GSE RC transmitter is for communication with the RRS. This transmitter will be responsible for signaling the RRS ground verification for the deployment, and the autonomous landing under rotor power of the MRS. It will also be responsible for firing the RRS manually from the ground if desired. This transmitter is a Spektrum DXe handheld radio with built a Spektrum DSMX transmitter.

5.3.3.3 Telemetry Module

The telemetry module is a 433 MHz 2-way radio. An identical module is attached to the Payload. Its purpose is to receive flight information from the Payload and display it within QGroundControl as discussed in the GSE Software section above.

5.4 RRS (Redundant Recovery System)

5.4.1 Overview of System

The redundant recovery system (RRS) is designed as a safety mechanism that ensures that the payload mission is carried out safely.

The Redundant Recovery System (RRS) is designed to ensure the payload lands with a kinetic energy less than 75 ft*lb. It controls the deployment parachute, power to MRS motors, and the recovery parachute. The recovery parachute cannot be deployed at this time. Upon the payload being deployed the recovery remains unarmed. The RSO must instruct the payload to activate, meaning the MRS is initialized and the RRS performs cutaway from the deployment parachute. The MRS motors are then activated.

At this point the RRS begins monitoring of the payload's descent and the recovery BP charges are armed. If the kinetic energy exceeds 75 ft*lb, or the RSO requires parachute landing, or the MRS determines the mission should be aborted, or the RRS loses power, the recovery parachute is deployed. In all instances power to the MRS's motors is inhibited. The deployment and recovery parachutes are the same type of parachute. Therefore, any descent path keeps the payload's kinetic energy low.

RRS Phase	RRS Mission	RRS Operation
1	Preflight and Ascent	Armed at initialization via an external switch on the launch pad.
2	Payload Deployment	Disconnects Payload from deployment parachute once the MRS initialization is completed and the permission of RSO is given.
3	Payload Mission	Monitor decent velocity of Payload to ensure safe descent.

Table 66: RRS Mission Sections with Corresponding Operations.

The three phases of the RRS's mission are summarized above in Table 66 and outlined in detail below in Figure 120.

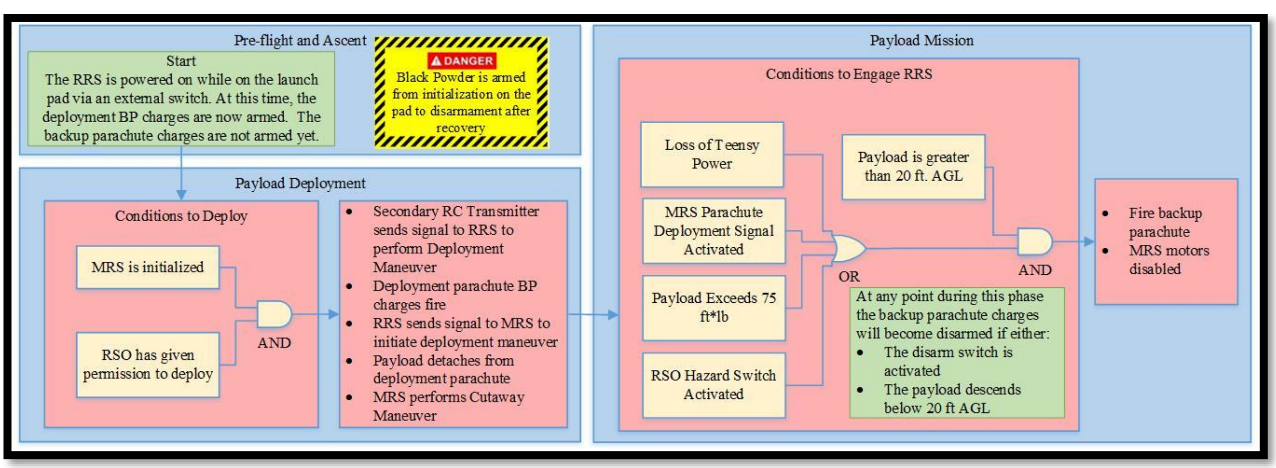


Figure 120: RRS mission overview block diagram.

5.4.1.1 Pre-flight and Ascent

The RRS is first powered on at the launch pad via an external switch. A piezo speaker on the RRS will provide a confirmation that the deployment black powder charges have been armed. This method of arming the charges complies with SOW requirements 2.7 and 2.9 starting on page 177.

5.4.1.2 Payload Deployment

After being initialized on the pad, the RRS enters the payload deployment phase of its mission where it awaits two conditions to deploy the payload, separating it from the deployment parachute. The first condition is that the MRS must have had a successful initialization. The second condition is that the RSO must have given permission to deploy the payload via the GSE controller.

5.4.1.3 Payload Mission

After the payload has been deployed and is performing its search for the targets, the RRS enters the payload mission phase. During this phase the RRS is monitoring for the conditions necessary to deploy the backup parachute and cut MRS power. An extra safety condition has been added to this phase where the black powder will be disarmed if the RRS is below 20 ft. AGL. This extra safety measure ensures that black powder is not armed while within an unsafe radius of possible bystanders. The backup parachute charges can also be disarmed via a disarmament switch on the GSE controller. The GSE disarmament switch will be used to disarm the backup parachute charges in the event of a successful payload mission.

5.4.2 Electrical Design

Figure 121 below shows the entirety of the RRS's circuitry. The schematic is subdivided according to the RRS's functionality; it includes the AARD control circuit (deployment parachute), the recovery parachute failsafe circuit (backup parachute), the multirotor power control circuit, and the Teensy 3.6. The ARRD enables the RRS to cut away from the deployment parachute. The power to multirotor motors section controls power to the MRS motors. The BMP180 is the major sensor for determining the payload's kinetic energy. The recovery parachute failsafe circuit is responsible for activating the backup parachute and is configured to activate even in the event that the Teensy loses power while in the armed state.

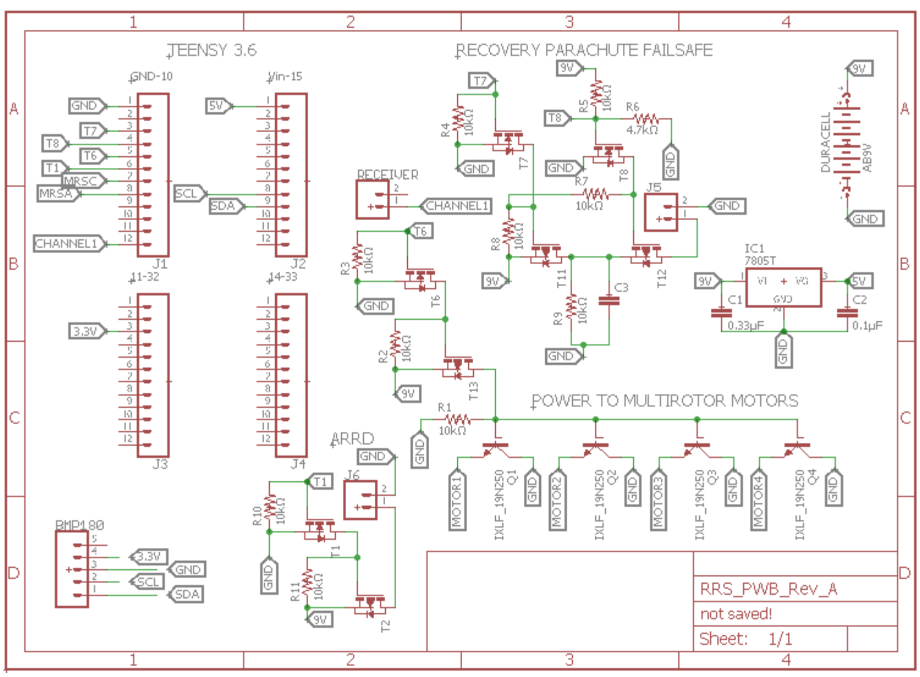


Figure 121: RRS schematic.

5.4.2.1 ARRD

The RRS's simplest circuit controls the Advanced Retention Release Device (ARRD) connected to the deployment parachute. Upon obtaining the RSO's command (CHANNEL1) to begin the MRS's mission this circuit is triggered (T1). The 9V battery is connected to the ARRD and the deployment parachute is released. From here the MRS is in command of the payload's flight.

5.4.2.2 Power to Multirotor Motors

Simultaneously to the deployment, another signal (T6) is sent to the MRS motor power controllers. This turns on the Insulated Gate Bipolar Transistors (IGBTs) and allows power to flow into the motors. The IGBTs were selected for their ability to withstand 625W continuously at high voltage and Amperage as shown in Figure 122Figure 122.

Power Control to MRS Motors							
Options:		IXYS IXXH80N65B4H1		D45H2A		IXYS IXBH12N300	
Mandatory Requirements							
Voltage Tolerance > 26V		Yes		Yes		Yes	
Amperage Tolerance > 20A		Yes		Yes		Yes	
Power Dissapation > 520W		Yes		No		No	
Wants	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Benefits							
Available Documentation (0-10)	25.00%	8	2.00	8	2.00	8	2.00
PWB Shadow (0-10)	40.00%	6	2.40	7	2.80	7	2.80
Costs							
Weight (g)	30.00%	6	1.80	2.1	0.63	6	1.80
Monetary Cost ($)	5.00%	$8.75	0.44	$1.11	0.06	$24.00	1.20
Calculations	**Total**						
Benefit	14.00	0.31		0.34		0.34	
Cost	5.92	0.38		0.12		0.51	
Total Score		**0.83**		**0.00**		**0.00**	

Figure 122: Power Control Trade Study

5.4.2.3 BMP180

After the deployment parachute has been released, the RRS monitors the kinetic energy of the payload. The BMP180 has an effective range of 300 to 1100 hPa (9000m to -500m below sea level). Within this range it is rated at ±0.25m. This accuracy was found to be false, and the BMP180 has an accuracy of ±1m. This inaccuracy is mitigated through taking many pressure readings and deriving an average with

$$P_{avg} = \frac{P_1 + P_2 + \cdots P_{10}}{10} \tag{43}$$

These values are used to determine the payload's current altitude from the launch pad. The time taken between each altitude reading is also stored and used to determine velocity. The falling velocity of the payload is calculated by using

$$v = \frac{h_n - h_{n-1}}{\Delta t} \tag{44}$$

where h_n is the current altitude, h_{n-1} is the previous altitude, and Δt is the time between altitude measurements. Then with knowledge of the Payload's exact mass [m], the equation

$$v = \sqrt{\frac{m}{2KE}} \tag{45}$$

calculates the Payload's velocity for a given kinetic energy [KE]. Using Table 67 if the payload is falling at a rate of 15.789 mph or greater the RRS will deploy the recovery parachute.

Payload Mass [lb]	Kinetic Energy [ft*lb]	Velocity [mph]

9	60	14.122
9	65	14.698
9	70	15.253
9	75	15.789
9	80	16.306

Table 67: Descent velocity for Payload at specific kinetic energies.

5.4.2.4 **Recovery Parachute Failsafe**

At any time after deployment the recovery parachute may be necessary. This could be due to the RSO desiring a parachute landing, the MRS deciding to abort the mission, the payload's kinetic energy going past 75 ft*lb, or the RRS losing power. This failsafe ensures that before arming there are no connections possible to the black powder charge, and after being armed the recovery parachute will be deployed if any failure state occurs.

5.4.3 RRS and Deployment Parachute

The RRS parachute is designed to be the exact same size as the deployment parachute to bring the multirotor back to a safe kinetic energy in the event that an off nominal flight condition occurs. The dimensions of the parachute are designed using the same criteria and equations as in section 3.3. The dimensions are shown below.

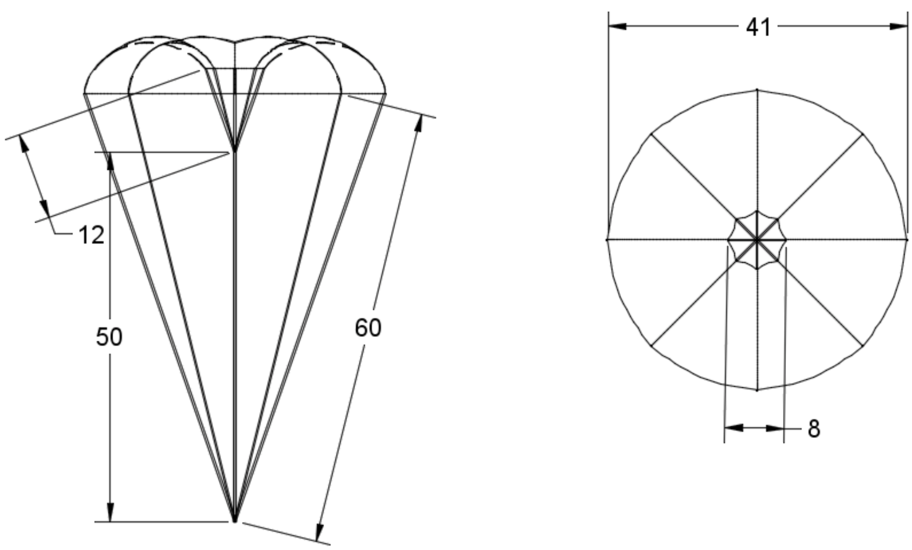


Table 68: RRS parachute dimensions. Units in inches.

5.4.4 RRS Mechanisms

The RRS mechanisms are centered around the use of black powder charges to release the Deployment Parachute and to deploy the RRS Parachute. Figure 123 displays the RRS mechanism.

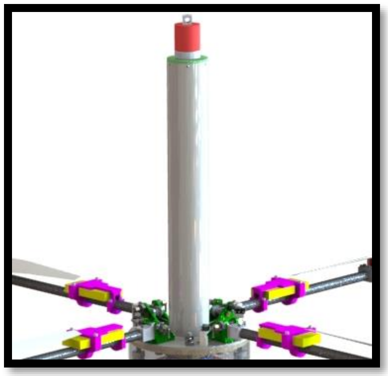


Figure 123: Rendering of the RRS mechanism.

5.4.4.1 Deployment Parachute Mechanism

The Deployment Parachute of the Payload will be controlled by the use of an ARRD mounted to the top of the RRS tube. This device will release the Deployment Parachute via two redundant E-matches from the RRS. The ARRD mechanism will be mounted onto the One-Way Shearing Bulkplate. The One-Way Shearing Bulk Plate is shown below in Figure 124.

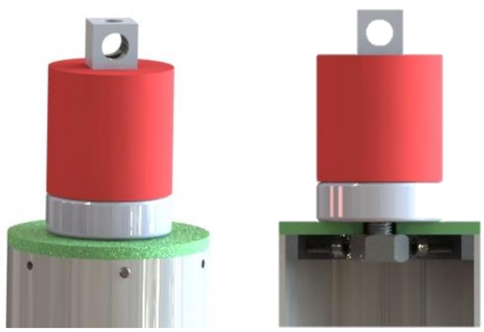


Figure 124: ARRD and One-Way Shearing Bulkplate with section view showing internal nylon shear pins.

5.4.4.2 RRS Parachute

The RRS Parachute of the Payload will deploy via redundant black powder charges. These charges will deploy the RRS Parachute by shearing the One-Way Shearing bulk plate up and off the RRS tube via internal nylon shear pins. This design was necessary to allow for the RRS tube to be integrated into the Deployment Bay. The black powder charge will be contained via the Removable Sealing Bulkplate located at the bottom to the RRS tube. This is a removable wooden bulkplate which incorporates a rubber o-ring to maintain a seal during the event of a deployment.

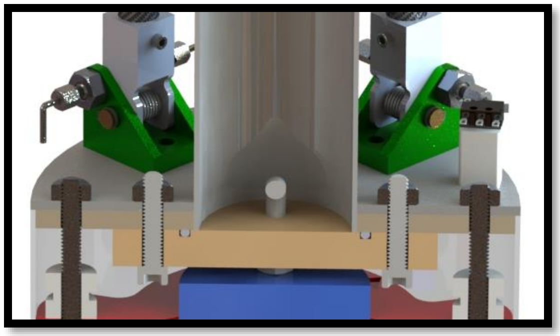


Figure 125: Section view of the Removable Sealing Bulkplate at the bottom of the RRS Tube.

5.5 TDS (Target Detection System)

5.5.1 Overview of System

The Target Detection System (TDS) is responsible for identifying and capturing pictures of targets found during flight. Implemented on a Raspberry Pi 3 and working in tandem with the MRS as a set of callable functions to provide a seamless integration and minimize the risk of interference between said systems. The TDS incorporates a Raspberry Pi Camera module to record still images captured during flight. The camera will be mounted at the bottom of the payload. Specifics regarding both the housing as well as the camera shall be explained in subsequent sections. The algorithm itself is based on a series of tests to determine if any captured entities match the physical characteristics of a target. Detail shall be provided below.

5.5.2 Camera System

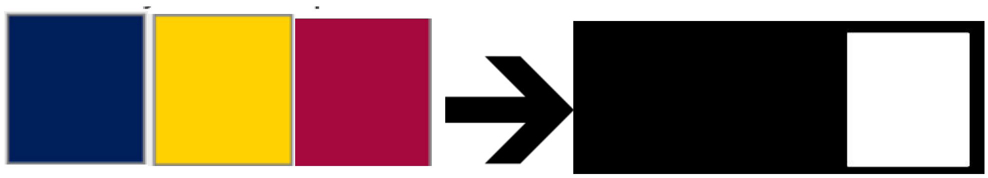
The camera system relies on a V1 5-megapixel PiCam. This module uses an OmniVision OV5647 sensor capable of taking both video and images in a wide range of resolutions and framerates. This module was selected primarily for its fixed focus sensor; this means that focus settings will not have to be configured during flight. While this renders the system incapable of capturing images at same resolutions of V2 module, trade studies indicated that this tradeoff was worthwhile as it greatly simplified use of the camera. The camera is accessed via a system call. During runtime however, a python library is used to control the PiCam. Through these functions it is possible to easily take still images, record flight footage, and otherwise control the camera from within the TDS. The camera system will be used to take in flight still images which will be analyzed for target detection purposes.

Constraints proposed by NASA require that this system is capable of detecting 40ft. x 40ft. targets at an altitude of 500ft. Subscale tests have conducted assert that this module shall be capable of meeting proposed requirements.

5.5.3 Detection Software

The MRS is responsible for calling the TDS functions, which minimizes the possibility of a conflict between the two systems. Below are the two main function calls the MRS shall make during normal flight, along with their corresponding descriptions and an overview of how they function.

When the MRS calls the objectDetect function, the TDS shall initialize the PiCam module via the onboard CSI connector and capture a single still image. Once this image has been obtained, it undergoes a series of transformations, such as resizing the image, converting it to a HSV color format, and blurring the image slightly to remove any distortions due to ambient light or similar defects; these steps prepare the still for processing. Once the still is prepared, the image is 'masked' with a color range *x* so that only objects with color that fall within *x* are maintained; the resulting image is black and white (BW). This BW image undergoes erosion and dilation techniques that remove any unnecessary blobs from the image. The image below depicts what happens during this process when searching for the red target.



Candidate targets are then selected from the image using contour detection; since the image at this point is BW, the contours detected are the objects with colors found in color range *x*. The shape of each contour is approximated using a provided OpenCV function; this function approximates the shape (or number of data points in the shape) using a given epsilon (or approximation accuracy) value; a lower epsilon yields a more accurate number of data points for the object in question. Since the targets in question are squares, only contours approximated with four data points are evaluated further; a bounding rectangle is calculated for these targets. In order to be precise, squares are differentiated from other four point figures using aspect ratio. A bounding rectangle of a square is, of course, a square. Calculations ensure that the ratio between the width and height of the bounding rectangle fall between 0.8 and 1.2. This allows for error that may arise from issues like the camera not looking directly down at the targets when the still is taken. Objects that pass the aspect ratio test are maintained and verified further in an attempt to approximate their size in relation to current altitude (distance) from the target. By taking experimental data and converting rough size estimates from feet to pixels, it is then possible to extrapolate the object's apparent size at a set distance, assuming resolution and focal length are known quantities. Since only one object should be detected for each color, if more than one object passes the final verification, the algorithm deduces that the target has not been found yet. This process is repeated for possible color of the targets. The algorithm eventually returns a 3-tuple, consisting of boolean values for each color option b (blue), r (red), and y (yellow). These booleans indicate if the target was detected.

Targets that have met all criteria are selected by drawing an outline of the shape over the original image. The target is then labelled based on its color. This image is saved to a special directory to differentiate it from other images obtained during the flight. Each time the object detect function is called, the algorithm first checks the special directory to see which targets have already been found. The algorithm then only searches for the targets that have not yet been found, which eliminates unnecessary computations.

5.5.4 Camera Housing

The TDS camera housing design is centered around a 3D printed housing which the Pi Camera fastens into. The Camera housing mounts onto the bottom bulkplate of the Payload and will allow for clear viewing of the targets via the acrylics lens.

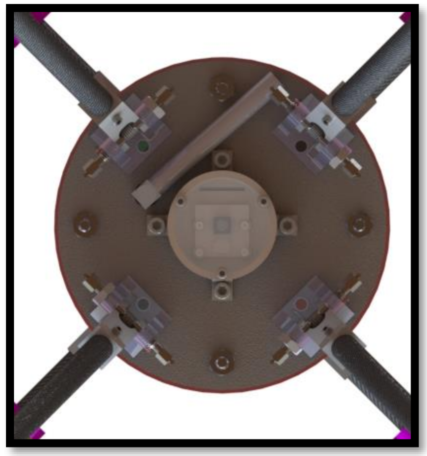


Figure 126: TDS Camera housing mounted onto Lower Bulkplate Assembly.

5.6 PSS (Payload Structural System)

5.6.1 Overview of System

The Payload Structural System (PSS) is defined as the system which houses and restrains all of the electrical and mechanical components of the Payload. The PSS is broken down into three main subassemblies which allow for the mounting of all required Payload subsystems shown below in Table 69.

PSS subassembly	Subassembly function
Upper Bulk Plate Assembly	The Upper Bulk Plate Assembly is responsible for mounting the MRS Propulsion Arms and the RRS mechanisms.
Coupler Body Assembly	The Coupler Body Assembly is responsible for containing all of the necessary electronics and for carrying the load induced by the Launch Vehicle during flight.
Bottom Bulk Plate Assembly	The Bottom Bulk Plate Assembly is responsible for mounting the LLS and TDS equipment.

Table 69: PSS subassemblies and their descriptions.

The overall dimensions for the PSS are shown below in Table 70. Figure 127 shows a rendering of the PSS components.

PSS Characteristic	Value
Coupler Body Diameter	6.0 in.
Coupler Body Length	12.0 in.
RRS Tube Diameter	2.0 in.
RRS Tube Length	14.125 in.

Table 70: Overall Dimensions of the PSS

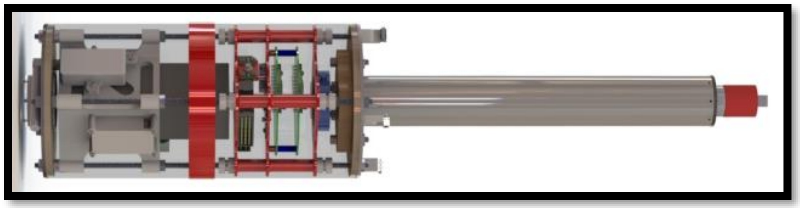


Figure 127: Rendering of PSS.

5.6.2 Upper Bulkplate and Lowerbulk plate Assemblies

The PSS Upper and Lower Bulkplate Assemblies consists of Fiberglass bulk plates coupled with a 0.25" wooden centering bulkplates. The Upper Bulkplate Assembly serves as the mounting structures for the MRS Propulsion Arms and the RRS mechanisms. The symmetric cutouts on the bulkplates give room for the power and control wires that run to the MRS propulsion system hardware. The Upper Bulk Plate Assembly is shown below in Figure 128. The Lower Bulkplate Assembly serves as the mounting structure for the LLS equipment, the TDS camera, and the mount for the telemetry module antenna. The Lower Bulkplate assembly is shown above in Figure 126.

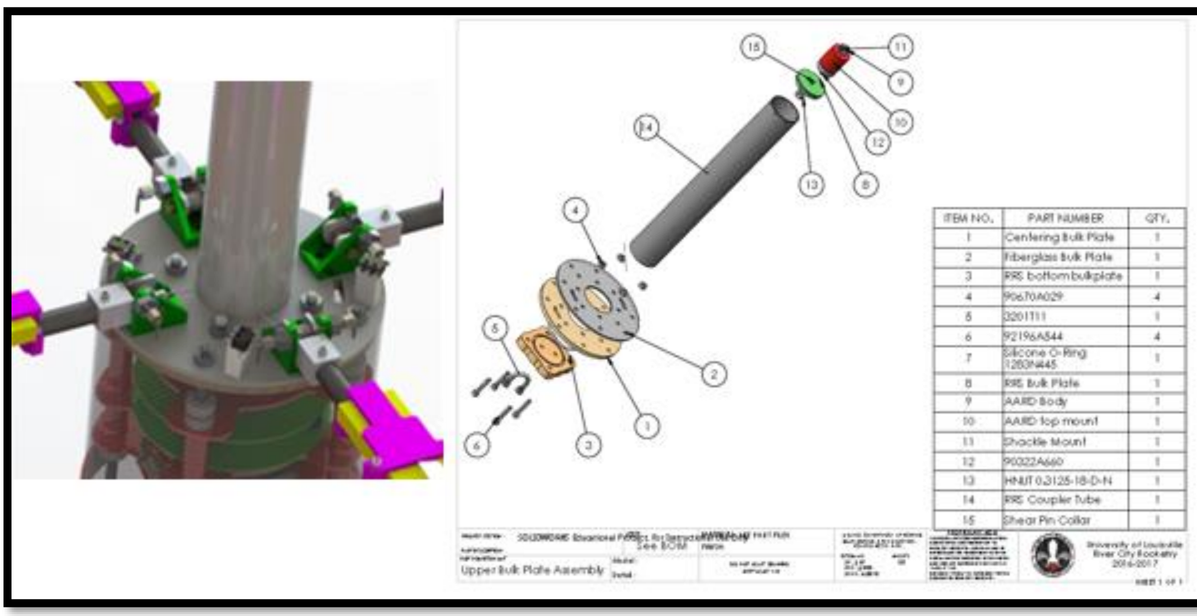


Figure 128: Rendering and detailed drawing of the Upper Bulk Plate Assembly.

5.6.3 Coupler Body

5.6.3.1 Support Structures.

The primary structure of the PSS is the coupler body which joins the Deployment Bay and Main Recovery Bay of the Launch Vehicle. The coupler utilizes four aluminum ¼"-20 all thread rods which are held between the Upper and Lower Bulk Plate Assemblies as mounting devices for the Payload Electronics.

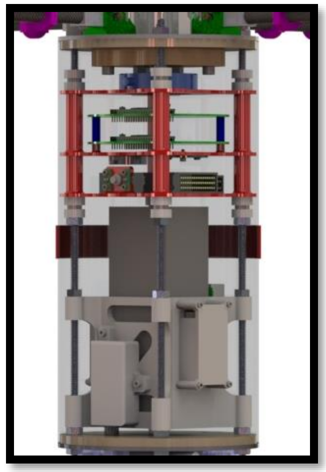


Figure 129: Coupler body with all thread mounting rods.

5.6.3.2 Electrical housings.

There are two main electrical housings in the coupler body, the flight controller bulkplate and the battery module. Both are 3D printed PLA plastic structures. This material and manufacturing technique was chosen for ease of manufacturing, lightweight, and reliability.

5.6.3.2.1 Flight and Recovery Electronics Assembly:

This assembly houses both MRS and RRS electronics and is located just below the top bulkplate assembly. The assembly is mounted on the aluminum all thread rods and has dampers between the ¼-20 mounting nuts and the Electronics Assembly Shelves to reduce vibrations to the flight controller sensors during flight. The flight and recovery electronics assembly is shown below in Figure 130.

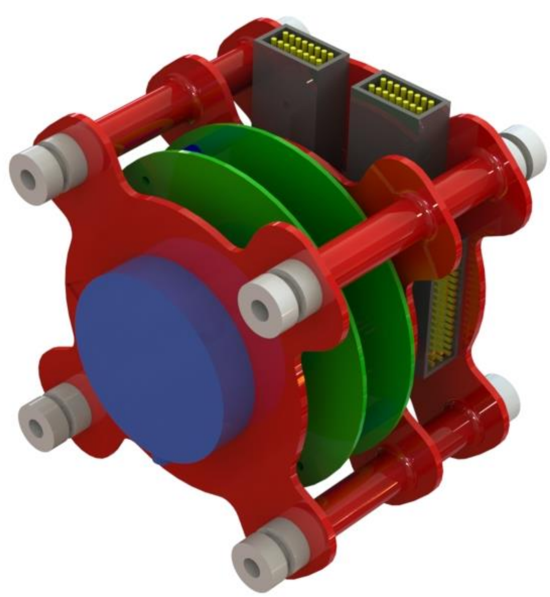
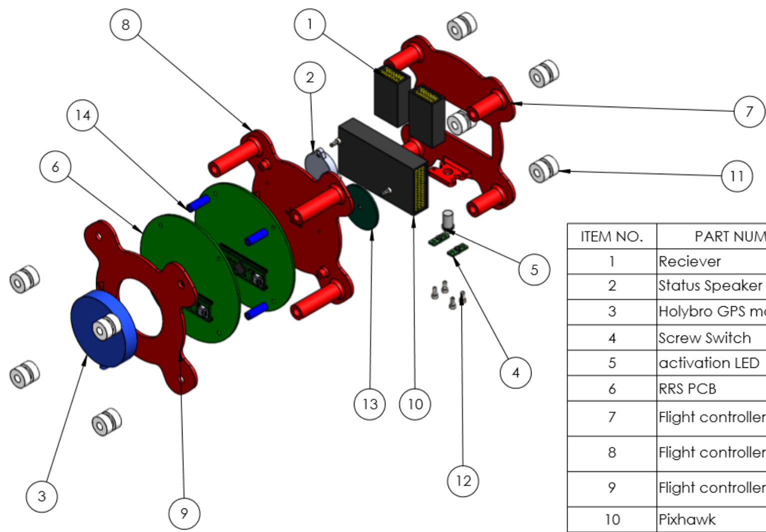


Figure 130. Rendering of Flight and Redundant Recovery Electronics Assembly.

The assembly has three bulkplates; the top, middle, and bottom bulkplates. The top bulkplate is in the figure foreground and the bottom is in the background. These bulkplates are pieces that can separate when needed for servicing the housed electronics. Figure 131 below shows the BOM for all the parts, fasteners, and electronics housed in this assembly.



ITEM NO.	PART NUMBER	QTY.
1	Reciever	2
2	Status Speaker	1
3	Holybro GPS module	1
4	Screw Switch	2
5	activation LED	1
6	RRS PCB	2
7	Flight controller mount	1
8	Flight controller mount	1
9	Flight controller mount	1
10	Pixhawk	1
11	All Thread Dampers	8
12	92196A106	7
13	Power Distribution Board	1
14	RRS Standoff	4

Figure 131. BOM for all parts, fasteners, and electronics housed in the assembly.

MRS electronics are located on all three bulkplates. The flight controller will be attached to the bottom bulkplate through mounting foam to reduce flight vibrations. Also attached to the bottom bulkplate is the MRS receiver. The status speaker and power distribution board are both mounted with 4-40 fasteners to the bottom of the middle bulkplate. The GPS module will be mounted with Velcro strips onto the top bulkplate for ease of assembly and access. The arming switches and activation LED are mounted orthogonal to the bottom bulkplate platform so that they can be accessed from the vehicle's exterior. This fulfills SOW Requirement 2.7.

RRS electronics are interspersed between the bulkplates. There are two RRS PCB's with Teensys mounted onto them. These are mounted in the bulkplate section between the top and middle bulkplates. 3D printed plastic standoffs separate them from one another and are fastened with 4-40 fasteners. The final RRS component is mounted on the bottom bulkplate and is the RRS receiver.

5.6.3.2.2 Battery Module:

The battery module is located below the flight controller bulkplate and above the bottom bulkplate assembly. This module is also mounted onto the aluminum all thread rods by ¼-20 nuts in the coupler interior. Figure 132 below shows the battery module assembly.

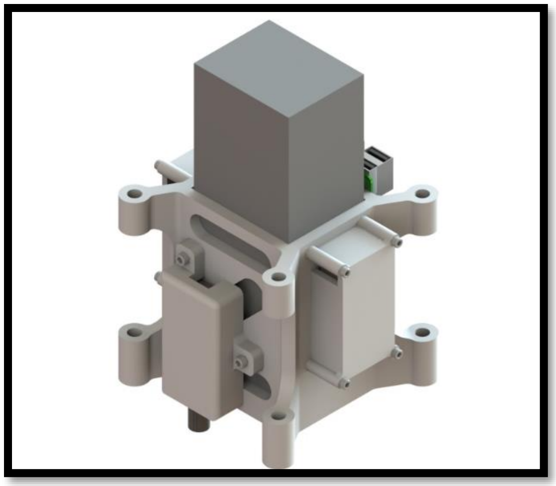
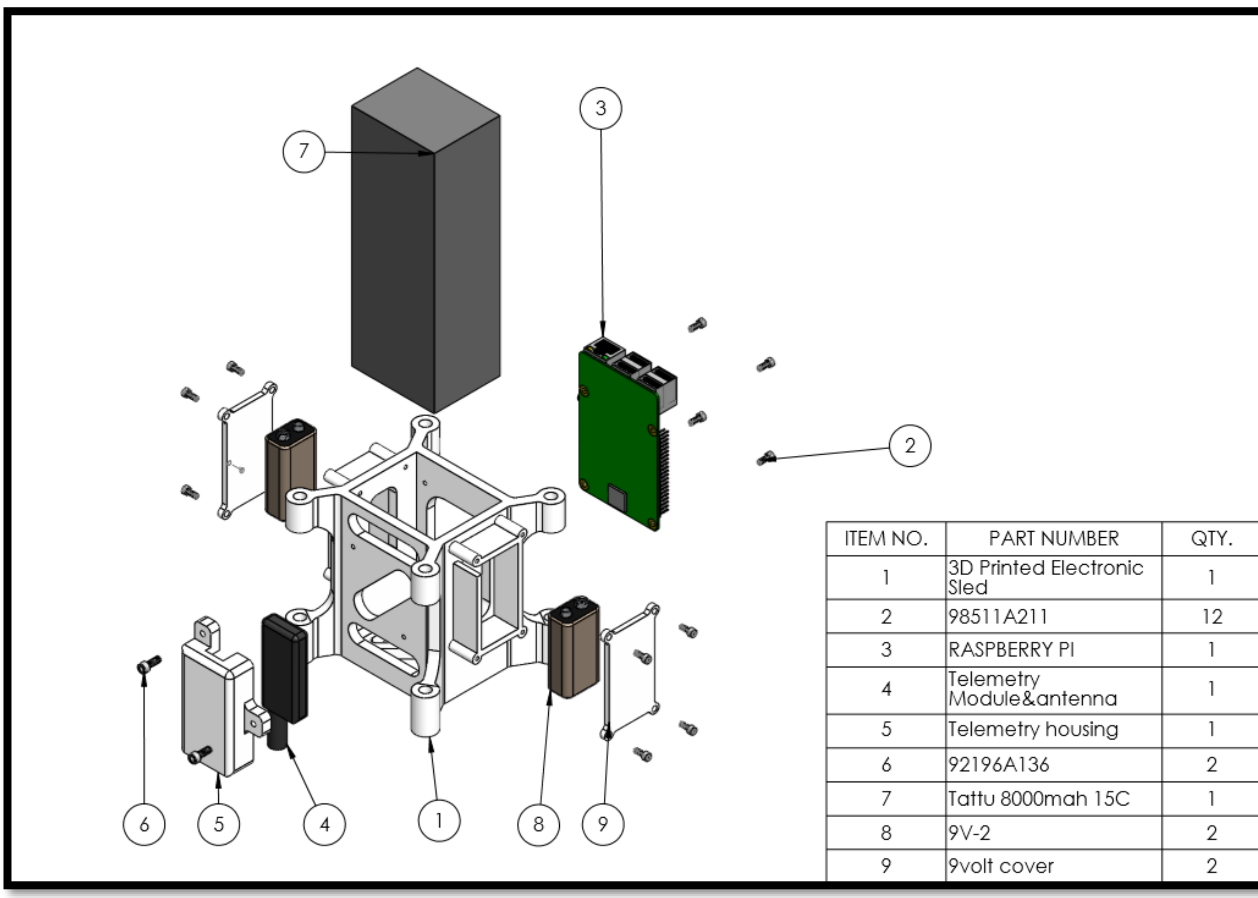


Figure 132. Battery Module Rendering.

This module is composed of the main battery mount this several more mounts on its four sides. These mounts house multitude of electronic components. Figure 133 shows the BOM for the battery module assembly.



ITEM NO.	PART NUMBER	QTY.
1	3D Printed Electronic Sled	1
2	98511A211	12
3	RASPBERRY PI	1
4	Telemetry Module&antenna	1
5	Telemetry housing	1
6	92196A136	2
7	Tattu 8000mah 15C	1
8	9V-2	2
9	9volt cover	2

Figure 133: Detailed drawing of the 3D Printed Batter Sled.

The main structural component to this assembly is the 3D printed electronic sled. This component's main role is to secure the main battery for the payload, which makes up most of the payload's weight. Mounted on the exterior of the electronic sled are two 9V batteries for the RRS electronics, a raspberry pi flight computer, and the telemetry module for the MRS. All four electronics components are mounted to the main sled with 4-40 fasteners. The main sled is secured to the structural aluminum threaded rods through 1/4 -20 nuts above and below the assembly.

5.7 LLS (Landing Leg System)

The Landing Leg System (LLS) is responsible for supporting the payload during landing. A fully assembled rendering of the LLS can be seen below in Figure 134.

Figure 134: Rendering of the LLS.

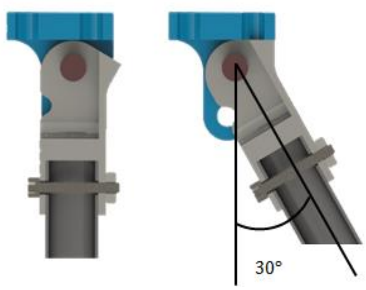
The LLS consists of two main subassemblies, the leg pivot assembly and landing leg assembly. Each subassemblies function is defined in Table 71: LLS subassemblies. below.

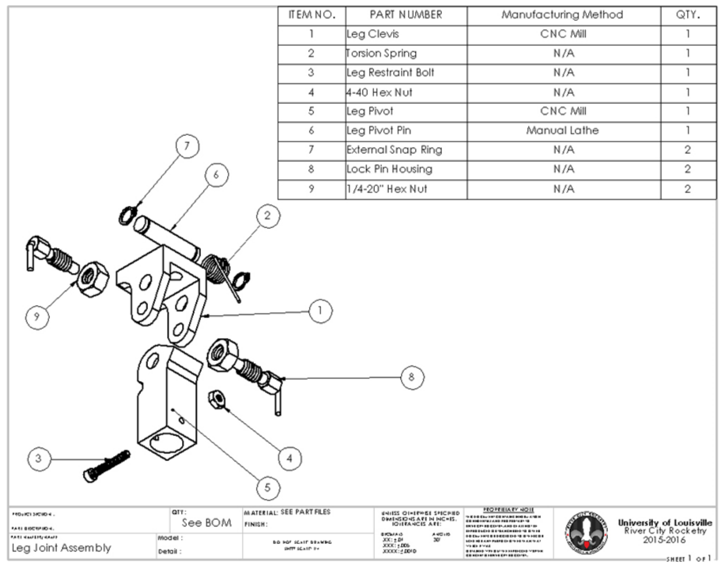
Subassembly	Definition	Function
Leg Pivot Assembly	The leg pivot assembly contains the leg pivot, leg clevis, torsion spring, lock pins, leg pivot pin.	Aluminum joint which connects the landing leg to the payload. The leg pivot allows the landing leg to swivel from a stowed configuration to a landing configuration.
Landing Leg Assembly	The landing leg assembly consists of the carbon fiber leg and foot insert.	The landing leg will attach to the leg pivot and hold the payload off the ground during landing. The foot insert prevents debris from entering the carbon fiber landing leg.

Table 71: LLS subassemblies.

5.7.1 Leg Pivot Assembly

The leg pivot's functionality is similar to the arm pivot's. It’s job is to lock the landing legs into the landing configuration. Tipping analysis was conducted in PDR and determined the optimum leg angle to resist tipping was 30 degrees. Renderings below in Figure 135 display the stowed and deployed configurations of the leg pivot. Figure 135 below shows a BOM of all parts contained in the leg pivot assembly.





ITEM NO.	PART NUMBER	Manufacturing Method	QTY.
1	Leg Clevis	CNC Mill	1
2	Torsion Spring	N/A	1
3	Leg Restraint Bolt	N/A	1
4	4-40 Hex Nut	N/A	1
5	Leg Pivot	CNC Mill	1
6	Leg Pivot Pin	Manual Lathe	1
7	External Snap Ring	N/A	2
8	Lock Pin Housing	N/A	2
9	1/4-20" Hex Nut	N/A	2

Figure 135: LLS stowed and deployed configuration with deployment angle and Detailed drawing of the Leg Pivot Assembly.

5.8 DS (Deployment System)

5.8.1 Deployment Bay

The deployment system is responsible for deploying the payload from the Deployment Bay and the Main Recovery Bay. The DS consists of structures within the Deployment Bay and Main Recovery Bay of the launch vehicle. The system is depicted in Figure 136.

