EFFECTIVE-1

Rocket Team at UC Santa Cruz

1156 High Street

Santa Cruz, CA 95064

NASA Student Launch Initiative

Flight Readiness Review

March 5, 2018

1. Summary

1.1 Team Summary

Team Name:	Rocket Team at UC Santa Cruz
University:	University of California, Santa Cruz
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Certification level:	3
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1.2 Vehicle Summary

After the team's rigorous design and laborious manufacture of the launch vehicle, the following dimensions are established for the rocket, **AS BUILT**.

Length	Outer Diameter	Rocket Mass	Rocket Mass with Wet Motor	Final Motor Selection	Recovery System	Rail Size
2.4 m [7.9 ft] [94.75 in]	78.7mm [3.1 in]	5.14 kg [11.3 lb]	6.41 kg [14.1 lb]	AeroTech K535	24 in drogue chute (at apogee) via StratoLoggerCF Altimeter 48 in main chute (at 500ft) 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.

To successfully recover the rocket, a two staged recovery consisting of a 24 in drogue chute released at apogee and a 48 in main chute released at 500ft during descent were found to meet the needed safety factors and drift limits.

1.3 Payload Summary

The team elected to participate in the target tracking challenge and has designed the TArget Recognition System (TARS) to meet the challenge. The TARS payload leverages a clear acrylic window integrated into the rocket's airframe and a wide-angle video camera pointed downward to record footage of the competition tarps during the rocket's ascent. This footage is processed in real-time using a custom software package encoded on a Raspberry Pi 3b. The ultimate output of the system will be a single video with the targets outlined and identified by their respective colors.

2. Changes Made Since CDR

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

2.1 Vehicle

Change	Rationale
The epoxy used to secure the acrylic window section of the airframe to its couplers has been swapped for a bonding agent designed for plastics.	The window sections couplers were the source of a failure found during the post-subscale vehicle inspection, and also failed during vehicle integration during the first full-scale launch attempt. A new bonding agent, Devcon Plastic Welder, was sourced and tested to withstand the expected loads.
Overall length of the rocket has changed from 2.44 m [8ft] to 2.4 m [7.9 ft]	Two inches were added to the recovery section of the airframe to prove more space for parachutes. Also, a mistake was made when ordering the rocket's nose cone such that a 4:1 Ogive nose cone was ordered in place of the planned 5:1 Ogive. It was determined that this would have an insignificant effect on the vehicle's overall performance. The 4:1 Ogive nose cone was adopted as the primary design. The dimensions of the rocket as built vary slightly from the designed dimensions. Ultimately these factor resulted in a change in overall length.
A vent hole was cut in the 24" drogue to increase the descent rate of the rocket and address concerns about the rocket's drift voiced during the CDR presentation.	These choices were made in order bring the rocket's projected drift in 20mph winds to be 2394 ft which is within the required 2500 ft. radius recovery area. From the full scale flight data, the rocket is predicted to remain within the recovery area up at winds up to 17.9 mph, and at winds speeds beyond this, the drogue chute will be replaced with a streamer to remain within the recovery range.
The 9 volt power sources for the TARS Payload, ADAS Flight computer, and GPS transmitter have been replaced with 7.4V 1200mAh 30C Lipo Batteries.	Preliminary performance models of the rocket showed that the rocket would require a large amount of ballast to achieve the target apogee, rather than carry that ballast as dead weight, the decision was made to upgrade the batteries to improve the vehicle's reliability.

2.2 Payload

Change	Rationale
Software change	Finalize image processing code and system output format with multi-threaded support.

Added accelerometer	A launch detection was added to the payload in order to minimize unnecessary data storage and processing. The launch requirement is a sustained g-load of over 3G for 0.2 seconds.

2.3 Project plan

Change	Rationale
The first full-scale launch attempt was unsuccessful; the team has modified their plans and ran the completed ADAS control system code during the full scale launch.	The initial plan was to do multiple launches of the full scale rocket with various ADAS deployment scripts in order to record a number of data sets and characterize the vehicle's drag at different deployment values of the aerobrake fins. However, the failure of the first full scale launch attempt forced the team to launch the vehicle in its full flight configuration, complete with the active ADAS control loop. Unfortunately, this refinement phase of the ADAS control loop design has largely been removed from the project plan.
The second full-scale launch was a partial success; a re-flight is necessary before the April 4th launch, and has been requested.	The flight vehicle sustained significant damage to the airframe upon landing. This is grounds for a re-flight. We are following protocol listed in 2.19.7.

2.4 Action Items

Action Item	Action Taken
Drift must be predicted to be under 2500 ft when using the equation "wind speed (ft/s) x descent time (s) = drift distance (ft)" in 20 mph winds	New drift prediction based on full scale flight descent rates predict that the rocket will remain in range at wind speeds up to 17.9 mph. If winds are above this, the drogue chute will be replaced with a streamer and the rocket will then still remain within the recovery range.

3 Vehicle Criteria

1 2 3 4 5 6 7

1. Thrust Section [24.4 in]
2. Adaptive Drag Aerobraking System (ADAS) [8.3 in]
3. Lower Avionics Bay [19.0 in]
4. TArget Recognition System (TARS) Window [7.4 in]
5. Upper Avionics Bay [10.0 in]
6. Recovery Section [9.0 in]
7. Nose Cone/GPS [16.5 in]

Length	Outer Diameter	Rocket Mass
2.4 m [7.9 ft] [94.75 in]	78.7mm [3.1 in]	5.14 kg [11.3 lb]

3.1 Design and Construction of Vehicle

3.1.1 Changes since the CDR

During the post flight inspection of the subscale rocket and during the first full scale launch attempt, the attachments of the blue tube couplers to the clear acrylic window section failed. Initially this failure was attributed the improper preparation of the window material for bonding (it was thought that a member of the team forgot to roughen the inner window surface before applying epoxy to bond the window and coupler together). After proper care was taken to ensure that the full scale window section was prepared properly, and the subsequent failure of the piece during preparation for the first full scale launch attempt, a further investigation was necessary.

It was found in the Loctite Two-Part Epoxy technical data sheet that the epoxy is “not recommended for Polyethylene, polypropylene, nylon, polytetrafluoroethylene (PTFE)/Teflon or flexible materials.” The acrylic plastic material used for the clear section of the airframe is Poly(methyl methacrylate), a similar material to those listed in the data sheet.

Fig. 3.1.1.1 Failure of the upper window coupler - window bond during first full-scale launch attempt

The new bonding agent used is Devcon Plastic Welder, which is designed to bond plastics. The two-part epoxy is rated for pressures well in excess of the forces felt in by the clear segment, and is specifically rated for acrylic. Sufficient testing has been done to ensure that the new epoxy is strong enough to withstand flight conditions. This change is necessary to prevent future failures of this coupler section. However, this solution did not prove to prevent a similar failure during the full scale launch. A new mechanically solution involving rivet is being elxpore to once full address this concern.

A mistake was made during order placement for the rocket’s nose cone: a 4:1 Ogive nose cone was ordered in place of the planned 5:1 Ogive.

Placing a new ... imeframe to make the firs ... mance were acceptable in ... light, it was determined t ... essful flight and thus a waste of the team's already stretched time and resources. Thus this change was found to be necessary largely out of scheduling constraints.

Fig. 3.1.1.2 4:1 Ogive nose cone (left) 5:1 Ogive nose cone (right)

During the subscale launch, it was determined that the section of the airframe allocated to house main parachute, drogue parachute, two jolly logic chute release devices, ejection charge, teflon protective cloth and harness was a tight fit. To alleviate this, the recovery section of the airframe was extended by 2 in.

In order to fully address the action item given to the team during the review of the CDR, the drogue chute was reduced from a 24 in. chute to an 18 in. chute with a central vent hole. From the full scale flight data, the rocket is predicted to remain within the recovery range up to 17.9 mph winds, in the case that winds are above this, the drogue chute will be replaced with a streamer in order to still remain within the recovery range.

3.1.2 Vehicle Features

3.1.2.1 Structural Elements

3.1.2.1.1 Airframe

The airframe is largely composed of Blue Tube 2.0 with a 3 in. inner diameter and a 0.062 in. wall thickness. Blue tube 2.0 is an extremely strong and lightweight material exclusively sold by Always Ready Rocketry. The material has its origins in tank ammunition rounds and thus is highly abrasion resistant, with massive acceleration potential. Always Ready Rocketry claims that the airframe material is able to withstand g-forces that exceed 10x anything a high-power rocket flight can present to it and provides the following crush test data:

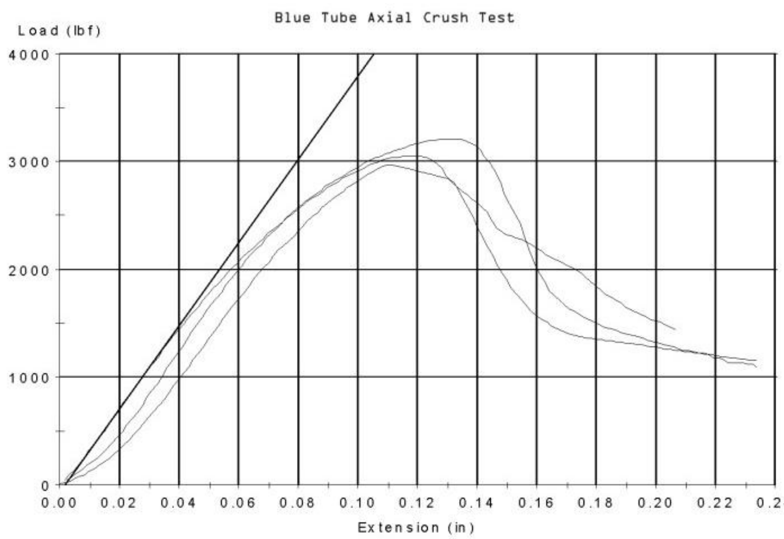


Fig. 3.1.2.1.1.1 Blue Tube 2.0 Crush Test data (source: Always Ready Rocketry)

The maximum load the airframe is expected to experience during a flight was calculated as follows:

$$Max\ Load\ =\ Max\ Thrust\ +\ Max\ Drag\ Force$$

The maximum thrust of the K535 rocket motor is 655 Newtons (147.25 lbf).

$$F_{T\,max} = 655\ N\ (147.25\ lbf)$$

To calculate the maximum expected force of drag:

$$F_{D\,max}\ =\ \frac{1}{2}\rho_{air} v_{max}^{2}\ C_D\ A_{eff}$$

As derived from the subscale flight data,

$$C_d = 0.44$$

The cross sectional area,

$$A_{eff} = 0.01823\ m^2\ (28.27\ in^2)$$

The maximum velocity expected as derived from models is approximately,

$$v_{max} = 200\ m/s$$

And the maximum value expected for ρ_{air} on the ground,

$$\rho_{air} = 1.225\ kg/m^3$$

Yielding,

Figure 3.1.2.1.1.2 The unpainted airframe, Blue Tube 2.0 (dark blue), Fiberglass (pale green)

$$F_{D\,max} = 197\ N\ (44.24\ lbf)$$

Thus,

$$Max\ Load\ = 655\text{ N (147.25 lbf)} + 197\text{ N (44.24 lbf)}$$
$$Max\ Load\ = 852\text{ N (246.55 lbf)}$$

According to the data provided by Always Ready Rocketry, at this load the Blue Tube is expected to deflect less than 0.02 in. and is well below the breaking load of 1548 lbf.

$$Blue\ Tube\ Airframe\ Factor\ of\ Safety\ =\ 6.3$$

A segment of Blue Tube material was tested to verify that the material can withstand the expected loads. (7.1 Testing Slotted Blue Tube Crush Test).

The acrylic window is another major segment of the airframe which experiences the entirety of the maximum load calculated above. From the vendor's (McMaster Carr) product description, the 3 in. acrylic tube has a 8,000 psi tensile strength

$$Tensile\ Strength\ = \frac{Max\ Load}{A}$$
$$Max\ Load\ =\ Tensile\ Strength\ *\ A$$
$$A\ =\ \pi\ *\ (3^{2} - 2.75^{2})\ in^{2}$$
$$A\ =\ 4.51\ in^{2}$$

Thus,

$$Max\ Load\ =\ 8000\ psi\ *\ 4.51\ in^{2}$$
$$Max\ Load\ =\ 36080\ lbf\ (160500\ N)$$

Yielding,

$$Window\ Section\ Factor\ of\ Safety\ =\ 146$$

A spare acrylic section was used to verify that the material would not break under loads (7.1 Blue Tube Coupler/Window Crush Test).

The acrylic window section integrates into the Blue Tube airframe via two couplers made of Blue Tube 2.0. The lower window coupler is 8 in. in over all length, 2 in. of that length is bonded to the acrylic window with the remaining 6 in. overlapping with the thrust section body tube. The upper window coupler is 10 in. overall in length and is bonded to the acrylic window with a 2 in. overlap identically to the lower window coupler. The upper window coupler then extends 8 in. into the recovery section of the Blue Tube airframe. The lower coupler meets the suggest of the team's mentor that the coupler should overlap by two times the rocket's diameter (2 x diameter of the rocket), while the upper coupler exceeds this suggestion(2.6 x diameter of the rocket).

The couplers are bonded to the window using devcon plastic welder. This product creates a hard bond with a 3500 psi tensile strength for hard plastic, styrene, PVC, acrylic and other similar material. No load is expected to be transferred through this bond, but the Blue Tube Coupler/Window Crush Test (Testing 7.1) has verified that the bond could withstand such loads.

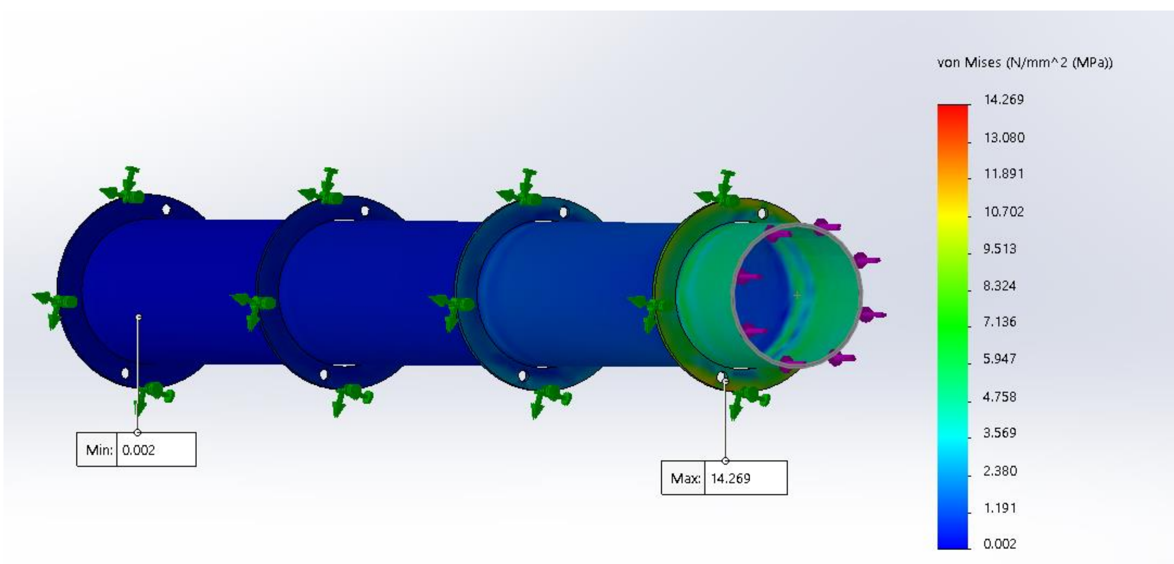
3.1.2.1.2 Fins

The fins are made of ⅛ inch thick fiberglass which has proven to provide sufficient rigidity. The shape of the fin was designed to provide the surface area need to create a stable center of pressure (CP) while also minimizing drag with its swept leading edge and mitigating the risk of a fin breaking during impact with the ground with its swept trailing edge. The rocket would need to land such that the angle it makes with the ground is less than 40 degrees in order to directly land on one of its fins.

Figure 3.1.2.1.2.1 The angle between the rocket and the ground necessary to land on a fin

3.1.2.1.3 Centering rings/Bulkhead

Four fiberglass ⅛" thick centering rings and a single ⅛" fiberglass bulkheads were found to be of sufficient strength to bond the motor tube to the airframe. An extensive stress simulation was performed as a part of the PDR,



summarized below.

