EFFECTIVE-1

Rocket Team at UC Santa Cruz

1156 High Street

Santa Cruz, CA 95064

NASA Student Launch Initiative

Critical Design Review

January 12, 2018

1. Summary

1.1 Team Summary

Team Name:	Rocket Team at UC Santa Cruz
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1.2 Vehicle Summary

By using a combination of SolidWorks, a custom written flight simulation script, and OpenRocket, the following general vehicle characteristics were established to fit the team's minimalist design strategy.

Length	Outer Diameter	Rocket Mass	Rocket Mass with Wet Motor	Final Motor Selection	Recovery System	Rail Size
2.44 m [8ft]	78.7mm [3.1 in]	4.51 kg [9.94 lb]	5.77 kg [12.72 lb]	AeroTech K535	24 in drogue chute (at apogee) via StratoLoggerCF Altimeter 48 in main chute (at 600ft) via Jolly Logic Chute Release	8 ft. 1010 rail

The thin diameter of the rocket is selected to minimize the rocket's drag, which is proportional to the cross sectional area of the rocket. This diameter is also selected for its compatibility with many of the commercially available high powered airframe and nose cone parts. The rocket's overall height was established to house the rocket's many subsystems while also maximizing the rocket's stability margin. Our final CAD model yields a rocket mass of 4.5kg. This mass will propel the rocket to a projected altitude of 1662 m (1.03 miles). This overshot of the target apogee is intentionally selected to allow the Adaptive Drag Aerobraking System (ADAS) to correct the rocket's vertical flight profile in the case of wind and turbulence uncertainties. In order to gently bring the rocket safely back to its terrestrial origin, a two staged recovery consisting of a 24 in drogue chute released at apogee and a 48 in main chute released at 600ft during descent were found to meet the needed safety factors.

1.3 Payload Summary

The team has elected to participate in the target tracking challenge using TARS, the TArget Recognition System. TARS is housed in a clear payload bay and relies on a wide-angle video camera pointed downward to track the positions of the competition tarps in real time. Tracking will be performed with a custom software package run on a Raspberry Pi 3b. The camera system was selected to maximize the camera's viewing time of the targets and medium- and high-altitudes.

2. Changes Made Since PDR

Several changes were made to the rocket design to maximize efficiency, safety, and build simplicity.

2.1 Vehicle

Change	Rationale
The avionics bay sled structure has been altered to consist of an hybrid structure of 3D printed bulkheads bonded to a central aluminum plate as opposed to the entirely 3D printed structure previously proposed.	The completely 3D printed avionics sled demanded extremely long manufacturing lead times and the 3D printer available for the team's use was found to be unreliable when constructing large parts. The new design is stronger, easier to manufacture and provides more board space to mount electronics at the cost of losing some of the modularity of the previous design.
Overall length of the rocket has changed from 2.05 m [6.74 ft] to 2.44 m [8ft]	The length the rocket has grown due to a number of design changes. The recovery section of the airframe was extended in order to more comfortably accommodate the parachutes, additionally the stability of the rocket was improved by lengthening the main section of the airframe.
The secondary altimeter which triggers the black powder charge ignition to deploy the drogue chute has been changed to EasyMini altimeter.	Inorder maximize the benefit of having redundant altimeters for drogue chute deployment, the new secondary altimeter was selected to be of different make and model than the primary altimeter. Thus, any manufacturing defects in one altimeter will not be present in the other.
A secondary altimeter for main chute deployment has been added for redundancy.	In order to ensure proper descent of the rocket, a second Jolly Logic Chute Release device will be attached in series to the first such that if one of these devices should fail the other will be able to successfully deploy the main parachute.
Cut outs in the centering rings have been removed.	These cutouts were initially made to provide clearance for the rail buttons when mating the motor tube to the airframe. However, the team has refined their manufacturing process such that the rail buttons are attached after the motor tube has been epoxied into the airframe, eliminating the need for these cutouts. This improves the strength of the connection of the motor tube to the airframe.
The altimeter and accelerometer sensors which interface with the Arduino 101 flight computer which controls ADAS have been upgraded to higher frequency and more precise sensors.	Higher frequency data recorded with better quality will improve the predicted performance of the ADAS system and allow for better models of the rocket's trajectory to be made during the post flight data analysis.

Main Parachute was changed from a 58” Nylon Parachute to a 48” Fruity Iris Ultra Parachute and the Drogue Parachute was increased to 24”	These choices were made in order to minimize the rockets drift and landing energy. The smaller main parachute was chosen since it shape produces more drag, therefore minimizes landing energy and drift. The drogue parachute was increased for the same reasons.
The motor selection has changed from AeroTech J540 to the AeroTechK535	This choice was made as the mass of the rocket has increased, meaning that the J540 is insufficient in getting to the necessary altitude. The K535 was chosen as models illustrate it will reach the required height while not exceeding the maximum allowed height of 5600 ft

2.2 Payload

Change	Rationale
The Raspberry Pi 3 which performs the image processing of for the TARS payload has been relocated from below the window section to above it.	This modification was made in order eliminate the need to route the camera data cable down through the window. This eliminates the visual obstruction the camera cable would have posed to the target recognition system.

2.3 Project plan

Change	Rationale
The avionics sled will be rebuilt for the full scale rocket, contrary to the initial plan of simply transferring the avionics sled from the subscale airframe to the full scale.	During the manufacture and launch of the subscale rocket, it was found that many design changes could be made to strengthen the avionics sled. Additionally slight the subscale avionics sled was slightly damaged, warranting the construction of a new sled for the full scale rocket.

2.4 Action Items

Action Item	Action Taken
Max altitude, assuming no airbrake deployment, must be under 5600 ft	The predicted altitude without airbrake deployment is currently 5456 ft
Main parachute deployment system must be made redundant	A second Jolly Logic Chute Release mechanism is planned to be connected in series with the primary device to provide redundancy for the main chute deployment

The team received a “needs improvement mark” on the Analysis of Failure Modes, Environmental Concerns, Team Requirements Derivation, and Preliminary Timeline of the PDR. Great effort has been put forth to include more detail on each of the mentioned subjects in this document.

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement and Success Criteria

The mission of the Rocket Team at UCSC is to provide an empowering, interdisciplinary, and hands-on educational experience to its members and the community united by our shared passion for aerospace and engineering .

The mission of the Effective - 1 rocket is to successfully perform corrective inflight adjustments to fit a model of the vertical flight profile while tracking ground targets in real time. The rocket will be lightweight, durable, and easily serviceable in its design while also minimizing its drag coefficient and maximizing its competition performance. The rocket is also designed with safety in mind, with redundant systems and safety features.

The success of the Effective - 1’s mission will be judged by the following criteria. The rocket must:

- Meet all safety criteria for pre-launch activities, and all FAA flight requirements and restrictions
- Be fully recoverable and reusable
- Follow a near-vertical trajectory
- Successfully deploy a drogue parachute at apogee and primary parachute at pre-specified altitude
- Include an Inertial Measurement Unit capable of sensing and record the vehicle’s flight profile
- Use sensor data to determine the its projected flight parameters
- Deploy ADAS if the demanded by the projected flight profile
- Perform fine adjustments to a model flight profile via ADAS at an appropriate frequency
- Achieve a pre-specified apogee of one mile to within 5%
- Activate TARS to locate and track tarps of different colors, even at high spin rates

And accomplish the following as secondary objectives:

- Achieve a one mile apogees to arbitrary precision within 0.5%
- Pair TARS with the avionics system to correct the video feed for angular velocity
- Repurpose TARS to track and observe topographical and atmospheric features

The Effective -1 rocket will accomplish these objectives while also aiming to

3.1.2 Design Alternative Selections from the PDR

3.1.2.1 Airframe

Blue Tube 2.0 was selected as the material for the airframe of the rocket for its strength and lower density when compared to the fiberglass alternative. Blue Tube 2.0 also has a history of success in the high powered rocket hobby and is available in standard sizes interfacing with other commercially available rocket components.

In regards to the avionics mounting system, the airframe all threaded rails were selected for the ease of accessibility they enables. Rather than having to encase the avionics electronics in a coupler diameter housing and then install that assembly into the rocket, the all-threaded structure allows for the avionics bay sled to be directly integrated into the rocket. However, isolating the electronics from the recovery charge gases has become more of a challenge than expected which will further be discussed in the Subscale Flight Results Section.

3.1.2.2 Motor Mount

The fiberglass based motor mount complete with fiberglass centering rings was selected as it proven sufficient to withstand the forces experienced by the structure during launch, as further explore in stress simulations included later in this document.

3.1.2.3 Nose Cone

The primary two nose cone shapes considered were the Von Karman (LD-Haack) and the tangent ogive nose cone shape. It was found that both offered sufficient drag numbers at the velocity regimes that the rocket is projected to experience, with the Von Karman nose cone shape having slight advantages at speeds approaching Mach. It was found in the flight simulations that the rocket was only expected to reach a maximum velocity of 215 m/s or Mach 0.6.

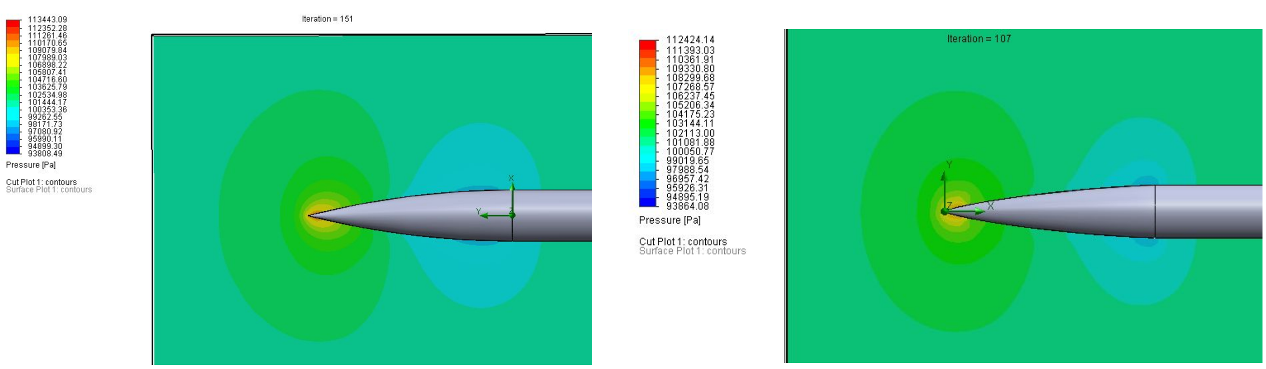


Figure 3-1 Snapshots from the nose cone flow simulations

3.1.2.4 Avionics Sled

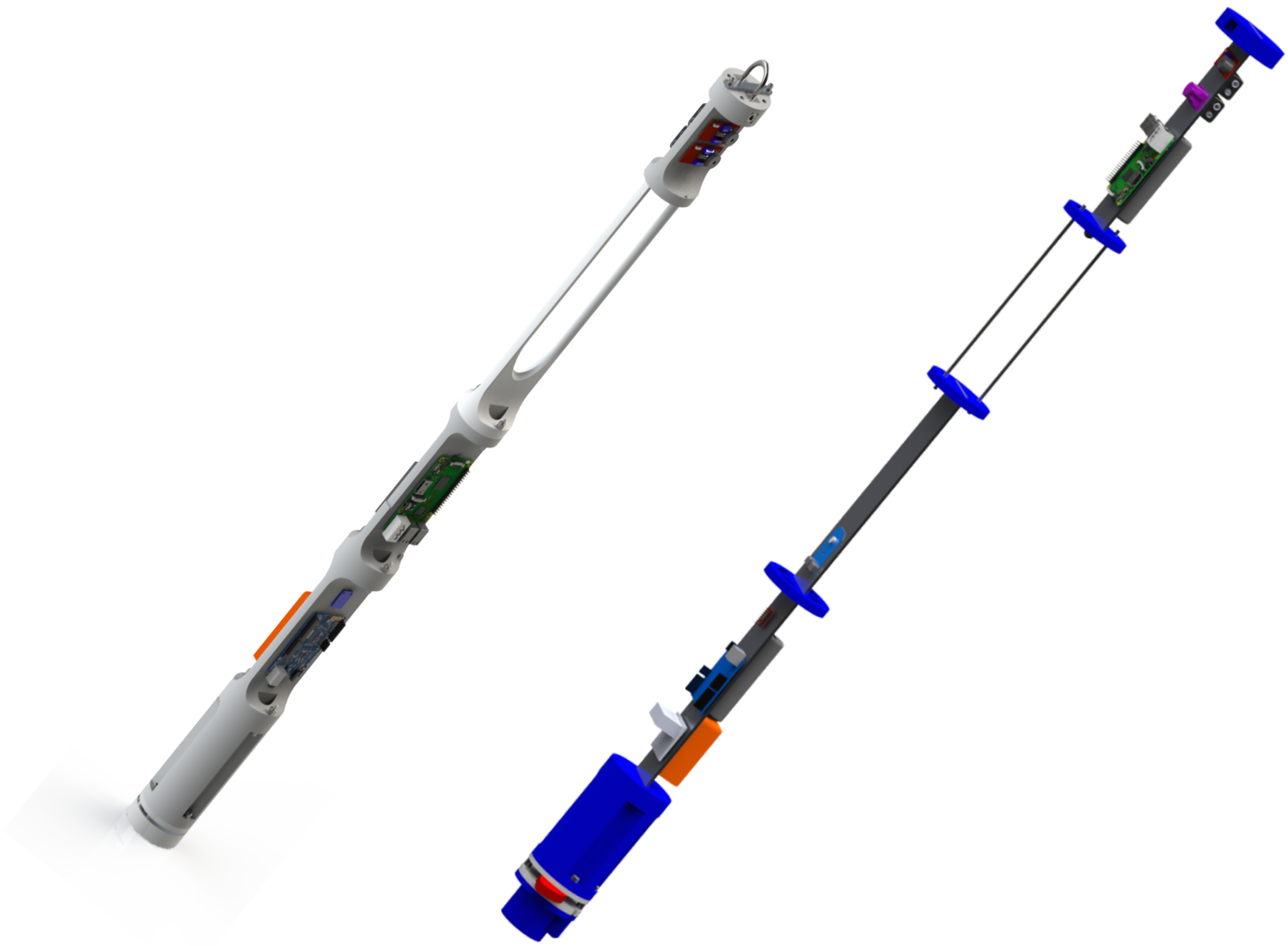


Figure 3-2 Left is the proposed completely 3D printed design from the PDR. On the Right is the refined hybrid design

From the comparison explored in the PDR, the 3D printed substructure was select to serve as the mounting fixture for the avionics. However during the manufacture of the 3D components, it was found that the long lead times for each 3D printed module was incompatible with the manufacturing schedule, especially if a part was found to be faulty or in need of modification, another 8hrs would be necessary to print a new one. The 3D printed modules also provided limited real estate for electronics. Through adopting a hybrid solution for the avionic sled, both of these flaws could be resolved. Rather than being entirely 3D printed, the sled will consist of a central aluminum plate bonded to periodically spaced 3D printed bulkhead in order to brace the sled against the airframe and keep the central aluminum place centered in the rocket. The avionics sled would no longer offer the modularity of the completely 3D printed design, but offers significantly more freedom for the placement of electronics to compensate. An in depth structural analysis of the sled structure was completed to verify the design integrity.

3.1.2.5 Fins

Figure 3-3 Fin Shape

The shape of the fins was selected to provide sufficient stability for the rocket as proven by computer simulation, success during the subscale launch, and the stress simulation investigating the ability of the fins to withstand a hard impact on the ground. The long leading edge slant and the tapered trailing edge help to reduce the drag created by the fins.

Four fins were selected over three in order to match the overall symmetry of the rocket. The fins mount to the rocket through 4 slots equally spaced radially around the rear of the rocket. The fins penetrate the airframe through these slots and are bonded to the motor tube. The fins are also secured to the airframe with epoxy fillets created on the exterior of the rocket.

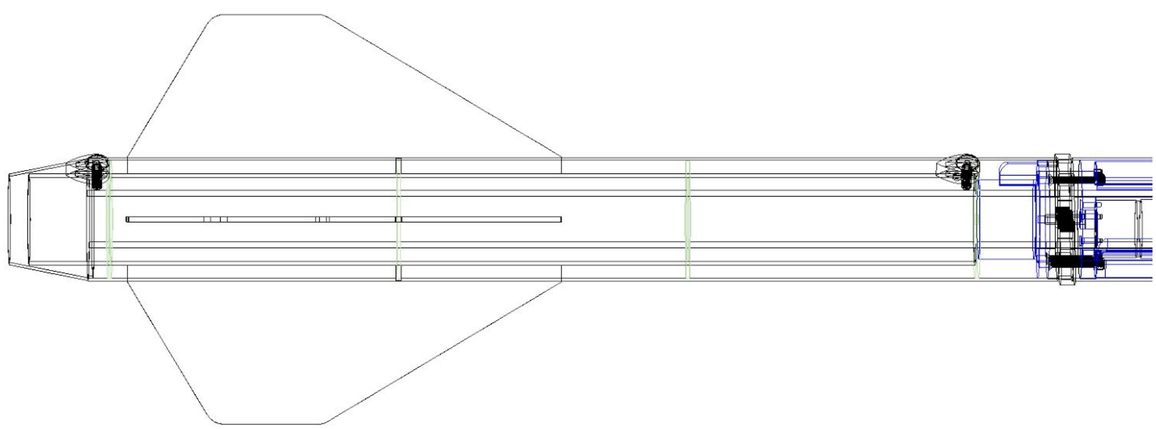


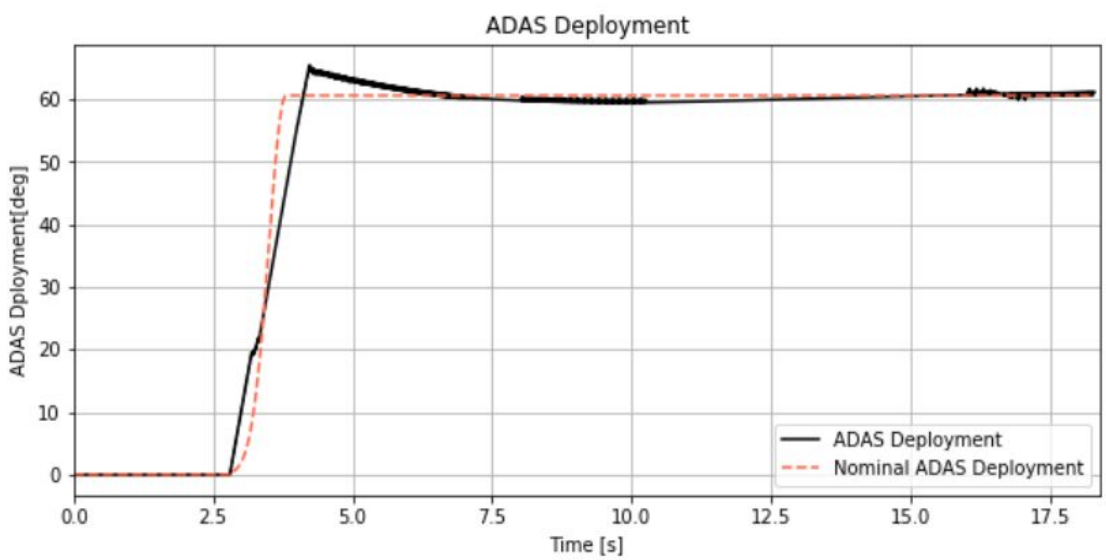
Figure 3-4 Wire frame CAD drawing of fin mount

3.1.2.6 ADAS

The single layer radial fin structure was selected for its mechanical simplicity and ability to provide the adequate correction needed to adjust the flight of the rocket. Expanding surfaces form the rocket's airframe was found to take up a significantly larger volume and demanded significantly more mechanical complexity.

3.1.2.7 ADAS Software

Controlling ADAS with a PID was found to be the best, incremental changes based on very fine measurements from instruments would allow small deployments to best fit calculated graphs. Below we ran prototypes to test our confidence in the system.



3-5 Prototype PID Graph

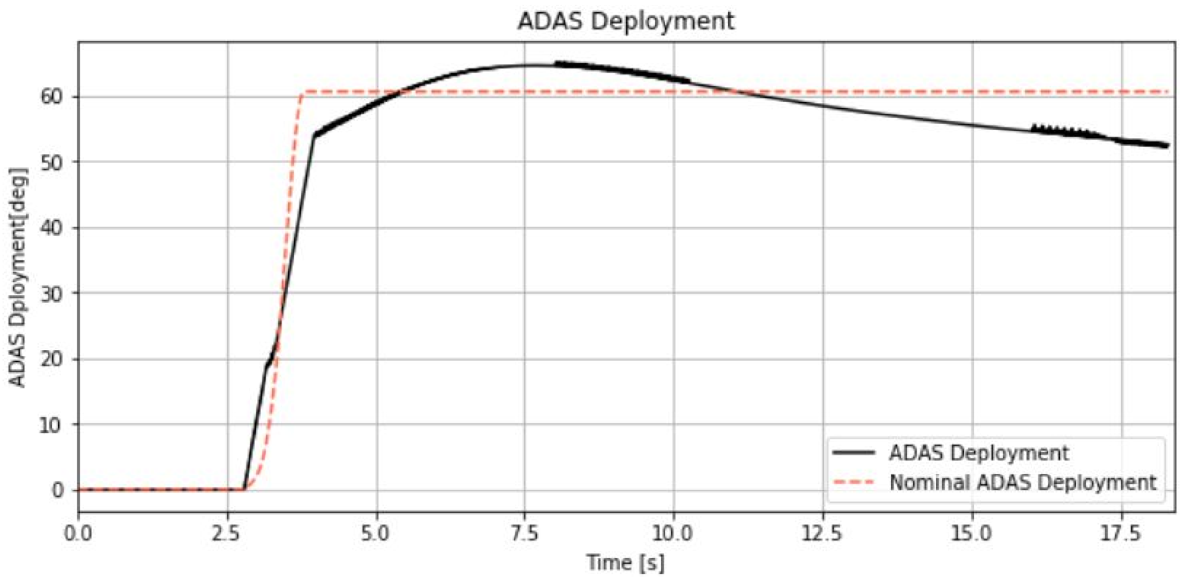


Figure 3-6 Prototype PID Graph

The software is now interfacing with a second independent Stratologger not associated with Stratologgers responsible for recovery charge detonation. NASA officials will judge our final maximum altitude from similar loggers, and as such we want to have as relevant data as possible for deploying ADAS.

3.1.2.8 Flight Computer

The Arduino 101 has been selected to be the Flight Computer though rigours tests. It has shown it can maintain a high hertz with intensive code, and having the on board IMU allows for easy data collection. We've tested multiple built in libraries and fine testing. The acceleration data is accurate and so is the gyroscopic data.

The Arduino also allows us to interface with the Stratologger through a proprietary cable. This will allows us the benefit of having better data, as stated in the previous section.

3.1.2.9 Avionics Sensors

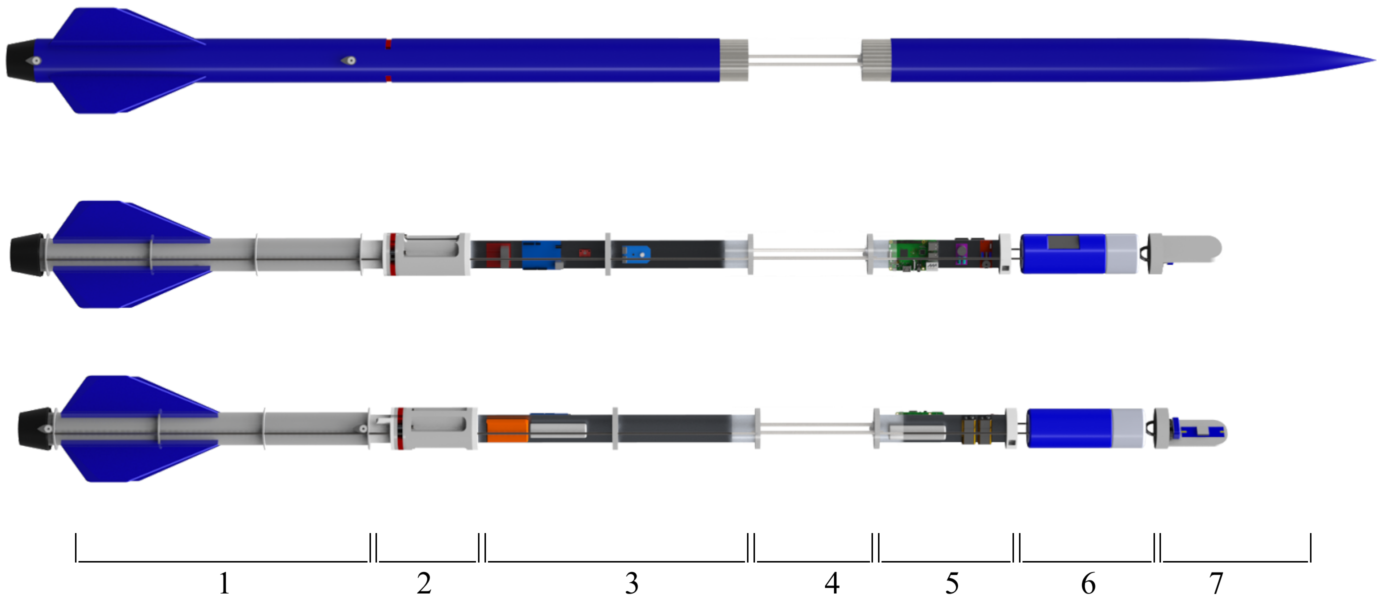
For recovery altimeters, we chose a stratologger CF and an EasyMini. These were selected for their size and accuracy. Two different brands were chosen for safety redundancy, if one manufacturers product fails under certain conditions, the second is used as a backup and is less likely to fail at the same section

The MS5607 altimeter module was selected as the primary altimeter for it's high accuracy (20cm) and ability to communicate over I2C at an extremely high frequency of up to 400 kH.

The Arduino 101 was selected as the primary flight computer for its native IMU and broad support documentation. An additional MPU6050 accelerometer was selected as an additional data source.

3.1.3 Dimensional and CAD Drawings

Figure 3-7 A CAD rendering of the rocket's exterior and both sides of its internals



- Thrust Section [62.5 cm / 24.6 in]
- Adaptive Drag Aerobraking System (ADAS) [18.3 cm / 7.2 in]
- Aft Avionics Bay [51.3 cm / 20.2 in]
- TArget Recognition System (TARS) [20.3 cm / 8 in]
- Forward Avionics Bay [25.4 cm / 10 in]
- Recovery Section [24.7cm / 9.7 in]
- Nose Cone/GPS [42cm / 16.5 in]

Figure 3-8 Rocket CAD images and subsystem breakdown with overall length dimensions

General Rocket Properties

Rocket Mass	Rocket Length	Rocket Outer Diameter	Take-Off Mass	CG aft of Nose	CP aft of Nose	Stability
4.5kg (10 lb)	2.44 m (8 ft)	78.7mm (3.1 in)	5.7kg (12.7 lb)	162 cm (63.8 in)	189 cm (74.5 in)	3.33 cal

3.1.3.1 Thrust Section

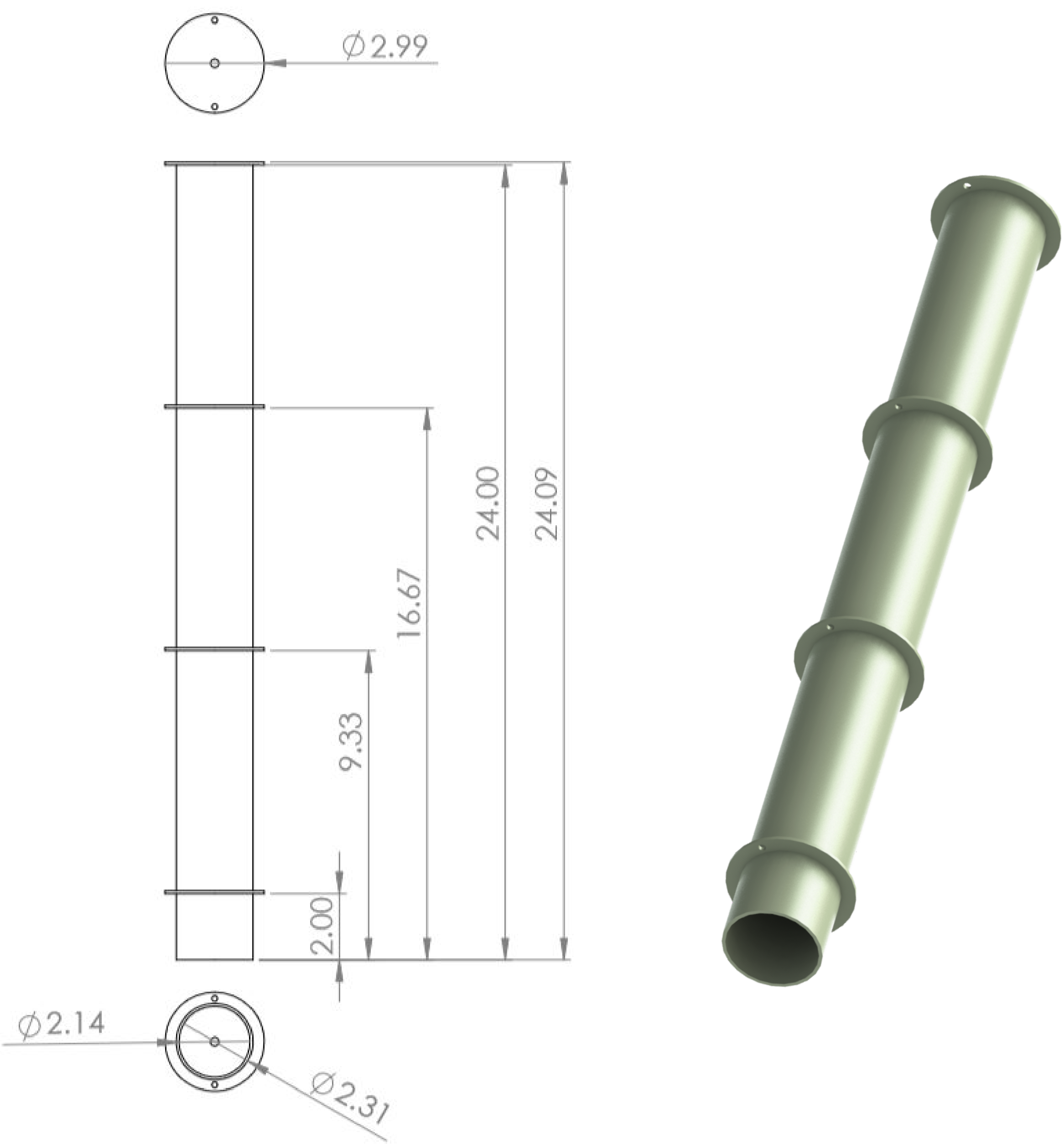


Figure 3-9 Rendering of the thrust section. Left is a dimensioned drawing (with units of Inches), right is an isometric view of the 3D model

The thrust section is made up of a central motor tube design to be capable of accommodating up to an Aerotech 2560 54mm motors casing, which is one size above the motor casing planned for the competition flight, which is the Aerotech 1706 casing. This design choice was made to allow for an upgraded motor if necessary for the final flight due to safety concerns as stated in the *NASA Student Launch College and University Handbook 2018 2.13.1*. The thrust section is bonded to the airframe via three centering rings and one bulkhead bonded at the top of the motor tube. The centering rings and bulkhead have two clearance holes diametrically opposed from one another in order to allow the all thread to pass through this section of the rocket. These all thread rails are also bonded to the thrust section at each hole. For verification that this design has meet the standards necessary to stay intact during the flight, a stress analysis was performed on these components.

3.1.3.2 Adaptive Drag Aerobraking System

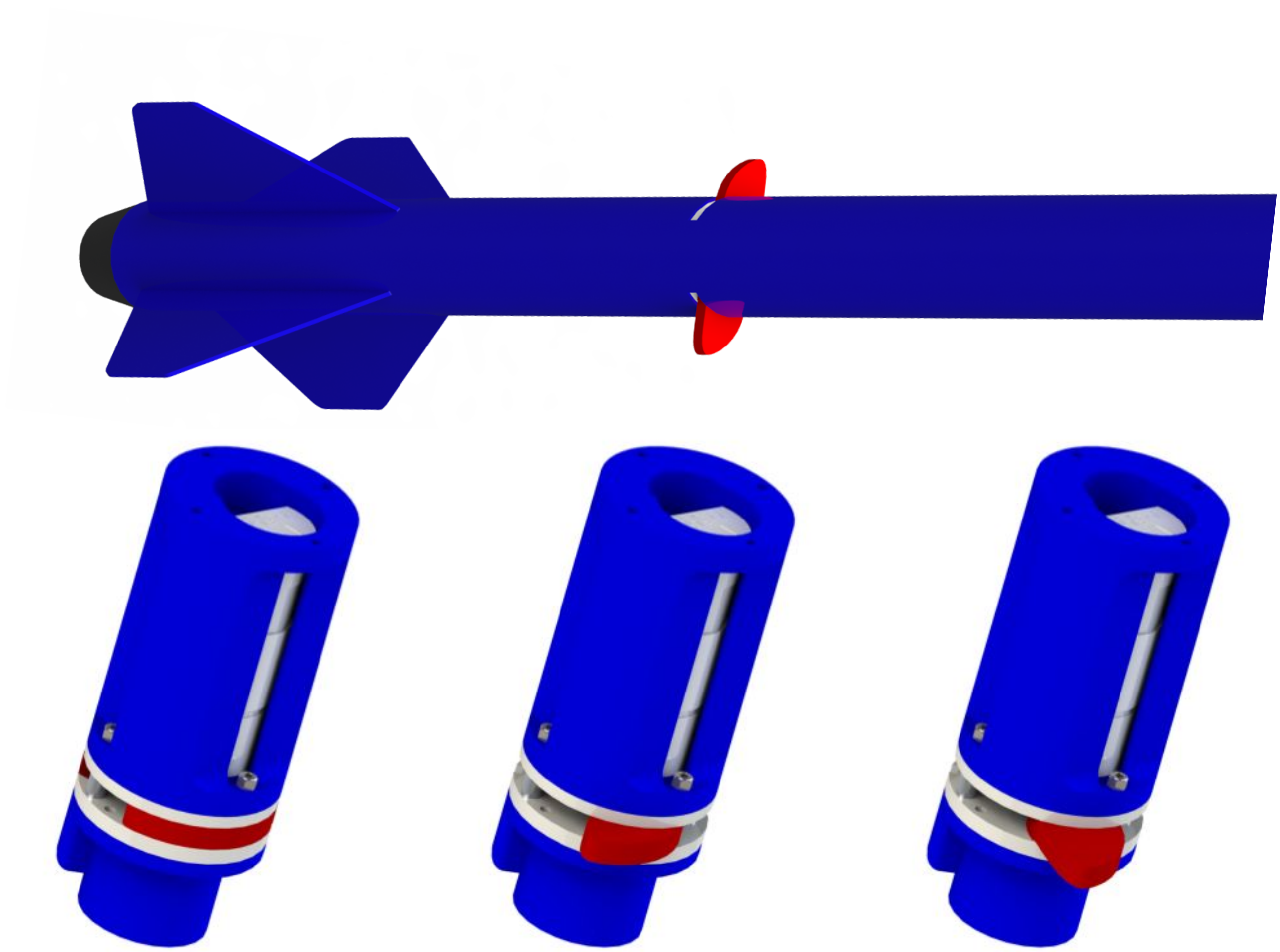


Figure 3-10 The top image is a perspective view of the aft end of the rocket with ADAS in full deployment, the lower row of CAD images depict the internal structure of ADAS at 0%, 50% and 100% deployment

The core of the ADAS system is the NeveRest Classic 40 Gearmotor. This motor drives a central gear which meshes with the fins which when driven will rotate and protrude out of the rocket's body. This central gear is 3D printed in addition to the fins. These fins pivot around two bolts located to maximize the amount of fin area rotated out of the rocket when ADAS is deployed. The ADAS fins are constrained by an upper and lower plastic plate, providing a low friction surface for the fins to slide against. The

ADAS system is mounted to the rocket via a 3D printed casing, the top most surface of which is bolted to the bottom of the aft avionics sled and the base of which serves as the end stop when the complete avionics sled is integrated into the rocket.