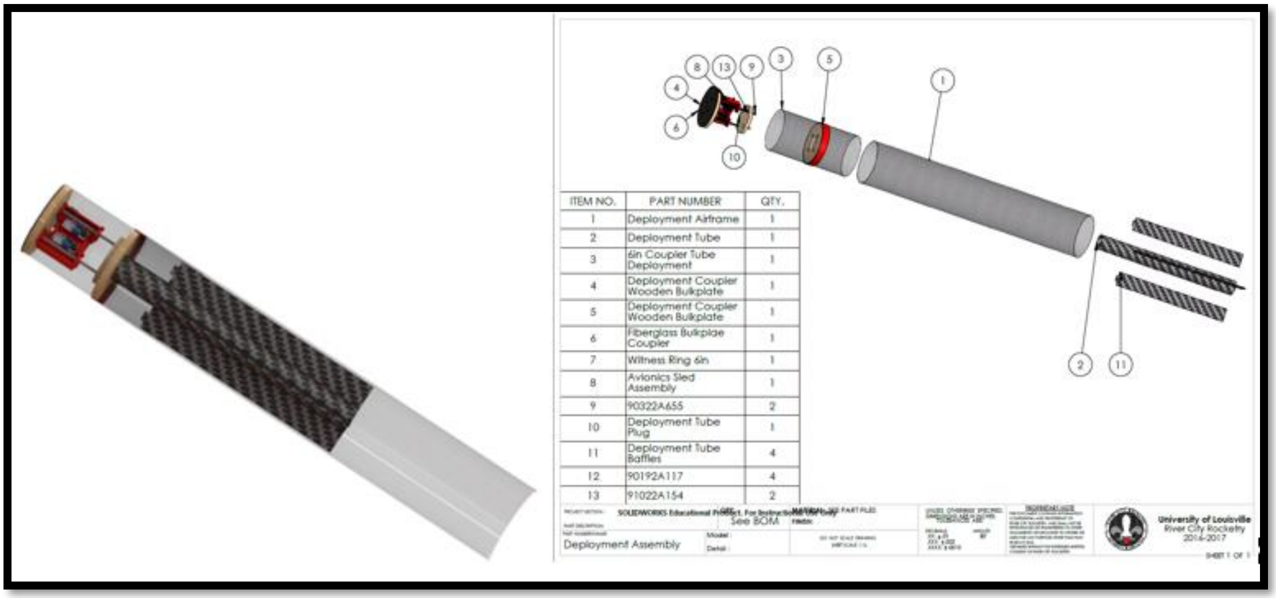


Figure 136: Deployment Bay section view rendering and detailed exploded view.

As seen in the figure above, the deployment bay components are the Deployment Bay Baffles, RRS tube sleeve, and the Deployment Bay Airframe. This assembly was designed to protect the MRS propulsion system during deployment and house both the RRS tube/Parachute assembly and the Deployment Parachute.

5.9 Integration

5.9.1.1 **Deployment Mechanisms**

5.9.1.1.1 Deployment Bay

The Payload integrates into the Deployment bay via the deployment tube and the Deployment Tube Baffles. The Deployment Bay Baffles are designed to separate the Propulsion arms and prevent blade breakage during deployment. The Deployment Tube within the bay allows for the blackpowder charge to separate the Payload in a controlled environment protecting the Propulsion Arms. The fitment of the deployment bay and the payload can be seen below in Figure 137.

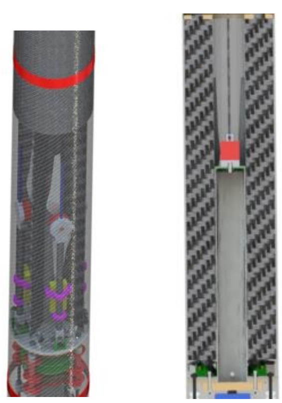


Figure 137: Deployment Bay integration.

5.9.1.1.2 Main Recovery Bay

The Main Recovery Bay features four leg sleeve components. These components facilitate the protection of the LLS from the Launch Vehicle's Main parachute while protecting the Main parachute from getting tangled with the LLS.

Figure 138: Main Recovery Bay with LLS Stowed into Leg sleeves.

5.9.1.2 **Payload Electronics**

5.9.1.2.1 MRS and RRS Interaction

The MRS and RRS are connected by 2 lines of I/O. One carries the RRS's signal of deployment. This signal is write only from the RRS, indicating that the MRS should perform its deployment maneuver. The second is write only by the MRS. This signal indicates that the payload's mission should be aborted. When it is sensed, the RRS will depower the multirotor motors, and deploy the recovery parachute. The final interaction between them is the depowering of the MRS's motors via RRS logic.

5.9.1.2.2 MRS and TDS Interaction

The MRS and TDS software is built using Python 2.7. Because of this, interaction between the two is handled according to standard object-oriented programming practice. The TDS is initialized from within the main MRS flight script. At the point in flight that target detection is required, the TDS system will be called from the MRS and allotted time to complete its mission. Once time has expired or it is finished with detection, the MRS will continue its flight.

6 Launch Operations Procedures

6.1 Launch Operation Checklist

The launch operations checklist contains all the items and steps required for the setup of a successful full scale launch. This checklist also features safety callouts, denoted by a ⚠**CAUTION**, ⚠WARNING, or ⚠ DANGER. These labels call attention to steps that have important safety concerns associated with them and also include notes on the mitigation of these concerns.

Another feature of the launch operations checklist is redundant responsibility. Two team members must verify all items pre-launch. This increases accountability and ensures that all steps are completed in accordance with the checklist.

6.1.1 General Preparations

To be checked and initialed by River City Rocketry team member.

River City Rocketry Team Member Signatures:

1. ______________________________ *2.* __________________________________

Prior to leaving for launch site:
Required Equipment and PPE:

- *Clear black powder capsules (x8Drill*
- *E-matches (x10)*
- *1/8" drill bit*
- *Electrical tape*
- *Scissors*
- Safety Glasses
- *Black powder*
- *Paper towels*
- *Black powder measurement kit*

6.1.1.1 Black Powder Charge Preparation

1. ___ Drill a 1/8" hole in the bottom of each of the clear black powder capsules.
   ⚠**CAUTION**: Safety glasses are to be worn while drilling.
2. ___ Unwind one e-match.
3. ___ Feed wire from the e-match through the hole in the base of a capsule. Ensure the pyrotechnic end of the e-match is inside the capsule.
4. ___ Wrap electrical tape to secure the e-match in place and to ensure that black powder will not leak from the capsule.
   ⚠WARNING If the capsules are not completely sealed, black powder will leak when the capsules are filled. Leakage could potentially result in ejection charges being too small or failing altogether, causing a catastrophic failure in recovery.
5. ___ Fill capsules with appropriate amount of cc's of black powder. Fill excess space with a cellulose insulation to ensure black powder remains in contact with the pyrotechnic tip of the e-match no matter the orientation of the capsule.
6. ___ Repeat steps 2 through 4 six times.
7. ___ Store modified capsules and e-matches in explosives box.
8. ___ Remove plastic protective covers from 6 e-matches.
9. ___ Insert the two modified e-matches into the ARRD's.
10. ___ Assembly ARRD's in accordance to their product manual.

11. ___ Store loaded ARRD's in the explosives box.

DANGER E-matches are explosive. The cartridges of the ARRD's and leads must be kept clear from batteries and any open flames to avoid accidental firing.

6.1.2 Recovery Checklist

6.1.2.1 Prior to leaving for launch site: Recovery

Prior to leaving for launch site:

Required Equipment for prep & at field:

- *Small Fabric hair ties/Rubber Bands*
- *Drogue (x2)*
- *Main Parachute (x3)*
- *ARRD (x2)*
- *Packing hook*
- *Deployment bag (x2)*
- *Main Shock Cord*
- *Drogue Shock Cord*
- *Quicklinks (x4)*
- *Clamp*
- *Triangular quick links (x2)*
- *Tender Descender*

1. ___ Inspect canopies and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
   a. Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

1. ___ Lay parachute canopy out flat.
2. ___ Ensure shroud lines are taut and evenly spaced and not tangled.
3. ___ Fold parachute per the folding procedures document in the team OwnCloud folder. Use clamps as necessary to ensure a tight fold.
4. ___ Place folded parachute(s) into respective deployment bag with shroud lines coming directly out of the bag.
   a. **WARNING** Ensure that the shroud lines are not wrapped around the parachute inside the deployment bag. This will result in the parachute getting stuck in the deployment bag. Verify that the parachute fits loosely in the deployment bag.

6. ___ Secure deployment flaps using shroud lines and fabric hair ties.
7. ___ Use hook to assist in securing extra length of shroud lines through loops stitched in deployment bag. Continue this pattern in the same direction around the deployment bag in order to prevent tangling.
8. ___ Repeat steps 1-7 for each main parachute.
9. ___ Prep and assemble ARRDs
10. ___ Attach ARRD to bulkplate.
11. ___ Atttach drogue shock cords to ARRD shackle

12. ___ Stow parachute bags in recovery tubes for transport.

6.1.2.2 At launch Site Procedure: Recovery

Redundant Recovery System (RRS) Parachute Assembly:

1. ___ Insert deployment bay main bag and attach ARRD tether to top of bag.

2. ___ Attach deployment bay drogue shock cord to ARRD on bulkplate via quick link.
3. ___ Install drogue.
4. ___ Insert booster main bag and attach ARRD tether to top of bag.
5. ___ Attach booster and deployment bay drogue shock cord to ARRDs on bulkplates.
6. ___ Install drogues.

River City Rocketry Recovery Lead and one other Lead Signatures:

1. ______________________________ *2.* ______________________________

6.1.3 Vehicle Checklist

6.1.3.1 Prior to leaving for launch site: Vehicle

Prior to leaving for launch site:

Required Equipment for prep & at field

- *Precision flathead screwdriver*
- *Standard Phillips head screwdriver*
- *Duracell 9V battery (x4)*
- *Nosecone altimeter sled*
- *StratoLogger altimeter (x4)*
- *Battery clips (x2)*
- *4x40 shear pins (x24)*
- *Battery holster cover*
- *Multimeter*

Vehicle Avionics Prep:

1. ___Verify proper shielding.
   a. **⚠WARNING** Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.
2. ___ Verify StratoLogger CF altimeters are properly programed in accordance with file in team OwnCloud folder.
3. ___Allow a NASA official at LRR during competition to mark the official altimeter used for scoring.
4. ___ Verify 9V battery has a minimum charge of 8.7V.
5. ___ Mount StratoLoggers onto standoffs on sustainer altimeter sled using #4-40 shear pins.
6. ___ Attach batteries to battery clips and install into holster.
7. ___ Attach battery holster cover using four, #4-40 shear pin.
8. ___ Ensure screw switches are turned off and wire screw switches to switch terminal on StratoLogger.
9. ___ Wire battery to +/- terminal on StratoLogger.
10. ___ Wire main and drogue terminals on StratoLogger to terminal blocks on the nosecone
11. ___ Install altimeter sled into avionics bay.

6.1.3.2 Prior to leaving for launch site: Stability and Propulsion

Prior to leaving for launch site:

Required Equipment for prep & at field

- Gorilla Glue
- Grease
- Booster stand
- AeroTech L2200-G motor
- Motor Retainer
- 10-32 Shoulder Bolt (x3)

1. ___The vehicle led will be responsible for preparing the motor within the casing.
   ⚠**CAUTION** Protective gloves are to be worn when applying grease to the motor.
2. ___Slide motor casing fully into the motor mount tube.
3. ___Attach the motor retainer to the fin retainer via 10-32 shoulder bolts.
4. ___Set completely assembled bay on stand; do not rest on fins.
   Note: If any damage is identified, immediately inform both of the team captains and the safety officer. The launch vehicle will be deemed safe to fly or a corrective action will be decided upon and implemented.

River City Rocketry Vehicle Lead and one other Lead Signatures:

1. ______________________________ 2. ______________________________

6.1.4 Payload Checklist

6.1.4.1 Prior to leaving for launch site: Payload

<u>Prior to leaving for launch site:</u>

Required Equipment for prep & at field

- *Socket wrench set*
- *Custom altimeter electronics mounting box*
- *Propulsion Arm Assemblies*
- *Landing Leg Assemblies*
- *3D printed electronics sleds*
- *MRS Electronics*
- *Secondary GSE RC Transmitter*
- *4-40 shear pins (x3)*
- *StratoLogger altimeter (x4)*
- *Altimeter mounting box cover*
- *Custom altimeter electronics*
- *GSE Laptop w/ charger*
- *Recovery Insulation (Dog Barf)*
- *E-matches (x2)*
- *Parachutes?*
- *9V batteries (x2)*
- *Primary GSE RC Transmitter*

Multirotor Recovery System (MRS):

1. ___ Attach ESC's and Motors to the Propulsion Arms.
2. ___ Attach MRS electronics to mounting sled.
3. ___ Attach GPS module, ESC control lines (x4), Telemetry module, Receiver, Safety Switch, Buzzer, Raspberry Pi communication lines, and 5V Regulator power lines to the Pixhawk.
4. ___ Attach Pixhawk and RRS communication lines to the Raspberry Pi.
5. ___ Insert the mounting sled into the payload.
6. ___ Ensure that propellers have been removed from payload and stored for travel.
7. ___ Verify charge of 22.2V LiPo batteries.
8. ___ Store batteries in LiPo bag for travel.
   a. ⚠ DANGER Lithium Polymer batteries can catch fire if punctured. The LiPo bag reduces this risk and contains the fire if this occurs, however handle with care.

Ground Station Equipment (GSE):

1. ___ Ensure that batteries are charged for Primary RC Transmitter and Laptop
2. ___ Ensure that Secondary RC Transmitter has fresh AA batteries (x4)

Redundant Recovery System (RRS):

1. ___Refer to section 6.1.2.1 when preparing deployment and recovery parachutes for shipment.
2. ___Attach the RRS electronics to mounting sled to the PSS section bulkplate.
3. ___ Insert the PSS electronics sled onto the payload.
4. ___Install both 9V Duracell batteries into the corresponding battery mount on the electronics sled.
5. ___ Connect RRS and DS E-matches to RRS electronics.
6. ___ Place upper bulkplate on top of payload.
7. ___ Fasten upper bulkplate to payload by installing 4x 1/4in-20 nuts onto PSS all thread rods.

Target Detection System (TDS

1. ___ Install PiCam into Camera Housing Assembly.
2. ___ Route PiCam Harness through Bottom Bulkplate Assembly.
3. ___Install PiCam Harness into Raspberry Pi.
4. ___Perform Inspection verifying proper visuals of the system.

6.1.4.2 **At launch Site Procedure: Payload**

1. ___Connect MRS to RRS communication leads
2. ___ Connect 22.2V LiPo and wait for Pixhawk to initialize
3. ___ Verify Telemetry connection to MRS
4. ___ Verify stable bind of MRS to Primary GSE Transmitter
5. ___ Connect to Rasberry Pi to verify proper startup of MAVROS and flight script.
6. ___ Install e-match leads to RRS
7. ___Connect 9V Duracell batteries to RRS power
8. ___ Verify stable bind of RRS to Secondary GSE RC Transmitter
9. ___ Verify position of ARRD ignition switch on Secondary GSE RC Transmitter
    a. ⚠WARNING If switch is in wrong state, the next step will cause the ARRD to ignite.
10. ___Initialize RRS, verifying piezo buzzer sounds.
    a. ⚠WARNING Deployment BP charge connected to the payload's ARRD is now armed. The signal from the secondary GSE transmitter is able to ignite charge if sent.
11. ___ Attach propellers to motors
12. ___Install Payload into flight vehicle

After Recovery:

1. ___Switch Secondary GSE RC transmitter to disarm RRS
2. ___Wait a minimum of 10 seconds before collecting the payload
    a. ⚠DANGER If the recovery parachute was not deployed it is still armed at this point. If the RRS loses power, it will ignite the BP charges. Do not unplug battery power until capacitor has been given sufficient time to discharge. If the LED is lit, it is still charged.
3. ___ Cut all e-match leads to RRS, ensuring remaining wiring is unable to contact power
4. ___ Remove remaining wiring from circuitry contacts
5. ___ Disconnect batteries from circuitry
6. ___ Remove batteries from mounts on electronics sled

7. ___ Remove RRS's SD card
8. ___ Review MRS Flight Log

River City Rocketry Payload Lead and one other Lead Signatures:

1. ____________________________ 2. ______________________________

6.1.5 VDS Checklist

6.1.5.1 Prior to leaving for launch site:

<u>Prior to leaving for launch site:</u>

Required Equipment for prep & at field

- *Small Screwdrivers*
- *SD Card*
- *Wire Cutters/Strippers*
- *7.4V LIPO battery*
- *11.1V LIPO battery*
- *Fuse*
- *Banana Plug Cables*
- *USB micro B cable*
- *SD Adapter*
- *Multimeter*
- *Black Tool Box*
- *VDS connector cable*
- *Fuse shunt*
- *Electronics Assembly*
- *Charged 9V battery*
- *Extra 22 AWG Wires*
- *Teensy 3.6*
- *Neverrest40 DC motor*
- *Encoder cable*
- *Electronics Enclosure*
- *Laptop*

Board Preparation:

1. ___Before handling VDS electronics. Ensure that you are properly grounded. This can be done at launch by touching the chassis of a car and removing extra layers of clothing.
2. ___Check battery connector for frayed or loose wires.
3. ___Flip power switches to 'off'.
4. ___Insert microSD into its slot.
5. ___Inspect the board for loose wires or connections.
6. ___Perform continuity checks for active signals.

Software Preparation:

1. __Turn off debugging.
2. ___Put software in test mode and perform unit test.
3. ___Ensure the software IS NOT in test mode.
4. ___Check mass parameters and other physical constants.
5. ___Upload this software and verify these things.
6. ___Zip up software and put in OwnCloud/2016-2017/VDS/VDS V2/Launch Data/[Launch Date]/ for posterity.

6.1.5.2 At launch Site Procedure: VDS

1. ___Install Teensy onto the electronics assembly
2. ___Plug in USB B into Teensy and computer.
3. ___Open putty (or any serial monitor).
4. ___Press button on Teensy to reset.
5. ___Connect to COM port (check device manager to learn what yours is).
6. ___Verify that the VDS V2 title screen prints out. If not type 'S'.

7. ___Type 'S' to run a system check. Verify that the SD card, BMP180 (BMP280), and BNO055 initialized correctly.
8. ___Type 'B' to verify that the BMP180 (BMP280) is reading nominally. Type anything to exit the test.
9. ___Type 'A' to verify that the BNO055 is reading nominally. Type anything to exit the test.
10. ___When ready, type 'F' to enter flight mode.
11. ___Verify that the software has entered flight mode.
12. ___Verify that there is no connection for the 7.4v and 11.1v batteries by checking power switches.
13. ___Plug in 7.4v LIPO to its clip. NOTE BATTERY POLARITY.
14. ___Insert 7.4v into slot.
15. ___Flip 7.4v power on.
16. ___Plug in 11.1v LIPO. NOTE BATTERY POLARITY.
17. ___Insert 11.1v LIPO into slot.
18. ___Flip 11.1v power on.
19. ___Perform motor check by pressing 'M'.
20. ___Verify motor actuates.
21. ___Unplug USB. Make sure LED on Teensy remains on.
22. ___Fix lid on enclosure.
23. ___Give to vehicle team to install.

After Recovery:

1. ___Remove cover from sled.
2. ___Shut down motor power.
3. ___Plug USB B into Teensy.
4. ___Launch Putty.
5. ___Press 'E' (or any character other than 'F') to end flight mode.
6. ___Remove SD card.
7. ___Shut down board power.
8. ___Store electronics in ESD-safe bag.

River City Rocketry VDS Lead and one other Lead Signatures:

1. ____________________________ *2.* ________________________________

6.1.6 Overall Final Assembly Checklist (requirement 1.7)

Required Equipment:

- *Allen Wrench Set – SAE*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *Masking tape*
- *Socket Cap Screws*
- *4-40 shear pins*
- *Socket Wrench Set for ¼-20 Nuts*

1. ___ Attach propulsion bay to VDS coupler using 3x 8-32 metal bolts.
2. ___ Attach upper VDS coupler to the propulsion recovery bay using x3 8-32 shear pins.
3. ___ Attach recovery bay to the payload coupler using x4 4-40 nylon shear pins.
4. ___ Attach the payload coupler to deployment bay using x4 4-40 nylon shear pins.
5. ___ Attach the deployment bay to the nose cone using x4 4-40 nylon shear pins.

6. ___ Check that the coupling does not allow for any flexing of the rocket between any airframe and coupler tubes. Should this occur, add layers of painters tape to the coupler tubing on the payload bay until sufficient coupling is achieved.
7. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
8. ___ A final visual inspection will need to be done to ensure all systems are go.

Final Assembly Representatives Signatures:

1. ______________________________ *2.* ______________________________

6.1.7 Clear to Leave for Launch Pad

All sections of the safety checklist preceding must be complete and signed prior to leaving for the launch pad. A signature from every lead, co-captains, and safety officer must sign off to proceed to the pad.

*Vehicle Lead:*____

*Recovery Lead:*____

VDS Lead: ____

Payload Lead: ____

Signatures indicating the rocket is a "Go" for launch:

Team Co-Captain: ____

Team Co-Captain: ____

Safety Officer Signature: ___________________________________

6.1.8 At Launch Pad Checklist

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *GoPro camera*
- *Level*
- *Precision flathead screwdriver*

1. ___Verify flight card has been properly filled out and permission has been granted by RSO to launch.
2. ___Place launch vehicle on launch pad.
3. ___Tilt and rotate the launch pad in desired direction, or in direction ruled necessary by RSO. Use level to ensure desired launch angle.
4. ___Ensure proper connection has been made with ground station electronics.
5. ___Arm all electronics in the following order: payload, cameras, and altimeters (in order as follows: AIM Xtra, StratoLoggers, and Teensey). Check for correct LED readout, beeping pattern, etc.
6. ___Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
7. ___Arm launch pad camera and begin recording.
8. ___ Clear launch pad area and do not return until range has been reopened by the RSO.

6.1.9 After Flight Recovery Checklist

1. ___Inspect all shroud lines for any damage or burn marks.
2. ___Inspect all shroud attachment points for damage.

3. ___Inspect entire canopy for any damage, or stretching.
4. ___Inspect deployment bag for damage.

6.1.10 After Flight Payload Checklist

6.1.11 After Flight Launch Vehicle Checklist

1. ___Inspect the vehicle for any post-recovery damage.
2. ___Inspect the official scoring altimeter for damage post-recovery by the safety officer.
3. ___Shut-down all audible electronics except the official scoring altimeter
4. ___Inspect the vehicle for the official competition altimeter beeps, which indicate the apogee altitude of the vehicle.
5. ___Report to the NASA official with the official scoring altimeter.

Damage found on shroud lines? Y / N

*Notes:*____

Damage found on attachment points? Y / N

*Notes:*____

Damage found on deployment bag? Y / N

*Notes:*____

Tearing or stretching found on canopy? Y/N

Recovery Representatives Signatures:

1. ____________________________ *2.* ________________________________

6.1.12 After Flight Analysis

Damage Notes:

____
____
____

Repair Plan:

____
____

Altitude Achieved: ________________
Motor Used: ______________________
Location: ________________________
Temperature: _____________________

Pressure: _______________________
Wind Speed: ____________________
Event #1 Success: Y or N
Event #2 Success: Y or N

Captain Approval: 1. ____

2. ____

7 Project Plan

7.1 Testing

7.1.1 Vehicle Component Test Plans

The following illustrates the completed tests which will be performed to guarantee the integrity of the designed vehicle system. The vehicle tests have been broken up into the following test campaigns:

- VDS Flight Test campaign
- Recovery Test Campaign
- Launch Vehicle Test Campaign

7.1.1.1 VDS Flight Test Campaign

The VDS Flight Test Campaign consists of several sub-tests which will prove the integrity of the design. These tests will verify the requirements that pertain to the VDS's braking power and the VDS's sensor fidelity. A summary of the sub-tests in this campaign are shown below in Table 72.

Test	Test Description	Requirements Verified	Status
Braking Power Test	Two full-scale launches will be used to find the work the VDS is capable of performing and the factor by which the VDS can increase the coefficient of drag of the full-scale vehicle.	VDS.1.1 VDS.1.2	Incomplete. Scheduled for 2/18/16.
Sensor Fidelity Test	The VDS software will be flown in a subscale launch where it will record data. The recorded flight data will be analyzed to determine if the state noise and data rate are acceptable.	VDS.2 VDS.2.1 VDS.2.2.2 VDS.2.3	Completed 12/18/16. Outcome: Fail.

Table 72: VDS flight sub-tests, test descriptions, requirements verified, and status.

7.1.1.1.1 Braking Power Test

This test will demonstrate the system's ability to slow the vehicle down during ascent.

Items to be tested

- Work performed by the VDS.
- Factor by which the VDS can increase the vehicle's coefficient of drag.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria	Results Summary
VDS.1.1	The VDS shall be designed to be capable of reducing the apogee of the vehicle to no less than 4,720 ft. AGL from 5,280 ft.	The difference in altitude between the control and full-deploy launches must be no less than 880 ft.	Test scheduled for 2/18/16
VDS.1.2	The vehicle shall be capable of increasing the coefficient of drag of vehicle by no less than 0.15	The coefficient of drag found for the full-deploy launch divided by the coefficient of drag found	Test scheduled for 2/18/16

		for the control launch must be greater than 0.15.	

Table 73: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

- VDS Electronics: The electronics that will control the VDS during the final competition launch will be completed by this time and used in this test series.
- Full-scale launch vehicle: The full-scale launch vehicle that will be launched at competition will be completed by this time and flown in this series of tests.

Setup

Control Launch Setup

In addition to the procedures for a full-scale launch of the VDS electronics, these additional steps must be added to the VDS setup procedure for the control launch.

1) Ensure that the VDS central sun gear is removed and the VDS blades secured in place with painters' tape to prevent them from deploying.
2) Upload the VDS software.

Full-deploy Test Launch Setup

In addition to the procedures followed for a full-scale launch of the VDS electronics, these additional steps must be added to the VDS setup procedure for the full-deploy test launch.

1) Ensure that the VDS central sun gear has been replaced and that the gears are meshing properly. Remove the painters' tape securing the blades so that they can actuate freely.
2) Upload the modified VDS software.

Safety Notes

When removing the central sun gear and taping the VDS blades in place make sure that the tape is flush with the airframe and is sufficiently adhered to the airframe. This will ensure that the painters' tape does not peel off during flight.

Procedure

The procedure for this test can be found in the VDS Electronics Checklist section.

Results

This test has not been conducted yet. It will be completed by February 18th.

7.1.1.1.2 Sensor Fidelity Test

This test will demonstrate the system's ability to determine the state of the vehicle on ascent.

Items to be tested

- Sensor noise on both the Bmp180 pressure sensor and the Bno055 nine degrees of freedom sensor.
- Speed at which the VDS Electronics can draw data from the sensors
- Ability of the Kalman filter to reduce state noise.

Items not tested

- VDS blade actuation.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria	Results Summary
VDS.2	The VDS shall be capable of determining the state of the vehicle (i.e. altitude and velocity) with noise limits of no more than +/- 8.5 m and +/- 5.0 m/s respectively.	The raw altitude signal reported by the BMP180 sensor must have a peak-to-peak noise less than 8.5 m. The raw velocity signal must have a peak-to-peak noise less than 5.0 m/s.	Pass. The p-p altitude noise was 1.8 m which is less than 8.5. The p-p velocity noise was 2.0 m/s which is less than 5.0 m/s.
VDS.2.1	The state of the vehicle shall be updated by the VDS at a rate no less than 48 Hz.	The rate at which the VDS Electronics pulls data from the sensors must be no less than 48 Hz.	Pass[3]. The VDS Test Electronics operated at an average data rate of 52 Hz which is greater than the required 48 Hz.
VDS.2.2.2	The VDS shall have a barometric pressure sensor capable of reporting altitude data with a noise limit of no more than +/- 8.5 m.	The raw altitude signal reported by the BMP180 sensor must have a peak-to-peak noise less than 8.5 m.	Pass. The p-p altitude noise was 1.8 m which is less than 8.5.
VDS.2.3	The VDS shall have a programmatic filter capable of reducing velocity data noise by no less than 25% as an added safety measure.	The peak-to-peak noise on both the filtered velocity and altitude signals must be no less than 25% smaller than on the raw signals.	Fail. The p-p noise on the filtered velocity and altitude signals was not 25% smaller than the raw signals. However, then signals did have an acceptable level of noise so the need for a Kalman filter will be re-evaluated by the FRR.

Table 74: Pass/fail criteria for all requirements tested.

Pre-test

Equipment:

- Small Screwdrivers
- SD Card
- Wire Cutters/Strippers
- 9V Battery Connector
- USB micro B cable
- SD Adapter
- Multimeter
- Black Tool Box
- Charged 9V battery
- Extra 22 AWG Wires
- Teensy 3.6

Setup

Board Preparation:

1) Before handling VDS electronics. Ensure that you are properly grounded. This can be done at launch by touching the chassis of a car and removing extra layers of clothing.

[3] This test as it was performed on 12/3/16 failed to pass because it exhibited an average data rate of 19.5 Hz, less than the required 48 Hz. This test is listed as a pass because after post-launch improvements, the software exhibited an average data rate of 52 Hz.

2) Check 9v connector for frayed or loose wires
3) Insert wire end of 9v connector into green terminal (red to white and black to black!!)
4) Insert microSD into its slot
5) Inspect the board for loose wires or connections
6) Insert board into its enclosure

Software Preparation:

1) Turn off debugging
2) Put software in test mode and perform unit test.
3) Ensure the software IS NOT in test mode.
4) Upload this software and verify these things.

<u>Safety Notes</u>

When installing the 9v battery make sure that the polarity is correct. It is possible to plug the battery in backwards which would result in the destruction of the VDS test electronics.

Procedure

Perform these steps after the vehicle team has given the 20-minute warning so as to maximize the battery life of the VDS Test Electronics.

1) Plug in USB B into Teensy and computer.
2) Open putty (or any serial monitor).
3) Press button on Teensy to reset.
4) Connect to COM port (check device manager to learn what yours is).
5) See that the VDS V2 title screen prints out. If not type 'S'.
6) Type 'S' to run a system check. Verify that the SD card, BMP180 (BMP280), and BNO055 initialized correctly.
7) Type 'B' to verify that the BMP180 (BMP280) is reading nominally. Type anything to exit the test.
8) Type 'A' to verify that the BNO055 is reading nominally. Type anything to exit the test.
9) When ready, type 'F' to enter flight mode.
10) Verify that the software has entered flight mode.
11) Plug in 9v to its clip. NOTE BATTERY POLARITY.
12) Insert 9v into slot.
13) Unplug USB. Make sure LED on Teensy remains on.
14) Fix lid on enclosure.
15) Give to vehicle team to install battery end up.

After Recovery:

1) Remove cover from sled.
2) Shut down motor power.
3) Plug USB B into Teensy.
4) Launch Putty.
5) Press 'E' (or any character other than 'F') to end flight mode.
6) Remove SD card.
7) Shut down board power.
8) Store electronics in ESD-safe bag.

Results

After conducting the subscale launch with the VDS Test Electronics, the following results were found. The outcome of the overall test resulted in a failed status.

VDS.2 & VDS.2.2.2 Results - Pass

Pass. The p-p altitude noise was 1.8 m which is less than 8.5. The p-p velocity noise was 2.0 m/s which is less than 5.0 m/s. The graph of this is shown below in Figure 139.

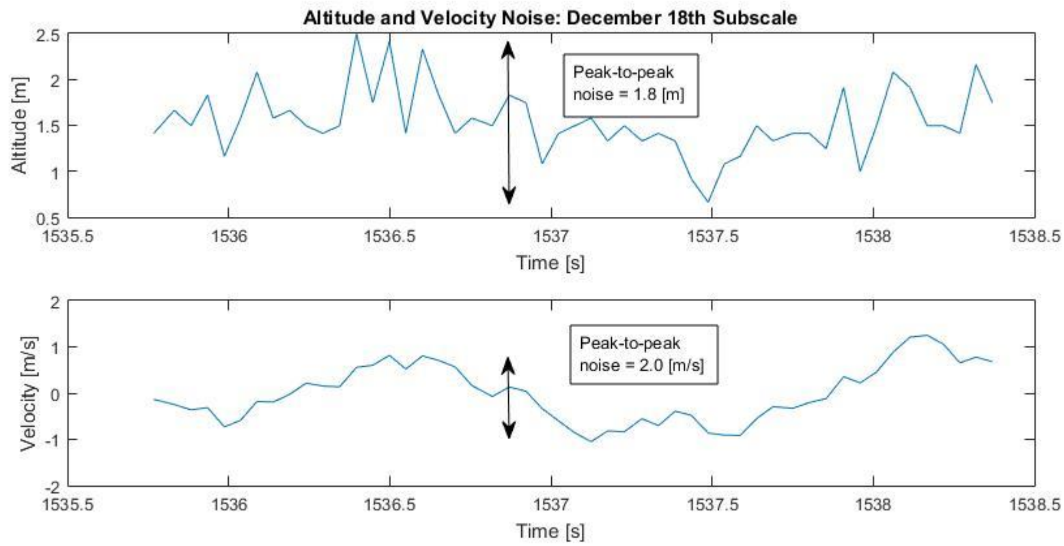


Figure 139: Altitude and Velocity Noise: December 18th Subscale.

A three second time window was taken from the VDS Test Electronics flight data. This three second time window was from several seconds before launch when the vehicle was motionless on the launch rail. It can be seen above that the signals don't perfectly represent a motionless rocket. This is due to the signal noise. This signal noise was measured to be within the required peak-to-peak severities of 8.5 and 5.0 for altitude and velocity respectively.

VDS.2.1 Results - Pass

Though the VDS Test Electronics operated at an average data rate of 19.5 Hz during flight which is less than the required 48 Hz, post-launch testing showed that the software is capable of 52 Hz. The low speed exhibited on December 18th was due to the use of an SD card with a low write speed. Swapping SD cards for one with a faster write speed showed significant improvement in the overall performance of the VDS test electronics. A comparison of software delays in these two cases can be seen below in Figure 140.

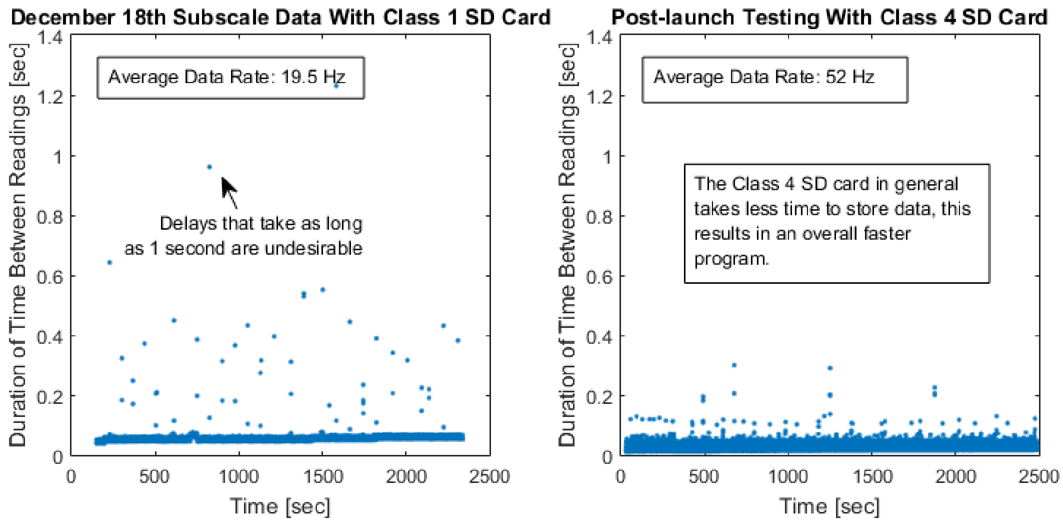


Figure 140: Visualization of delays in VDS Test Electronics software.

It can be seen above that a class 4 SD card has a significant impact on the average data rate. SD card class also affects the consistency of data write-time. A class 1 card can be seen to take as long as one second to write data while the longest instance of data writing for the class 4 card can be seen to be 0.3 seconds.

VDS.2.3 Results - Fail

The p-p noise on the filtered velocity and altitude signals was worse than the raw due to known errors. The filtered and raw state signals can be seen below in Figure 141.

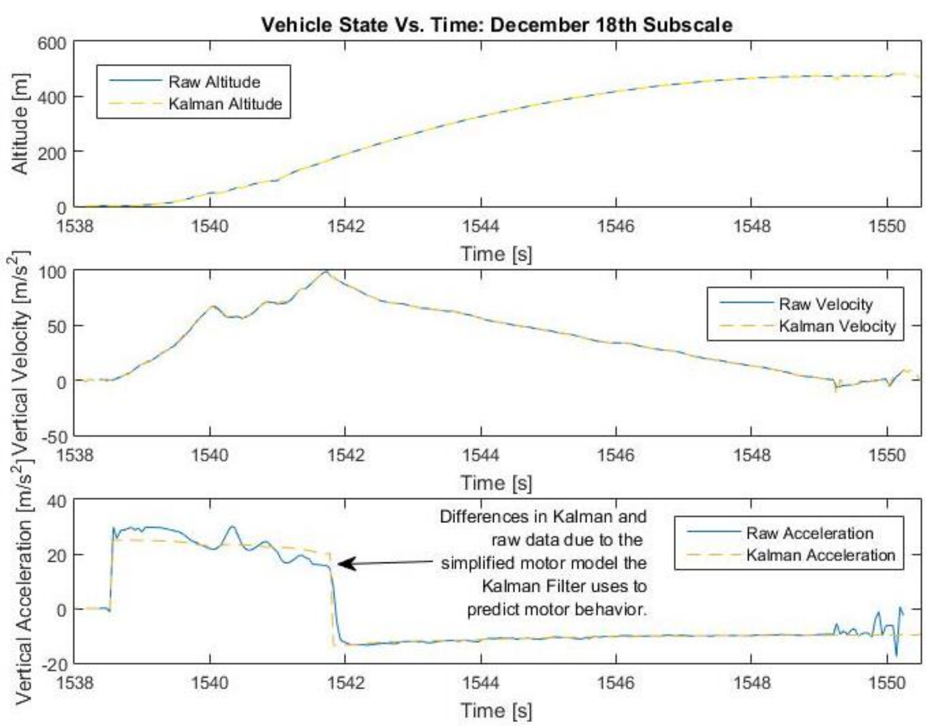


Figure 141: Kalman filtered and raw state signals.

It can be seen above that the Kalman filter returned results that were not noticeably better than the original raw data. This may be due to several factors including:

- The tuning constants used for the Kalman filter may have been unbalanced. These constants determine how much weight the filter applies to its own prediction vs. the weight it applies to the raw sensor data.
- The original raw signals had very little noise to begin with.

Despite that the end result of the signal was very clean and had little noise, the test is marked as failed because the Kalman Filter did not reduce the noise of the raw signal by more than 25 %. However, because the raw signals had very little noise to begin with, this test's failure does not put the team behind schedule and the need for a Kalman Filter will be discussed in the FRR.

7.1.1.2 Launch Vehicle Test Campaign

The Launch Vehicle Test Campaign consists of several sub-tests which will prove the integrity of the design. These tests will verify the requirements that pertain to the performance of the full scale launch vehicle. A summary of the sub-tests in this campaign are shown below in Table 75.

Test	Test Description	Requirements Verified	Status
Subscale Vehicle Separation Test	The separation of the subscale vehicle will be test by igniting pyrotechnic charges inside the vehicle on the ground to ensure proper separation of the vehicle to allow successful recovery of the vehicle.	Vehicle.4.2	Completed 12/2/16 and 12/17/16. Outcome: Pass.
Subscale Vehicle December 3rd Flight	A subscale vehicle flight will be used to estimate the coefficient of drag of the full scale launch vehicle, verify construction techniques, and confirm simulation accuracy.	1.16 2.3	Completed 12/3/16. Outcome: Fail.
Subscale Vehicle December 18th Flight	A subscale vehicle flight will be used to estimate the coefficient of drag of the full scale launch vehicle, verify construction techniques, and confirm simulation accuracy.	1.16 2.3	Completed 12/18/16. Outcome: Pass.
Bulkplate Assembly	The bulkplate assembly will be placed under 399 lbs of load to simulate at least twice the maximum forces applied by the parachute during descent.	Vehicle.4.3	Incomplete. Scheduled for 1/21/17
Full Scale Vehicle Separation Test	The separation of the subscale vehicle will be test by igniting pyrotechnic charges inside the vehicle on the ground to ensure proper separation of the vehicle to allow successful recovery of the vehicle.	Vehicle.4.2 Recovery	Incomplete. Scheduled for 2/8/17.
Full Scale Control Vehicle Flight	A full scale launch vehicle test flight will be used to test the stability of the vehicle and the integrity of the mechanical design of the vehicle.	1.2.6.3 1.4 1.15 Vehicle.1.1 Vehicle.1.1.3 Vehicle.4 Vehicle.1.1.3.1 Vehicle.1.1.3.3 Vehicle1.1.3.5	Incomplete. Scheduled for 2/11/17.
Filament Winding Angles	Airframe will be wound at angles from 10 to 0, relative to the radial axis, to determine the limit of manufacturing capabilities.	Vehicle.2.1	Incomplete. Scheduled for February.
Volumetric Ratio	Airframe samples will be tested for void and volumetric ratio via photomicrographs and the burnout method (ASTM D2584-02).	Vehicle.2.2	Incomplete. Scheduled for February.