Figure 3.1.2.1.3 Thrust section stress simulation

The figure above 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 other centering rings are included to stabilize the motor mount in addition to serve as backups incase the first two break.

3.1.2.1.4 Attachment Hardware

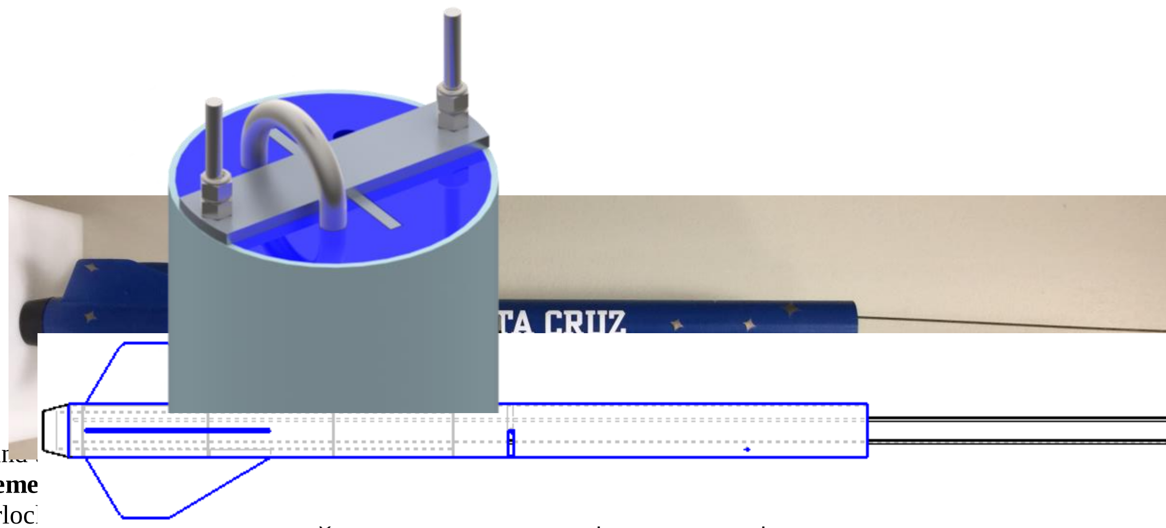
The most critical piece of attachment hardware is the all threaded rods which span the majority of the rocket. These rods serve as both rails and securement points for the avionics sleds.

Figure 3.1.2.1.4.1 The all threaded rods protruding out of the thrust section of the airframe

There are two M4 18-8 Stainless Steel Threaded Rod, diametrically opposed from one another. These rods are bonded into the thrust section of the airframe at each of the motor tube's centering rings in addition to being secured with two nylon locking nuts at the end of the lowest centering ring.

Figure 3.1.2.1.4.2 The all threaded rods continue all the way to the lowest centering ring of the thrust section

Once both avionics sleds have been integrated into the rocket by sliding them down these rails, they are locked into place at the top bulkhead of the upper avionics bay. An aluminum plate spans between the two all threaded rods and extends slightly beyond the bulkhead in order to also serve as a backup securement for the window section which will be discussed later. Two nylon lock nuts are threaded onto each all thread rod and tightened to secure the

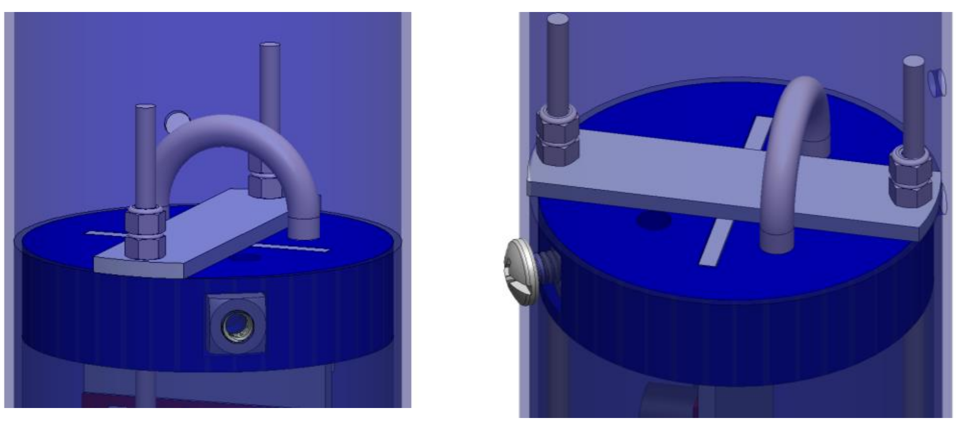


aluminum plate in place an

Figure 3.1.2.1.4.3 Secureme

The window section interloc

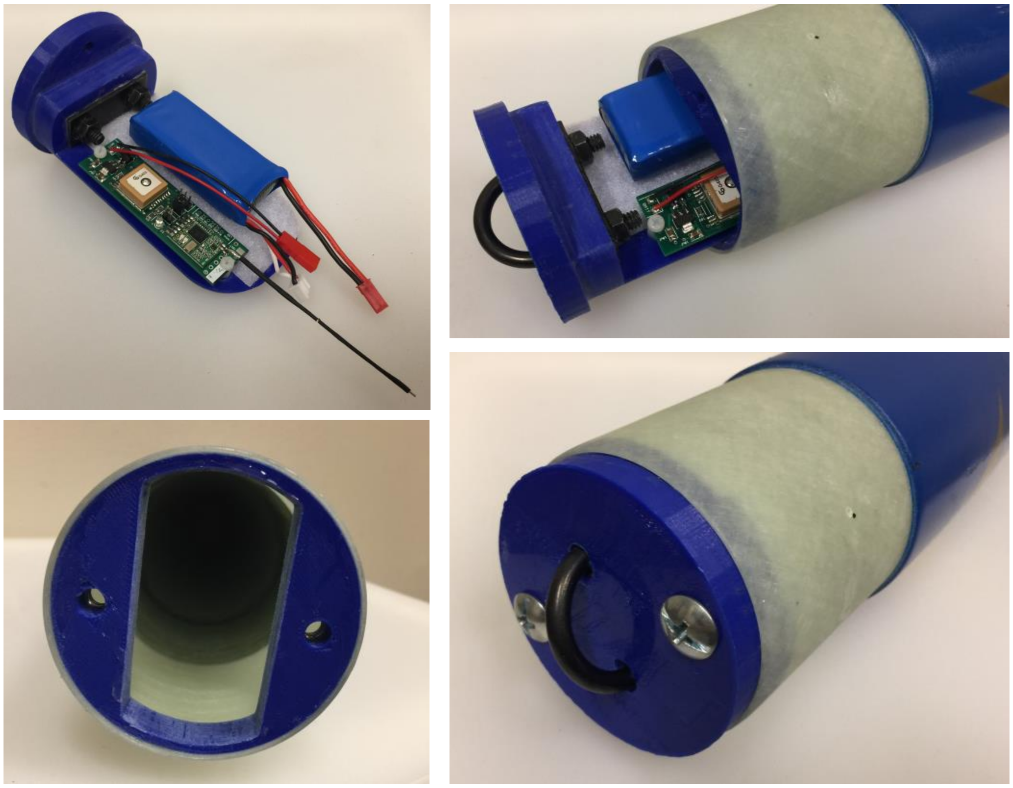
airframe. It is secured into place via two pan head combination phillips/slotted bolts with 1/4"-20 threads that are 5/8" long. These bolts also secure the recovery section of the airframe in place. The bolts pass through clearance holes in the recovery section and upper window coupler into ¼"-20 square nuts embedded



into the top bulkhead of the upper avionics bay.

Figure 3.1.2.1.4.4 with the upper window coupler and recovery section of the airframe semi-transparent, the embedded nut is shown (left) and with the bolt which secures the coupler and recovery section to the avionics bay sled/rest of the airframe

The last major hardware connection is the securement of the GPS sled into the nose cone. The nose cone has been prepared by bonding a 3D printed piece into place with captive ¼”-20 square nuts. Numerous tests have shown that neither the satellite connectivity nor the receiver connectivity are impeded by the battery or nose cone. This



configuration is fully functional.

Figure 3.1.2.1.4.5 GPS mounted on its sled (top left) nose cone with receiving part complete with embedded nuts (bottom left) sled entering the nose cone (top right) sled secured in place (bottom right)

3.1.2.2 Electrical elements

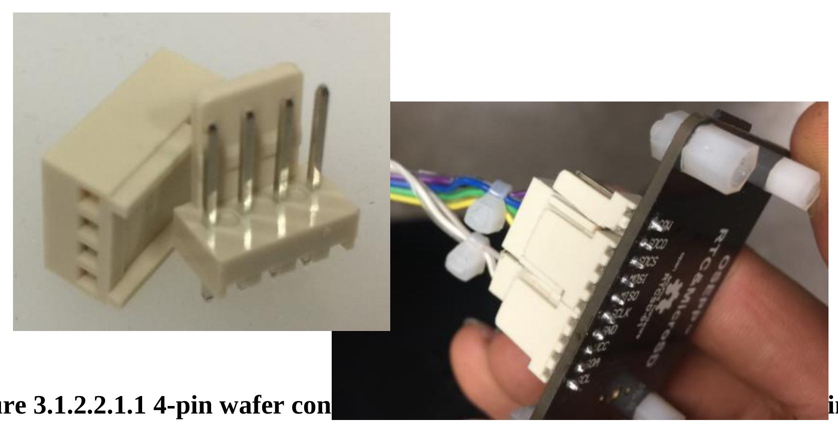


Figure 3.1.2.2.1.1 4-pin wafer con in wafer connectors (right)

In order to ensure that the 22 gauge copper wires which connect the various avionics board to one another stay in place, the pins of each board were replaced with 4 pin wafer connectors. The new connectors offered improved strength over the jumper cable-style connections used in the subscale rocket, while also allowing a degree of flexibility not offered by the alternative of directly soldering the wires to each board.

These wires are also kept within a braided cable sleeve to ensure that they are not pinched or unplugged during the integration of the avionics into the airframe.

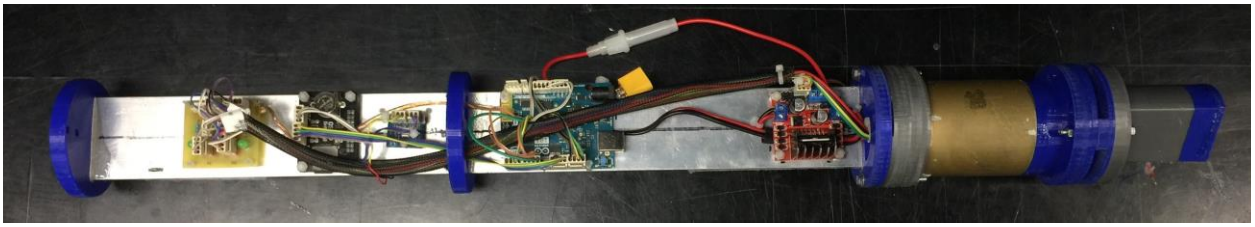


Figure 3.1.2.2.1.2 Lower Avionics bay with wires enclosed in braided cable sleeve (black).

3.1.2.2.2 Switches

The various avionic systems are enabled from the exterior of the rocket via screw switches. These switches involve a bolt which is accessed through a hole in the rocket's airframe. These screw switches lock into the on position during flight.

3.1.2.2.3 Battery Retention

The 9v batteries which power the StratologgerCF and Easy Mini altimeters are secured within custom designed, 3D printed housing which are bonded to the aluminum plate of the upper avionics sled.

Figure 3.1.2.2.3.1 9v Battery in its custom 3D printed holder

The 7.4V 1200mAh 30C Lipo batteries which power the GPS transmitter, TARS computer and ADAS computer are

retained by velcro and wrapped with [illegible]dancy. The velcro in use has and an approximate average shear strength of 14 lbs per square inch. Given that the LiPo batteries each weight 0.046 kg, and are secured with a one strip of velcro 1 in in thickness and the maximum expected acceleration of the rocket is 10g,

$$Expected\ shear\ force\ on\ velcro\ =\ 0.046\ \times\ 10\ \times\ 9.8$$

$$Expected\ shear\ force\ on\ velcro\ =\ 4.508\ N\ (1.01\ lbf)$$

$$LiPo\ Battery\ Retention\ Safety\ Factor\ =13.9$$

Finally, the battery which powers the ADAS electric motor is 0.149 kg is secured in a similar way.

$$Expected\ shear\ force\ on\ velcro\ =\ 0.149\ \times\ 10\ \times\ 9.8$$

$$Expected\ shear\ force\ on\ velcro\ =\ 14.602\ N\ (3.28\ lbf)$$

$$ADAS\ Battery\ Retention\ Safety\ Factor\ =4.3$$

3.1.2.2.4 Battery Fuse

A 3 Amp fuse is included in the circuit containing the ADAS LiPo battery to ensure that if the electric motor attempts to draw too much current, the circuit will be broken. This prevents any potential damage that could be caused to the battery if such a current draw was allowed to take place unhindered.

3.1.2.2.5 Retention of Avionics Boards

The various avionics boards are secured to the aluminum plates of the avionics sled via m3 nylon bolts. The nylon material isolated the electronics from the aluminum plate. An m3 nylon nut can withstand up to 329 N of shear load before breaking. As the heaviest avionics board included in the rocket design is the 0.042 kg Raspberry Pi 3 computer, the maximum expected shear load during flight is,

$$Expected\ shear\ force\ on\ nylon\ screws\ =\ 0.042\ \times\ 10\ \times\ 9.8$$

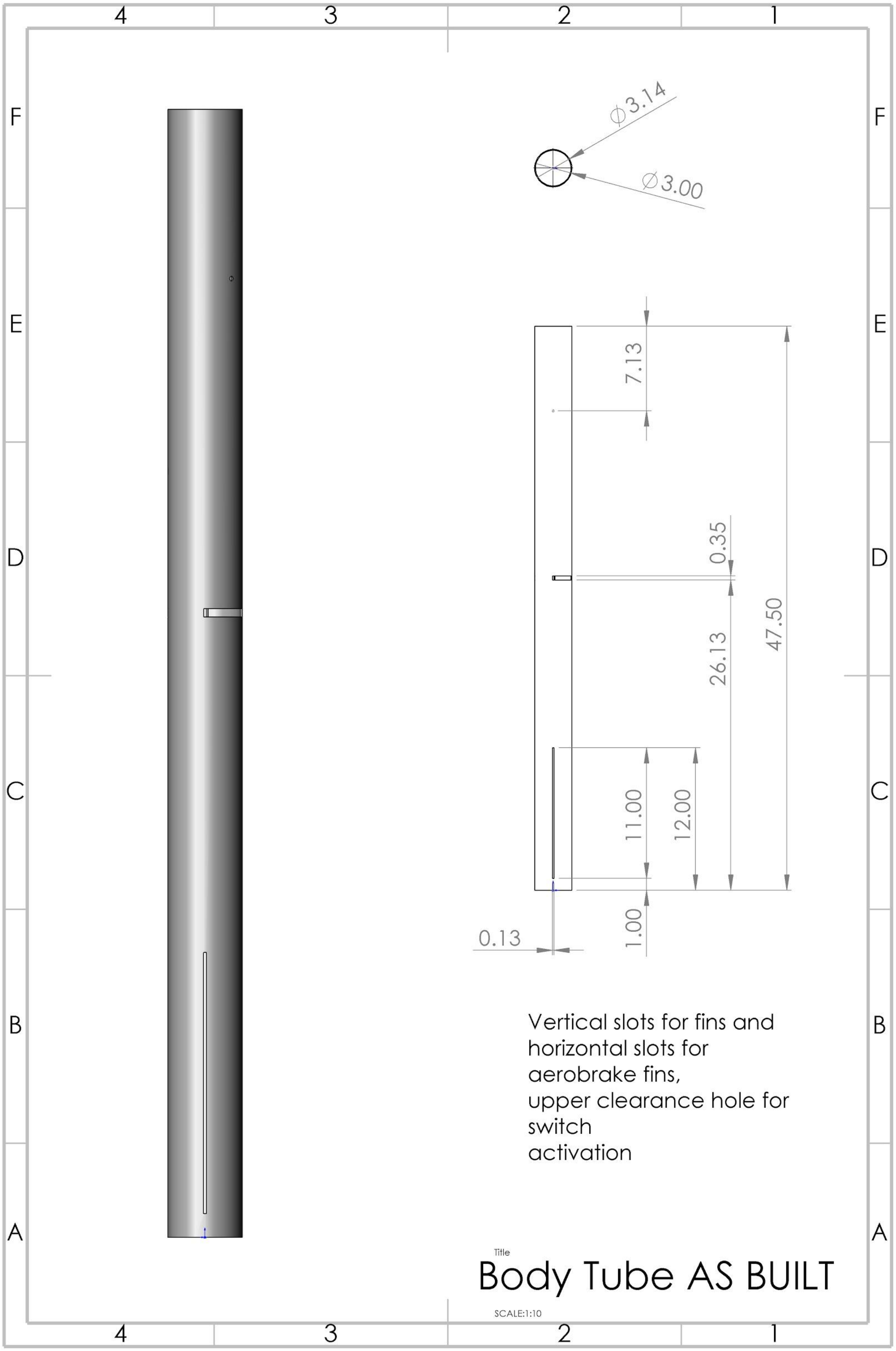
$$Expected\ shear\ force\ nylon\ screws\ =\ 4.12\ N\ (0.93\ lbf)$$

$$Avionics\ Boards\ Retention\ Safety\ Factor\ = 79.9$$

Multiple screws will be used per board to fully constrain the board. The nylon nuts which secure the boards to the nylon screws do pose a concern if they come loose during the flight. To ensure that this is not the case a pre-flight checklist item is include to check that the nylon nuts are tight and all avionics boards are secure.