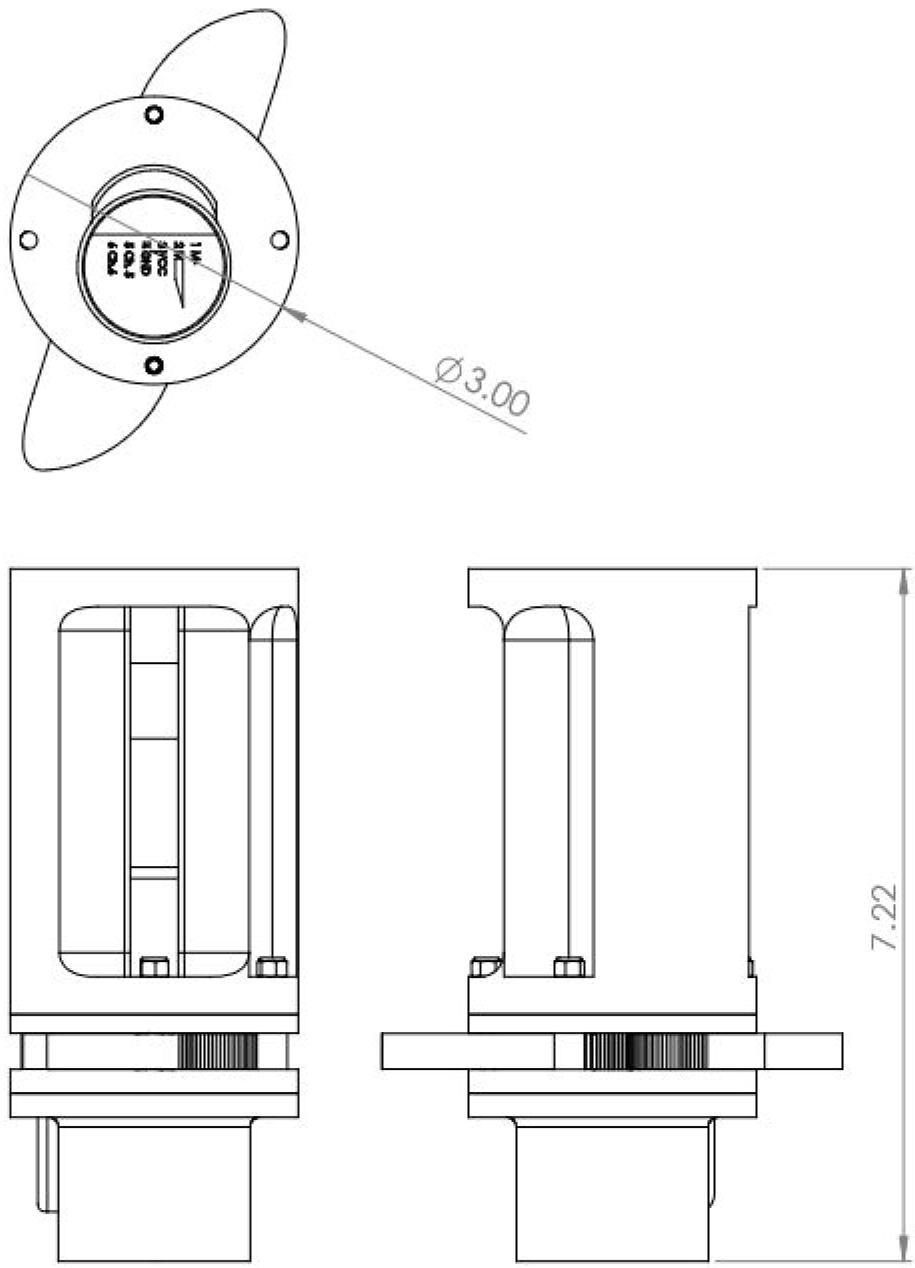
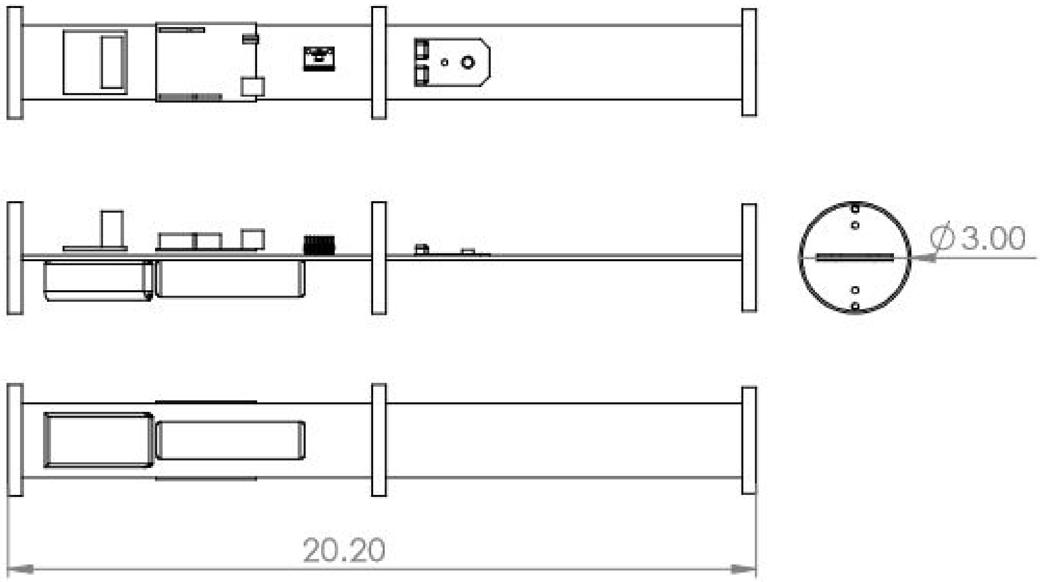


Figure 3-11 Shows the primary overall dimensions of the ADAS Assembly in inches

3.1.3.3 Aft Avionic Bay



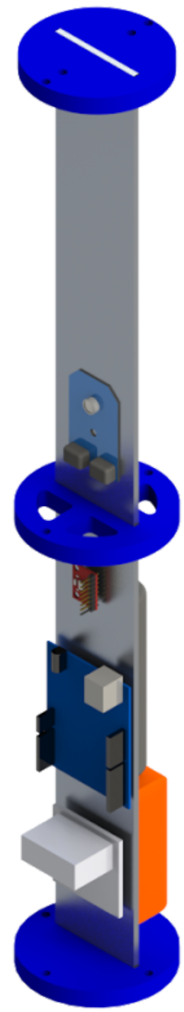
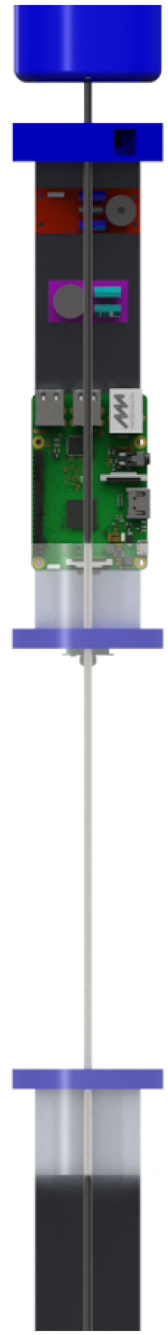


Figure 3-12 Depicts a CAD Rendering of the Aft avionics bay to the right and general dimensions of the avionics bay above.

The Aft Avionics houses the arduino 101 which function as the rocket's primary flight computer in addition to a sweet of sensors and the electronics necessary to control the ADAS Electric motor. These include the Arduino 101 flight computer, the MS5607 altimeter module, MPU6050 accelerometer, the H-Bridge necessary to control the ADAS motor, the ADAS electric motor battery, and the battery to power the Arduino 101.

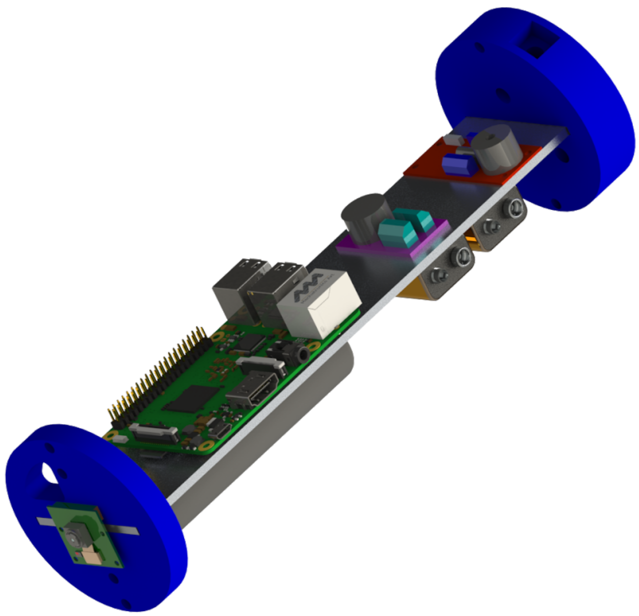
3.1.3.4 TARS



The TARS Payload is situated between the aft and forward avionics bays. The payload consists of a clear window section, through which a downward facing camera secured to the bottom of the forward avionics bay can view the ground as the rocket ascends. The stresses of the airframe are transmitted through this clear section which is made of polycarbonate, which has proven to forces. The load of the parachutes during descent and deployment is transferred via a pair of all threads which only span the length of the window, between the two bulkheads on either side of the window. These secondary all threads pass parallel to the major all thread which span the length of both avionics sleds. The Image processing is accomplished by a Raspberry Pi 3.0 included on the lower half of the forward avionics bay.

The polycarbonate section of the airframe extends for 12in. The upper and lower window couplers both overlap 2 inches into the window section. Thus the overall unobstructed window is 8 inches. The outer diameter of the window section is 3.1 inches to match the outer diameter of the airframe.

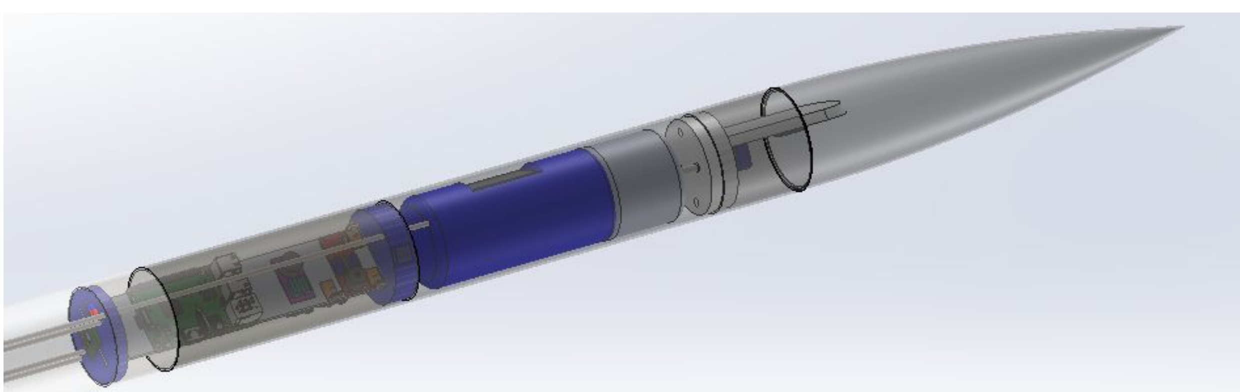
3.1.3.5 Forward Avionics Bay



The forward avionics bay houses the computer for the TARS payload in addition to both of the redundant altimeters responsible for parachute deployment and the associated batteries for these systems. The raspberry pi v2 camera which records video for the TARS payload is mounted to the aft bulkhead of this avionics bay such that is faces downward into the clear window section of the airframe.

The overall length of the sled is 10 inches. The diameter of each bulkhead is 3 inches in order to fit within the airframe.

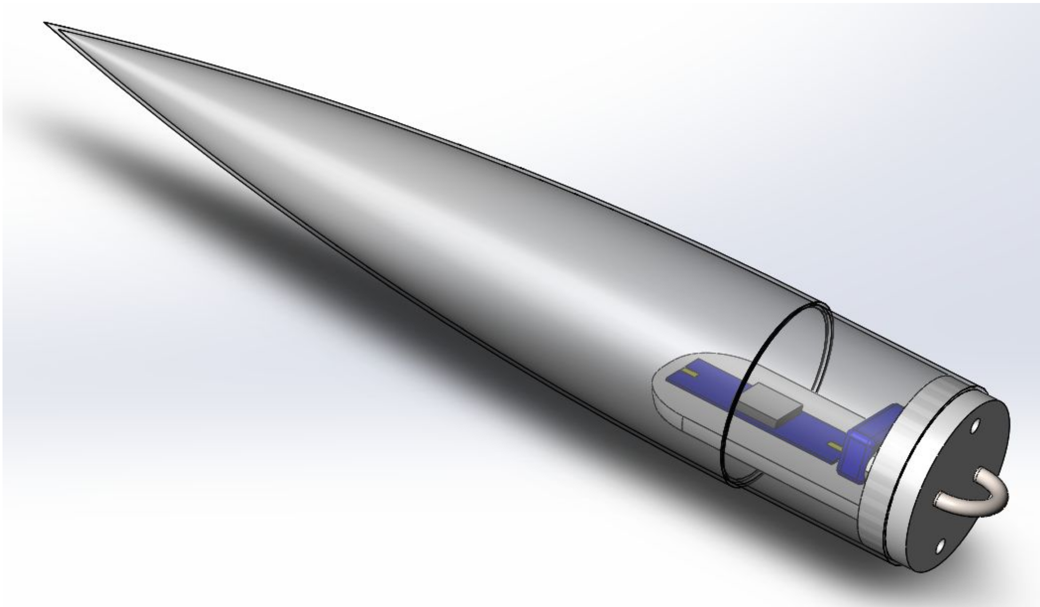
3.1.3.6 Recovery Section



The recovery harness will be consist of a 20ft shock cord made of Kevlar Cord 1500#. Along this cord will be attached a 24 inch nylon drogue and a 48 inch Fruity Chutes: Iris Ultra main parachute via swivel joints.

The recovery bay section provides a volume to house the parachutes 10 inches in length and 3 inches in diameter to match the inner airframe.

3.1.3.7 Nose Cone/GPS



The nose cone is 16.13 inches overall in length with 3 inches of that length consisting of the shoulder. A 3D printed part in bonded to the inside of the nose cone to provide an attachment points for the GPS sled.

As described in the PDR, the Eggfinder GPS transmitter will be placed onto the sled and used to accurately track and locate the real-time coordinates of the rocket. Eggfinder has not been set-up and tested as of this writing, however, but the wiring diagram is again displayed for reference in Fig. 3-17.

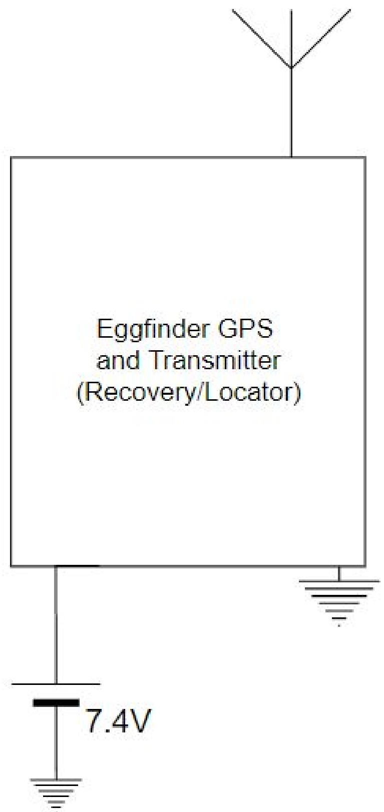


Figure 3-17 Eggfinder GPS Transmitter Circuit

3.1.4 ADAS

As described initially from the PDR and seen in Section 3.1.2, ADAS will play the key role of the E-1 rocket's accurate ascent to an apogee of 5,280 feet. The system is realized through an electric motor powered by a microcontroller handling sensor data to determine when to deploy and retract the drag fins connected to the motor. This module eliminates the need to use ballast weights or other components to adjust peak height of the vehicle's flight as it is a self-aware manifestation of altitude control.

3.1.4.1 ADAS Electronics

Since the PDR, some electronics responsible for control and operation of ADAS have been modified, or entirely new components added, to better handle the needs of the system as it currently intends to be used.

3.1.4.1.1 Altimeter

As discussed by the PDR, the ADAS flight controller requires real-time information on altitude, and thus an altimeter is needed for such data. Original plans were to use a HP206C altimeter, but that has since changed to a MS5607 device. This altimeter uses a MEMS barometric pressure sensor to report its altitude, similar to the HP206C, but has a smaller form factor and uses 3.3V digital signals, which works with the Arduino 101 digital voltage levels.

3.1.4.1.2 IMU

Instead of occupying the lower avionics with two separate sensors (accelerometer and gyroscope), it was instead decided that an IMU would suffice. A MPU6050 was chosen as a suitable component. The replacement here allows for a comparison between the onboard IMU of the Arduino 101 and this external device, helps increase space in the lower avionics, and will allow for more data in the software processes of ADAS.

3.1.4.1.3 Limit Switch

Although the ADAS motor reports change in angular position, it does not report absolute position. In order to ensure a known starting position, and to indicate the position in which the ADAS fins are fully retracted, an optical limit switch was added to each ADAS fin. Optical limit switches were chosen because of their shock tolerance and repeatability.

3.1.4.1.4 LED

A status LED was added to the Arduino 101 to allow for visual feedback indicating the Arduino 101 power state and to report data recording errors.

3.1.4.2 ADAS Software

The ADAS software has been meticulously planned out and has many major components.

1. <u>Start Sequence</u>
    a. Once the ADAS system is live, it collects data determines if it has launched yet. Once it has, pass execution to Feedback loop.
2. <u>Feedback loop condition</u>
    a. Determines if rocket has hit apogee.
        i. If no, continue loop.
        ii. If yes, commence cleanup.
3. <u>Commence of cleanup</u>
    a. Clean and save and data, retract ADAS fins.
4. <u>Sensor Interface</u>
    a. First thing at start of iteration is to read sensor data.
    b. Interface with gyroscope driver.
    c. Interface with accelerometer driver.
    d. Receive x,y,z values from both and store in variables/data structure.
5. <u>Kalman Filter</u>
    a. Feed raw sensor data into kalman filter.
    b. Apply weights on sensors and models.
    c. Initial state creation if beginning of feedback loop.

    d. Can be done recursively, but that will take up too much stack space. Using loop techniques.

6. Calculate dt
    a. Change in time since last loop iteration.
    b. Interface with clock hardware.
7. 3.D. Calculations
    a. With updated sensor data and dt:
        i. += linear acceleration (x,y,z,t) <- from kalman filter.
        ii. += linear velocity(x,y,z,t) <- integration from linear acceleration.
        iii. += position(x,y,z,t) <- integration from linear velocity.
        iv. += angular acceleration(x,y,z,t) <- from kalman filter.
        v. += angular velocity(x,y,z,t) <- integration from angular velocity.
        vi. += angle(x,y,z,t) <- integration from angular velocity.
8. Integration Function
    a. Trapezoidal Integration.
9. Write data to SD Card
    a. Interface with SD card driver.
    b. Must write 18 new values from 3.D. calculations to log.
10. Calculate Control Variables
    a. |Angle(t)|.
    b. acceleration(t).
    c. velocity(t).
    d. altitude(t).
    e. Calculate using 3.D. Calculations and |angle(t)|.
    f. Pass control to ADAS Control.
11. ADAS Control Start Condition
    a. ADAS does not deploy during burn phase, determine state from acceleration.
12. Get model stats
    a. Recieve best fit data from function provided by modeling team.
13. Calculate deltas
    a. Calculate deltas between best fit model and current control variables
14. Calculate f
    a. Calculate f from equation .
15. Deploy ADAS f
    a. Interface with DC motor
    b. Deploy it f
16. Return control to feedback loop from ADAS control system

3.1.5 Design Completeness and Readiness

The resemblance of the subscale rocket to the full scale rocket and the subscale rocket's success shows the designs maturity. The completion of the subscale rocket has demonstrated a majority of the manufacturing techniques required for the full scale rocket. Thus the components of the design not present in the subscale rocket will be the primary concerns for readiness.

ADAS was not included in the subscale rocket. However the team has acquired the motor and the necessary electronic components to drive the motor on a workbench. The components left to manufacture are the 3D printed casings, gear, and fin/gears. With a complete CAD model of the system, and the team's proven ability to manufacture parts with the 3D printer we have access to, the ADAS system is ready to manufacture.

The only other different component of concern is the GPS. The mounting sled has already been manufactured and was integrated into our subscale rocket. The GPS and its associated battery are on order and will be ground tested extensively when both components arrives.

3.1.6 Integrity of Design

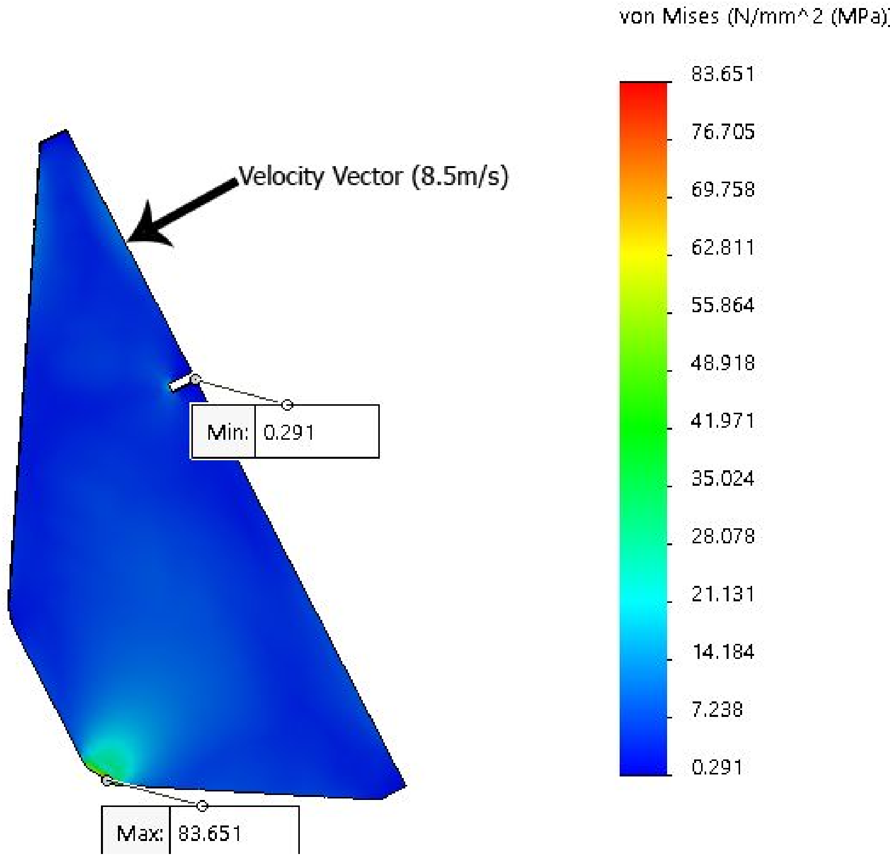
3.1.6.1 Fin Shape and Style

The fin shape was selected to provide the proper surface area needed to stabilize the rocket, while also minimizing the drag that the fins created in addition to being shaped such that a direct impact with the ground would pose a minimal risk to snapping one of the fins. These characteristics were incorporated into the design of the fins in CAD which were then imported into OpenRocket for full simulation and refinement. The final fin design as presented in the document have been found to sufficiently meet each of these criteria.

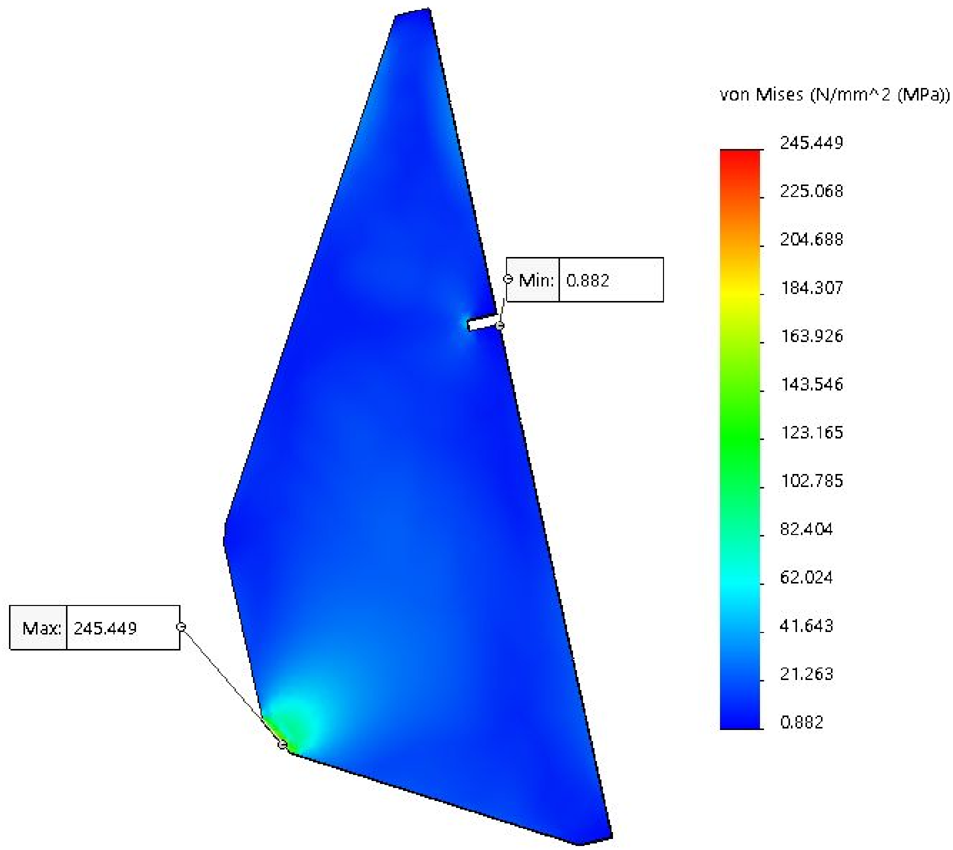
3.1.6.2 Proper Materials

3.1.6.2.1 Fins

The fins will be constructed from ⅛ inch G10 fiberglass sheets. A number of drop tests were simulated to ensure that the fins made of this material and of the proposed geometry could survive a landing, during which the fin was directly impacted. The following figures describe the result from these simulations.



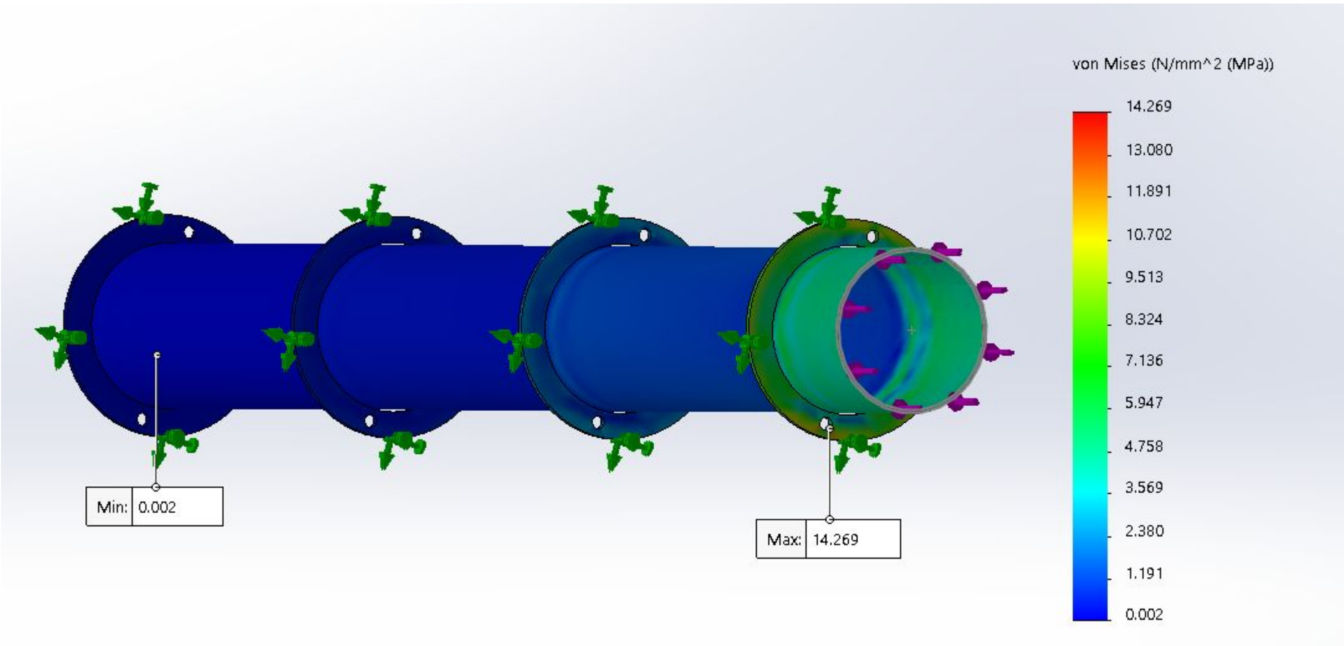
Drop Test Figure 1 shows a drop test study that simulates the touchdown of the rocket carried by the main parachute of 8.5 m/s, with added velocity to account for tangling and an increased mass of the rocket, onto the edge of a singular fin. The test reveals that such a landing will result in a maximum pressure of 83.65 MPa at the tip of the fin, below the breaking threshold of the fiberglass used. We used G10 Fiberglass for the fins which has been found to have a Tensile Strength at Break of between 268 and 310 MPa.



Drop Test Figure 2 is the same as the previous Fin Drop Test, but with a drop velocity of 25 m/s. This is in the event of the main parachute failing to deploy, along with added velocity for an increased mass. While the maximum pressure was found to be 245.449 MPa, below the breaking point of G10 Fiberglass, the simulation shows that there is still a chance for the fin to break upon a direct landing.

3.1.6.2.2 Bulkheads

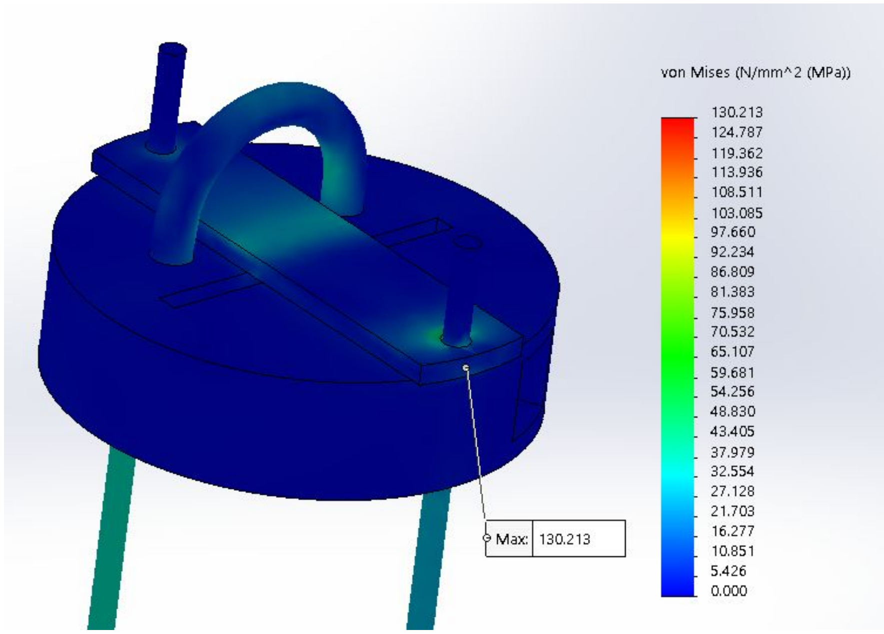
This motor tube is bonded to the airframe via a series of three centering rings and a top bulkhead each made of G10 fiberglass of 0.09" (0.24 cm) thickness. Stress simulations were performed to verify that the design and material was sufficient to withstand the max thrust generated by possible motor choices of 900 Newtons. The results are displayed in the following figure:



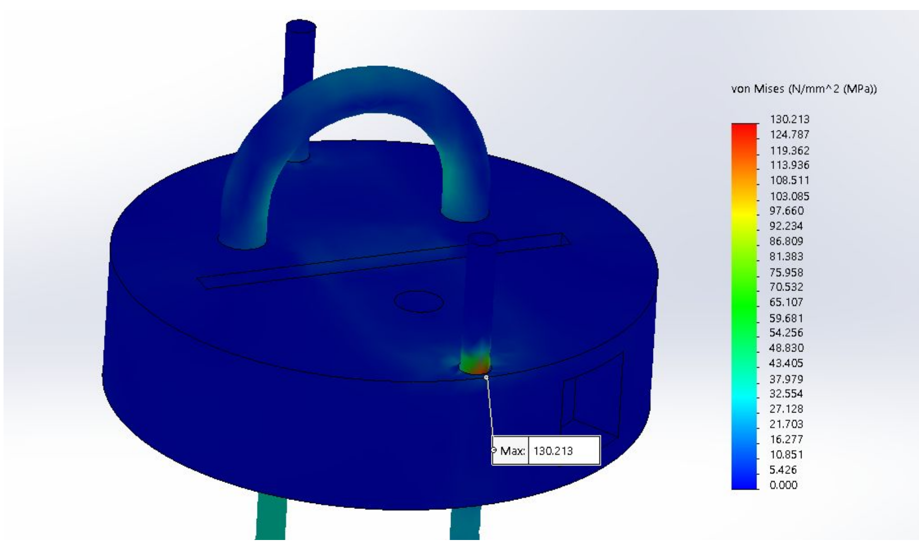
Bulkheads Stress Test Figure 1 shows the stress propagating through the centering rings and motor tube at the maximum thrust provided by possible motor choices, 900N. The maximum stress is below the breaking threshold of the fiberglass. The majority of the force of the engine was found to be transferred to the airframe of the rocket via the first two centering rings. The others centering rings are included to stabilize of the motor mount in addition to serve as backups incase the first two break.