Airframe Tensile Strength	MTS equipment will test for tensile strength and AMTAS CLT program will determine ideal layers and filament characteristics.	Vehicle.2.3	Incomplete. Scheduled for Febrary.

Table 75: Full scale launch vehicle tests, test descriptions, requirements verified, and status.

7.1.1.2.1 Subscale Vehicle Separation Test

This test will demonstrate the system's ability to separate sections of the vehicle to allow the recovery equipment to deploy during flight.

Items to be tested

- Ejection charges are properly sized in order to successfully separate the launch vehicle during recovery.

Pass/Fail Criteria

- The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.4.2	Nose cone successfully separates, forcing the drogue parachute and shock cord to be removed from the recovery bay. The pin of the ARRD is ejected, which allows the main parachute to deploy.

Table 76: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

Equipment

- The subscale vehicle shall be utilized to ensure proper volume of the recovery bay.
- An electronic ignition station shall be utilized in order to ignite the ejection charge from a safe distance.
- Prepared black powder ejection charges shall be utilized in order to separate the section.

Setup

Ejection charges shall be inserted into the appropriate terminal block of their associated recovery bay. Recovery bays shall be attached to the corresponding sections of the electronics bay in accordance with the launch vehicle.

Safety Notes

All spectators and testers shall be a minimum of 12 feet from the launch vehicle during testing. No person or object shall be directly in front of or being launch vehicle during ejection charge testing. All spectators shall wear safety goggles during preparation of charges and during separation testing.

Procedure

1) Prepare ejection using the specified amount of black powder measured using the black powder measuring kit located in the explosives box.
2) Connect the prepared ejection charge to the drogue terminal block.
3) Assemble the electronics bay and recovery bay using the #4-40 UNC nylon shear pins.

4) Connect the electronic ignition station to the terminal block.
5) Ensure the area is clear around the launch vehicle.
6) Fire the ejection charge using the electronic ignition station.
7) After nose cone separation, repeat steps one through six for the main deployment instead of the drogue deployment.

Results

V. 4.2 - Pass

The drogue deployment ejection charge successfully separated the nose cone from the rest of the subscale vehicle. The main deployment ejection charge successfully released the ARRD pin to release the main parachute from the recovery bay.

7.1.1.2.2 Subscale Vehicle December 3rd Flight

This test will demonstrate the flight characteristics, recovery, and structural integrity of the subscale vehicle.

Items to be tested

- The subscale vehicle shall be utilized to ensure proper volume of the recovery bay.
- An electronic ignition station shall be utilized in order to ignite the ejection charge from a safe distance.
- Prepared black powder ejection charges shall be utilized in order to separate the section.

Items not tested

- The VDS and payload will be tested due to size constraints of the subscale vehicle,

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
1.16 Subscale Test	The launch of the subscale vehicle is considered a success if the exit rail velocity and the achieved apogee altitude is within 10% of the simulated apogee altitude. The recovery of the subscale vehicle is considered a success if the subscale recovery data verifies predicted drag coefficient of parachutes.

Table 77: Pass/fail criteria for all requirements tested.

Pre-Test

The following sections describe information about the setup and approach being used for the test.

Equipment

- Subscale vehicle
- Two PerfectFlite CF Stratologger altimeters
- Two Duracell 9 volt batteries
- Altimeter sled
- VDS electronics
- VDS electronics Sled
- 12 foot rail
- Launch Pad
- Launch System
- Cesaroni I150 Motor
- Two ejection charges
- Cruciform drogue
- Toroidal main
- Main and drogue shock cords
- ARRD assembly

Setup

The recovery equipment for the subscale vehicle was inserted into a single recovery bay with a separation point at the avionics bay located in the center of the vehicle.

Safety Notes

All spectators and launch attendees shall be at the appropriate distance from the launch vehicle as outlined by the NAR Safety Code.

Procedure

Subscale Vehicle Preparation

1) Program the two PerfectFlite Stratologger CF altimeters to ignite an ejection charge at apogee and at a lower specific altitude.
2) Mount altimeters to altimeter sled and connect each altimeter to a Duracell 9 volt battery.
3) Create two ejection charges by inserting an appropriate amount of black powder into an ejection charge canister with a e-match and seal them off with electrical tape.
4) Check continuity between terminal barrier blocks and altimeters.

Subscale Recovery Preparation

1) Inspect shroud lines, panels, and stitching for compromising damage.
2) Fold drogue arms under center overlap of panels. Neatly fold shroud lines and wrap assembly in nomax.
3) Fold main parachute panels sequentially in half on top of each other.
4) Fold shroud lines into S folds.
5) Stow main parachute in deployment bag with S folded shroud lines tucked neatly inside bag.
6) Inspect and clean ARRD of any black powder residue.
7) Install redundant E-matches through hole in black canister.
8) Fill black powder canister to line with black powder and cover with retaining sticker.
9) Install shackle pin, ball bearings, spring, and piston into red ARRD body.
10) While depressing piston just past threads and holding shackle in place, screw black powder canister into ARRD body. Test integrity by pulling and twisting shackle.
11) Install ARRD onto bulkplate.
12) Connect drogue and main to their respective shock cords.
13) Carefully slide recovery bay tube over assembly for transportation to launch field.

Launch Site Subscale Preparation

1) Insert motor into motor mount and secure using the motor retainer.
2) Insert altimeter sled and VDS-Tronics sled into the avionics coupler and secure to propulsion bay by using three 6-32 SCHS fasteners.
3) Seal avionics coupler with bulkplate, which holds the terminal barrier blocks, ARRD, and eye bolt for attaching recovery equipment.
4) Connect ejection charge and ARRD to its respective terminal barrier block.
5) Connect shock cord marked "MAIN" to eyebolt. Connect shock cord marked "DROGUE" to ARRD shackle.

6) Connect main deployment bag tether to ARRD shackle.
7) Insert dog barf under main bag and slide airframe over coupler.
8) Connect nose cone to vehicle via a friction fit.
9) Setup launch pad 100 feet away from spectators. For more detail, reference see the NAR Safety Code.
10) Attach 12 foot rail to launch pad and prepare launch system.
11) Transport subscale vehicle to launch pad location and attach subscale vehicle to launch rail by sliding rail buttons into the rail.
12) Arm each altimeter by turning each screw switch to the on position, which are accessible via the vent hole in the avionics bay.
13) Insert the igniter into the motor, ensuring that the igniter tip is inserted far enough into the motor.
14) Connect to the igniter to the lanch system via alligator clips.
15) Check continuity between the igniter and the launch system.
16) Launch subscale vehicle.

Results

After conducting the subscale vehicle launch, the following results were found. The outcome of the overall test resulted in a failed status.

1.16 Subscale Test – Fail

2.3 – Fail

The subscale launch was a success, however, the tether connecting the nose cone to the bulkplate produced tangling with the drogue shock cord, locking the main in the recovery bay and preventing main release. This resulted in a higher kinetic energy upon landing than allowed, and no data regarding the drag coefficient of the toroidal parachute. Full details of the results of the subscale vehicle flight results can be found in Subscale Flight Results.

7.1.1.2.3 Subscale Vehicle December 18th Flight

This test will demonstrate the flight characteristics, recovery, and structural integrity of the subscale vehicle.

Items to be tested

- The subscale vehicle will be be launched safetly and re

Items not tested

- The VDS and payload will be tested due to size constraints of the subscale vehicle,

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
1.16 Subscale Test	The launch of the subscale vehicle is considered a success if the exit rail velocity and the achieved apogee altitude is within 10% of the simulated apogee altitude.
2.1 Staging	Considered a success if the staging of the recovery gear via ARRD release succeeds and produces a clean main deployment.

2.3 Kinetic Energy	Considered a success if drag coefficient of recovery gear is consistent with expected value.

Table 78: Pass/fail criteria for all requirements tested.

Pre-Test

The following sections describe information about the setup and approach being used for the test.

Equipment

See the Equipment section of the Subscale Vehicle December 3rd Flight

Procedure

See the Procedure section of the Subscale Vehicle December 3rd Flight.

Results

After conducting the subscale vehicle launch, the following results were found. The outcome of the overall test resulted in a pass status.

1.16 Subscale Test – Fail

2.1 Staging – Success

2.3 Kinetic Energy – Success

The subscale launch and recovery was a success. The details of the flight can be seen in the Subscale Flight Results.

7.1.1.2.4 Full Scale Launch Vehicle Separation Test

This test will demonstrate the system's ability to separate sections of the vehicle to allow the recovery equipment to deploy during flight.

Items to be tested

- Ejection charges are properly sized in order to successfully separate the launch vehicle during recovery.

Pass/Fail Criteria

- The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.4.2	Propulsion and VDS bay successfully separate from rest of vehicle, forcing the drogue parachute and shock cord to be removed from the booster recovery bay. The pin of the ARRD is ejected, which allows the main parachute to deploy. The nose cone successfully separated from the payload recovery bay.

Table 79: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

Equipment

- The full scale launch vehicle shall be utilized to ensure proper volume of the booster recovery bay and payload recovery bay.
- An electronic ignition station shall be utilized in order to ignite the ejection charge from a safe distance.
- Prepared black powder ejection charges shall be utilized in order to separate the section.

Setup

Ejection charges shall be inserted into the appropriate terminal block of their associated recovery bay. Recovery bays shall be attached to the corresponding sections of the electronics bay in accordance with the launch vehicle.

Safety Notes

All spectators and testers shall be a minimum of 12 feet from the launch vehicle during testing. No person or object shall be directly in front of or being launch vehicle during ejection charge testing. All spectators shall wear safety goggles during preparation of charges and during separation testing. Area surrounding rocket ground separation test will be cleared.

Procedure

1) Prepare ejection using the specified amount of black powder measured using the black powder measuring kit located in the explosives box.
2) Connect the prepared ejection charge to the drogue terminal block.
3) Assemble the electronics bay and recovery bay using the #4-40 UNC nylon shear pins.
4) Connect the electronic ignition station to the terminal block.
5) Ensure the area is clear around the launch vehicle.
6) Fire the ejection charge using the electronic ignition station.
7) After nose cone separation, repeat steps one through six for the main deployment instead of the drogue deployment.

7.1.1.2.5 Full Scale Control Vehicle Flight

This test will demonstrate the flight characteristics, recovery, and structural integrity of the subscale vehicle.

Items to be tested

- The full scale launch vehicle shall be utilized to ensure proper volume of the recovery bay.
- An electronic ignition station shall be utilized in order to ignite the ejection charge from a safe distance.
- Prepared black powder ejection charges shall be utilized in order to separate the section.

Items not tested

- The VDS and payload will be tested due to size constraints of the subscale vehicle,

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
1.2.6.3 Waiver Exceeded	If any of the PerfectFlite Stratologger CF altimeters reports an apogee altitude over 5,600 feet AGL, then the requirement is not verified.

1.4 Reusability	If the launch vehicle is able to be launched again immediately after recovery without any modifications or repairs, then the launch vehicle will be verified as reusable.
1.15 Rail Exit Velocity	This requirement is considered a pass if the rail exit velocity is 52 fps or higher.
Vehicle.1.1 Apogee Altitude	This requirement is considered a pass if the launch vehicle achieves an apogee altitude greater than 5,500 feet and less than 5,600 feet.
Vehicle.1.1.3 Coefficient of Drag	If the analyzed coefficient of drag of the launch vehicle from the control launch is determined to be 0.5 or less, this requirement will be considered a pass.
Vehicle.1.4 Safe Ascent	This requirement is considered a pass if the launch vehicle ascent performs as intended.
Vehicle.1.1.3.1 Rail Exit Velocity	This requirement is considered a pass if the rail exit velocity is 56 fps or higher.
Vehicle.1.1.3.3 Rotation	This requirement will be considered a pass if the observed rotations of the vehicle during the control launch is equal to or less than one.
Vehicle.1.1.3.5 Maximum Tilt Angle	This requirement is considered a success if the angle of tilt of vehicle during the control launch never exceeds 10 degrees.
Recovery.1.2.1 Payload Deployment Altitude	Considered a success if deployment bay main, and MDP inflation are complete no lower than ~710 feet AGL.
Recovery.1.3 Collision Avoidance	Considered a success if predicted drift paths of independent sections are verified as accurate.

Table 80: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

- Full scale launch vehicle
- Four PerfectFlite Stratologger CF altimeters
- Steel ballasts to simulate the weight of the payload
- VDS and VDS electronics
- Ejection charges
- AeroTech L2200-G motor
- 12 foot rail and launch pad
- Launch system
- ARRD
- Booster Main and Drogue
- Booster Main and Drogue shock cords
- Booster

Procedure

A complete launch operations checklist and steps of procedure can be seen in the Launch Operations Procedures/Checklist

7.1.1.3 Launch Vehicle Components Test Campaign

The following illustrates the completed tests which will be performed to guarantee the integrity of the designed vehicle system. The vehicle tests have been broken up into the following test campaigns:

- Bulkplate/U-bolt Assembly Test Campaign
- Carbon Fiber Test Campaign

7.1.1.3.1 Bulkplate Assembly Load Testing

The Bulkplate Assembly Test will prove the integrity of the design with the expected load from the opening force of the recovery equipment. This test will verify that the carbon fiber plate, wood plate and u-bolt together can withstand 399 lbs, twice the maximum force of the parachute during decent. A summary of the test in this campaign is shown below in Table 1.

Test	Test Description	Requirements Verified	Status
Bulkplate Assembly	The bulkplate assembly will be placed under 399 lbs of load to simulate at least twice the maximum forces applied by the parachute during descent.	Vehicle.4.3	Incomplete

Table 81: Bulkplate Assembly test descriptions, requirements verified, and status.

Bulkplate Assembly

This test will demonstrate the bulkplate assembly's ability to withstand twice the maximum force applied by the parachute during descent.

Items to be tested.

- Carbon Fiber Plate
- Wood Plate
- U-Bolt and Washer

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.4.3	Shall not yield under 399 lbs

Table 82: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

Bulkplate Assembly: The bulkplate will be assembled with wood plates of various thicknesses and washers of various diameters.

Test Fixture

Test Load

Setup

Bulkplate Assembly Setup: The bulkplate must be assembled in the correct order and orientation.

1. The wood plate is placed on top of the carbon fiber plate.
2. The u-bolt is inserted, from the bottom, through the carbon fiber plate and wood plate, with the washers and nuts installed on top of the wood plate.

3. The assembly is then suspended, carbon fiber side down, from the all thread on the test fixture with nuts and washers installed on the carbon fiber side.

Safety Notes

Keep all body parts clear of test fixture and potential falling objects.

Procedure

1) Assemble bulkplate.
2) Install bulkplate in test fixture, with carbon fiber side down.
3) Check that u-bolt and all nuts are properly secured.
4) Suspend load from bulkplate.
5) Gradually increase load to 878 lbs, checking for signs of failure.

7.1.1.3.2 Filament Winding Angles Test

This test will determine the lowest angle, relative to the radial axis, at which the airframe can be wound without significant manufacturing defects (filament slippage and bunching)

Items to be tested.

- Filament winding angle

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.2.1	Wound filament must visibly maintain tension on mandrel.

Table 4: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

X-Winder
Laptop w/ X-Winder
Mandrel
Carbon Filament
Resin
Mandrel Film

Setup

Mandrel

1. Cut mandrel film to size.
2. Wrap mandrel with 1 smooth and tight layer of film, free of wrinkles and creases, sealing with tape.

X-Winder

1. Connect laptop and load predetermined winding pattern.
2. Load filament.
3. Tape filament to far right end of mandrel with duct tape.

Fill bath with resin to 1”.

Procedure

1) Connect laptop and load winding pattern.
2) Load mandrel onto X-Winder.
3) Load filament into X-Winder and tape to mandrel.

4) Mix resin and fill bath to 1".
5) Start X-Winder.
6) Monitor resin levels, refill as necessary.
7) Document loss of filament tension.

7.1.1.3.3 Volumetric Ratio

This test will determine the lowest optimal winding angle, relative to the radial axis, based on porosity and volumetric ratio.

Items to be tested.

- Volumetric ratio

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.2.2	Volumetric ration must be between 45% and 65%.

Table 5: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

Airframe samples: Samples cut into small squares.
Autoclave
Microscope
Camera
Computer with micrograph analysis software

Setup

Airframe Samples

1. Cut four samples of each winding angle to be analyzed.
2. Each sample shall be a 2"x1" rectangle, with the 2" edge cut circumferentially to the airframe.
3. Polish 2" sides of rectangles with 400, 800 and 1000 grit sandpaper.
4. Finish 2" sides with 1200 grit wet sand.

Procedure

1) Cut samples from airframe and clean edges.
2) Place each sample under microscope with 2" edge up.
3) Make micrograph of both 2" sides of each sample.
4) Load micrographs onto computer and determine volumetric ratio and void ratio.
5) Weigh each sample.
6) Set autoclave to appropriate temperature.
7) Load all samples of same winding angle.
8) After resin has completely burned off remove remainder of samples.
9) Weigh remainder of samples.
10) Calculate volumetric ratio.

7.1.1.3.4 Airframe Tensile Strength Test

This test will determine ultimate tensile strength of the aiframe.

Items to be tested.

- Airframe tensile strength

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Pass/Fail Criteria
Vehicle.2.3	Airframe shall not yield under 1500 lbs.

Table 6: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

20,000 Lbs MTS
Laptop with MTS software
1"x14" airframe sample

Setup

Airframe Samples

1. Cut 1"x14" strips from airframe.
2. Sample strips shall be cut parallel to the radial axis of the airframe.
3. Reinforce 1" from both ends of sample strips, front and back, to distribute clamping force.

Procedure

1) Connect laptop to 20,000 Lbs MTS.
2) Enter sample specs into MTS program.
3) Set MTS gap to match sample length.
4) Secure sample in MTS clamp.
5) Run program/tensile test.
6) Record yield stress.

7.1.2 Payload Test Plans

The following illustrates the completed tests which will be performed to guarantee the integrity of the designed payload system. The Payload tests have been broken up into the following test campaigns:

- **MRS Test Campaign**
- **DS Test Campaign**
- **RRS Test Campaign**
- **TDS Test Campaign**
- **Full Scale Flight Test Campaign**

7.1.2.1 **MRS Test Campaign**

The MRS Test Campaign consists of sub tests which will guarantee the systems flight worthiness. These test will be accomplished to verify the system's ability to fly the payload autonomously and safely for the duration of the payloads mission.

Table 83 displays the MRS flight sub-tests which will be accomplished to verify MRS requirements through the MRS Test Campaign:

Test	Test Description	Requirements Verified	Status
Propulsion Testing	This test series will verify the thrust of the selected motors, demonstrate the structural integrity of the design, and demonstrate the ability of the arms to lock into place.	MRS.2.1 MRS.2.1.1 MRS.2.2 MRS.2.4	Completed 12/29/16 Outcome: Pass
Autonomous Flight Testing	This test series will demonstrate the MRS's overall ability to maneuver the flight platform in the air, perform specific flight maneuvers, and its ability to perform autonomously.	MRS.1.1 MRS.1.3.1 MRS.3 GSE.1 GSE.2 GSE.3	Incomplete. Scheduled for 1/28/2017
Payload Integration Flight Testing	This test series will demonstrate the MRS's overall ability to maneuver the fully assembled Payload in the air, perform specific flight maneuvers that will performed in full scale flight, and its ability to perform these operations autonomously while fully integrated with all other payload systems.	MRS.3 RRS.2.2 RRS.3 RRS.4	Incomplete. Scheduled for 2/4/2017

Table 83: MRS flight sub-tests, test descriptions, and requirements verified through testing.

7.1.2.1.1 Propulsion Testing

This sub tests will verify the thrust of the selected motors, demonstrate the structural integrity of the design, and demonstrate the arms ability to lock into place.

Items to be Tested

- Max thrust of the selected multirotor motor.
- Structural integrity of the multirotor arm design under maximum loading conditions.
- Stable actuation of the arm system.

Items Not Tested

- N/A

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
MRS.2.1	The Arm Pivot Assembly must provide stable actuation of the	The Arm Pivot Assembly must start at the deployed position, actuate into the deployed position, and allow for the locking spring pins to seat to receive a passing score.

	propulsion assembly upon payload deployment.	If the actuation isn't completed successfully or and assembly yield/ fails the test will receive a failing score.
MRS.2.1.1	The MRS Propulsion Arms shall deploy and lock into their flight positions upon separation from the deployment bay.	See Pass/Fail requirements for MRS.2.1
MRS.2.2	The Arm Pivot Assembly must be capable of handling the max thrust of 2.1 kg and a torque load of 0.546 N*m from the motor assembly.	The arm pivot assembly must be capable of receiving the max thrust of the motor without causing any excessive deflections to receive a passing score.
MRS.2.4	The selected multirotor system must have a thrust/rotor rating of at a minimum 4.25lbs.	At 100% throttle, the multirotor motors must be capable of 4.25lbs to receive a passing score. Any value lower will receive a failing score.

Table 84: Pass/fail criteria for all requirements tested.

Pre-Test

The following sections describe information about the setup and approach being used for the test.

Equipment

1) Arm Pivot Assembly: A prototype Arm Pivot Assembly was used in this test made of their respective designed materials.
2) See-saw pivot test rig: A custom made thrust test rig was designed and manufactured to accurately measure the thrust of the multirotor motor at varying throttle percentages.

Setup

Propulsion Arm Installation: The Propulsion Arm Assembly shall be assembled as shown in section 5.2.4.

See-Saw Pivot Test Rig integration: The Propulsion Arm Assembly shall be integrated onto the See-Saw Pivot Test Rig shown in **Figure** 142.

Arduino Control Circuit: An Arduino Microcontroller will be used to control the throttle value sent to the motors by using one data line to the ESC.

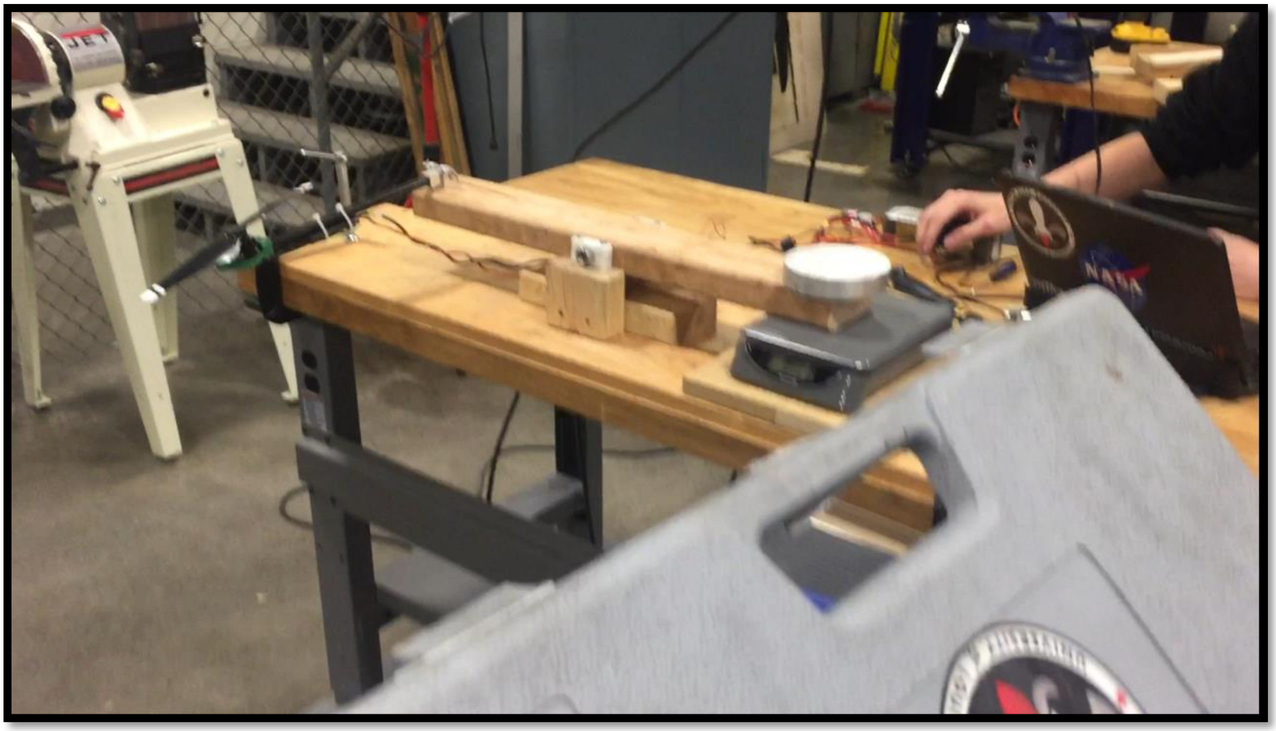


Figure 142: See-Saw Pivot Test Rig with Propulsion Arm

Safety Notes

Follow the following steps when handling the Propulsion Arm assembly with the E800 motor set installed.

- Verify that the Propulsion Arm Assembly has been installed and mounted correctly.

1 Once the E800 Motor is installed and power is connected to the assembly, a 5 ft clearing zone must be enforced to ensure no one is in the vicinity of the propellers while they are spinning or have potential to spin.

Procedure

1. Install scale
2. Install plank via shoulder pin to base mount of See-Saw Test Rig.
3. Mount the Propulsion Arm Assembly onto the bolt pattern of the See-Saw Test Rig
4. Connect the ESC control leads to an Arduino with a program allowing the setting of throttle percentages.
5. Connect the ESC power leads to the 22.2V LiPo
6. Use the Arduino to send throttle values while noting the thrust seen by the scale in the See-Saw Test Rig for each throttle value sent

Results

After using the See-Saw Test Rig to determine the thrust provided by each motor, the test was considered an overall pass.

MRS.2.1 & MRS.2.1.1 Results -Pass

By holding the Propulsion Arm assembly in the upright position and allowing the arm to actuate into the locked position, the reliable actuation and locking of the Propulsion Arm Pivot was verified. The assembly was able to lock into place without fault every time.

MRS.2.2 & MRS.2.4 Results – Pass

By attaching the Propulsion Arm to the See-Saw Test Rig, these two requirements were able to be verified. The Propulsion Arm assembly was able to provide 4.30lbs of thrust per arm at full throttle. Also at full throttle, a trivial amount of arm deflection was seen. **Table 85** below shows the results of the thrust tests at various percentages of throttle.

Percentage of Throttle	Thrust Measured (lbs)
< 25	0.00
50	0.13
70	1.15
80	2.12
100	4.30

Table 85: Measured Thrust Values compared to Throttle Percentage

7.1.2.1.2 Autonomous Flight Testing

This test series will demonstrate the MRS's abilities to maneuver in the air, perform specific flight maneuvers, and demonstrate its ability to perform these operations autonomously.

Items to be Tested

- Retrieval and storage of GPS and altitude values upon initialization of the flight script.
- Calculation of relative vector of travel while MRS is falling under the Payload Deployment Parachute, and the use of this vector to determine and execute a maneuver away from the parachute.
- Reliability of GSE laptop computer for flight telemetry

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
MRS.1.1	The MRS shall obtain the GPS and altitude values upon initialization while on the launch rail.	The MRS must be able to accurately retrieve the GPS and altitude readings of the launch location and utilize them later in the program to score a pass.
MRS.1.3.1	The MRS shall maneuver into the direction of the wind and with a magnitude no less than 50 meters.	The MRS must be able to determine its vector of travel and accurately maneuver no less than 50 meters in the opposite direction to score a pass.
GSE.1	A laptop computer shall be utilized as a ground station control center and will allow real-time monitoring of MRS flight conditions.	The laptop computer must reliably monitor the test platform during flight. Any anomaly in connection status that could result in mission failure will score a fail.

GSE.2	There shall exist a primary RC transmitter capable of overriding all autonomous flight procedures.	The primary RC transmitter must be capable of stopping the performance of autonomous behavior and returning control of the MRS to the operator to score a pass.

Table 86: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

- MRS Electronics
- MRS Propulsion System
- TDS Electronics
- Primary GSE Transmitter
- GSE Laptop w/Telemetry Module
- Backup GSE Telemetry Device with connecting cable
- Assembled MRS test platform

Figure 143: The MRS test platform.

Setup

See Payload preflight checklist in Launch Procedures.

Safety Notes

Refer to Multirotor Flight Safety document.

Procedure

1. Connect 22.2V LiPo and wait for Pixhawk and Raspberry Pi to initialize
2. Verify stable bind of Primary GSE RC Controller
3. Connect to Raspberry Pi and verify that MAVROS is running
4. Attach propellers to motors

5. Utilize pre-written (verified by the simulator) flight scripts to verify all maneuvers and commands necessary for the full scale flight. Commands will be verified in the following order:
    1. Takeoff to set altitude and land
    2. Takeoff and move via the local positioning system before landing
    3. Takeoff and move via GPS coordinates before landing
    4. Takeoff and move via velocity setpoints before landing
6. When complete, disconnect 22.2V LiPo before removing propellers

Results

These tests are ongoing and have not been fully completed. They are scheduled for completion by 01/18/2017.

7.1.2.1.3 Payload Integration Flight Testing

This test series will demonstrate the ability of the MRS to adequately control the fully assembled Payload.

<u>Items to be Tested</u>

- Maneuverability of fully assembled Payload
- Ability of GSE to provide necessary communication to the RRS during flight
- Ability of MRS to trigger RRS recovery mode

<u>Pass/Fail Criteria</u>

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
MRS.3	The MRS shall have the ability to navigate and land in winds up to 20mph.	The Payload must be capable of performing its mission in any acceptable weather condition during the day of launch to score a pass.
GSE.3	There shall exist a secondary RC transmitter that provides input to the RRS.	The secondary RC transmitter must be capable of triggering actions on the RRS to score a pass.
RRS.2.2	The reserve parachute shall land the payload below the 75 ft-lb kinetic energy requirement if deployed.	Examination of flight logs must verify that the Payload is landed below the desired kinetic energy threshold.
RRS.3	The RRS shall be armed via a remote signal from the GSE secondary RC transmitter.	The RRS must charge the backup parachute capacitor upon activation by the secondary GSE RC transmitter to score a pass. This will be verified by triggering the RRS recovery mode.
RRS.4	The RRS shall have a dedicated I/O pin connected to the MRS for triggering an immediate activation of the RRS recovery mode.	Autonomous flight of the MRS must begin as soon as the RRS triggers it to score a pass.

Table 87: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

- MRS Electronics
- MRS Propulsion System
- RRS Electronics
- TDS Electronics
- E-match and Black Powder Charge
- Primary GSE Transmitter
- Secondary GSE Transmitter
- GSE Laptop w/Telemetry Module
- Backup GSE Telemetry Device with connecting cable
- Assembled Payload

Setup

See Payload preflight checklist in Launch Procedures.

Safety Notes

Refer to Multirotor Flight Safety document.

Procedure

1. Connect 22.2V LiPo and wait for Pixhawk and Raspberry Pi to initialize
2. Verify stable bind of Primary GSE RC Controller
3. Connect to Raspberry Pi and verify that MAVROS is running
4. Attach propellers to motors
5. Verify flight characteristics of Payload via manual control with the Primary GSE
6. Utilize pre-written (verified by the simulator) flight scripts to verify maneuvers and commands necessary for the full scale flight. Commands will be verified in the following order:
    1. Takeoff to set altitude and land
    2. Takeoff and move via GPS coordinates before landing
    3. Takeoff and move via velocity setpoints before landing
    4. Takeoff, move to a pre-determined GPS Coordinate and hold position to wait for clearance to land. When no clearance is given, the RRS will fire landing the Payload under parachute.
7. When complete, disconnect 22.2V LiPo before removing propellers

Results

These tests have not been completed yet. They are scheduled to be completed 01/28/2017.

7.1.2.2 DS Test Campaign

The deployment system test campaign will prove that the payload can be safely and repeatedly jettisoned from the body of the launch vehicle. Both ground and flight tests will be done of the DS. The ground test will be completed prior to the flight tests.

Test	Test Description	Requirements Verified	Status

Ground Deployment Bay Testing	This test will demonstrate the separation of the payload and the deployment bay along with MRS arm deployment.	DS.1.1 DS.1.3 DS.1.4	Incomplete 01/28/2017
Ground Main Recovery Bay Testing	This test will demonstrate the separation mechanisms for the lower half of the payload. This test will demonstrate the LLS actuation, TDS anti-blur mechanism, and will verify that main parachute deploys correctly.	DS.1.2 DS.3 LLS.1.1 LLS.3	Incomplete 01/28/2017

Table 88. DS sub-tests, test descriptions, requirements verified, and status.

7.1.2.2.1 Ground Deployment Bay Testing

This will test the ability of the payload to separate from the deployment bay.

Items to be tested:

- Ability of the payload to properly deploy from the deployment tube.
- Ability of the payload coupling to deploy from the deployment bay airframe.
- MRS arm deployment from stowed flight position inside deployment bay.
- MRS propulsion motors' performance before and after deployment test.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
DS.1.1	The DS shall not inhibit deployment of MRS arms.	All four MRS arms must be locked into place after deployment.
DS.1.3	Deployment shall not negatively affect the performance of the MRS propulsion motors.	Performance characteristics of the motors after the test must be within 5% of pre-test performance characteristics.
DS.1.4	The DS shall not damage any electrical harnessing or limit switches associated with the MRS propulsion system or the LLS.	All limit switches and electronics harnessing must be intact after deployment.

Table 89. Pass/Fail criteria for all requirements tested.

Pre-Test

Equipment

- Payload: PSS, RRS tube, and the MRS assembled together. Other payload sub-systems are not included in this test because their requirements are not being tested and they could become damaged if rapid unscheduled disassembles occur during this test.
- Deployment Bay: Deployment bay tube, MRS arm guides, the bottom centering bulkplate, and the deployment bay airframe assembled together.
- Test Stand: The test stand consists of a ladder with a shock cord suspended from the top down through the center.
- Black powder, e-matches, and dog-barf.
- Shear pins.

- Test recovery shock cord.

Setup.

1. Pack the black powder charge and dog-barf in the deployment tube and wire the e-match through the top of the deployment bay.
2. Attach the payload to the deployment bay by attaching the test recovery shock cord from the U-bolt on the RRS bulkplate to the U-bolt on the deployment bay
3. Slide the payload into the deployment bay. This includes folding the MRS arms in to fit in the deployment bay and sliding the RRS tube into the deployment tube while packing the test recovery shock cord in as well.
4. Screw the shear pins in to secure the payload to the deployment bay.
5. Hang the coupled sections from the shock cord on the test stand with the deployment bay on top.

Safety Notes

Setup must be done outside as black powder charges are used. Never arm the detonator during setup. All tests conducted within the DS test campaign must be conducted in a large, clear outdoor area. During testing setup no personnel should be directly below the suspended rocket. Personal must maintain a safe distance from the payload during testing. Eye protection will be worn at all times.

Procedure

1) Clear the area and check for any safety hazards.
2) When the safety officer has given the go ahead, detonate the black powder charge.
3) Observe and record results.

Results

Not completed yet.

7.1.2.2.2 Ground Main Recovery Bay Testing

This will test the ability of the payload to separate from the main recovery bay.

Items to be tested

- Ability of payload coupling to deploy from the main recovery bay.
- LLS deployment from stowed position.
- TDS viewing capabilities before and after deployment.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
DS.1.2	Deployment shall not inhibit deployment of LLS legs.	All four LLS legs must be locked into place after deployment.

DS.3	The system shall protect the TDS camera from becoming blurred during deployments.	Camera must detect targets with the same degree of accuracy before and after the deployment.
LLS.1.1	LLS shall remain functional after black powder separation	The LLS must demonstrate ability to snap into place from stowed position after the test is ran.
LLS.3	The LLS shall lock into the landing configuration after deployment from the main vehicle recovery bay.	LLS legs must be in locked position after deployment.

Table 90. Pass/Fail criteria for all requirements tested.

Pre-Test

Equipment

- Payload: TDS, LLS, and PSS assembled together.
- Test Stand: Two PVC airframe table stands, ratchet straps, folding table.
- Main recovery bay and main recovery parachute.
- TDS anti-blur mechanism.
- Shear pins and hex keys.
- Black powder, e-match, detonator, and dog-barf.

Image Test

An image test needs to be completed twice during the main recovery bay test. Once before the main recovery bay test and once after. The results from these two tests will be compared to determine if the anti-blur mechanism worked. The image test consists of taking a picture of three adjacent 3”x3” blue, yellow, and red squares on a whiteboard from 5’ and 10’ away.

Setup

- Turn on the TDS camera and perform the image test.
- Place the black powder charge in main recovery bay and wire the e-match out the bottom bulkplate.
- Pack the main parachute into the main recovery bay, packing the dog-barf as well.
- Setup the folding table in a large, open, and grassy area away from people.
- Place the two PVC airframe stands adjacent to each other on the table.
- Place the payload section on one PVC stand with the LLS legs facing the other stand. Make sure the LLS legs have enough room to actuate to their fully deployed position. If they do not, add supports to raise the PVC stand to give the legs more room.
- Ratchet strap the payload to the table by running the strap around the payload and under the table. Tighten down and secure the payload.
- Start the TDS recording video to record the test.
- Couple the payload with the main recovery bay. This includes folding the LLS legs in, stowing them in the main recovery bay sheathes, and sliding the main recovery bay airframe onto the payload airframe. The second PVC test stand shall be placed under the main recovery bay. The anti-blur mechanism shall be placed in here as well.
- Ratchet strap the second PVC test stand to the table. DO NOT ratchet strap the main recovery bay to the table.
- Screw in the shear pins to secure the two sections together.

Safety Notes

Black powder precautions must be followed. This test involves the separation of sections which can occur at high speeds. Inspect the area that the section will propel to before the test.

Procedure

1) Clear the area and check for any safety hazards. Give room for the main recovery bay to propel away from the test stand table.
2) When the safety officer has given the go ahead, detonate the black powder charge.
3) Observe results, checking specifically for LLS leg deployment and main parachute deployment.
4) Perform the image test on the TDS camera.
5) Compare imaging results to results before the test.

Results

7.1.2.3 RRS Test Campaign

The Full Scale Flight Test Campaign consists of sub tests which include the full mission duration of the payload. These test will verify the entire system functionality during an intended nominal flight. Displays the Full Scale Flight Test which will be accomplished to verify the entirety of the payload system.

Test	Test Description	Requirements Verified	Status
Fire Tower Drop Test	The RRS shall be brought to the top of the Fire Tower. It will be dropped with a recovery parachute and be expected to recover itself	RRS.2.2 RRS.2.3 RRS.2.4 RRS.3.1	Incomplete Test scheduled for 1/21/17

7.1.2.3.1 Fire Tower Drop Test 1

This test will demonstrate the RRS's ability to recover from a free fall scenario.

Items to be tested

- Logic to understand signals sent from ground control remote.
- Acquisition of altitude based on initialized ground level, and detection of velocity.
- Activation of recovery sequence after achieving a kinetic energy greater than 75 ft*lb.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria	Results Summary

RRS.2.2	The RRS shall deploy a parachute capable of lowering the kinetic energy of the payload below 75 ft*lb during the event of a flight anomaly.	Should the payload exceed a decent kinetic energy of 75 ft*lb the RRS must deploy the recovery parachute. Data will be taken of its fall to ensure the parachute utilized reduces the payload's kinetic energy below the specified levels.	Incomplete Scheduled for 1/21/17
RRS.2.4	The RRS shall determine altitude and velocity using a commercially bought pressure sensor.	The RRS must record the entire flight of the payload in a microSD card. This shall consist of an instantaneous altitude and velocity every 0.61s	Incomplete Scheduled for 1/21/17
RRS.3.1	The RRS shall be armed via ground team remote.	The RRS must activate the detachment maneuver when the ground team gives the signal.	Incomplete Scheduled for 1/21/17

Table 91: Pass/fail criteria for all requirements tested.

Pre-Test

Equipment

- Altitude and Velocity Detection circuit
  - Teensy 3.6
  - LM7805 Voltage Regulator
  - 9V Duracell Battery
  - BMP180 Altimeter
- Recovery Parachute Failsafe

Setup

This test is performed to verify the RRS's operation under failure conditions of a flight anomaly. The RRS shall track the altitude and velocity of the drop rig throughout its decent. This data will be written to the Teensy 3.6's microSD card.

Safety Notes

- Ensure no individuals are within drop zone of tower.
- Exercise caution when handling black powder charges and the electronics used to activate them.
- RRS shall beep when armed and black powder charge may be ignited
- Post drop, verify that the black powder charge has detonated
  1) If not verify that the RRS beeps
  2) Then disarm the RRS and wait for beeping to stop
     - If beeping does not occur, disarm RRS and wait a minimum of 1 minute before retrieving
  3) Cut leads to e-match

Procedure

1) Open Arduino
2) Connect RRS to computer via the Teensy's micro-USB port.
3) Check Devices and Printers for which port your computer assigned the Teensy
4) Press button on Teensy to reset program

5) Initialize RRS via serial command "Start"
6) Wait until RRS recognizes command and sends "Initialized"
7) Connect 9V battery to RRS
8) Disconnect RRS from computer
9) Install RRS to Drop Rig
10) Climb tower
11) Arm RRS
12) Release Drop Rig
13) Verify release of recovery parachute. *If this does not occur, refer to Safety Notes
14) Retrieve Drop Rig and extract RRS
15) Remove microSD card

Results

Unavailable until test date

7.1.2.4 **TDS Test Campaign**

The Target Detection System test campaign shall prove that the TDS is capable of taking still images, analyzing these images in real time, and correctly identifying/detecting targets. Ground, subscale, and flight tests shall be conducted to verify these capabilities under the constraints set by the NASA Student Launch Competition guidelines.