3.1.2.3 Drawings as Built

The following pages include drawings of the rocket's components as they were build, annotated with dimensions in inches.



4
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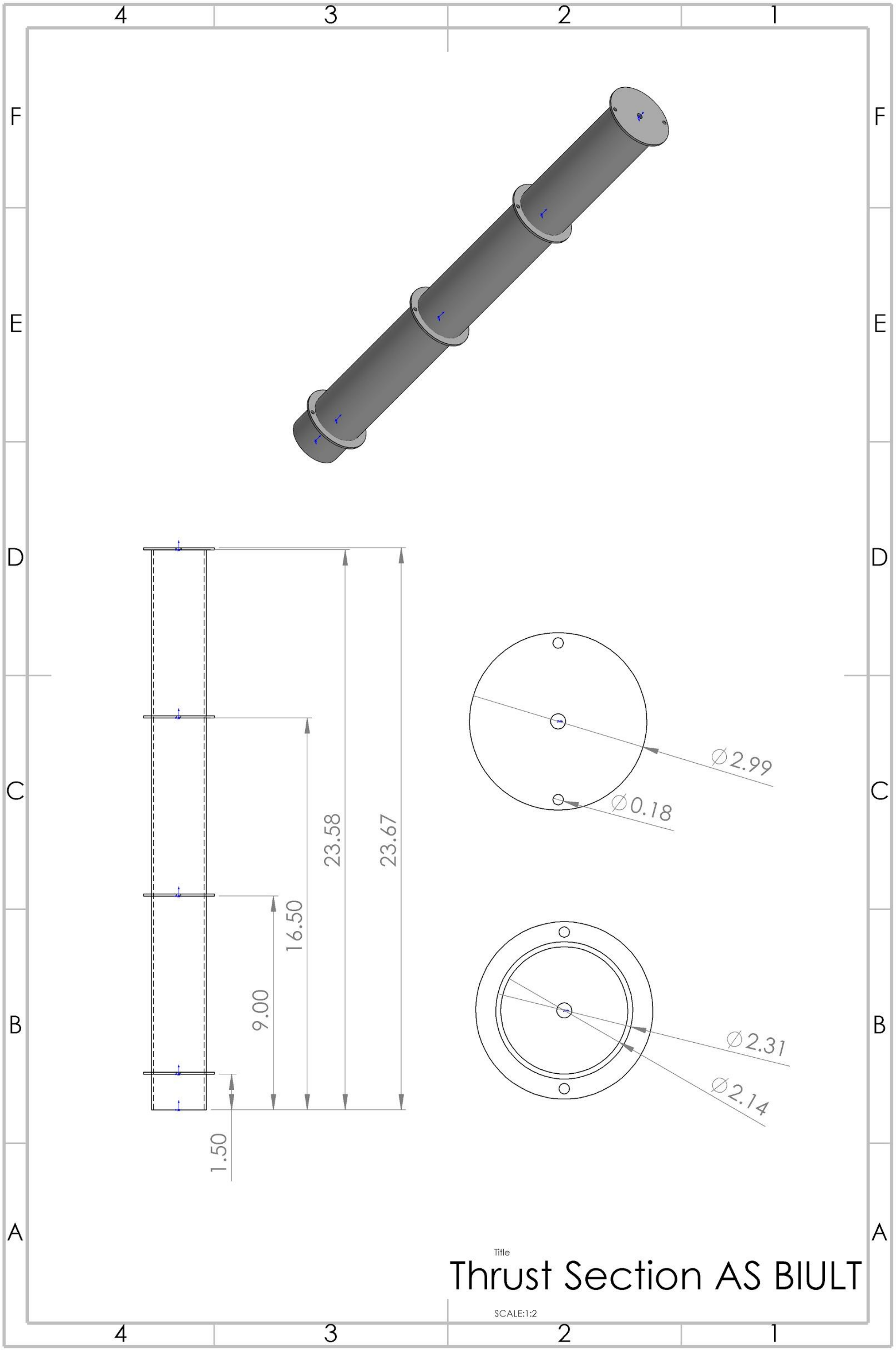
0.13
Vertical slots for fins and
horizontal slots for
aerobrake fins,
upper clearance hole for
switch
activation
Title
Body Tube AS BUILT
SCALE:1:10



23.58
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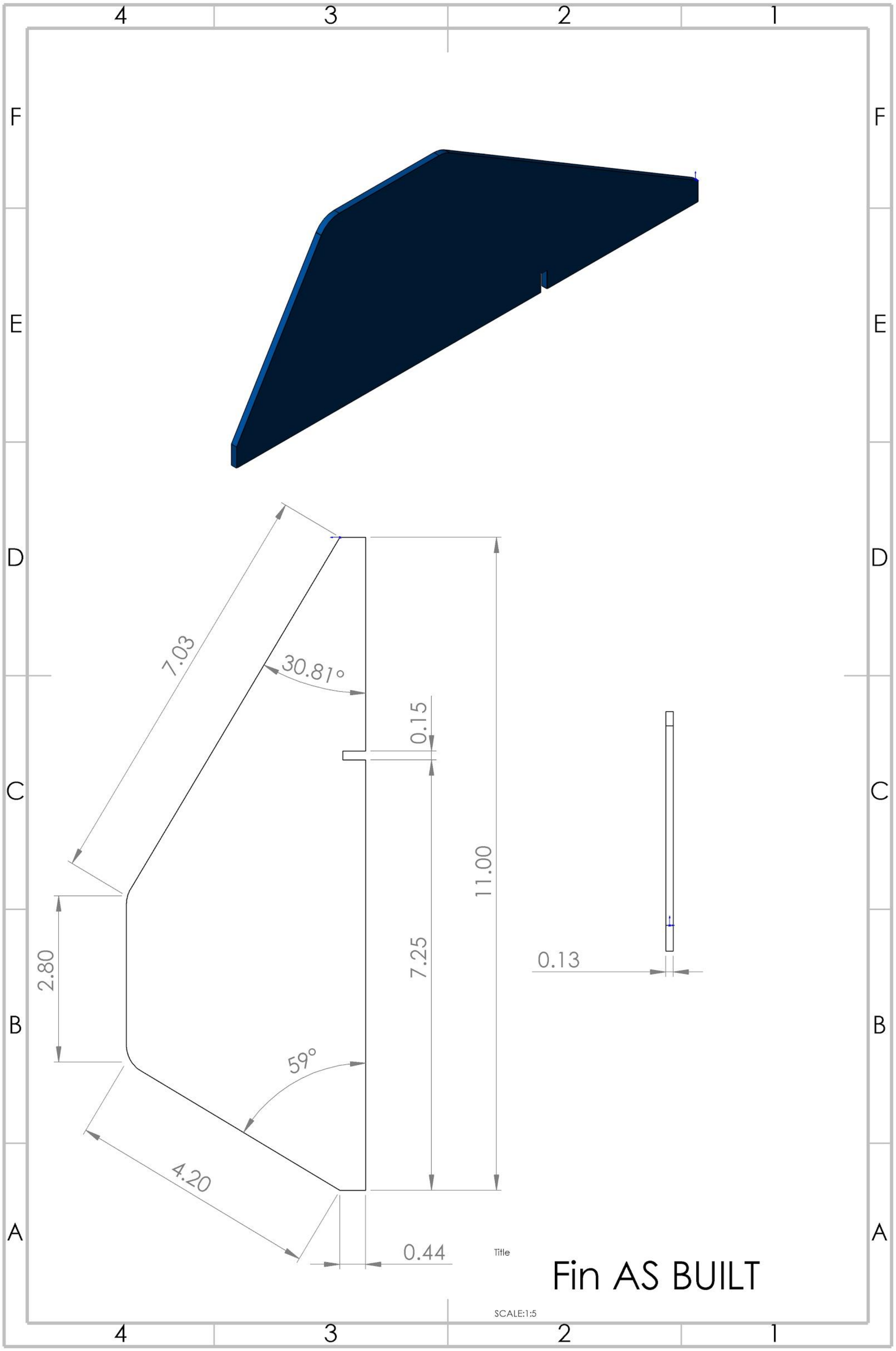
Thrust Section AS BIULT
SCALE:1:2



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59°
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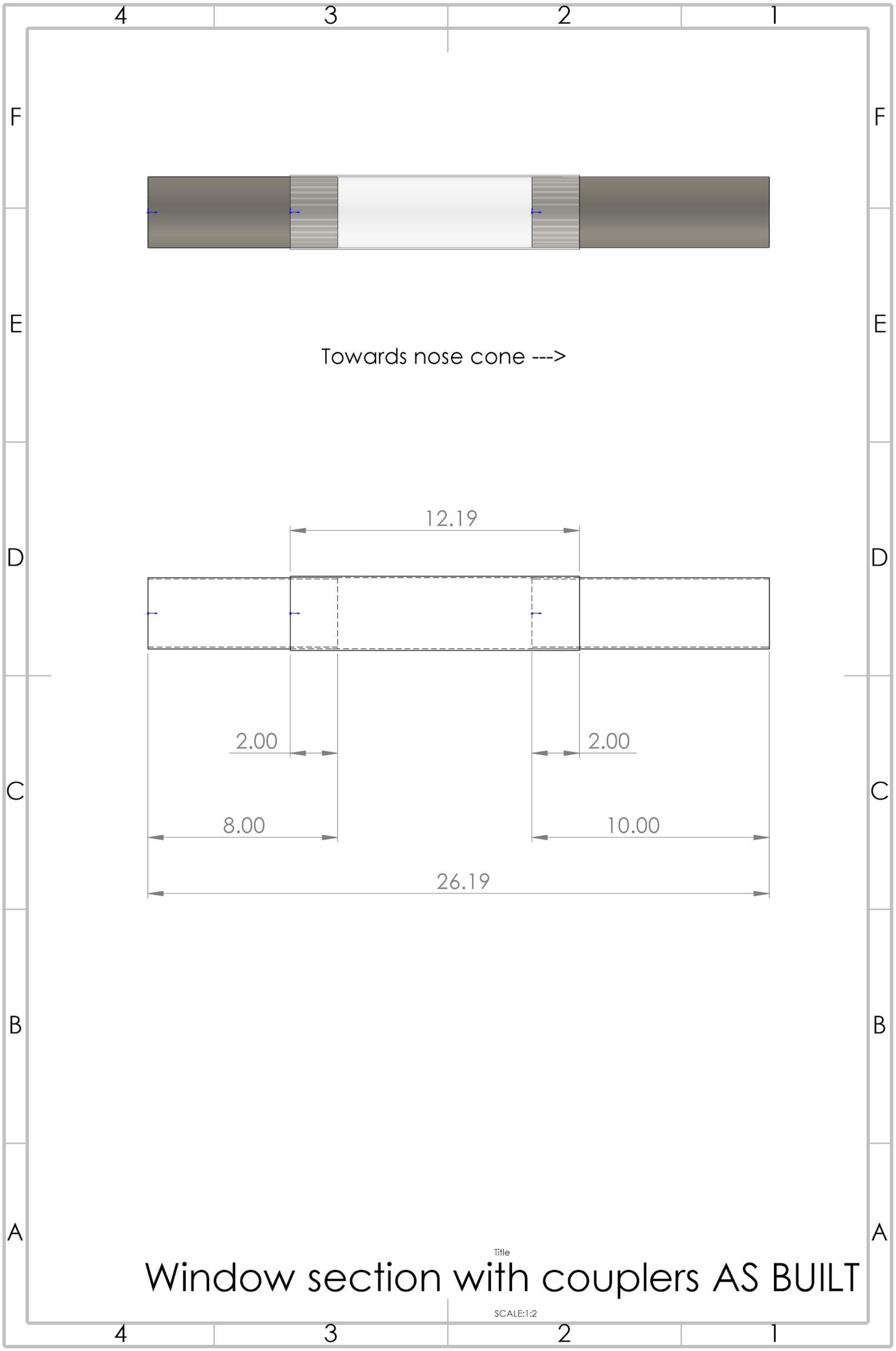
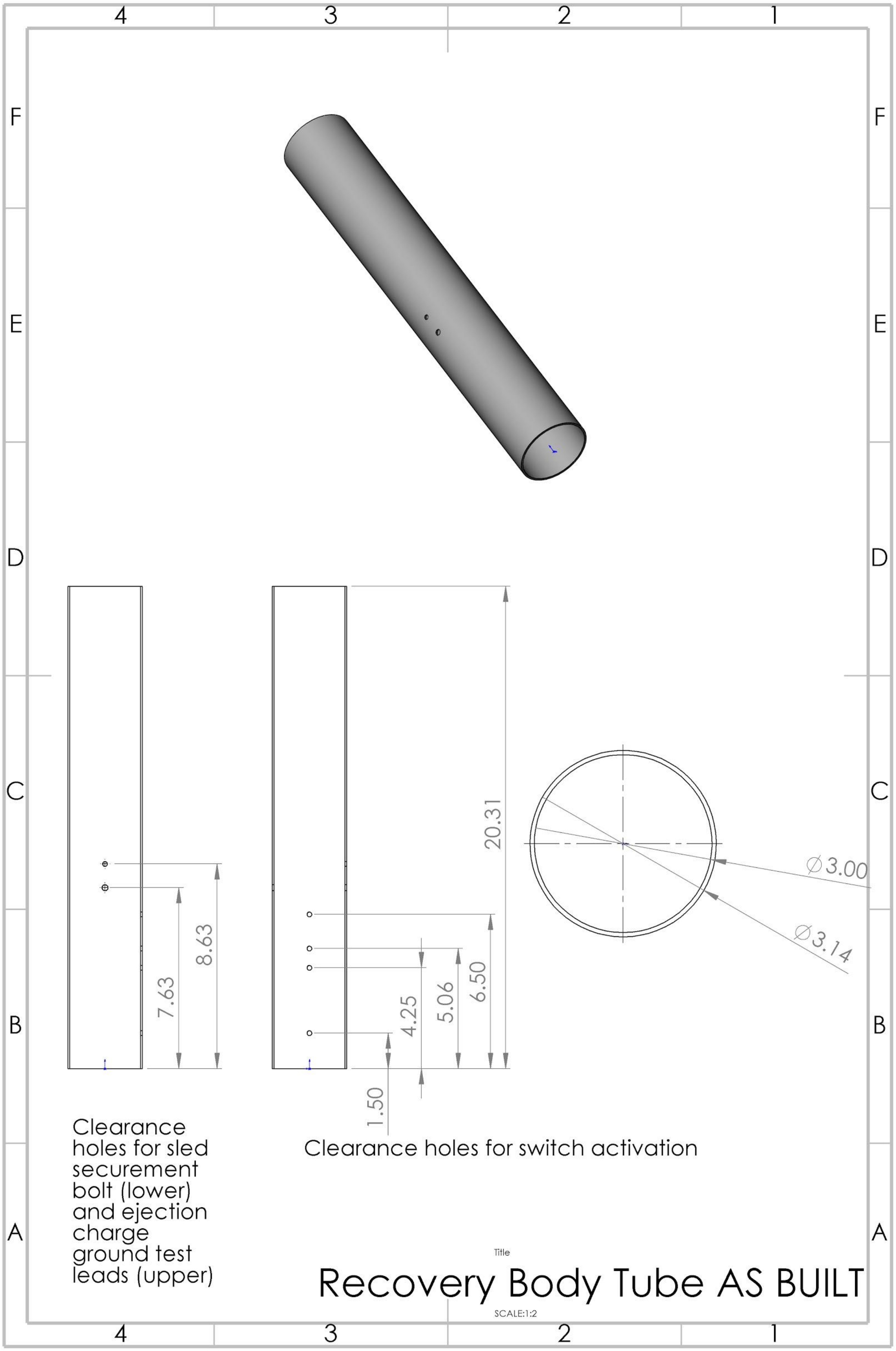
0.44
Title
Fin AS BUILT
SCALE:1:5