3.1.6.2.3 All threads/Upper U-Bolt Recovery Support Structure

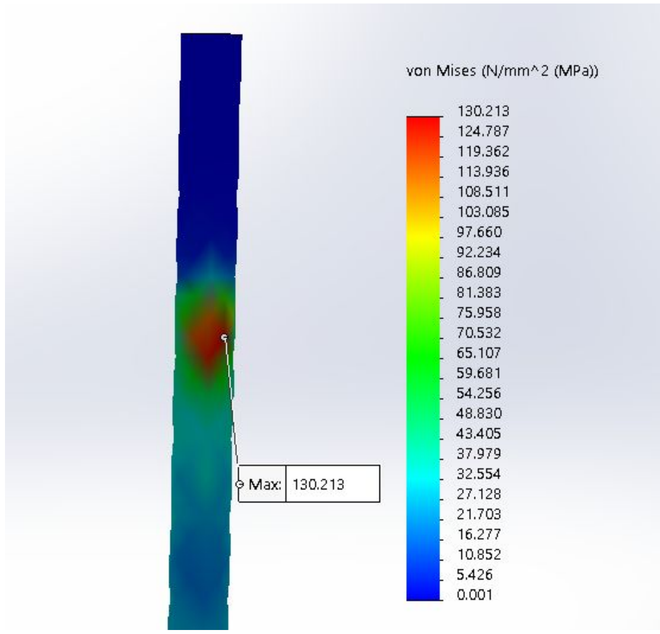
The all threads included in the vehicle design serve both as rails for the avionics sled to slide onto and as structures to transfer the load of the parachutes to the airframe. A force of 100N was found to be the expected load during the deployment of the main chute as the rocket transitions form descent under drogue. In order to prove sufficient capability of the designed structure to withstand the expect loads, a maximum yank force of 800 Newtons was used in the simulations to evaluate the design. This force was applied the upper U-Bolt which is the attachment point of the recovery harness will be attached to. The components included in the simulation are the two all threads (which are fixed at their aft surface to mimic their securement to the thrust section), the upper bulkhead of the avionics bay (through which some the load is distributed to the all threads), the Upper U-Bolt which is attached to the top bulkhead of the avionics bay (the recovery harness is attached to this component and thus the force will be applied to this component), and the plate which crosses between the all threads to secure the avionics bay in place. The following figures show the results of the simulation:



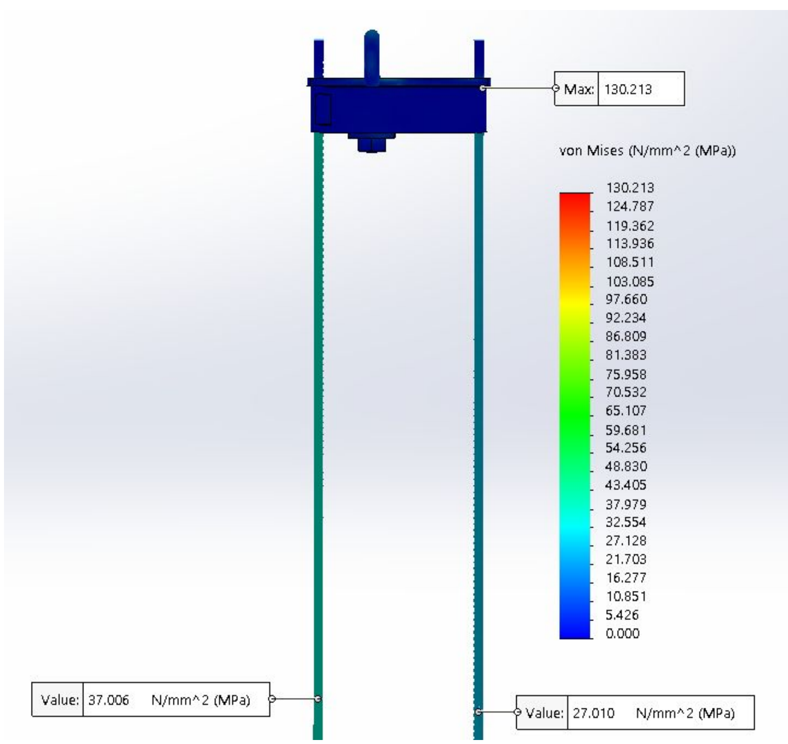
Recovery Structure Stress Figure 1 Illustrates the force exerted on the Upper-Bulkhead system during main chute deployment of 800N. The maximum pressure was found to be 130.213 MPa located on one of the all-threads (shown in following figures). It was found that there is very little pressure on the bulkhead and the majority of the pressure is exerted on the all-threads and U-Bolt.



Recovery Structure Stress Figure 2 focuses on the maximum force exerted on the system. The photo has the aluminum plate removed so as to show the location of the maximum force. We can see that force is located on the all-thread further most from the U-Bolt. This attributed to the leveraging action from the U-Bolt pulling the aluminum plate when the parachute is deployed. The same force is not found to exist on the opposite all-thread, which further proves our hypothesis.



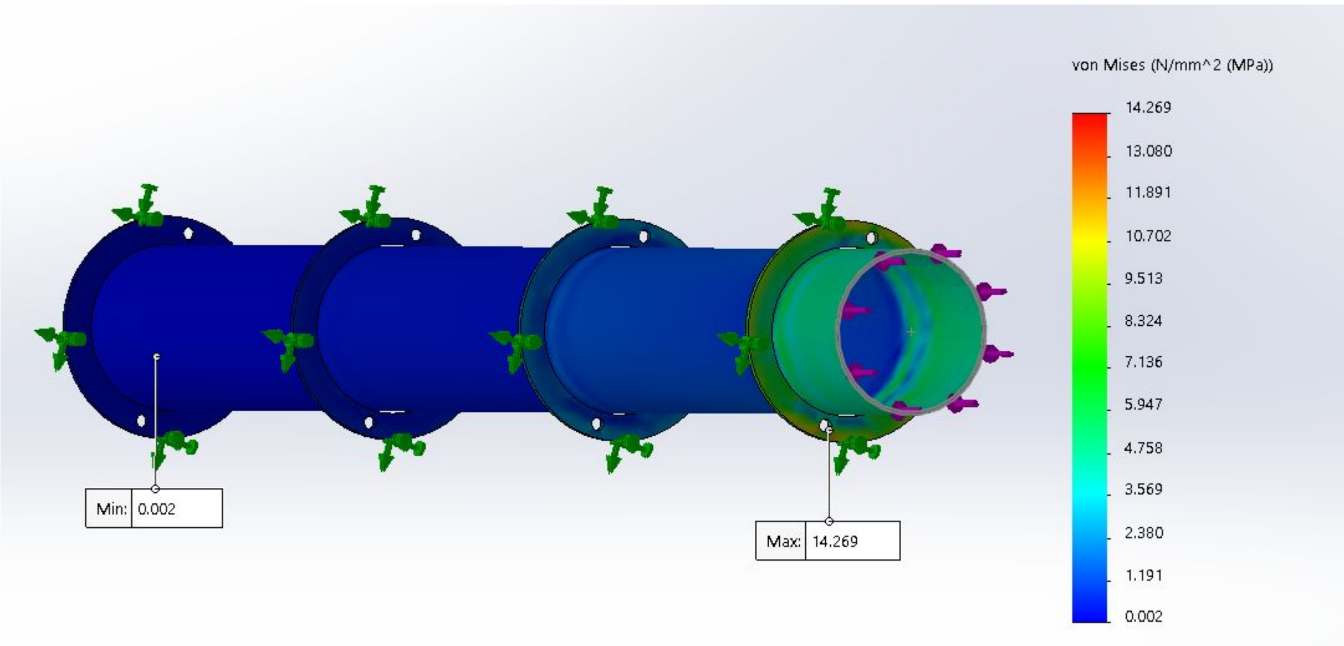
Recovery Structure Stress Figure 3 focuses on the all-thread with which the maximum pressure is located. We can see that the pressure is only applied in a small area relative to the rest of the all-thread.



Recovery Structure Stress Figure 4 shows the difference in stress that is exerted on the all-threads from the parachute deployment. We can see that more pressure is applied to the all-thread closest to the U-Bolt, as the U-Bolt is located off center on the bulkhead.

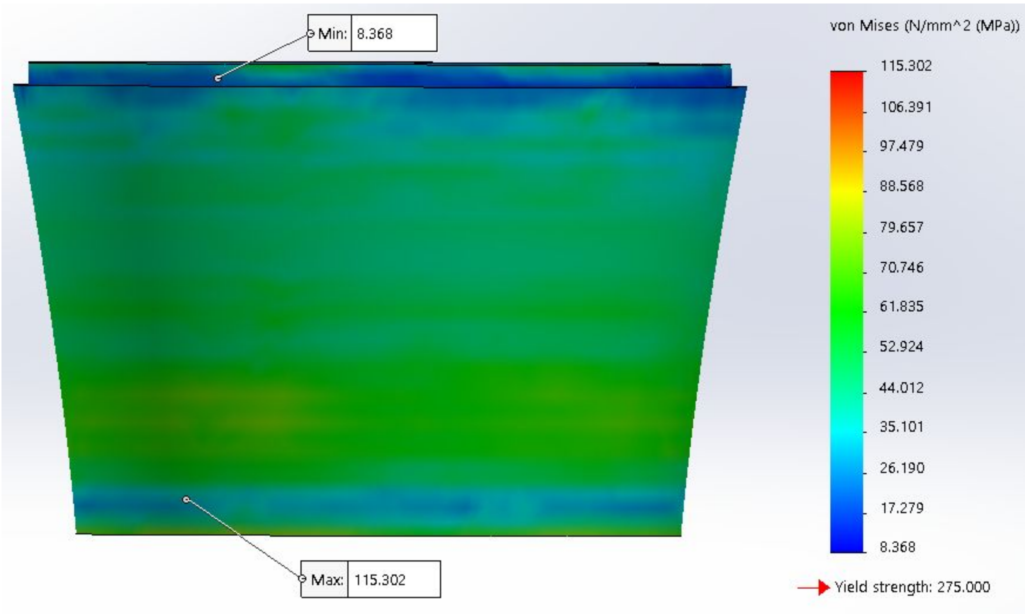
3.1.6.3 Motor Mounting and retention

The motor is housed within a 2.152" (5.47 cm) inner diameter, 2.230" (5.66 cm) outer diameter Fiberglass G12 tube. This motor tube is then bonded to the airframe via a series of three centering rings and a top bulkhead. A stress simulation was performed to verify that the design and material was sufficient to withstand the max thrust generated by motor choices of 900 Newtons. Within the same simulation discussed in the Bulkheads section, the motor tube was also proven to be sufficient to withstand the thrust of the rocket.

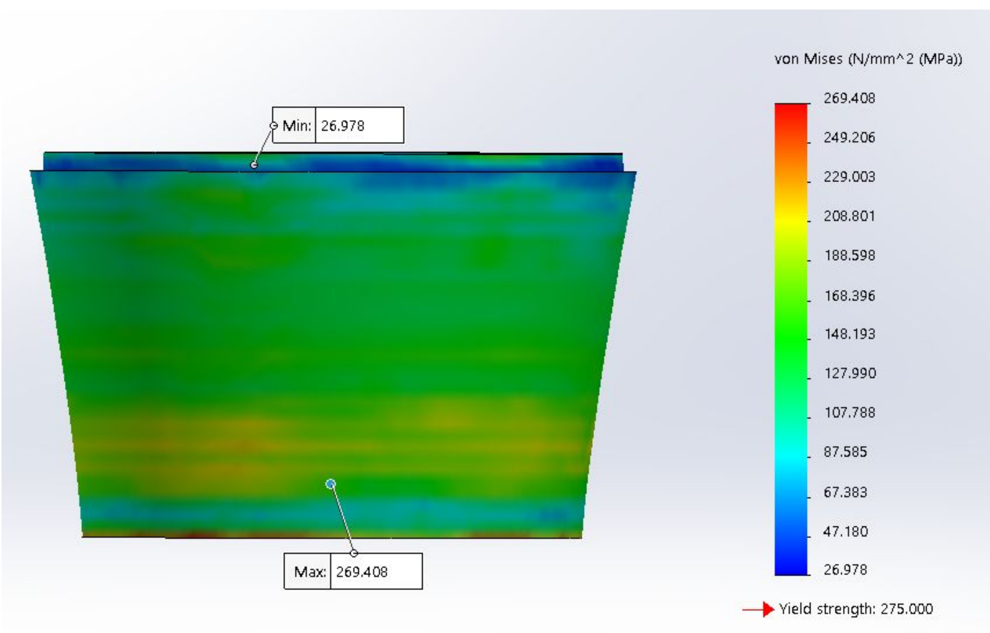


Motor Mount Stress Test Figure 1 shows the stress propagating through the centering rings and motor tube at the maximum impulse provided by the chosen motor, 900N. The maximum stress on the motor tube is found to be localized to the aft end of the motor housing. It was found that the motor mount and material was sufficient to withstand the expected loads.

Motor retention is achieved via a 54L/3" tail cone retainer. As a commercially available motor retainer the component has a proven history of sufficiently retaining high powered rocket motors. This ability was also proven during the subscale flight when a similar motor retainer was used for that flight. Stress simulations were performed to investigate the motor retainer's behavior during a direct impact with the ground. The results are presented in the following figures.



Tailcone Drop Test Figure 1 simulates a landing on the tail cone at velocity of 8.5 m/s. This velocity was chosen as it accounts for tangling of the parachute. The maximum pressure exerted on the tail cone was found to be 115.302 MPa, only a fraction of the Ultimate Tensile Strength of the aluminum used of 310 Mpa.



Tailcone Drop Test Figure 2 simulates a landing on the tail cone at a velocity of 25 m/s. This is in the event the main parachute failing to deploy. The maximum pressure reaches 269.408 which, again, is under the breaking point of the aluminum used. While the tail cone is not expected to fail, it is likely that the force will travel upwards in the rocket, potentially damaging the airframe and other sensitive components.

These simulations have proven that the motor mount is sufficient to withstand the maximum thrust of the motor and transfer the loads to the airframe. Additionally, the tail cone has been proven sufficient to retain the motor even during a direct impact with the ground after descent.

3.1.6.4 Mass

The final mass of the rocket is projected to be 4.49 kg. The mass of each subsystem is predicted to be:

- Thrust Section [1766 grams]
- Adaptive Drag Aerobraking System (ADAS) [702 grams]
- Aft Avionics Bay [551 grams]
- TArget Recognition System (TARS) [350 grams]
- Forward Avionics Bay [437 grams]
- Recovery Section [416 grams]
- Nose Cone/GPS [297 grams]

Based on these mass prediction, the team will be able to add a maximum ballast of 0.44 kg to the rocket in accordance with the requirement 2.21.8

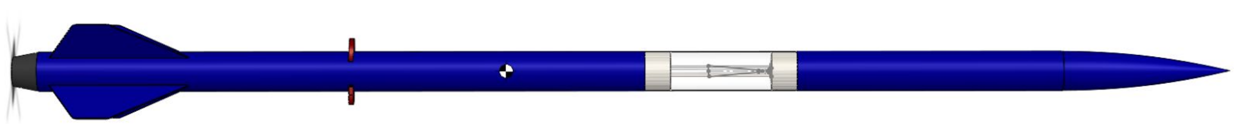
3.1.7 Unique Design Justifications

Effective - 1 features a number of unique design decision. The thin diameter of the rocket was one of the first decisions made when designing the vehicle in order to reduce the cross section and thrust drag of the rocket. As a result of the thin diameter, the electronics required a vertical mounting style to fit and thus in order accommodate everything, the rocket is tall.

The all thread rail system was design to avoid the “box inside a box” principle of the traditional avionics bay structure and additionally offered improved ease of access.

The downward facing camera and clear section of TARS was the result of an extensive optics study explored in the PDR.

The ADAS was found to be the aerobraking solution within the team’s current manufacturing capabilities. The location of ADAS was chosen to ensure that the rocket remained stable during all phases of ADAS deployment. This positions the protruding fins behind the rocket CG per rule 2.20.



ADAS and CG Figure 1 ADAS deployed relative the the rocket CG

The GPS location was selected to be housed within the nose cone to avoid any interference by the other electronics or the large steel all threads.

3.2 Subscale Flight Results

The subscale rocket, *She'll Be Right* (*SBR*), is designed to be very similar in structure to the full-scale vehicle, *Effective-1*. The competition rocket is planned to have the same diameter, fin profile, airframe, CG and CP, total length, and recovery system. *E-1*, however, will weigh approximately 20% more (not including ballast mass), have a modified payload sled, include the aerobraking system ADAS, and have a 10% longer recovery bay to accommodate a larger parachute. The most important difference between the vehicles is that the subscale rocket's motor mount accommodates 38mm-class motors, whereas *E-1* will house a 54mm motor mount. Nonetheless, *SBR* serves as an excellent benchmark for the flight performance of *E-1*, and provides a testbed for the avionics, recovery, and payload technologies. It will serve to provide insight and improvements into the design of the full-scale rocket.

As of the writing of this document, there has been one flight of *SBR*. The test launch was successful on all counts: the vehicle performed as expected with no hazards or failures. The flight also yielded very high-resolution accelerometer and altimeter data, as well as onboard camera footage. The subscale flight, as well as its measured telemetry, are discussed in detail in this section.

3.2.1 Subscale Motor Selection

An Aerotech J420 motor was used for the subscale flight. The primary motivation behind motor selection was to test the performance of the vehicle at high velocity and acceleration. This was to ensure the build quality of the airframe and fins, and most importantly, the motor mount assembly. Models showed that the selected motor would accelerate the vehicle to ~120 m/s with a peak acceleration of ~10.5 G. These conditions are similar to the projected flight characteristics of *E-1*, ensuring a valid stress comparison. Models also projected an apogee of ~760 m, keeping the rocket in sight for the entirety of the flight. This was the deciding factor: visual confirmation of the vehicle's successful recovery deployment was a key element of the test launch.

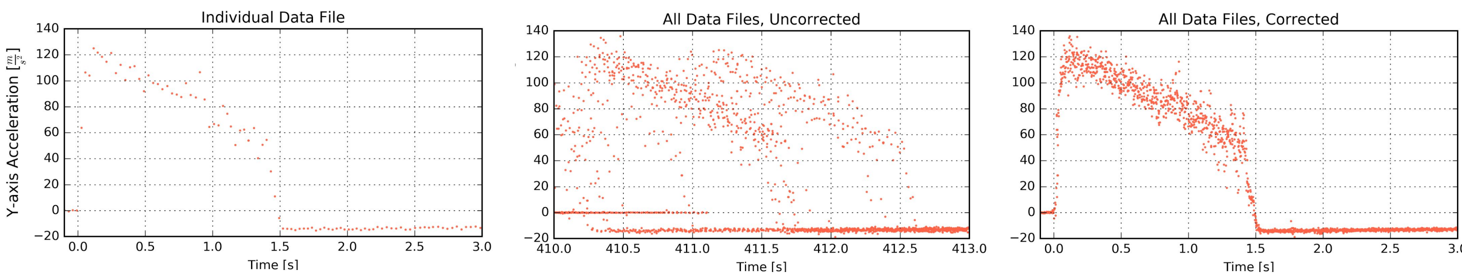
Total Impulse	Average Thrust	Max. Thrust	Burn Time	Wet Mass
658.0 N	420.0 N	563.5 N	1.6 s	0.65 kg

3.2.2 Launch Conditions

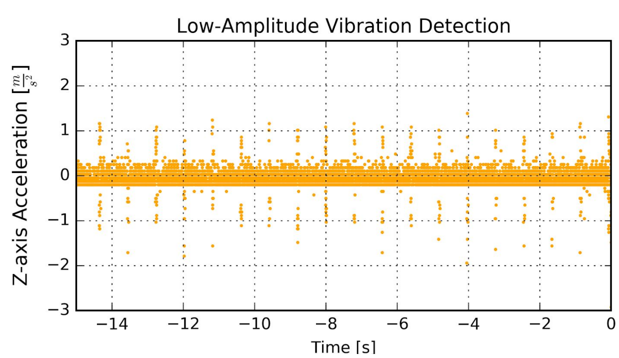
The vehicle was launched from Snow Ranch, a cattle ranch often used by LUNAR for launch events. The air temperature was ~20° C, with minimal wind. From a simple analysis of the video footage, the vehicle's exhaust plume traveled approximately 100 meters in 100 seconds, yielding an average wind speed of ~1 m/s. There were no clouds visible.

3.2.3 Data Properties and Reduction

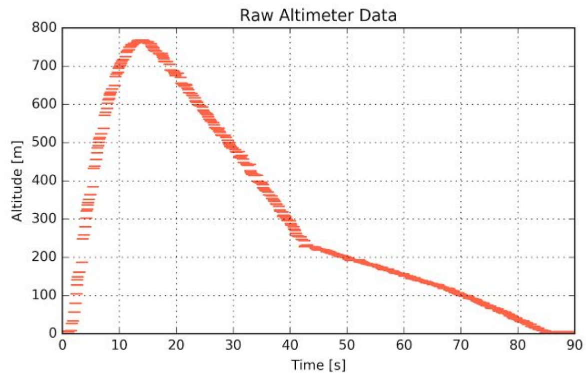
Due to an unforeseen software issue, the flight computer saved the data points into several separate files. Each file's time signatures were inconsistent with each other, resulting in multiple low-resolution recordings of the flight offset in time. The low resolution of the individual launch profiles made them unusable for analysis. However, a detailed and robust approach was taken to effectively combine the datasets into one. Each time array was normalized to the weighted center of the vertical acceleration thrust curve. That is, the centerpoint of each file's measured thrust profile was used as a standardized starting point for the time arrays. Minor (< 0.1 s) by-eye adjustments were performed to maximize the quality of fit. While the original data rate could not be fully recovered, this combined dataset has a high resolution and smooth, self-consistent features.

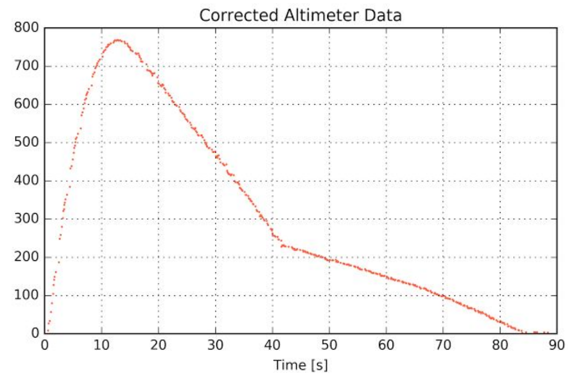


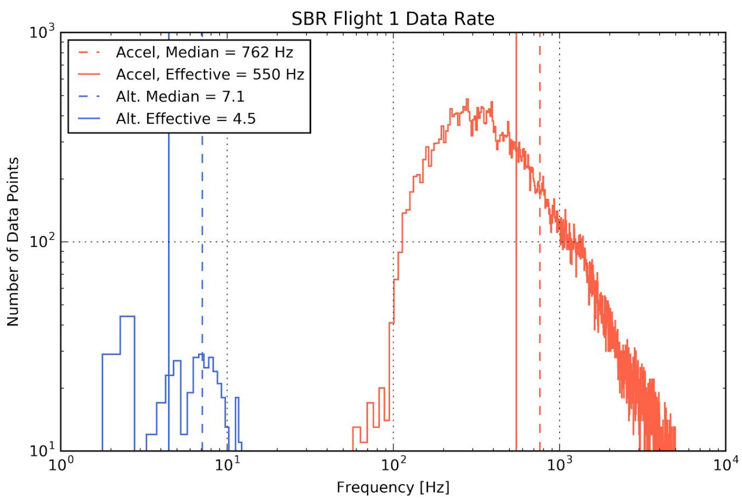
This corrective measure revealed the exquisite sensitivity and time resolution of the ADXL345 accelerometer. Very low amplitude, short-duration acoustic pulses were detected emanating from the beeping Stratologger system, which has the same time signature. These pulses propagated through the interior structure of the rocket, creating minute perturbations of the accelerometer along one of its axes. This detection validates the data reduction technique used and demonstrates the quality of data recorded.



The resulting data rate is not constant due to the imperfect alignment method and the unstable timekeeping of the Raspberry Pi. Rather, there is a data frequency distribution, with a nominal frequency of 550 Hz for the accelerometer. The altimeter data shows additional issues. Namely, the measured altitude profile contains several redundant points that make analysis impossible. To correct for this, we write a function to select only unique data points with their respective minimum time. This removes the redundant data points and leaves the relevant ones. The cause of this error is not known definitively.





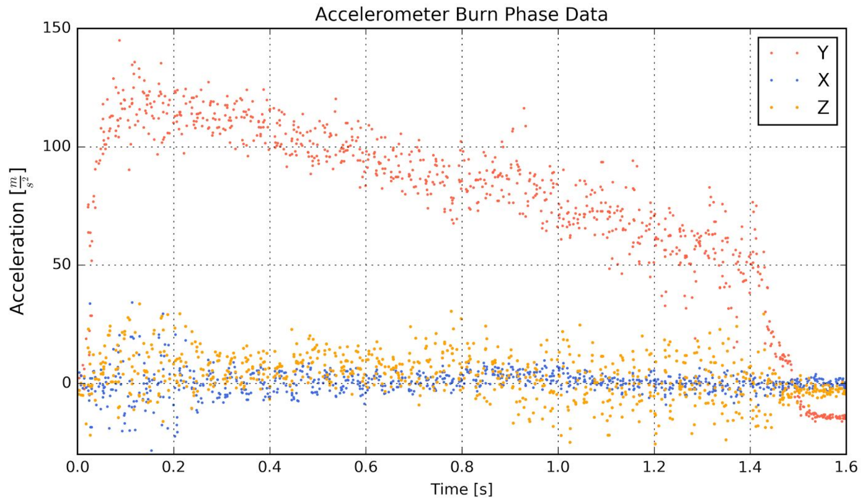


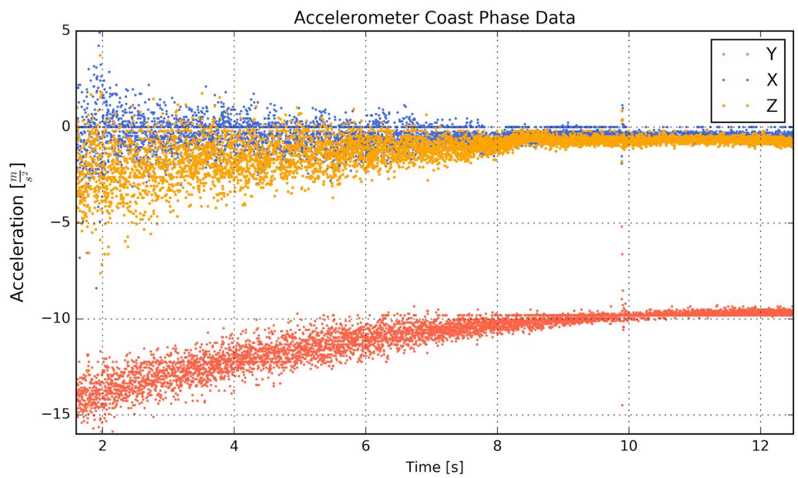
The data rates achieved vary between the accelerometer and the altimeter. The accelerometer achieved a nominal effective rate of 550 Hz, whereas the altimeter underperformed and reached a nominal rate of 4.5 Hz. Nonetheless, the altimeter data was sufficiently high resolution for the purposes of this analysis.

3.2.4 Data Summary

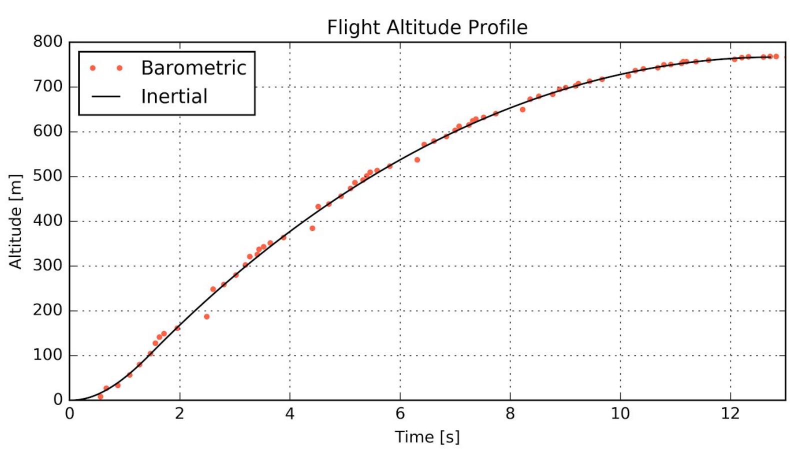
3.2.4.1 Ascent

The onboard accelerometer recorded reliable data for the duration of the ascent. Significant scatter was measured in all 3 axes. The scatter in acceleration due to turbulence is high in amplitude (up to ± 20 m/s^2). Between 0.2 and 0.9 seconds, high-frequency oscillations are apparent in the x-axis data. It appears that these oscillations begin at rail exit and decay in amplitude as the rocket accelerates. The oscillation frequency and damping coefficient relate to the lateral drag properties of the rocket, as well as its stability margin. The one-sidedness of this affect (the fact that it is more present along the x-axis than the z-axis) suggests that the oscillation occurred along one axis of the rocket, perhaps fixed by a pair of fins. The increasing stability margin worked to correct a perturbation of the rocket's angle. It is also possible that these are spin artifacts due to poor mounting of the accelerometer away from the rocket's CG. However, these effects are minor and beyond the scope of this analysis. These flight properties are not detrimental to the flight performance of the rocket, nor its safety margin, as they are transient and low-impact effects.





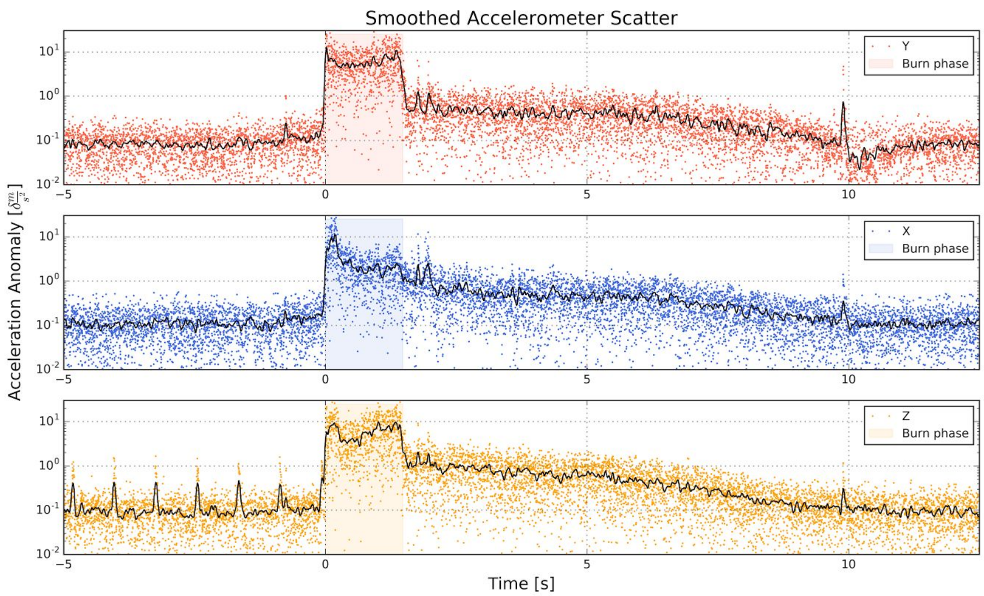
A simple numerical trapezoidal summation integration scheme is used to solve for the velocity and subsequent position profile of the rocket in the inertial reference frame. Remarkably, the altimeter and accelerometer yield apogees of 768.7 and 766.5 meters, respectively. This corresponds to a disagreement of $< 0.3\%$. This demonstrates the stability of the sensors, the stability of the weather conditions, and further validates the data reduction methods.



Peak Acceleration	Time to Apogee	Maximum Velocity	Inertial Apogee	Altimetric Apogee
136 m/s^2	12.5 s	124.7 m/s	766.5 m	768.7 m

3.2.4.2 Turbulence

The vehicle experiences significant turbulence throughout its flight, with high frequency amplitudes of up to 10 m/s^2 during burn phase, and 2 m/s^2 during coast phase. The scatter is at a maximum during the burn phase and decreases sharply at motor burnout. The factor of ~5 enhancement in turbulence during the motor burn phase is likely caused by unstable flow from the nozzle due to small irregularities in the grain. These defects are also likely present in the lateral axes, as the nozzle ejects gas in a conical shape. After



burnout, the scatter in all axes decreases quadratically with velocity. This suggests that the magnitude of the turbulence experienced by the rocket is a function of the force of drag, which also scales with the velocity squared.

The turbulence properties were extracted from the data by subtracting highly smoothed acceleration curves from the full unsmoothed accelerometer curves, yielding only scatter and sharp changes in the profiles over time. The magnitude, (or absolute value) of this residual yields the turbulence properties of the rocket throughout its flight. It is evident that turbulence is an important effect throughout the rocket's flight, implying that it is aerodynamically inefficient, particularly along the lateral axes. We speculate that this is due in part to parasitic drag from the rail buttons and surface imperfections, asymmetrically shaped fins, irregularities in the rocket's aerodynamics due to its high rotational velocity, and turbulent vortices in the rocket's wake.