Test	Test Description	Requirements Verified	Status
TDS Ground Test	This test series will demonstrate the TDS's ability to accurately detect targets and provide evidence of detected targets using stills. The stills used will be gathered during flight-like conditions.	TDS.1 TDS.2	Incomplete Scheduled for 2/4/17
TDS Flight Test	This test series will demonstrate the MRS's abilities to maneuver the payload in the air, perform specific flight maneuvers, and demonstrate its ability to perform these operations autonomously.	TDS.1 TDS.2 TDS.3	Incomplete Scheduled for 2/4/17

Table 5: TDS flight sub-tests, test descriptions, and requirements verified through testing.

7.1.2.4.1 TDS Ground Test

This test series will demonstrate the TDS' ability to accurately detect targets and provide evidence of detected targets using stills. The stills used will be gathered during flight-like conditions. Target(s) similar to those used in competition will be placed and stills will be taken from a pre-defined altitude. This stills will then be run through the target detection algorithm. This test will be conducted multiple times so that different operating conditions can be tested.

Items to be Tested

- TDS object detection algorithm
- Ability of TDS to provide evidence of detected target

Items Not Tested

- MRS Compatibility

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
TDS.1	TDS shall have ability to detect and differentiate between all three randomly placed targets.	Each target placed is detected in one of the stills used.
TDS.2	The TDS shall provide adequate evidence that targets were detected.	Stored image(s) exists that outlines target(s).

Table 6: Pass/fail criteria for all requirements tested.

Pre-test

The following sections describe information about the setup and approach being used for the test.

Equipment

A stand in camera/drone system will be required to take pictures for the TDS algorithm to analyze. Target(s) resembling the ones used in competition will be placed and photos will be taken at a predetermined altitude.

Setup

Drone/Camera system shall be taken to a set altitude above target(s) at several different times in order to mimic different flight conditions. Images shall be captured and returned to be analyzed. This images will be run through the target detection algorithm that will be used in competition. Visual inspection will be required to determine if the test passed.

Safety Notes

Only team members experienced with drone flight should handle/fly drone.

7.1.2.4.2 TDS Flight Test

This test series will demonstrate the MRS's abilities to maneuver the payload in the air, perform specific flight maneuvers, and demonstrate its ability to perform these operations autonomously.

Items to be Tested

- TDS object detection algorithm
- Ability of TDS to provide evidence of detected target
- MRS Compatibility

Items Not Tested

- None

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	TDS detects target(s)	Each target placed is detected in one of the stills used.
2	TDS provides evidence of detected target(s)	Stored image(s) exists that outlines target(s).
3	TDS interacts appropriately with MRS	Both systems must execute without failure

Table 7: Pass/fail criteria for all requirements tested.

Pre-test

The following sections describe information about the setup and approach being used for the test.

Equipment

MRS will be required to take pictures for the TDS algorithm to analyze. Target(s) resembling the ones used in competition will be placed and photos will be taken at a predetermined altitude.

Setup

MRS shall be taken to a set altitude above target(s) at several different times in order to mimic different flight conditions. Images shall be captured and returned to be analyzed. This images will be run through the target detection algorithm that will be used in competition. Visual inspection will be required to determine if the test passed.

Safety Notes

Only team members experienced with drone flight should handle/fly drone.

- Propulsion arms
- Landing Legs
- Jam nuts
- Camera Assembly
- Bulk plates

7.1.2.5 **Full Scale Flight Test Campaign**

The Full Scale Flight Test Campaign consists of sub tests which include the full mission duration of the payload. These test will verify the entire system functionality during an intended nominal flight. Displays the Full Scale Flight Test which will be accomplished to verify the entirety of the payload system.

Test	Test Description	Requirements Verified	Status
Full Scale Flight Test 1	This test series will demonstrate the payloads ability to perform the entirety of its designed mission during a launch vehicle flight.	MRS.1 MRS.2 MRS.3 GSE.1 GSE.2 GSE.3 RRS.1 TDS.1 TDS.2 LLS.4 DS.1	Incomplete. Scheduled for 02/18/2017
Full Scale Flight Test 2			Incomplete. Scheduled for 02/25/2017

Table 92. Full Scale Flight Test, test descriptions, and requirements verified through testing.

7.1.2.5.1 Full Scale Flight Test 1

This test will demonstrate the Payload's ability to perform the entirety of its designed mission.

Items to be tested

- Deployment and Separation of the Payload from the Launch Vehicle.
- Initialization of the Payload Flight Systems under descent of the deployment parachute.
- Cutaway and flight maneuvering of the Payload.
- Target detection and identification.
- Payload landing capability.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria	Results Summary
MRS.1	The payload shall be recovered and landed upright via the autonomous Multirotor Recovery System.	The Payload must be recovered via its multirotor system to be considered a pass. If the RRS deploys the reserve parachute this will score a fail.	Incomplete Scheduled for 02/25/2017
MRS.2	The MRS propulsion assembly shall be capable of deploying from the launch vehicle and reacting all flight loads induced by the multirotor.	The multirotor system must successfully deploy from the Deployment Bay and Main Recovery Bay to score a pass. If the multirotor system does not successfully deploy from the Deployment and Recovery Bays then this will score a fail.	Incomplete Scheduled for 02/25/2017
MRS.3	The MRS shall have the ability to navigate and land in winds up to 20mph.	The Payload must be capable of performing its mission in any acceptable weather condition during the day of launch to score a pass.	Incomplete Scheduled for 02/25/2017

GSE.1	A laptop computer shall be utilized as a ground station control center and will allow real-time monitoring of MRS flight conditions.	The GSE laptop computer must provide continuous communication with the payload after deployment to be to score a pass.	Incomplete Scheduled for 02/25/2017
GSE.2	There shall exist a primary RC transmitter capable of overriding all autonomous flight procedures.	Review of the flight log from the Flight Controller must show no instance of "RC Signal Lost" after deployment to score a pass.	Incomplete Scheduled for 02/25/2017
GSE.3	There shall exist a secondary RC transmitter that provides input to the RRS.	Review of the RRS flight log must show no instance of "RC Signal Lost" after deployment to score a pass.	Incomplete Scheduled for 02/25/2017
RRS.1	The RRS shall sever the connection of the MRS from the deployment parachute.	The RRS must successfully deploy the ARRD releasing the deployment parachute to score a pass. If the ARRD is not engaged and the parachute isn't released this will score a fail.	Incomplete Scheduled for 02/25/2017
TDS.1	TDS shall have ability to detect and differentiate between all three randomly placed targets.	The TDS must detect and differentiates between the three randomly placed targets during flight this will score a pass. If the targets aren't recognized this will score a fail.	Incomplete Scheduled for 02/25/2017
TDS.2	TDS shall provide adequate evidence that targets were detected.	The TDS must generate a file which contains evidence of the targets being differentiated to receive a passing score. If this results file is not generated then this will score a fail.	Incomplete Scheduled for 02/25/2017
LLS.4	The LLS shall provide enough rigidity and stability to support the entire payload system upon landing.	The LLS must be capable of supporting the Payload during its landing maneuver. If the legs buckle and or the Payload tips over, this will score a fail.	Incomplete Scheduled for 02/25/2017
DS.1	The Deployment System shall safely deploy the payload from the Deployment Bay and Main Recovery Bay.	The DS must separate the payload from the Deployment Bay and the Main Recovery Bay at their designed separation altitudes to score a pass. Failing to separate or separation at the wrong altitudes will score a fail.	Incomplete Scheduled for 02/25/2017

Table 93: Pass/fail criteria for all requirements tested.

Pre-Test

<u>Equipment</u>

Experimental Payload: The entire Payload system will be tested during the Full Scale Test Flight. This includes the fully developed MRS, RRS, TDS, LLS, PSS, DS, and GSE systems. The major components under test during the Full Scale Flight Test include the following:

- MRS Electronics
- MRS Propulsion System
- RRS Electronics
- TDS Electronics
- Deployment Parachute
- Deployment Bay
- E-match and Black Powder Charge
- Primary GSE Transmitter
- Secondary GSE Transmitter
- GSE Laptop w/Telemetry Module
- Backup GSE Telemetry Device with connecting cable

Setup

See Payload preflight checklist in Launch Procedures.

Safety Notes

- When operating the Payload and MRS, follow the preflight check list.
- Exercise caution when handling black powder charges and the electronics used to activate them.
- Verify all fasteners have been sufficiently tightened and Loctite has been applied to all threading surfaces.

Procedure

Follow the Payload launch procedures.

Results

These tests have not been completed yet. These tests are scheduled to be completed 02/18/2015 and 02/25/2017.

7.2 Requirements Compliance

7.2.1 Request for Proposal (RFP) Requirements Verifications

The statement of work requirements are organized according to Figure 144 below.

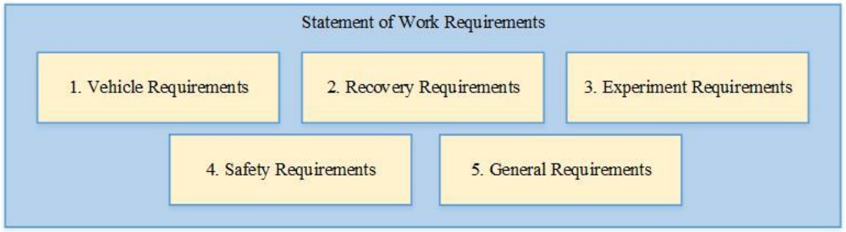


Figure 144: SOW requirements categories.

Requirement ID	Requirement	Verification Plan	Status
Vehicle			
1.1 Mission	The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	Test Full-scale launch testing will verify this requirement. See SOW Requirement 1.17 for details on this test. Also see the vehicle testing section.	Incomplete Three test launches of the launch vehicle will be performed once all components are manufactured and assembled. These launches are scheduled to take place on February 25, March 11, and March 25 in Elizabethtown, Kentucky. See Launch Vehicle Test Campaign.
1.2 Launch Day	The vehicle shall 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. The altitude score will be equivalent to the percentage of altitude points remaining after and deductions.	Inspection The official scoring altimeter will be inspected and marked by the judges at the LRR. The value of apogee reported by this altimeter will be recorded at the judge's tent post recovery.	Incomplete This requirement will be verified in April at competition. See the Vehicle Checklist for a complete list of launch vehicle inspections.
1.2.1 Official Scoring Altimeter	The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	Inspection The official scoring altimeter will be inspected pre-launch for the functionality of its speaker.	Incomplete This requirement will be verified in April at competition. See the Vehicle Checklist for a complete list of launch vehicle inspections.

1.2.2 Additional Altimeters	Teams may have additional altimeters to control vehicle electronics and payload experiment(s).	Demonstration Additional altimeters will be included in sub systems of the vehicle such as the VDS and payload.	Complete The launch vehicle was designed to incorporate additional altimeters into VDS and payload. See the VDS section in Vehicle Design.
1.2.3 Marking of Official Altimeter	At the LRR, a NASA official will mark the altimeter that will be used for the official scoring.	Inspection The safety officer will be present at the LRR to ensure that a NASA official marks one of the altimeters as the official scoring altimeter.	Incomplete This requirement will be verified in April at competition. See the Vehicle Checklist for a complete list of launch vehicle inspections.
1.2.4 Method of Ascertaining Altitude	At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.	Inspection The official altimeter, marked by a NASA official at the LRR, will be brought to the judges' tent for altitude scoring. The altimeter will not be turned off or reset between recovering the vehicle and presenting the altimeter to preserve the altitude data. This procedure will be demonstrated in a full-scale test before the competition launch.	Incomplete This requirement will be verified in April at competition. See the After Flight Vehicle Checklist.
1.2.5 Off-switch	At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	Demonstration The shut-down of all audible electronics except the official scoring altimeter will be demonstrated in a full-scale test before the competition launch.	Incomplete This requirement will be verified in April at competition. See the After Flight Vehicle Checklist.
1.2.6 Zero Score Cases	The following circumstances will warrant a score of zero for the altitude portion of the competition:	N/A	N/A
1.2.6.1 Official Altimeter Damaged	The official, marked altimeter is damaged and/or does not report and altitude via a series of beeps after the team's competition flight.	Inspection The official scoring altimeter will be inspected for damage post-recovery by the safety officer.	Incomplete This requirement will be verified in April at competition. See the After Flight Vehicle Checklist.
1.2.6.2 Team Absence	The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.	Inspection The safety officer will ensure that the team reports to the designated NASA official.	Incomplete This requirement will be verified in April at competition. See the After Flight Vehicle Checklist.
1.2.6.3 Waiver Exceeded	The altimeter reports an apogee altitude over 5,600 feet AGL.	Test The full-scale vehicle will be flown in a control launch on 2/11/17 to verify that it does not exceed 5,600 ft. AGL. This requirement will be verified for both cases with and without the VDS.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
1.2.6.4 No Flight	The rocket is not flown at the competition launch site.	Inspection The safety officer will ensure that all necessary preparations are made such that the team will be able to launch the vehicle at competition.	Incomplete This requirement will be verified in April at competition. See the Launch Operations Checklist.
1.3 Recovery Batteries	All recovery electronics shall be powered by commercially available batteries.	Demonstration All altimeters will be powered by Duracell 12 volt batteries.	Complete Each altimeter will utilize a Duracell 12-volt battery. See the Avionics section.

1.4 Reusability	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Test The parachutes will be designed to ensure every section of the launch vehicle lands with a kinetic energy below the maximum kinetic energy laid out in the Statement of Work. Through appropriate material selection and manufacturing techniques, the rocket will be able to land at the maximum allowable kinetic energy without incurring any damage. Landing within these constraints will leave the launch vehicle in a reusable state.	Incomplete Three test launches of the launch vehicle will be performed once all components are manufactured and assembled. These launches are scheduled to take place on February 25, March 11, and March 25 in Elizabethtown, Kentucky. See the Launch Vehicle Test Campaign.
1.5 Max Sections	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Demonstration The launch vehicle will be comprised of four independent sections: the nose cone, the payload, and the rest of the launch vehicle, which includes the recovery bay, the VDS bay, and the propulsion bay.	Complete The launch vehicle has been designed to be recovered in four independent sections. See the Design Overview in the Vehicle Design section.
1.6 Stage Limit	The launch vehicle shall be limited to a single stage.	Analysis Having a limited altitude of 5280 feet eliminates any need for staging of our launch 1. Motor selections have been made to accomplish all necessary altitude requirements on a single stage launch vehicle.	Complete The launch vehicle has been designed to use a single motor for propulsion of the launch vehicle. See the Motor Selection section.
1.7 Prep Time	The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Inspection A comprehensive launch procedure checklist will be constructed by the team to allow for accurate and expedited vehicle assembly while preparing for flight.	Incomplete This requirement is scheduled to be verified on February 25th, before a fully integrated full scale launch vehicle flight. See the Launch Operations Checklist.
1.8 Pad Time	The launch vehicle shall 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 component.	Inspection The power supplies for the payload electronics, altimeters, and flight event devices have been chosen to eliminate the chances of power failure for an extended period of time.	Incomplete The launch vehicle on-board electronics will be demonstrated to last a minimum of 1 hour turned on inside the launch vehicle. Each 9 volt altimeter battery will inspected to proper charge. This requirement is scheduled to be verified in March. See Vehicle Checklist.
1.9 Firing System	The launch vehicle shall 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.	Inspection The launch vehicle will utilize proven launch igniters purchased from Wildman Rocketry. The igniters are designed to ignite the vehicle's motor by use of a standard 12 volt direct current firing system	Incomplete This requirement will be verified on February 11 during the first control flight of the full scale launch vehicle.
1.10 Ground Support Equipment	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	Demonstration The launch vehicle will not require external circuitry or special ground support equipment to initiate launch.	Complete The launch vehicle has been designed to not require external circuitry or special ground support equipment to initiate launch. See the Launch Vehicle Design section.
1.11 Motor	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is	Demonstration The team will use an AeroTech L2200-G motor for its full scale launch vehicle.	Complete This requirement was verified in October. See the Motor Selection section.

	approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).		The first launch of the full scale launch vehicle using the Aerotech L2200-G will occur on February 11th. See the Motor Selection section.
1.11.1 Motor Choice Deadline	Final motor choices must be made by the Critical Design Review (CDR).	Analysis The full scale launch vehicle will utilize the Aerotech 2200-G Motor for the competition launch.	Complete This requirement was verified in October. See the Motor Selection section.
1.11.2 Deadline Exceptions	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.	N/A	N/A
1.12 Pressure Vessels	Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:	Demonstration The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.	Complete This requirement was verified in October. See the Launch Vehicle Design section.
1.12.1 Burst Factor of Safety	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.	Demonstration The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.	Complete This requirement was verified in October. See the Launch Vehicle Design section.
1.12.2 Low-Cycle Fatigue	The low-cycle fatigue life shall be a minimum of 4:1.	Demonstration The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.	Complete This requirement was verified in October. See the Launch Vehicle Design section.
1.12.3 Pressure Relief Valve	Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.	Demonstration The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.	Complete This requirement was verified in October. See the Launch Vehicle Design section.
1.12.4 Tank Pedigree	Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	Demonstration The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.	Complete This requirement was verified in October. See the Launch Vehicle Design section.
1.13 Motor Impulse	The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Demonstration The total impulse of the AeroTech L2200-G is 5,104 Newton-seconds.	Complete This requirement was verified in October. See the Motor Selection section.

1.14 Rail Exit Stability	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Analysis OpenRocket simulations will be created to calculate the static stability margin and hand calculations will be used to verify the OpenRocket simulations.	Complete Multiple OpenRocket simulations were performed under several different weather conditions and rail lengths to ensure that the stability margin at rail exit was above 2.2. This requirement was verified in December. See the OpenRocket Simulation section under Mission Performance Predictions.
1.15 Rail Exit Velocity	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Test OpenRocket simulations will be created to calculate the exit rail velocity and hand calculations will also be used to check the OpenRocket simulations. A control test flight of the launch vehicle will be conducted to verify the exit rail velocity.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
1.16 Subscale Test	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Test A 1:2 scaled model of the full scale launch vehicle has been designed. The subscale launch vehicle will be used to test stability and integration of various systems seen in the full scale launch 1.	Complete The subscale vehicle completed a successful launch and recovery on December 18th in Bowling Green, Kentucky.
1.16.1 Subscale Purpose	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.	Demonstration The subscale vehicle's will be proportional to the full scale vehicle and will have a nearly identical rail exit stability of the full scale launch 1.	Complete The subscale vehicle has been constructed and tested. This requirement was verified on December 18th. See the Subscale Flight Results section.
1.16.2 Altimeter	The subscale model shall carry an altimeter capable of reporting the model's apogee altitude.	Demonstration The subscale vehicle will carry two PerfectFlite Stratologger CF altimeters to record the apogee altitude of the subscale vehicle.	Complete The subscale vehicle carried two PerfectFlite Stratologger CF altimeters that reported its apogee altitude during its flight on December 18th. See the Subscale Flight Results section.
1.17 Full-scale Test	All teams shall 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 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:	Test The team plans to conduct several full scale test flights throughout the season to test the rigidity and effectiveness of the VDS and payload design.	Incomplete Three full scale launch vehicle test launches which incorporate all sub systems that will be used at competition will be carried out on February 25th, March 11th, and March 25th. See the Launch Vehicle Test Campaign section.
1.17.1 Function as Designed	The vehicle and recovery system shall have functioned as designed.	Test Several test launches of the full scale launch vehicle will be performed to ensure that the vehicle and recovery system work as designed.	Incomplete Three full scale launch vehicle test launches which incorporate all sub systems that will be used at competition will be carried out on February 25th, March 11th, and March 25th. See the Launch Vehicle Test Campaign section.

1.17.2 No Payload	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	Test A control launch of the full scale launch vehicle without the payload and VDS will be performed.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
1.17.2.1 Mass Simulators	If the payload is not flown, mass simulators shall be used to simulate the payload mass.	Inspection Three launches of the full scale vehicle are scheduled before FRR. For the control launch on February 11th and the VDS test launch on February 18th, the vehicle will incorporate a ballast system to simulate the weight of the payload. The integration launch that is scheduled on February 25th will test the integration of the payload with the vehicle	Incomplete The launches that will include a ballast system to simulate the payload will occur on Februarys 11th and February 18th. See the Launch Vehicle Test Campaign.
1.17.2.1.1 Mass Simulator Location	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	Inspection The coupler tube that will house the payload will feature a ballast system.	Incomplete The launches that will include a ballast system to simulate the payload will occur on Februarys 11th and February 18th. See the Launch Vehicle Test Campaign.
1.17.3 Yes Payload	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 shall be active during the full-scale demonstration flight.	Demonstration The payload will be active during the scheduled integration test launch on February 25th.	Incomplete The integration launch with the payload is scheduled to occur on February 25th. See the Launch Vehicle Test Campaign.
1.17.4 Full-scale Motor	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 simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.	Demonstration The selected full scale launch vehicle motor, which is the AeroTech L2200-G, will be flown during the full scale test flight.	Incomplete The full scale integration test flight is scheduled to occur on February 25th. See the Launch Vehicle Test Campaign section.
1.17.5 Ballast	The vehicle shall 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.	Demonstration The launch vehicle will not utilize a ballast system for the full scale test flight.	Complete The launch vehicle will not utilize a ballast system. See the Launch Vehicle Design section.
1.17.6 No Design Changes Post Test	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Inspection The full scale launch vehicle will not be modified after the first successful test flight.	Incomplete This requirement is scheduled to be verified in February.
1.17.7 Deadline	Full scale flights must be completed by the start of FRRs (March 6th, 2016). If the Student Launch office determines that a re-flight is necessary, than an	Demonstration	Incomplete The full scale integration launch is scheduled to occur on February 25th.

	extension to March 24th, 2016 will be granted. This extension is only valid for re-flights; not first time flights.	The full scale integration launch is scheduled for February 25th. If the test flight is unsuccessful, the team will request for an extension.	
1.18 Structural Protuberances	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Inspection The only structural protuberance on the launch vehicle are the drag blades of the VDS. The launch vehicle was designed to place the VDS as far aft on the vehicle as possible. As a result, all structural protuberances are located aft of the burnout center of gravity.	Incomplete Once the full scale launch vehicle is manufactured and assembled, the center of gravity will be verified to ensure that the VDS drag blades are aft of the burnout center of gravity.
1.19 Vehicle Prohibitions	The following constraints shall be placed on the launch vehicle:	N/A	N/A
1.19.1 Forward Canards	The launch vehicle shall not utilize forward canards.	Demonstration The current design of the full scale launch vehicle does not incorporate forward canards.	Complete The launch vehicle has been designed to not incorporate forward canards.
1.19.2 Forward Firing Motors	The launch vehicle shall not utilize forward firing motors.	Demonstration The current design of the full scale launch vehicle does not incorporate forward firing motors.	Complete The launch vehicle has been designed to not incorporate forward firing motors.
1.19.3 Titanium Sponges	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Demonstration The full scale launch vehicle will utilize an Aerotech 2200-G motor, which does not expel titanium sponges.	Complete The launch vehicle has been designed to not incorporate motors that expel titanium sponges. See the Motor Selection section.
1.19.4 Hybrid Motors	The launch vehicle shall not utilize hybrid motors.	Demonstration The full scale launch vehicle will utilize an Aerotech 2200-G motor, which is not a hybrid motor.	Complete The launch vehicle has been designed to not incorporate hybrid motors. See the Motor Selection section.
1.19.5 Clustering	The launch vehicle shall not utilize a cluster of motors.	Demonstration The full scale launch vehicle will utilize an Aerotech 2200-G motor, which does not expel titanium sponges.	Complete The launch vehicle has been designed to not incorporate a cluster of motors. See the Motor Selection section.
1.19.6 Friction Fitting	The launch vehicle shall not utilize friction fitting for motors.	Demonstration The launch vehicle will utilize a thrust ring to transmit the thrust to the motor mount.	Complete The launch vehicle has been designed so that it will not utilize a friction fitting motor. See the Motor Selection section.
1.19.7 Max Q	The launch vehicle shall not exceed Mach 1 at any point during flight.	Analysis OpenRocket simulations of the full scale launch vehicle have been conducted and verified that the maximum velocity of the launch vehicle is below Mach 1.	Complete This requirement was verified in October. See the OpenRocket Simulations section.
1.19.8 Max Ballast Weight	Vehicle ballast shall not exceed 10% of the total weight of the rocket.	Demonstration The full scale launch vehicle will not utilize a ballast system.	Complete This requirement was verified in October.

Recovery			
2.1 Staging	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery 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 Range Safety Officer.	Test The vehicle will descend in two untethered sections under drogue parachutes to 1700 and 600 ft AGL, respectively where they will then stage and descend under main.	Complete Proof of concept has verified drogue to main deployment via ARRD during subscale flight on December 18th.
2.2 BP Testing	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 launches.	Demonstration Ground ejection tests will be conducted for every potential deployment event, including deployment of the MDP, and MRP.	Incomplete This requirement has been verified for subscale. Full scale verification scheduled for early Ferbuary
2.3 Kinetic Energy	At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Test/Analysis Each section under main will have no more than 75 ft-lb of kinetic energy and will be facilitated by calculating parachute diameters accordingly and verifying drag coefficients in test flights.	Complete This requirement was verified upon confirmation of parachute drag coefficients during December 18th test flight and further verified by analysis in recovery section.
2.4 Independent Circuits	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Analysis The main vehicle recovery circuits will feature independent circuitry, and the multirotor abort electronics will be independent from all other GNC systems aboard the multirotor.	Complete This requirement was verified in January. See the vehicle Avionics section and the VDS electronics section.
2.5 Altimeters	The recovery system shall contain redundant, commercially available altimeters. The term altimeters includes both simple altimeters and more sophisticated flight computers.	Demonstration Each main vehicle recovery event will be controlled by redundant pairs of StratologgerCF altimeters. The multirotor abort system will feature more sophisticated, redundant, kinetic energy-dependent deployment computers.	Complete The launch vehicle is designed to contain redundant, commercially available altimeters as well as more sophisticated flight computers for payload.
2.6 Motor Ejection	Motor ejection is not a permissible form of primary or secondary deployment.	Demonstration Black powder charges will be used for each deployment.	Complete This requirement was verified during subscale flight on December 18th.
2.7 Altimeter Arming	Each altimeter shall 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.	Demonstration Each arming switch will be accessible via standard vent holes with screwdriver.	Complete Full scale vehicle is designed to enable arming of altimeters from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch. See the Avionics section.
2.8 Power Supplies	Each altimeter shall have a dedicated power supply.	Demonstration Each StratologgerCF will be powered with 9V Duracell batteries. The RRS circuits will also be powered by independent 9v Duracell batteries.	Complete This requirement is confirmed in the Avionics section.

2.9 Arming Switch	Each arming switch shall be capable of being locked in the ON position for launch.	Demonstration Each arming switch will be accessible via standard vent holes with screwdriver.	Complete This requirement is verified in the Avionics section.
2.10 Shear Pins	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Demonstration Both main vehicle recovery bays will feature removable shear pins, as will the bay for the MDP and reserve parachute.	Complete This requirement was verified in October. See the Airframe section in Launch Vehicle Design.
2.11 Tracking Devices	An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	Demonstration Each independent section, including the multirotor, will carry a GPS tracker.	Complete This requirement was verified in November. See the GPS Tracking section.
2.11.1 Per Section	Any rocket section, or payload component, which lands untethered to the launch vehicle, shall also carry an active electronic tracking device.	Demonstration Each independent section, including the multirotor, will carry a GPS tracker.	Complete This requirement was verified in November. See the GPS Tracking section.
2.11.2 Fully Functional	The electronic tracking device shall be fully functional during the official flight on launch day.	Inspection GPS trackers will be fully charged before each launch.	Complete This requirement was verified in November. See the GPS Tracking section.
2.12 EMI	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Demonstration The main recovery electronics will be shielded from any potential EMI in dedicated, isolated avionics bays.	Complete There are no transmitting electronics devices in the avionics bays. See the Launch Vehicle Design section.
Experiment			
3.1 Experiment Overview			
3.1.1 Experiment Choice	Each team shall choose one design experiment option from the following list.	Target Detection and Upright Landing has been chosen from the following list.	Complete This selection was made at PDR.
3.1.2 Additional Experiments	Additional experiments (limit of 1) are encouraged, and may be flown, but they will not contribute to scoring.	No additional Payloads will be flown.	Complete During the PDR phase, it was decided that the experimental Payload set forth by NASA would be the only experiment carried.
3.1.3 Additional Experiments Documentation	If the team chooses to fly additional experiments, they shall provide the appropriate documentation in all design reports so experiments may be reviewed for flight safety.	N/A	N/A
3.2 Target Detection and Upright Landing			

3.2.1 Mission	Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.	Test The custom designed onboard camera system will be tested to prove its ability to visually detect and identify	Incomplete Full scale flight tests of the payload are scheduled to occur starting on 02/18/2017
3.2.3 Target Detection	Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.	Demonstration The Payload camera system will be designed to interpret three individual targets on the launch field.	Complete The TDS system has been designed with this requirement as an assumption for the system.
3.2.1.1 Target Diversity	Each target shall be represented by a different colored group tarp located on the field.	Inspection The Payload team lead will verify that the target samples have been received.	Incomplete The team has yet to receive the target samples.
3.2.1.2 Target Deliverable	Target samples shall be provided to teams upon acceptance and prior to PDR.	Demonstration The TDS is designed to be capable of recognizing targets of this size.	Incomplete Insufficient calibration data to fully demonstrate this functionality.
3.2.1.3 Target Size	All targets shall be approximately 40'X40' in size.	Demonstration The TDS will be designed using these assumptions.	Complete The TDS system has been designed with this requirement as an assumption for the system.
3.2.1.4 Target Placement	The three targets will be adjacent to each other, and that group shall be within 300 ft. of the launch pads.	Demonstration The MRS has been designed to successfully land the Payload after target detection and differentiation.	Complete The MRS shall ensure a successful upright landing.
3.2.2 Target Identification	After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.	Demonstration The TDS is designed to incorporate an onboard custom designed software package to differentiate the targets	Complete The TDS system has been designed to accomplish this requirement.
Safety			
4.1 Checklist	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	Inspection The launch and safety checklist will be reviewed and implemented before FRR submission.	Complete The team has created a launch procedures checklist that covers the launch and safety both the prep before a launch and the at the field checklist. More detail can be found in the Launch Operations Procedures section. This can be changed be altered by FRR if necessary.
4.2 Safety Officer	Each team must identify a student safety officer who shall be responsible for all items in section 4.3.	Inspection A team member has been identified for the 2016-2017 competition season. Kevin Compton will be the Safety Officer.	Complete Kevin Compton was selected as the Safety Officer at the time of the PDR on November 11th.
4.3 Safety Officer Responsibilities	The role and responsibilities of each safety officer shall include, but not limited to:	Inspection Responsibilities are further defined in lower level requirements for the identified Safety Officer.	Not Applicable

4.3.1 Monitor Team Activities	Monitor team activities with an emphasis on Safety during:	Inspection Team activities are further defined below and are monitored by the Safety Officer.	Not Applicable
4.3.1.1 Design	Design of vehicle and launcher	Inspection Launch Vehicle Lead, Justin Johnson, and the Safety Officer review design of vehicle to ensure there are no outstanding safety concerns.	Complete The launch vehicle's design has been addressed from a safety aspect and is completed upon the submission of the Critical Design Review.
4.3.1.2 Construction	Construction of vehicle and launcher	Inspection Construction of the vehicle and launcher is monitored by the Safety Officer.	Incomplete This item is a constant process and won't be marked complete until the full-scale vehicle is constructed to ensure all safety precautions were taken during the manufacturing process.
4.3.1.3 Assembly	Assembly of vehicle and launcher	Inspection Assembly of vehicle and launcher is overseen by the Safety Officer.	Incomplete This item is complete for the sub-scale vehicle, however, will not be marked complete until the first assembly of the full-scale on February 11th (which is the first full-scale flight test).
4.3.1.4 Testing	Ground testing of vehicle and launcher	Inspection The Safety Officer is notified and signs off on all ground testing of vehicle.	Incomplete This item is considered complete for the sub-scale vehicle after successful ground testing and flights. This item will be marked complete once the full-scale is ground tested and flown on February 11th.
4.3.1.5 Subscale	Sub-scale launch test(s)	Inspection The Safety Officer is present for all sub-scale launch test(s). His signature must be present on all steps and items before a launch can proceed.	Complete The Safety Officer was present for all sub-scale flights which resulted in a successful test flight. For further see the Flight Analysis section.
4.3.1.6 Full-scale	Full-scale launch test(s)	Inspection The Safety Officer is present for all full-scale launch test(s). His signature must be present on all steps and items before a launch can proceed.	Incomplete This item will become complete at the first full-scale flight test on February 11th. However, the Safety Officer has approved of proper launch procedures to ensure a safe flight.
4.3.1.7 Launch Day	Launch day	Inspection Launch operations checklist has all appropriate signatures and is verified by the Safety Officer before launch is initialized.	Complete The Safety Officer has implemented a safety briefing and a launch procedures list that is implemented before every launch so everyone is aware of all caution items at a launch site.
4.3.1.8 Recovery	Recovery activities	Inspection The Safety Officer oversees all recovery activities.	Complete The Safety Officer has overseen all recovery activities during sub-scale construction and will do so for the full-scale construction.
4.3.1.9 Educational Engagement	Educational Engagement Activities	Inspection The Safety Officer is aware of all educational outreach activities and will apply all safety standards and PPE at his disposal to educational outreach events.	Complete The Safety Officer is aware of all outreach events and ensures if he cannot attend that the members of RCR know the safety standards when attending an Educational Outreach

			Event. The safety standards are closely related to the Human Safety requirements.
4.3.2 Procedures	Implement procedures developed by the team for construction, assembly, launch, and recovery activities	Inspection The Safety Officer develops a launch operations checklist that is performed before every launch is initialized.	Complete The Safety Officer has completed a launch procedures list with the assistance of all RCR leads.
4.3.3 Documentatio n	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	Inspection The Safety Officer keeps an up to date document of all hazard analyses, failure modes analyses, procedures, and MSDS data throughout the competition season.	Complete The Safety Officer is constantly updating the hazard analyses and MSDS sheets throughout the season and from year to year so that River City Rocketry maintains a high level of safety.
4.3.4 Documentatio n	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Inspection The Safety Officer complies with the development of the team's hazard analyses, failure modes analyses, and procedures for the 2016-2017 competition season.	Complete This task has been overseen by the Safety Officer and completed by all associated leads with River City Rocketry. For further detail see the Safety section.
4.4 Mentor	Each team shall 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 shall 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 the rocketeer shall 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 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.	Inspection The Safety Officer ensures that the team has a mentor for the 2016-2017 competition season that has his Level 3 TRA Certification.	Complete The Safety Officer has been in contact with Darryl Hankes as the teams mentor. His information can be found in the beginning of our PDR.

4.5 RSO	During test flights, teams shall 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.	Inspection The Safety Officer ensures that the team abides by all NAR rules as well as taking position as the teams RSO during launches that are ran by River City Rocketry.	Complete The Safety Officer has assured that all team members are aware of the NAR Safety Code as shown by the signatures in the teams Safety Manual.
4.6 FAA	Teams shall abide by all rules set forth by the FAA.	Inspection The Safety Officer ensures that all team members abide by the rules set forth by the FAA. Launch site waivers and notice to airmen submissions are available upon request.	Complete The Safety Officer makes sure that all members follow the rules set forth by the FAA by the signing of the Safety Manual.
General			
5.1 Student Work	Students on the team shall 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).	Demonstration The team will demonstrate its full responsibility for the project.	Complete. Pass. The team has demonstrated that it can operate autonomous of adult/faculty help in its series of documentary-style videos.
5.2 Project Plan	The team shall 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.	Inspection Both Co-Captains will ensure all leads and themselves are monitoring the organization of the team.	Complete Throughout the season both Co-Captains are updating and checking in with all leads on their individual schedules and status of their project. This can be illustrated in the Timeline section.
5.3 Foreign Nationals	Foreign National (FN) team members shall 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.	Inspection The team will inspect its roster for FN members. Each member will be asked whether or not they are a FN.	Complete The team has verified that it contains no foreign nationals (FN) and has done so by PDR.
5.4 Attending Members	The team shall identify all team members attending launch week activities by the Critical Design Review (CDR). Team members shall include:	Inspection The Co-Captains will ensure each member signs the proper documentation to attend launch week.	Complete The Co-Captains have verified the signing of media release forms by all eligible members for competition week.
5.4.1 Engaged Members	Students actively engaged in the project throughout the entire year.	Inspection RCR team leads will gauge the level of work their members contribute to the project and will include this information in the decision-making process.	Complete All actively engaged members have submitted their media release forms.

5.4.2 Mentor	One mentor (see requirement 4.4).	Demonstration Pas. Obtaining one individual willing to mentor River City Rocketry.	Complete Darryl Hankes is the one and only mentor for River City Rocketry and was chosen in our Proposal.
5.4.3 Adult Educators	No more than two adult educators.	Inspection No adult educators with the exception of one mentor (see above) will be accompanying the team to competition.	Complete Pass. No adult educators with the exception of one mentor (see above) will be accompanying the team to competition.
5.5 Educational Outreach	The team shall 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 shall 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 28 of the handbook.	Demonstration The team posts photos of all educational outreach events as well as submits the proper paperwork within two weeks of each event to count towards our overall Educational Outreach score.	Complete River City Rocketry completed this task two weeks after the Preliminary Design Review, however, outreach is continuous until the Flight Readiness Review
5.6 Web Site	The team shall develop and host a Web site for project documentation.	Inspection The team website will be inspected on a weekly basis for maintenance and upkeep.	Complete Visit us at the team site.
5.7 Web Site Deadlines	Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	Demonstration The team acknowledges the due dates for PDR, CDR, FRR, and PLAR where RCR will post the required deliverables to the team site by the assigned dates.	Incomplete The team has demonstrated punctuality in posting its documents for proposal, PDR, and CDR. FRR and PLAR have yet to be completed
5.8 PDF Format	All deliverables must be in PDF format.	Demonstration The team will demonstrate that its deliverables are capable of being in PDF format before posting them to the team site.	Incomplete The team has demonstrated PDF format for proposal, PDR, and CDR. FRR and PLAR have yet to be completed
5.9 Table of Contents	In every report, teams shall provide a table of contents including major sections and their respective sub-sections.	Inspection A table of contents will be present in every document.	Incomplete The team has included a table of contents for proposal and PDR. CDR. FRR, and PLAR have yet to be completed
5.10 Page Number	In every report, the team shall include the page number at the bottom of the page.	Inspection A page number will be present at the bottom of each page of every report.	Incomplete The team has included page numbers for proposal, PDR, and CDR. FRR and PLAR have yet to be completed
5.11 Video Conference	The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of speakerphone capability.	Inspection The team will provide means for proper and professional teleconferencing. Equipment will be inspected for functionality no less than one hour prior to design reviews.	Incomplete This requirement will be verified after the FRR. Currently the team has met this requirement for all its past design reviews.
5.12 Launch Pads	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	Inspection The team will use the provided launch pads at the competition launch.	Incomplete

	launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.		This requirement will be verified at the competition launch. Currently the team has been using a 12' rail to emulate launch day conditions.
5.13 EIT Report	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Demonstration Provide all information on a public viewing level, especially on the team's website.	Complete The team has a public viewing website that can be seen on http://www.rivercityrocketry.org/home/.

7.2.2 Team-derived Requirements

The team-derived requirements are organized according to Figure 145 below.

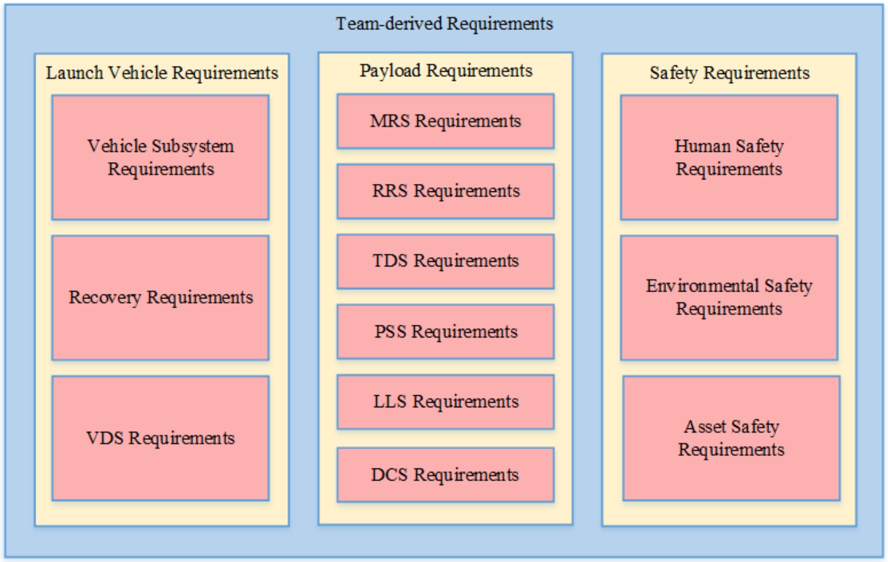


Figure 145: Team-derived requirements organization.

7.2.2.1 Launch Vehicle Requirements

The complete list of vehicle requirements are shown below. This includes the subsystems of recovery, vehicle, and VDS.