Towards nose cone --->
12.19
2.00
2.00
8.00
10.00
26.19
Title
Window section with couplers AS BUILT
SCALE:1:2



4
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∅3.00
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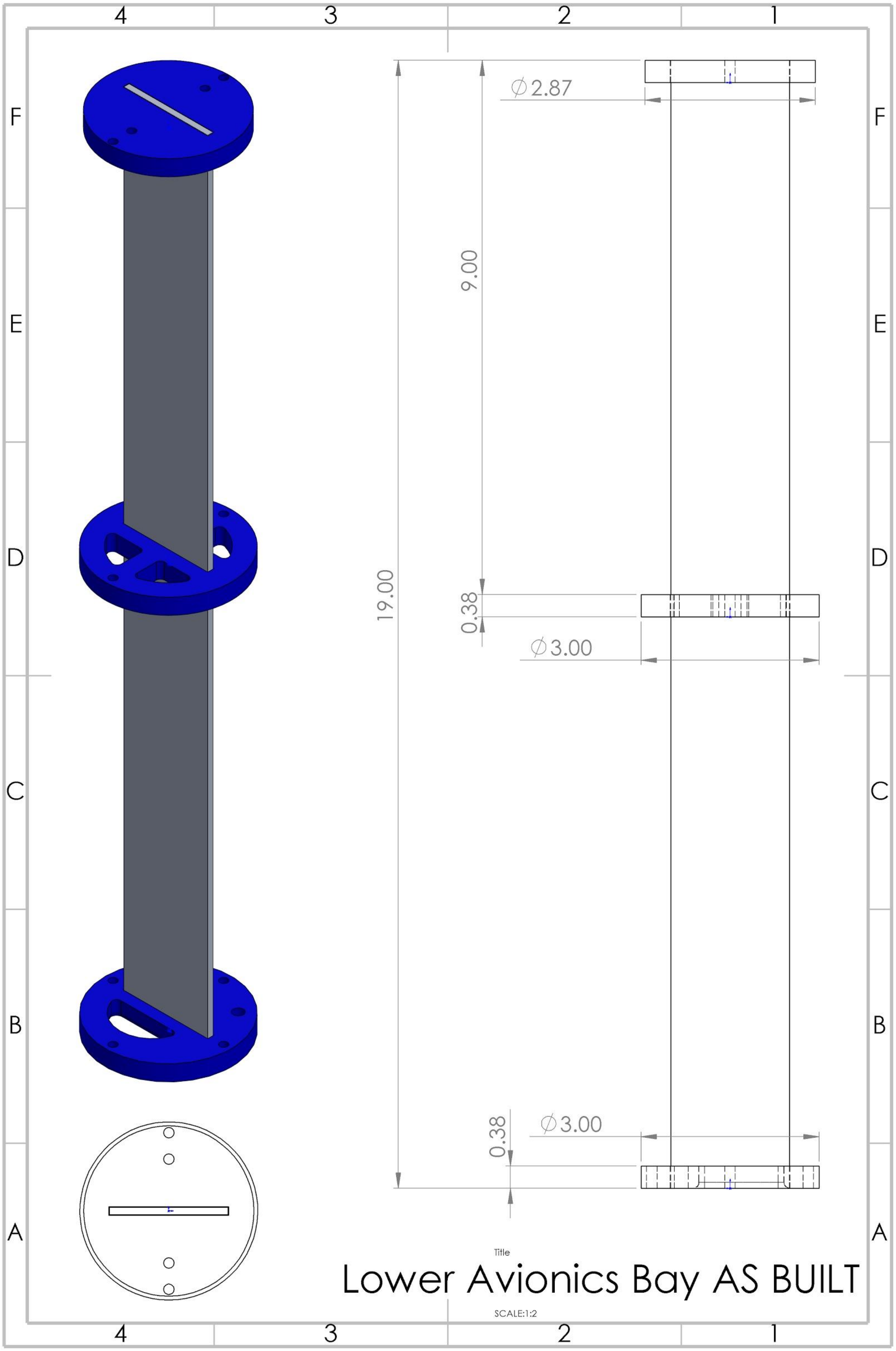
8.63
7.63
6.50
5.06
4.25
1.50
Clearance holes for sled securement bolt (lower) and ejection charge ground test leads (upper)
Clearance holes for switch activation
Title
Recovery Body Tube AS BUILT
SCALE:1:2



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9.00
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Ø3.00
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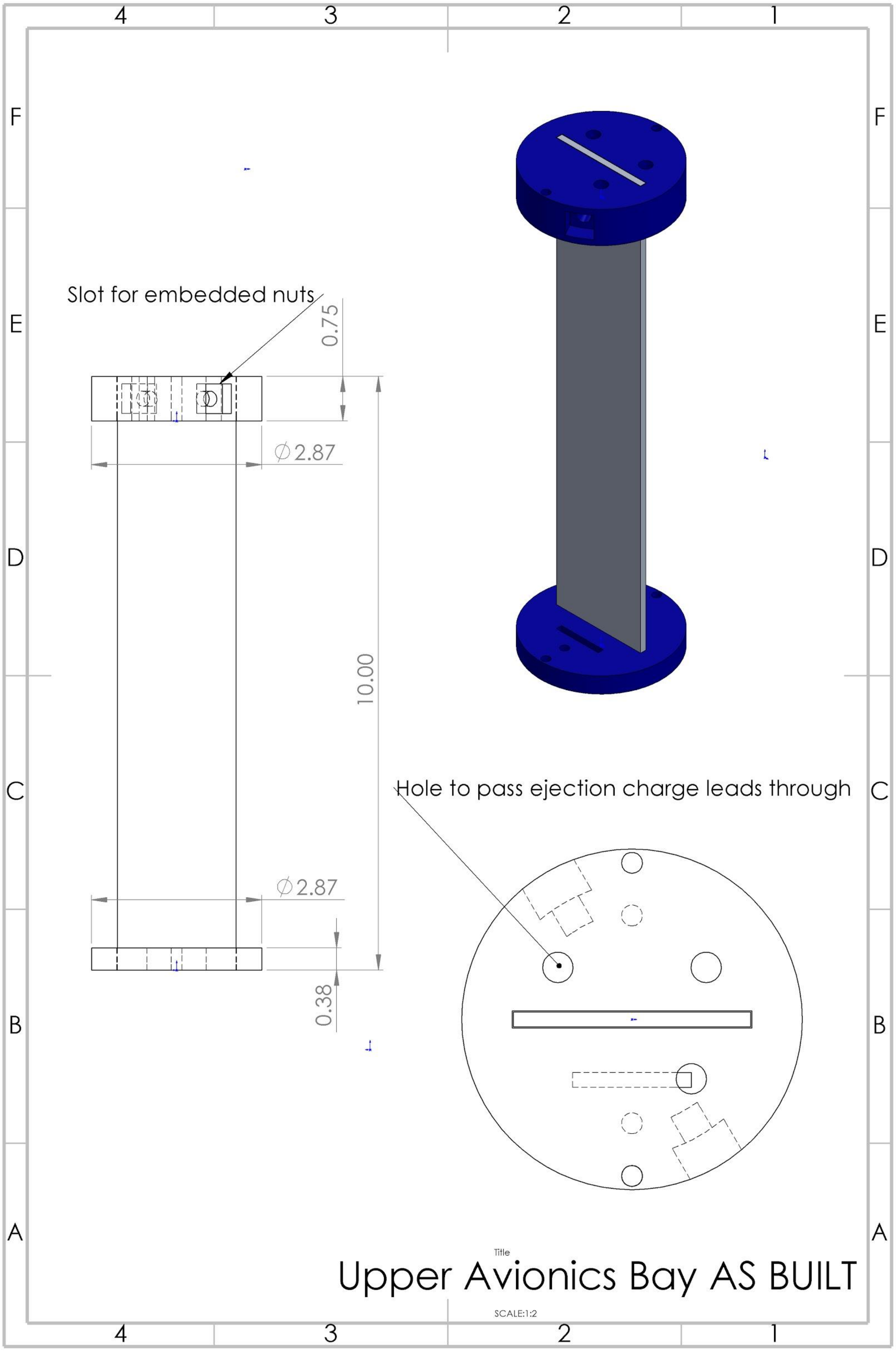
Ø3.00
Title
Lower Avionics Bay AS BUILT
SCALE:1:2


Slot for embedded nuts
0.75
⌀2.87
10.00
⌀2.87
0.38
Hole to pass ejection charge leads through
Title
Upper Avionics Bay AS BUILT
SCALE:1:2

3.1.3 Flight Reliability

The vehicle is designed with an ample amount of redundancy and robustness to minimize all risks which pose a threat to the mission. The recovery system is designed with dual modular redundancy, while the other systems onboard the rocket which cannot accommodate such redundancy are designed with robustness in mind. Materials and fastening techniques were chosen for their ability to withstand the expedited loads on the vehicle. Extensive simulations and tests were performed to verify that this was the case. Electrical components and the systems which they form have proven reliable in the many workbench tests conducted.

The mission statement 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 ultimate mission success criteria were defined as follows:

Mission success criteria	**How the design meets the criteria**
Meet all safety criteria for pre-launch activities, and all FAA flight requirements and restrictions	The rocket has been design to abide by all safety requirements and restrictions.
Be fully recoverable and reusable	The Effective-1 rocket is fully recoverable as enabled by its two stage recovery system and all of its components are fully reusable.
Follow a near-vertical trajectory	Great care has been taken to ensure that the rocket has the appropriate CG and CP values, and exit rail velocities to follow a vertical trajectory.
Successfully deploy a drogue parachute at apogee and primary parachute at pre-specified altitude	The recovery system is design to feature dual modular redundancy minimizing the likelihood of an unsuccessful parachute deployment.
Include an Inertial Measurement Unit capable of sensing and record the vehicle’s flight profile	The Effective-1 rocket include a number of sensors and independent data recording systems to log the rocket’s trajectory. An external Inertial Measurement Unit is included in addition to the onboard IMU which is a part of the Arduino 101 computer. Data from both sensors will be written to an SD card during the flight.
Use sensor data to determine the its projected flight parameters	The Arduino 101 flight computer processes the data it collects from its various sensor and feed in a predictive PID control algorithm, giving the rocket the ability to anticipate its future trajectory during flight.
Deploy ADAS if the demanded by the projected flight profile	ADAS is controlled by an Arduino 101 running a carefully designed PID algorithm which constantly compares incoming flight data with a stored model and adjust the drag fin deployment based on the difference between the two.
Perform fine adjustments to a model flight profile via ADAS at an appropriate frequency	ADAS has proven capable of adjusting the drag fin deployment angle at a 240 Hz.
Achieve a pre-specified apogee of one mile to within 5%	The full scale flight proved that the system was capable of achieving an apogee within 1.8% of the target mile.
Activate TARS to locate and track	Ground tests have shown that the system is capable of recording and

tarps of different colors, even at high spin rates	identifying target.

3.1.4 Construction

The manufacture process consisted of first cutting the motor tube to length, drilling the proper holes in the fiberglass centering rings and then bonding them together with epoxy. The all threaded rods were then also bonded into place before fixing the motor tube to airframe with epoxy. The fiberglass fins were then cut to size and bonded into place through the slots in the airframe. Fillets were create between the fins and airframe using epoxy clay and the spiraling gaps in the blue tube material were filled in also with epoxy clay. The threaded portion of the tail cone was secured to the motor tube with epoxy.

Figure 3.1.4.1 The rocket airframe unpainted during its manufacture

A FlashForge Creator Pro 3D Printer was used to manufacture the bulkheads for the avionics bay sleds and create the custom gears and plates which makeup ADAS. Over the course of the various 3D prints, the printer experienced a number of malfunctions and glitches, mostly likely due to the unreliability of the cheaply made FlashForge Creator Pro 3D Printer which delayed manufacturing. As the 3D printed parts were completed they were integrated into their various parts. Once the aluminum plating which composes the main portion of the avionics sleds were cut to size, the bulkheads were bonded to them using epoxy.

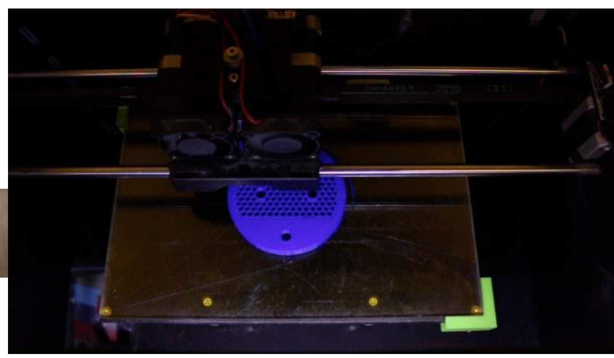


Figure 3.1.4.2 the GPS sled in the process of being 3D printed

Once the avionics sled were built, the location of the numerous electronic boards were laid out and the points at which mounting holes needed to be drilled were marked. These holes were then drilled and the boards mounted using insulative nylon hardware.

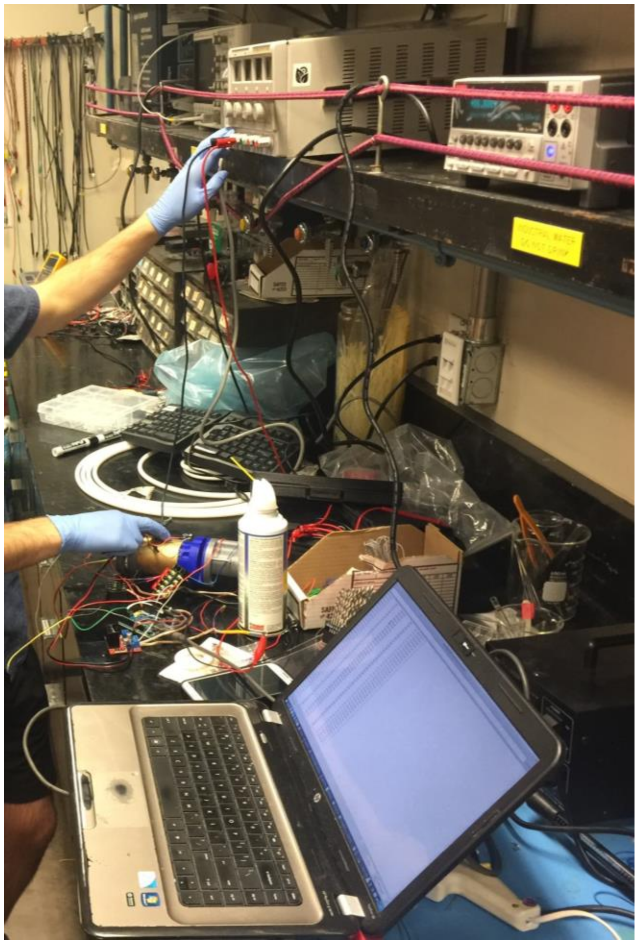
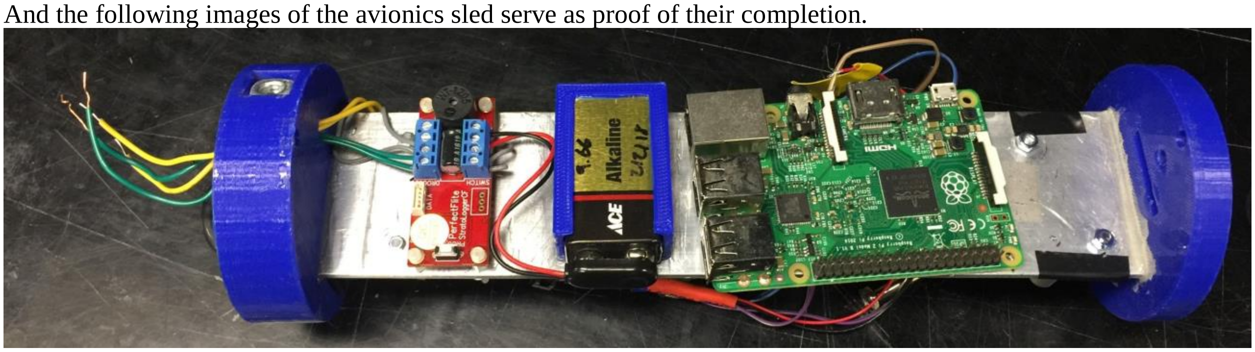


Figure 3.1.4.3 Assembly of the electronics
Once the wiring was competed, the vehicle was prepared for testing. After numerous tests, troubleshooting and re-wirings, the avionics were declared ready for flight.