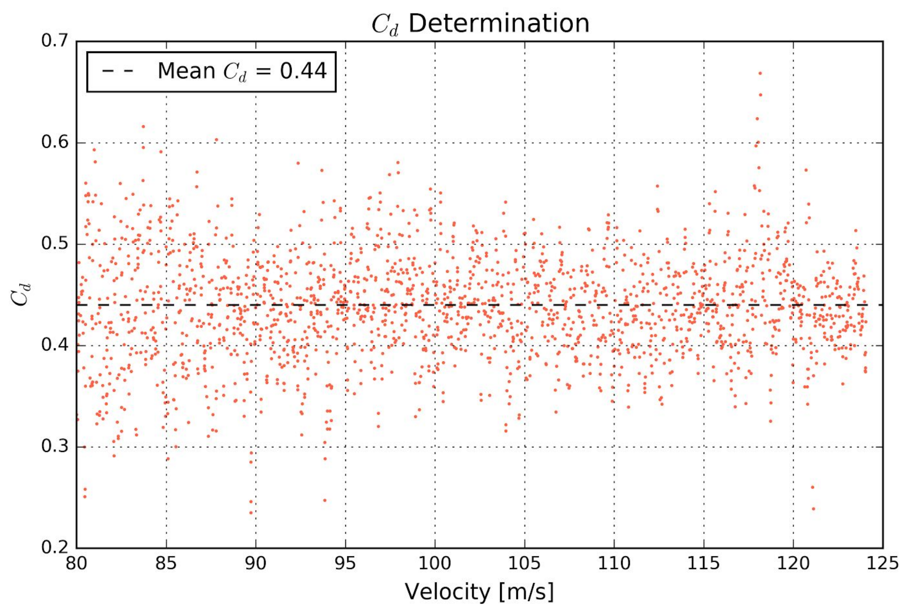
This analysis also constrains the noise floor, or the detection limit, of the accelerometer. The noise limit is approximately 0.2 m/s^2, or 0.02 G at low-G. The noise limit at high-G is unconstrained.

3.2.4.3 Drag Coefficient

An important data product is the vehicle's drag coefficient, C_d. This is measured by calculating the magnitude of the rocket's deceleration during coast phase as a function of velocity. The drag force experienced by a moving body is given by

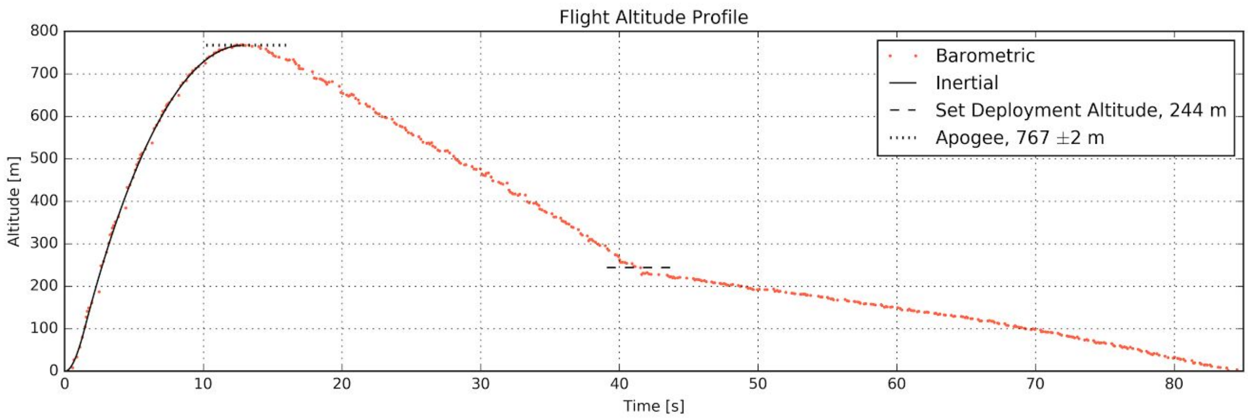
$$F_D = \frac{1}{2}\rho_{air}(z)\, v(t)^2\, C_D(v)\, A_{eff}$$

Where C_D is the drag coefficient and A_{eff} is the effective cross sectional area. The density of air varies with altitude, and the drag coefficient varies with rocket velocity. Using the smoothed coast phase deceleration profile, the integrated inertial velocity, an estimate for the effective cross sectional area, and an altimeter-derived air density profile (which is discussed later), we find the drag coefficient of the vehicle as a function of velocity. The coast phase deceleration is not useful at low velocities, as the rocket's angle changes near apogee. This skews the vertical deceleration measurements, yielding an unrealistic estimate of the drag coefficient. The coefficient is stable over medium and high velocities at 0.44.

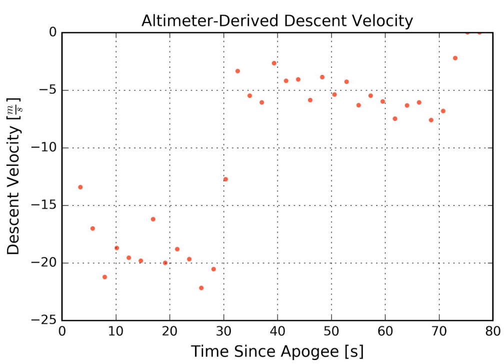


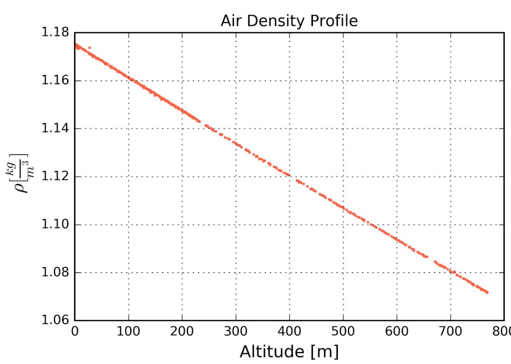
3.2.4.4 Descent

The parachute descent data was of very high quality and resolution. The main result of this portion of the dataset is that the parachute system was successful in recovering the vehicle.

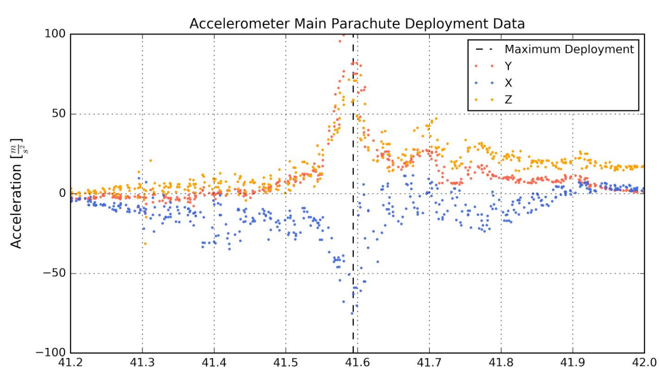


The parachute descent data provided by the altimeter yielded a descent velocity and the density of air as a function of altitude. The drogue and main chute descent phases had average descent rates of ~ -19 m/s and ~ -6 m/s, respectively. However, the main parachute descent velocity increased significantly from -5.5 to -8 m/s, likely as a result of line tangling.



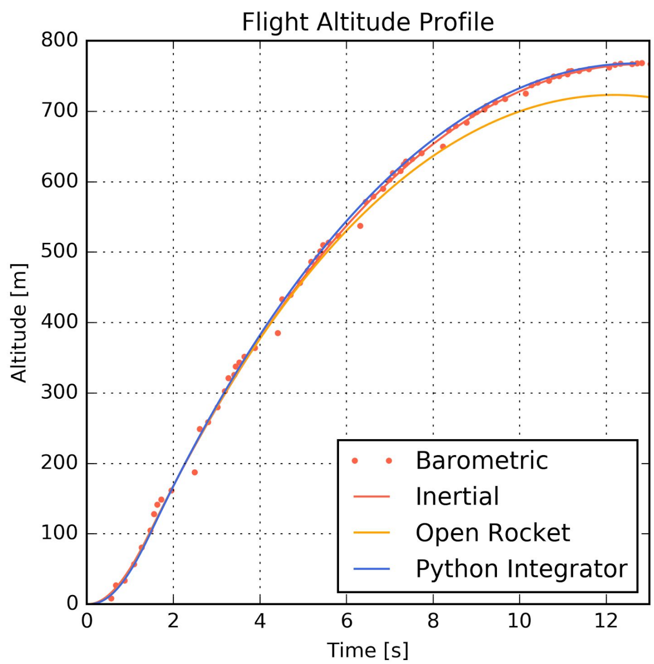


The high-resolution accelerometer data also yielded constraints on the deployment time for the main parachute. The data shows that the main parachute deployment (as facilitated by the Jolly Logic Chute Release mechanism) occurred rapidly, achieving maximum deployment within 0.4 seconds of the specified altitude.



3.2.5 Analysis and Model Comparison

Open Rocket and a custom-written python software were used to simulate the launch beforehand, and compare it to the flight data. It was found that the Open Rocket simulations overestimated the drag coefficient of the rocket by a significant amount. The Open Rocket models suggested a drag coefficient of about 0.7, while the Python script used the drag coefficient measured during flight one (0.44). The numerical integrator shows excellent agreement with the measured inertial and barometric altitude profiles, while Open Rocket's severe overestimation of the drag coefficient yielded poor agreement.



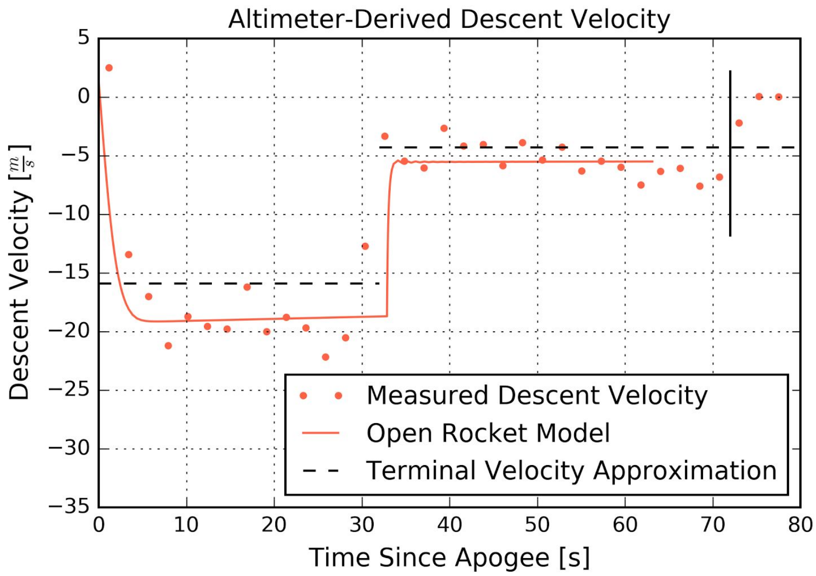
This agreement validates the python integrator, giving it credibility in some aspects. The validity of Open Rocket's method for computing the drag coefficient is questionable, however.

To compute the terminal velocity of the rocket descending on a parachute of given diameter, we use the formula:

$$V_t = \sqrt{\frac{2ma}{C_d \rho A}}$$

Where m is the mass of the rocket, a is the acceleration due to gravity, C_d is the parachute drag coefficient, ρ is the density of air, and A is the cross-sectional area of the parachute. We estimate values for the descent rate of the rocket with the two different parachutes, and compare it to both the Open

Rocket data and the descent data. The agreement is close, but the flight data shows an increase in the main chute descent rate at approximately t = 50.



The kinetic energy of a mass moving at velocity v is given by the equation:

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

We compute the impact kinetic energy of the subscale rocket to be 134.4 J, which exceeds the 101 J requirement specified in handbook regulation 3.3. This is due to an unforeseen tangling in the parachute cords before flight. A test has been implemented to ensure this is checked and fixed before any further flight.

3.3 Recovery Subsystem

The components of recovery subsystem were selected to provide a comprehensive and redundant ability for the rocket to survive a launch undamaged.

Since the PDR the rocket mass has varied slightly and thus a new pair of drogue and main parachutes were selected to adequate decelerate the rocket. These parachutes are: 24 inch nylon drogue and 48 inch Fruity Chutes: Iris Ultra parachute.

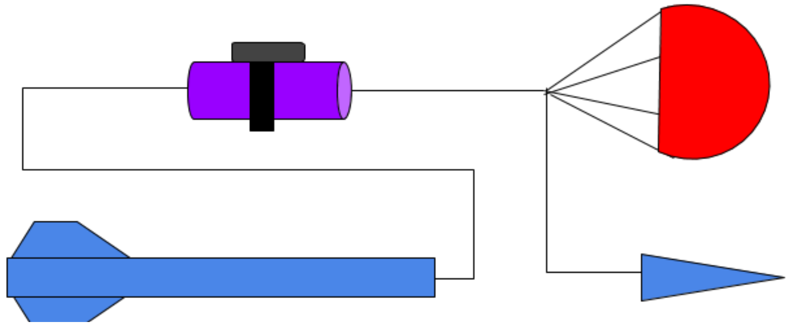
The shock cord is constructed of Kevlar Cord 1500#. The length of this Cord will be 20 ft in length.


The ends of the Kevlar shock cord are fastened to the rocket through a U-Bolt. The lower U-Bolt attaches to the avionics bay, while the other end of the cord is attached to the nose cone.

The parachutes will be attached to the recovery harness through a ball bearing swivel joint in order to allow the parachutes to rotate freely without entanglement.

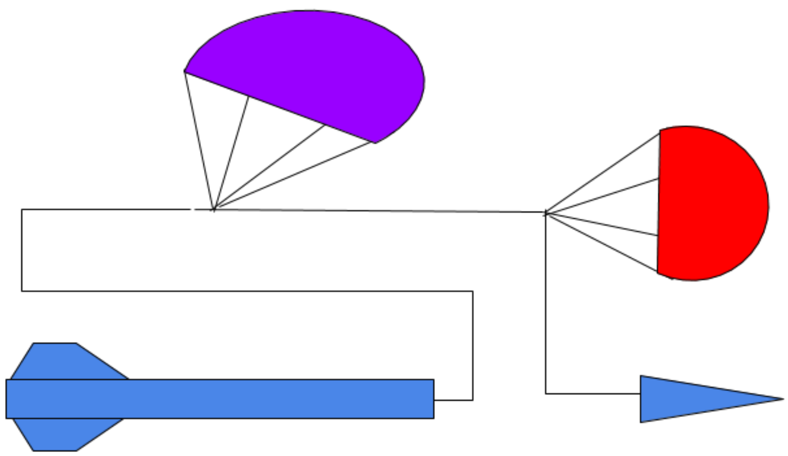
The two phase recovery system is controlled by commercially available electronics. The first phase of recovery is accomplished by detonating a black powder charge to separate the nose cone from the rocket and eject the drogue chute. This is triggered primarily by the Stratologger CF altimeter with the EasyMini altimeter serving a backup. The EasyMini altimeter is powered by a separate source and is connect to its own black powder charge of greater strength than the primary charge connected to the Stratologger. This ensures that if the Stratologger does not trigger ejection, or the Stratologger triggered charge is not sufficient to separate the rocket, the EasyMini will have the highest chance of completing the ejection process. The EasyMini backup trigger will also be delayed from apogee to ensure that both charges do not go off simultaneously.

The black powder ignition also frees the main chute from the airframe, but while it is still wrapped with the Jolly Logic Chute Release devices. Two of these devices are included in series to provide redundancy for the main chute deployment.



Phase 1 Recovery Figure During the first phase of recovery a black powder charge ejects the drogue chute which is free to inflate (pictured in red), while the main chute (pictured in purple) is also released it is kept wrapped up by the Jolly Logic Chute Release devices (pictured in black wrapped around the main chute).

These devices can be programed to release at a predefined altitude during the rocket's descent. To ensure that rocket stays within the recovery range and hits the ground below the maximum kinetic energy, these devices shall be set to release the chute at 600ft. The release of the main chute by these devices marks the second phase of recovery.



Phase 2 Recovery Figure The second phase of recovery is triggered by the release of the main chute by the Jolly Logic Chute Release devices. Once complete, both the main and drogue chutes are free to inflate.

The rocket will then located using the eggfinder GPS housed within the rocket's nose cone. The eggfinder GPS module will transmit a RF radio signal on the 900 MHz license-free ISM band at 100 mW.

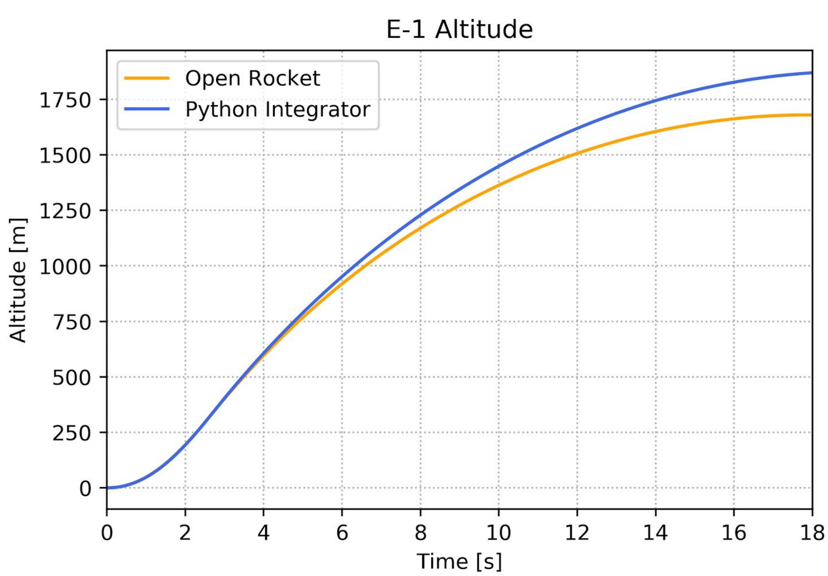
3.4 Mission Performance Predictions

Due to unfavorable speeds in our subscale flight, we decided to increase the diameter of our drogue and decrease the size of the main parachute, but change the shape of the main parachute so as to increase the coefficient of drag. This is in order to slow the rocket down sufficiently to stay under the landing energy requirement, as well as avoid any possible damage to the rocket itself. As you increase the diameter of the parachutes, drift becomes a larger and larger factor in the efficacy of the rocket. In order to keep drift to a minimum, and under the 2500' bounds, we decided to deploy the main parachute at 600'. The lower you deploy the parachute, the less drift there is due to the parachute being open for less time. Along with drift, we found it necessary to increase the parachutes size to minimize our landing energy. Due to the increased mass from the subscale to the full scale rocket, the landing velocity has to be lower in order to counteract this change. From our OpenRocket simulations we have found that with these new parachutes we achieve a landing velocity of 5.24 m/s. Since the rocket's mass is equal to 4.181 kg, we then plug these values into the equation for kinetic energy:

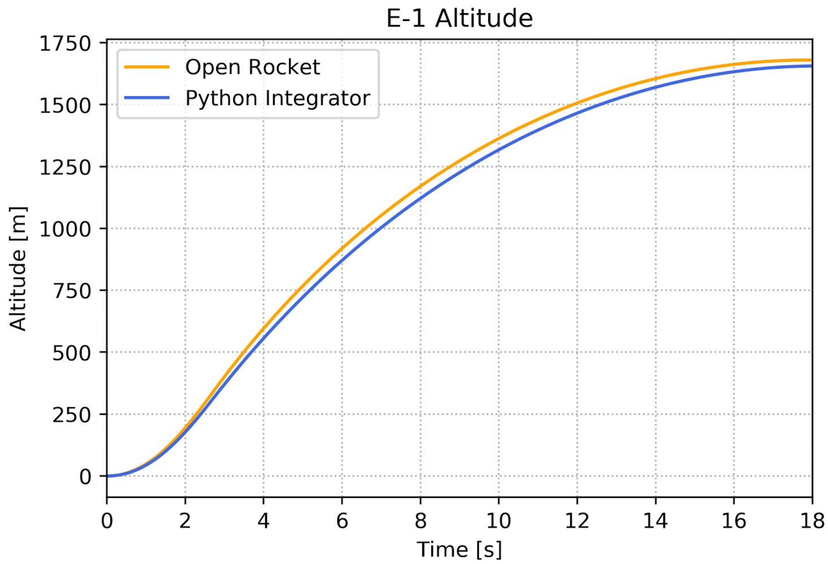
$$KE = \frac{1}{2}mv^2$$

This gives us a landing energy of 57.4 Joules (42.336 ft-lbf), well below the maximum energy of 101.686 Joules (75 ft-lbf).

The Open Rocket models show that **E-1** will obtain a max velocity of 216 m/s, and a max acceleration of 102 m/s². The coast phase will last 15.1 seconds, providing sufficient time for ADAS to make any necessary corrections. The rocket's velocity off the rod is 22 m/s, which is beyond the handbook regulation 2.17, and has a stability of 3.29, which is in accordance to handbook regulation 2.16. **E-1** will be flying with the AeroTech K535 motor. This motor was chosen for it predicted apogee under various situations, along with its rail exit velocity and total impulse



The above graph shows the predicted flight trajectories of the rocket using Open Rocket and our Python Integrator. Both models had the same mass of 9.94lb and the Python integrator used a coefficient of drag of 0.44, as measured in our subscale flight. The Python integrator predicts that using a K535 motor will breach the altitude limit of 1707 meters. However, E-1 will have slightly different aerodynamics compared to the subscale rocket, such as a longer body tube. Hence, using a slightly higher coefficient of drag of 0.5 and adding ballast, we get the following predicted trajectory below



The above graph shows a reached altitude of 1656 meters, below the maximum reachable altitude of 1707 meters and well within the range of the altitudes that the ADAS system can work with to produce an apogee of 1 mile.

3.4.1 Python Integrator

The python script utilizes Euler's method and by calculating the forces present on the rocket at every time step it calculates the acceleration, velocity and height of the next iteration. The acceleration due to gravity is assumed to be constant at -9.81 ms^{-2} . This is a very reasonable assumption as this value only changes by 0.05% when moving through to an altitude of 1 mile. The thrust from the motor is obtained from http://www.thrustcurve.org/ which gives the thrust of the motor over time. The drag force was calculated from SolidWorks by running flow simulations at different wind speeds with intervals of 20 m/s from 20 m/s to 240m/s and interpolating in-between to calculate the drag force at any speed. The drag force at any given velocity and height could then be calculated by multiplying the interpolated value at the required parameters by the ratio of the air densities at the required height compared with the air density at ground level, carried out at ground level air density.

$$F_{height} = \frac{1}{2} \rho_{height} A v^2$$

$$= F_{ground} \frac{\rho_{height}}{\rho_{ground}}$$

Using these forces and stepping through with a step size of 0.005 seconds as this is a small enough step size to get good accuracy.

The drag forces were off by some factor as the pressure and density of the air in the simulations was inaccurate. We calculated that if the drag forces are adjusted by a factor of about 10% then the simulation for the Subscale model matches perfectly with the collected data. This factor was then used to adjust the drag forces.

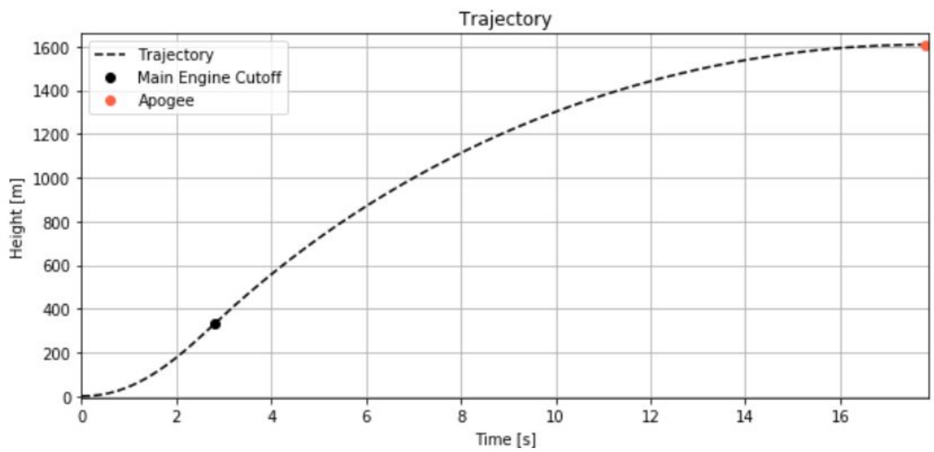
The motor selected would take the rocket to a height greater than 1 mile in height, this means that our ADAS system can adjust the altitude while accounting for spontaneous events such as wind or higher/lower air densities. To do this it must be provided with a curve to follow, and by implementing PID control it adjusts the apogee to 1 mile.

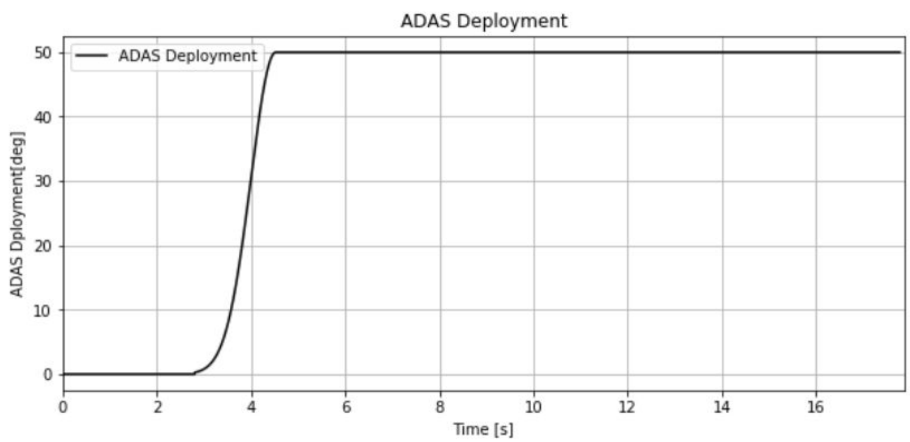
In designing the nominal trajectory that the rocket should follow the ADAS deployment had to be accounted for. Optimally, if no wind is present and all factors such as air pressure, launch angle, no friction along the launch rod etc. are in line with the model, then PID will not have to account for these, if it follows the precise nominal trajectory curve, it must deploy ADAS in a very specific manner. This is the complimentary ADAS deployment curve to that specific trajectory. Since there is a one to one correspondence between the ADAS deployment curve and the nominal trajectory, designing the nominal trajectory boils down to designing an ADAS deployment curve that ensures the trajectory curve reaches an apogee of 1 mile and is feasible, that is ADAS isn't forced to deploy faster than it actually can or protrudes its boundaries of deployment between 0 to 72 degrees.

This motivated the writing of a custom made python script that simulates the launch of the rocket. By running flow simulations on our model with different levels of deployment for ADAS a 2D array of drag forces consisting of different ADAS deployments and wind speeds was generated. Interpolating this array gives a function of the drag force at any velocity and ADAS deployment. This allowed us to simulate deploying ADAS mid flight. We decided that the nominal flight trajectory will be the one with a complimentary ADAS deployment curve that requires ADAS to deploy at half deployment for the longest amount of time, as this gives it the most amount of freedom, meaning that if unforeseen factors such as wind change the state of the rocket the control loop has enough ADAS deployment to work with for both upwards and downwards drift to adjust the discrepancy.

Since the ADAS fins must begin at 0 deployment, the deployment curve chosen is a half Gaussian deploying to some preset deployment and finally remaining at that deployment until hitting apogee. The preset deployment should be as close as possible to half deployment, giving the control system the most amount of freedom. It was essential that the steepest part of the Gaussian was not steeper than the fastest deployment speed capable by our ADAS motor as that will result in a bad nominal trajectory curve, as even under optimal conditions the control system cannot follow the nominal trajectory curve.

With all this in mind, several ADAS deployment curves were tested and optimised in order to calculate the optimal trajectory for the final rocket. The resulting trajectory curve and its corresponding ADAS deployment curve are shown below





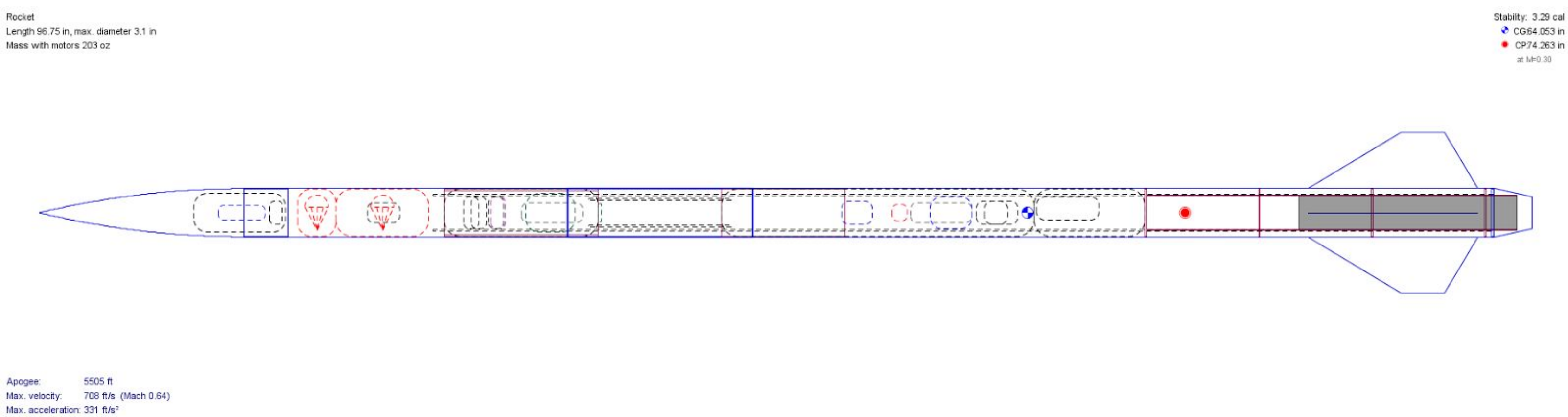
As shown, the trajectory reaches 1609 meters in height, and the ADAS deploys to a maximum deployment of 50 degrees, out of 72, giving the control system less room to account for unexpected events.

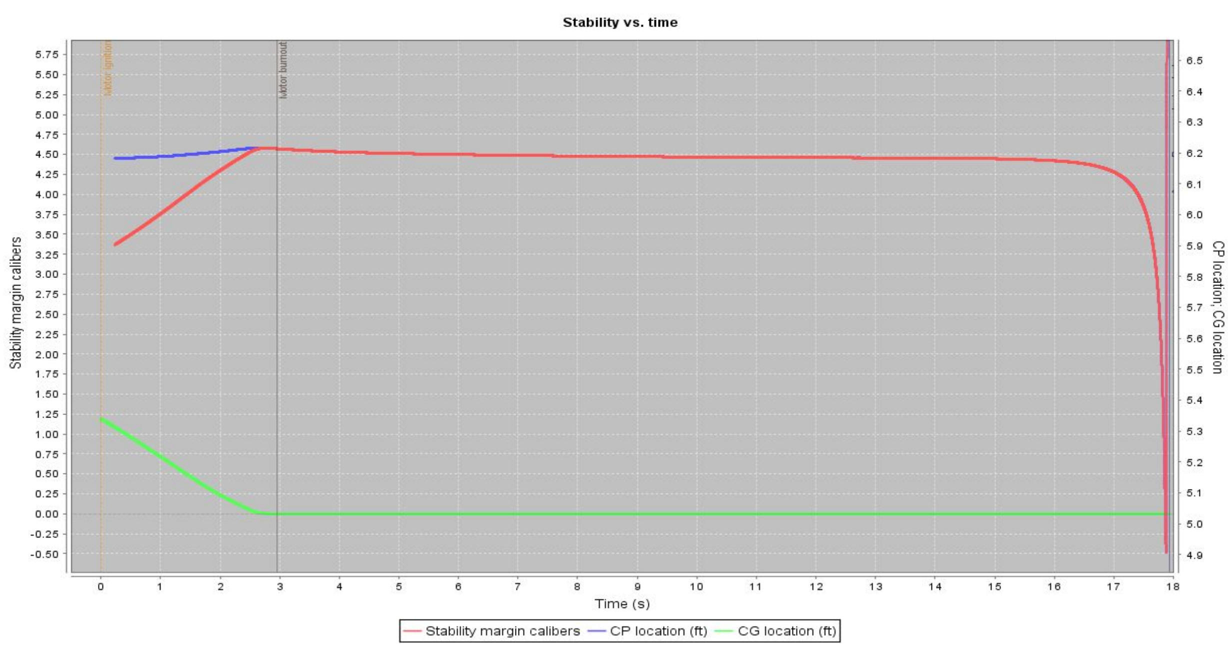
3.4.2 Drift

The following chart shows the drift of the rocket at various wind speeds from two methods, using the 24”/48” parachute pair. The first method of calculation was done by using OpenRocket and setting the simulation wind speed to the desired value. From there we plotted Lateral Distance vs Time and found the maximum distance traveled. The second method was found by multiplying the desired wind speed and the total flight time given by OpenRocket. We can see that under both of these circumstances and through both methods of calculation, the drift stays under the 2500’ maximum.

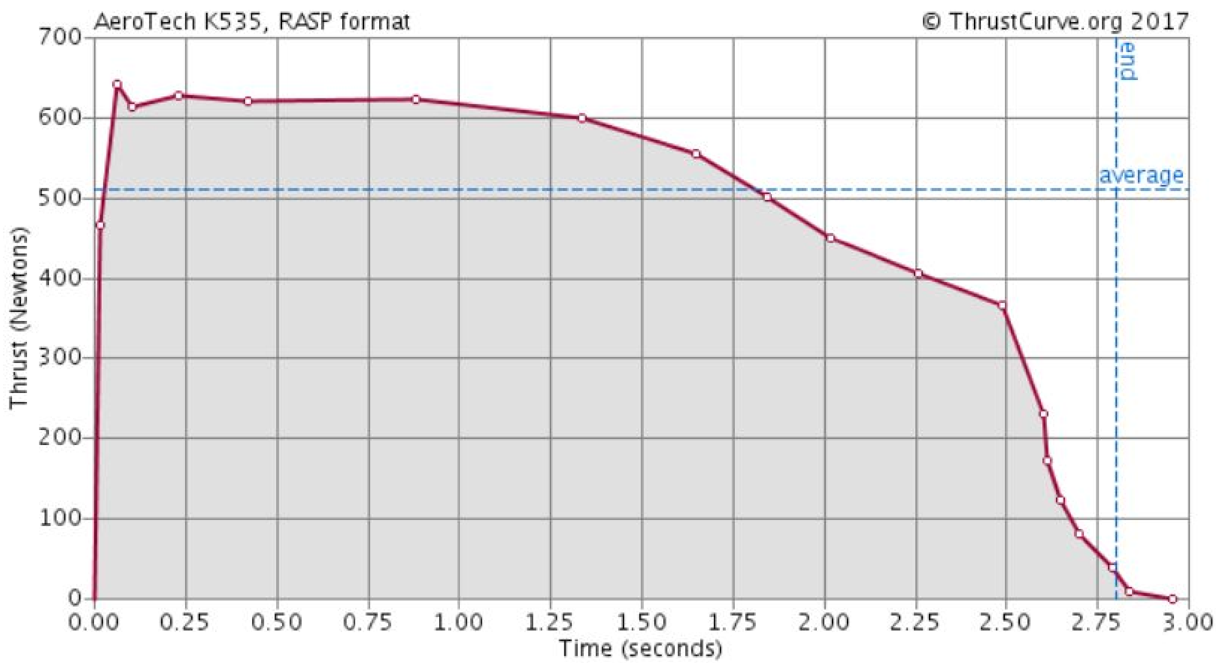
Wind Speed (mph)	0	5	10	15	20
Drift (ft) (OpenRocket)	7	701	1461	1504	2169
Drift (ft) (Wind Speed * Flight Time)	0	735	1460	1680	2220

Both simulation methods show that even at the highest wind speeds of 20 mph the rocket will not drift more than the maximum 2500’. Both calculation methods result in very similar drifts, corroborating each other, this implies that the calculations are accurate and represent the actual drift well.