Requirement ID	Requirement	Derivation	Verification Plan	Status
Vehicle Subsystem				

Vehicle.1.1 Apogee Altitude	The launch vehicle shall have a safe ascent up to 5,500 [ft] with the VDS disengaged and be as efficient as possible.	Derivation can be found in PDR section 5.3.1	Test The launch vehicle integrated with the VDS will be tested through several test launches.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.1.1.1 Weight	The launch vehicle shall not exceed an overall weight of 50 [lbs].	Derivation can be found in PDR section 5.3.1	Inspection The launch vehicle will be efficiently documented and all material and component weights will be recorded throughout the design and manufacturing. The weight of the fully assembled launch vehicle will be measured before every test launch.	Incomplete The launch vehicle will be weighed once all components have been manufactured and assembled. This requirement is scheduled to be verified in January.
Vehicle.1.1.2 Hand Calculations	Hand calculations shall be computed to verify OpenRocket simulations results for stability and apogee altitude predictions.	Derivation can be found in PDR section 5.3.1	Analysis The center of pressure and center of gravity will be calculated by hand and compared to OpenRocket simulation results.	Complete The center of gravity and center of pressure of the launch vehicle were calculated in December. See the OpenRocket Simulation and Center of Pressure Analysis under Mission Performance Predictions
Vehicle.1.1.3 Coefficient of Drag	The coefficient of drag of the launch vehicle shall be less than 0.5.	Derivation can be found in PDR section 5.3.1	Test CFD simulations will simulate flight conditions and compute the coefficient of drag of the entire launch 1. A control launch of the launch vehicle will be performed to calculated the coefficient of drag of the 1.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.1.4 Safe Ascent	The ascent of the launch vehicle shall be safe.	Derivation can be found in PDR section 5.3.1	Test Test launches will be carried out to ensure the launch vehicle performs as intended. The launch vehicle will be designed and constructed in accordance will all NAR safety regulations.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.1.1.1. Deployment Bay Weight	The deployment bay and booster recovery bay shall not exceed an overall weight of 10 [lbs].	Derivation can be found in PDR section 5.3.1	Inspection Every component will be predicted based on material densities and weighed before every flight.	Incomplete The launch vehicle will be weighed once all components have been manufactured and assembled. This requirement is scheduled to be verified in January.
Vehicle.1.1.1.2 Payload Weight	The payload shall not exceed an overall weight of 15 [lbs].	Derivation can be found in PDR section 5.3.1	Inspection Every component will be predicted based on material densities and weighed before every flight.	Incomplete The launch vehicle will be weighed once all components have been manufactured

				and assembled. This requirement is scheduled to be verified in January.
Vehicle.1.1.1.3 Propulsion Bay Weight	The propulsion bay shall not exceed an overall weight of 23 [lbs].	Derivation can be found in PDR section 5.3.1	Inspection Every component will be predicted based on material densities and weighed before every flight.	Incomplete The launch vehicle will be weighed once all components have been manufactured and assembled. This requirement is scheduled to be verified in January.
Vehicle.1.1.1.4 Nose Cone Weight	The nose cone shall not exceed an overall weight of 2 [lbs].	Derivation can be found in PDR section 5.3.1	Inspection Every component will be predicted based on material densities and weighed before every flight.	Incomplete The launch vehicle will be weighed once all components have been manufactured and assembled. This requirement is scheduled to be verified in January.
Vehicle.1.1.3.1 Exit Rail Velocity	The launch vehicle shall accelerate to a minimum velocity of 56 fps at rail exit.	Derivation can be found in PDR section 5.3.1	Test OpenRocket simulations will be created to calculate the exit rail velocity and hand calculations will also be used to check the OpenRocket simulations. A control test flight of the launch vehicle will be conducted to verify the exit rail velocity.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.1.1.3.2 Exit Rail Stability	The launch vehicle shall have a minimum static stability margin of 2.2 at the point of rail exit.	Derivation can be found in PDR section 5.3.1	Analysis OpenRocket simulations will be created to calculate the static stability margin and hand calculations will be used to verify the OpenRocket simulations.	Complete Multiple OpenRocket simulations were performed under several different weather conditions and rail lengths to ensure that the stability margin at rail exit was above 2.2. This requirement was verified in December.
Vehicle.1.1.3.3 Rotation	The launch vehicle will not experience more than one rotation during ascent.	Derivation can be found in PDR section 5.3.1	Test An on-board camera recording system will determine how rotations the launch vehicle experiences during test launches. All centering rings will be precision cut with a Maxiem waterjet to ensure a secure fit attachment to the launch vehicle and the launch vehicle will utilize a custom jig to ensure proper centering ring alignment.	Incomplete The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.1.1.3.4 Centering Rings	All centering rings shall have a factor of safety of two with an applied load of 350 pounds.	Derivation can be found in PDR section 5.3.1	Analysis FEA simulations will be performed to ensure that each centering ring has a factor of safety two with an applied load of 350 pounds.	Complete This requirement was verified in November. See Centering Ring Design in the Vehicle Design section.

Vehicle.1.1.3.5 Maximum Tilt Angle	The full scale launch vehicle shall not oscillate about the center of gravity with an amplitude greater than 10 degrees on ascent.	Derivation of requirement 1.1.1.1.3.5	Test The full scale launch vehicle will be launched to identify flight characteristics with the selected motor.	Incomplete. The control launch of the launch vehicle will be performed once all components are manufactured and assembled. This launch is scheduled to take place on February 11, 2017 in Elizabethtown, Kentucky.
Vehicle.2 Airframe	The launch vehicle shall be designed to optimize mechanical properties and manufacturability	Derivation of requirement Vehicle.2 - Airframe	Test Several tests will be conducted to maximize mechanical properties and manufacturability.	Incomplete This requirement is scheduled to be verified in March. See the Vehicle Component Test Campaign.
Vehicle.2.1 Filament Winding Angles	Filament may not visibly slip or bunch during winding.	Derivation of Vehicle.2.1 – Filament Winding Angles	Test Airframe sections will be test wound at varying angles between 10 and 0 degrees relative to the longitudinal axis of the airframe.	Incomplete This requirement is scheduled to be verified in February. See the Filament Winding Angles Test plan.
Vehicle.2.2 Volumetric Ratio	The airframe must have a volumetric ratio between 45-60% and porosity less than 5%.	Derivation of Vehicle.2.2 – Volumetric Ratio	Test Airframe samples will be visually inspected via micrograph and physically tested via burnout method.	Incomplete This requirement is scheduled to be verified in March. See the Volumetric Ratio Test plan.
Vehicle.2.3 Airframe Tensile Strength	Airframe shall not yield under 1500 pounds.	Derivation of Vehicle.2.3 – Airframe Tensile Strength	Test Airframe samples will be tested for maximum tensile strength in a 20,000 pounds MTS.	Incomplete This requirement is scheduled to be verified in March. See the Airframe Tensile Strength Test plan.
Vehicle.4 Recoverable	The launch vehicle shall be designed to be recoverable and reusable.	Derivation can be found in PDR section 5.3.2	Test Several test launches will be conducted to verify the reusability and recoverability.	Complete This requirement was verified in November. See the Launch Vehicle Test Campaign.
Vehicle.4.1 Modular Subsystems	The launch vehicle shall utilize modular subsystems in case of unexpected recovery conditions.	Derivation can be found in PDR section 5.3.2	Demonstration Systems will be implemented to easily repair components of the launch vehicle, as evident in the removable fin system.	Complete This requirement was verified in November.See the Removable Fin System section.
Vehicle.4.2 Separation Mechanisms	The launch vehicle shall utilize proper separation mechanisms.	Derivation can be found in PDR section 5.3.2	Test Multiple test launches will be conducted to verify that all separation mechanisms operate as intended.	Incomplete This requirement was verified in February. See the Launch Vehicle Test Campaign.
Vehicle 4.3 Bulkplate Assembly	The bulkplate assembly shall withstand the maximum force (400 pounds) applied by the parachute during deploymet.	Derivation of Vehicle.4.3	Test A test fixture will be created and the bulkplate assembly will be tested to withstand the maximum force of the parachute.	Incomplete This requirement is schedule to be verified in February. See the Launch Vehicle Components Test Campaign.
Vehicle.4.1.1 Removable Fin System	The launch vehicle shall implement a modular fin mounting	Derivation can be found in PDR section 5.3.2	Inspection A removable fin system was designed to easily install and remove fins from the launch vehicle.	Complete

	system that has the ability to easily remove and replace fins.			This requirement was verified in October. See the Removable Fin System section.
Vehicle.4.2.1 Vent Holes	Properly sized vent holes shall be drilled in the launch vehicle for on board altimeters.	Derivation can be found in PDR section 5.3.2	Demonstration The proper vent hole size for each bay which contains an altimeter will be calculated and implemented within the launch vehicle.	Incomplete The vent holes for each avionics bay will be drilled into the airframe of the launch vehicle once the launch vehicle is fully assembled. This requirement is scheduled to be verified in January. See the Vent Hole Sizing section for analysis on the size of the vent holes.
Vehicle.4.2.2 Shear pins	The launch vehicle shall use nylon 4-40 SHCS shear pins for all separations.	Derivation can be found in PDR section 5.3.2	Inspection 4-40 SHCS shear pins will be installed into all separating sections of the launch vehicle before every launch.	Incomplete The installation of the 4-40 SHCS shear pins will be verified for each separating section once the launch vehicle is fully assembled. This requirement is scheduled to be verified in January. See the Airframe section.
Vehicle.4.2.3 Joining Fasteners	The launch vehicle shall use steel 6-32 SHCS for joining non-separating sections.	Derivation can be found in PDR section 5.3.2	Inspection Steel 6-32 SHCS shear pins will be installed into all separating sections of the launch vehicle before every launch.	Incomplete The installation of the 6-32 SHCS shear pins will be verified for each separating section once the launch vehicle is fully assembled. This requirement is scheduled to be verified in January. See the Airframe section.
Vehicle.4.2.4 Pyrotechnic Charges	All pyrotechnic charges shall be located in isolated bays from the payload bay and on-board electronics.	Derivation can be found in PDR section 5.3.2	Inspection The launch vehicle will be designed so that all pyrotechnic charges isolated from any on-board electronics.	Complete The launch vehicle has been designed so that all ejection charges are in isolated bays from on-board flight electronics.
Vehicle.4.2.5 Altimeter	All pyrotechnic charges shall be controlled by PerfectFlite Stratologger CF altimeters.	Derivation of requirement Vehicle.4.2.5	Demonstration The vehicle has been designed so that PerfectFlite Stratologger CF altimeters will control all separations of the launch vehicle.	Complete All altimeters have been purchased. See the Avionics section.
Vehicle.4.2.5.1 Altitude Detection	Each PerfectFlite Stratologger CF altimeter shall be capable of detecting apogee and specific altitudes.	Derivation of requirement Vehicle.4.2.5.1	Inspection Vacuum chamber tests of each PerfectFlite Stratologger CF altimeter will demonstrate each altimeters ability to detect apogee and specific altitudes.	Incomplete This requirement is scheduled to be verified in January.
Recovery				
Recovery.1 Multirotor Deployment	The recovery system must successfully and safely enable the deployment of the multirotor.	Derivation of requirement Recovery.1	Test Fully integrated full-scale test flights will be conducted to confirm the verifications in the child requirements of this requirement.	Incomplete This requirement can only be complete once child requirements have reached completion.

Recovery.1.1 Multirotor Recoverability	The multirotor must be safely recoverable in the event of off-nominal operation.	Derivation of requirement Recovery.1.1	Analysis All recovery phases of multirotor will be designed and calculated to be under kinetic energy requirement, or capable of aborting to such a mode.	Complete This requirement has been verified in section 3.4.7.2.
Recovery.1.1.1 MDP Kinetic Energy	MDP must reduce multirotor kinetic energy to less than 75ft-lb. after deployment.	Derivation of requirement Recovery.1.1.1	Analysis Multirotor deployment parachute will be designed and sized to bring payload to ~70 ft-lb of kinetic energy.	Complete This requirement has been verified in section 3.4.7.2.
Recovery.1.1.2 MRP Kinetic Energy	MRP must be capable of reducing multirotor kinetic energy to less than 75ft-lb.	Derivation of requirement Recovery.1.1.2	Analysis MRP will be designed and sized to bring payload to ~70 ft-lb of kinetic energy.	Complete This requirement has been verified in section 3.4.7.2.
Recovery.1.2 Preflight Condition Duration	Deployment bay recovery system must maximize and provide no less than 30 seconds between to MDP deployment and MDP cutaway.	Derivation of requirement Recovery.1.2	Analysis Recovery system parameters will be calculated to verify that the elapsed multirotor descent time when under MDP is ≥ 30s.	Incomplete This requirement is scheduled to be complete after retrieval of test data from full scale test flights in February.
Recovery.1.2.1 Payload Deployment Altitude	Recovery system must deploy payload no lower than ~710 feet AGL.	Derivation of requirement Recovery.1.2.1	Test Full scale test flights will be used to ensure that full inflation of deployment bay main is complete before ~710 feet AGL.	Incomplete This requirement is scheduled to be complete during recovery test flights scheduled for February.
Recovery.1.2.2 Deployment Bay Drift	Deployment bay assembly must not drift outside of ½ mile radius after multirotor deployment.	Derivation of requirement Recovery.1.2.2	Analysis Drift values for 0, 5, 10, 15, and 20 mph wind speeds as a function of multirotor deployment altitude will be calculated to find maximum possible deployment altitude.	Complete This requirement has been verified as per the analysis in section 3.3.
Recovery.1.3 Collision Avoidance	Concurrent recovery of launch vehicle sections must not interfere with multirotor flight.	Derivation of requirement Recovery.1.3	Test Fully integrated full-scale test flights will be conducted to verify accuracy of predictive recovery data given to multirotor enables collision avoidance.	Incomplete This requirement is scheduled to be complete during fully integrated test flights scheduled for February.
Reovery.1.3.1 Deployment Bay Terminal Velocity	Deployment bay assembly must have lower terminal velocity than multirotor while under MDP descent.	Derivation of requirement Recovery.1.3.1	Analysis Deployment bay main and MDP will be designed and sized such that the multirotor under MDP has greater terminal velocity than unloaded deployment bay	Complete This requirement has been verified as per the analysis in section 3.3.
Recovery.1.3.2 Booster Avoidance	Recovering booster section must not collide with multirotor.	Derivation of requirement Recovery.1.3.2	Analysis 2 dimensional drift path will be calculated as a function of terminal velocity and wind speed and used by multirotor for booster avoidance protocol.	Incomplete This requirement will be verified by analysis in late January.

VDS				
VDS.1 Braking Power	The VDS shall be designed to be capable of reducing the apogee of the vehicle by no less than 880 ft from 5,600 ft to 4,720 ft.	Derivation can be found in PDR section 4.2.1	Test The full scale vehicle will undergo a control launch where no brakes are deployed to determine the brakeless apogee of the 1. The full scale vehicle will also undergo a launch where the brakes are fully deployed at burnout. The difference in apogee in these two launches will be used to verify this requirement.	Incomplete The control launch is scheduled to take place on February 11th at the Elizabethtown field. The full-brakes launch is scheduled to take place on February 18th at the Elizabethtown field.
VDS.1.1 Projected Area	The vehicle shall be capable of increasing the projected cross-sectional area by no less than 29%.	Derivation can be found in PDR section 4.2.1	Demonstration This requirement was verified by utilizing CAD programs to determine the increase in projected area of the launch vehicle after actuation.	Complete This requirement was verified June 1st. See PDR section 4.
VDS.1.2 Coefficient of Drag	The vehicle shall be capable of increasing the coefficient of drag of vehicle by no less than 0.15	Derivation can be found in PDR section 4.2.1	Test This requirement will be verified in the first two full-scale launches. A control launch will be used to determine the coefficient of drag of the full-scale vehicle and a full-deploy launch will be used to find the coefficient of drag of the vehicle with brakes fully-deployed.	Incomplete The control launch is scheduled to take place on February 11th at the Elizabethtown field. The full-brakes launch is scheduled to take place on February 18th at the Elizabethtown field.
VDS.2 Sensor Fidelity	The VDS shall be capable of determining the state of the vehicle (i.e. altitude and velocity) with noise limits of no more than +/- 8.5 m and +/- 5.0 m/s respectively.	Derivation can be found in PDR section 4.2.2	Test This requirement will be verified in December flight testing. The recorded flight data will be analyzed to determine if the state noise is acceptable.	Complete Pass. This requirement was verified on December 18th during the subscale launch. See Sensor Fidelity Test.
VDS.2.1 DataRate	The state of the vehicle shall be updated by the VDS at a rate no less than 48 Hz.	Derivation can be found in PDR section 4.2.2	Test This requirement will be verified in December flight testing. The recorded flight data will be analyzed to determine if the state noise is acceptable.	Complete Pass. This test performed on December 18th during the subscale launch but failed to meet the necessary criteria. Additional post-launch testing was performed and showed the average data rate to be 52 Hz. See Sensor Fidelity Test.
VDS.2.2 Sensor Types	The VDS shall have sensors capable of reporting the altitude and acceleration of the 1.	Derivation can be found in PDR section 4.2.2	Demonstration The datasheets of the chosen sensors will be inspected to ensure that they are capable of reporting altitude and acceleration.	Complete Pass. Sensors have been chosen to meet the necessary criteria. This requirement was verified in October 2016. See PDR section 4.3.1.
VDS.2.2.1 Accelerometer	The VDS shall have a unified accelerometer, gyroscope, and magnetometer sensor capable of	Derivation can be found in PDR section 4.2.2	Demonstration This requirement was verified December 18th by	Complete Pass. This requirement was verified December 18th by running the flight

	reporting the vertical component of acceleration with no greater than 0.1 [m/s^2] zero offset.		running the flight software and demonstrating the zero offset error.	software and demonstrating the zero offset error. See Sensor Fidelity Test.
VDS.2.2.2 Barometric Pressure Sensor	The VDS shall have a barometric pressure sensor capable of reporting altitude data with a noise limit of no more than +/- 8.5 m.	Derivation can be found in PDR section 4.2.2	Demonstration This requirement was verified Dec 18th by running the flight software and demonstrating the VDS altitude noise limit.	Complete Pass. This requirement was verified on December 18th during the subscale launch. See Sensor Fidelity Test.
VDS.2.3 Filter	The VDS shall have a programmatic filter capable of reducing velocity data noise by no less than 25% as an added safety measure.	Derivation can be found in PDR section 4.2.2	Test The recorded flight data will be analyzed to determine if the improvement in state noise is acceptable.	Complete Fail. This test performed on December 18th during the subscale launch but failed to meet the necessary criteria. See Sensor Fidelity Test.
VDS.3 Main Controller	The VDS shall have a main controller capable of autonomously responding to sensor data and commanding blade actuation.	Derivation can be found in PDR section 4.2.3	Analysis The main controller datasheet will be analyzed to determine if it is capable of sensor input, computation, and pin I/O.	Complete Pass. The main controller has been selected to be capable of sensor input, computation, and pin I/O. This requirement was verified in October. See PDR section 4.3.1.
VDS.3.1 Floating Point	The VDS main controller shall be capable of IEEE Standard 754 32-bit floating point arithmetic.	Derivation can be found in PDR section 4.2.3	Analysis The main controller will be chosen to be capable of IEEE Standard 754 32-bit floating point arithmetic.	Complete Pass. The main controller has been selected to be capable of IEEE Standard 754 32-bit floating point arithmetic. This requirement was verified in October. See PDR section 4.3.1.
VDS.3.2 Communication	The VDS main controller shall have hardware that supports the i2c and UART protocols.	Derivation can be found in PDR section 4.2.3	Analysis The main controller datasheet will be inspected to determine whether or not it is capable of i2c and UART communication.	Complete Pass. The main controller has been selected to be capable of i2c and UART. This requirement was verified in October. See PDR section 4.3.1.
VDS.3.3 Power	The VDS main controller shall be powered by an onboard regulated power supply.	Derivation can be found in PDR section 4.2.3	Analysis The main controller design will include an onboard regulated power supply.	Complete Pass. The Teensy 3.6 microcontroller was powered through an external power supply in November. See PDR section 4.3.1.
VDS.3.3.1 Battery Life	The main controller battery shall have at least a factor of safety of 2 on battery life.	Derivation can be found in PDR section 4.2.3	Demonstration The battery life safety margin will be verified by monitoring the battery charge during extensive operation.	Incomplete The battery has not undergone extensive system operation. This test will be conducted once the final batteries are available.
VDS.3.3.2 Regulator Voltage	The power regulator shall be capable of supplying 5 Volts.	Derivation can be found in PDR section 4.2.3	Demonstration The power regulator will be demonstrated by outputting 5V from an external supply input.	Complete Pass. The Teensy 3.6 was functional with a 5 volt external power supply. This was demonstrated in November. See VDS Electronics Design

VDS.3.3.3 Current Draw	The main controller battery shall be capable of 225 Milli-Amperes of current draw.	Derivation can be found in PDR section 4.2.3	Demonstration The current draw will be quantified under full system operation. The recorded current shall be within the safety margin	Incomplete The main controller has not undergone full system operation. The test will be performed once all final components are available. Expected 1/30/17.
VDS.3.4 Non-volatile Storage	The VDS main controller shall have a non-volatile storage greater than 64 kB.	Derivation can be found in PDR section 4.2.3	Analysis The main controller will be chosen such that it has non-volatile storage greater than 64 kB.	Complete Pass. The Teensy 3.6 microcontroller contains 1MB of non-volatile memory (Flash). See PDR section 4.3.1.
VDS.4 Actuation	The VDS shall be capable of continuous control over the drag force it induces on the 1.	Derivation can be found in PDR section 4.2.4	Demonstration The VDS will utilize an actuating mechanism that can extend and retract the drag blades at any point during its actuation.	Incomplete The actuation of the drag blades will be demonstrated once all components are acquired and the VDS is assembled. Expected by 2/5/17.
VDS.4.1 Speed	The method of actuation shall be such that the VDS can induce the full drag force that it is capable of within half of a second.	Derivation can be found in PDR section 4.2.4	Analysis The actuation device will be chosen so that the actuation time of the drag blades will be minimized.	Complete A DC motor was so that the drag blades would be able to fully actuate in less than half of a second. This requirement was verified in October. See Actuation in the VDS mechanical design section.
VDS.4.2 Range of Control	The method of actuation shall have continuous control over its deployment.	Derivation can be found in PDR section 4.2.4	Demonstration The VDS will utilize a gear system to actuate the drag blades, thus giving the motor the ability to quickly actuate or retract the drag blades to drastically adjust the drag force at any point during the ascent of the flight.	Complete The VDS has been designed to incorporate a gear actuation method for the drag blades to ensure continuous control over deployment. This requirement was verified in October. See Actuation in the VDS mechanical design section.
VDS.4.2.1 Encoder	The drag blades shall be able to retract and actuate based on DC motor feedback.	Derivation can be found in PDR section 4.2.4	Demonstration The VDS encoder will be demonstrated to report the position of the drag blades.	Incomplete This requirement will be verified in February before the first test flight.
VDS.4.3 Simultaneous Control	The drag shall be simultaneously controlled.	Derivation can be found in PDR section 4.2.4	Demonstration The drag blades shall actuate via the meshing between radial gear teeth located on the drag blades and the central gear to reduce the quantity of moving parts as well as simplify the system.	Complete The current VDS design incorporates a central gear to control actuation of all three drag blades. See PDR section 4.3.3.
VDS.4.4 Actuation Limits	The drag blades shall not attempt to over-actuate the drag blades past their mechanical limit.	Derivation can be found in PDR section 4.2.4	Demonstration Limit switches shall communicate complete actuation and retraction of the drag blades to the control system.	Incomplete The demonstration of the communication of the limit switches with the control system will occur once the VDS is fully assembled. Expected 2/5/17.

VDS.4.5 Motor Torque	The DC motor shall not experience a reactive torque of 388 [oz-in] or more.	Derivation can be found in PDR section 4.2.4	Analysis The drag blades actuate perpendicular to the air flow during flight, thus reducing the torque that the motor directly has to counteract in order to actuate the drag blades. The friction force will be calculated to ensure proper motor selection.	Complete The reactive torque experienced by the motor was calculated to be below 388 [oz-in] using previous test launch data. See Section 4.2.4 in the VDS Mechanical Design of PDR.
VDS.4.5.1 Surface Friction	The VDS shall utilize a material with a coefficient of friction on the drag blades of no more than 0.5 to provide a bearing surface for the drag blades to slide across.	Derivation can be found in PDR section 4.2.4	Inspection Delrin Acetal Resin was chosen for the bearing surface due to its coefficient of friction of 0.3 on aluminum as well as its stiffness.	Complete Delrin Acetal Resin has a coefficient of friction of 0.3 on aluminum, which is below 0.5. See Components in VDS mechanical design section.
VDS.5 Software	The VDS software shall be designed to receive sensory input and command drag blade actuation.	Derivation of Requirement VDS.5 – Software	Analysis The Software will be designed to receive sensory input and command drag blade actuation.	Complete Pass. The software has been designed to receive sensory input and command blade actuation. See Software. This requirement was verified in November.
VDS.5.1 Run-time	All software shall be capable of maintaining nominal operation for a duration of no less than two hours.	Derivation of Requirement VDS.5.1 – Run-time	Demonstration The software will be demonstrated to maintain nominal operation for two hours. During this time, no variable can overflow or lose precision beyond an acceptable amount.	Incomplete This requirement will be verified February 4th.
VDS.5.1.1 Primary Time Precision	The program time variable shall be precise to no less than the sixth decimal place for the duration of expected run-time (one hour).	Derivation of Requirement VDS.5.1.1 – Primary Time Precision	Demonstration The software will be exercised for one hour during which the time variable is precise to at least the sixth decimal place.	Incomplete This requirement will be verified February 4th.
VDS.5.1.2 Backup Time Precision	The program time variable shall be precise to no less than the third decimal place for the duration of the worst-case runtime (two hours).	Derivation of Requirement VDS.5.1.2 – Backup Time Precision	Demonstration The software will be exercised for two hours during which the time variable is precise to at least the third decimal place.	Incomplete This requirement will be verified February 4th.
VDS.5.1.3 Data Storage	The non-volatile data storage (SD card) shall have a memory no less than 20 Mb.	Derivation of Requirement VDS.5.1.3 – Data Storage	Inspection The memory of the non-volatile data storage (SD card) will be inspected for the required amount of storage.	Complete This requirement was verified in November. See Hardware.

Table 94: Team-derived launch vehicle requirements.

7.2.2.1.1 Derivation of Requirement Vehicle.1.1.1.1.3.5 – Maximum Tilt Angle

As observed from subscale flights, large angles of oscillation during motor burn significantly decrease the magnitude of the apogee altitude by diverting motor impulse in directions other than vertical. This requirement ensures that the launch vehicle's achieved apogee altitude will be as similar to the OpenRocket simulated altitudes as possible. See team-derived requirement Vehicle.1.1.1.1.3.5.

7.2.2.1.2 Derivation of Requirement Vehicle.4.3 – Bulkplate Assembly

The bulkplate assembly is the only point of contact between the vehicle and the parachute. The bulkplate assembly must be able to withstand the maximum force (400 Lbs) applied by the parachute on descent. See team-derived requirement Vehicle.4.3.

7.2.2.1.3 Derivation of Requirement Vehicle.2 – Airframe

In order to maximize the efficiency of the launch vehicle, the airframe will be optimized by utilizing the mechanical properties of carbon fiber. See team-derived requirement Vehicle.2.

7.2.2.1.4 Derivation of Requirement Vehicle.2.1 – Filament Winding Angles

In order for the carbon fiber of the airframe to yield optimal mechanical properties 50% of the fibers should run as close to 0˚ as possible. Filament winding becomes increasingly difficult and encounters more manufacturing defects as winding angles approach 0˚. This test will find the minimum defect free winding angle. See team-derived requirement Vehicle.2.1.

7.2.2.1.5 Derivation of Requirement Vehicle.2.2 – Volumetric Ratio

In order for the carbon fiber of the airframe to yield optimal mechanical properties 50% of the fibers should run as close to 0˚ as possible. Filament winding becomes increasingly difficult and encounters more manufacturing defects as winding angles approach 0˚. This test will find the winding angle with the most optimal volumetric ratio and lowest porosity. See team-derived requirement Vehicle.2.2.

7.2.2.1.6 Derivation of Requirement Vehicle.2.3 – Airframe Tensile Strength

The airframe must be able to withstand the maximum forces exerted during ascent. This test will determine that the airframe can withstand all inflight forces and find the ultimate tensile strength. See team-derived requirement Vehicle.2.3.

7.2.2.1.7 Derivation of Requirement Vehicle.4.2.5 - Altimeters

Due to the team's experience and success with PerfectFlite Stratologger CF altimeters, the team will continue to use them for all pyrotechnic charge seperations of the launch vehicle. See team-derived requirement Vehicle.4.2.5.

7.2.2.1.8 Derivation of Requirement Vehicle.4.2.5.1 - Altitude Detection

In order for the launch vehicle design to function as intended and execute proper recovery deployments, each Stratologger CF altimeter must be able to detect apogee and a specific altitude after apogee for a main parachute deployment. See team-derived requirement Vehicle.4.2.5.1.

7.2.2.1.9 Derivation of Requirement Recovery.1 – Multirotor Deployment

High level requirement that pertains to ultimate success of payload. See team-derived requirement Recovery.1

7.2.2.1.10 Derivation of Requirement Recovery.1.1 – Multirotor Recoverability

The multirotor is inherently a complex point of failure – as such, the recovery system must be designed to default the multirotor to a state that is safely recoverable. See team-derived requirement Recovery.1.1.

7.2.2.1.11 Derivation of Requirement Recovery.1.1.1 – MDP Kinetic Energy

In order to safeguard against potential failure modes during multirotor deployment, the MDP must bring the multirotor under 75ft-lb of kinetic energy. See team-derived requirement Recovery.1.1.1

7.2.2.1.12 Derivation of Requirement Recovery.1.1.2 – MRP Kinetic Energy

In order to safeguard against potential failure modes during autonomous multirotor flight, the MRP must be capable of aborting the multirotor to a recoverable state under 75 ft-lb of kinetic energy. See team-derived requirement Recovery.1.1.2

7.2.2.1.13 Derivation of Requirement Recovery.1.2 – Multirotor Preflight Condition Duration

The multirotor recovery system must provide no less than 30 seconds between MDP deployment and cutaway in order to satisfy the minimum time required for the multirotor to execute preflight safety checks and ensure the safety of autonomous flight. See team-derived requirement Recovery.1.2

7.2.2.1.14 Derivation of Requirement Recovery.1.2.1 – Payload Deployment Altitude

The recovery system must enable payload deployment no lower than ~710 feet AGL. Deployment of the payload at any lower altitude will not provide enough time for preflight safety checks. See team-derived requirement Recovery.1.2.1

7.2.2.1.15 Derivation of Requirement Recovery.1.2.2 – Deployment Bay Drift

The deployment bay, once the payload is deployed, is left with an oversized parachute due to requirement Recovery.1.3.1. As such, the drift distance of the empty payload bay determines the maximum payload deployment altitude. See team-derived requirement Recovery.1.2.2

7.2.2.1.16 Derivation of Requirement Recovery.1.3 - Collision Avoidance

The multirotor, once under autonomous flight power, has the potential to inadvertently navigate into the path of a recovering launch vehicle section. The recovery system must be designed to be capable to avoid this, or analyzed sufficiently to inform the methods to avoid it. See team-derived requirement Recovery.1.3

7.2.2.1.17 Derivation of Requirement Recovery.1.3.1 – Deployment Bay Terminal Velocity

The unloaded deployment bay has a lower weight than the deployed multirotor payload. As such, the deployment bay can still satisfy the kinetic energy requirement at a higher terminal velocity than the payload. For this reason, the deployment bay parachute will be oversized to ensure that it will have a lower terminal velocity to fully clear the deployed payload. See team-derived requirement Recovery.1.3.1

7.2.2.1.18 Derivation of Requirement Recovery.1.3.2 – Booster Avoidance

The recovering separated booster has the potential to interfere with autonomous multirotor flight. As such, the recovery drift path must be fully predicted as a function of wind speed in order to adequately provide decision-making information to the multirotor. See team-derived requirement Recovery.1.3.2

7.2.2.1.19 Derivation of Requirement VDS.5 – Software

The VDS software shall be designed to receive sensory input and command drag blade actuation. This requirement ensures that the software installed on the VDS main controller allows the main controller to satisfy its requirement (team-derived requirement VDS.3).

7.2.2.1.20 Derivation of Requirement VDS.5.1 – Run-time

All software shall be capable of maintaining nominal operation for a duration of no less than two hours. This requirement ensures that the VDS software can meet the SOW requirement 1.8 with a factor of safety of two. See team-derived requirement VDS.5.1.

7.2.2.1.21 Derivation of Requirement VDS.5.1.1 – Primary Time Precision

The program time variable shall be precise to no less than the sixth decimal place for the duration of expected run-time (one hour). This requirement ensures that the VDS can operate with microsecond precision for the expected runtime of one hour. See team-derived requirement VDS.5.1.1.

7.2.2.1.22 Derivation of Requirement VDS.5.1.2 – Backup Time Precision

The program time variable shall be precise to no less than the third decimal place for the duration of the worst-case runtime (two hours). This requirement ensures that the software time variable complies with VDS.5.1 where the software must be able to perform for no less than two hours. Though the backup time variable is not as precise as the primary time variable, it will still allow the VDS to perform its basic functions if run-time exceeds one hour. See team-derived requirement VDS.5.1.2.

7.2.2.1.23 Derivation of Requirement VDS.5.1.3 – Data Storage

The non-volatile data storage (SD card) shall have a memory no less than 180 Mb. This requirement satisfies its parent requirement in that it allows the software to record the flight variables without storage overflow for a minimum of two hours. The minimum required storage of 20 Mb was arrived at via the following calculation. See team-derived requirement VDS.5.1.3.

$$2\ (hrs) \cdot \frac{8{,}220\ (kb)}{0.8893\ (hrs)} \cdot \frac{1\ (Mb)}{1000\ (kb)} = 18.4865\ (\text{Mb}) \qquad ()$$

Where $\frac{8{,}220\ (kb)}{0.8893\ (hrs)}$ is the rate of data storage observed during the December 3rd subscale launch on the VDS Test Electronics.

7.2.2.2 Payload Requirements

Requirement ID	Requirement	Derivation	Verification Plan	Status
Payload Subsystem				
MRS.1 Multirotor System	The Payload shall be recovered and landed upright via the autonomous Multirotor Recovery System.	Derivation can be found in PDR section 7.3.1	Test The MRS's functionality will be demonstrated through a minimum of two successful full scale test flights.	Incomplete Payload must be fully assembled to successfully test all maneuvers necessary for verification of this requirement.

MRS.1.1 MRS GPS	The MRS shall obtain the GPS and altitude values upon initialization while on the launch rail.	Derivation of Requirement MRS.1.1	Test This will be tested during Payload Integration and Flight Testing. The data will be verified by analyzing flight logs.	Complete
MRS.1.2 MRS Initialization	The MRS shall wait for successful deployment of the Propulsion Arms and Landing Legs before arming motors.	Derivation of Requirement MRS.1.2	Demonstration The MRS will demonstrate its ability to detect successful deployment of the Propulsion Arms and Landing Legs through a ground test.	Incomplete Propulsion Arms and Landing Legs have not been assembled.
MRS.1.2.1 MRS Communication	The MRS shall be capable of signaling the GSE when the Propulsion Arms and Landing Legs are deployed.	Derivation of Requirement MRS.1.2.1	Demonstration The MRS will demonstrate its ability to signal GSE upon successful deployment of the Propulsion Arms and Landing Legs through a ground test.	Incomplete Propulsion Arms and Landing Legs have not been assembled.
MRS.1.2.1.1 Limit Switch	Limit switches shall be attached to the locking mechanisms of the Arm Pivot Assembly and LLS to determine engagement.	Derivation of Requirement 1.2.1.1	Demonstration The Arm Pivot Assembly and Landing Leg Assemblies will be actuated with the limit switches installed to verify this method of determining mechanical engagement.	Incomplete This is scheduled to occur during the manufacturing phase of the project.
MRS.1.2.1.1.1 Limit Switch Durability	The selected limit switches shall have an IP rating of IP6X.	Derivation of Requirement 1.2.1.1.1	Inspection The selected limit switches will be inspected upon purchasing to verify their ingression protection.	Complete The selected limit switches chosen have an IP rating of 6X.
MRS.1.3 Ariel Flexibility	The MRS shall maneuver away from the Payload Deployment Parachute before navigating to the target observation point.	Derivation can be found in PDR section 7.3.1	Analysis and Demonstration Flight simulations will be performed to determine the appropriate vector of safe travel for the MRS. Subsequently, a minimum of one successful full scale flight test will be used to verify real-world functionality.	Incomplete Awaiting assembly of Payload to determine flight characteristics and required maneuver for avoidance of the Payload Deployment Cutaway Parachute.
MRS.1.3.1 MRS Cutaway	The MRS shall maneuver into the direction of the wind and with a magnitude no less than 50 meters.	Derivation of Requirement 1.3.1	Analysis and Test Analysis will be performed through flight simulations to verify the autonomous maneuver. Subsequently, a real-world test flight will be performed simulating the ability of the MRS to react to drift from wind.	Incomplete Awaiting simulation testing and real-world autonomous flight testing.
MRS.1.3.2 MRS Cutaway timing	The maneuver away from the Payload Deployment Parachute shall occur immediately after a signal from the RRS is received.	Derivation of Requirement 1.3.2	Demonstration The MRS will demonstrate its ability to monitor a signal from the RRS through ground and flight testing.	Incomplete This demonstration will be completed post manufacturing of the full-scale Payload.
MRS.1.4 MRS Return	The MRS must return to the launch site at an altitude of 160 meters for target observation using the previously determined GPS coordinate.	Derivation of Requirement 1.4	Analysis and Demonstration Flight simulations will be performed to verify accurate travel to specific GPS set-points. Real world flight tests will be performed with a mock launch site coordinate to verify system performance.	Incomplete Testing with GPS coordinates has not been conducted, however tests utilizing a relative coordinate system have been successfully simulated.

MRS.1.5 MRS Return Coordinate	The MRS shall maneuver to a predetermined GPS coordinate north of the launch site at an altitude of 160 meters before attempting autonomous landing procedures.	Derivation of Requirement MRS.1.5	Analysis and Demonstration A map of the launch site will be examined prior to launch to determine a safe landing location. Flight simulations will be performed to verify accurate travel to specific GPS set-points. Subsequently, real world flight tests will be performed with a mock landing site coordinate to verify system performance.	Incomplete Testing with GPS coordinates has not been conducted, however tests utilizing a relative coordinate system have been successfully simulated.
MRS.1.5.1 MRS Pause	The MRS shall wait for a signal from the GSE primary RC transmitter before attempting an autonomous landing.	Derivation of Requirement 1.5.1	Demonstration Flight tests will be conducted to demonstrate that the MRS is capable of hovering at a specific location while waiting to receive a signal from the GSE before autonomously landing.	Incomplete Flight simulations with the MRS have been conducted however, real world tests with the MRS in combination with the GSE have not yet been attempted.
MRS.1.5.1.1 Default Recovery	If the MRS does not receive a signal to land from the GSE primary RC transmitter within 1 minute, it will manually trigger the RRS recovery mode.	Derivation of Requirement 1.5.1.1	Demonstration The ability of the MRS to trigger the RRS recover mode will be demonstrated through ground and flight testing.	Incomplete The MRS and RRS have not been integrated.
MRS.2 Deployment	The MRS propulsion assembly shall be capable of deploying from the launch vehicle and reacting all flight loads induced by the multirotor.	Derivation can be found in PDR section 7.3.1.1	Test Ground testing of the deployment mechanisms will be accomplished to verify repeatability of the system.	Complete Bench testing was performed on the Propulsion Arm Assembly to verify mechanical properties. This test was performed on the 12/30/2016.
MRS.2.1 Stable Propulsion Arm	The Propulsion Arm shall provide stable actuation of the multirotor motor upon Payload deployment.	Derivation can be found in PDR section 7.4.5.	Analysis and Demonstration Analysis will be conducted to predict impact loading and lock mechanism reaction forces. A demonstration of the Arm Pivot Assembly will be conducted to verify structural integrity of the design.	Complete Deployment impact analysis and Arm Pivot Actuation was conducted in section 5.2.4 of this document.
MRS.2.1.1 Locking Propulsion Arm	The Propulsion Arms shall deploy and lock into their flight positions upon separation from the deployment bay.	Derivation of Requirement 2.1.1	Analysis and Demonstration Analysis will be conducted on the lock mechanism to determine locking loads from actuation and from flight loads. A demonstration will be performed to verify the integrity of the lock design.	Complete The Arm Pivot lock pin mechanism Analysis and Demonstration were conducted in section 5.2.4 of this document.
MRS.2.1.1.1 1 Second Locking time	The Propulsion Arms shall lock into their flight positions within a second after the Payload is deployed from the Deployment Bay.	Derivation of Requirement 2.1.1.1	Analysis Analysis will be completed on the Propulsion Arm assembly to predict deployment time. Testing will be accomplished on the Propulsion Arm Assembly to verify deployment time.	Complete Propulsion Arm deployment analysis was conducted in section 5.2.4.
MRS.2.2 Max Torque and Load	The Propulsion Arm shall be capable of handling the max thrust of 2.1 kg and a torque	Derivation can be found in PDR section 7.4.5.	Analysis and Test FEA analysis will be conducted on the Arm Pivot Assembly to ensure the structural integrity of the	Complete

	load of 0.546 N*m from the motor assembly.		Payload arm design. The design will also be manufactured and subjected to these maximum thrust conditions.	Propulsion Arm FEA Analysis was conducted to verify the strength of the system in section 5.2.4.
MRS.2.4 Rotor rating	The selected multirotor system must have a thrust/rotor rating of at a minimum 4.25lbs.	Derivation of Requirement 2.4	Demonstration The Propulsion Arm assembly will demonstrate the ability to provide no less than 4.25lbs of thrust through a test of the thrust from the motors	Complete The Propulsion Arm Assembly was verified to deliver 4.30lbs of thrust in thrust test carried out on 12/29/16
MRS.3 Wind Speeds	The MRS shall have the ability to navigate and land in winds up to 20mph.	Derivation can be found in PDR section 7.3.1.1	Test Test flights will be conducted to verify predicted flight performance of the Payload in worst case wind scenarios.	Incomplete Further flight testing will prove the airworthiness of the Payload in allowable weather conditions.
MRS.4 RRS inhibiting	The MRS shall not electrically or physically inhibit the RRS.	Derivation can be found in PDR section 7.3.1.1	Demonstration The design of the payload verifies the physical clearances between the systems. The systems also have separate electronic control systems.	Incomplete MRS, RRS, and RRS Deployment Parachute have not been integrated yet.
MRS.5 TDS requirements	The MRS flight computer shall meet all related requirements set forth by the TDS.	Derivation can be found in PDR section 7.3.1.1	Inspection These requirements will be considered during the choice of flight computer.	Complete A Raspberry Pi 3 Model B was chosen as the flight computer and meets all requirements set forth by the TDS.
GSE.1 Real time ground staton monitoring	A laptop computer shall be utilized as a ground station control center and will allow real-time monitoring of MRS flight conditions.	Derivation of Requirement GSE.1	Test The ability of the laptop computer to perform real-time monitoring of flight conditions will be tested through full-scale flight testing.	Complete A laptop running QGroundControl has been setup to communicate with the MRS in real-time.
GSE.1.1 MRS altitude data	The laptop computer shall receive and display MRS altitude.	Derivation of Requirement GRE 1.1	Demonstration The capabilities of the laptop computer will be demonstrated via a ground test of the MRS.	Complete A laptop running QGroundControl has been setup to communicate with the MRS and display real-time altitude.
GSE.1.2 MRS velocity data	The laptop computer shall receive and display MRS velocity.	Derivation of Requirement GSE 1.2	Demonstration The capabilities of the laptop computer will be demonstrated via a ground test of the MRS.	Complete A laptop running QGroundControl has been setup to communicate with the MRS and display real-time velocity.
GSE.1.3 Vehicle mode	The laptop computer shall receive and display the vehicle mode (i.e. stabilized, hold, land, offboard).	Derivation of Requirement GSE 1.3	Demonstration The capabilities of the laptop computer will be demonstrated via a ground test of the MRS.	Complete A laptop running QGroundControl has been setup to communicate with the MRS and display real-time vehicle mode information.
GSE.2 RC override	There shall exist a primary RC transmitter capable of overriding all autonomous flight procedures.	Derivation of Requirement GSE 2	Test Flight logs will be used to verify the functionality of the primary RC transmitter following a full-scale flight.	Incomplete Awaiting full-scale flight test. Test scheduled for 2/18/17.
GSE.2.1 RC operation	The primary RC transmitter shall be held by a trained operator during flight.	Derivation of Requirement GSE 2.1	Inspection	Complete A pre-flight checklist item has been added to the launch procedures.