Figure 3.1.4.4 The fully constructed E-1 Rocket being prepared for its full scale flight

Let the above image of the E-1 rocket being prepared for flight serve as proof that the vehicle is full constructed. And the following images of the avionics sled serve as proof of their completion.



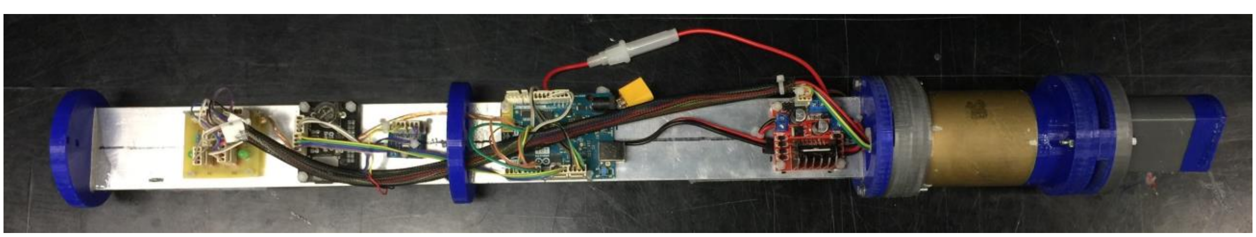


Figure 3.1.4.5 Completed upper avionics sled
Figure 3.1.4.6 Completed lower avionics sled

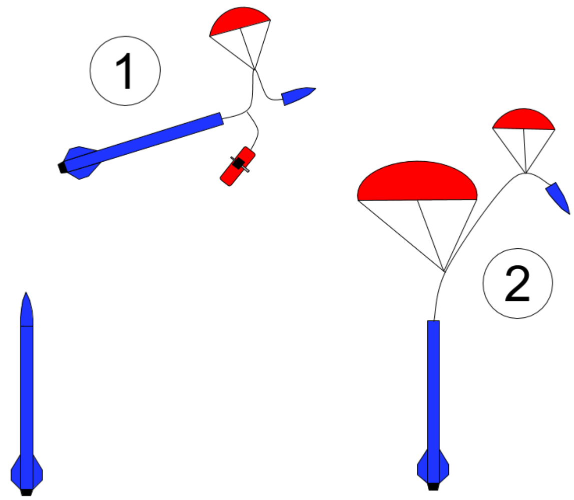
3.1.5 Differences in the constructed vehicle

Models predicted that the rocket would require a sizable ballast to achieve the desired flight, thus rather than take up dead mass, the batteries which power the electronic systems on board were swapped from 9Vs to LiPo batteries. This decision was made mid way through the manufacturing process and thus varies from the initially proposed design of the vehicle. This alteration has affected the CG of the vehicle.

Initially when the slots in the airframe were cut for the ADAS fins, there was a slight misalignment. An additional spacer was added to the bottom of the lower avionics sled in order to align ADAS fins with the slot cut for them in the airframe. This is the reason why the top most bulkhead of the lower avionics sled is now visible in the clear section of the rocket.

The constructed rocket features a 4:1 Ogive nose cone instead of planned 5:1 due to a misplaced order. The difference in performance did not justify the time lost in placing a new order and preparing another nose cone, so the 4:1 nose cone was adopted as the primary design.

3.2 Recovery Subsystem

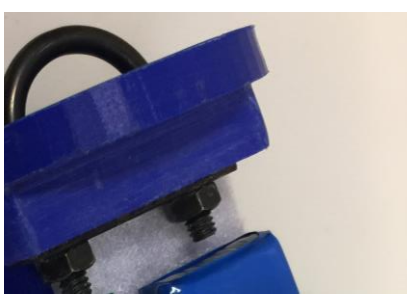


The rocket features a two phase recovery system. During the first phase, the 24” Nylon with a 6” radius vent drogue chute is released at apogee. The main chute is also ejected from the rocket during the phase but is prevented from inflating by the Jolly Logic chute release devices. Once the rocket has descended under the drogue chute to an altitude of 500 ft, the Jolly Logic chute release devices release, allowing the 48" Fruity Chutes: Iris Ultra Parachute to inflate. The rocket then lands and is located with an Egg Finder GPS device.

3.2.1 Structural Elements

3.2.1.1 Bulkheads/Attachment

The ends of the recovery harness are attached to rocket’s structure through two Black-Oxide Steel U-Bolts with Mounting Plate, 1/4"-20 Thread Size, and 1" ID. One of these U-bolts is mounted through the lower bulkhead of the GPS sled, while the other is mounted through the top bulkhead of the upper avionics bay. The nuts which hold the U-bolts in place are secured with loctite and the mounting plate is bonded to the respective bulkhead with epoxy. The harness is then tied to these U-bolts using a figure 8 knots.



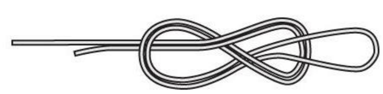


Figure 3.2.1.1.1 U-Bolt (left) U-bolt mounted through the GPS sled bulkhead (center) figure 8 knot (right)

3.2.1.2 Harnesses

The shock cord is made of Kevlar cord #1500 which has a rate load of 1500 lb and connects the drogue chute, main chute and Nomex protective cloth to the U-Bolt attachment points on the rocket.

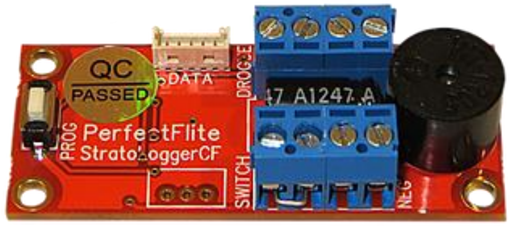
3.2.1.3 Swivels

Each parachute is tied to the recovery harness through swivel bearings. The purpose of the swivels are to prevent entanglement of the parachutes, which could lead to a faster than expected descent rate.

3.2.1.4 Shear Pins

In order to ensure that the nose cone stays securely in place until the detonation of the ejection charge, two 2-56 X 1/4" long Round Slotted Nylon Machine Screw are tapped through the top of the recovery section and into the nose cone. The breaking load for one of these screws in double shear is less than 50 lbf. Thus the 208 lbf force generated by one gram of black powder will be sufficient to break both screws.

3.2.2 Electrical Elements



3.2.2.1 Altimeters

Figure 3.2.2.1.1 StratologgerCF (top left) Easy Mini (bottom left) and Jolly Logic Chute Release (right) altimeters

The recovery system employs a system of four altimeters. One StratologgerCF which serves as the primary altimeter responsible for the initiation of the first recovery stage separating the rocket, deploying the drogue chute and ejecting the wrapped main chute at apogee. In order to ensure that the system has sufficient redundancy, an Easy Mini altimeter is also included with its own separate power source and ejection charge. The Easy mini altimeter is connected to a larger black powder charge such that if the Stratologger does not fire at apogee or the charge is

insufficient to separate the rocket (which is extremely unlikely given the success of the ground ejection test), the Easy mini's larger charge energy will serve as a second chance to successfully complete the first recovery stage. The Easy Mini is also and programed with a 2 second delay from apogee to avoid the simultaneous detonation of both ejection charges.

Once the StratologgerCF or Easy Mini trigger the drogue chute deployment at apogee, the rocket descends under the drogue chute until the second stage of recovery. This stage is triggered by the release of the main chute via one of the two Jolly Logic Chute Release devices wrapped around the main chute. The devices are self-contained altimeters which are programmed to release a pin at a configurable altitude. The recovery system includes two of these devices with their straps connected in series in order to ensure that the main chute will be released in the case that both function as planned, or only one functions as planned.

Both the StratologgerCF and Easy Mini altimeter have been proven to perform as expected during vacuum tests. The Jolly Logic Chute Release device have a self test feature which has been executed multiple times on each device and is a part of the preflight checklist (Preflight checklist).

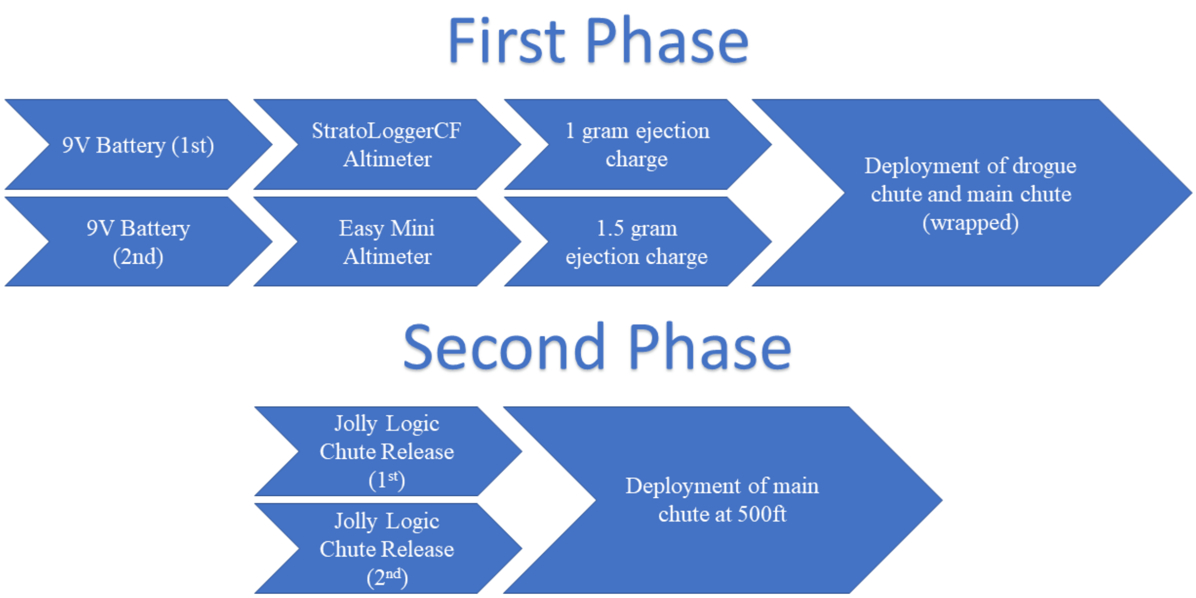
3.2.2.2 Switches

The recovery system is armed externally using screw switches which lock into the on position.

3.2.2.3 Connectors

The ejection charge leads will be connected to wires protruding into the recovery bay via crimp connectors with insulating sleeves to ensure that the system does not short..

3.2.3 Redundancy Features



During the first phase of recovery, the StratologgerCF and Easy Mini altimeters provide independent dual modular redundancy. The two altimeters are connected to seperate power sources and seperate black powder charges. Thus if one device should fail, the other is capable of completing the first stage of deployment. The two distinct altimeter models were selected to avoid any manufacturing defects that could be the root cause in the failure of one device or the other.

The second stage of recovery is redundant in the inclusion of two Jolly Logic Chute Release devices with their straps wrapped in parallel around the main chute. This configuration provides dual modular redundancy for the second stage of recovery. Due to the unique functionality of this device, the secondary device is identical to the first in model and vendor, unfortunately not providing the same level of immunity to manufacturing defects as is present in the first stage recovery system.

The final stage of the recovery process, the location of the rocket is done by using the Egg finder GPS device further discussed in Section 3.2.7. There is not a redundant transmitter on board the launch vehicle, but recorded video from the ground from multiple position should allow the triangulation of the rocket's landing site if the GPS transmitter should fail.

3.2.4 Parachute Sizes and Descent Rates

Parachute	Size	Descent Rate [Predicted]	Descent Rate [Actual]
ft/sDrogue	18” Nylon with a 6” radius vent	26.5 m/s (87.04 ft/s)	20.67 m/s (67.8 ft/s)
ain	48" Fruity Chutes: Iris Ultra Parachute	5.46 m/s (17.94 ft/s)	6.15 m/s (20.2 ft/s)

The descent rate above were calculated using the following method:

$$F_G = Mg$$

$$F_D = \frac{1}{2}\rho_{air}v^2 C_D A$$

By equating the force of gravity and the drag force produced by the parachutes, the net force will be 0, and thus by Newton’s Second Law there will be no acceleration present and a constant descent rate can be obtained.

$$F_G = F_D$$

Parachute	Area	Cd [Predicted]
Drogue	141 in^2 (0.091 m^2)	1.2 (estimate)
Main	1809 in^2 (1.167 m^2)	2.2

$$v_{Drogue} = \sqrt{\frac{2F_D}{C_D\rho A}}$$

$$v_{Drogue} = \sqrt{\frac{2Mg}{C_D\rho A}}$$

$$M = 5.0\ kg$$

$$v_{Drogue}\ m/s = \sqrt{\frac{2(5)(9.8)}{1.2(1.225)(0.091)}}$$

$$v_{Drogue} = 26.5\ m/s\ (87.04\ ft/s)$$

During the second stage of recovery, both the drogue and main chutes are exerting a drag force on the vehicle,

$$F_G = F_{D\,Drogue} + F_{D\,Main}$$

$$F_{D\,Drogue} + F_{D\,Main} = \frac{1}{2}\rho_{air} v^2 \left(C_{D\,Drogue} A_{Drogue} + C_{D\,Main} A_{Main} \right)$$

Solving for v,

$$v_{Main} = \sqrt{\frac{2\,Mg}{\rho(C_{D\,Drogue}A_{Drogue} + C_{D\,Main}A_{Main})}}$$

$$v_{Main}\,m/s = \sqrt{\frac{2\,(5)(9.8)}{1.225[(1.2)(0.091) + (2.2)(1.167))}}$$

$$v_{Main} = 5.46\,m/s\ (17.94\,ft/s)$$

3.2.5 Ejection Charge Sizing

The sizes of the ejection charges were calculated using the following equation:

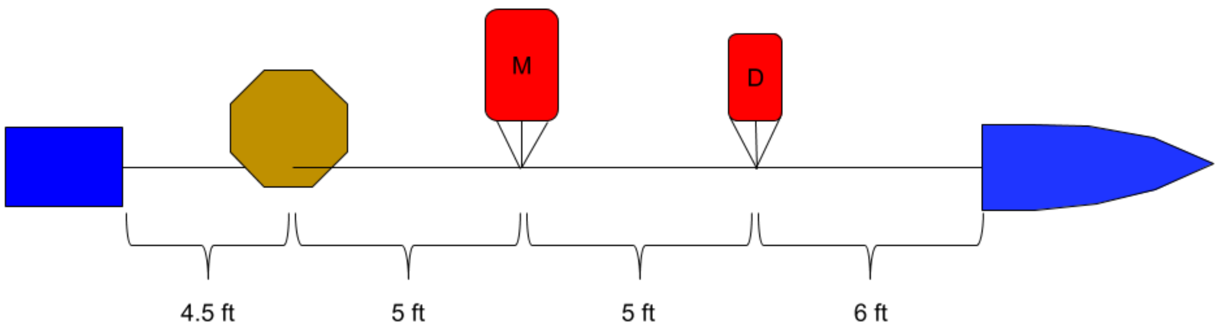
$$Black\ Powder\ (grams): N = \frac{Pressure \times Volume}{266\frac{in\ lbf}{lbm} \times 3307\ {}^{\circ}R}\left(\frac{454\ grams}{1\ lbf}\right)$$

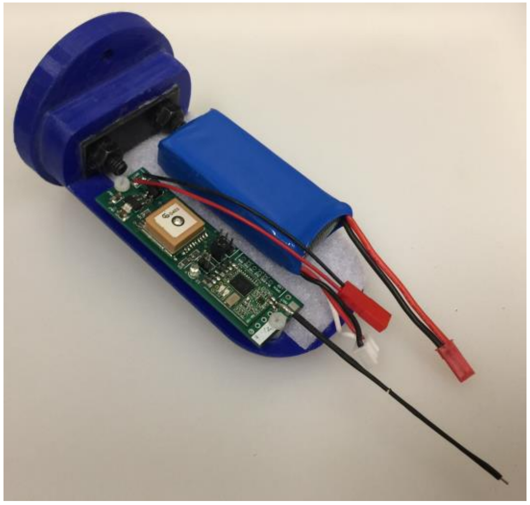
With the "Volume" representing the volume of the recovery section as,

$$Volume = \pi\,(3in)^2\,9\frac{5}{16}in$$
$$Volume = 263\,in^3$$

A one gram charge will produce a pressure of 7.3 psi in the recovery section, generating a 208 lbf force on the nose cone to achieve separation. This force is above the 100 lbf maximum force necessary to break both nylon shear pins

3.2.6 Drawings





3.2.8 Rocket Locating Transmitter

Figure 3.2.8.1 The Egg Finder GPS, its battery and sled

To locate the rocket after its flight, an Egg Finder GPS is housed within the rocket's nose cone. The Eggfinder has a range of 8000 feet and operates at a frequency of 900 MHz at 100mW.