The above figures show the stability components of the rocket during flight. These are calculated in OpenRocket, as shown the stability margin of the rocket is consistently above the required value of 2. The location of the center of gravity changes over time as the propellent is burnt, increasing the stability margin from 3.3 to 4.5. The high stability margin implies that our rocket could be prone to weather cocking. For this reason the K535 motor was chosen, due to it's high off rail velocity, mitigating the effects of any wind present.



The above graph shows the Thrust Curve of the AeroTech K535 motor. This motor is quick burning, and front-heavy motor which allows ADAS ample time to make adjustments to the rocket's apogee.

4. Safety

4.1 Launch Concerns and Operating Procedures

4.1.1 Recovery Preparation

Main Chute
Hazards: None
PPE Required: None

- ❏ Lay the main parachute completely flat on a solid surface
- ❏ Inspect the parachute for burns, tears, or loose threads
- ❏ Straighten the lines and untangle them if necessary
- ❏ Ensure that the **large** swivel joint is connected to the main parachute lines with a Lark's head style knot if not, tie the knot
- ❏ Fold the parachute in into wedge shaped such that each gore of the parachute is folded in half and all the lines exit the same end of the wedge (team members can view the a video on the shared google drive for a step by step tutorial on how to fold parachutes properly)
- ❏ Once the parachute is folded into a wedge, roll the wedge starting from the pointed edge which should also be the center of the canopy
- ❏ Secure the **2** Jolly Logic Chute Release devices which are connected in parallel around the main chute
- ❏ Wrap the parachute line around a portion of the parachute not covered by the Jolly Logic Chute Release devices

Safety Officer Initial of verification: _________________

(improper main chute folding could prevent the main chute from deploying properly and thus force the rocket to impact the ground with higher than expected kinetic energy)

Drogue Chute
Hazards: None
PPE Required: None

- ❏ Lay the drogue chute out completely flat on a solid surface
- ❏ Inspect the parachute for burns, tears, or loose threads
- ❏ Straighten the lines and untangle them if necessary
- ❏ Ensure that the **small** swivel joint is connected to the main parachute lines with a Lark's head style knot if not, tie the knot
- ❏ Fold the parachute in into wedge shaped such that each gore of the parachute is folded in half and all the lines exit the same end of the wedge (team members can view the a video on the shared google drive for a step by step tutorial on how to fold parachutes properly)

- ❏ Once the parachute is folded into a wedge, roll the wedge starting from the pointed edge which should also be the center of the canopy
- ❏ Wrap the parachute lines around the parachute

Safety Officer Initial of verification: _________________

(improper drogue chute folding could prevent the drogue chute from deploying properly and thus force the rocket to impact the ground with higher than expected kinetic energy)

Recovery Harness
Hazards: None
PPE Required: None

- ❏ Lay the Kevlar recovery shock cord out flat straight along the ground
- ❏ Tie the drogue chute approximately 3ft down the cord from the end that will be attached to the **nose cone** by tieing a Lark's head style knot in the shock cord around the end of the swivel joint not attached to the drogue chute
- ❏ Tie the main chute chute approximately 4ft down the cord from the end that will be attached to the **rocket body** by tieing a Lark's head style knot in the shock cord around the end of the swivel joint not attached to the drogue chute
- ❏ Tie the kevlar cloth which will protect the parachutes from burning during charge ejection approximately 3 ft down the cord from the end that will be attached to the **rocket body** by tieing a Lark's head style knot in the shock cord around the attachment point of the kevlar cloth

Safety Officer Initial of verification: _________________

(improper preparation of the recovery harness could result in parachute entanglement and at worse cause the rocket to lawn dart)

Nose cone and GPS
Hazards: Low voltage circuits
PPE Required: None

- ❏ Check that the GPS battery is fully charged by measuring the voltage across its leads
- ❏ Ensure that the GPS and GPS battery are properly mounted to the GPS sled
- ❏ Ensure that the U-Bolt is securely attached to the GPS sled
- ❏ Tie the nose cone end of the recovery harness to the U-Bolt of the GPS sled
- ❏ Set this assemble aside until avionics bay integration is completed

Safety Officer Initial of verification: _________________

(improper preparation of the GPS and nose cone could result in unplanned separation of rocket segments or malfunction of the GPS system)

Recovery Altimeters

Hazards: Low voltage circuits
PPE Required: None

- ❏ Check the voltage across both altimeter 9v batteries to ensure that both are charged
- ❏ Ensure that the recovery altimeters are securely mounted
- ❏ those are for attaching the GPS sled into the nose cone which should have been done already, if not do it now)
- ❏ In this order, slide the recovery components into the recovery section of the airframe along with the proper length of shock chord between each components:
    - ❏ Kevlar protective cloth
    - ❏ Main chute
    - ❏ Recovery chute **Check that a black powder charge is not attached to either recovery altimeter**
    - ❏ Check that the screw switches are in the off position
    - ❏ Connect the battery batteries
    - ❏ Ensure that the charge leads are connected to the wire terminal mounted to the top of the avionics bay

Safety Officer Initial of verification: _________________

Initial of lead Electronic Personnel: ________________

(improper recovery altimeter preparation could result in a failure to deploy either parachute and result in the rocket lawn darting)

*****Complete the avionics bay integration checklist*****

*****Once avionics bay integration is completed*****

Final Recovery Preparation
Hazards: Low voltage circuits, Black powder charge, Pinching
PPE Required: Safety Glasses

- ❏ Connect the GPS battery to the GPS to power on the system
- ❏ Secure the GPS sled into the nose cone housing with the proper hardware
- ❏ Thread the end of the recovery harness which is going to be attached to the rocket segment through the recovery section of the airframe. Ensure that the recovery airframe section is orientated properly.
- ❏ Tie the end of the shock cord to the U-Bolt of the avionics bay
- ❏ **Once again ensure that the screw switches to arm the recovery altimeters are in the off position**
- ❏ Connect the black powder charges to the terminal
- ❏ Align the large holes of the recovery section of the airframe with the large holes in the top of the upper window coupler, these should also align with the embedded nuts of the avionics sled.
- ❏ Screw in the short ¼-20 button head bolts (if there are longer ones in the hardware case

- ❏ Slide the nose cone into the top of the recovery section of the airframe and align the markings
- ❏ Thread shear screws into place and verify they are secure
- ❏ Ensure that the ignitor is NOT installed in the rocket motor
- ❏ Insert the motor into the motor mount and secure with the tail cone retainer

Verification that the rocket is prepared to be moved to the launch pad:

Safety Officer Initial of verification: _________________

Initial of verification a Team Captain: ________________

(Improper final recovery preparations could result in the failure of the parachute deployments and ultimately the lawn drafting of the launch vehicle)

*****Move on to the Setup Launcher Checklist*****

4.1.2 Motor Preparation

Motor preparation shall be handled by our certified mentor, David Raimondi, or another certified individual if David is not present. The team shall provide safety glasses to team members who wish to observe the assembly of the rocket motor. Protective gloves shall also be available to team members if they gain permission from David to assist in the assembly of the rocket motor. Working alongside David, or another certified individual, the safety officer will ensure that the instructions for the assemble of the rocket motor are strictly adhered to.

Hazards: Highly flammable material, Oils which could cause skin irritation
PPE Required: Safety Glasses, Protective Gloves

- ❏ Do not get grease on either end of the delay grain if doing motor eject
- ❏ Place grains in liner
- ❏ Grease O-Rings
- ❏ Place O-Rings in motor
- ❏ Tighten front end of the motor first
- ❏ Tighten aft closure until there is pressure on the O-Ring
- ❏ Forward closure must be screwed in very tight, screwed in all the way until it touches the casing
- ❏ Do not install the igniter

Safety Officer Initial of Verification: _________________

Initial of Certified Mentor: ________________

(Improper preparation of the motor could be result in catastrophic failure of the rocket via a rapid unplanned disassembly)

4.1.3 Avionics Bay Integration

Hazards: Low voltage circuits, Pinching
PPE Required: Safety Glasses

- ❏ Have a team member securely hold primary airframe of the rocket (ensure that the motor is not installed in the rocket at this time)
- ❏ Ensure that the ADAS fins are in the full closed position
- ❏ Ensure that all electronics are prepared for flight but not on
- ❏ Slide the avionics sled down the all-threads making sure that the sled is orientated properly by aligning the markings at the base of the sled (which is the base of ADAS)
- ❏ Slide the window section and couplers over the sled and into position, be careful when doing this because often times the bulkheads of the sled may catch on the transition between the window and the upper coupler. (If this is the case reach in from the top and grab the U-bolt of the sled and try to shift the sled to clear the transition)
- ❏ Once the window is inplace, the top of the coupler should align with the top of the sled. Verify that this is the case
- ❏ In order to insert the retaining plate which connects the two all threads and locks the sled in place, raise the sled back up out of the rocket slightly such that the top ends of the all threads are flush with the top surface of the sled. Slide the plate through the U bolt and align its holes with the holes for the all threads.
- ❏ Slide the sled back into place, and verify that the all threads now go through the retainer plate.
- ❏ Lock the retainer plate and thus the avionics sled into place by tightening a nut onto each all thread. Once tight, thread a second nut down the all thread and tighten it to **ensure that the avionic sled is secured with redundant nuts**.

Safety Officer Initial of verification: _________________

Initial of lead Electronic Personnel: ________________

(Improper integration of the avionic bay could result a failure of the on board electronics to function properly or a failure of the structural system of the rocket resulting in an unplanned disassembly during flight)

*****Now complete the remainder of the Recovery preparation checklist*****

4.1.4 Setup Launcher

The following fields will be filled in and checked by the Safety Officer during launch day.

Total Impulse (N*sec)	

Minimum Diameter of Cleared	
Minimum Personnel Distance (ft)	
Minimum Launch Site Diameter (ft)	
Wind Speed (mph)	

- ❏ RSO will determine minimum distances from Minimum Distance Table (NAR).
- ❏ Ensure above distances are within Minimum Distance Table thresholds (NAR) and are in accordance with NFPA 1127 4.14.2 and 4.15.3.

  "4.15.3 Launch shall be at least 1500 ft or minimum spectator distance for the largest high power rocket launching, whichever is greater, from the following locations:

1. An occupied building
2. A public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch."

- ❏ Ensure wind speed is below 20 mph (NFPA 1127 4.17.2).
- ❏ In accordance with FAA regulations (CFR Title 14, Chapter I, Subchapter F, Part 101, Subpart C, Section 101.25).

1. At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
2. At any altitude where the horizontal visibility is less than five miles;
3. Into any cloud;
4. Between sunset and sunrise without prior authorization from the FAA;
5. Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;
6. In controlled airspace without prior authorization from the FAA;
7. Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations: Not less than one-quarter the maximum expected altitude; 457 meters (1,500 ft.);
8. Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
9. Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

- ❏ Launch rod will be tilted no greater than 20 degrees from vertical (NFPA 1127 4.12.3).
- ❏ Launch device has a jet deflector (NFPA 1127 4.12.2) and there is no combustible material beneath launch device.
- ❏ Team members will be educated on misfire procedures at the pre-flight briefing

  "A high power rocket that has misfired shall not be approached until all of the following have occurred:

1. The safety interlock has been engaged.
2. One minute has passed
3. The RSO has given permission for one person to approach the misfired rocket to inspect it. (NFPA 1127 4.18.4)"

  "If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket. (NAR)"

- ❏ Recovery team will be made aware at the pre-flight briefing to not attempt to recover the rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it may recover in spectator areas or outside the launch site, or attempt to catch it as it approaches the ground (NAR).

- ❏ Team members will be made aware of the Range Safety Officer's role and responsibilities during pre-flight briefing.

4.1.5 Preparing the Rocket on the launch pad

Hazards: Highly flammable material, Pinching
PPE: Safety glasses

- ❏ Tilt the rail to horizontal with the ground (some launch rails have a pin which will allow the launch rail to pivot downward for easy rocket installation, use this feature if present)
- ❏ Inspect the rail for dirt or other debris that could inhibit the rocket from smoothly sliding along the rail
- ❏ With one member holding the rocket, a second team member shall guide the lowest launch rail button into the rail.
- ❏ The second rail button will then be carefully guided into the rail
- ❏ The rocket will be checked by hand to smoothly slide the length of the rail
- ❏ Tilt the launch rail and rocket back to a horizontal position
- ❏ Arm each flight circuit in the following order by turning the proper screw switch into the on position (the order also follows from the furthest aft switch on the rocket to the farthest forward). Aslo verify that the expected response is given with the arming of each circuit.
    - ❏ ADAS / Arduino 101
        - ❏ ADAS indicator LED
    - ❏ TARS / Raspberry Pi 3
        - ❏ TARS indicator LED
    - ❏ Stratologger
        - ❏ Audible Beep
    - ❏ Easy Mini Altimeter
        - ❏ Audible Beep

*****The rocket is prepared for igniter installation*****

4.1.6 Igniter Installation

- ❏ Install the igniter into the rocket motor
- ❏ Verify that the igniter is sufficiently deep within the rocket motor
- ❏ Connect the igniter leads to the launch circuit (usually via alligator clips)
- ❏ Check for continuity
- ❏ Verify that all personnel outside of the established range from the rocket and all other previously mentioned safety concerns are still in acceptable conditions

Safety Officer Initial of verification: _________________

❏ Launch

4.1.7 Troubleshooting

Potential Hazards: Low voltage circuits, Black powder charge, rocket motor handling
PPE necessary to deal with hazards: Safety glasses, protective gloves

If troubleshooting is every required, the vehicle will be brought into a configuration safe for repair prior to any extensive work is done to investigate and fix the issue. In order to reach this safe configuration, the rocket motor will be removed from the rocket if present, altimeter circuits will be disarmed and the black powder charges removed.

4.1.8 Post Flight Inspection

Potential Hazards: Power lines, Trees, Rough Terrain, Exposed low voltage circuits, heated sections of the rocket
PPE necessary to deal with hazards: Safety glasses, protective gloves, full toed shoes

Prior to team members handling the rocket during the recovery process, the vehicle and its surroundings will be checked to be safe to approach and clear of all hazards such as power lines and not in dangerous places such as on the edge of a ravine. If such hazards are present the safety officer will advise the recovery team on how to proceed.

Once the recovery sight is declared safe, the rocket will be inspected for damage. If the rocket has sustained significant damage which poses a risk to harm the recovery team such as exposed circuits or sharp edges. Proper action will be taken to address such hazards under the supervision of the safety officer.

Once the area and rocket have been declared safe, the safety officer will give the recovery team approval to proceed with powering down the rocket and returning the rocket to the launch area.

4.3 Hazard Analysis

4.3.1 Personnel Hazard Analysis

Hazard	**Cause**	**Effect**	**Likelihood and Severity (RAC)**	**Mitigation**	**Verification**
Allergic	Member	Allergic	2E	Ensure that members	A list of team members

Reaction	exposed to allergen	reaction, severity is largely dependent on individual case		with allergies avoid relevant foods and carry medication, safety officer to be aware of any allergies.	with special dietary needs and other unique medical conditions shall be kept up to date on the team drive.
Improper handling of epoxy	Lack of proper training, accidental spillage, misuse of safety equipment	Injury of team member(s)	3C	Team members dealing with the resin will wear full sleeve clothing, protective gloves, respirator and eyewear. A eyewash station and shower are located in the hallway within 20 yards of the lab.	All team members handling epoxy are informed of the proper procedures and are encourage to stop others members if the proper procedures are not being followed.
Improper handling of fiberglass (during cutting)	Lack of proper training, misuse of safety equipment	Injury of team member(s)	3C	Team members dealing with the resin to wear full sleeve clothing, protective gloves, respirator and eyewear.	All team members handling fiberglass are informed of the proper producers and are encourage to stop others members if the proper procedures are not being followed.
Improper use of hand tools	Lack of proper training or experience	Injury of team member(s)	3C	When team members are in the lab space, it is necessary for a highly trained individual to be present with them, overseeing work. A first aid kit containing adequate supplies is easily accessible in the lab space.	The first aid kit in the lab will be regularly check to be complete, in addition a first aid kit shall be included as an item on the packing checklist.
Improper use of drill press	Lack of proper training or experience	Injury of team member(s)	3D	All guidelines in the Drill Press operator's manual will be adhered to. Team members have access to this manual on the website (https://ucscrocketry.org/documents.html)	Team members shall only be allowed to use the drill press once properly trained.
Catastrophe At Take-Off	Damage to motor or	High-velocity shrapnel and	3E	The team will follow the NAR Code when	Motor assembly procedures in section

(CATO)	improper motor assembly	debris injuring team and spectators.		conducting all launches including the minimum distance guidelines in Appendix B. NOTE: The NAR minimum distances will be used, not the NFPA 1127 minimum distances because the NAR distances are safer. This will ensure all individuals are at the least possible risk of harm during a launch event.	4.1.2 help prevent a CATO.
Improper recovery	Lack of recovery training during pre-flight briefing	Injury of team member(s) and/or spectators	3E	The team will follow the NAR provision on recovery safety located in Appendix C part 13.	The safety officer is responsible for educating the team on recovery safety during the pre flight briefing as stated in section 4.1.4.
Misfire (Team members/spectators approaching rocket after a misfire)	Improper ignition installation	Injury of team member(s) and/or spectators	3D	The team will follow the NAR provision on misfire's located in Appendix C part 5.	At the pre flight briefing the safety officer will state that the RSO will determine when it is safe to approach the rocket as stated in section 4.1.4.
Improper handling of rocket during ignition installation	Lack of certification or knowledge	Injury of team member(s) and/or spectators	3E	The team will abide by regulations in NFPA 1127 4.13, especially 4.13.6 which mandates the rocket be pointed away from spectators during ignition installation.	Assembly Checklist section 4.1.6 ensures that the proper procedures are followed during igniter installation.

4.3.2 Failure Modes and Effects Analysis

The following Failure Modes and Effects Analysis (FMEA) tables describe the describe potential failures that could occur during the mission of Effective - 1. The mission of Effective - 1 is divided into 10 phases:

1. Liftoff
2. Ascent
3. Drogue Deployment
4. Descent Under Drogue
5. Main Deployment
6. Descent Under Main
7. Landing
8. Recovery
9. ADAS
10. TARS

Each phase of flight has its own table of failure modes, sources of that failure, effects that the failure is predicted to have in addition the likelihood, severity, and preventability of that failure rated on a scale from 1 to 10. The likelihood, severity, and preventability ranking system is clarified by the following tables:

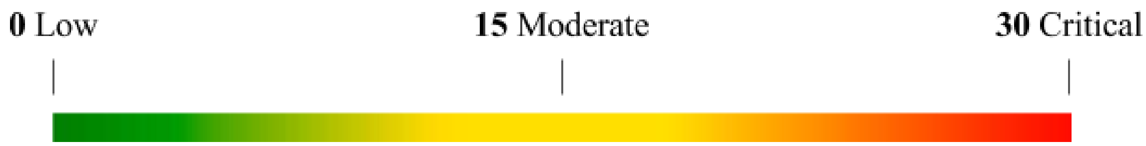
Likelihood:		
0	**5**	**10**
Impossible	**Anomalous**	**Expected**

Severity:		
0	**5**	**10**
Low	**Moderate**	**Critical**

Preventability:		
0	**5**	**10**
Preventable	**Manageable**	**Unstoppable**

These numbers are then added together to give an overall risk factor for each failure mode. This risk factor can take on values from 0, representing no risk to 30, representing a major concern.

Overall Risk Factor



In order to conserve space, the Likelihood, Severity, Preventability, and Overall Risk columns headers shall be abbreviated to L, S, P, and R respectively

Flight Preparation FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Recovery Altimeter Circuits (StratoLogger CF and EasyMini)	Premature Ejection Black Powder Igniting	Injury to Personnel	Improper wiring or assembly of the recovery charge circuits	High energy detonation	2	9	3	14	Proper assembly procedures for vehicle assemble are written to prevent such a failure. The altimeter will only be armed once the rocket is prepared on the pad and far from all personnel.	The safety officer shall oversee the assembly of the rocket and ensure that the checklist is followed. One of the initial items on that checklist is to ensure that the altimeter is disabled prior to assembly. The altimeter circuit shall be verified to be built as specified by checking the circuit against the designated wiring diagram.
Arming switches	Failure of on-board electronic systems to initialize properly or damage to circuit components	Low voltage shock	Improper wiring, manufacturing defect, or computer code not properly running	Delayed launch	4	1	1	6	Proper diagrams and procedures written to connect circuit components before being turned on. Circuits and computer code will be run and tested on a preliminary basis to ensure functionality. Backup components will be used if necessary.	The safety officer shall oversee the assembly of the rocket and ensure that the checklist is followed. All circuits will be verified as operating by checking the circuit diagrams and instructions during construction, and then checked by either hearing for audio indicators, or looking for sets of LEDs lighting up on the rocket in visibly apparent locations to detect which circuits are working or not.
TARS computer SD card	Failure to boot or error when powering on TARS	Loss of software	Damage to SD card containing TARS operating system	Delayed launch	4	1	1	6	A backup SD card complete with up to date code will be included with the equipement taken to the launch. Also the code will be stored on the cloud as an additional backup.	The backup SD card will be included on the team's launch packing list.

Payload Integration FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification

Payload section	Damage to the avionics sled or associated electronics	Improper handling of the avionics sled during integration	Improper Integration	Electrical damage to rocket components	2	3	6	11	Redundancy exist for in all flight critical electrical circuit and components. The payload integration section of the checklist ensures that the vehicle is assembled with minimal risk of damaging to flight critical components.	The preflight checklist contains all checks needed to ensure that critical systems are still in operational conditions when the rocket is primed on the launch pad. Any damage that is made to the vehicle during payload integration shall manifest as a failure in one of these test.The safety officer shall also oversee the process of payload integration and ensure that the checklist is adhered to.
				Mechanical damage to rocket components	2	6	3	11	The payload integration section of the checklist ensures that the vehicle is assembled with minimal risk of damaging to flight critical components.	A visual inspection of the at various stages of vehicle assemble shall be performed in order to identify any structural damage if it has occured during payload integration.

Liftoff FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Ignitor system	Misfire	The rocket could still be in a launch condition	Defective Ignitor	Delayed launch	3	6	4	13	Ignitors shall only be sourced from trusted manufactures with reliable ignition detonation record.	At the time of purchase of ignitors, the manufacturer and vendor shall be checked for their reliability.
			Disconnected Ignition circuit		2	6	2	10	Most launch systems are equipped with a conductivity check circuit to ensure that the ignitor circuit is complete before the launch is initiate.The team shall verify that such a device is in use for the launch.	The safety officer shall work with the RSO and other ground support personnel to ensure that conductivity of the circuit is checked before launch.
Rocket Motor			Faulty motor		1	6	5	12	Motor shall be sourced from reliable vendors	The reliability of the vendor shall be checked at the time of motor purchase.
			Improper motor assemble		1	6	5	12	The team's certified and experienced mentor shall handle the assembly of the motor	The Safety officer shall work with the team's mentor to ensure that the motor is properly assembled according to the specific moto's instructions.
Exit Rail	Premature detachment form exit rail	Deviation of the rocket from the planned trajectory	Jamming caused by foreign object present in the rail	The Rocket could take an unpredictable trajectory	1	8	3	12	The launch rail shall be checked to be free of foreign object which could cause jamming before launch.	During the process of loading the vehicle onto the launch rail, a checklist step shall be included to verify that the rail is clear of debris.
Rail Buttons			Pulling of of rail buttons from the vehicle		2	8	5	15	Rail buttons shall be bonded to the rocket in such a way to withstand moderate pulling loads in addition to the expected shear load during raile launch	Design stress analysis and physical tests shall be performed to verify the security of the rail buttons' attachment to the rocket.
Exit Rail	Lifting of launch rail with vehicle	Deviation of the rocket from the planned trajectory	Jamming caused by foreign object present in the rail	The Rocket could take an unpredictable trajectory	1	8	3	12	The launch rail shall be checked to be free of foreign object which could cause jamming before launch.	During the process of loading the vehicle onto the launch rail, a checklist step shall be included to verify that the rail is clear of debris.

Rail Buttons			Misalignment of rail buttons		1	8	1	10	Proper manufacturing procedures are established to ensure that the rail buttons are in proper alignment	The vehicle shall be verified to slide properly along the rail by testing the rocket's ability to do so by hand prior to launch. This is included as an item in the pre flight checklist.
Motor Retainer	Motor becomes detached from the rocket and slides out	The motor could be primed to ignite and seperate form the rocket	Incomplete securement of the tail cone retainer	Delayed launch	2	8	5	15	The motor shall be checked to be firmly mounted once assembled into the rocket	The design shall be provet to retain the motor securely on the launch pad and throughout the flight. A pre-flight checklist item is included to check motor security. The safety officer will ensure that this item is check off prior to launch.
Centering Rings	Fracture of breakage of the centering rings	The rocket or rocket fragments could threaten to collide with personnel	Insufficient Design or improper manufacture	Rocket components or the rocket following unplanned trajectories	1	9	5	15	The centering rings have been designed to withstand all forces involved during the launch of the vehicle with redundant supports.	Detailed stress simulations have been performed to ensure that these components will perform nominally during the launch of the rocket.Proper bonding of the centering rings to the motor tube and airframe shall be verified during an inspection by the team's mentor prior to launch.
Airframe	Buckling or rupture of the airframe	The rocket or rocket fragments could threaten to collide with personnel	Insufficient Design or improper manufacture	Rocket components or the rocket following unplanned trajectories	2	9	1	12	The airframe has been designed to withstand all expected stresses during launch	Detailed stress simulations have been performed to ensure that these components will perform nominally during the launch of the rocket.

Ascent FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Airframe	Rapid Unplanned Disassembly	The rocket or rocket fragments could threaten to collide with personnel	Failure of the airframe under the loads of flight	Destruction of the vehicle	1	7	1	9	The rocket is designed to withstand the forces present throughout the launch.	The airframe design has been tested and refined through a number of stress simulation.
	Bulking	The rocket will be damaged and could impact personnel	Insufficient design	The rocket will adopt an unplanned trajectory	3	7	1	11		
Fin attachment	Shearing of a fin off of the rocket	The rocket or rocket fragments could threaten to collide with personnel	Insecure bondage of the fin to the rocket	The rocket will follow an unpredictable trajectory	2	7	1	10	The fins are designed to be bonded to the rocket with high strength epoxy along two surfaces (interiorly tot eh motor tube and exteriorly along the interface with the airframe).	The team's experienced mentor shall inspect the fin connections to ensure proper attachment.

Drogue Deployment FMEA

Source	Failure	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification

	Mode									
StratoLogger CF Altimeter	Primary drogue altimeter failure only	-None- (Redundant system)	Improper wiring or manufacturer defect	-None- (Redundant system)	1	0	2	3	If the StratoLogger altimeter fails to fire, the EasyMini altimeter will be capable of performing the deployment.	Checklist items are included to verify that both the StratoLogger and EasyMini altimeters are armed before launch via an external switch for each altimeter. Each altimeter will then make an audible confirmation that it is in launch configuration.
EasyMini Altimeter	Secondary drogue altimeter failure only	-None- (Redundant system)		-None- (Redundant system)	1	0	2	3	If the primary StratoLogger altimeter functions as expected then the single failure of the EasyMini Altimeter will have no effect on the flight.	
StratoLogger CF, EasyMini	Both recovery altimeters fail to deploy drogue chute	Damage to the rocket upon impact with the ground and risk to personnel if in the path of the rocket		The drogue chute fails to deploy, also preventing main chute deployment, resulting in the vehicle impacting the ground at high velocity	1	9	1	11	Redundant altimeter from two different makes and models are included to ensure to ensure that the likelihood of both devices failing is kept to an absolute minimum.	
Black Powder Charge	Black powder charge insufficient to eject parachutes	Damage to the rocket upon impact with the ground and risk to personnel if in the path of the rocket	Improper portioning of black powder charge	The drogue chute fails to deploy, also preventing main chute deployment, resulting in the vehicle impacting the ground at high velocity	2	3	3	8	Calculations for the amount of black powder necessary to eject the parachutes were performed.The secondary altimeter shall be connect to a large blackpowder charge in case the first charge failed to deploy the chutes.	A ground test will be performed by the team's certified mentor to ensure that the proper amount of black powder is used in the deployment charge.
Shear screws		Damage to the rocket upon impact with the ground and risk to personnel if in the path of the rocket	Improper installation of shear screws.		2	3	2	7	Only proper shear screw designed for such applications in high powered rocketry will be used.	Shear screw will be installed as part of the ejection charge ground test.

Descent Under Drogue FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Recovery Harness	Recovery harness snap	Rocket segments falling at higher then planned velocities	Insufficient recovery harness line strength or excessive yank	The rocket will separate into unplanned segments.	2	4	2	8	The recovery harness line material was selected to withstand the forces expected.	A pull test will performed to verify that the recovery harness can withstand the maximum expected tension in the line.
U-Bolt	Disconnection of parachutes from rocket	Rocket segments falling at higher then planned velocities	Insufficient design	The rocket will separate into unplanned segments.	2	4	2	8	Stress simulations were performed to verify that the design of the rocket was sufficient to handle the yank of parachute deployment	A checklist item is included to verify that the U Bolts are properly mounted and bonded into place and locked tight in section 4.1.1.

Parachute chords	Parachute Tangling	Rocket descent at higher than expected velocities	High wind speeds or improper folding	The Rocket will descent at higher than planned velocity	5	2	2	9	The parachutes are attached to the primary recovery harness chord via two swivel joint that allow the parachutes to freely turn and prevent tangling.	A checklist item is included to verify that the parachutes are attached to the recovery harness via swivel joints in section 4.1.1.

Main Chute Deployment FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Primary Jolly Logic Chute Release	Only primary jolly logic chute release failure	-None- (Redundant system)	Failure to be enabled or binding of release mechanism	-None- (Redundant system)	1	0	2	3	The two Jolly Logic Chute Release devices are wrapped around the main parachute in series to ensure redundancy. If the primary chute release should fail, there is the backup redundant device.	There are steps within the preflight checklists, section 4.1.1, to verify that both jolly logic chute release mechanisms are on and set to the correct opening altitude Additionally a ground test shall be performed prior to launch with each jolly logic device on the day of the launch..
Secondary Jolly Logic Chute Release	Only secondary jolly logic chute release failure	-None- (Redundant system)	Failure to be enabled or binding of release mechanism	-None- (Redundant system)	1	0	2	3	The two Jolly Logic Chute Release devices are wrapped around the main parachute in series to ensure redundancy. If the primary chute release successfully deploys but the secondary chute release should fail, the main shute will still be released.	
Both Jolly Logic Chute Releases	Double main chute release failure	The rocket will descend only under the drogue chute.	Failure to be enabled or binding of release mechanism	Main chute is not released. And the vehicle will impact the ground with higher than expected kinetic energy	1	9	1	11	The redundant jolly logic chute release devices are both included to ensure that the likelihood of this failure mode is kept to a minimum.	There is a checklist item is present to verify that both chute release devices are wrapped in series around the main chute before it is assembled into the vehicle.

Descent Under Main Chute FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Recovery Harness	Recovery harness snap	Rocket segments falling at higher then planned velocities	Insufficient recovery harness line strength or excessive yank	The rocket will separate into unplanned segments.	2	4	2	8	The recovery harness line material was selected to withstand the forces expected.	A pull test will performed to verify that the recovery harness can withstand the maximum expected tension in the line.
U-Bolt	Disconnection of parachutes from rocket	Rocket segments falling at higher then planned	Insufficient design	The rocket will separate into unplanned	2	4	2	8	Stress simulations were performed to verify that the design of the rocket was sufficient to handle the yank of parachute	A checklist item is included to verify that the U Bolts are properly mount and bonded into place with locktight.

		velocities		segments.					deployment	
Parachute chords	Parachute Tangling	Rocket descent at higher than expected velocities	High wind speeds or improper folding	The Rocket will descent at higher than planned velocity	5	2	2	9	The parachutes are attached to the primary recovery harness chord via two swivel joint that allow the parachutes to freely turn and prevent tangling.	A checklist item is included to verify that the parachutes are attached to the recovery harness via swivel joints.

Landing FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Wind	Excessive Drift	Complications during recovery	Wind blowing the rocket excessively during descent	Rocket drifting outside of range	5	2	5	12	The two stage parachute system is designed to keep the rocket within the given range even at high wind speeds.	Simulations have been performed to ensure that the parachute sizes selected will keep the rocket within a reasonable range of its launch site.
Landing impact on a rock or other object	Hard landing	Damage to rocket	Landing on a hard object	Impact with hard surface	2	2	5	9	The rocket will only be launch at sites general clear of large obstructions.	Satellite images of the competition field in Alabama and Snow Ranch, which is the launch location for the team's subscale and full scale rockets show generally open fields with rare obstructions.

Recovery FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Egg finder GPS Unit	Failure of the GPS to transmit location correctly	Difficulty in locating the rocket	Improper assembly or defective manufacturing	GPS either transmits no signal or incorrect coordinate signal	3	3	7	13	The vehicle will be tracked by eye in addition to camera footage recorded from the ground.	Multiple team members shall be present at each launch and a majority will watch the rocket ascent and track it's descent by eye.
Tree or other tall structure	Entanglement	Potential injury to personnel if improper recovery procedures are not followed.	The rocket lands in a tree	The rocket will need to be recovered from the tree	1	1	9	11	The rocket will only be launch at sites general clear of large obstructions.	Satellite images of the competition field in Alabama and Snow Ranch, which is the launch location for the team's subscale and full scale rockets show generally open fields with rare obstructions.
Various	Unplanned vehicle separation into untracked parts	Potential to lose track of vehicle components	Snapping of the recovery harness or structural failure.	Both the GPS equipped section and non-GPS equipped section will need to be recovered	3	5	2	10	The vehicle will be tracked by eye in addition to camera footage recorded from the ground.	Multiple team members shall be present at each launch and a majority will watch the rocket ascent and track it's descent by eye.