			Preflight checks will include visual and audible verification that the trained operator is prepared with the primary RC controller.	
GSE.2.2 RC override	The primary RC transmitter shall be capable of overriding the flight computer and placing the MRS immediately into a position hold state.	Derivation of Requirement GSE 2.2	Demonstration The capabilities of the primary RC transmitter will be proven via ground and flight tests.	Incomplete Awaiting testing of offboard control by flight controller.
GSE.2.3 RC override	The primary RC transmitter shall be capable of overriding the flight computer to provide manual, stabilized control of the MRS to the operator.	Derivation of Requirement 2.3	Demonstration The capabilities of the primary RC transmitter will be proven via ground and flight tests.	Incomplete Awaiting testing of offboard control by flight controller.
GSE.3 Secondary RC	There shall exist a secondary RC transmitter that provides input to the RRS.	Derivation of Requirement GSE 3	Test Flight logs will be used to verify the functionality of the secondary RC transmitter following a full-scale flight.	Incomplete Awaiting full-scale flight test. Test scheduled for 1/20/17.
GSE.3.1 Secondary RC operator	The secondary RC transmitter shall be held by a trained operator during flight.	Derivation of Requirement GSE 3.1	Inspection Preflight checks will include visual and audible verification that the trained operator is prepared with the secondary RC controller.	Complete A pre-flight checklist item has been added to the launch procedures.
GSE.3.1.1 Secondary RC location	The operator of the secondary RC transmitter shall be within audible range of the RSO during launch and be ready to react to the RSO's commands.	Derivation of Requirement GSE 3.1.1	Inspection Preflight checks will include verification that the operator is within audible range of the RSO.	Complete A pre-flight checklist item has been added to the launch procedures.
GSE.3.2 Secondary RC and RRS	The secondary RC transmitter shall provide inputs to the RRS corresponding to the Deployment Parachute Cutaway procedure and manual activation of the RRS recovery mode.	The secondary GSE RC controller is essential to the operation of the manually-induced safety features of the RRS.	Demonstration The functionality of the switches will be shown through ground and flight testing.	Complete Preliminary testing has shown reliable communication between the secondary RC transmitter and the RRS.
RRS.1 RRS serves MRS	The RRS shall sever the connection of the MRS from the deployment parachute.	Derivation of Requirement RRS 1	Demonstration Ground and flight demonstrations of severance will be conducted.	Incomplete Logic must be developed for cutaway maneuver and hardware must be tested. Full Scale integration Test Scheduled for 02/04/2017
RRS.1.1 Cutaway executable	The cutaway shall not be executable until successful initialization of the MRS.	Derivation of Requirement RRS 1.1	Demonstration Ground testing will be performed to verify no execution before proper signaling from the MRS.	Incomplete Logic for verifying initialization of MRS must be developed. Full Scale integration Test Scheduled for 02/04/2017

RRS.1.2 Secondary RC and RSO	The cutaway shall be executed under the direction of the RSO via the secondary RC transmitter.	This requirement has been added to give the RSO further control over the Payload's recovery to maximize safety.	Demonstration Demonstration of RSO directed cutaway will be shown during ground tests and full scale launch.	Incomplete Cutaway device and mountings have not been assembled.
RRS.1.2.1 RSO disapproval	If the RSO does not approve of executing the cutaway, the payload shall continue to descend and land under the deployment parachute.	If the RSO does not feel that it is safe to deploy the MRS, this requirement ensures that the Payload safely lands under the deployment parachute.	Demonstration A landing under the deployment parachute will be demonstrated.	Incomplete Payload must be constructed before deployment parachute may be tested.
RRS.2 RRS response	The RRS shall react in the event of a deployment or flight anomaly within the MRS or DS or from a trigger given by the GSE.	Derivation can be found in section 7.3.1.2	Test Flight Test of the RRS will be performed to verify system functionality. A pre-flight checklist will be developed which will be completed prior to all test and competition flights.	Incomplete RRS system is still in development and has not undergone final testing.
RRS.2.1 RRS permissions	The RRS shall have the ability to deploy a reserve parachute.	Derivation of Requirement RRS 2.1	Demonstration Ability of the RRS to deploy the reserve parachute will be tested.	Incomplete RRS system has not been tested for parachute deployment.
RRS.2.2 Landing KE	The reserve parachute shall land the payload below the 75 ft-lb kinetic energy requirement if deployed.	Derivation of Requirement RRS 2.2	Test Data will be read from test flights to ensure reserve parachute deployment lowers decent energy below 75ft*lb.	Incomplete RRS system has not been tested for parachute deployment at specified forces. Test scheduled for 1/20/17.
RRS.2.3 Parachute Deployment	The reserve parachute shall deploy in the event of the payload losing flight stability or exceeding 75 ft-lb of kinetic energy.	This requirement serves as the criteria for deploying the RRS parachute.	Test Simulated and real flight scenarios of deployment will be tested.	Incomplete Drop Testing is scheduled to occur on 01/21/2017.
RRS.2.1.1 RRS failsafe	RRS shall have failsafe circuit to ensure parachute deployment in case of system failure.	This requirement was added to ensure that the RRS possesses the ability to deploy a reserve parachute.	Demonstration RRS will undergo simulated failure, power removed from system, causing e-match charge to ignite.	Incomplete Failsafe is able to perform all operations upon LEDs, but was damaged during transit to test site. This caused the e-match to not ignite during demonstration.
RRS.2.4 RRS redundancy	The RRS shall have control system redundancy.	Derivation of Requirement RRS 2.1.1	Inspection Prior to final build, two RRS systems will be constructed and integrated.	Incomplete Final RRS system requires development before redundant system may be constructed.
RRS.2.5 MRS power	In the event of a flight anomaly, the RRS shall cut power from the MRS motors.	Derivation of Requirement RRS 2.5	Demonstration Power cutoff system will be shown to work in lab settings while under simulated flight.	Complete RRS has demonstrated ability to cut power from multirotor motors.

RRS.2.5.1 RRS controls	The RRS shall control IGBT circuitry that powers the MRS motors.	Derivation of Requirement RRS 2.5.1	Demonstration Under full load, RRS will apply gate voltage to turn on MRS flight electronics. MRS will be shown to function under power.	Complete RRS is able to reliably force conduction of IGBTs and cease conduction at will. Conduction ceases if power is lost to system as previously required.
RRS.2.6 Pressure Sensor data	The RRS shall determine altitude and velocity using a commercially purchased pressure sensor.	Derivation of Requirement RRS 2.6	Test Accurate data will be gathered from pressure sensor prior to testing.	Incomplete RRS electronics shall be tested for data gathering and failure states on 1/20/17.
RRS.2.6.1 BMP180 pressure sensor	The RRS shall utilize the BMP180 pressure sensor and library for all altitude measurements.	Derivation of Requirement RRS 2.6.1	Inspection Circuit and logic shall use consumer parts and available programing to determine altitude.	Complete All hardware of RRS is commercially available and utilizes its software package when determining altitude.
RRS.2.6.1.1 Altitude readings	The RRS shall take multiple readings before deriving altitude from average pressure in order to reduce error.	Derivation of Requirement RRS 2.6.1.1	Demonstration All 10 readings must be verified as having been read, saved and are within tolerances.	Complete RRS measurement system takes readings, and complies data within ±0.5 m accuracy.
RRS.2.6.2 Altitude calculations	Altitude calculations shall occur at a rate of 1 Hz minimum.	Derivation of Requirement RRS 2.6.2	Demonstration Internal clock timer must verify that every altitude calculation occurs within 1 second of the previous value.	Complete Altitude is calculated every 0.61s by the RRS.
RRS.2.7 RSS functions	The RRS shall be able to function for the entirety of the launch vehicle's flight and Payload's mission	Derivation of Requirement RRS 2.7	Demonstration The RRS will be shown to be active for over 2 hours.	Incomplete The RRS must be fully constructed and able to run a longevity demonstration
RRS.2.7.1 RSS data	The RRS shall be able to take altitude and velocity measurements for the entire Payload mission.	Derivation of Requirement RRS 2.7.1	Demonstration The RRS will perform readings for over 20 minutes without ceasing.	Incomplete The RRS is missing microSD card and the Teensy is unable to store all of the required data.
RRS.3 RRS arming	The RRS shall be armed via a remote signal from the GSE secondary RC transmitter.	Derivation of Requirement RRS 3	Test The RRS shall be shown to perform initialization, readings, and undergo failure states without igniting e-match until armed by the GSR secondary RC transmitter.	Incomplete The RRS has been demonstrated as controllable through receiver connected to RC transmitter, but range is untested.
RRS.4 RRS conncections	The RRS shall have a dedicated I/O pin connected to the MRS for triggering an immediate activation of the RRS recovery mode.	Derivation of Requirement RRS 4	Test The activation of the RRS via the MRS will be demonstrated through during the Payload Integration Flight Testing.	Complete
TDS.1 TDS detection	TDS shall have ability to detect and differentiate	Derivation can be found in PDR section	Test	Incomplete

	between all three randomly placed targets.	7.3.1.3	TDS shall undergo significant ground testing to ensure targets are identified precisely and accurately.	Significant, repeated ground and subscale testing will be required to ensure the detection system is fully vetted
TDS.1.1 Image detectability	Images shall be detectable at a predefined operational altitude.	Derivation can be found in PDR section 7.5.2	Test Flight recordings shall be created and analyzed to determine camera angle configurations.	Incomplete Subscale & drone launch tests shall be conducted as scheduled to obtain accurate footage. Ground test footage has been created and utilized to assist in target calibration.
TDS.1.1.1 TDS Images	The TDS shall accurately 'see' objects directly below the drone's current location.	Derivation can be found in PDR section 7.5.2	Test Flight data and recording will be analyzed to obtain accurate information on image quality & viability.	Incomplete Drone and flight tested has not yet been conducted.
TDS.1.2 TDS detection	The TDS shall be able to determine which of the three targets has been detected in frame.	Derivation can be found in PDR section 7.5.2	Test Ground testing will be conducted to ensure all footage is seen accurately by the TDS.	Incomplete Subscale footage has yet to be obtained
TDS.1.2.1 Color validation	The TDS shall use HSV value ranges in order to determine if object is valid color.	Derivation can be found in PDR section 7.5.2	Test Color calibration testing shall be conducted to ensure only valid colors are accepted.	Incomplete Have not yet received target color samples with which to test HSV ranges with
TDS.1.2.2 Aspect verification	The TDS shall check aspect ratio of object contours to see if object is square/rectangular in nature.	Derivation can be found in PDR section 7.5.1	Test Ground and subscale testing will be conducted to determine effectiveness of detection system. Results will be analyzed and adjustments made depending on results.	Incomplete Additional test materials are required to fully meet requirements.
TDS.1.2.3 Target evaluation	The TDS shall use altimetry data provided by the MRS (TDS.3.1) to evaluate potential targets based on relative size.	Derivation can be found in PDR section 7.3.1.3	Test Subscale tests shall be conducted to determine requirement's effectiveness and the degree of accuracy required for accurate detection.	Incomplete Subscale testing footage required.
TDS.2 Target evidence	The TDS shall provide adequate evidence that targets were detected.	Derivation can be found in PDR section 7.5.1	Demonstration Footage shall be reviewed and assessed to ensure targets are detected visibly.	Incomplete Detection algorithm still undergoing development/testing
TDS.2.1 Detection algorithm	The TDS shall apply detection algorithm to all images during flight.	Derivation can be found in PDR section 7.5.1	Demonstration Test footage will be reviewed and the system assessed to ensure target detection is happening timely, and is acting as expected.	Incomplete Requirement will be demonstrated after subscale testing

TDS.2.1.1 Image Saving	The TDS shall outline all detected targets and save any images containing targets to disk.	Derivation can be found in PDR section 7.3.1.3	Demonstration Test footage will be used to evaluate the TDS' ability to outline selected targets and that all frames containing a detected target are saved to a different directory.	Incomplete Additional test footage required
TDS.2.2 TDS communication	The TDS shall inform MRS if a target has been detected & report which targets were captured.	Derivation can be found in PDR section 7.5.1	Test Integration testing shall be conducted to ensure systems are communicating as expected.	Incomplete Integration testing has not yet been conducted
TDS.3 TDS and MRS communication	The TDS shall interface with MRS.	Derivation can be found in PDR section 7.5.1	Test Integration testing shall take place to determine that both systems function correctly.	Incomplete Integration testing has not yet been conducted
TDS.3.1 TDS and MRS communication	The TDS shall send information about targets back to the MRS, as well as receive information from the MRS regarding current altitude and execution instructions.	Derivation can be found in PDR section 7.5.1	Test Subscale and integration tests shall occur in order to confirm that systems send and receive expected values and utilize information provided as expected.	Incomplete Integration testing has not yet been conducted
TDS.3.2 Camera programming	The TDS shall run on the same Raspberry Pi 3 as the MRS to detect and mark targets. A 5MP PiCamera shall be used to take still images.	Derivation can be found in PDR section 7.5.1 7.5.2	Test Subscale and integration testing shall be used to confirm that both systems are capable of running on the same RPi. Tests shall be conducted using the PiCam to assess it's effect range, view angle, and accuracy when searching for targets.	Incomplete Integration and subscale tests have not yet been completed
PSS.1 Loads	The PSS shall carry all flight, deployment, and landing loads experienced during launch and Payload recovery. (Section of airframe)	Derivation can be found in PDR section 7.3.1.6	Demonstration The structural support of the PSS will be demonstrated during flight tests of the Payload.	Incomplete Requirement will be verified during flight testing.
PSS.2 Organization	The PSS shall organize and house all Payload subsystem components to be easily accessible.	Derivation can be found in PDR section 7.3.1.6	Demonstration A demonstration of the assembled Payload will be done to ensure that all of the subsystem components fit properly.	Incomplete This requirement will be verified during the manufacturing phase of this project.
PSS.2.1 MRS housing	The PSS shall provide housing for all MRS flight electronics.	Derivation can be found in PDR section 7.3.1.6	Demonstration All flight electronic housings will demonstrate their ability to support and enclose the flight electronics from CAD and during manufacturing.	Incomplete Requirement will be demonstrated during manufacturing.
PSS.2.2 Redundant Recovery Housing	The PSS shall house all Redundant Recovery equipment.	Derivation of Requirement PSS 2.2	Demonstration A demonstration will be performed to verify fitment of the recovery parachute, black powder charge, and redundant recovery electronics from CAD and during manufacturing.	Incomplete Requirement will be demonstrated during manufacturing.
PSS.2.2.1 Recovery arming	The PSS shall allow for the arming of all recovery	Derivation can be found in PDR section	Demonstration	Incomplete

	electronics prior to flight (fulfills SOW 2.7)	7.3.1.6	A demonstration of all recovery electronics being armed from outside the airframe will be conducted.	During all flights of the Payload, the recovery electronics will be armed from outside the airframe.
PSS.2.2.2 Black powder isolation	The PSS shall protect and isolate all other systems from the black powder detonation charge of the RRS system.	Derivation of Requirement PSS 2.2.2	Demonstration A demonstration will be performed on the RRS assembly to verify that black powder charge is controlled and will not adversely affect all other components of the Payload.	Complete Black powder charge testing has been completed verifying the structural integrity of the removable sealing RRS bulk plate.
PSS.2.3 Propulsion housing	The PSS shall house all propulsion equipment.	Derivation of Requirement PSS 2.3	Demonstration A demonstration will be performed to verify fitment of the Propulsion Arm Assemblies from CAD and during manufacturing.	Complete The Demonstration of the fitment and integration of all Propulsion components can be found in section 5.5.2.
PSS.2.4 LLS housing	The PSS shall house all LLS Equipment.	Derivation of Requirement PSS 2.4	Demonstration A demonstration will be performed to verify fitment of the Propulsion Arm Assemblies from CAD and during manufacturing.	Complete The Demonstration of the fitment and integration of all LLS components can be found in section 5.5.4.
PSS.2.5 TDS housing	The PSS shall house all TDS equipment.	In order to satisfy Statement of Work Requirement 3.2.1 the Payload structure must adequately support the mounting of all TDS systems.	Demonstration A demonstration will be performed to verify fitment of the TDS equipment from CAD and during manufacturing.	Complete The Demonstration of the fitment and integration of all TDS components can be found in section 5.5.3 and 5.5.4.
LLS.1 LLS placement	LLS shall be stowable into the recovery bay	Derivation can be found in PDR section 7.8.1	Demonstration Fitment of the leg assemblies will be demonstrated through CAD models and will be verified during assembly.	Incomplete Requirement will be verified during manufacturing of LLS.
LLS.1.1 LLS integrity	LLS shall remain functional after black powder separation	Derivation can be found in PDR section 7.8.1	Test Further testing will verify that limit switches and mechanical components can function properly after a black powder separation	Incomplete Requirement will be verified during separation tests.
LLS.1.2 LLS housing and legs	LLS housing and legs shall fit into sheathes along inner airframe of recovery bay	Derivation can be found in PDR section 7.8.1	Demonstration Demonstration of leg fitment into sheathes, and testing of leg deployment will verify that leg properly fit into recovery bay sheathes.	Incomplete Requirement will be verified during full scale flight tests.
LLS.2 LLS and recovery	The LLS shall not interfere with the main vehicle recovery system.	Derivation can be found in PDR section 7.8.1	Inspection Inspection of the recovery bay will ensure necessary space allocation for the LLS and launch vehicle recovery system.	Incomplete Requirement will be inspected prior to each full scale flight test.
LLS.2.1 LLS and interferences	LLS shall not contain any protrusions or edges that	Derivation can be found in PDR section 7.8.1	Inspection	Incomplete Final inspection will occur at the end of the manufacturing process.

	might cause interference with recovery systems		During manufacturing inspection of all component surfaces, edges, and joints will guarantee no protrusions or sharp edges.	
LLS.2.2 Limit Switches	Limit switches shall confirm to flight controller that legs have successfully deployed.	Derivation can be found in PDR section 7.8.1	Test Testing will ensure that limit switch location allows for consistent differentiation of the deployed configuration vs. the stowed configuration.	Incomplete Requirement will be tested in separation tests.
LLS.3 LLS locking	The LLS shall lock into the landing configuration after deployment from the main vehicle recovery bay.	Derivation can be found in PDR section 7.8.1	Test Black powder testing will be accomplished to verify proper deployment and separation of the LLS from the recovery bay.	Incomplete Requirement will be tested in separation tests.
LLS.3.1 Locking pins	The Lock Pin mechanisms shall be able to consistently lock the leg pivot into landing configuration.	Derivation can be found in PDR section 7.8.1	Demonstration Ground demonstration will be conducted to simulate deployment and prove pin can consistently snap into place.	Incomplete Requirement will be verified in separation tests.
LLS.4 Rigidity	The LLS shall provide enough rigidity and stability to support the entire Payload system upon landing.	Derivation can be found in PDR section 7.8.1	Demonstration LLS stability will be demonstrated through flight tests.	Incomplete Requirement will be verified in Payload flight tests.
DS.1 Payload deployment	The DS shall safely deploy the Payload from the Deployment Bay and Main Recovery Bay.	Derivation can be found in PDR section 7.3.17	Test Deployment testing of the Payload will be conducted following RCR safety guidelines.	Incomplete Requirement will be verified in separation tests.
DS.1.1 MRS arm deployment	The DS shall not inhibit deployment of MRS arms.	This requirement was added to ensure that the MRS arms are not hindered or rendered unable to perform their functions during deployment.	Test Proper MRS arm deployment will be demonstrated during separation tests.	Incomplete Requirement will be verified in separation tests.
DS.1.2 LLS leg deployment	Deployment shall not inhibit deployment of LLS legs.	This requirement was added to ensure that the LLS legs are not hindered or rendered unable to perform their functions during deployment.	Test Proper LLS leg deployment will be demonstrated during separation tests.	Incomplete Requirement will be verified in separation tests.
DS.1.3 MRS performance	Deployment shall not negatively affect the performance of the MRS propulsion motors.	This requirement was added to ensure that black powder deployment does not render the MRS propulsion motors’	Test The performance of the MRS motor will be tested before and after deployment tests.	Incomplete

		ability to perform its mission.		
DS.1.4 MRS and LLS	The DS shall not damage any electrical harnessing or limit switches associated with the MRS propulsion system or the LLS.	This requirement ensures that the propulsion system electronics will not be negatively affected by the charge.	Test Deployment testing will be performed to verify that the separation of the Payload from the Launch Vehicle doesn't result in damage to electrical components on the either the top of bottom bulk plates.	Incomplete These test are scheduled to occur after the manufacturing phase of the project has been completed.
DS.2 Parachute deployment	The DS shall not inhibit the deployment of the parachute.	The DS shall remain secondary to a safe deployment of the deployment parachute to reduce the risk of a catastrophic failure. The deployment parachute must properly inflate during deployment in order for the Payload to continue its mission.	Test Ground and flight demonstrations of parachute deployment will be conducted.	Incomplete Deployment parachute separation demonstrations will be conducted during Full Scale Test flights.
DS.3 Camera protection	The system shall protect the TDS camera from becoming blurred during deployments.	Being that deployment of the Payload is achieved using a black power charge, it is crucial that the lens of the camera is protected in order to allow for proper operation later in the mission.	Test Camera imaging tests will be done prior to and after deployment tests.	Incomplete

7.2.2.2.1 Derivation of Requirement MRS.1.1

In order for the Payload to return to a position where the required camera system can detect and differentiate the targets, a reference coordinate must be established in space relative to the targets. The GPS coordinate of the launch rail was selected as the reference coordinate due to the fact that the targets will be at most 300ft around this point.

7.2.2.2.2 Derivation of Requirement MRS.1.2

To ensure that the initialization process of the MRS does not occur on the rail, flight, or before the Payload is deployed from the vehicle during descent, this requirement was implemented to protect the flight systems and the integrity of the Payload.

7.2.2.2.3 Derivation of Requirement MRS.1.2.1

The Payload and ground team must know the mechanical deployment state of the Propulsion Arm's and Landing Legs so that the ground team and RSO will be able to decide whether the Payload is capable of flight. This requirement guarantees that the Payload will only perform its flight mission if its mechanical systems are properly deployed.

7.2.2.2.4 Derivation of Requirement MRS.1.2.1.1

The deployment state of the Propulsion Arms and Landing Legs must be detected via limit switches. This requirement provides a reliable method of determining the mechanical state of deployment of the Propulsion Arms and Landing Legs.

7.2.2.2.5 Derivation of Requirement MRS.1.2.1.1.1

The limit switches will be installed on the top and bottom bulk plates of the Payload. These areas are subject to debris from the black powder charges which separate the Payload from the launch vehicle. Designing the system to incorporate limit switches with an IP rating of IP6X will guarantee that the debris will not ingress into the component causing damage and potential component failure.

7.2.2.2.6 Derivation of Requirement MRS.1.3.1

Flight simulations are necessary to the prediction of proper aerial maneuvering of the Payload. Modeling the deployment maneuver through flight simulations will mitigate potential risk of entangling with the Deployment Parachute during the maneuver.

7.2.2.2.7 Derivation of Requirement MRS.1.3.2

During the cutaway of the Deployment Parachute, the MRS system must act quickly in order to maneuver away from the parachute. Along with cutting activating the ARRD mechanism, the RRS will send a signal through an I/O pin to the MRS alerting it to begin the cutaway maneuver. This requirement was derived in order to prevent entangling of the Deployment Parachute with the MRS propellers.

7.2.2.2.8 Derivation of Requirement MRS.1.4

In order to mitigate potential safety concerns, NASA has presented the requirement via a conference call that the Payload must perform the target detection at an altitude of 500ft above ground.

7.2.2.2.9 Derivation of Requirement MRS.1.5

Variabilities in the placement of the launch rails may cause problems in predetermining a Landing Location for the Payload. This requirement ensures that on the day of the Launch, a safe landing location is selected via GPS. This information will be relayed to the RSO and to NASA.

7.2.2.2.10 Derivation of Requirement MRS.1.5.1

This requirement is derived from a self-defined safety requirement. This requirement states that the payload will only land if manually commanded to do so once the RSO has given final approval of the maneuver.

7.2.2.2.11 Derivation of Requirement MRS.1.5.1.1

In order to allow time for the RSO to ensure a safe autonomous landing is possible, the MRS is required to wait for a manual command to land. If no command is received within 1 minute, it will default to performing a parachute landing by manually triggering the RRS recovery mode. The RSO can also request that a parachute landing be performed immediately. In this case, the RRS recovery mode is activated via the GSE secondary RC transmitter.

7.2.2.2.12 Derivation of Requirement MRS.2

In order to satisfy SOW.3.2.2, the Propulsion Assembly must be capable of being stowed within the Launch Vehicle during flight due to the design of the body of the Payload being a coupler section. This Assembly must also be capable of being deployed and locked into place once the Payload is separated from the Launch Vehicle. This Assembly must also react and rolling, pitching, yawing, and thrust vectoring the Payload during flight. This requirement guarantees the structural integrity of the Propulsion Assembly during all flight scenarios.

7.2.2.2.13 Derivation of Requirement MRS.2.1.1

The Propulsion Arms locking into place is crucial to the flight mission of the payload. This requirement ensures that a locking mechanism will be implemented into the system to reliably rigidly lock the arms in to the flight position.

7.2.2.2.14 Derivation of Requirement MRS.2.1.1.1

The Propulsion Arms must be capable of deploying into their flight positions rigidly and quickly. This requirement was implemented to ensure that the designed actuation mechanisms would quickly seat the Propulsion arms into their flight configurations.

7.2.2.2.15 Derivation of MRS.2.4

The Propulsion Arm assembly must have a thrust per arm of no less than 4.25lb to maintain the 2:1 thrust to weight rule allowing the multirotor enough to efficiently maneuver in the air.

7.2.2.2.16 Derivation of Requirement GSE.1

A ground station for real-time telemetry monitoring is essential for determining the state of the payload at all times in order to react appropriately in the event of a flight anomaly.

7.2.2.2.17 Derivation of Requirement GSE.1.1

Real-time monitoring of the altitude will make rapid changes obvious to the ground team and serve as a tool for soliciting an appropriate reaction from the operators in the event of a flight anomaly.

7.2.2.2.18 Derivation of Requirement GSE.1.2

Real-time monitoring of the velocity will make rapid changes obvious to the ground team and serve as a tool for soliciting an appropriate reaction from the operators in the event of a flight anomaly.

7.2.2.2.19 Derivation of Requirement GSE.1.3

The GSE laptop computer must be capable of monitoring the Payload mode in order to notify the ground team and RSO that it is ready to be severed from the Deployment Parachute. It will also serve to notify the ground team in the event of an anomalous autonomous operation.

7.2.2.2.20 Derivation of Requirement GSE.2

The primary GSE RC controller is critical in allowing the ground team to override autonomous flight procedures and take manual control of the Payload in the event of an anomaly. It will also allow specific commands to be given to the MRS during flight.

7.2.2.2.21 Derivation of Requirement GSE.2.1

Only someone trained to fly the MRS under manual control and fully comfortable with its operation will be allowed to assume control of the aircraft. This operator must have a thorough understanding of the vehicle in order to remain calm in the high stress situation of a flight anomaly.

7.2.2.2.22 Derivation of Requirement GSE.2.2

In the event of a flight anomaly the GSE primary RC transmitter must be capable of immediately placing the Payload in a position hold state to restrict further movement. At this post the Payload will remain stationary to allow further analysis of the situation by the ground team and RSO.

7.2.2.2.23 Derivation of Requirement GSE.2.3

The GSE primary RC transmitter must allow full control of the Payload flight system (in stabilized/auto-level mode) to be assumed in the event of an anomaly. This will allow for safe maneuvering under the control of a trained operator.

7.2.2.2.24 Derivation of Requirement GSE.3.1

Only someone trained and comfortable in the operation of the RRS will be allowed to command its actions. This is to ensure the ability of the operator to remain calm and act appropriately in the event of a flight anomaly.

7.2.2.2.25 Derivation of Requirement GSE.3.1.1

The operator of the secondary GSE RC transmitter must stand within visual and audible range of the RSO at all times during flight. This will ensure that there is no issue with communication in the event that the RSO has to request a safety-related action be taken that utilizes the RRS.

7.2.2.2.26 Derivation of Requirement GSE.3.2

Due to requirement MRS.1.5.1, the secondary GSE RC transmitter must be capable of commanding the RRS to detach the payload from the deployment parachute and begin flight. It must also provide the operator with the ability to manually and immediately trigger the RRS recovery mode in the event of a flight anomaly.

7.2.2.2.27 Derivation of Requirement RRS.1

This requirement was moved to the RRS to allow the Payload to have the ability land under the deployment parachute in the event of an off-nominal flight case.

7.2.2.2.28 Derivation of Requirement RRS.1.1

The cutaway releases the Payload from the deployment parachute. This requirement ensures that the Payload is ready to take flight before the cutaway.

7.2.2.2.29 Derivation of Requirement RRS.2.2

This requirement ensures that the payload will land under the kinetic energy requirement if the RRS is utilized, fulfilling Statement of Work Requirement 2.3.

7.2.2.2.30 Derivation of Requirement RRS.2.1.1

In the event of system failure, the battery may no longer be able to deploy the recovery parachute. The RRS must default to recovery. This requirement necessitates a failsafe to deploy the recovery parachute when the system fails.

7.2.2.2.31 Derivation of Requirement RRS.2.4

The RRS must be able to sense flight anomalies. If one system is experiencing an unforeseen error, a second RRS shall perform the mission. Facilitating this is logic built into the RRS that causes recovery of the Payload in the event that either system determines an anomaly has occurred.

7.2.2.2.32 Derivation of Requirement RRS.2.5

If the MRS motors are powered during retrieval they could interfere with deployment of parachute or decent.

7.2.2.2.33 Derivation of Requirement RRS.2.5.1

The MRS motors require 25 Volts at 20 Amps to function at 100%. The RRS must be able to interrupt that power flow. Power FETs generally may sustain either high voltage or high current, but IGBTs are able to handle both. The RRS is able to control the gate voltage of an IGBT and so it may operate as a switch for high power motors.

7.2.2.2.34 Derivation of Requirement RRS.2.6

In order to obtain accurate and reliable altitudes the RRS utilizes a BMP180 pressure sensor.

7.2.2.2.35 Derivation of Requirement RRS.2.6.1

The BMP180 pressure sensor has been proven reliable previously. The RRS must be reliable in every instance, to that end it is enabled by a BMP180.

7.2.2.2.36 Derivation of Requirement RRS.2.6.1.1

The BMP180 has inherent inaccuracies associated with its operation. These must be mitigated to prevent false positives and missions aborting early. Obtaining and average over multiple readings reduces error in the system.

7.2.2.2.37 Derivation of Requirement RRS.2.6.2

If the RRS calculates velocity over too long of a period it ceases to be an instantaneous velocity and thus an accurate read of the Payload's energy. A minimum frequency of readings at 1Hz enables the RRS to accurately determine its kinetic energy.

7.2.2.2.38 Derivation of Requirement RRS.2.7

The RRS must be able to spend an hour on the launch pad and still perform all mission requirements. The Payload's mission is expected to take a maximum of 20 minutes. In order to provide additional leeway on possible battery variance, the RRS must be capable of 2 hours of operation.

7.2.2.2.39 Derivation of Requirement RRS.2.7.1

The Payload's mission should not be cut short by the RRS unless a catastrophic failure of MRS, DS or RRS occurs. Therefore the RRS should be able to calculate altitude and velocity for the entirety of the Payload's worst case time frame.

7.2.2.2.40 Derivation of Requirement RRS.3

During ascent of the launch Vehicle, if an error in the RRS occurred it would default to recovery. This would cause a catastrophic mission failure. To mitigate this, the RRS will be initialized on the launch pad, but remain unarmed until the RSO determines the mission should start.

7.2.2.2.41 Derivation of Requirement RRS.4

As stated in requirement MRS.1.5.1.1, the Payload must wait for a signal from the ground team to perform an autonomous landing upon completion of the mission. If this signal is not received, it must have a way of triggering the deployment of a parachute for landing. This is achieved through the use of this I/O line. Any toggling of the line will instantly activate the RRS recovery mode.

7.2.2.2.42 Derivation of Requirement PSS.2.2

The Redundant Recovery System is a crucial backup safety system and the integrity of its components must be preserved for the integrity of its flight. This requirement ensures that the RRS will be properly and securely restrained within the Payload.

7.2.2.2.43 Derivation of Requirement PSS.2.2.2

A removable bulkplate will seal the RRS tube from the inside of the payload. Since the bulkplate is removable, this requirement will ensure that an adequate seal must exist between bulkplate and it's mating surface to ensure the black powder charge deploy the RRS parachute and protects the Payload electronics.

7.2.2.2.44 Derivation of Requirement PSS.2.3

In order for the Payload to be recovered via the MRS system, this requirement was derived so that the PSS would house and carry the propulsion systems of the MRS.

7.2.2.2.45 Derivation of Requirement PSS.2.4

The LLS is the essential system necessary to completing Statement of Work Requirement 3.2.2. This requirement guarantees the Payload will be able to accommodate a landing systems necessary to complete the Statement of Work Requirement.

7.2.2.2.46 Derivation of Requirement PSS.2.5

In order to satisfy Statement of Work Requirement 3.2.1 the Payload structure must adequately support the mounting of all TDS systems.

7.2.2.2.47 Derivation of Requirement DS.1.1

This requirement was added to ensure that the MRS arms are not hindered or rendered unable to perform their functions during deployment.

7.2.2.2.48 Derivation of Requirement DS.1.2

This requirement was added to ensure that the LLS legs are not hindered or rendered unable to perform their functions during deployment.

7.2.2.2.49 Derivation of Requirement DS.1.3

This requirement was added to ensure that black powder deployment does not render the MRS propulsion motors' ability to perform its mission.

Table 95: Team-derived payload requirements.

7.2.2.3

Requirement ID	Requirement	Derivation	Verification Plan	Status
Human Safety				

Safety.1 Human Safety	The Safety Officer shall ensure the safety of the public and members of River City Rocketry throughout the 2016-2017 season.	This requirement ensures the overall health of the team while making sure a return to next year's competition occurs. This requirement is derived from SOW requirement 4.2 which requires the safety officer to be responsible for the safety of the team.	Inspection Each member is required to sign the safety manual before the start of the season.	Complete See Safety Manual on website.
Safety.1.1 Vehicle	The vehicle lead shall be responsible for the overall safety of his sub-team members during low risk hazards that won't require the Safety Officer's observation.	This requirement promotes human safety by dolling safety responsibility to the team leaders who can better monitor the activities of their sub-teams.	Inspection Every low risk hazard is approved by the Safety Officer and shown in the respective risk assessment table.	Incomplete This requirement will be verified January 13th. See Safety section.
Safety.1.1.1 Manufacturing	Vehicle team members shall have proper training on equipment and tooling that is specific to their sub-team before construction can take place.	This requirement ensures that every member of the vehicle team knows which equipment or tool to use during manufacturing to save time and make the best product possible.	Inspection All heavy machinery must be signed off proving that that member can properly use the machine. All hand and power tools must be cleared by the vehicle lead to ensure that member knows how to properly use that tool.	Complete This requirement was verified January of 2016. See the Safety Manual.
Safety.1.1.2 Testing	All vehicle team tests that need to be performed outside shall be overseen by the safety officer. This includes test flights, black powder ejection tests, and any other large scale tests.	This requirement protects the overall health of the vehicle team and adds one more safety feature in case something were to go wrong during a black powder ejection charge test or any other large scale tests.	Inspection All testing equipment is double checked by both the vehicle lead and the safety officer before test is administrated.	Incomplete This requirement will be verified March 25th.
Safety.1.2 Payload	The Payload lead shall be responsible for the overall safety of his sub-team members during low risk hazards that won't require the Safety Officer's observation.	This requirement promotes human safety by dolling safety responsibility to the team leaders who can better monitor the activities of their sub-teams.	Inspection Every low risk hazard is approved by the Safety Officer and shown in the respective risk assessment table.	Incomplete This requirement will be verified January 13th. See Safety section
Safety.1.2.1 Manufacturing	Payload team members shall have proper training on equipment and tooling that is specific to their sub-team before construction can take place.	This requirement ensures that every member of the payload team knows which equipment or tool to use during manufacturing to save time and make the best product possible.	Demonstration The payload lead witnesses all sign offs of heavy machinery that his team members get certified for.	Complete This requirement was verified June 29th. See the Safety Manual.
Safety.1.2.2 Testing	All payload team tests that involve multiple personal shall be overseen by the safety officer and the payload lead must be notified before any test is administrated.	This requirement protects the overall health of the payload team and adds one more safety feature in case something were to go wrong during a black powder ejection charge test or any other large scale tests.	Inspection All test documents will signoffs for two test engineers validating the reason for the test and results gathered from the test.	Incomplete This requirement will be verified March 25th. See Payload Test Plans

Safety.1.2.2.1 MRS Tests	Payload team shall sign the MRS test document before all flight tests.	This requirement ensures that either the payload lead or the Safety Officer is aware that a flight test will be administrated. This allows the safety officer an opportunity to review the safety of non-standard tests such as MRS tests.	Inspection The Safety Officer or payload lead must be notified of each MRS flight test before they are initialized.	Incomplete This requirement will be verified March 25th. See Payload Test Plans.
Safety.1.2.2.2 RRS Tests	The payload lead shall inspect all individual electrical components for functionality before a full test is administrated.	This requirement ensures that the RRS is ready for a test by having all the components checked by the Safety Officer before test is administrated.	Inspection The Safety Officer will visually confirm the functionality of each component with the payload lead before test is administrated.	Incomplete This requirement will be verified March 25th. See Payload Test Plans.
Safety.1.2.2.3 DS Tests	The payload lead shall ensure of zero binding concerns or obstruction with the recovery harnesses between sections before any separation tests occur.	This requirement makes sure that components are functioning properly so that the test is as accurate as possible.	Inspection The Safety Officer, recovery lead, and payload lead shall perform a visual check of the separation sections before test commences.	Incomplete This requirement will be verified March 25th. See Payload Test Plans.
Safety.1.3 Recovery	The Recovery lead shall be responsible for the overall safety of his sub-team members during low risk hazards that won't require the Safety Officer's observation.	This requirement promotes human safety by dolling safety responsibility to the team leaders who can better monitor the activities of their sub-teams.	Inspection Every low risk hazard is approved by the Safety Officer and shown in the respective risk assessment table.	Incomplete This requirement will be verified January 13th. See Safety section
Safety.1.3.1 Manufacturing	Recovery team members shall have proper training on equipment and tooling that is specific to their sub-team before construction can take place. The two most pressing pieces of equipment consist of a hot knife and sewing machine.	This requirement ensures that every member of the recovery team knows which equipment or tool to use during manufacturing to save time and make the best product possible.	Inspection The recovery lead goes through a tutorial of the hot knife and sewing machine and validates his recovery team member's knowledge of each machine by overseeing their first encounter of each machine.	Complete This requirement was verified early October where a lesson on correct use of the hot knife was demonstrated by the recovery lead.
Safety.1.3.2 Testing	All recovery team tests that need to be performed outside shall be overseen by the safety officer. This includes test flights, black powder ejection tests, deployment tests, and any other large scale tests.	This requirement protects the overall health of the payload team and adds one more safety feature in case something were to go wrong during a black powder ejection charge test or any other large scale tests.	Inspection Both the recovery lead and safety officer are present for all test flights, black powder ejection tests, and deployment tests. Before testing is administrated both the recovery lead and safety officer double check the equipment before test is performed.	Incomplete This requirement will be verified January 13th. See Recovery Tests for validation.
Safety.1.4 VDS	The VDS lead shall be responsible for the overall safety of his sub-team members during low risk hazards that won't require the Safety Officer's observation.	This requirement promotes human safety by dolling safety responsibility to the team leaders who can better monitor the activities of their sub-teams.	Inspection Every low risk hazard is approved by the Safety Officer and shown in the respective risk assessment table.	Complete This requirement was verified November 4th. See Safety Manual.
Safety.1.4.1 Manufacturing	Variable Drag System team members shall have proper training on equipment and tooling that is specific to their sub-team before construction can take place.	This requirement ensures that every member of the VDS team knows which equipment or tool to use during manufacturing to save time and make the best product possible.	Inspection The VDS lead demonstrates the use of all major equipment and oversees their first uses of said equipment.	Complete This requirement has been verified November 4th. See PPE tables.