3.2.9 Sensitivity of Recovery system to onboard generated electromagnetic fields

The only major electromagnetic field of worth of investigation on the rocket is that produced by the Egg Finder GPS transmitter. With the transmitter located in the nose cone, setting it 13 in. apart from the recovery altimeters, which is sufficient to prevent any electromagnetic interference.

3.3 Mission Performance Predictions

3.3.1 Simulations

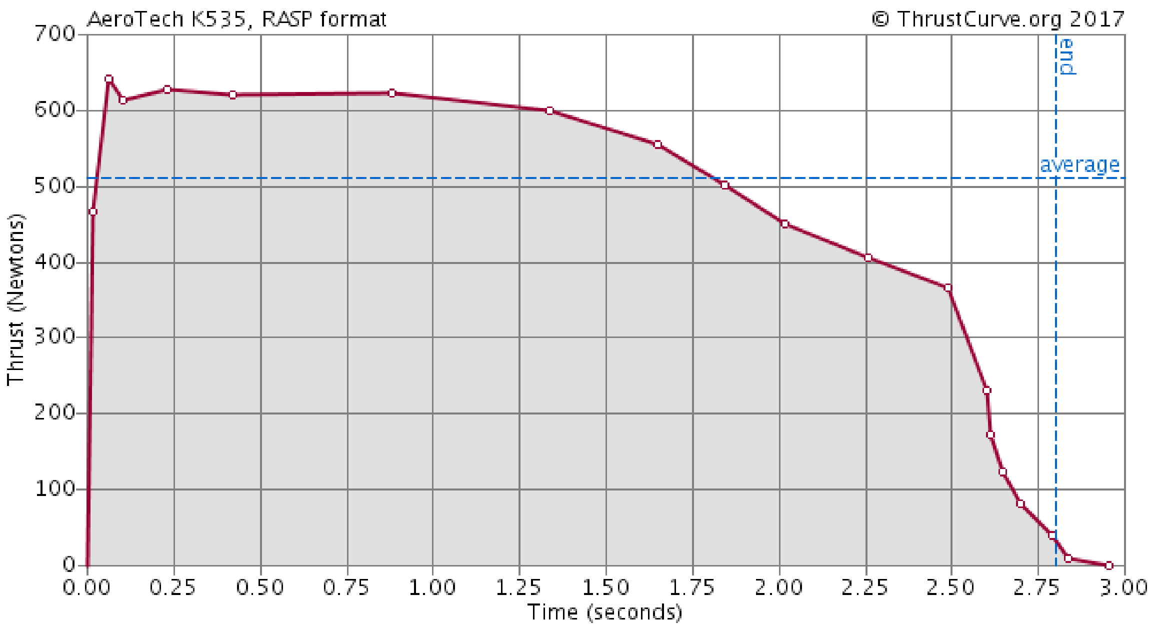


Figure 3.3.1.1 K535 Thrust curve

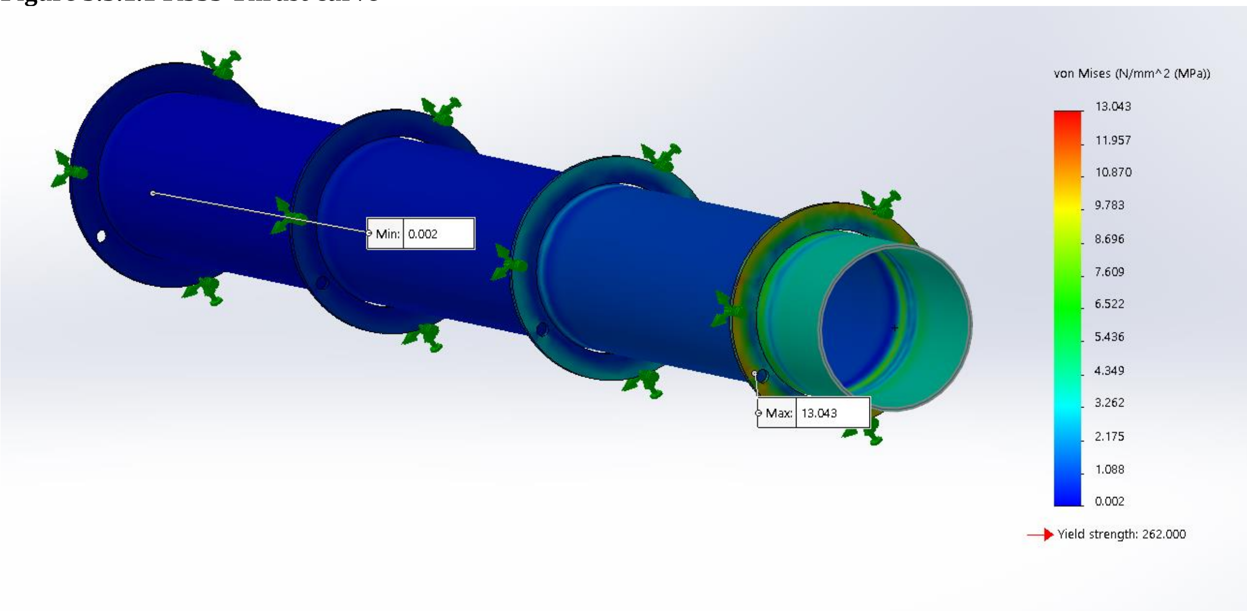


Figure 3.3.1.2 Stress simulation on the motor housing at maximum thrust

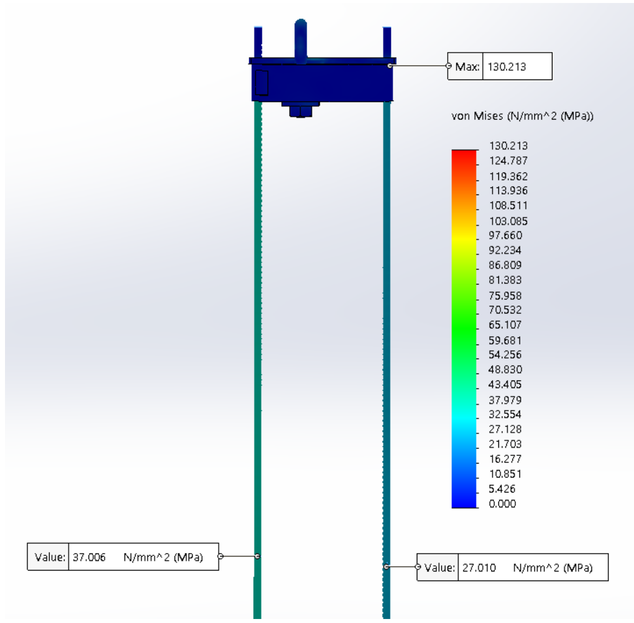


Figure 3.3.1.3 Stress simulation of the force of the recovery harness on the U-bolt and all threaded rod assembly

Current simulations using Open Rocket and the complete mass of the rocket predict an apogee of 5236 ft without the deployment of the aerobraking system, and in the case of no wind. It has been shown that Openrocket does overestimate drag forces in some cases and as the data collected from the the full scale launch was not sufficient to reconstruct the rocket's drag coefficient with accuracy, the custom python script was not used to determine mission performance predictions.

3.3.2 Stability Margin AS BUILT

CG AS BUILT	CP AS BUILT	Stability margin AS BUILT	Rail Exit velocity
152 cm from nose cone tip	189 cm from the nose cone tip	4.65	17 m/s (55.7 ft/s)

The CG was measure by balancing the completed rocket. The CP was calculated in Open Rocket using the rocket's as build dimensions. The stability margin was calculated by taking the difference of these two and dividing by the rocket's diameter. The exit rail velocity is above the required 52 fps.

3.3.3 Landing Kinetic Energy

Given that the rocket descends at the rate predicted in 3.2.4 Parachute Sizes and Descent Rates, the rocket will impact the ground with a velocity of 5.36 m/s (17.6 ft/s).

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

A the time of impact, the rocket is separated into two tethered segments, the nose cone/GPS segment and the remainder of the rocket.

$$m_{nose\ cone/GPS} = 0.295kg$$

$$m_{\quad Main\ Rocket\ Segment} = 4.404kg$$

The two segments sum to lower than the 5 kg total rocket mass because the parachutes and recovery harness account for 0.301 kg of the overall mass. Thus the kinetic energy for each segment is:

$$KE_{\quad nose\ cone/GPS} = 4.40\,J\ (3.25\,ft - lbf)$$
$$KE_{\quad Main\ Rocket\ Segment} = 65.65\,J\ (48.4\,ft - lbf)$$

Both of these values are significantly below the 75 ft-lbf limit.

From the test flight data the kinetic energy of the entire rocket is

$$KE_{\quad Flight\ Data} = 96.4\,J\ (71.1\,ft - lbf)$$

3.3.4 Drift

To calculate the maximum expected drift, the following equations will be used:

$$Max\ Drift = Descent\ Time \times Wind\ Speed$$

$$Descent\ Time = \frac{Distance\ Traveled\ under\ Drogue}{Drogue\ Descent\ Rate} + \frac{Distance\ Traveled\ under\ Main}{Main\ Descent\ Rate}$$

The target apogee of the vehicle is 1 mile (5280ft) and with the main chute programed to deploy at 500ft,

$$Distance\ Traveled\ under\ Drogue = 4680\ ft$$

$$Distance\ Traveled\ under\ Main = 500\ ft$$

Thus,

$$Descent\ Time = \frac{4680}{87.04} + \frac{500}{17.92}$$

$$Descent\ Time = 81.64\ sec$$

$$Full\ Scale\ Descent\ Time = 95.25\ sec$$

Wind Speed	Predicted drift from launch pad	Predicted drift calculated from full scale flight data
No wind	0 ft	0 ft
5 mph (7.33 ft/s)	598.7 ft	698.5 ft
10 mph (14.66 ft/s)	1197 ft	1397 ft
15 mph (22 ft/s)	1796 ft	2095.6 ft
17.9 mph (26.4 ft/s)	-	2500 ft
20 mph (29.33 ft/s)	2394 ft	2794.1 ft (see condition below)

As shown, our predicted drift using the full scale descent rates stays within the available 2500 ft radius recovery area within the range of up to a 17.9 mph wind speed.

If the wind speed is above 17.9 The drogue chute will be replaced with a streamer, and the main chute deployment altitude increased to ensure complete inflation. In the modified high wind speed configuration, the predicted drift is as follows:

Predicted descent rate with streamer	85 ft/s
New main chute deployment altitude	600 ft
Time spend under streamer	55.1 sec
Time spent under main	29.7 sec
Total descent time	84.76 sec
20 mph drift	2486.4 ft

Thus the rocket is predicted to remain within the available 2500 ft radius recovery area within the range of up to a 20 mph wind speed.

3.3.5 Separate Calculation Verification

Using an Open rocket simulations, the total descent time was predicted to be 93 seconds.

Wind speed	Predicted Drift
No wind	0 ft
5 mph (7.33 ft/s)	681 ft
10 mph (14.66 ft/s)	1363 ft
15 mph (22 ft/s)	2045 ft

20 mph (29.33 ft/s)	2727 ft

These figures are in near total agreement with those calculated above.

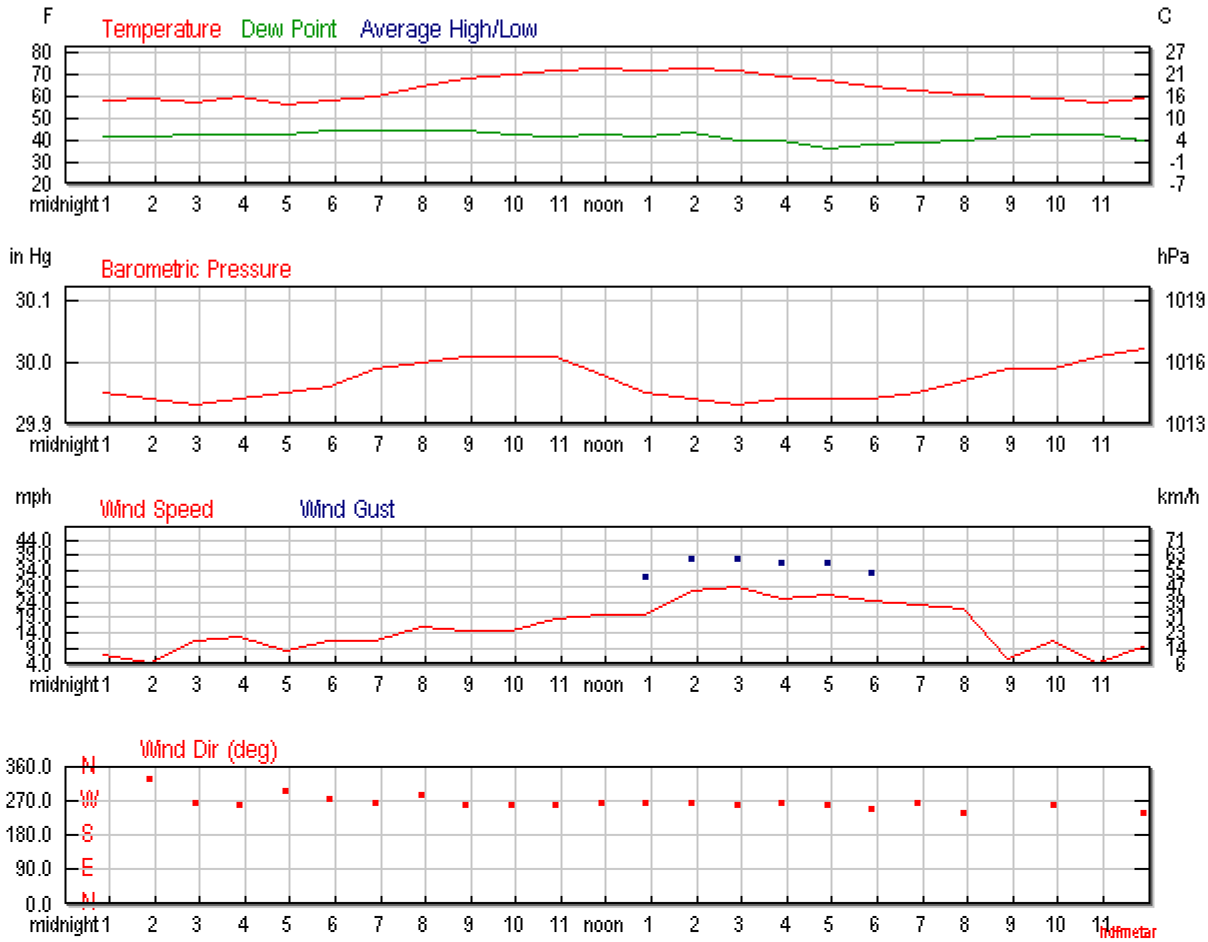
3.4 Full Scale Flight

The full-scale launch was carried at the Holtville Havoc launch event on Saturday, March 3rd, 2018. The usual launchsite in Snow Ranch, CA was rained out, and all other launch events (most notably, two in Nevada) were also cancelled due to rain. The Team resorted to driving to the Holtville launchsite, near the California-Mexico border. The launch was facilitated in part by TRA members, most notably, Level-3 certified rocketeers Dave Nord and Ron Rickwald, who facilitated our motor and ejection charge assembly. They were contacted on behalf of our mentor, David Raimondi for emergency assistance, and oversaw all of our operations.