ADAS FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
Drag Fins	Unplanned detachment of fins during flight	The rocket will be damaged and could impact personnel	Weakness of the fins to withstand aerodynamic forces	The rocket will adopt an unplanned trajectory	3	6	2	11	Stress simulations have been performed to ensure that the mechanical design of the fins are compatible with the expected loads.	A test of the ADAS fin strength is planned to verify that the fins will support the expect loads.
Batteries	Failure of any number of batteries to provide sufficient power to ADAS systems	Potential loss of one or more ADAS system functionality	Improper wiring, manufacturer error, g-forces tearing apart storage cells internally	Battery affected will either be impaired or unusable in flight	1	5	1	7	Proper diagrams and procedures written to connect circuit components before being turned on. Circuits and computer code will be run and tested on a preliminary basis to ensure functionality. Backup components will be used if necessary.	A checklist item is included to check that the batteries are fully charged prior to their assembly into the vehicle.
NeveRest Motor	Failure of ADAS motor to supply sufficient power to operate drag fins	Potential loss of control of drag fins	Improper wiring, manufacturer error	Control over drag fins is impaired or lost	3	2	1	6		The motor in addition to the entire ADAS system shall be extensively test to verify proper behavior prior to launch.
Arduino 101	Failure of the 101 microcontroller to operate and handle ADAS systems	Potential loss of flight data and control over ADAS motor	Improper wiring, manufacturer error, faulty code	Malfunction of the Arduino 101	3	3	3	9		The ability of the Arduino 101 to correctly operate will be tested on the ground prior to launch.
H-bridges	ADAS electric motor draws more than 4 amps of current for an extended amount of time	Potential to ruin entire ADAS flight control system, damage to lower avionics bay	Improper wiring, manufacturer error	Permanent damage to Arduino 101 controller and all of its systems connected to it	1	5	1	7		The H-Bridge in addition to the entire ADAS system shall be extensively test to verify proper behavior prior to launch.
2 Amp Fuse	Failure of fuse to limit the current between NeveRest battery and motor	Potential for high current and damage to motor circuitry	Improper wiring, manufacturer error	Fuse will not blow and thus cannot prevent excessive current	5	4	1	10		The fuse shall be sourced from a reliable manufacture and an identical product will be verified to break the circuit at the limiting current

TARS FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
V2 Camera	View Obstruction	Prevention of target detection	Dirt or scratches on the window section	Targets are obstructed or blurred	8	5	1	14	The window section shall be kept clean and free of any scratches.	The window section will be inspected for obstructions prior to launch.
Raspberry Pi 2	Target detection code failure	Failure of TARS to complete its mission	Error in code	Target footage is not processed	3	8	1	12	The TARS code shall be carefully written and checked for errors	The TARS system will be ground and verified to function as expected.

4.3.3 Environmental Hazard Analysis

The evaluation of the effects which the environment can have on the rocket and vice versa are explored in the following tables similar in format to the FMEA tables above.

Environmental Effects on Rocket										
Source	**Failure Mode**	**Hazard**	**Cause**	**Effect**	**L**	**S**	**P**	**R**	**Mitigation**	**Verification**
Precipitation	Failure to properly encase the rocket	Water damage to the rocket	Exposure to precipitatio n	Moisture saturating the rocket causing it to be permanently inoperative.	2	8	3	13	Safely securing the rocket in a waterproof casing before moving it into a potentially moist environment.	Weather forecast will be monitored for any period in which the rocket could be exposed to such elements.
Trees	Entanglement	Potential injury to personnel if improper recovery procedures are not followed.	The rocket lands in a tree	The rocket will need to be recovered from the tree	1	4	9	13	The rocket will only be launch at sites general clear of large obstructions.	Satellite images of the competition field in Alabama and Snow Ranch, which is the launch location for the team's subscale and full scale rockets show generally open fields with rare obstructions.
Wind	Drift	The rocket could drift out of the expected field range	Weather	The rocket's trajectory is changed	5	2	3	10	Wind effects are taken into account during modeling of the rocket's potential trajectories.	Wind speed measurement shall be taken prior to launch to ensure that wind speeds are within the acceptable range.

Rocket Effects on Environment										
Source	**Failure Mode**	**Hazard**	**Cause**	**Effect**	**L**	**S**	**P**	**R**	**Mitigation**	**Verification**

Motor	Improper use of launch deflector.	Exposing unnatural chemicals into the environment.	Chemicals entering water sources, soil, and being released into the air.	Contributes to water pollution, air pollution, soil contamination. Can cause these pollutants to bioaccumulate in a system.	2	1	1	4	Proper use of a launch deflector of adequate size will prevent such contamination. The rocket must be launched far enough from streams to avoid water contamination and no flammable materials should be near the launch site .	Chemical properties of the motor(primarily ammonium perchlorate, synthetic rubber, aluminum metal fuel, etc) have been researched and all team members understand how to safely handle any parts containing such chemicals. A pre-flight checklist ensures that no streams and no flammable material is present near the launch pad. Following the NFPA 1127 4.12.2 code, the launch device must have a launch deflector that deflects flame from flammable material underneath the launch pad.
		Fire on launch pad	Deflector is not big enough and flammable materials under launch pad	Environmental destruction.	1	2	1	4		
	Misplacement of launch	Noise pollution	Placement of launch pad in close proximity to wildlife	Nearby wildlife will experience hearing damage	1	1	1	3	Inspection of wildlife in close proximity to launch rail must be done to assure no harm.	A pre-flight checklist ensures that inspection of wildlife in close proximity to launch is not jeopardized.
Various areas of the rocket.	Manufacturing error, disassembly of rocket during flight.	Physical injury to wildlife.	Damage to habitats, injury or fatality of animals.	Endangering species of launch site ecosystem.	1	1	1	3	Separate parts of the rocket will be carefully monitored during descent. Rocket will be launched away from natural habitats to avoid harm to wildlife.	A checklist of potentially missing parts will be used while finding the rocket to avoid leaving behind a piece that will disturb its surroundings.
		Pollution to surrounding environment.	Loss of rocket parts	Parts not properly disposed of will contaminate the environment.	1	1	1	3		
Rocket material waste	Improper disposal of materials during manufacturing process	Pollution to surrounding environment.	Misinformed members unaware of proper disposal of certain materials	Improper disposal allows contaminants to enter into the environment and can pose a danger to wildlife.	1	1	1	3	Team members follow a protocol on how to properly handle and dispose of waste and other hazardous material.	A disposal checklist is in place for hazardous materials. Team members will follow the checklist step by step to ensure no materials are left behind endangering the environment and wildlife.

5 Payload Criteria

E-1's payload will satisfy this year's target detection experiment requirement with TARS, the TArget Recognition System.

5.1 Changes made since PDR

Category	Change	Reason
Image Capturing Software	Now we use a python library	Interfacing with the camera through its default shell program was problematic. We needed finer control and the ability to have an API with our python programs.
TARS Activation	Electronic switch epoxied to bulkhead to trigger video recording seconds instead of minutes/hours before launch	We needed a way to start recording before launch without needing a specialist and having unpredictable temporal conditions at launch.
Error Indication	LEDs have been visibly added	Error indicators and a manual were needed so special technicians weren't required at every launch.

Since the PDR we've had three separate launch builds (each with their own software and electronic improvement) , and one successful launch. The outcome from implementing our initial PDR designs for each attempted subscale launch helped us improve, cut, add, and redesign parts of our payload assembly. We've made marginal improvements with respect to the software, and larger changes with respect to the electronics. The manufacturing design has had one change made to it since the Preliminary Design Review.

5.2 System Design

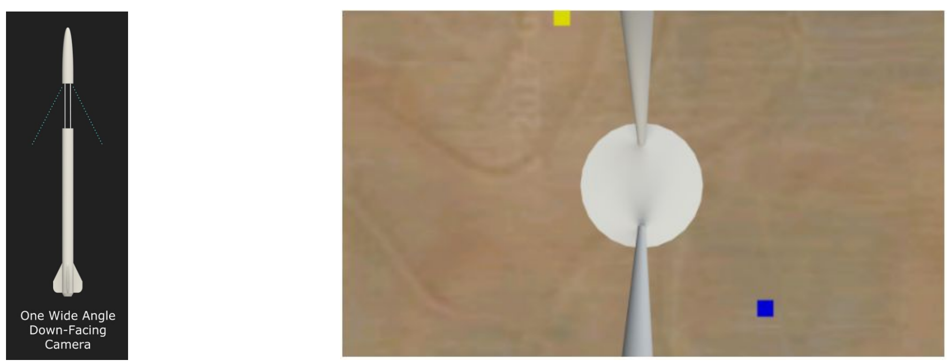
5.2.1 Overall Description of Payload

We are still on the path to completing objectives that were initially stated in the PDR:

- Identify all ground targets based on predefined color criteria in real time
- Provide proof of target identification via saved data which can be recovered after flight
- Obtain at least 10 frames with successful target detections during ascent
- Perform well at high spin rates
- Use gyroscope measurements to spin-stabilize the video feed in real time

Resulting in a recorded video of the rocket's ascent from the onboard camera's perspective with the ground targets identified and outlined. System success will be determined by a quality analysis of the footage, focusing on the clear identification of the ground targets.

To accomplish this we will be using a single board computer with the ability to attach a recording device. This recording device will view the ground through a manufactured clear tube section in our rocket, and record images of the ground where the targets are located. This captured footage will then be processed on-board in real time and clearly identify these targets and relay this information to judges.



(a) (b)

Figure 5-1 Rocket Transparent Renderings

Fig. 5-1 shows the final choices we've made regarding the transparent section of the rocket. Fig. 5-1a shows the overall integration of a clear section into the rocket. Fig. 5-1b shows a rendered image of what the camera will see. Fig. 5-7 shows actual recorded frames from our December 9th subscale flight.

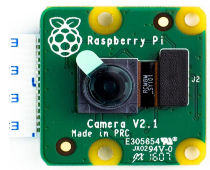
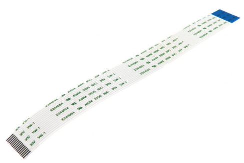
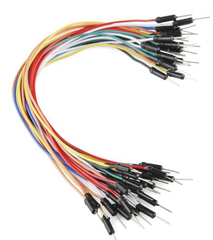
 **Raspberry Pi 2**	• SoC: Broadcom BCM2836 (CPU, GPU, DSP, SDRAM) • CPU: 900 MHz quad-core ARM Cortex A7 (ARMv7 instruction set) • Memory: 1 GB (shared with GPU) • Storage: MicroSD • Peripherals: 17 GPIO plus specific functions, and HAT ID bus • Power rating: 800mA (4.0 W) • Power source: 5V via MicroUSB or GPIO header • Size: 85.60mm × 56.5mm • Weight: 45g (1.6 oz) • Cost: $35 • Quantity: 1:	 **Raspberry Pi Camera V2.1**	• 8 megapixel native resolution high quality Sony IMX219 image sensor • Camera capable of 3280 x 2464 pixel static images • Capture video at 1080p30, 720p60 and 640x480p90 resolutions • 1.12 µm X 1.12 µm pixel with OmniBSI technology for high performance (high sensitivity, low crosstalk, low noise) • Optical size of 1/4" • Dimensions: 25mm x 23mm x 9mm / 0.98" x 0.90" x 0.35" • Weight (camera board + attached cable): 3.4g • Cost: $30 • Quantity: 1
 **Pi Camera Flex Cable**	• Dimensions: 10" x 16mm x 0.2mm / 3.3ft x 0.6" x 0.01" • Weight: 0.5g • Cost: $2.20 • Quantity: 1	 **SanDisk MicroSD Card**	• Capacity: 16 GB • Form Factor: microSDHC • Video Speed: c4 • Cost: $7.00 • Quantity: 1
 **5mm LED**	• Intensity: 17,000mcd • Colour Freq: x=31 y=32 • Viewing Angle: 30º • Lens: Water Clear • Voltage: 2.9v-3.4v • Typical: 3.1v • Current: 20mA • Cost: $0.50 • Quantity: 2	 **Jumper Wires**	• 28 AWG • Cost: $0.10 per cable • Quantity: 10+
Battery 	• 5 V 5000 mAh • Cost: $10.99 • Quantity: 1	**Resistors** 	• 5% 700 Ω ¼ W • Cost: $0.10 • Quantity: 2

Table 5-1 TARS electronic components and their specifications

Listed in Tab. 5-1 are all final parts and specification of the TARS payload. We will be utilizing the Raspberry Pi 2 as the single board computer and controller of the TARS system. It provides enough general purpose input-output (GPIO) pins for switches and LEDs, as well as having an on board housing for a camera. Its memory and CPU speed meet the requirements necessary for running the camera at 60fps and processing at the same time. The weight of the entire system minus the battery is 50g, thus not affecting such design factors as center of gravity in any significant manner. The Raspberry Pi Camera V2.1 comes with native support on the Raspberry Pi and with an open source python library we are able to easily control it.

5.2.2 Assembly of Payload

The remaining subscale and full-scale vehicles will have TARS placed onto the upper portion of the avionics sled, see Fig. 5-2 for a rendered version of the mounted assembly of TARS and Fig. 5-3 for a assembled but not mounted picture of the current configuration.

1. The Raspberry Pi 2 (Fig. 5-3.1) is mounted using non-conductive mounting screws and holes drilled into the sled such that the aluminum does not interfere with circuit operation.
2. The Raspberry Pi Camera (Fig. 5-3.2) is attached to the lower bulkhead on the ground side, facing the ground. It is mounted via two pieces of velcro, one on the bulkhead one on the backside of the camera. We used pieces of plastic to stabilize it for a pure 90° camera angle with the wide lens.
3. The flex cable (Fig. 5-3.3) pictured in Fig. 5-3 but not 5-2, is threaded through the bulkhead hole and attached to the Raspberry Pi.
4. The SD card (Fig. 5-3.4) is partitioned to hold the Raspbian O.S., but is also the memory we store the captured footage on. For space and protection reasons we have it on the bulkhead side (see Fig. 5-2), and to remove video streams we insert a flash drive into the USB port.
5. Both LEDs (Fig. 5-3.5) are mounted on another bulkhead hole and are visible through the transparent section of the rocket, and have their cables managed via a braided sleeve inside the avionics bay.
6. The battery, detailed at greater length in section 5.3.3, is mounted via non-conductive mounting screws and holes drilled into the sled close to the lower bulkhead. It powers the Raspberry Pi via a USB cable (Fig. 5-3.6) that is broken out into a power and ground jumper wire. This saves us room inside of the avionics bay and gives greater strain tolerance to a potentially catastrophic failure.
7. The screw switch (pictured in Fig. 5-2 but not 5-3) is epoxied to the ground side of the upper bulkhead, and uses jumper wires threaded to the Raspberry Pi's GPIO pins and managed by a braided sleeve.

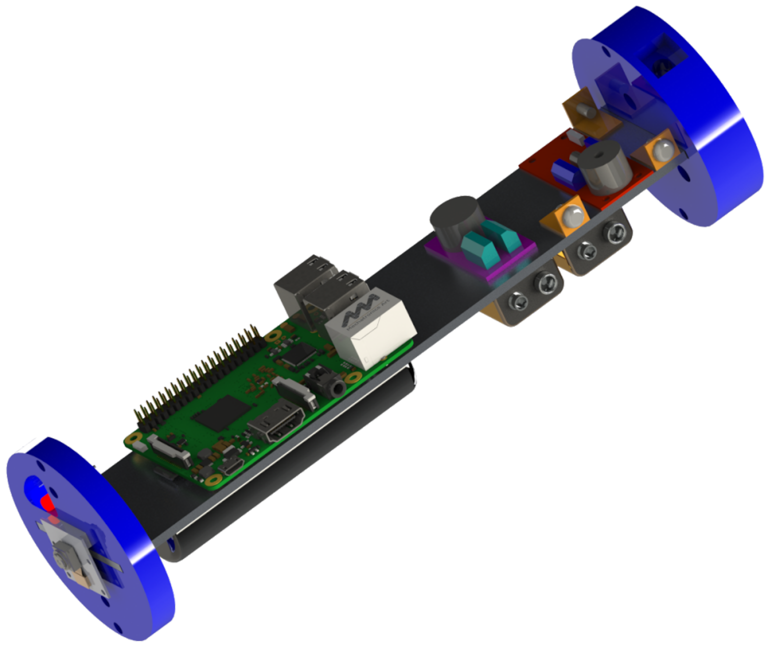


Figure 5-2 Rendered image of TARS assembly into the upper avionics bay

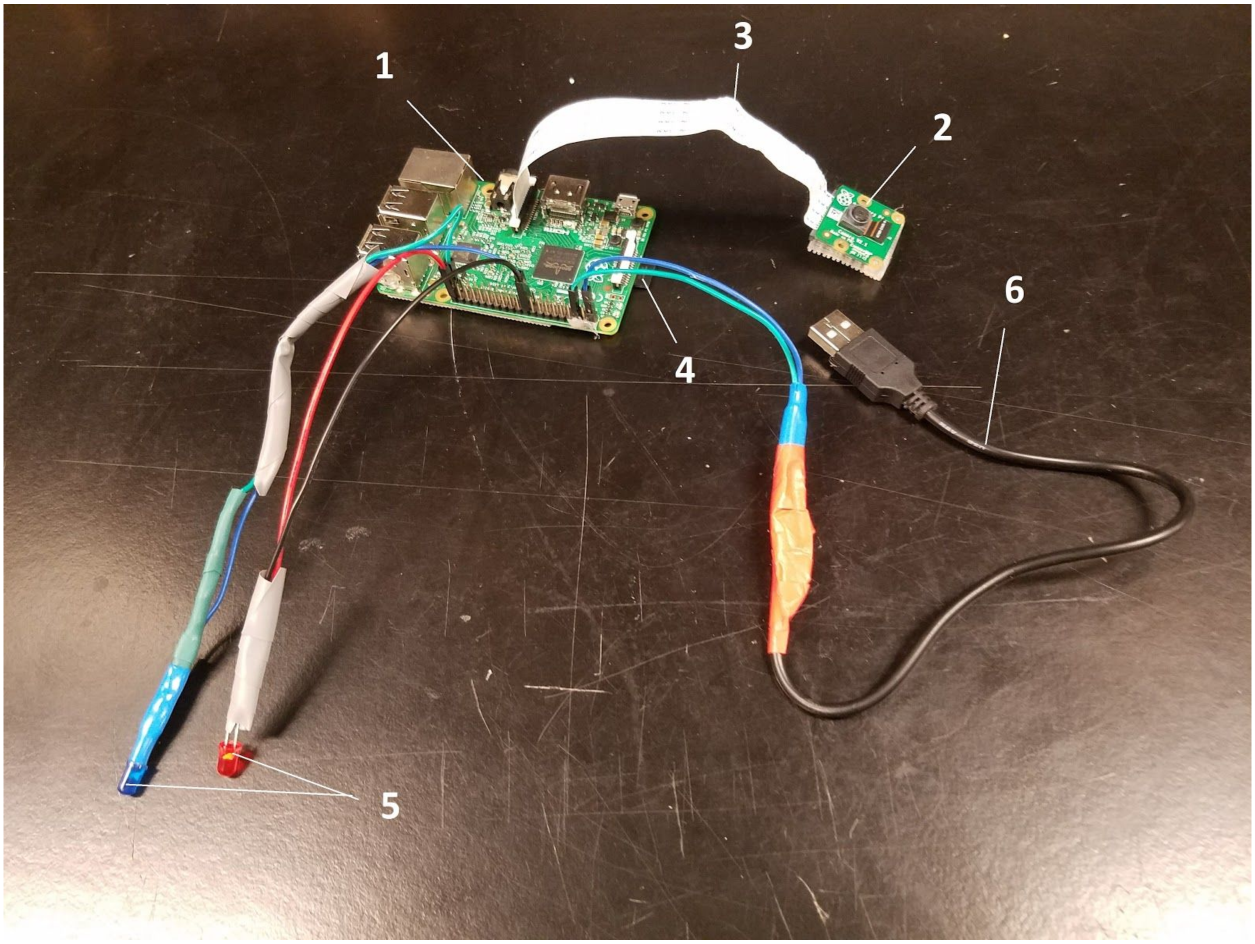


Figure 5-3 Assembly of electronic components of TARS. (1) The Raspberry Pi 2 board (2) The Raspberry Pi Camera V2.1 (3) Raspberry Pi Camera flex cable (4) SanDisk MicroSD card (5) LEDs (6) USB power breakout (7) *Not Shown* Screw Switch

5.2.3 Component Interaction

Component interaction is all controlled through a series of python libraries and several pieces of additional software the team has written. The screw switch and LEDs are easily controlled by the python GPIO library. The Pi Camera is also controlled by an additional python library discussed in section 5.4.1. Each role is written about and justified throughout the document, but here is a complete list of roles performed by components referenced in Figure 5-3:

1. **Raspberry Pi**: Single board computer controlling each part of the TARS system as well as processing actual on board footage for target identification.
2. **Raspberry Pi Camera**: Responsible for capturing footage of ground targets.
3. **Raspberry Pi Camera Flex Cable**: Connection between Raspberry Pi and camera.
4. **MicroSD Card**: On board persistent storage.
5. **LEDs**: Error indication unit.
6. **USB power breakout**: Ability to power over GPIO from a rechargeable battery.
7. **Screw Switch**: Ability to start and stop video with rocket assembled and on launch pad.

5.3 Payload Electronics

5.3.1 Component Outline

Pictured below in Fig. 5-4 is the schematic level view of the TARS system. The V2 camera is connected to the Raspberry Pi 2 through general purpose input-output (GPIO) ports, a 5V rechargeable battery designed for the Pi is connected as per manufacturer specifications, and the LEDs are also GPIO connected.

We've introduced two new electronic components since our PDR submission. The first is two 5mm LEDs, the second is a screw switch. Both of their roles and subsequent programming will be discussed in section 5.4.

5.3.2 Schematic and Setup of TARS Circuitry

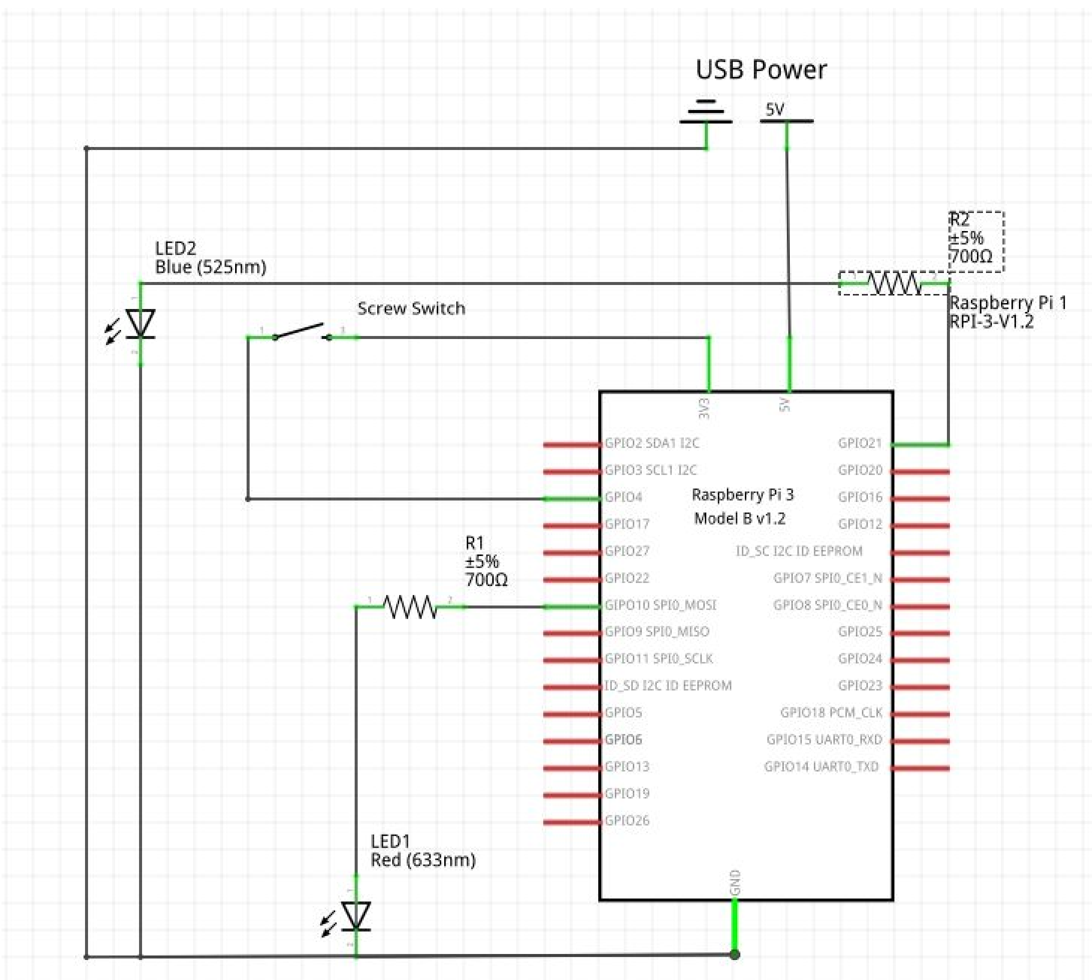


Figure 5-4 TARS system as made in a Fritzing schematic drawing

Fig. 5-4 is used as the primary guide to connecting components each time the circuitry is prepared for launch as a redundant measure to quickly and effectively connect wires as needed.

5.3.3 Power Usage and Safety

All components will be operated according to manufacturer specifications such that no excessive current and power is drawn by any electronic equipment of TARS while active. This is to ensure the safety of anyone configuring the electronics, as well as to prevent having to repurchase parts that might be affected by a potential overloading. Listed in Table 5-2 are the components maximum power ratings and the expected (nominal) power usage during flights.

5.4 Payload Software

The software-architecture contains two separate modules to satisfy the requirements of the TARS system.

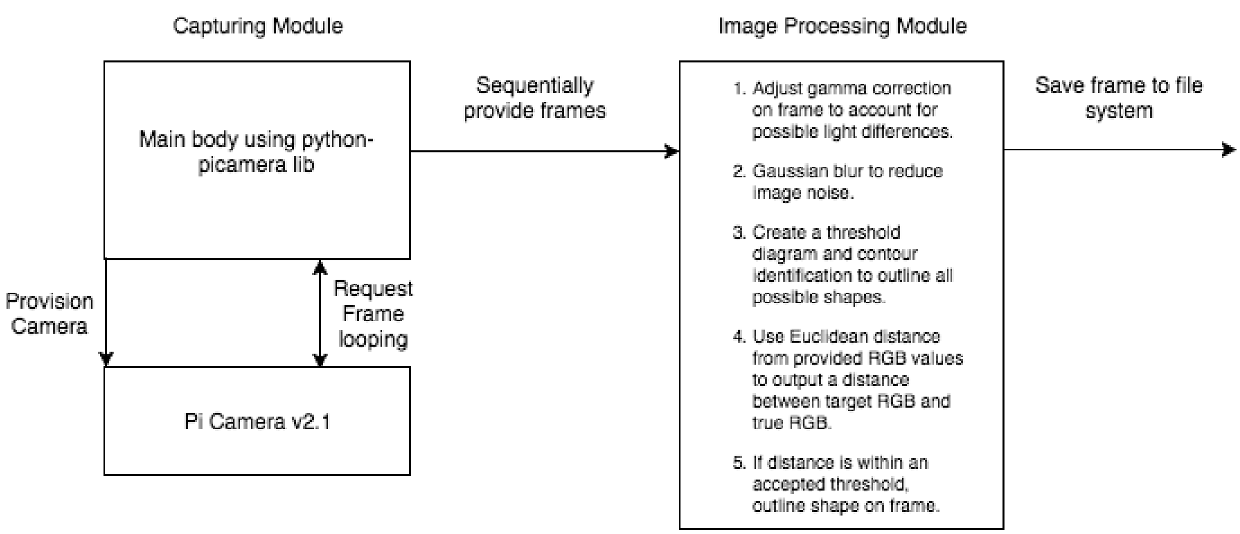


Figure 5-5 The Block Diagram of TARS software

All software Rocket Club at UCSC has written can be found open source at:

https://github.com/UCSC-Rocket-Club

5.4.1 Image Capturing Software

The image capturing software is software responsible for capturing video frames saving these frames, and passing them to the image processing module.

During subscale we discovered a powerful python library: python-picamera.

- Documentation: http://picamera.readthedocs.io/en/release-1.13/
- Source code: https://github.com/waveform80/picamera

This library lets us programmatically capture a frame at 60fps and be able to pass it easily to our next module also in python. There are several library calls such as ***capture*** and ***capture_continuous*** that allow us very fine control over the amount of frames we want to be processing through the module.

During subscale testing we noticed that the python library would corrupt the video if the Raspberry Pi lost power or somehow had a hard shutdown like post launch landing. This was too much risk on our part so we changed to capturing individual frames and saving frames at 60 frames per second. This gave us the advantage of already having frames broken down for future TARS programming, as well having uncorrupted data saved if there is a catastrophic failure (i.e. already saved to file system).

5.4.2 Image Processing Software

This module will be written in python and will be identifying targets in flight. We currently have some of the module built and plan on using the following plan for identification:

1. Adjust gamma correction on frame to account for possible light differences.
2. Gaussian blur to reduce image noise.
3. Create a threshold diagram and contour identification to outline all possible shapes.
4. Use Euclidean distance from provided RGB values to output a distance between target RGB and true RGB.
5. If distance is within an accepted threshold, outline shape on frame.
6. If module 2 is completed, implement confidence level decision making on area of frame targets are being identified on.

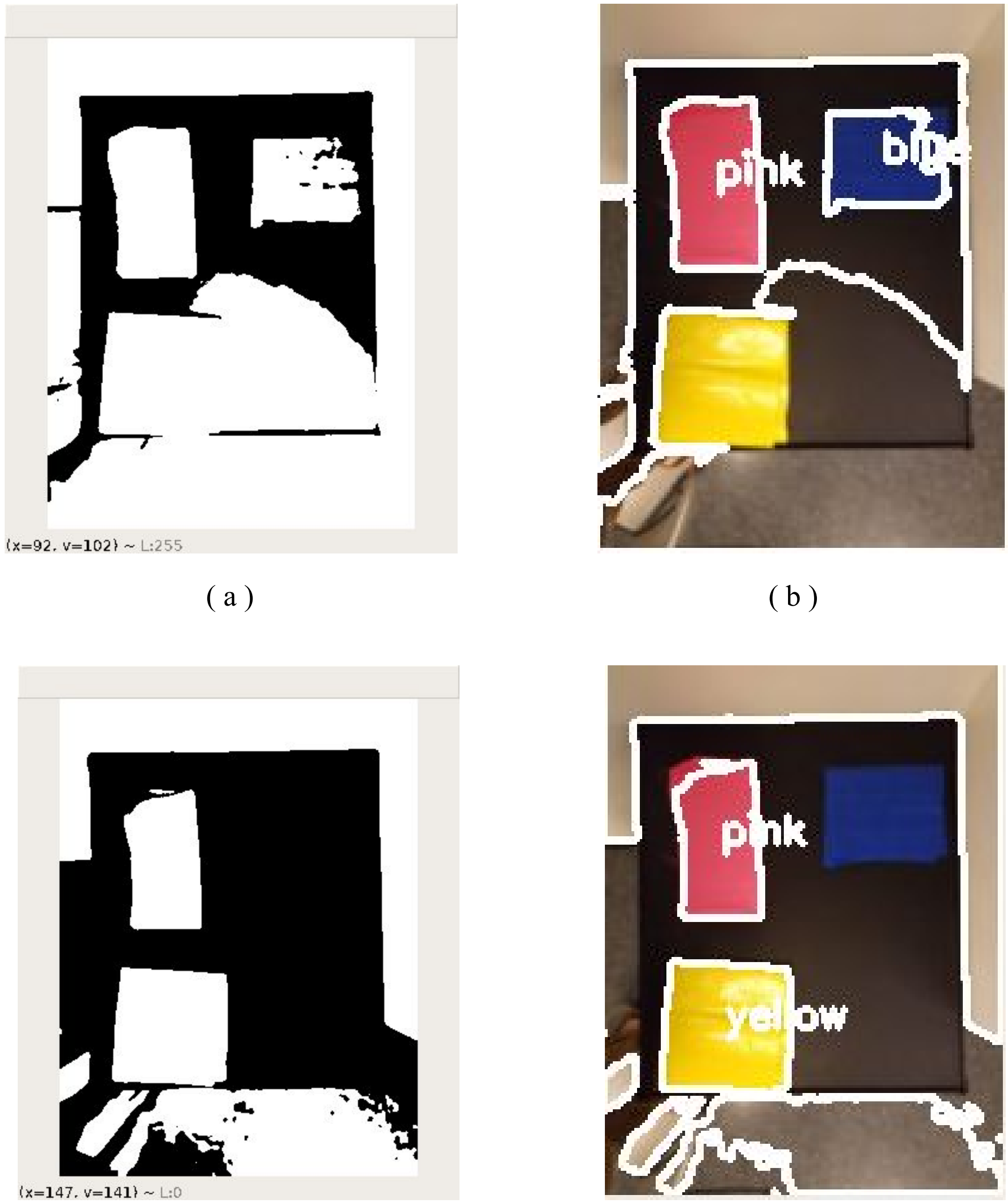


Figure 5-6 Output of image-processing software. As you can see there are two separate sets of identifiable targets depending on levels of gamma correction we choose. The top row is a lower gamma correction value, the bottom row is a higher and more normal gamma correction value (closer to 1). The left column is the threshold diagram and the right column is outputted frames.

5.4.3 Control Software

We decided to create a third category of software for the TARS payload that is considered control software. This includes error indication and start/stop of the frame recording.

The screw switches were introduced to solve a temporal problem. We were unsure of the time between turing on the payload system, and the actual end of flight. In previous builds we solved it with a simple equation, but because of our budget it was a little risky to brute force record everything. The risk of running out of storage space was and still is a problem, and our solution is to make a switch accessible from the exterior of the rocket. With this switch, which was designed to have a small screwdriver fit through a hole, our control software would trigger the recording of the frames. Once the Pi boots on, it triggers a program through /etc/profile on Raspbian that listens on a GPIO pin for a signal from the switch, and activates when power is passed through. This allowed us to add finer control and a guarantee that our payload would not be processing and saving and exorbitant amount of unneeded frames.

We also had a need to include error indication. Fixing any problems during testing and our subscale launches required a specialized technician and a computer monitor. We wanted to remove both of these resources from the procedure and included one LED. We soon found out that was not enough and switched to two distinctly colored LEDs, which gave us the option of 3^2 number of displayable codes.