Safety.1.4.2 Testing	All VDS team tests shall be monitored by an experienced member and notify the Safety Officer if additional supervision is needed.	This requirement protects the overall health of the VDS team and adds one more safety redundancy.	Demonstration The VDS lead appoints the experienced members and has verified that the experienced members are qualified for all tests by witnessing visually.	Incomplete This requirement will be verified January 13th. See VDS tests for validation.
Safety.1.5 Launch Day	The Safety Officer shall ensure all members are present for the safety briefing before every launch and follow the proper launch site rules set for any particular field.	This requirement protects each River City Rocketry member by ensuring they know the rules and procedure for every launch site that the team attends.	Inspection The Launch Procedures shall be fully completed and verified of completion from the Safety Officer and both captains.	Incomplete This requirement will be verified February 11th. See Launch Procedures for validation.
Environmental Safety				
Safety.2 Environmental Safety	The Safety Officer shall ensure that all environmental concerns are mitigated.	This requirement helps reduce River City Rocketry's effect on the atmosphere by briefing the team on the characteristics of the environment at any launch site that the team attends.	Inspection A safety briefing must be performed before every event that involves the environment.	Complete This requirement was verified this past October with risk assessment tables. See Launch Concerns for validation.
Safety.2.1 Team Affecting the Environment	The Safety Officer shall ensure each sub-team is aware of their effect on the environment and mitigate hazards throughout the season.	By making sure each team member is aware of their impact on the environment, the team's overall effect on the environment will be mitigated by the end of the season.	Inspection The Safety Officer will perform monthly check-ins with each sub-team lead to ensure environmental hazards are mitigated throughout the season.	Incomplete The risk assessment tables will be updated until last full-scale launch March 25th. See Launch Concerns for validation.
Safety.2.1.1 Chemical and Material Disposal	The team shall dispose of batteries and other chemicals in accordance with appropriate MSDS sheets.	This requirement makes the team aware of the hazards associated with chemical and material disposal.	Inspection Every team member must read and sign the safety manual to ensure an understanding of all MSDS sheets.	Complete This requirement was verified November 4th. See Safety Manual.
Safety.2.1.2 Motor Handling	The team shall store and handle all rocket motors while being monitored by the safety officer and vehicle lead.	This requirement ensures that proper attention is applied to highly flammable materials.	Inspection The team will buy all motors from a commercially certified manufacturer such as Aerotech, Cesaroni, and Loki.	Complete This requirement was verified this past October. See Safety Manual.
Safety.2.1.3 Handling of Reactive Chemicals	The team shall separate all potential reactive chemicals to prevent exposure to the environment.	This requirement ensures that the team is aware of the potential hazards involved in handling reactive chemicals.	Inspection Signing of the safety manual by all team members ensure proper knowledge of reactive chemicals across the entire team.	Complete This requirement was verified this past October. See Safety Manual.
Safety.2.1.4 Handling of Fiberglass	The team shall use a vacuum when possible when cutting fiberglass to control the amount of styrene into the atmosphere.	This requirement makes sure the team is conscious of how much our team is affecting the environment.	Inspection All sub-team leads and the safety officer ensure all team members are aware of cleaning after themselves during manufacturing. This is vocalized during general team meetings.	Complete This requirement was verified this past October with risk assessment tables. See Launch Concerns for verification.

Safety.2.1.5 Spray Painting	Team members shall be given approval from the safety officer before spray painting any part of the launch vehicle.	This requirement controls how much Chlorofluorocarbons (CFCs) are released into the atmosphere.	Inspection All spray painting must be performed in a designated location such as a spray paint booth, if possible, or location outside that is specified by the safety officer.	Complete This requirement was verified September 10th. See Launch Concerns.
Safety.2.1.6 Waste management	All team members shall properly dispose of waste materials both on and off the launch field.	This requirement ensures the team is respectful towards the land owner in picking up after ourselves as well as properly disposing of our waste to protect the environment and health of all team members.	Inspection Proper waster receptacles will be available at launch fields and work shop to ensure proper disposal.	Complete This requirement was fulfilled this past August. See Launch Concerns.
Safety.2.1.7 CO2 Emissions	The team shall monitor how much CO2 emissions are emitted during transportation to and from launch sites.	The team shall drive more efficiently and obtain vehicles with higher MPG statistics which will help eliminate the teams overall CO2 emissions into the atmosphere.	Inspection The leads will ensure that drivers are obeying the United States Department of Transportation laws as well as obtaining a reasonable miles per gallon mark.	Complete This requirement was fulfilled this past June. Launch Concerns for verification
Safety.2.2 Environmental Concerns	The Safety Officer shall make sure weather conditions are suitable for flight and meet NAR High Power Rocket Safety Code 9.	This requirement ensures that the team abides by the NAR High Power Safety Code 9 so that River City Rocketry can protect themselves from the environment.	Inspection Check the local weather for the appropriate launch site every day up to a week before launch day to ensure weather is fit for flight.	Complete This requirement was verified by August. The team read and understood NAR Safety Code. See Safety Code here.
Safety.2.2.2 Launch Field Obstacles	The team shall angle the launch tower appropriately if ponds, creeks, and other bodies of water are present at the launch site to avoid the vehicle being submerged into water. This requirement also covers swampy ground and other obstructions that might be present at a desired launch site.	This requirement is necessary for the team to perform especially at our own field location where the Safety Officer is the RSO. This ensures that the launch vehicle has the best chance of a successful flight.	Demonstration A survey of the location of all bodies of water and any other obstacles will be taken into account during the location and angle of the launch tower before a launch is green lit.	Complete This requirement was verified by November 4th. See Launch Procedures.
Safety.2.2.3 Cold Temperatures	During cold temperatures the team shall check the charge of batteries prior to launch to ensure there is enough charge to power the flight.	This requirement ensures that the team will have functional batteries for every major component in the launch vehicle before a launch is green lit.	Inspection All respective team leads shall ensure that they have proper charge in their batteries and store them appropriately before a launch is commenced in cold temperatures.	Complete This requirement was verified by November 4th. See Launch Concerns.
Safety.2.2.4 Humidity	The team shall contain both motors and black powder charges to ensure they don't become moist and don't ignite.	This requirement will ensure that the team has a successful ignition and proper separation due to black powder charges.	Inspection The team will store motors and black powder charges free from moisture exposure.	Complete This requirement was verified by November 4th. See Launch Concerns.

Safety.2.2.5 Sun Exposure	The team shall prevent the vehicle from long periods of exposure to sunlight.	This requirement keeps the launch vehicle electronics from overheating.	Inspection Shelter will be constructed at every launch site to cover the vehicle during pre-launch procedures.	Complete This requirement was verified by November 4th. See Launch Concerns.
Asset Safety				
Asset Safety.1	The Safety Officer shall ensure all hardware and equipment are maintained with an acceptable level of risk.	This requirement ensures that the team is using the safest hardware and equipment for the 2016-2017 season.	Inspection Each lead will check their hardware that will be going on their sub-system accordingly to ensure hardware meets the manufacturer criteria.	Incomplete This requirement will be verified by the FRR on March 6th.
Safety.3.1 3D Printed Component Check	All 3D printed components shall be inspected before use to verify the structural integrity of the components.	This requirement ensures each component can be cleared for testing and eventually full-scale tests.	Inspection 3D printed component shall be inspected by the lead who own the component to verify no cracks exist between layers.	Incomplete This requirement will be verified by January 25th. See the Payload design for the verification of this inspection.
Safety.3.2 Multirotor Propeller Check	All Multirotor propellers shall be inspected before use to verify their integrity.	This requirement makes sure the team inspects every propeller for cracks and its overall structural integrity before a flight is administrated.	Inspection The Payload lead will inspect all blades for cracks before use.	Complete This requirement was verified when the blades were delivered from the manufacturer DGI on October 26th.
Safety.3.3 Battery Charge Check	All associated leads shall ensure the proper batteries are fully charged before leaving for the launch site.	This requirement ensures that the team will have a complete functional system before a launch is green lit.	Inspection The launch procedures check list will include a battery charge check for all items that need to be powered.	Complete This requirement was verified October 30th. See Launch Procedures for validation.
Safety.3.4 Equipment Storage	All equipment shall be stored in designated storage units within the teams work space while not in use.	This requirement allows the team to maintain a clean workspace and ensure equipment does not get lost or damaged throughout the course of the season.	Inspection The Safety Officer will do routine checks every week to verify all equipment in storage is kept organized and in a safe location.	Complete This requirement was verified November 4th. See Safety Manual.
Safety.3.5 Tool Safety	Before a tool is used, the member operating the tool must prove thorough understanding of the safety manual created by the team and the PPE procedures.	This requirement prevents injuries that members might inflict on themselves.	Inspection The Safety Officer must verify that the team member has proven their understanding of how to operate the tool, signed the safety manual and read PPE procedures before using the tool.	Complete This requirement was verified November 4th. See Safety Manual.
Safety.3.6 ARRD Cleaning	All ARRD devices shall be inspected and cleaned post flight.	This requirement ensures that the ARRD functions properly for every single use.	Inspection All ARRDs will be visually inspected for black powder charge residue before loading for additional charge for a subsequent flight.	Complete This requirement was verified December 3rd. See Recovery section Launch Procedures.
Safety.3.7 Rigging Check	The recovery lead shall conduct post-flight rigging checks to verify all lines and stitching are intact and ready to fly for subsequent tests.	The team derived this requirement to make sure all harnesses, lines, stitching, and other recovery components are intact post-flight so subsequent tests can take place.	Inspection Recovery lead or appointed sub team member shall mark all inspected and repaired recovery gear with a	Complete This requirement was verified December 3rd. See Recovery section Launch Procedures.

			Ready To Fly (RTF) tag after inspection and/or repair.	
Safety.3.8 Recovery Insulation	Recovery insulation (dog barf) shall be installed for protection of recovery gear for flight.	This requirement ensures that all recovery gear comes back with minimal burn holes.	Inspection The Safety Officer shall conduct visual pre-flight inspection of sufficient dog barf packing.	Complete This requirement was verified December 3rd. See Recovery section Launch Procedures.
Safety.3.9 ARRD Prep	Recovery lead shall load black powder into and prepare ARRD for flight before departure for flight.	This requirement expedites the launch vehicle prep process and makes sure the team launches in an appropriate amount of time at any given launch site.	Inspection Prepared ARRD's shall be marked with RTF sticker after loading and preparation.	Complete This requirement was verified December 3rd. See Recovery section Launch Procedures.
Safety.3.10 Redundant Stratos	Recovery lead and safety officer shall ensure that two redundant black powder charges are on board and functional for each flight.	The team ensures that each separation has redundant altimeters to increase the chance of parachute deployment during the recovery process.	Inspection Launch vehicle shall be visually inspected for proper installation of two redundant stratos. Auditory confirmation for proper beep sequence will be conducted when vehicle is loaded onto launch rail.	Complete This requirement was verified December 3rd. See Recovery section Launch Procedures.
Safety.3.11 Separation Test	Separation testing of every component of the launch vehicle shall be performed before every launch to ensure all separating sections of the vehicle properly eject from the rest of the 1.	A black powder ejection charge test shall be performed before every launch to ensure proper separation during flight. This requirement mitigates the risk of a non-separation during the recovery process.	Test Black powder charges will be created and utilized to eject all separating sections of the launch vehicle on the ground before every launch.	Complete This requirement was verified December 3rd. See Vehicle Checklist in launch procedures.
Safety.3.12 Continuity Check	All terminal blocks and all other major electrical connections shall be inspected to ensure continuity before every flight.	This requirement makes sure the team has an electronic system that is completely functioning on the launch vehicle before a launch is green lit.	Inspection Each respective lead will check each terminal block or major electrical connection on their sub-system with a multimeter to ensure continuity.	Complete This requirement was verified December 3rd. See Vehicle Checklist in launch procedures.
Safety.3.13 Epoxy Joint Check	Every Joint on the vehicle that uses epoxy for construction shall be inspected for cracks and applied properly where a construction fillet is made that adheres to both faces of fillet.	This requirement ensures that proper inspections are performed on all epoxy joints and the structural integrity of the launch vehicle is not compromised during the manufacturing process.	Inspection The Safety Officer and the respective lead for that sub-system of the vehicle will visual check and approve each epoxy joint.	Complete This requirement was verified December 3rd. See Vehicle Checklist in launch procedures.
Safety.3.14 Rail Button Alignment	The rail buttons shall be placed so that access to the electronics control panel is not obstructed by the launch rail.	This requirement ensures the launch vehicle the maximum amount of off the rail velocity as well as to fly as straight as possible coming off the rail.	Inspection The Safety Officer and vehicle lead will oversee the placement of the rail buttons to ensure correct placement of the rail buttons.	Incomplete This requirement was verified December 3rd for sub-scale and will be verified February 11th for full-scale. See Vehicle Checklist in launch procedures.

Safety.3.15 Main Parachute Protection	Main parachutes shall be stowed for flight in a deployment bag.	This requirement ensures the main parachute is stowed within a deployment bag to protect the parachutes from burn holes due to the black powder charges.	Inspection Visual confirmation of deployment bag packing will be conducted by the Safety Officer and recovery lead.	Complete This requirement was verified December 3rd. See Launch Procedures.
Safety.3.16 Proper Fastening	All structural loaded components mounted inside the launch vehicle via threaded rod will be secured using nuts with proper thread engagement with the addition of Loctite.	This requirement ensures that each nut is fastened correctly on the launch vehicle and has Loctite applied to prevent loss of engagement throughout flight.	Inspection The Safety Officer and each sub-team lead will visually verify that all fasteners are properly secured for their respective team.	Complete This requirement was verified December 3rd. See Launch Procedures.
Safety.3.17 Carbon Fiber Airframe Construction	Carbon fiber inspections of the airframe shall be performed to ensure proper finishing and structural integrity before used for full-scale 1.	The team shall inspect all carbon fiber airframe to make sure it can withhold black powder charge testing, and be cleared for full-scale flight tests.	Inspection The Safety Officer and the respective sub-team lead must inspect every carbon fiber airframe tube before cleared for flight.	Incomplete This requirement will be verified February 11th after the validation of the first full-scale flight tests.
Safety.3.18 VDS Circuit Protection	The VDS electronics shall be protected by an appropriately sized fuse(s).	This requirement ensures that the VDS electronics are protected from surges and shorts that may occur during testing.	Analysis The design will be shown to include fuses to protect against surges and shorts that may occur during testing.	Complete This requirement was verified November 4th. See the VDS section for validation of this requirement.
Safety.3.19 Electrostatic Discharge (ESD) Safety at Launch	Team members handling electronics shall be properly grounded.	This requirement ensures that team members do not induce electrostatic discharge to the electronics by properly grounding themselves before work can begin.	Inspection The launch procedures checklist has been updated to include notes on proper grounding while at launch sites.	Complete This requirement was verified November 4th. See Safety Manual.
Safety.3.20 ESD Safe Storage	While not in use, the VDS electronics shall be stored in ESD-safe bags.	This requirement ensures that no external sources induce electrostatic discharge while they are stored throughout the season.	Inspection The launch operations procedure will be updated to include proper storage after use.	Complete This requirement was verified early October. See Safety Manual.

Table 96: Team-derived safety requirements.

7.3 Budget

7.3.1 Comprehensive Budget

A critical aspect of the success of any projects is a comprehensive budget. This is budget is a formulated item which gets broken down into categories to closely monitor funds and show where those funds are being allocated. Figure 146 showcases the breakdown of how River City Rocketry is distributing their funds for the 2016-2017 competition season to date.

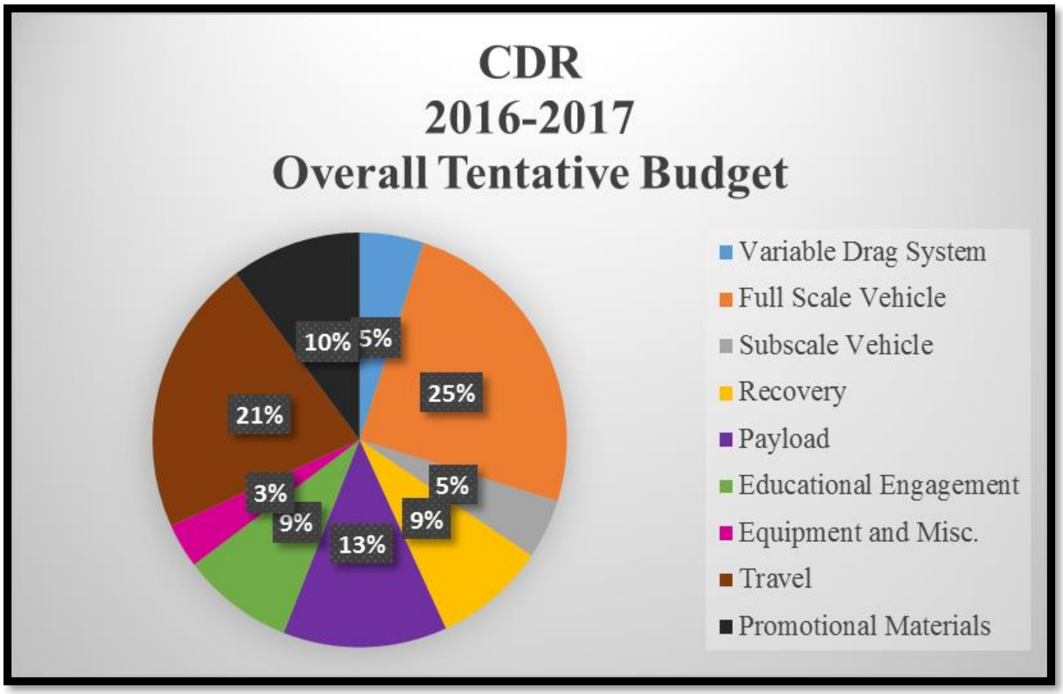


Figure 146: Overall tentative budget.

Throughout the course of the season the budget will be constantly monitored to account for fluctuation in as the design changes. By having a close eye on the budget, it ensures that the leadership understand where the team is financially while setting constraints on designs based off cost. Understanding the budget also allows for more informed requests for sponsorship and gives leadership goals to set when raising funds.

The detailed breakdown of each subsystem provides an accurate description of how funds are being spent and allows for corporations to support by knowing exactly where there money is going. By specifying materials, companies aren't restricted to cash donations and can make material donations which have assisted the team in the past. Each subsystem that is showcased in Figure 146 has a detailed budget shown below.

Variable Drag System Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
1/4" Thick 12" x 48" Delrin	1	$85.22	$85.22
1/8" Dowel Pins 3/4" Length (pkg of 25)	2	$10.63	$21.26
M3-16 mm Socket Head Cap Screws (pkg of 50)	1	$10.20	$10.20
AndyMark DC Motor	4	$28.00	$112.00
Adafruit 9-dof absolute orientation IMU Fusion Breakout BNo055	2	$34.95	$69.90
Raspberry Pi 3 - Model B - ARMv8 with 1G RAM	2	$39.95	$79.90
SD/microSD 8Gb	2	$9.95	$19.90
Short Feather Male Headers - 12-pin and 16-pin Male Header Set	20	$0.50	$10.00
gps	1	$39.95	$39.95
banana to alligator clip cables	1	$3.95	$3.95
banana to IC hook cables	1	$4.95	$4.95
HP Pavilion 21.5-inch LED HDMI VGA Monitor (used) (black)	2	$88.49	$176.98
Neiko® 01924A Self-Adjusting 3-in-1 Automatic Wire Stripper, Cutter and Crimping Tool	1	$14.99	$14.99
PanaVise 381 Vacuum Base PanaVise	1	$66.99	$66.99
Omron SS-5GL Limit Switch	2	$1.80	$3.60
Hall effect encoder cable	1	$5.00	$5.00
DC/DC converter breakout	1	$29.95	$29.95
10-Pin Connector w/ Header, 0.1" Spacing	2	$2.90	$5.80
Bannana Plug to T-Connector	2	$5.99	$11.98
Encoder Cable	2	$1.11	$2.22
Male D-Sub Connector	2	$0.81	$1.62
Female D-Sub Connector	2	$0.87	$1.74
Power Switch	2	$2.11	$4.22
4A Fuse	2	$0.75	$1.50
5A Fuse	2	$0.72	$1.44
3A Fuse	2	$0.75	$1.50
Limit Switch	2	$1.11	$2.22
MegaMotor	1	$49.99	$49.99
Break Aqay Headers - 40-pin Male (Long Centered, PTH, 0.1")	2	$0.75	$1.50
Teensy Header Kit	2	$1.50	$3.00
10 Pin Header	6	$0.50	$3.00
Heat Shrink	1	$8.95	$8.95
Banana Plug Post (Black)	2	$0.35	$0.70
Banana Plug Post (Red)	2	$0.35	$0.70
BMP180	3	$9.95	$29.85
7.4V Lipo Battery	1	$5.20	$5.20
11.1V Lipo Battery	1	$26.90	$26.90
12" x 24" 6061 Aluminum plate .125 thick	1	$48.55	$48.55
Delrin Acetal Resin 1/8" thick 12" x 24"	1	$104.93	$104.93
Limit Switches	4	$1.80	$7.20
		Overall Total	**$1,079.45**

Full Scale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
6K Carbon Ribbon Toe, 4.65lbs	2	$279.00	$558.00
Fiberglass Toe, 15lbs	1	$245.00	$245.00
6" Plywood Bulkplate - 1/2" Thick (Coupler)	5	$5.90	$29.50
6" Plywood Bulkplate - 1/2" Thick (Airframe)	5	$5.90	$29.50
1/4"-20 x 4' Threaded Rod (Aluminum)	3	$4.46	$13.38
1/4"-20 Hex Nuts (Aluminum) (pkg of 100)	3	$6.74	$20.22
4-40 Black Nylon Shear Pins (pkg of 100)	2	$5.42	$10.84
3/8"-16 for 2.5" OD Black-Oxide (18-8 SS) (pkg of 25)	5	$1.55	$7.75
1/4" Flat Washer (Alumium) (pkg of 100)	1	$6.64	$6.64
3/8" Flat Washer Black-Oxide (18-8 SS) (pkg of 100)	1	$8.49	$8.49
6" x 12" Carbon Fiber Coupler	5	$110.00	$550.00
Professional Paint Job for Competition	1	$250.00	$250.00
3 pack of Large Motor Igniters	1	$7.50	$7.50
Cesaroni I150 Blue Streak	4	$49.99	$199.96
Phenlolic Airframe	2	$18.99	$37.98
LOC motor mount	1	$8.03	$8.03
54mm retainer body	2	$16.99	$33.98
Rail Buttons	3	$10.00	$30.00
2.1 Coupler	1	$14.99	$14.99
2.1 Airframe	1	$14.99	$14.99
2 quart rocket poxy	1	$65.00	$65.00
Ejection lighters	2	$15.79	$31.58
Terminal Blocks	3	$4.99	$14.97
3" Sub scale Nose Cone	1	$20.74	$20.74
E-Matches	3	$15.79	$47.37
AeroTech 2200G Propellant	6	$249.99	$1,499.94
AeroTech L2200G Hardware	1	$550.00	$550.00
3 in Coupler	1	$31.95	$31.95
3 in Airframe	1	$29.95	$29.95
Stratologger CF	6	$49.46	$296.76
Featherweight Screw Switch	6	$5.00	$30.00
Carbon Fiber Sheet 24" x 48"	1	$430.00	$430.00
Cat5E Cable 100 ft	1	$18.35	$18.35
12" x 24" 6061 Aluminum plate .25" thick	1	$45.56	$45.56
Nylon Shear Pins 3/8" length 4-40 (100pkg)	3	$5.75	$17.25
10-32 All Thread (6ft)	2	$7.32	$14.64
10-32 Hex Nuts (100 pkg)	3	$3.98	$11.94
Derakane 8084/8090 quart + 2oz hardener	2	$34.19	$68.38
		Overall Cost	**$5,301.13**

Subscale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Fiberglass Tow, 15lbs	1	$245.00	$245.00
3" Phenolic Airframe Tube	1	$29.95	$29.95
3" Phenolic Coupler Tube	1	$31.95	$31.95
3" Sub-Scale Nose Cone	1	$20.74	$20.74
1/8" Thick 24" x 36" Fiberglass	3	$35.78	$107.34
3" Plywood Bulkplate - 3/16" Thick (Coupler)	5	$1.64	$8.20
3" Plywood Bulkplate - 3/16" Thick (Airframe)	5	$1.66	$8.30
2" Plywood Centering Rings - 3/16" Thick	4	$1.62	$6.48
1/4"-20 x 4' Threaded Rod (Aluminum)	2	$4.46	$8.92
1/4"-20 Hex Nuts Black-Oxide (pkg of 50)	2	$4.53	$9.06
1/4"-20 for 1.5" ID Black -Oxide U-Bolt (Steel)	5	$1.14	$5.70
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
1/4"-20 Flat Washer (Aluminum) (pkg of 100)	1	$6.64	$6.64
PerfectFlight Stratologger	4	$54.95	$219.80
Electric Matches	15	$1.25	$18.75
4FA Powder (1lb)	1	$29.94	$29.94
9V Duracell Batteries (x4)	3	$12.73	$38.19
Cesaroni I150 Blue Streak Motor	4	$49.99	$199.96
		Overall Cost	**$1,000.34**

Recovery Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
18" X 18" FCP Nomac	4	$10.95	$43.80
1/4"-20 Eyebolts	2	$9.71	$19.42
1/4"-20 U-Bolt	1	$0.75	$0.75
5/16"-18 U-Bolt	1	$1.04	$1.04
Flame Resistant Fabric 54"	3	$10.99	$32.97
1/4" Quick Links	3	$3.10	$9.30
9/32" Quick links	5	$3.10	$15.50
Electric Matches	50	$1.25	$62.50
11/16" Vials (pkg of 36)	1	$14.47	$14.47
4FA Black Powder (1lb)	1	$24.20	$24.20
9V Duracell Batteries (x4)	3	$12.73	$38.19
Garmin Astro GPS Unit	2	$189.99	$379.98
Nylon Thread	2	$20.99	$41.98
Ripstop Nylon 1.10oz (black)	25	$10.80	$270.00
Ripstop Nylon 1.10oz (Red)	25	$10.80	$270.00
3/8 inch Shock Cord	18	$0.30	$5.40
1.8mm 400 lb utility cord	1	$34.99	$34.99
Double sided sticky tape	5	$11.06	$55.30
Sewing Needles	2	$4.48	$8.96
ARRD	3	$119.00	$357.00
Triangle-Shaped Threadd Connecting Link	2	$6.84	$13.68
9/32" Thick Oval Shaped Threaded Connecting Link	4	$1.21	$4.84
Tender Descender Level 2	2	$85.00	$170.00
		Overall Cost	**$1,874.27**

Payload Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
DJI E800 Propulsion System	1	$469.00	$469.00
Extra E800 3510 Motors	4	$39.00	$156.00
Tattu 8000mAh 22.2V Lipo Battery Pack	2	$141.98	$283.96
Rasberry pi	2	$35.00	$70.00
Rasberry pi cam	1	$20.00	$20.00
6061-T6 Aluminum 1 -1/2" x 2' x 2'	1	$650.00	$650.00
Holybro PX4 2.4.5 "PixhHawk" Flight Controller Set	1	$204.00	$204.00
GPS sensor module	0	$100.00	$0.00
fastening hardware	1	$50.00	$50.00
Torsion spring	8	$2.00	$16.00
Helical compression spring	4	$2.00	$8.00
6" Phenalic Coupler Tube	1	$14.99	$14.99
6" Phenalic Airframe Tube	1	$41.99	$41.99
Carbon Fiber .5" tube 45551-HM	2	$83.99	$167.98
8691A21 Spring plunger	2	$17.75	$35.50
1/4-20 aluminum allthread	1	$8.91	$8.91
1/4-20 aluminum threaded nuts	1	$7.20	$7.20
Aluminum shcs 8-32	5	$14.87	$74.35
9271K606 torsoin spring	1	$5.01	$5.01
9271K48 torsion spring	1	$7.62	$7.62
86985K68 2ft aluminum rod 1/4" dia stock	1	$6.00	$6.00
TEENSY 3.2 + HEADER	2	$19.95	$39.90
BMP180	2	$9.95	$19.90
FrSky X8R 2.4G 16CH SBUS Smart Port Telemetry Receiver	1	$32.98	$32.98
DJI CP.BX.000062 Rotor Adapters for 1345s Quick-Release Props (Pair)	1	$3.99	$3.99
Raspberry PI 5MP Camera Board Module	1	$19.95	$19.95
Lipo Battery Indicator	2	$2.97	$5.94
BMP 180 Sensor	3	$2.67	$8.01
1/4"-20 thread, 3/4" ID, 1-1/4" Height	1	$0.72	$0.72
DJI 1345 Propellers	3	$5.98	$17.94
TP-Link N300 Wireless Wi-Fi Router	1	$21.99	$21.99
Spring pin Housing (without thread locker)	7	$17.75	$124.25
ABS Rod Black	1	$3.70	$3.70
Snap Rings	1	$7.82	$7.82
Velcro	1	$14.45	$14.45
1.25" square x 16" long 6061-T6 Aluminum	1	$30.00	$30.00
9 Volt Battery Clip	6	$0.89	$5.34
Featherweight Screw Switch	6	$5.00	$30.00
OrangeRx R615X DSM2/DSMX Compatible 6Ch 2.4GHz Receiver w/CPPM	1	$21.98	$21.98
Raspberry Pi 3 Model B Motherboard	1	$36.90	$36.90
SanDisk 8GB	1	$5.89	$5.89
		Overall Cost	**$2,748.16**

Educational Engagement Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Orbit 1" 24V Electronic Valve	3	$12.97	$38.91
7/8" Tire Valve (pkg of 2)	2	$2.09	$4.18
1 NPT Pipe Size Threading Bushing (Brass)	3	$7.70	$23.10
2-1/2" Tube ID x 1/2 Male Pipe Size Barbed Fitting (Brass)	3	$4.66	$13.98
2-1/2" Male x 1 NPT Female Bushing (PVC)	3	$2.80	$8.40
7/32" to 5/8" Hose Clamp (pkg of 10)	1	$5.87	$5.87
1/4" Wide x 14 Yards Teflon Tape	1	$5.19	$5.19
2 Pipe Size x 4' Length (PVC)	1	$36.94	$36.94
2 Pipe Size Cap (PVC)	3	$0.94	$2.82
Plastic Pipe Cement	1	$12.94	$12.94
3/4 Male Adapter to Female Slip (PVC)	6	$0.30	$1.80
3/4 Pipe End male x 1/2 Female Bushing (PVC) 3	3	$0.36	$1.08
3/4 Pipe Size x 5' Length (PVC)	1	$3.25	$3.25
1/2 Pipe Size x 4' Length (PVC)	1	$9.08	$9.08
2 Pipe End Male x 3/4 Female Slip Bushing (PVC)	3	$1.57	$4.71
6mm, SPDT-NO Push Button Switch	3	$6.18	$18.54
15" Length Red Nylon Cable Tie (pkg of 25)	1	$6.12	$6.12
9V Battery (pkg of 12)	1	$14.36	$14.36
9V Battery Snap, I-Style	6	$0.68	$4.08
24 GA 25' Stranded Wire (Black)	1	$3.18	$3.18
24 GA 25' Stranded Wire (Red)	1	$3.18	$3.18
Starhwak Model Rocket Kit (pkg of 25)	2	$149.67	$299.34
Estes Tandem Model Rocket Launch set	2	$26.18	$52.36
1/2A3-4T Engine Bulk Pack (pkg of 24)	0	$57.79	$0.00
Scotch Tape (pkg of 3)	40	$4.74	$189.60
BristleBot Kit	50	$19.99	$999.50
Estes B6-4 Engines Bulk Pack	1	$56.93	$56.93
Estes AB-3 Engines Bulk Pack	1	$57.59	$57.59
		Overall Cost	**$1,877.03**

Travel Expenses Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Hotel (Competition in Huntsville, AL) [unit is per week, quantity per room]	6	$499.80	$2,998.80
Hotel (Testing in Manchester, Tennessee, Music City Missiles Club) [unit is for max 2 days]	3	$186.00	$558.00
Gas per gallon (Competition in Huntsville, AL)	200	$2.39	$478.00
Gas per gallon (For all out of town testing)	250	$2.39	$597.50
		Overall Cost	**$4,632.30**

Equipment and Misc.			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Launch Equipment Set	1	$351.00	$351.00
Breather Cloth - 30" 1 yard	20	$2.00	$40.00
White Peel Ply 30" - 1 yard	20	$8.00	$160.00
Nylon Vaccum bag film 60" - 1 yard	20	$3.50	$70.00
Dremel Cutting Wheels	2	$22.75	$45.50
X winder PVC Rollers	1	$19.95	$19.95
Nylon Bag Tubing - 18"	25	$1.50	$37.50
Quick Lock Seals	1	$18.00	$18.00
		Overall Cost	**$741.95**

Promotional Materials Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Shirts	20	$20.00	$400.00
Polos	40	$40.00	$1,600.00
Stickers	750	$0.25	$187.50
		Overall Cost	**$2,187.50**

Overall Tentative Budget	
Budget	**Total Cost**
Variable Drag System	$1,079.45
Full-Scale Vehicle	$5,301.13
Sub-Sscale Vehicle	$1,000.34
Recovery	$1,874.27
Payload	$2,748.16
Educational Engagement	$1,877.03
Equipment and Misc.	$741.95
Travel	$4,632.30
Promotional Materials	$2,187.50
Overall Cost	**$21,442.13**

Throughout the season the team is aware that the budget is subject to fluctuation. With constant monitoring of the teams funds we can track that fluctuation and predict the cost of the each sub-system by the end of the season. As seen in Figure 147 the team can ensure that there is enough funds to support the remainder of the season.

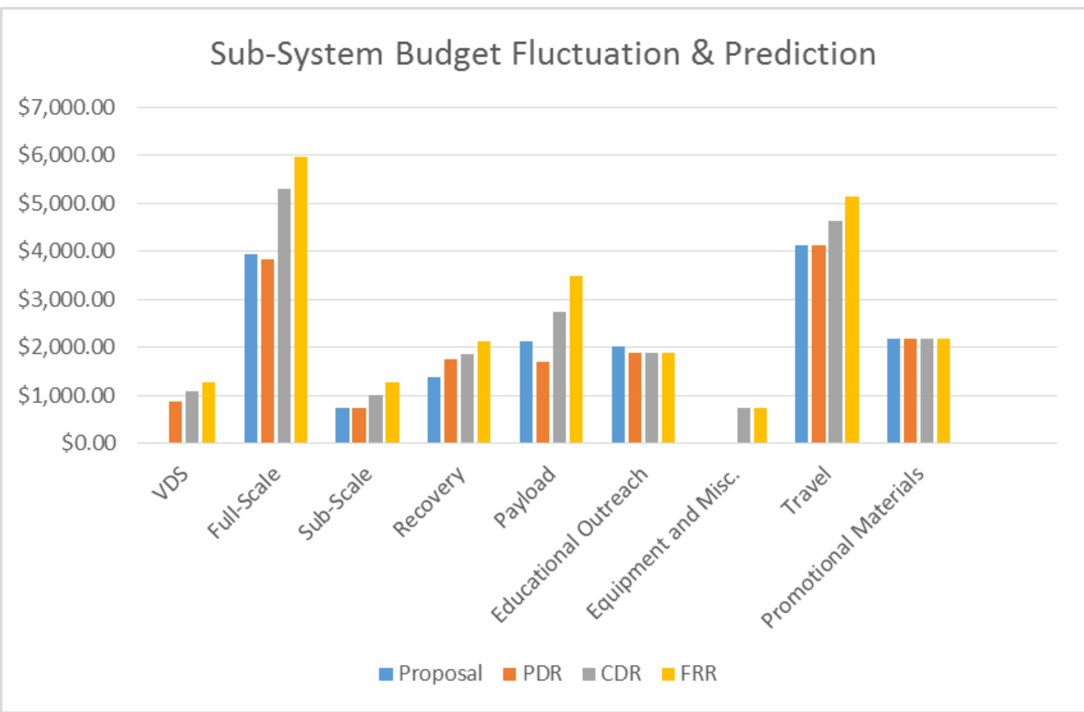


Figure 147: Sub-system fluctuation & prediction of the 2016-2017 budget.

Any sub-system that has less than three (3) bars has been incorporated into the budget scheme for better allocation of funds. With this method the team can predict the overall cost of the season as illustrated below in Figure 148.

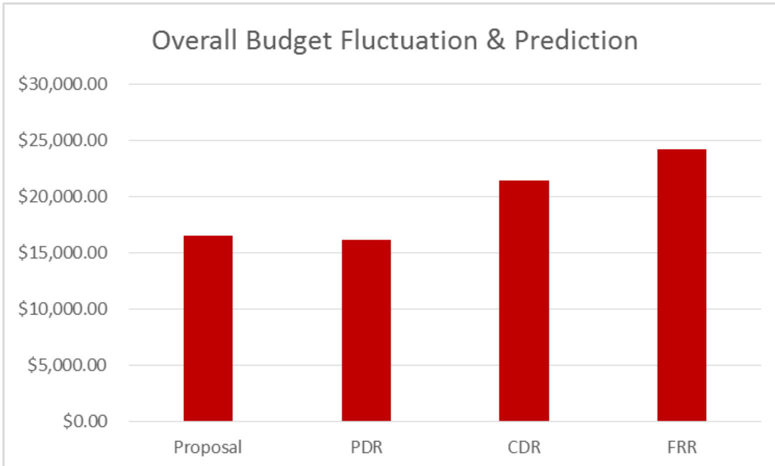


Figure 148: Overall budget fluctuation & prediction of the 2016-2017 season.

7.3.2 Funding

The team utilizes the innovation and success of River City Rocketry to propose funding to multiple commercial companies and grants throughout the year. Each year the team puts effort to reach a remainder balance of $10,000 for next year's team, the breakdown of how the team will sustain its budget is outlined below in Table 74.

Sustainable Budget					
Inflow					
Donor	**Description of Donation**	**Date Submitted**	**Date Received**	**Amount Requested**	**Accepted**
2015-2016 RCR Remaining Balance	Remaining balance of the teams expenditures from the 2015-2016 NASA Student Launch Competition	N/A	N/A	$23,799.00	Y
J.B. Speed School	The University of Louisville J.B. Speed School donates based off presentation of materials and amount requested/needed by the organization.	Thursday, September 22, 2016	Friday, October 28, 2016	$5,000.00	Y
Raytheon Missle Systems	Assistance in outreach event MathMovesU.	Thursday, October 13, 2016	Thursday, October 27, 2016	$1,000.00	Y
SpaceX	Grant for university teams not only NASA Student Launch but a multitude of competitions. They have no specific ceiling on the amount to request.	Tuesday, November 1, 2016	TBD	$10,000.00	TBD
U of L, Department of Mechanical Engineering	The Department of Mechanical Engineering donated to the team for continued success in the NASA SL competition and persevering of River City Rocketry	Saturday, November 12, 2016	Monday, December 5, 2016	$2,000.00	Y
Dr. Kelly Donation	An alumni of the University of Louisville who has worked in the aerospace industry and expressed continuous interest in the teams aggressive and innovative designs.	Thursday, December 8, 2016	TBD	$10,000.00	Y
			Overall Income	**$41,799.00**	
Outflow					
			Expected Team Expenses	**$21,442.13**	
			End of the Season Expected Total	**$20,356.87**	

Table 97: 2016-2017 River City Rocketry sustainable budget.