3.4.1 Launch Day Conditions

The launch day was sub-nominal. There were intense and variable winds that persisted throughout the morning and gained strength at noon, and gusts exceeded 30 mph. There were also frequent lulls in the wind, allowing for windows of opportunity for launch. The cloud coverage increased significantly throughout the day during avionics assembly, and persisted throughout our launch window. The RSO deemed that the clouds were high enough for safety, and allowed our launch during a lull in the wind.

Time	Wind Speed	Wind Gusts	Wind Direction	Temperature	Pressure	Conditions
13:05 PST	19.6 ± ~5 mph	~30 mph	269° (W)	62° F	29.9 Hg	Windy with occasional intense gusts. Mostly cloudy.



3.4.1.1 Weather Underground data from a nearby weather station near the Holtville launchsite

3.4.2 Analysis of Full Scale Flight

The full-scale launch of E-1 was a partial success. In spite of the high winds, the vehicle flew stably along a fairly vertical trajectory. Drogue and main deployment were confirmed visually. Upon inspection, the vehicle maintained a severe fracture along the diameter of the airframe, over the ADAS slits. Inspection of the onboard electronics revealed that both computer systems failed during flight. The avionics and ADAS SD card contained only 12 seconds of data (during vehicle assembly), and the TARS payload SD card was found to be physically damaged and corrupted. Additionally, the EasyMini altimeter was not enabled on the launch pad due to an issue with its arming switch.

3.4.2.1 Flight Failures

There were a few failures associated with this launch, and we aim to fix and repair them before re-flight. Many issues stem from excessive landing forces, which could be greatly reduced with a larger main parachute.

Failure	Working Rationale	Potential Solutions
Failure to engage EasyMini altimeter	Poorly attached screw-switch detached during arming process on pad	➢ Implement a different switch mechanism ➢ Reinforce screw switch attachment with epoxy
ADAS data write failure	ADAS SD card jostled during	➢ Reinforce and guard SD card with tape

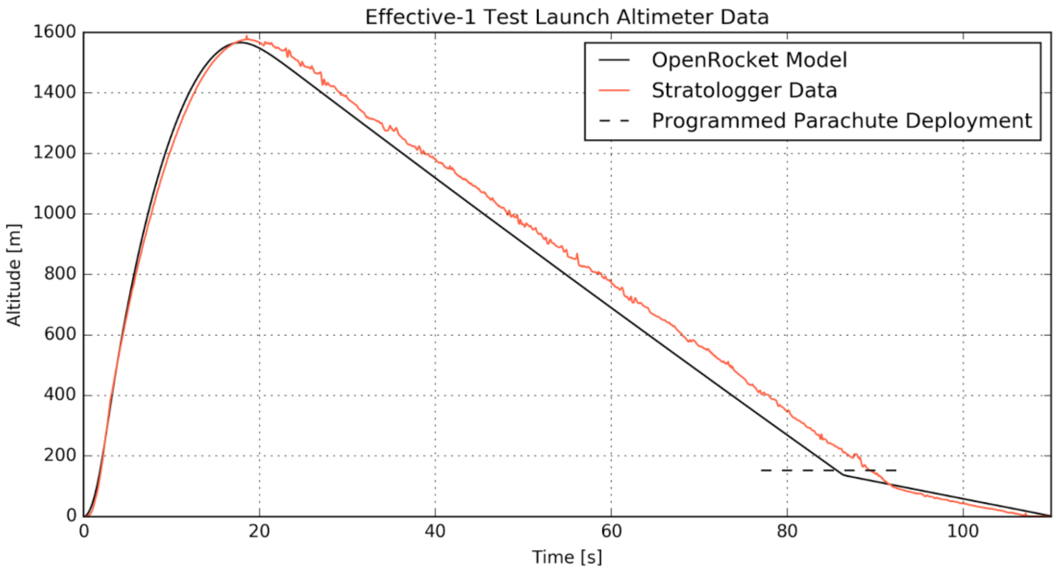
	assembly; lost contact with flight computer	➢ Reposition and secure nearby wires ➢ Use an SD card extension cable and route it to a safer and less occupied region of the avionics sled ➢ Have a backup redundant SD card
TARS SD card write failure	Raspberry Pi SD card was bent and cracked during flight due to strong landing forces; poorly secured computer moved around during flight/landing, putting a load on the card against nearby components	➢ Better secure Raspberry Pi computer with additional mounting struts (4 rather than 2) ➢ Use an SD card extension cable and route it to a less occupied region of the payload sled ➢ Use lightweight padding to protect SD card from external forces ➢ Use a larger parachute to decrease landing loads
Airframe fracture 	The blue tube airframe surrounding the ADAS slits suffered a fracture that propagated around the majority of the circumference of the body tube along its spirals.This failure occurred upon ground impact.	➢ Reinforce the existing airframe with a long interior coupler held in with epoxy (mentor's recommendation) ➢ Use an externally-mounted piece of airframe material to reinforce the vehicle ➢ Modify the aerobrake fins to accommodate smaller slits; reduce slit size ➢ Use a larger parachute to decrease landing loads

3.4.2.2 Data Analysis and Model Comparison

Due to the failure, of the rocket electronics, the only flight data from the full scale flight collected was altimeter data from the stratologger. Due to the windy conditions, the altimeter data is noisy, and taking it's second derivative to determine the vehicle's acceleration profile was not feasible. Below are the plots of altitude and velocity versus time of the stratologger data and the model data.

Because a drag coefficient could not be determined from the course data set and the uncertainty if ADAS deployed as programed the python model was not used for post flight model fitting and rough Open Rocket estimates were used in its place.

The rocket ascended to an apogee of 5180 ft. exactly 100 ft. of the competition goal, but this result is neither meaningful nor informative due to the uncertainty if ADAS deployed, the numerous electronics failures, the abnormally high wind conditions, and the loss of sensor data.



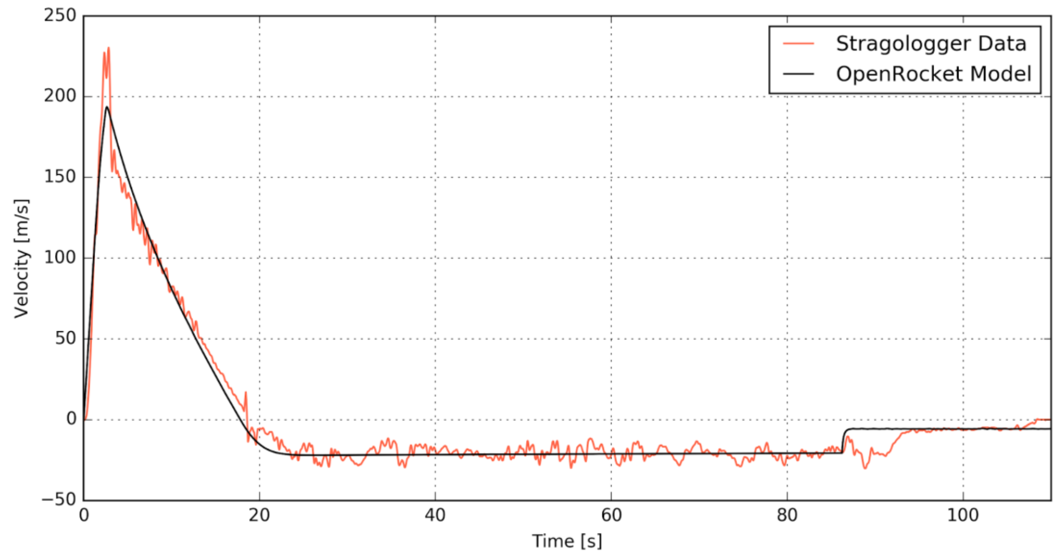


Figure 3.4.2.2.1 Altitude versus time plot of the model and full scale flight data

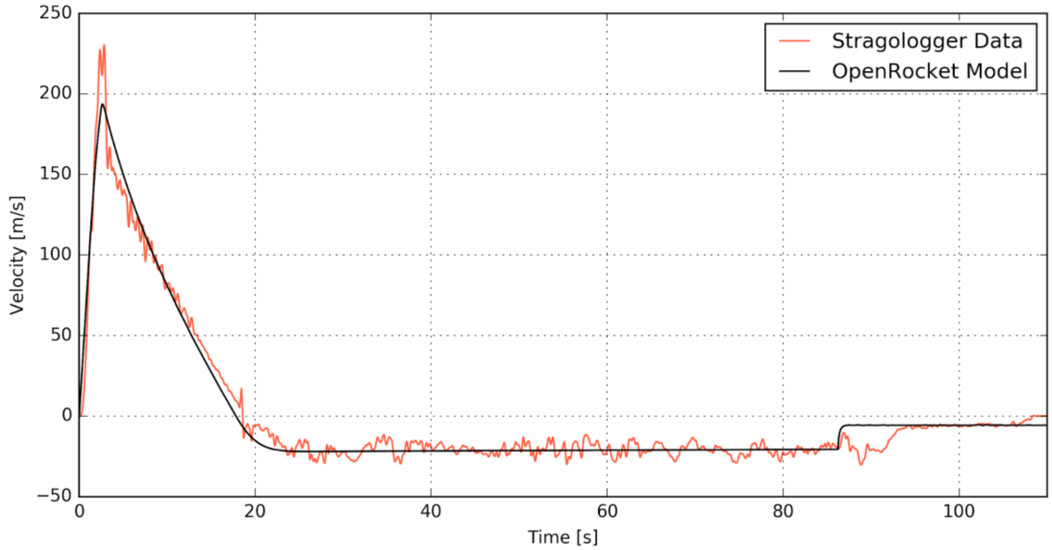


Figure 3.4.2.2.2 Velocity versus time plot of the model and full scale flight data

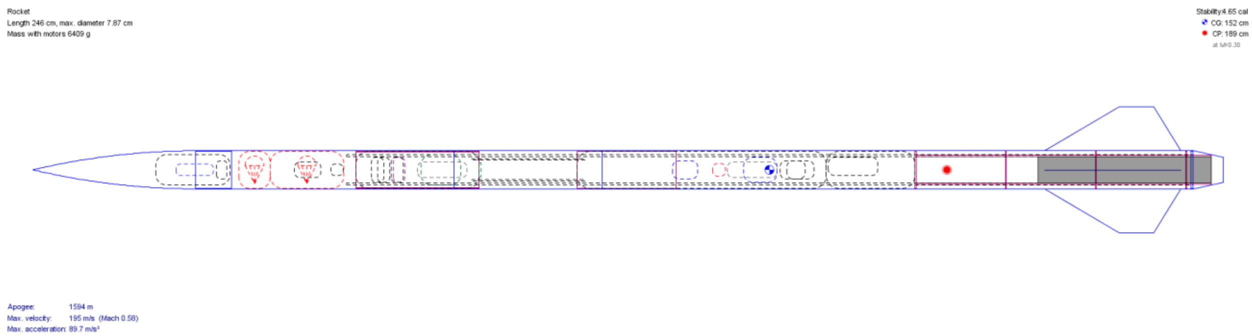
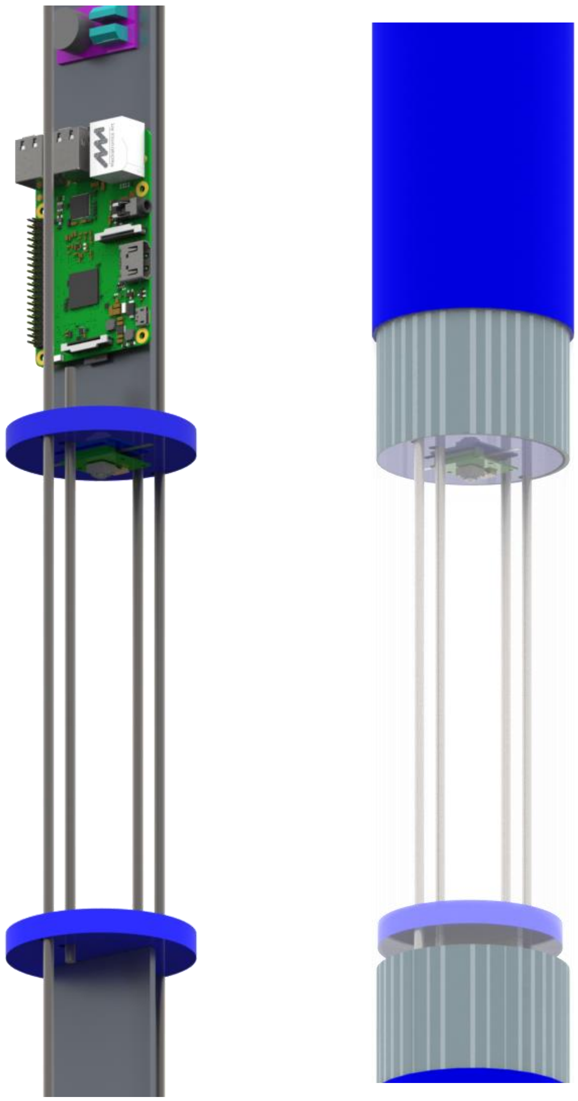


Figure 3.4.2.2.3 Open Rocket model of the rocket



4 Target Recognition System (TARS) Payload

Figure 4.1 view of TARS interior (left) TARS fully enclosed in the rocket (right)

The Target Recognition System (TARS) Payload is designed to meet the target detection payload challenge. It features a Raspberry Pi V2 camera facing downward into a clear window section. The footage from this camera is sent to a Raspberry Pi 3 computer housed directly above the window in the upper avionics bay. During the ascent of the rocket, TARS will be recording and analyzing the footage from the camera to correctly identify the three targets based on their color.

4.1 Changes Since the CDR

The TARS hardware and software has been modified to provide faster, more versatile image processing while being more intelligent about when and what to record. A new lithium-polymer (LiPo) battery and accelerometer help to power and interface with the TARS computer, and additional programming optimized in-flight recording and frames.

4.2 Unique Features

4.2.1 Structural

In order to minimize the amount of drag produced by the camera system, rather than having an exterior camera with a shroud, it was decided to house the camera within the rocket, requiring that a section of the airframe be made of clear material.

4.2.2 Electrical

The TARS is the circuit comprising the camera and computer system responsible for identifying and analyzing the ground targets designed for the SLI competition. It specifically uses a Raspberry Pi 3 board and a V2 camera to directly accomplish this task in real-time and saves the data to an SD card.

All wiring connections between components have been structurally reinforced through a combination of soldering and crimping wire leads throughout the TARS circuitry. The system is turned on externally via a screw switch.

Just as for the sub-scale vehicle design, the TARS has an indicator LED to detect its condition while on the launchpad as well as immediately post-flight during vehicle recovery. A summary of the different LED blinking modes of operation is given in Table 4.2.3.1 below.

An ADXL345 accelerometer module was added to the TARS circuitry for E-1 after the CDR. The relatively small and light board adds a way to determine launch and thus begin video recording, all while fitting conveniently and connecting to the Raspberry Pi 3 in a minimally invasive way.

Due to the amount of current needed to supply the TARS systems, it was determined that a different battery would be needed to satisfy the hour long launchpad maximum idle time yet also serve as a structurally secure power source while in flight. With the consideration of the current drawn by the Raspberry Pi 3 and ADXL345 (which draw about 200 mA while idle and almost 800 mA at full load), the 9-V Duracell battery (about 170 mAh at 0.5 A of discharge current) and USB battery pack (structurally insecure) options originally considered for the system have been replaced for a 7.4-V 1200mAh LiPo battery.