LED 1	LED 2	Indicator
On	On	• **If screw switch triggered:** active recording
Off	On	Could not provision camera
Blinking	On	Could not begin recording
On	Off	GPIO setup on screw switch pin failed
Off	Off	Program dead
Blinking	Off	Error 6
On	Blinking	Error 7
Of	Blinking	Error 8
Blinking	Blinking	Systems fine. Waiting on signal to start recording

Table 5-2 Breakdown of LED indication for TARS error-checking

This has several improvements over the previous system, since there are far more possible error codes, and they are not temporally or rate dependent (i.e the error can display continuously, and there is only one rate of blinking).

5.4.4 Subscale Flight Results

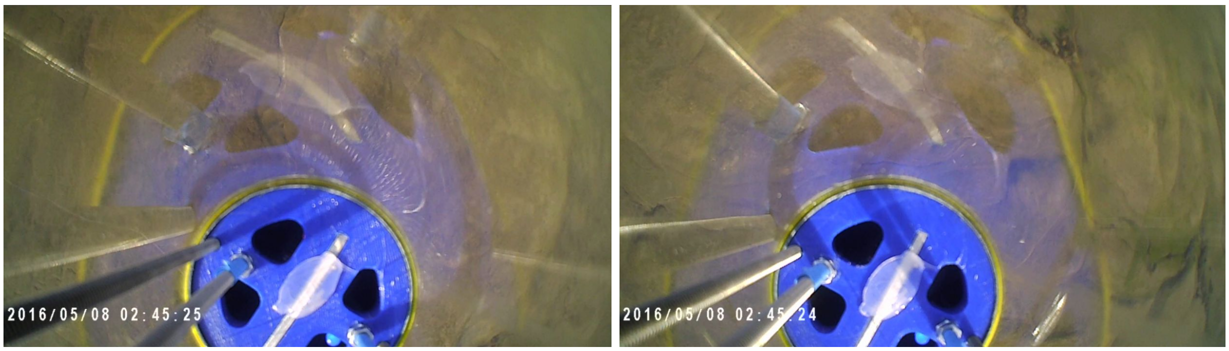


Figure 5-7 Footage from onboard camera during our subscale launch.

5.4 Completion of Design

To determine the completion of design for the TARS payload, we reason we must exhibit four different qualities about the entire system:

1. Identification of targets (i.e. it actually works)
2. Redundancy
3. Fault Tolerant
4. User indifferent

Through prototyping and the subscale launch we've determined that both the camera can record film at high speeds and the software is capable of identifying targets. We've taken redundant methods with the design of how to power the device, and introduced fault tolerance by including error indicators. Through the manual and these error indicators and user manual with solutions to those errors, we've made the design user indifferent, and as such complete.

6 Project Plan

6.1 Testing

Every test will be carried out with safety precautions in mind. The testing of the components will be done in a thorough and controlled manner to ensure the viability and safety of the test. All mechanical and electrical tests will be supervised by the safety officer who will primarily ensure the safety of the testers, as well as the parts being tested.

1. Mechanical Testing

Test	Purpose	Specifics	Method	Hazards	Mitigations	Results
1.1 Nose cone with internal attachments, coupler, fins, all threads nuts, electronics secured, camera secured, rail buttons, and tail cone secured	Ensure that all mechanisms will withstand the rocket's flight.	All mechanisms should be unharmed and fully functional once retrieved after flight.	The full scale launch of the rocket as well as various simulations will test the strength of all components.	Damage to surroundings or bystanders	The area near the base of the drop zone will be corded off and no bystanders will be allowed into the area for the duration of the drop test. Personnel will stand at the edge of the dropzone to direct people to not cross into the area.	All passed during subscale launch except for the coupler which separated. Another test will be completed by 02/03/2018
				Damage to the rocket	All components will be checked several times to ensure that they are secured and functioning adequately before launch.	
1.2 Parachute Secured	Ensure the parachute attachment can withstand the tension experienced during the flight.	The cord attaching the parachutes to the rocket body should be able to withstand a simulated tension equivalent to the tension experienced during the flight. No permanent deformation or snapping shall occur.	Equipment: - Parachutes - Cord - Mass simulator The parachutes will descend from the roof of McHenry library with a mass simulator attached matching the mass of the mechanism inside the rocket. The mass simulator will have a mass of 12 pounds to simulate that of the rocket plus 20% for redundancy.	Damage to surroundings or bystanders	The area near the base of the drop zone will be corded off and no bystanders will be allowed into the area for the duration of the drop test. Personnel will stand at the edge of the dropzone to direct people to not cross into the area.	Test will be completed by 02/03/2018
					The parachutes shall be inspected before the test to ensure the folding is correct and they will not get tangled during the test.	

1.3 U Bolt Strength Test	Ensure the U bolt can transmit the force from the parachutes to the all threads and the rest of the rocket	The U bolt should be able to interface between the parachutes and the rocket without being deformed and the nuts holding it in place should not come undone.	Equipment: - Parachutes - Full rocket with all threads and mass simulators for all missing components The parachute cords will be attached to the U bolt and the rocket will slowly be lifted so that the entire rocket is supported by the cord and U bolt alone.	Damage to the rocket	Rocket will be lifted very slowly and only to a maximum height of a few inches above the ground. At least one person will be ready to steady the rocket in case of unexpected failures.	Test will be completed by 02/03/2018
1.4 Motor Housing Secured	Ensure the motor housing can withstand the forces exerted on it during the burn phase of the rocket's flight	The motor housing should be able to withstand a force of 900N without deformation or causing any failures in any other component of the rocket	The full scale launch along with various simulations will test the durability of the motor housing.	Damage to the rocket	The motor housing will be checked for imperfections several times before launch.	Test will be completed by 02/03/2018

2. Electronics Tests

Test	Purpose	Specifics	Method	Hazards	Mitigations	Results
2.1 ADAS Electronics Current Draw Test	Ensure the ADAS electronics power up and are free of electrical shorts.	The Arduino 101 and all connected sensors (MPU 6050 IMU, MS5607 altimeter, NeveRest 40 motor encoder) and output (status LED, H-bridge) shall together draw no more than 100 mA and no less than 75 mA.	Equipment: - Arduino 101 - MPU 6050 - MS5607 - Status LED - H-Bridge - NeveRest 40 motor encoder - Ammeter / Multimeter The Arduino 101 and all connected sensors and output are powered with their respective batteries. The Arduino 101 is supplied through an ammeter or multimeter and the current measured. The current supplied to the Arduino 101 must be less than 100 mA and more than 75 mA during a simulated launch.	Excessive current may damage electronics.	If excessive current or heat is detected, shut off power immediately.	Test will be completed by 02/03/2018
2.2 TARS Electronics Current Draw Test	Ensure the TARS electronics power up and are free of electrical shorts.	The Raspberry Pi 3B with 3 status LEDs and the Raspberry pi V2 camera shall together draw no more than 650 mA and no less than 300 mA.	Equipment: - Raspberry Pi 3B - Raspberry Pi V2 Camera - 3 Status LEDs - USB Ammeter / Multimeter - USB Battery Pack	Excessive current may damage electronics.	If excessive current or heat is detected, shut off power immediately.	Test will be completed by 02/03/2018

			The Raspberry Pi 3B, 3 status LEDs, and Raspberry Pi V2 camera are powered with a USB battery pack through a USB multimeter. The current supplied to the Raspberry Pi 3B, 3 status LEDs, and the Raspberry Pi V2 camera must be less than 650 mA and more than 300 mA during a simulated launch.			
2.3 Storage Test	To test the available storage on systems.	Since the micro SD card in the Raspberry Pi contains the Raspberry Pi OS and the micro SD card in the Arduino 101 contains flight data, it is essential that these storage devices be defect free. Flash memory has an internal controller which features such as wear-levelling, thus it is difficult to detect write errors and even counterfeit storage devices. The software utility "f3" is designed to detect counterfeit devices and can check capacity and storage integrity by filling the device with data. Since this test is destructive, it must be performed before use.	Equipment: - Personal Computer - "f3" Software Install "f3" on a personal computer and run ./f3probe --destructive --time-ops /dev/<device> on each micro SD card.	Data destruction	Only perform test on empty storage device.	Test will be completed by 02/03/2018
2.4 StratoLogger and EasyMini Vacuum Test	To confirm apogee drogue parachute charge deployment.	By partially evacuating a chamber containing the StratoLogger and EasyMini altimeters, then allowing the chamber to equalize to room pressure, the altimeters should detect apogee at the point when the pressure in the chamber increases.	Equipment: - Vacuum Desiccator - Vacuum Line - 9 V Battery, 2x - LED, 2x - StratoLogger - EasyMini Connect 9V batteries to the StratoLogger and EasyMini altimeters. Connect an LED across each parachute charge terminal taking care to match the polarity of the terminal with the LED. Place the altimeters into a vacuum desiccator. Leave the vent valve open on the desiccator and attach a vacuum line to the desiccator. Once desiccator chamber drops, close the vacuum valve and allow the desiccator vent to equalize the pressure in the chamber to the outside air. Watch the LEDs. LEDs should light up soon after the valve is opened	Vacuum desiccator implosion	Safety goggles must be worn when performing test.	Test will be completed by 02/03/2018
				Damage to altimeters due to excessive vacuum	To avoid the application of strong vacuum, the vent on the desiccator must be left open during the test.	

2.5 NeveRest 40 ADAS DC Electric Motor Winding Resistance Test	To ensure the ADAS motor windings are intact and free of short circuits.	The ADAS motor windings should not exceed 15 Ω nor should they be less than 10 Ω.	Equipment: - Ohmmeter / Multimeter - NeveRest 40 Motor Measure resistance across the motor power connectors.	Motor Wiring may be damaged by excessive handling	Perform motor tests with wires secured to terminal blocks	Test will be completed by 02/03/2018
2.6 NeveRest 40 ADAS DC 2.7 Electric Motor Spin Test	To ensure the ADAS motor shaft and gearbox spin freely when unloaded and powered.	The ADAS motor should spin easily under power with no load. High current draw may indicate a bearing or gearbox issue. Low current draw may indicate a gearbox issue.	Equipment: - Ammeter / Multimeter - NeveRest 40 Motor - 12 V Power Supply Power the motor while unloaded using a 12 V power supply through a multimeter set on current mode. The motor current at steady-state must be (400 ± 20) mA in both current directions.	Excessive current may damage motor	If excessive current is detected, or the shaft does not spin, shut off power immediately.	Test will be completed by 02/03/2018
2.8 9V Battery High Current Load Test	To ensure 9V batteries can output high current and are not depleted or damaged.	To fire the electric match for the drogue parachute, a 9V battery must supply a brief high current spike of power. To be considered good, the battery must supply at least 2 amps short circuit through an ammeter.	Equipment: - Ammeter / Multimeter - 9V Battery In current mode, briefly place the multimeter probes across the 9V battery. The multimeter must read at or above 2.5 A for the battery to pass this test. In order to conserve battery charge, this test should be brief and only performed once on a battery on final assembly before launch.	Battery may leak or explode under high loads	Perform tests wearing gloves and goggles. Do not test for more than 3 seconds.	Test will be completed by 02/03/2018
2.9 USB Battery Pack Load Test	To ensure the USB battery pack is charged to within 20% of its stated capacity.	Testing the full capacity of a USB battery pack is a strong indicator of its integrity.	Equipment: - USB Multimeter - USB Battery Pack - USB 10W Dummy Load While battery pack is fully charged, insert the USB dummy load, start the stopwatch, and measure the voltage with a USB multimeter. The voltage should not drop below 4.5 V until after 80% of the stated mAh capacity of the USB battery pack is exceeded as measured with the multimeter.	Battery may leak or explode under high sustained loads	If battery heats up or expands, remove dummy load immediately.	Test will be completed by 02/03/2018
2.10 Screw Switch Drop Test	To verify the robustness of the screw switches.	Screw switches are custom fabricated and used for all critical components of the rocket including the altimeters and flight computer. These must resist high g forces and be reliable under high vibration and over many uses.	Equipment: - Oscilloscope - Resistor, 1 KΩ - Screw Switch - Power Supply Open the switch. Connect screw switch and resistor in series. Apply a small voltage across the resistor and switch series combination. Attach oscilloscope lead across the resistor. Repeatedly tap the switch on a lab bench surface and look for spikes on the oscilloscope. None should appear. Close the switch. Repeatedly tap the	Screw or switch assembly could come loose and fly while tapping switch on surface.	Wear safety goggles while performing this test.	Test will be completed by 02/03/2018

			switch on a lab bench surface and again, no spikes should appear on the oscilloscope.			
2.11 MPU 6050 IMU Data Test	To verify IMU functionality.	This test ensures the IMU is producing plausible data output using simple test code provided by Arduino libraries.	Equipment: - MPU 6050 - Arduino 101 - USB Cable - Personal Computer Plug the USB cable into the Arduino 101 and the personal computer. Upload the MPU 6050 sample sketch to the Arduino 101. Rotate the MPU 6050 through each axis, then accelerate the MPU 6050 through each axis. Observe the magnitude changes in each respective axis output in the Arduino serial output window.	Excessive force could cause damage to equipment and people	Use small movements to test the IMU.	Test will be completed by 02/03/2018
2.12 Internal Arduino 101 IMU Data Test	To verify IMU functionality.	This test ensures the IMU is producing plausible data output using simple test code provided by Arduino libraries.	Equipment: - Arduino 101 - USB Cable - Personal Computer Plug the USB cable into the Arduino 101 and the personal computer. Upload the Arduino 101 IMU sample sketch to the Arduino 101. Rotate the Arduino 101 through each axis, then accelerate the MPU 6050 through each axis. Observe the magnitude changes in each respective axis output in the Arduino serial output window.	Excessive force could cause damage to equipment and people	Use small movements to test the IMU.	Test will be completed by 02/03/2018
2.13 MS5607 Altimeter Test	To verify altimeter functionality	This test ensures the altimeter is producing plausible data output using simple test code provided by Parallax libraries.	Equipment: - Arduino 101 - USB Cable - Personal Computer - MS5607 Plug the USB cable into the Arduino 101 and the personal computer. Upload the Arduino MS5607 sample sketch to the Arduino 101. Read the output in the Arduino serial output window. Move the MS5607 one foot above its original position. Verify the output changes accordingly.	Dropping the MS5607 or Arduino 101 could cause damage	Perform this test over a soft surface.	Test will be completed by 02/03/2018

3. TARS Testing						
Test	**Purpose**	**Specifics**	**Method**	**Hazards**	**Mitigations**	**Results**

3.1 Code Hertz Requirement	Ensure our TARS payload can run at correctly intended speeds.	The TARS subsystem needs to run at 60fps with a resolution of 720x1280. Concurrently the system also needs to process those frames for identification. This process can lag behind, but must not interfere with the 60fps.	Equipment: - Built components of the TARS system mounted to the payload. With enough motion (both linearly and gyroscopically) we will test this by running the software. This needs to be done as close to launch scenarios as possible for correct data to be returned. We can judge success of 60fps by internally timing the flight on the Raspberry Pi and counting the number of frames in the file system.	All hazards associated with launching a rocket as specified in the Safety section.	As specified in the safety section.	Test will be completed by 02/03/2018

3.2 Redundancy of Data in TARS	Ensure data in TARS has a persistent store in case of hard shutdown of Raspberry Pi.	If the TARS system fails in some way, the data already processed needs to be saved for later examination.	Equipment:
			- Built components of the TARS system.
			Setup:
			- Lab environment. Not mounted to avionics bay.
			Procedure:
			- Begin recording and identifying images frame by frame at 60 fps.
			- Test three scenarios several times
			  - Battery slowly runs out of power
			  - Battery is quickly disconnected.
			  - Raspberry Pi experiences a soft shutdown.
			Success is determined if with each of these failures, some data is saved to persistent storage and is recoverable on reboot or on another system.
				Loss of data and damage caused to components	As specified in the safety section.	Test will be completed by 02/03/2018

3.3 Target Identification	Ensure we can detect targets of similar RGB value to NASA Targets.	The payload will not meet its objective if it cannot consistently identify targets from our transparent section. TARS should correctly identify the targets under multiple environmental/lighting conditions.	There are four tiers of this test: - Tier 1: Controlled lab images with actual material. Perfect lighting and clear image. - Tier 2: Real time footage with RGB value boxes photoshopped in. - Tier 3: Real time footage out of rocket with actual material. - Tier 4: Real time rocket with actual material.	Hazards of rocket launch are already mentioned. With Tier 3 we will be at a high elevation holding a system over the ground.	As specified in the safety section.	Tier 1 complete with success. Tier 2-4 will be completed by 02/03/18

			Equipment: - Built components of the TARS system mounted to the payload with assembled rocket. Setup: **Tier 1:** Capture images in perfect light of actual pieces of material. Still images that are easy to identify for the software to test correctness. **Tier 2:** Real time flight footage with photoshopped materials in. Tests that the system can handle real time input, but still easy to identify targets. **Tier 3:** Real time footage out of rocket, on top of our library at 150'. No movement of rocket, but targets will be real and harder to identify at distances. Shading and sunlight become a factor in this test. **Tier 4:** Full system test. Materials on ground with rocket launching in normal conditions. Every factor comes into this test. Procedure: Run footage collected from each scenario through software system. As tests advance through tiers, running software during the test will be required. Success is determined by humans examining the footage afterwards. If targets are identified, and no other items are identified, tier is successfully passed.	Make sure that that ground is clear of people and that rocket is safely secured to side of building.		
3.4 Recording Camera Data	Ensure that the camera can record data.	The camera is a sensor and as such needs to be tested and show that it can reliably record data, at rest and in a rigorous environment.	Equipment: - Built components of the TARS system mounted to the payload. Setup: Lab environment, as well as outdoor rocket launching facility. Procedure: - First test is in the lab to see if camera can record in a non-rigorous environment. If we can record data for the entire flight, it is successful. - Second test is on a rocket to test camera in a rigorous environment. We will test if it can withstand high Gs as well as intense spinning.	See above rocket launch hazards.	As specified in the safety section.	Test successfully completed.

3.5 Clear Section Clean and Non-reflective	Ensure that the clear section can allow the camera to take relevant and reliable data.	The camera can work perfectly, but if the clear section had reflection or is dirty false positives or false negatives can appear. We need a perfectly clear transparent tube. The camera should successfully image the tarps through the clear section and be able to identify them with different lighting scenarios.	Equipment: - Built components of the TARS system mounted to the payload, built components of the clear section of the rocket. Setup: Lab environment, as well as outdoor rocket launching facility. Procedure: - First test is in the lab to see if in a highly lighted environment the clear section reflects. We will test multiple angles of refraction and intensity of light. - Second test is on a rocket to test reflection in a real world scenario while spinning at high speeds. Success is determined by examining footage from the TARS system after running each test, and identifying if the glare or reflection is hampering the view of the camera on its targets.	See above rocket launch hazards.	As specified in the safety section.	Test will be completed by 02/03/2018

4. ADAS Tests

Test	Purpose	Specifics	Method	Hazards	Mitigations	Results
4.1 Proper Mechanical Assembly of ADAS	Ensure the ADAS assembly functions and the mechanics are properly built to the standard required to ensure the safety and success of the mission.	The motor should turn freely and without disturbance. The connection between the gears of the motor and the ADAS fins should not slip even under a load of 4.7kg on the ADAS fins; simulating the maximum aerodynamic pressure that will be present on the ADAS fins. The gears are well oiled to not stick and are fastened so that no extra unwanted or unexpected movement is present in the ADAS fins or the motor housing.	Equipment: - ADAS assembly - Masses and strings - Spanner The ADAS assembly will be built and every component will be tested for its stability and proper motion. This will be done with both no load and a 4.7kg load on each ADAS fin to simulate the air pressure it experiences.	Mechanical failure of a component	Ensure that the test is carried out only to the expected limit of the components, no hyperextensions or extra pressure should be unnecessarily applied to any component. Masses will be added gradually to the ADAS fins to avoid a sudden shock that could damage components. In the case that a component breaks the procedure will be assessed to ensure the failure did not occur due to misuse and follow up designs. Simulations will be carried out before a new part is produced.	Test will be completed by 02/03/2018

4.2 Electronic Control of ADAS Motor	To ensure that the software can control the deployment of the ADAS fins, even under pressure conditions experienced during flight.	The software should be able to extend and retract the ADAS fins to a specified deployment accurate to within 3.2%, that is to within one cog tooth. This should be the case for both with and without load.	Equipment: - ADAS assembly - Computer - Masses and strings The ADAS motor will be commanded to deploy to certain deployments first without and then with weights simulating the load of the aerodynamic drag acting on the fins. The motor should turn with ease and stop at the correct deployment. An encoder will be used to measure the deployment of the ADAS fins and ensure that they are deployed to the correct deployment and in agreement with the software commands.	Electronic Failure	Spare parts will be readily available. The cause of the problem will be investigated.	Test will be completed by 02/03/2018
				Uncontrollable of the ADAS motor	There will be an easily accessible backup mechanical switch to cut off the power to the ADAS motor present during the test.	
4.3 ADAS Motor Constraints	To ensure the ADAS motor will not turn beyond its constraints of 0% to 100%, as this could damage the fins, rocket body and yield inaccurate and un-calibrated ADAS deployments.	This tests both the hardware and the software. The ADAS positions will be recorded independently of the commands sent to the ADAS motor using an encoder. The fins should never exceed the maximum or minimum deployment. The commands sent to the ADAS motor should never exceed maximum or minimum deployment.	Equipment: - ADAS assembly - Arduino 101 - Computer - Masses and strings The motor will be made to deploy the ADAS fins to full deployment, then retract them back to no deployment. This will be done at full speed, half speed and slow speed. The pressure on the ADAS fins will also be varied using the masses, each speed being carried out with no load, half load and full load, with full load being a 4.7kg mass on each fin to simulate the pressure acting on the fin at the maximum speed during the flight.	Damage caused to components from overextension/underextension of the fins	Safety devices will be put in place to stop the fins from over/under extending.	Test will be completed by 02/03/2018.
4.4 ADAS Motor Speed	To ensure that the ADAS motor can continue to turn the ADAS fins at the required speed even under the maximum dynamic pressure in the flight.	The motor should be able to turn the ADAS fins at a speed of around 80 RPM, while having the same aerodynamic pressure on it as the maximum it will have during the flight.	Equipment: - ADAS assembly, including motor, fins and housing - Arduino 101 - Computer - Masses with strings Masses of 4.7kg will be placed on the ADAS fins to simulate the pressure experienced by the fins at maximum velocity during the flight. Two 2.35kg masses will be used hanging either side with a string attaching to each ADAS fin while fully deployed. The fin will then be commanded to retract to 50% and back to full deployment and the time taken for the maneuver to occur will be measured, as well as the speed of the motor.	Damage caused to components from overextension/underextension of the fins	Safety devices will be put in place to stop the fins from over/under extending	Test will be completed by 02/03/2018
				Uncontrollable movement of ADAS motor	There will be an easily accessible backup mechanical switch to cut power to the ADAS motor present during the test	
4.5 Sensor Data Acquisition Rate	To ensure the sensors all work and are able to	The sensors recording data feeding into the ADAS system should be	Equipment: - MS5607 Altimeter - MPU6050 IMU	Electronic failure	Spare parts will be readily available. The	Test passed during subscale launch.

	record data at the required rate	capable of recording data at least at 100Hz. The Arduino 101 should be able to communicate with the sensors and record the data at least at 100 Hz.	- NeveRest 40 Motor Encoder - Arduino 101 The sensors will be attached to the Arduino 101 and set to record for a duration of 10 minutes, the expected length of the flight.		cause of the problem will be investigated.	
4.6 Coefficients of Drag (1)	Ensure the calculated coefficients of drag from SolidWorks are accurate and agree with real life tests.	The calculated drag coefficients from SolidWorks of the rocket with different ADAS deployments should be within 1% error of the measured drag coefficients.	Equipment: - Full outer rocket with ADAS system and mass simulator for any missing parts - Wind Tunnel We are trying to get time at a wind tunnel, this will be used to measure the drag coefficient of the rocket at different deployments of ADAS. These can be calculated by measuring the drag force acting on the rocket at different wind-speeds with the desired ADAS deployment in place.	Injury caused to personnel	The safe running of the wind tunnel will be ensured by having qualified personnel on site supervising the tests.	Test will be completed by 02/03/2018
				Damage caused to rocket	The wind speeds will be kept under the expected maximum of 220m/s. The proper assembly of the rocket will be ensured by the mechanical team with predefined checklists to confirm that every component is fitted properly and securely for the test	
4.7 Coefficients of Drag (2)	Ensure the calculated coefficients of drag from SolidWorks are accurate and agree with real life tests. This is a backup test incase we cannot get access to a wind tunnel.	The calculated drag coefficients from SolidWorks of the rocket with different ADAS deployments should be within 15% error of the measured drag coefficients.	Equipment: - Full rocket - AeroTech K535 motor - Computer for analysis - Full ADAS assembly We will conduct a launch using the K535 motor. The ADAS fins will be programed to deploy slowly and continuously to full deployment. The acceleration of the rocket is being measured by an onboard accelerometer so the drag force acting on the rocket can be determined along with the coefficient of drag at every point in time. Comparing this to the deployment of the fins recorded by the encoder the coefficients of drag can be determined at every deployment.	All hazards relating to a launch are laid out in the Safety section.	As specified in the safety section.	The Subscale launch revealed that the drag coefficient of the rocket is in fact 0.44, while the SolidWorks simulations calculated a coefficient of 0.40. The Open Rocket simulations estimated a coefficient of drag of about 0.7, way over the actual amount.
4.8 Full System Ground Test	To ensure the whole system is working and capable of recording data, processing it and adjusting the deployment of the ADAS fins at the required rate.	The whole system should run without intervention. The sensors should record data at least at 100Hz, the arduino 101 should make adjustments to the ADAS fins with response times of 0.01 seconds at a maximum, so it should be running at	Equipment: - ADAS assembly - Computer - Masses and strings A deployment curve will be designed for the software to follow, an encoder will measure the actual deployment of the fins over time and record that independently. The script will	Damage caused to rocket mechanically or electronically	Each team will inspect their respective components before the test with premade checklists to ensure that every component will perform as expected. Spare electronic parts	Test will be completed by 02/03/2018.

		least at 100Hz. The fins should be able to deploy through a preset course both with and without a load. The PID control system should follow a nominal ADAS deployment curve, not deviating by more than 3.2% while adjusting for simulated unexpected events such as wind, reacting within 0.01 seconds.	simulate wind by adding a random up to 5% error from the sensor readings and record when this was done, the reaction of the system and ADAS fin deployment will be observed, the response should be a slight correction response in relation to the deviation from the nominal flight path. This will be carried out using no masses on the fins and with masses on the fins to simulate the drag forces acting on the fins. The speed of deployment and reaction time should not exceed 0.01 seconds even with full load on the fins.		should be readily available in case a component fails.	
4.9 ADAS Braking Test	To ensure the ADAS fins reduce the drag coefficient sufficiently and are able to provide enough drag to reduce the apogee of the rocket by the required amount. Ensure the rocket does not exceed the maximum altitude limit.	The coefficient of drag of the rocket should rise by 25%. The apogee of the rocket should be able to drop by 8% with ADAS deployment. The altitude of the rocket should not exceed the FAA altitude limit of 5600 ft.	Equipment: - Full Rocket - Two K535 motors - Computer Two rockets will be flown. One with no ADAS deployment, its apogee should be below 5600ft, as has been predicted by our models. The second launch will have ADAS deploying at various amounts, as detailed in the Coefficient of Drag test. The apogee should drop by 8%	All hazards relating to a launch, laid out in the Safety section	As specified in the safety section.	Test will be completed by 02/03/2018
4.10 Full ADAS System Test	Ensure the whole ADAS system is working as expected and is able to follow a nominal trajectory curve.	The PID system should control the ADAS fins with no discrepancy between the command data and the encoder data regarding the ADAS fin deployment. The trajectory of the rocket should not exceed a 5% deviation from the nominal flight path unless if acted on by adverse wind or turbulence, in which it should act in the appropriate manner to correct its course towards the nominal trajectory.	Equipment: - Full rocket - K535 motor The full rocket will be launched equipped with the PID control system. The altitude of the rocket is constantly measured and recorded so the flight trajectory can be compared to with the nominal trajectory. The behaviour of the PID system will also be recorded to aid in developing and improving the code for future launches.	All hazards relating to a launch, laid out in the Safety section	As specified in the safety section.	Test will be completed by 02/03/2018.

5. Recovery Systems Tests

Test	Purpose	Specifics	Method	Hazards	Mitigations	Results
5.1 Cord Strength Test	Ensure the cords connecting the parachutes to the rocket can withstand the tension that will	The cords should not deform or break while holding 150% of the maximum tension expected during the flight. The redundancy is	Equipment: - Cords - Masses The cord will be secured to a bar and masses will be attached to the bottom	Injury to personnel	A safe distance of the length of the rope will be kept from all non testers	Test will be completed by 02/03/2018

	be present during the flight.	to ensure that during an unexpected event such as a premature or late parachute deployment the cords will not snap.	of it until the desired tension is achieved	Damage caused to Equipement	Equipment shall be inspected before the test. The knots tied into the cord will be inspected for strength and to ensure they do not cause long-term damage to the cord	
5.2 Parachute Deployment	Ensure the folding and length of cord are fitting for the size of the rocket and will not prevent the parachutes from opening.	The cord and parachutes should deploy smoothly and with no knots or tangling in any way. Full opening of the parachutes should be achieved within 2 seconds of ejection.	Equipment: - Parachutes and cords - Subscale rocket The parachutes were folded and an ejection was simulated by running with the parachutes until they opened. The subscale launch will be used to test the cord length and another parachute deployment test	Parachutes do not open. All hazards relating to a launch.	Ground test will be carried out to ensure that the folding does not yield any tangled cords or parachutes.	The subscale launch yielded successful results for this test.
5.3 Touchdown Speed	To ensure the touchdown velocity of the rocket is within the required speed range, that is, it is not too fast that the kinetic energy on impact is larger than allowed, but not too slow that it will cause the rocket to be prone to drifting too far.	The touchdown speed should not exceed the constraints of 6m/s and 4m/s.	Equipment: - Parachutes and cords - Mass simulator - Camera - Meter long stick The parachutes will be attached to a mass simulator with the same mass as the dry rocket. These will be dropped from the top of the McHenry Library. The meter stick will be at the base and used as a calibration for the camera that will video the base of the descent in order to calculate the speed of touchdown.	Damage caused to parachute	The folding and assembly of the parachutes will be inspected beforehand to ensure no damage is caused to the parachutes	Test will be completed by 02/03/2018
				Damage to surroundings or bystanders	The area near the base of the drop zone will be corded off and no bystanders will be allowed into the area for the duration of the drop test. Personnel will stand at the edge of the dropzone to direct people to not cross into the area.	
5.4 Ejection Test	Ensure the amount of black powder in the ejection system is sufficient to push out the parachutes.	The ejection charges should be ejected when connected to the battery immediately. The parachutes should get fully ejected from the rocket body without the cords getting tangled between themselves or with the parachutes.	Equipment: - Parachutes and cords - Rocket body with internal structure - Black powder charges - Battery - Spare wires The black powder charges will be loaded into their compartments. The parachutes will be folded away as required and placed into the rocket. Shear pins will be used to keep the nose cone attached to the rocket. The ejection charges will be ejected using a spare battery.	Injury to personnel	Qualified personnel shall conduct and supervise the test	An ejection test was carried out before the subscale launch, this was a success. Another will be conducted before the full scale launch.
				Damage caused to the the internal structure of the rocket.	Fire wadding will be used to protect the parachutes. The seal at the top of the clear section, right below the recovery system, shall be tight so that the gasses will not damage any electronics or the clear section	

5.5 Jolly Logic Chute Release Test	Ensure the Jolly logic system deploys the main parachute at the correct altitude.	The main parachute should deploy at 600 ft of altitude. The dual device redundancy should also deploy the parachute even if one of the devices fails.	Equipment: - Subscale rocket The jolly logic will be onboard the subscale flight. Another flight will carry the dual device redundancy system with one set to deploy at 600ft and the other at 500ft. This will allow us to see the effects of one device failing and not releasing the main parachute.	All hazards related to a launch covered in the safety section	As specified in the safety section.	The single Jolly Logic Chute Release system worked, deploying the main parachute during the subscale launch at 700 feet, as that is what it was set to at the time. The dual device system will be completed by 02/03/2018
5.6 StratoLogger CF, EasyMini Altimeter Drogue Chute Release Test	Ensure the two dedicated altimeters release the drogue chute soon after apogee.	The drogue parachute should release soon after the vehicle has reached its highest point of flight, regardless of peak altitude. Redundancy ensures that the drogue should be released even if one altimeter were to fail to send its electric charge signal.	Equipment: - Subscale rocket The drogue parachute will be onboard the subscale flight. Another flight will carry the dual device redundancy system allowing us to see the effects of one device failing and not releasing the drogue parachute.	All hazards related to a launch covered in the safety section	As specified in the safety section.	StratoLogger successfully deployed drogue after apogee on December 9th test flight. EasyMini will be tested in the future under similar procedures.
5.7 Eggfinder GPS Tracking Test	Ensure the functionality of the GPS module in the transmission and detection of GPS coordinates over the effective transmitting range of the device.	The GPS will need to be sending constant, accurate signals of its location in order to find and track the vehicle, especially as vision from human and camera might worsen at paths that take longer trajectories from the launch site.	Equipment: - Eggfinder TX and RX Modules - Laptop computer or smart-phone device - Subscale rocket Placing the transmitter (TX) equipment within the nose cone along with the necessary battery to power the module. Receiver module (RX) then detects and .	GPS battery runs out	Pre-flight checklist ensures that the GPS is on and has a full charge to last through the entire launch and retrieval of rocket	Test will be completed by 02/03/2018

6. Stability Tests						
Test	**Purpose**	**Specifics**	**Method**	**Hazards**	**Mitigations**	**Results**
6.1 Margin of Stability, CG and CP Locations	Ensure the locations of the center of gravity and center of pressure are as expected.	The locations of the center of pressure and center of gravity should be within 2 inches of the predicted locations. The margin of stability should not drop below the minimum required stability margin of 2.	Equipment: - Rocket with every component installed or mass simulated - Rope - Tape measure The rocket will be populated with its various components or mass alternatives to simulate the distribution of mass throughout the rocket as it flies. The center of gravity will be located by balancing the rocket, the center of pressure will be estimated by measuring the areas of	Damage caused to the rocket	Backup personnel will balance the rocket to ensure it does not drop or fall	Test will be completed by 02/03/2018

			the components, an approximation to the pressure around the rocket.			
6.2 Margin of Stability	Ensure the rocket aerodynamics are fit for launch and that the rocket has a high enough stability margin.	The rocket should face towards the wind even when it's heading is disturbed by up to 30 degrees.	Equipment: - Wind tunnel - Full rocket with mass simulation for missing components We are trying to get access to a wind tunnel, where the stability of the rocket can be tested by mounting it and observing its behaviour as its heading is changed in relation to the incoming wind. A gyroscope will be installed in the rocket so its exact angular position can be measured accurately for the duration of the test.	Damage to the rocket Operation and supervision of the test will be carried out by trained personnel	All components will be checked to be fastened securely before the test	Test will be completed by 02/03/2018

6.2 Requirements Compliance

6.2.1 General Requirements

Requirement and summary	**Verification Plan**
1.1 Students will do 100% of the project except for motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches	Only students are allowed access to the team's various organizational application such as the team Slack channel, Google team drive, Grab CAD, and Github repositories. All work is completed using in these tools which are carefully administered to only include actively involved students. In regards to motor preparation, checklists item are included to verify that motor preparation and the associated tasks are done by the team's certified mentor.
1.2 The team shall keep and provide a project plan	The team constantly updates a project plan located on the team's Google drive. Section of it are organized and presented in the respective sections of documents such as this one.
1.3 Foreign Nationals must be identified by the PDR	One team member has been identified as a Foreign National.
1.4 A list of members attending launch week must be submitted by the CDR	A list of individuals and necessary information has been compiled and submitted through the proper channels.
1.4.1 Student actively engaged in the project throughout the year	Such students were identified and given first priority to accept invitations to attend the competition.
1.4.2 One mentor	The team shares a mentor with another NASA University SLI team and is

	coordinating with all those involved to plan for the mentor's accommodations.
1.4.3 No more than two adult educators	The team has one adult educator who works with the team as a mentor who will be unable to attend the competition.
1.5 Outreach to a minimum of 200 participants by the FRR	The team has been working closely with local school to plan outreach events which are scheduled before the FRR date including: ● Branciforte Middle School (4 science classrooms) ● WISE club Science Saturday event (~30 middle school girls) ● Monarch Elementary School Friday courses (8-10 students, we are invited to do 8 one hour sessions) ● ROV and TARC group (middle school aged, want to form a partnership/mentor style relationship with us) The Outreach coordinator while be responsive for the completion and submission of Educational Engagement Activity Report following each even
1.6 The team will have a website	The team has a number of members responsible for the creation and management of the team's website. The Webmaster is responsible for verifying that the website is online and functional at all times. The link to the team's website is: https://ucscrocketry.org/
1.7 The team will post required documents to the website prior to their due dates	In the days leading to the submission of a major document the team discusses availability of website team members to post the required documents to the website. Ontime postage is then verified by the webmaster and the team captains.
1.8 Deliverables are in PDF Form	Verifications that documents are in this form is completed by all those involved in the process. Once a document is ready to be submitted, it is converted to a PDF.
1.9 Each reports will have a table of contents	This will be verified by team members during the final proof reading of each report.
1.10 Every Report will include page numbers at the bottom of each page	This will be verified by team members during the final proof reading of each report.
1.11 The team will provide the proper equipment to perform a video call and dial into the conference call for presentations	While scheduling the presentation, presenting team members shall coordinate to ensure that such equipment is present and functional as verified in previous presentations.
1.12 The team shall select from one of the available launch rail sizes	The team currently plans to use the 8 ft. 1010 rails. Simulations of the rocket's flight indicate that this rail is of sufficient length for the rocket to build up the required exit velocity before the first rail button exits the rail. A final simulation with physically measure properties of the rocket will be performed to verify that this rail will be adequate.