By striving to reach and go beyond our $10,000 goal, the team is able to perform research on potential payloads for the following season, make equipment improvements, as well as facilitate manufacturing, design, and overall cost of next season if no sponsorships were obtained the following year.

7.4 Timeline

7.4.1 RCR Overview Schedule

The master schedule for the RCR 2016-2017 season can be seen below in Figure 149.

When developing the schedule the team is constantly monitoring the status of a task based on its critical path criteria. If a task is deemed critical then the end product date of that timeline is subject to change if a delay were to occur. If a task is deemed non-critical than a specific amount of time is assigned for an individual task to be on delay before that task becomes critical.

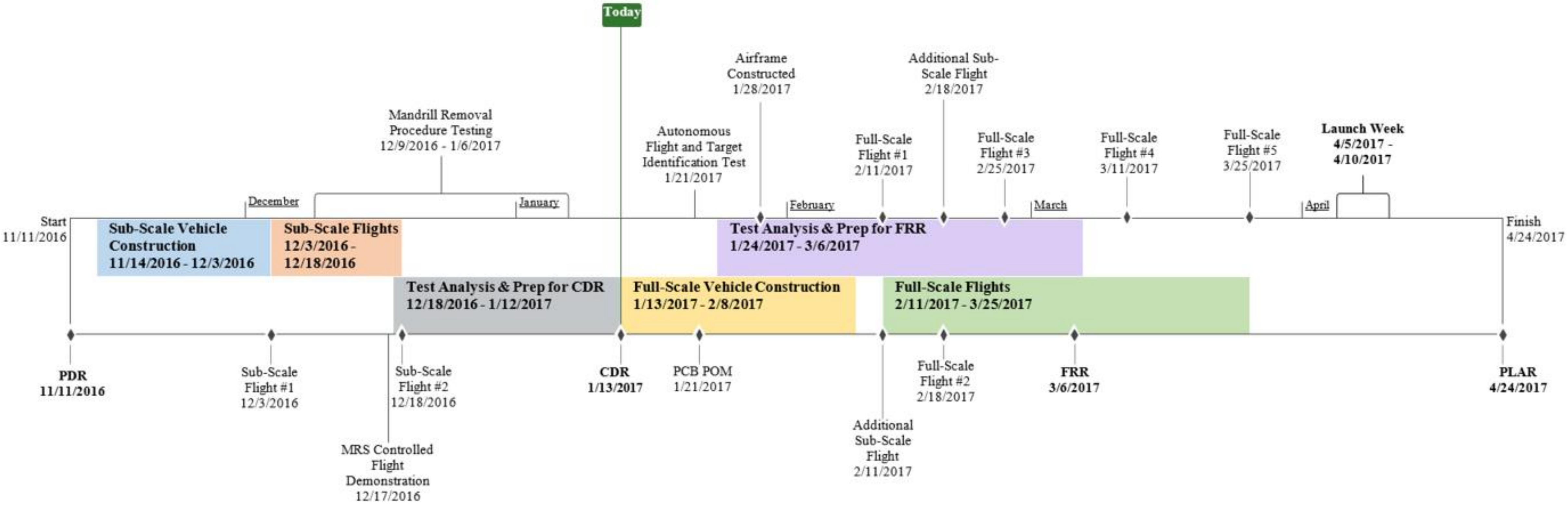


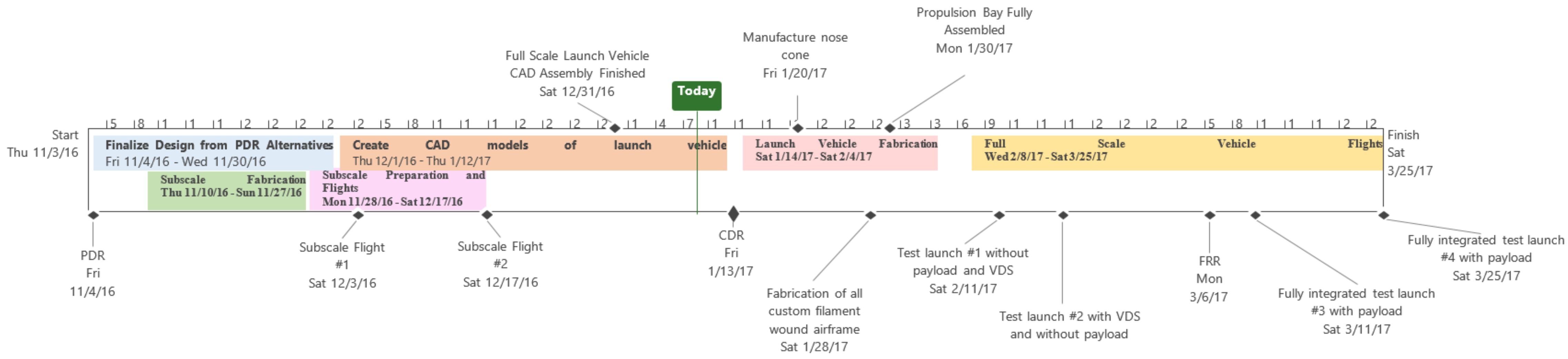
Figure 149: River City Rocketry overview timeline.

Major Tasks				
Date	**Title**	**Description**	**Critical Path (Y/N)**	**Consequence of Delay**
11/14/2016 to 12/03/2016	Sub-Scale Vehicle Construction	This task represents the deadline the team has made for the sub-scale vehicle construction where a ½ scale of the teams launch vehicle has been manufactured. The design can be seen in the Vehicle section.	Y	If this deadline was delayed, the team would have only one opportunity to launch the sub-scale vehicle before CDR, giving the team a greater chance for failure.
12/03/2016 to 12/18/2016	Sub-Scale Flights	This task represents the overall time allotted for sub-scale flight tests. Over the course of ten (10) days the team was able to have two launches, perform analysis, and validate the stability of the launch vehicle. For further detail visit the Vehicle section.	Y	If this task was delayed, the team would jeopardize the full-scale vehicle design by failing to show NASA a successful sub-scale flight.
12/18/2016 to 01/12/2017	Test Analysis & Prep for CDR	This task represents data gathering and analysis of the sub-scale flight tests as well as preparing the team for the Critical Design Review. For further detail on our test analysis see the Subscale Flight Results section.	N	If this task was delayed, the team would lose time to perform test analysis that would prevent us from providing adequate sub-scale results. This task could only be delayed a maximum of 16 days in order to submit CDR in time.

01/13/2017 to 02/08/2017	Full-Scale Vehicle Construction	This task represents the time allotted for manufacturing of the full-scale vehicle. This encompasses the inspections, tests, and overall manufacturing that needs to take place in order to have the full-scale vehicle ready for the first test flight. For further detail on the full-scale vehicle design see the Vehicle section.	Y	If this task gets delayed, the team would lose the amount of launches necessary to fully test the launch vehicle and ensure a successful competition launch.
1/24/2017 to 03/06/2017	Test Analysis & Prep for FRR	This task represents data gathering and analysis of the full-scale flight tests as well as preparing the team for the Flight Readiness Review. For further detail on what tests are being planned see the Vehicle Component Test Plans sections.	N	If this task gets delayed, the team would lose time performing data analysis that could prevent proper full-scale results. This task can only be delayed by 16 days in order to submit FRR on time.
02/11/2017 to 03/25/2017	Full-Scale Flights	This task represents the overall amount of time allocated for full-scale flight tests. Over the course of thirty (30) days the team will perform five (5) full-scale flight tests with three (3) flights scheduled before the FRR submittal date. This schedule ensures the team that the full-scale vehicle has been thoroughly tested and is safe for competition flight. For further detail on the full-scale vehicle see Vehicle section.	Y	If this task gets delayed, the team could lose launch dates and reduce the confidence of a safe flight at competition.
Milestones				
Date	**Title**	**Description**	**Critical Path**	**Consequence of Delay**
12/03/2016	Sub-Scale Flight #1	This task represents the first sub-scale vehicle test that will test the stability and overall design of the vehicle.	N	If this task gets delayed, the team loses a launch date and gives the team only one more chance to have a successful flight. This task can be delayed 15 days until 12/18/2016 for the next sub-scale flight.
12/09/2016 to 01/06/2017	Mandrel Removal Procedure Testing	This task represents the time which different mandrel removal techniques were tested in order to find the optimal method of manufacturing custom carbon fiber filament wound airframe	N	If this task gets delayed, the team loses the ability to produce custom filament wound airframe. However, the team would still have the option to buy factory manufactured airframe.
12/17/2016	MRS Controlled Flight Demonstration	This milestone represents the first flight of the MRS propulsion and electronics system.	N	If this task gets delayed, the team would need to reschedule a day closer to the Fully Integrated Payload Flights causing schedule build up.
12/18/2016	Sub-Scale Flight #2	This task represents the second and last chance to test fly the sub-scale vehicle.	Y	If this task gets delayed, the team risks the chance of not having a successful subscale flight test by CDR.
01/21/2017	Autonomous Flight and Target Identification Test	This milestone represents the first fully autonomous test flight with the TDS identifying the full scale targets.	Y	If this task gets delayed, the team risks pushing the First Full Scale Test Flight with the Payload integrated into the Launch Vehicle.
01/21/2017	PCB POM	At this milestone the team will have an internal design review focused on reviewing improvements implemented from the prototype.	N	If delayed or cancelled, the PCB might suffer small losses in quality but no critical events happen at this milestone.
01/28/2017	Airframe Constructed	This task represents the time which the airframe and motor mount for the full scale launch vehicle will be constructed using a 4-Axis X-Winder.	Y	If this task gets delayed, the team will be required to push back the date at which a control launch of the full scale launch vehicle, thus increasing the risk of not being able to perform a successful flight of the launch vhicle before FRR. This can be delayed 7 days in order to launch successfully before FRR.
02/11/2017	Full-Scale Flight #1	This task represents the first full-scale flight test. This will strictly be a recovery based flight to ensure our recovery scheme works properly before a fully integrated flight occurs.	Y	If this task gets delayed, the team loses valuable integrated test flights with the payload and VDS. The recovery must work properly before an integration flight occurs.
02/11/2017	Additional Sub-Scale Flight	The additional subscale flights will be used as a training exercise for new members and will also serve as an additional opportunity to collect flight data which will be used to improve the VDS simulation.	N	If delayed, this task will not immediately affect this season’s schedule. This task will never become a critical path.
02/18/2017	Full-Scale Flight#2	This task represents the time which the full scale launch vehicle is tested with full actuation of the drag blades of the VDS during the entirety of the flight.	N	If this task gets delayed, the braking power requirements for the VDS will not be verified.
02/18/2017	Additional Sub-Scale Flight	The additional subscale flights will be used as a training exercise for new members and will also serve as an additional opportunity to collect flight data which will be used to improve the VDS simulation.	N	If delayed, this task will not immediately affect this season’s schedule. This task will never become a critical path.
02/25/2017	Full-Scale Flight #3	This milestone were to get delayed, the full integration launch with the payload would get delayed.	Y	If this task gets delayed, the team will risk its final chances to get a full scale test flight w/ Payload for practice.
03/11/2017	Full-Scale Flight #4	This milestone represents the 1st backup full scale test flight w/ Payload integrated.	N	If this task gets delayed, the team will risk its final chances to get a full scale test flight w/ Payload for practice.
03/25/2017	Full-Scale Flight #5	This milestone represents the 2nd backup full scale test flight w/ Payload integrated.	N	If this task gets delayed, the team will risk its final chances to get a full scale test flight w/ Payload for practice.

Table 98: Master Timeline items.

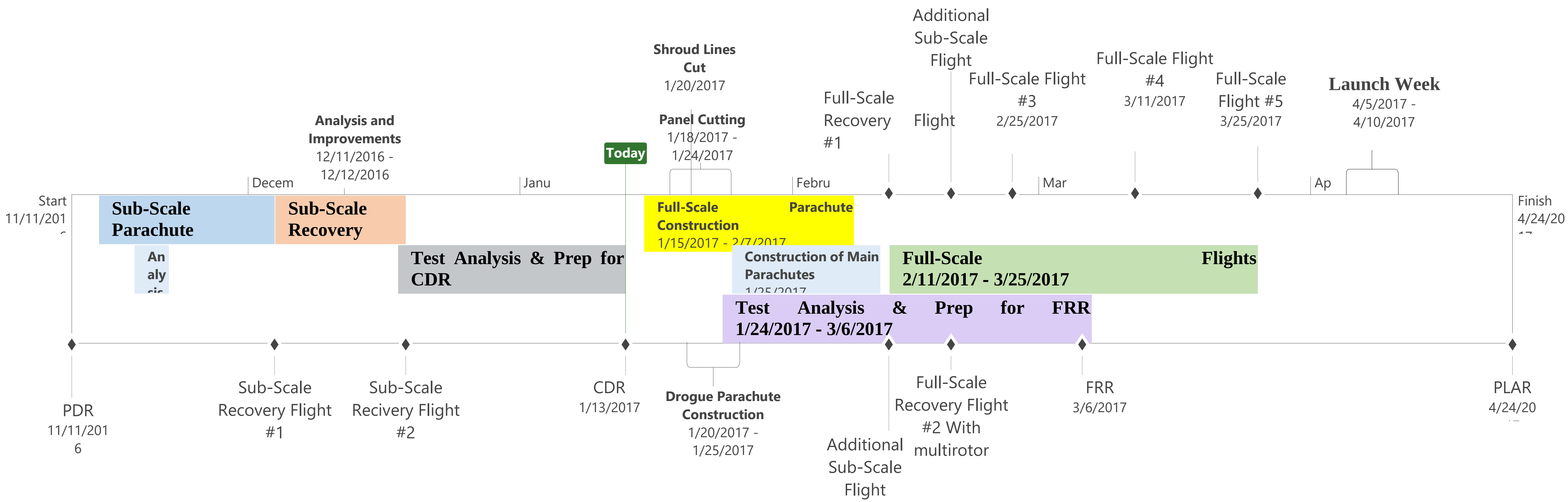
7.4.2 Launch Vehicle Overview Timeline



Major Tasks				
Date	**Title**	**Description**	**Critical Path (Y/N)**	**Consequence of Delay**
11/4/16 - 11/30/16	Finalize Design from PDR Alternatives	This task represents the time which the final design solutions from the Preliminary Design Review will be selected. By the end of this task all components will be finalized and all manufacturing methods will be selected.	Y	If this deadline was delayed, the creation of the finalized overall design of the launch vehicle will be delayed, resulting in a shorter time frame to create CAD models of the vehicle. This can be delayed 7 days in order to submit CDR in time.
11/10/16 - 11/27/16	Subscale Fabrication	This task represents the time which the subscale vehicle will be fabricated. By the end of this task the subscale vehicle will be fully assembled.	Y	If this deadline gets delayed, the subscale vehicle will not be able to launch on the scheduled launch date. This task can be delayed 14 days in order to submit the CDR report on time.
11/28/16 – 12/17/16	Subscale Preparation and Flights	This task represents the time which the subscale vehicle will be tested for flight readiness as well as actually tested. By the end of this task the subscale vehicle will be successfully launched and recovered.	Y	If this deadline gets delayed, a subscale launch will not be able to occur before CDR. This task cannot be delayed.
12/1/16 – 1/12/17	Create CAD Models of Launch Vehicle	This task represents the time which all components and sub-assemblies of the launch vehicle will be modeled in Solidworks and integrated together. By the end of this task a complete, fully integrated model of the launch vehicle will be created.	Y	If this deadline gets delayed, the manufacturing of the full scale launch vehicle will get delayed, thus increasing the risk of missing the first control launch that is scheduled for February 11th. This task can be delayed 5 days in order to launch the full scale launch vehicle by February 11th.
1/14/17 – 2/4/17	Launch Vehicle Fabrication	This task represents the time which the launch vehicle will be manufactured and prepared for flight. By the end of this task the launch vehicle will be completely assembled and ready for flight.	Y	If this deadline gets delayed, the full scale launch vehicle will not be launched on February 11th. This will leave one other possible launch date to get a successful flight of the full scale launch vehicle completed before FRR, which is February 25th. This task can be delayed 7 days in order to get a full scale launch vehicle flight in before FRR is due.
2/6/17 – 3/25/17	Full Scale Launch Vehicle Flights	This task represents the time which the full scale vehicle will tested along with the integration all of the sub-systems, such as the VDS, recovery system, and payload. By the end of this task the full scale launch vehicle will be tested to function as designed.	Y	If this deadline gets delayed, a successful launch of the full scale launch vehicle will not be completed before FRR. This task cannot be delayed in order to complete a successful launch before FRR.
Milestones				
Date	**Title**	**Description**	**Critical Path**	**Consequence of Delay**
12/3/16	Subscale Flight #1	This milestone represents the point at which the subscale vehicle was tested for a successful launch and recovery.	Y	If this deadline was delayed, the subscale vehicle launch would need to be delayed in order to successfully launch a subscale vehicle by CDR. This task can be delayed 21 days.

12/17/16	Subscale Flight #2	This milestone represents the point at which the subscale vehicle was tested for a successful launch and recovery.	Y	If this milestone was delayed, the subscale vehicle launch would need to be delayed in order to successfully launch a subscale vehicle by CDR. This task can be delayed 7 days.
12/31/16	Full Scale Launch Vehicle CAD Model Finished	At this milestone, a complete CAD model of the full scale launch vehicle has been created as well as integrated with all sub-systems.	Y	If this milestone gets delayed, the manufacturing of the full scale launch vehicle will get delayed, thus increasing the risk of missing the first control launch that is scheduled for February 11th. This task can be delayed 5 days in order to launch the full scale launch vehicle by February 11th.
1/20/17	Manufacture Nose Cone	This milestone represents the point at which the nose cone for the full scale launch vehicle has been fabricated from carbon fiber.	Y	If this milestone gets delayed, the control launch of the full scale launch vehicle could potentially be delayed. This task can be delayed by 5 days.
1/28/17	Fabrication of all custom filament wound airframe	At this milestone, all sections of the airframe that make up the exterior of the full scale launch vehicle have been manufactured using an X-Winder.	Y	If this milestone gets delayed, the control launch of the full scale launch vehicle will be delayed. This milestone can be delayed by 14 days in order to complete a successful flight by FRR.
1/30/17	Propulsion Bay Fully Assembled	This milestone represents the point at which the centering rings, fins, and motor mount have been assembled and are ready for flight.	Y	If this milestone gets delayed, the launch of the full scale launch vehicle will be delayed. This can be delayed 3 days in order to complete a successful launch on February 11th.
2/11/17	Test Launch #1 without VDS and Payload	This milestone represents the point at which the full scale launch vehicle is launched for the first time, verifying the predicted flight characterless of the launch vehicle as well as the structural	Y	If this milestone gets delayed, the VDS braking power launch will be delayed as well. This can be delayed 14 days.
2/18/17	Test Launch #2 with VDS and without Payload	This milestone represents the point at which the full scale launch vehicle is tested with just the VDS system, which will verify the braking power of the system.	Y	If this milestone gets delayed, the braking power of the VDS will not be unknown. This milestone can be delayed 14 days.
3/11/17	Fully integrated test launch #3 with payload	This milestone represents the point at which the full scale launch vehicle is launched for the first time with the integration of the payload and VDS.	Y	If this milestone gets delayed, one other date will be available to launch the full scale launch vehicle before competition. This milestone can be delayed by 14 days in order to complete a successful launch before competition.
3/25/17	Fully integrated test launch #4 with payload	This milestone represents the last point at which a successful full scale launch vehicle flight can be completed before competition.	Y	If this milestone gets delayed, a successful full scale launch vehicle flight will not occur before competition. This milestone cannot be delayed.

7.4.2.1 Recovery Schedule



Major Tasks				
Date	**Title**	**Description**	**Critical Path (Y/N)**	**Consequence of Delay**
11/14/2016 to 12/03/2016	Sub-Scale Parachute Construction	This task represents the deadline the team has made for the sub-scale recovery construction.	Y	If this deadline was delayed, the team would have only one opportunity to launch the sub-scale vehicle before CDR, giving the team a greater chance for failure.
12/03/2016 to 12/18/2016	Sub-Scale Recovery Flights	This task represents the overall time allotted for sub-scale recovery tests. Over the course of ten (10) days the team was able to have two launches, perform analysis, and validate the drag coefficients and opening forces of the recovery gear. For further detail visit the Subscale Flight Results section.	Y	If this task was delayed, the team would jeopardize the full-scale vehicle design by failing to show NASA a successful sub-scale recovery.
12/18/2016 to 01/12/2017	Test Analysis & Prep for CDR	This task represents data gathering and analysis of the sub-scale recovery tests as well as preparing the team for the Critical Design Review. For further detail on recovery analysis see the Subscale Flight Results section.	N	If this task was delayed, the team would lose time to perform recovery analysis that would prevent us from providing adequate sub-scale results. This task could only be delayed a maximum of 16 days in order to submit CDR in time.
01/15/3017 to 02/10/2017	Full-Scale Parachute Construction	This task represents the time allotted for manufacturing of the full-scale recovery gear. This encompasses the inspections, tests, and overall manufacturing that needs to take place in order to have the full-scale vehicle ready for the first test flight. For further detail on the full-scale recovery design see the Recovery section.	Y	If this task gets delayed, the team would lose the amount of launches necessary to fully test recovery gear and ensure a successful recovery at competition.
1/24/2017 to 03/06/2017	Test Analysis & Prep for FRR	This task represents data gathering and analysis of the full-scale recovery tests as well as preparing the team for the Flight Readiness Review. For further detail on what recovery tests are being planned see the Vehicle Component Test Plans sections.	N	If this task gets delayed, the team would lose time performing data analysis that could prevent proper full-scale results. This task can only be delayed by 16 days in order to submit FRR on time.
02/11/2017 to 03/25/2017	Full-Scale Recovery Flights	This task represents the overall amount of time allocated for full-scale recovery tests. Over the course of thirty (30) days the team will perform five (5) full-scale flight tests – one (1) exclusively for recovery gear and the other four (4) with the fully integrated payload. This schedule ensures the team that the full-scale recovery systen has been	Y	If this task gets delayed, the team could lose launch dates and reduce the confidence of a safe flight at competition.

		thoroughly tested and is safe for competition flight. For further detail on the full-scale recovery gear see Recovery section.		
Milestones				
Date	**Title**	**Description**	**Critical Path**	**Consequence of Delay**
12/03/2016	Sub-Scale Recovery Flight #1	This task represents the first sub-scale recovery test that will test drag coefficients and opening forces of the recovery gear.	N	If this task gets delayed, the team loses a launch date and gives the team only one more chance to have a successful flight. This task can be delayed 15 days until 12/18/2016 for the next sub-scale flight.
12/18/2016	Sub-Scale Flight #2	This task represents the second and last chance to test fly the sub-scale recovery gear.	Y	If this task gets delayed, the team risks the chance of not having a successful subscale recovery by CDR.
02/11/2017	Full-Scale Recovery Flight #1	This task represents the first full-scale recovery test. This will strictly be a recovery based flight to ensure our recovery scheme works properly before a fully integrated flight occurs.	Y	If this task gets delayed, the team loses valuable integrated test flights with the payload and VDS. The recovery must work properly before an integration flight occurs.
02/18/2017	Full-Scale Recovery Flight t#2 With Multirotor	This task represents the first time which the full scale recovery gear will be attempting to recover the multirotor payload in a full scale test launch.	N	If this task gets delayed, the payload deployment requirements for the recovery gear will not be verified
02/25/2017	Full Scale Recovery Flight #3	This milestone represents the 1st backup full scale recovery flight w/ Payload recovery integration	Y	If this task gets delayed, the team will risk its final chances to get a full scale recovery of payload for practice.
03/11/2017	Full-Scale Recovery Flight #4	This milestone represents the 2nd backup full scale recovery flight w/ Payload recovery integration	N	If this task gets delayed, the team will risk its final chances to get a full scale recovery of payload for practice.
03/25/2017	Full-Scale Recovery Flight #5	This milestone represents the 3rd backup full scale recovery flight w/ Payload recovery integration	N	If this task gets delayed, the team will risk its final chances to get a full scale recovery of payload for practice.

7.4.2.2 VDS Schedule

Below is the detailed schedule for the VDS team.

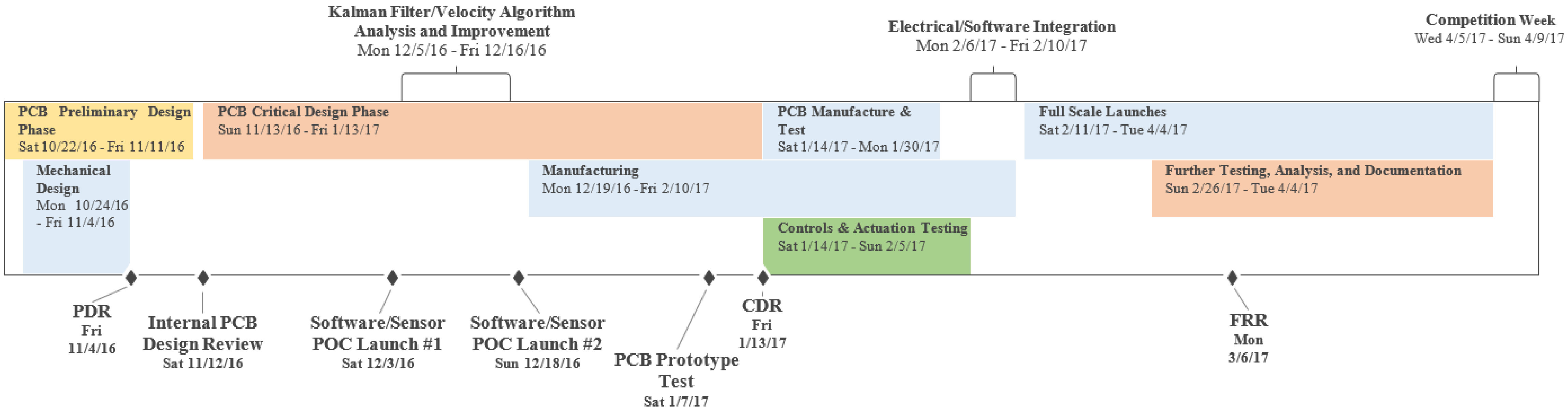


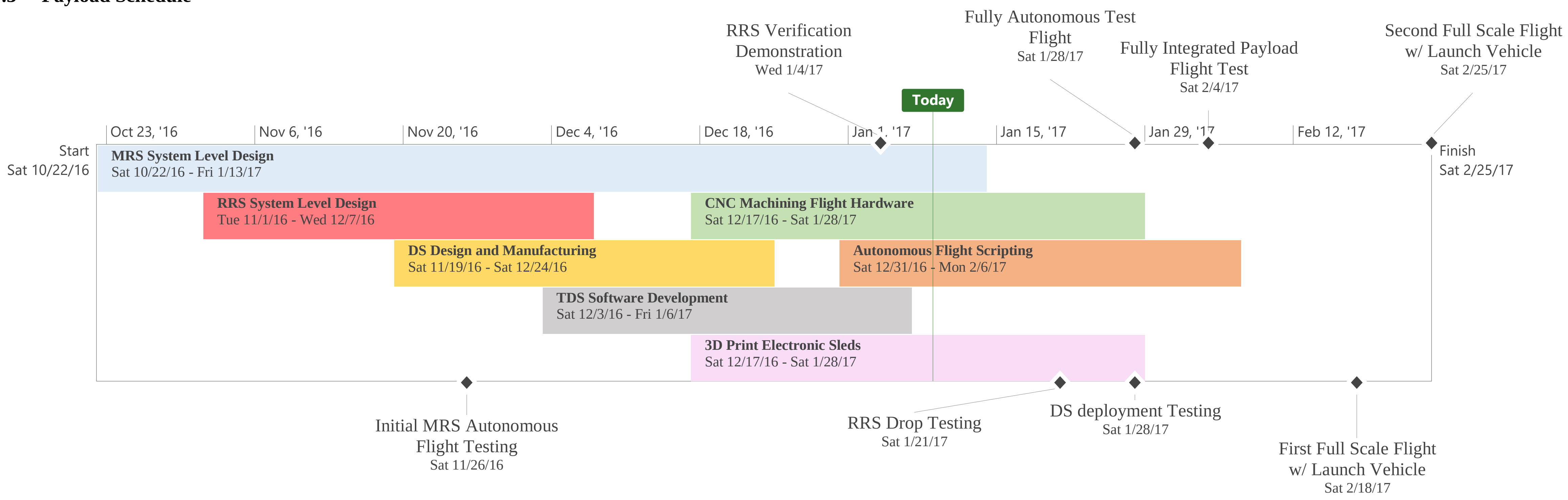
Figure 150: VDS team timeline.

Currently the team is nearing completion on its PCB critical design with a full prototype test expected by January 7th. The software/sensor proof of concept launches (subscale) have demonstrated the reliability and accuracy of the sensors and data acquisition. The team is now ready to move to manufacturing PCBs and writing an actuation class for the software.

Major Tasks				
Date	**Title**	**Description**	**Critical Path (Y/N)**	**Consequence of Delay**
10/22/2016 to 1/11/17	PCB Preliminary Design Phase	This task represents the time during which the VDS electronics PCB is initially designed. By the end of this task, a schematic and preliminary board layout should be completed.	Y	If this deadline was delayed, the team would not be able to complete the internal PCB design review by the scheduled time.
12/24/2016 to 11/4/2016	Mechanical Design	This task represents the time during which the mechanical sub-system of the VDS is being designed. By the end of this task a complete Solidworks assembly is created of the VDS and is ready for manufacturing.	N	Delays in this deadline would not delay the date of the full scale launch because manufacturing was not scheduled to begin until January. Two months before item becomes critical.
	Manufacturing	This task represents the time during which the VDS is manufactured. By the end of this task, the VDS will be completely constructed and ready for flight.	Y	If this task was delayed, the VDS full scale tests would be delayed.
11/13/2016 to 01/13/2017	PCB Critical Design Phase	This task represents the time during which the PCB design is refined. Exact connectors are chosen, harnessing is decided upon, and mounting solutions become finalized.	Y	If this task was delayed, the team would not be able to proceed to the manufacturing phase of the PCB design on time. This would ultimately delay the full scale testing of the VDS.
01/22/2017 to 02/5/2017	PCB Manufacture and Test	This task represents the time during which the final PCB has been ordered and soldering and testing can begin. By the end of this milestone the PCB should be completely finished and ready to be installed in the vehicle for full scale testing.	Y	If this task gets delayed, the VDS full scale tests would either be delayed or the full scale tests would have to happen on the prototype PCB.
2/6/2017 to 2/10/2017	Electrical/Software Integration	This task represents the time during which the hardware and software teams begin integrating their work together. This involves running 'launch playback tests' on the Teensy using the final PCB and performing sensor initializations.	Y	If this task gets delayed, the team would risk the postponement of full scale VDS testing.
02/11/2017 to 03/25/2017	Full-Scale Flights	During this time, the VDS electronics will undergo five total flights. The first two will be characterizations of drag and the latter three will be tests of the controls scheme.	Y	If this task gets delayed, the team could lose launch dates and reduce the confidence of a safe flight at competition.
Milestones				
Date	**Title**	**Description**	**Critical Path**	**Consequence of Delay**
11/12/2016	Internal PCB Design Review	This milestone represents a point in the VDS team's schedule when the VDS electronics PCB were completed in EagleCad. The purpose of this review was to allow the team to give preliminary feedback and improve the design.	Y	Delays in this milestone would have put PCB manufacturing behind schedule and could have delayed VDS full-scale testing.
12/3/2016	Software/Sensor POC Launch #1	This milestone, the first subscale launch, served to test the data acquisition and storage portion of the VDS electronics software.	Y	Delays in this milestone would have put VDS full-scale testing behind schedule.
12/18/2016	Software/Sensor POC Launch #2	This milestone, the second subscale launch, served to test the data acquisition and storage portion of the VDS electronics software.	N	Delays in this milestone would not have put full scale VDS testing behind schedule because the first software/sensor POC launch was adequate for the purposes of proving the concept.
1/7/2017	PCB Prototype Demonstration	At this milestone the team will have milled a prototype PCB for the VDS electronics and the main components will have been soldered on and tested. This prototype demonstration, if passed will allow the team to have the VDS electronics PCB milled professionally.	Y	If delayed the team will either have to order the design without a tested prototype and risk small design errors, or the ordering of the PDB will have to be delayed.
1/21/2017	PCB POM	At this milestone the team will have an internal design review focused on reviewing improvements implemented from the prototype.	N	If delayed or cancelled, the PCB might suffer small losses in quality but no critical events happen at this milestone.

Table 99: VDS timeline items.

7.4.3 Payload Schedule



Major Tasks				
Date	**Title**	**Description**	**Critical Path (Y/N)**	**Consequence of Delay**
10/22/2016 to 1/13/17	MRS System Level Design	This task represents the time in which the flight system was selected, implemented, and drone simulation software was utilized. By the end of this task a fully functioning flight system is operating autonomously via programmable scripts.	Y	Delays in this dead line would cause significant pushback in current scheduling during the testing and autonomous flight scripting phase beginning in mid-January.
11/1/2016 to 12/7/2016	RRS System Level Design	This task represents the time in which the layout of the circuitry and logic design is completed for the Redundant Recovery System onboard the Payload. By the end of this task a fully functioning and RRS circuit will be ready to be manufactured.	Y	Delays in this deadline would cause significant pushback in current scheduling of the fully integrated payload test flight and First Full Scale Flight of the Payload with the Launch Vehicle.
11/19/2016 to 12/24/2016	DS Design and Manufacturing	This task represent the time in which the DS bays and hardware were designed and fabricated. By the end of this task, the Deployment Bay and Main Recovery designs will be completed and fabrication of test bays and the final flight bays will be underway	N	There is sufficient enough margin between when the test are scheduled to occur and when the design and fabrication took place. If delayed, the work could be rescheduled for a later date in which the test date could still be met.
12/03/2016 to 1/06/2017	TDS Software Development	This task represents the time in which the TDS software is developed and demonstrated for functionality on the ground. By the end of this task, the TDS software should be fully developed and ready for flight testing.	N	Delays in this date would not significantly delay the Full Scale Test Flight. Delays in this item could potentially delay the Autonomous Test Flights and/or Fully Integrated Payload Test Flights.
12/17/2016 to 01/28/2017	CNC Machining Flight Hardware	This task represent the time in which all structural aluminum flight hardware will be manufactured. By the end of this task all of the MRS propulsion and LLS hardware will be ready to be integrated into the final design.	Y	Delays in this task may result in delays in critical deployment and flight testing. Priority will be given to guaranteeing this task be completed in the time frame currently scheduled.
12/17/2016 to 01/28/2017	3D Print Electronics Sleds	This task represents the time which all electronics mounts are manufactured. By the end of this task all of the MRS and RRS electronics will be ready to be integrated into the final Payload Design.	Y	Delays in this task would directly affect the test flight dates of the Payload. Priority will be given to guarantee this task is completed in the time frame scheduled.
12/31/2016 to 02/06/2017	Autonomous Flight Scripting	This task represents the time which the flight programing of the MRS will occur during. By the end of this task, the Payload will be ready to run its autonomous flight scripts.	Y	Delays in this task would directly affect Full scale Flight Testing. Priority will be given to guarantee this task in completed in the time frame scheduled.

Milestones				
Date	**Title**	**Description**	**Critical Path**	**Consequence of Delay**
11/26/2016	Initial MRS Autonomous Flight Testing	This milestone represent the first autonomous flight testing using the test frame.	N	Delays in this milestone pose risks in schedule stack up during the autonomous testing phase.
01/04/2017	RRS Verification Demonstration	This milestone represents the RRS system demonstration of the RRS circuit functionality demonstrating the system's ability to detect failure criteria and act accordingly.	N	Delays in this milestone pose risks in delaying RRS drop testing schedule.
01/21/2017	RRS Drop Testing	This milestone represent the RRS drop test which will test the full systems ability to monitor the state of the payload and deploy the RRS parachute accordingly.	Y	Delays in this milestone pose risks in delaying the Full Scale Flight w/ Launch Vehicle.
01/28/2017	DS deployment Testing	This represent DS deployment testing of the Payload.	Y	Delays in this milestone pose risks in delaying the Full Scale Flight w/ Launch Vehicle.
01/28/2017	Fully Autonomous Test Flight	This milestone represents the Fully autonomous test flight using the test frame. This test will demonstrate the entire autonomous flight protocol.	Y	Delays in this milestone pose risks in delaying the Full Scale Flight w/ Launch Vehicle.
02/04/2017	Fully Integrated Payload Flight Test	This milestone represent the fully built flight of the payload with all designed subsystems present.	Y	Delays in this milestone would directly affect and delay the Full Scale Flight w/ Launch Vehicle
02/18/2017	First Full Scale Flight w/ Launch Vehicle	This milestone represents the first Full Scale Flight test of the Payload integrated into the Launch Vehicle.	Y	Delays in this milestone may compromise the team's ability to perform full scale test launches prior to FRR.
02/25/2017	Second Full Scale Flight w/ Launch Vehicle	This milestone represents the second Full Scale Flight test of the Payload integrated into the Launch Vehicle.	Y	Delays in this milestone may compromise the team's ability to perform full scale test launches prior to FRR.

Table 100: Payload timeline items.

8 Conclusion

River City Rocketry started the 2016-2017 season with several goals in mind. This includes the continued effort to keep setting the standard for safety in the NASA Student Launch Competition, as River City Rocketry has for the past 3 years. In terms of Community Outreach, the team has pledged to engage 2,000+ students in STEM-centered outreach events, encouraging enthusiasm for rocketry, science, and the larger STEM fields. Some of our events are outlines below:

1. Participating in such events as MathMovesU.
2. Youth Science Summit with the Kentucky Science Center.
3. Engineering Expo with annual water rocket competition.
4. Pursuing more ambitious recruiting, developing relationships with contacts in Louisville and the University, and establishing relationships with aerospace companies.

River City Rocketry also has design goals that set them apart from other competitors. The main proponent of this is to design a Variable Drag System (VDS), which raises the bar for reliable and consistent apogee accuracy in every NSL flight. Payload design is the other key identifier that the team has set out to highlight: the goal of creating a reliable target detection system, with the capability of upright landing at a defined location, to further push for an increase in not only higher engineering standards but to also promote the research-based nature of the University of Louisville. Finally, the team's intention is to foster a healthy growth of the team, from all disciplines of study; expanding the team's cumulative knowledge of rocketry and ensuring a sustained and continuous improvement in the team's ability to achieve its goals.

The team has been working throughout the year to meet these goals through multiple resources. Safety has been a crucial part of all RCR projects. By drawing an emphasis on safety on every part of a project, the team is able to construct the most safety-conscious design, evaluating every system and procedure and subjecting them to a thorough vetting process.

9 Appendix I – Safety Risk Assessments

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderat e	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.
Rain	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage.
High winds	N/A	1. Have to launch at high angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the salt flats being extremely soft, as well as local launch sites, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.

Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Moderate	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.
Humidity	N/A	Motors or black powder charges become moist and don't ignite.	1	5	Moderate	Motors and black powder should be stored in a location free from moisture to remove
UV exposure	Rocket left exposed to sun for long periods of time.	Possibly weakening materials or adhesives.	4	4	Low	Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought.

Table 101: Environmental to rocket risk assessment table.

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**

Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, work their way into humans, causing illness.	4	3	Low	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any EHS standards.
Release of hydrogen chloride into the atmosphere.	Burning of composite motors.	Hydrogen chloride dissociates in water forming hydrochloric acid.	4	1	Moderate	While the probability of hydrochloric acid forming is high, the amount that would be produced over the course of a season is negligible. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals work to deplete ozone layer.	4	1	Moderate	While the probability of releasing reactive chemicals into the environment is high, the quantity released will result in negligible effects. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	4	1	Moderate	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.
Production of styrene gas.	Through the use of fiberglass in the overall design, fiberglass is manufactured by a second party.	Toxic air emissions.	4	1	Moderate	Productions methods for fiberglass produces toxic air pollutants, particularly styrene, which evaporate during the curing process. Due to the quantity of fiberglass utilized on the rocket, the amount of pollutants produced throughout manufacturing process will have a negligible effect on the environment.
Spray painting.	The rocket will be spray painted.	1. Water contamination. 2. Emissions to environment.	2	5	Low	All spray painting operations will be performed in a paint booth. This prevents any overspray from entering into the water system or air.
Soldering wires.	All wires will be soldered together to retain strength and proper connection.	1. Air contamination 2. Ground contamination	4	1	Low	The amount of vapor from the soldering process is at such a low quantities that no action will be needed.

Use of lead acid battery leakage.	Old or damaged housing to battery	1. Acid will leak onto the ground and get into the water system. 2. Chemical reaction with organic material that could potentially cause a fire.	3	4	Low	1. We are using new batteries that have been factory inspected and tested. 2. Proper lifting and storing procedures according to manufacturer's specifications will be adhered to.
Plastic waste material.	Plastic using in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested by an animal. 2. Plastic could find its way down a drain and into the water system.	3	5	Low	1. All plastic material will be disposed of in proper waste receptacles.
Wire waste material.	Wire material used in the production of electrical components.	1. Sharp bits of wire being ingested by an animal if improperly disposed of.	3	5	Low	1. All wire material will be disposed of in proper waste receptacles.
CO2 emissions.	Travel to launch sites and competition.	Destroying the ozone layer.	4	1	Moderate	While the effects of CO2 emissions cannot be reversed, the amount produced is negligible.

Table 102: Hazards to environmental risk assessment table.