1.13 Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): § 1194.21	The team shall ensure that all custom written software complies with the accessibility guidelines in 1194.21. As shall be verified by the author of the software in question. Additionally the team's website will comply with all the requirements of 1194.22 as verified and tested by the webmaster.
1.14 Team Mentor	The team has identified David Raimondi NAR number: 82676 Certification level: 3 As the team's mentor

6.2.2 Vehicle Requirements

Requirement and summary	**Verification Plan**
2.1 The vehicle will deliver the payload to 5,280 feet	The vehicle has been designed to meet such a goal. A number of simulations have been run and will be re-run to ensure that the rocket reaches its target apogee of 5,280 feet. This shall also be verified during the launch of the full-scale test flight prior to the competition flight.
2.2 The rocket will carry a commercially available barometric altimeter for apogee judging	The vehicle is planned to carry two such altimeters, the Stratologger CF and the EasyMini Altimeters. The subscale flight has proven that the Stratologger CF altimeter reports all required information.
2.3 Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket when the rocket is on the pad	The design of the rocket includes 4 screw switches which are accessible from the exterior of the rocket when the rocket is in flight configuration on the launch pad. Each switch enables one and only one of the following devices the Stratologger CF altimeter, the EasyMini, the TARS payload, and the ADAS computer. Verification that these switches perform as expect will be done on the ground during construction and the system as a whole proved to work successfully for the subscale launch and will once again be verified during the full scale launch.
2.4 Each altimeter will have a dedicated power supply	This requirement was taken into account during the design of the circuits containing each altimeter. Verification that the rocket was built to these specifications shall be completed by inspection once construction of the rocket is complete.
2.5 Each arming switch will be capable of locking in the ON position for launch	Each switch will be physically tested to remain in the on position during a physically simulated launch. The subscale launch has proven that the current screw switches are capable of withstanding such forces.

2.6 The rocket will be fully reusable and launch again on the same day without repairs or modification	The design of the rocket has constantly be performed with this in mind. The redundant parachute recovery system is included to ensure that the vehicle is not damaged significantly during the recovery process. This is verified through a number of simulation techniques to verify that the rocket will impact the ground with a survivable kinetic energy, and stress simulations have been performed to ensure that the material of the rocket is capable of withstand the launch and recovery forces without damage. This ability will be verified by the full scale launch.
2.7 Max 4 independent sections	The design calls for the rocket to separate into 2 tethered sections for recovery
2.8 The launch vehicle will be single stage	The rocket is designed to only house one motor and will be launched with only one motor
2.9 The launch vehicle will be capable of being prepared for flight within 3 hours	The checklists and design of the rocket were made with this requirement in mind. Preparation time will be rehearsed and time in the lab with a final timing performed during preparations for the full scale launch for final verification.
2.10 The rocket will be able to remain on the launch pad for a minimum of 1 hour	The rocket's batteries are at a high enough capacity for the rocket to remain in a pre-launch state for a minimum of an hour until launch. This shall be tested and verified once the system is fully constructed with a endurance test.
2.11 The launch vehicle will be capable to be launched by a standard 12-volt direct firing system	The rocket shall use standard commercially available rocket motor which shall be compatible with igniters that can be fired by a 12 volt direct system. This will be verified by an inspection of the igniter's associated documentation.
2.12 The rocket will not require external circuitry or special ground equipment to launch	The design of the rocket was done with this in mind. Verification of this requirement shall be confirmed with the full scale launch.
2.13 The rocket will use commercially available motors	The rocket will use an APCP motor purchased from a reputable dealer. Verification of this will be within the purchase itself.
2.13.1 The final motor choice will be made by the publication of this document	The rocket will us a AeroTech K535 motor. Verification of this will be the purchase of the motor.
2.13.2 Any need for changes to motor choice will be reported to NASA Range Safety Officer and not acted upon until approved	We will report any necessary changes in motor to the NASA Range Safety Officer before making any decisions on the subject. This will be verified by logging any changes made to the rocket from this point on.
2.14 No pressure vessels will be used on the vehicle	The rocket will not use any pressure vessels. This will be verified by the RSO.

2.15 Total impulse of the launch vehicle will not exceed 5,120 Newton-seconds (L-class)	The rocket will not use an L-class motor. This will be verified by using an AeroTech K535 motor.
2.16 The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit	Our models indicate that the rocket's static stability margin at takeoff is greater than 2.0 at rail exit. This will be verified by continuously running these models with every design revision.
2.17 The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	The motor our vehicle will be suing exceeds 60 fps velocity when launched from an 8 ft rail. Flight data from the full scale launch will verify this.
2.18 Our team will successfully launch and recover a subscale model of our rocket prior to CDR	Our team has launched a subscale model of our rocket prior to CDR. This is verified through data included in the CDR.
2.18.1 The subscale model should resemble and perform as similarly as possible to the full-scale model but will not be the full scale itself	The subscale model was very similar to the full scale rocket, with the exception of the motor tube, which housed a J-class motor. This is verified through our schematics of our full scale rocket.
2.18.2 The subscale model will carry an altimeter capable of reporting the model's apogee altitude	The subscal carried two redundant altimeters, each capable of reporting the model's apogee altitude. This is verified through data collected from the subscale flight.
2.19 Our team will successfully launch and recover our full-scale rocket prior to FRR in its final flight configuration and will be the same rocket flown on launch day	A full scale rocket is currently in production and will be identical to the vehicle flown on launch day. This will be verified by the schematics included in CDR.
2.19.1 The vehicle and recovery system will function as designed	Ground testing of the recovery system will verify that the system will function during the full scale test.
2.19.2 The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	It is the intention of the team to fly the payload during the full scale test, but shall observe the applicable requirements if the team is unable to do so. This will be verified through the full scale launch.
2.19.2.1 If the payload is not flown, mass simulators will be used to simulate the payload mass	A mass simulator will be designed and constructed prior to the full scale launch. This will be verified by the full scale launch if we do not launch the payload.
2.19.2.1.1 The mass simulators will be located in the same approximate location on the rocket as the missing payload mass	The mass simulator will be designed such that this requirement is met. This will be verified by the full scale launch if we do not launch the payload

2.19.3 If the payload changes the external surfaces of the rocket or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight	The payload window section shall be included as a part of the full scale rocket, and can be included separate from the camera system itself. This will be verified through the schematics of the full scale rocket in CDR.
2.19.4 If the full-scale motor is not flown during the full-scale flight, the motor will simulate the predicted maximum velocity and maximum acceleration of the launch day	The full-scale motor is intended to be identical to the competition motor, but if that is altered, careful modeling will be performed to verify that the proper characteristics are present in the full scale test flight. This will be verified by the full-scale launch.
2.19.5 The vehicle will be flown in its fully ballasted configuration during the full-scale test flight	If the vehicle is determined to include ballast, it shall be included during the full scale flight. This shall be verified during the preparations for the full scale flight.
2.19.6 After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO)	This requirement shall be observed and is the responsibility of the team member making the modification to make it known to the team leadership who shall contact the RSO. This will be verified through logging all changes made to the rocket.
2.19.7 Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights	It is the intention of the team to complete the full scale flight prior to March 6th, if an extension is required it is the responsibility of the team leadership to contact the proper personnel. This will verified through our timeline.
2.20 Any structural protuberance on the rocket will be located aft of the burnout center of gravity. 2.21. Vehicle Prohibitions	The only structural protuberance on the rocket would be the deployed ADAS fins during flight corrections, which are located aft of the burnout center of gravity as modeled and verified in CAD. This will be verified by the physical location of the CG.
2.21.1 The launch vehicle will not utilize forward canards	The rocket design does not use forward canards. This can be verified through the full-scale rocket schematics.

2.21.2 The launch vehicle will not utilize forward firing motors	The rocket does not use forward firing motors. This can be verified through the full-scale rocket schematics.
2.21.3 The launch vehicle will not utilize motors that expel titanium sponges	All motors being considered do not expel titanium sponges as verified by information provided the vendors
2.21.4 The launch vehicle will not utilize hybrid motors	The rocket design does not include hybrid motors as verified by information provided the vendors
2.21.5. The launch vehicle will not utilize a cluster of motors	The rocket design does not include a cluster of motors. This is verified through the rocket's schematics.
2.21.6. The launch vehicle will not utilize friction fitting for motors	The motor shall be held in back by a threaded motor retainer. This is verified through the rocket's schematics.
2.21.7. The launch vehicle will not exceed Mach 1 at any point during flight	Models verify that the vehicle shall not exceed Mach 1 during any point in the flight.
2.21.8 Vehicle ballast will not exceed 10% of the total weight of the rocket	The design of the rocket has been taken into consideration. It will be checked during anytime the ballast is added to the rocket that this requirement is respected. This will be verified through said checks.

6.2.3 Recovery System Requirements

Requirement and summary	**Verification Plan**
3.1 The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude	The rocket is designed to deploy a drogue chute at apogee, triggered by redundant altimeters, and then deploy a main chute at a low altitude, slowing the vehicle down to meet the maximum Kinetic energy requirement. This is verified through various simulations.
3.2. Our team will perform a successful ground ejection test for both the drogue and main parachutes. This will be done prior to the initial subscale and full-scale launches	The system has been designed to accommodate such a test successfully. This was verified through the subscale launch and will again be verified through the full-scale launch.

3.3. At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf. 8	Detailed modeling was done to select the proper parachute size to meet this requirement. This is verified through various simulations.
3.4. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The electronics of the rocket are designed such that the recovery and payload circuits are completely separate. This can be verified through the schematics of the rocket.
3.5. All recovery electronics will be powered by commercially available batteries	The recovery system was designed with this in mind. This can be verified purchasing the batteries from a reputable vendor.
3.6. The recovery system will contain redundant, commercially available altimeters	The Recovery system includes two PerfectFlite Stratologger CF altimeters, each wired to separate ejection charges to ensure full redundancy. This can be verified through the rocket schematics.
3.7. Motor ejection is not a permissible form of primary or secondary deployment	The motor shall be held within the rocket by a threaded retainer which shall be in place during the entirety of the rocket's flight. This can be verified through the rocket schematics.
3.8. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The vehicle design includes shear pins. This can be verified through the rocket schematics.
3.9. Recovery area will be limited to a 2500 ft. radius from the launch pads.	Detailed drift models have been performed and verify that this requirement is met.
3.10. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	The vehicle includes a GPS transmitter in the nose cone which shall serve such a purpose. The system shall be verified via multiple ground tests prior to launch.
3.10.1. Any rocket section, or payload component, which lands untethered to	The rocket design consists of two sections, tethered to one another. This can be verified through the rocket schematics.

the launch vehicle, will also carry an active electronic tracking device.	
3.10.2. The electronic tracking device will be fully functional during the official flight on launch day.	The subscale has verified this and a number of ground tests and inclusions on the full scale test flight shall continue to verify this system's functionality.
3.11. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system is designed to be completely isolated from any other potential form of interference. The subscale launch verifies this.
3.11.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system altimeters are designed to be located on the avionics sled which is in a separate compartment than the GPS transmitter which is located in the nose cone. This can be verified through the rocket schematics.
3.11.2. The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	The recovery system electronics is shielded from the GPS transmitter by the parachutes, metallic avionics sled securement plate and the avionics sled upper bulkhead. This is verified through the rocket schematics.
3.11.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The rocket design does not include any of these devices, as verified by the rocket design and submitted design proposals.
3.11.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Extensive ground testing has been done on the subscale to verify that this is the case; testing will continue on the full scale rocket.

6.2.4 Experiment Requirements

Requirement and summary	Verification Plan
4.1. Each team will choose one design experiment option from the following list.	The team has chosen to participate in the target detection experiment. This is verified in the mission statement and success criteria in the PDR.
4.2. Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	The team does not plan to fly additional payloads. This is verified in the mission statement and success criteria in the PDR.
4.3. If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety. Option 1 Target detection Option 2 Deployable rover Option 3 Landing coordinates via triangulation 9	The team does not plan to fly additional payloads. This is verified in the mission statement and success criteria in the PDR.
4.4.1. Teams will design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.	The rocket design incorporates the TARS (TArget Recognition System) to identify these ground targets. This will be verified through TARS development, testing, and data analyses.
4.4.1.1. Each target will be represented by a different colored ground tarp located on the field.	The team shall use the sample provided to catalog these different targets.This is verified in the mission statement and success criteria in the PDR.
4.4.1.2. Target samples and RGB values will be provided to teams upon acceptance and prior to PDR.	The team has measured the RGB values of these targets from the samples provided. This is verified in the mission statement and success criteria in the PDR.
4.4.1.3. All targets will be approximately 40’X40’ in size.	This shall be taken into account during all testing and evaluation of the payload performance. This is verified in the mission statement and success criteria in the PDR.

4.4.1.4. The three targets will be adjacent to each other, and that group will be within 600 ft. of the launch pads.	This has be taken into account during the design of the system and shall be considered during all testing of the TARS. This will be verified through TARS development, testing, and data analyses.
4.4.2. Data from the camera system will be analyzed in real time by a custom designed on-board software package that shall identify, and differentiate between the three targets.	The rocket design incorporates custom software to identify the targets in real time. This will be verified through TARS development, testing, and data analyses.
4.4.3. Teams will not be required to land on any of the targets.	This was taken into account during the design of the rocket. This is verified in the mission statement and success criteria in the PDR.
4.5. Deployable rover	The team did not select to participate in the rover challenge. This is verified in the mission statement and success criteria in the PDR.
4.6. Landing coordinates via triangulation	The team did not select to participate in the triangulation challenge. This is verified in the mission statement and success criteria in the PDR.

6.2.5 Safety Requirements

5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The safety officer developed the launch and safety checklist prior to the subscale launch, and thus will be used at all following launches with updated items if such an update is necessary. The team's staff mentor will verify the current status of the checklist and use of the safety checklist before each launch.
5.2. Each team must identify a student safety officer who will be responsible for all items in section 5.3.	The team identifies Michael Scudder (mscudder@ucsc.edu) as the team's safety officer. Note that the individual in this position has changed since the proposal. Verification of Scudder's position can be found in the submitted PDR.
5.3. The role and responsibilities of each safety officer will include, but not limited to:	Researching and compiling safety procedures in all aspects of rocket development, construction, and flight, as well as for outreach programs involving activities requiring safety procedures. Additionally, each safety officer will be responsible for ensuring that all team members are informed of these procedures and follow them in their entirety. At least one safety officer must be present in all activities for which a procedure has been written. Team

	Co-Captains verify that the safety officers are following through with all of their responsibilities via weekly status reports and frequent updates.
5.3.1. Monitor team activities with an emphasis on Safety during:	The safety officer will monitor team activities with an emphasis on safety during all team activities. The team's mentor and Co-Captains verify this through the student's appointment to the position of Safety Officer and collaboration with the safety officer.
5.3.1.1. Design of vehicle and payload	The safety officer will continue to be informed of the vehicle's design by the lead designers. The Team Co-Captains verify that this is done.
5.3.1.2. Construction of vehicle and payload	The safety officer continues to actively oversee construction and takes responsibility for the team's adherence to all safety regulations and recommendations during the construction of the vehicle. This is verified by Team Co-Captains at the beginning of all related activities.
5.3.1.3. Assembly of vehicle and payload	The safety officer accompanies the team during all launch activities and is present at all major system tests where the vehicle or payload are assembled.
5.3.1.4. Ground testing of vehicle and payload	The safety officer is informed of all ground testing it is performed and ensures that the proper procedures are followed during such tests. Team Co-Captains verify that the safety officer has been informed.
5.3.1.5. Sub-scale launch test(s)	The safety officer accompanies the team during all launch activities to ensure that proper safety procedures are followed. This is verified by the record of attendance taken at each launch.
5.3.1.6. Full-scale launch test(s)	The safety officer accompanies the team during all launch activities to ensure that proper safety procedures are followed. This is verified by the record of attendance taken at each launch.
5.3.1.7. Launch day	The safety officer attends all launch days and personally ensures that all safety regulations are respected and followed. This is verified by the record of attendance taken at each launch.
5.3.1.8. Recovery activities	The safety officer is present during vehicle recovery and instructs all team members to avoid improper recovery prior to launch. The Team Co-Captains verify that this is done.

5.3.1.9. Educational Engagement Activities 10	The safety officer approves all educational activities prior to the event.This is verified by the Team Co-Captains and the third parties involved with the educational activities.
5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities	The safety officer will continue to research the proper procedures involved in these activities and compile them. The safety officer has composed a collection of documents that are strictly followed by the members involved in these activities. This is consistently verified through collaboration between the Student Safety Officer and the Team Co-Captains.
5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	The safety officer has taken full responsibility for this task and has taken steps to host the documents on the team's website, accessible to all team members. Additional physical copies are displayed in the lab space with the materials. This was verified by the Team Co-Captains.
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	The safety officer takes a leading role in the development of this documentation. Physical copies of these analyses and procedures are displayed in the team's lab space. This was verified the team's staff mentor.
5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The team respects the judgement of all higher level authorities on the rocket's safety, configuration, or other concerns. This was verified by RSO David Ramandi during the subscale launch.
5.5. Teams will abide by all rules set forth by the FAA	The team has all intentions of abiding by, and has abided by, the regulations put forth by the FAA by launching at designated launch sites during cleared times. This is verified by the FAA.

6.2.6 Team Requirements and Compliance Plans

6.2.7 Vehicle

Team Requirement	**Compliance Plan**
Follow a near-vertical trajectory.	The full scale demonstration launch will verify this requirement.
Record precise sensor measurements throughout the duration of the flight.	The team found that the Arduino 101, with its embedded IMU, yields the highest frequency and most precise data. The full scale demonstration launch will verify the working ability of the onboard computer system.
Use sensor measurements to determine its flight parameters at each time step.	The Software Subteam will verify that flight parameters are determined and recorded at each time step through the successful implementation of software that controls the ADAS.
Deploy ADAS if the demanded by the flight profile.	All measures shall be taken to ensure that ADAS is in working order before the rocket's launch, and will be verified with a systems check as well as through operational use during the full scale demonstration.
Perform fine adjustments to a model flight profile at a rate of 10 Hz.	ADAS was designed with this in mind. This will be verified with a ground test.
Achieve a pre-specified apogees to within 5%.	Flight data shall be analyzed post flight to evaluate how well the team met this requirement and design modifications shall be made to meet this requirement if necessary.

(Secondary Requirement) Achieve pre-specified apogees to within 0.5%.	A continuous effort will be put forth to update the control algorithm of the ADAS system with every flight and simulation.
(Secondary Requirement) The vehicle shall be capable of supporting atmospheric research efforts at the university.	The vehicle is design to accommodate large motors, and the with avionics bay section completely removable and modular to allow for additional configurations. Its capability for atmospheric research will be verified by the instructor involved with the research, Professor Patrick Chuang.

6.2.8 Payload

Activate TARS to locate and track tarps of different colors, even at high spin rates.	Extensive testing of TARS shall be performed including testing the performance of the system during a roll. The data from these tests will then be used to improve the system and ensure that this requirement is met. Once the improvements, if necessary, have been made, a final test during a full scale demonstration launch to verify that the requirement has been met.
(Secondary Requirement) Repurpose TARS to track and observe topographical and atmospheric features.	If the performance of the target detection software for TARS is sufficiently developed, an additional algorithm will be developed to recognize topographical features. This will be verified through field tests, data analysis, and Professor Patrick Chuang.

6.2.9 Recovery

The team shall not lose the rocket after a flight.	Tests of the locating system will verify that it is in proper working order during all stages of the launch. Visual cues from the ground will further reinforce the recovery of the rocket’s location.

6.2.10 Safety

The team shall exceed the safety requirements mandated.	The safety officer shall take responsibility for enacting a comprehensive safety plan covering all relevant activities and hazard that the team could potentially encounter. The team's university staff instructor and the Team Co-Captains will verify that all safety measures have been met and exceeded.

6.2.11 General

Maintain a professional relation with all organizations which the team interfaces with.	The Business Subteam Lead will coordinate with the Team Co-Captains to verify that every interaction maintains a courteous and professional standard of communication.

6.3 Budget

6.3.1 Expenses

The complete budget of the team comes out to roughly **$15098**. A breakdown of the Effective-1 Rocket Budget, Subscale Rocket Budget, Travel Budget, and General Budget are included in the following tables. These budgets are subject to change.

6.3.1.1 Effective-1 Rocket Budget

Airframe						
Item	**Vendor**	**Unit Price**	**Qty.**	**Shipping**	**Tax**	**Price**
Blue Tube 2.0 3"x48"	Always Ready Rocketry	29.95	1	12.95	2.24	45.14
CNC Fin Slots	Always Ready Rocketry	16.00	1		1.20	17.20
CNC Fin Templates	Always Ready Rocketry	1.00	4		0.30	4.30
3" FIBERGLASS 4:1 OGIVE NOSE CONE	Apogee	30.95	1	50.00	2.32	83.27
AERO PACK 54L/3" TAILCONE RETAINER	Apogee	47.08	1		3.53	50.61

54MMX48" G12 THIN-WALL FIBERGLASS FW AIRFRAME TUBE	Apogee	65.77	1		4.93	70.70275
Centering Ring G10 FIBERGLASS CR 54MM/3"	Apogee	13.18	2		1.97	28.337
3" Fiberglass Bulkhead	Apogee	5.41	1		0.40	5.81
Class 8.8 Medium-Strength Steel Threaded Rod	McMaster-Carr	9.52	2	20.00	1.42	40.46
Fiberglass Resin	Homedepot	20.00	1		1.50	21.50
Fin Material	Apogee	27.00	1		2.02	29.02
Launch Lugs	Apogee	10.00	1		0.75	10.75
Fasteners	McMaster-Carr	10.00	1		0.75	10.75
Airframe Sub Total						417.87
Avionics Sled						
Item	**Vendor**	**Unit Price**	**Qty.**	**Shipping**	**Tax**	**Price**
Sled Raw Material (Resin)	Kudo	110.00	1		8.25	118.25
U-bolt Parachute Fastener	McMaster-Carr	1.00	2		0.15	2.15
Fasteners	McMaster-Carr	10.00	1		0.75	10.75
USB Power Pack	Amazon	10.99	1		0.91	11.90
Avionics Sled Sub Total						143.05
Adaptive Drag Aerobraking System (ADAS)						
Item	**Vendor**	**Unit Price**	**Qty.**	**Shipping**	**Tax**	**Price**
Altimeter MS5607	Control Everything	29.99	1	10	2.47	32.46

Arduino 101	Arduino	30.00	1	10	2.25	42.25
Drag fin raw material	McMaster-Carr	16.64	1	20	1.24	37.88
Slide plate raw material	McMaster-Carr	16.00	1		1.20	17.20
Electric Motor Battery (12V LiPo)	Amazon	28.00	1		2.10	30.10
Fuse (2A)	Hobbyking	4.00	1		0.30	4.30
Fasteners	McMaster-Carr	10.00	1		0.75	10.75
IMU MPU 6050	SparkFun	39.95	1		2.60	42.55
L298N Motor Module	Amazon	7.00	1	6.52	0.00	13.52
Adaptive Drag Aerobraking System (ADAS) Sub Total						231.01
Recovery						
Item	**Vendor**	**Unit Price**	**Qty.**	**Shipping**	**Tax**	**Price**
PerfectFlite StratoLogger Altimeter CF	PerfectFlite	58.80	1	20	6.30	85.10
EasyMini Altimeter	Apogee	85.60	1	20	8.45	114.05
Drogue Chute 24" NYLON ROUND PARACHUTE	Apogee	9.79	1		0.78	10.57
Main Chute 48" Fruity Iris Ultra	Apogee	146.59	1		11.73	158.32
Eggfinder GPS Tracking System	Eggtimer Rocketry	100.00	1	30	7.50	137.50
Jolly Logic Chute Release	Jolly Logic	130.00	2	15	22	297.00
2 Cell 7.4V Lipo Battery for GPS	Amazon	8.00	1		0.60	8.60
9V Duracell Batteries	Local	3.00	2		0.45	6.45

9V Battery holders	Amazon	5	2		0.75	10.75
Fasteners	McMaster-Carr	10	1		0.75	10.75
Recovery Sub Total						839.09
Payload (TARS)						
Item	**Vendor**	**Unit Price**	**Qty.**	**Shipping**	**Tax**	**Price**
U-bolt Parachute Fastener	McMaster-Carr	1.00	1		0.07	1.07
Raspberry Pi B	Amazon	48.99	1	10	3.67	62.66
Raspberry Pi Battery Pack	Amazon	7.00	1		0.52	7.52
AAA Batteries (large pack)	Local	10.00	1		0.75	10.75
Raspberry Pi Camera	Amazon	35.00	1		2.62	37.62
Clear Cast Acrylic Tube	McMaster-Carr	42.00	1	10	3.15	55.15
Fasteners	McMaster-Carr	10.00	1		0.75	10.75
Payload (TARS) Sub Total						185.53
						Total Cost
Effective-1 Rocket Total						**$1816.55**

6.3.1.2 Subscale Rocket Budget

The final cost of the subscale rocket was found to be $1622.45 which was slightly higher than the predicted cost of $1580.70. A charge of $315 was also necessary for van rental in order to transport the team to the subscale launch attempts.

6.3.1.3 Travel Budget

Any additional funds raised beyond those necessary to build the rockets and support general team activities shall be directed towards subsidizing the cost burden of members to attending the competition. However, in the state of California,

“state-funded travel to any states that have enacted a law that voids or repeals any existing state or local protections against discrimination based on sexual orientation, gender identity, and gender expression or have the enacted laws that have the effect of voiding or repealing any of these protections" (Bill AB 1887).

Which Governor Brown signed into law on September 27, 2016. Since Alabama is among the states listed as of June 23, 2017, all travel to the competition must be funded via sources not associated with the state. For this reason it is critical for the team to adopt a well-rounded funding campaign as described in Section 6.2.2.

Item	**Vendor**	**Unit Price**	**Qty.**	**Tax**	**Price**
Roundtrip Flight	South West	600.00	14	48 per	9072.00
Hotel Room	The Hotel reserved for competition participants if possible	109.00 per night per room of five people	1 room for 4 nights	40	1910.00
Rental Car	TBD	50.00 per day	Four days	20	220.00
Travel Total					**$10202.00**

With these estimated, each team member attending the competition will be responsible for $730 of the travel and hotel costs. Team members shall be given the option to raise money for the team which shall go to covering their travel costs or simply pay the $730 to attend. Unfortunately this has become necessary as the team was unable to secure adequate funds to cover travel at this time.

6.3.1.4 General Budget

Item	**Vendor**	**Unit Price**	**Qty.**	**Tax**	**Price**
T-Shirts	TBD	20.00	30	60.00	660.00
Outreach Materials	TBD	100.00	1	10.00	110.00
Spare parts	Various	-	-	-	300
Subscale Motor (J420)	Aerotech	69.54	1	5.56	75.10
Full Scale Motor (K535)	Aerotech	288.88	2	23.11	312.00
General Total					**$1457.10**

6.3.2 Funding

An aggressive funding campaign is planned to draw capital from a variety of sources. A GoFundMe campaign has been started, which has raised $635.00 for the team thus far. Additionally the team has received sponsorship from the $2000 Gene Haas Foundation. The team continues to seek corporate sponsorship with commercial company, sustain the GoFundMe campaign, prepare for the UCSC giving day and plan additional fund raisers. In summary,

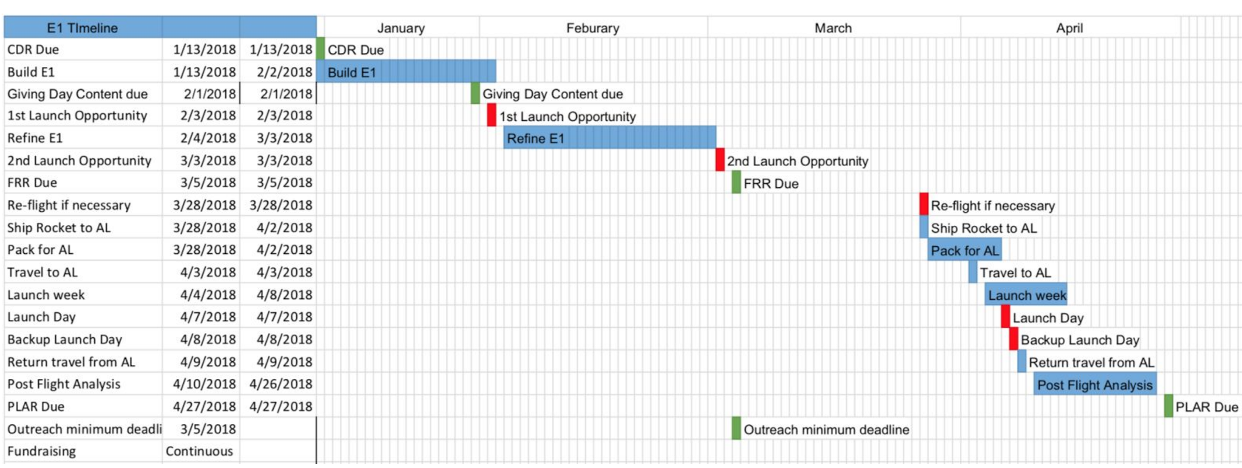
Money Spent	Income	Projected Cost Left	Projected Future Income
$1937.45	$2635.00	$3231	$4000 ($2000 from crowd funding) ($1000 from corporate sponsors) ($1000 from additional fundraisers)

The travel costs to the competition has been excluded from this summary as the financial burden will fall upon members attending the competition unless surplus funds are acquired.

6.3.3 Material Acquisition Plan

Material shall be acquired through item purchase requests made by team members to the team captains.The team captains shall then seek refunds for their purchases by filing the proper documentation to be reimbursed from the team account linked to university. Major purchases which are to be made using the team account linked to the university must be approved by the team's university advisor. Once the team captains receive ordered parts, they will be promptly stored in the lab space.

6.4 Timeline



Appendix A - Safety Form

All members shall be required to sign the following form before admission into the team, and prior to engaging in team activities:

I, Zafar Rustamkulov, agree to observe the following laws, regulations, rules, and guidelines, in addition to all others not listed which pertain to my activity as a member of the UCSC Rocketry Team:

Laws and Regulations:

1. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
2. Code of Federal Regulation 27 Part 55: Commerce in Explosives
3. NFPA 1127
4. Local laws regarding amateur rocketry

Launch Rules:

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Safety Guidelines

1. As specified in the UCSC online lab safety training curriculum
2. As briefed by the safety officer

By signing this document, I acknowledge that I have read and understood the information listed above, and agree to abide by the aforementioned laws, regulations, rules, and guidelines. Failure to do so will result in immediate discharge from the team.

Zafar Rustamkulov
(Name Print)

(Signature) 9/20/17
(Date)

Appendix B - Minimum Distance Chart

MINIMUM DISTANCE TABLE

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

Revision of August 2012

Adapted from NAR - "High Power Rocket Safety CodeEffective August 2012." *National Association of Rocketry*, Aug. 2012, www.nar.org/safety-information/high-power-rocket-safety-code/.

Appendix C- NAR Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

Adapted from NAR - "High Power Rocket Safety CodeEffective August 2012." *National Association of Rocketry*, Aug. 2012, www.nar.org/safety-information/high-power-rocket-safety-code/.