To operate the new battery and not damage the Raspberry Pi 3, a DC-DC buck converter board was added to step-down the voltage of the LiPo from 7.4-V to 5-V. The device, a LM2596 module, was mounted onto the avionics sled, mediating the connection between the battery and its switch to the TARS computer.

A full schematic and picture of the realized TARS design is given in the upcoming sections.

4.2.3 Software

Since we now have an ADXL345 onboard the Raspberry Pi 3, we are able to start the program and record exactly when the rocket launches. Our approach is different from the previous method where recording started as soon as the power switch was turned on. This way we do not take up precious storage. Our new process is accomplished through programming the Raspberry Pi 3 with a looping idle state on startup wherein the code constantly checks for a consistent magnitude of acceleration exceeding 3G’s in a short period of time. When the rocket detects launch via the accelerometer, it starts recording video frame by frame in a new loop. Those frames are saved as jpeg images in the file system of the Raspberry Pi 3. Simultaneously, another program running on three threads takes in those images from the buffer of frames and analyzes the images one by one. Those two programs are able to run in conjunction because of python multithreading which allows us to run multiple python scripts at the same time and to process the images and video much faster. When the camera stops recording, the final set of analyzed frames are combined to create a video. To ensure that we do not disrupt this process, we added a green LED and programmed additional light patterns to improve communication as to where in the program the Raspberry Pi 3 is running for on-ground diagnostics.

This table shows the different LED light patterns and what they mean:

Table 4.2.3.1 TARS LED Indications

LED Condition	**Description**
Steady, non-blinking	TARS Raspberry Pi 3 is armed and ready for take-off. Currently waiting for acceleration reading greater than 3G's from the accelerometer to start recording and processing.
~1 Hz blinking	Each time a frame is analyzed and saved to the video, the green LED changes from on to off or off to on.
0.33 Hz blinking	Indicates all recording, processing, and video saving have been completed and exited successfully.

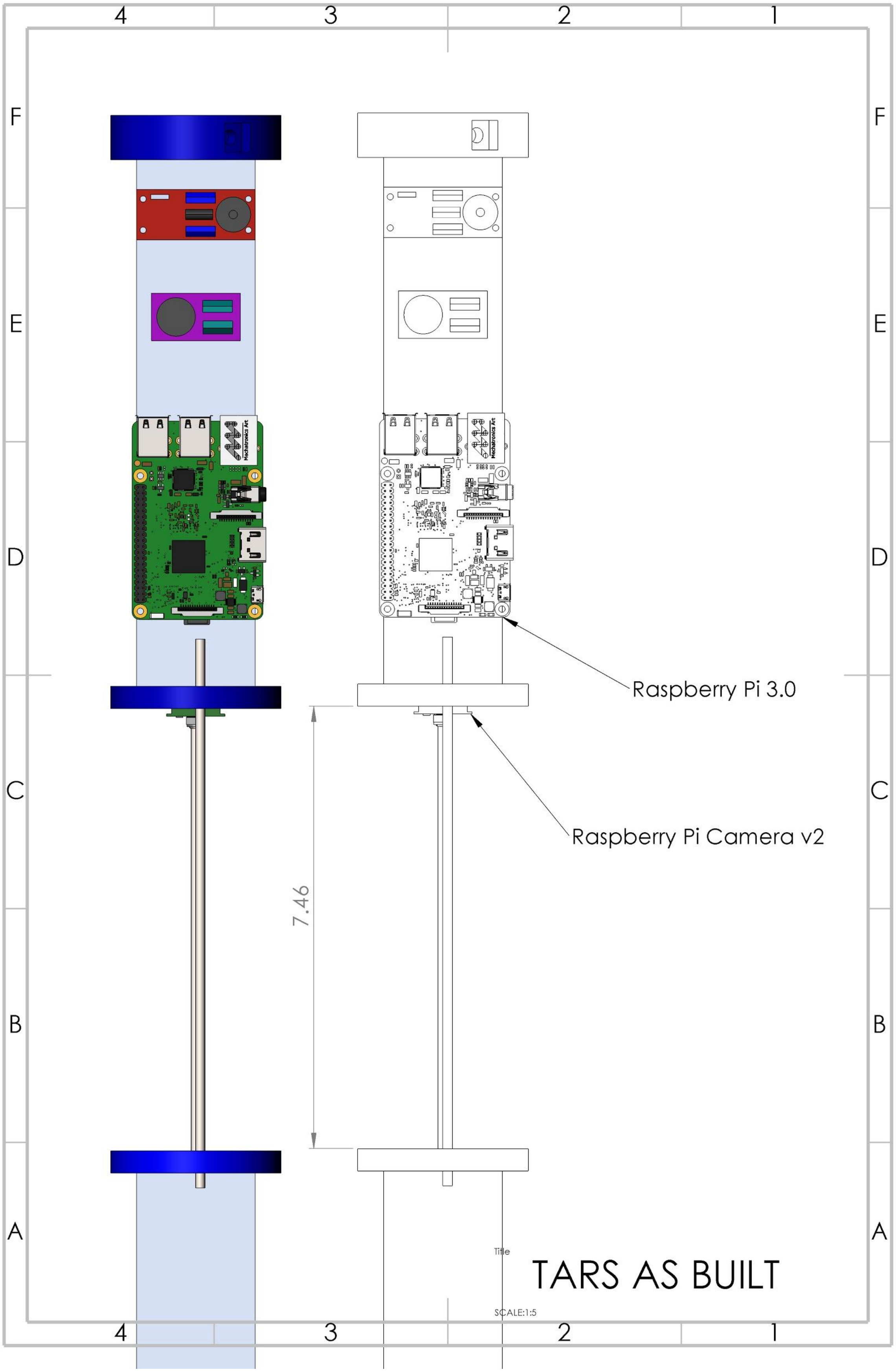
We also greatly changed and improved our image processing software to make it run real-time. It can now actively identify blue, pink, and yellow in multiple lightings. This is done by converting each frame to the HSV color space and setting a color threshold in HSV for each color. By doing this, the computer will search colors within the three color ranges for blue, pink, and yellow when processing each frame. When identified and larger than an area of 300 pixels, the targets are highlighted with a contour and labeled by its respective color. This is done by finding the area of the object. In order to cut down noise, a median blur filter is applied to each frame at the beginning of processing. This process occurs as the frames are being recorded.

We also made some small tweaks to our video settings. We changed the camera to record at 480p and 22 FPS. This is due to the code recording the frames not being able to run fast enough for 30 fps. This limitation is due to python being an interpreted language and the Raspberry Pi 3 not being fast in single threaded workloads. We obviously cannot multithread the actual script recording each frame.

An image from the current TARS algorithm:

4.2.4 Drawing AS BUILT

The following is a drawing of TARS as built. As shown the space between the bulkheads which window border the top and bottom of the window are slightly closer than designed, due to the additional length added to the avionics sled in order to align the ADAS drag fins with the slits cut into the airframe.



Raspberry Pi 3.0
Raspberry Pi Camera v2
7.46
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TARS AS BUILT
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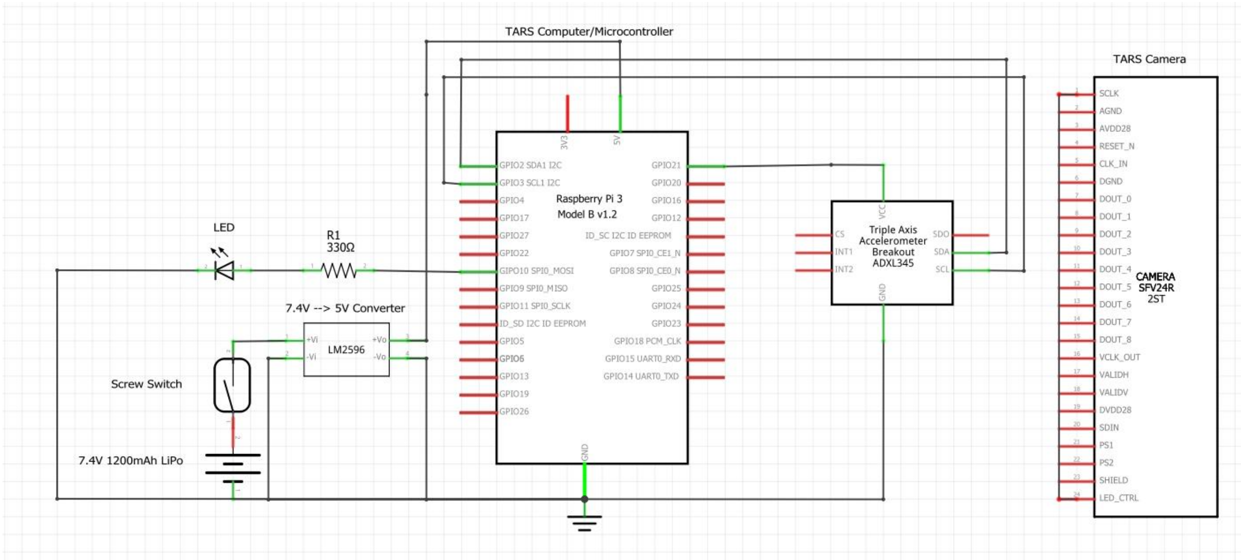
4.2.5 Schematics AS BUILT



4.3 Reliability

TARS is equipped with a battery to last approximately 4 hours and a thoroughly tested launch detection system to ensure that TARS only records data during the flight. The mounting of the primary computer for TARS proved unreliable in the full scale test flight, measures are being taken to address this.

4.4 Construction

The window section was the first portion of TARS which was build. The acrylic plastic clear section was bonded to

the upper and lower blue tube couplers with Devcon Plastic Welder.

Figure 4.4.1 Team members bonding the clear window section to the blue tube coupler

The upper avionics bay was then constructed once the two 3D printer bulkheads were manufactured and the aluminum plate which makes up the man structure of the avionics sled was cut to size. The bulkheads were then bonded to the aluminum plate using epoxy. Once the upper avionics sled was completed it was populated with electronics and tested on the workbench. After a series of trouble shooting, modifying the software and retesting, the TARS payload was completed in time for the full scale launch.

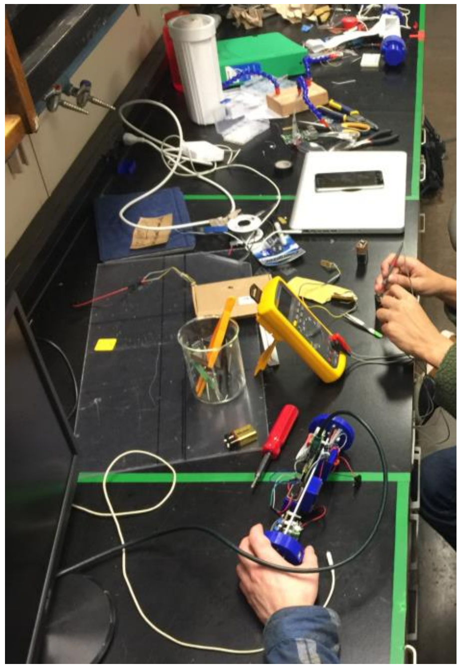
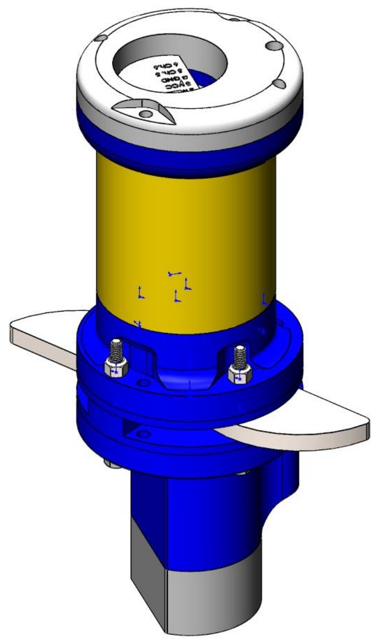


Figure 4.4.2 TARS being test on a workbench (left)

4.5 Differences in the constructed payload

During the first preliminary fit-check of the TARS, it was realized that the Raspberry Pi 3, raised by its nylon standoffs, now did not fit within its coupler housing. The solution reached by the team was to unsolder and remove one of the USB ports on the Raspberry Pi 3's circuit board which was causing the interference. These ports are not used by the TARS payload, and the process safely removed 2 out of the 4 USB ports available on the Raspberry Pi 3 without damaging any other features of the board or the TARS functionality.

5 Adaptive Aerobraking System (ADAS)



5.1 Changes Since the CDR

Since the CDR, a few design changes have been made. The structure which encompasses the ADAS electric motor is now made of a combination of 3D printer parts and PVC pipe. This alteration was made in order to reduce manufacture time.

New software was written for motor control and data recording. The new software includes a watchdog timer to retract ADAS in case of a critical software error as well as a beep code to indicate errors such as swapped motor polarity or a failed limit switch. The data recording software implements reliability improvements to the SD card write routine as well as features to enable faster sensor polling and data transfer.

Electronically, the system has undergone a few minor additions to its hardware, including a piezoelectric buzzer device and a power distribution board. The buzzing module emits different tones and sounds to indicate the status of the ADAS for diagnostics on the ground. Also, there is a 11.1-v LiPo battery replacing the original 9-V Duracell for powering the Arduino board and its circuits.

Since the air frame was fractured along the slits for ADAS during the full scale test launch, the system will be redesigned to fit within a coupler diameter to fit within the repaired airframe. This modification will only alter the overall diameter of the mechanism, not the mechanical or electrical workings.

5.2 Unique Features

5.2.1 Structural

The entire mechanism of ADAS is uniquely designed to fit within the narrow diameter of the rocket and extend through slits in the rocket's airframe. A majority of the components of ADAS are 3D printed. This new manufacturing technique allowed for greater design flexibility and unique geometries.

5.2.2 Electrical

The ADAS system is operated by an Arduino 101 controlling over other sensors and a DC electric motor, which is the device required to extend the fins. External sensors send real time data through an I^2C master-slave communication network, where the data is used by an algorithm within the Arduino to control a NeveRest40 brushed DC motor and the two deployable fins in real-time as the rocket is flown.

Sensors connected to the Arduino include a MPU-6050 IMU breakout, which measures gyroscopic and acceleration in three dimensions, a MS5607 altimeter, and a photoresistor acting as an optically-sensitive element. Natively, the Arduino 101 supports an on-board IMU within the main processor chip, a BMI160, which is also incorporated into the control loops. The photoresistor is technically part of an optical limiting switch circuit designed for the motor housing to determine the position in which the motor has returned to its retracted state. A small red laser LED is connected to a coin cell battery on the other side of the motor housing, thus enabling a photoresistor to give an analog change in resistance that is measured by the Arduino to safely stop supplying power to the motor so that the gears and fins are not damaged and jeopardize the flight.

In order to safely have the Arduino communicate to the NeveRest motor, a L298N H-bridge is connected as a medium with which to effectively drive the motor via the board's pulse width modulation (PWM) abilities. H-bridges are designed to prevent back currents from the motor from penetrating the Arduino, and in the case for the team, this board can be used such that power from one large 11.1-V 2000+mAh LiPo battery can provide enough power to the entire lower avionics bay. The motor's encoder can directly interact with the Arduino, and is used to gauge how much the fins have deployed based on the number of pulses sent from the encoder. These pulses relate the angular position of the motor since it is counting optical light pulses from within the motor's housing. By taking count of these pulses constantly, the Arduino can derive the position of the fins as a percentage of maximum allowable deployment.

A power electronics distribution board was created for the ADAS components so as to have a common area of digital voltages, most notably it is designed with three power rails, one for 5-V, 3.3-V and ground or 0-V. The board also contains an LED and resistor series combination on the 3.3-V and 5-V rails. These LEDs can determine if the Arduino is drawing too much power because when they begin to flash, it means the Arduino is restarting its systems as a response to overloading.

5.2.3 Software

The ADAS control and data recording software are designed to be fast and reliable. The motor control software consists of an interrupt routine, ADASpulse, that catches the encoder pulses; a function which updates the ADAS state based on the target position (move ADAS forward, reverse, or stop); and a function which moves the ADAS motor in the requested direction. The motor control software monitors the limit switch using an interrupt and this prevents ADAS from retracting the fins further than their fully closed position. The motor control software also implements a soft start system which ramps up the motor speed when the motor is starting, stopping, as well as changing direction. This limits the forces on the rocket due to motor accelerations.

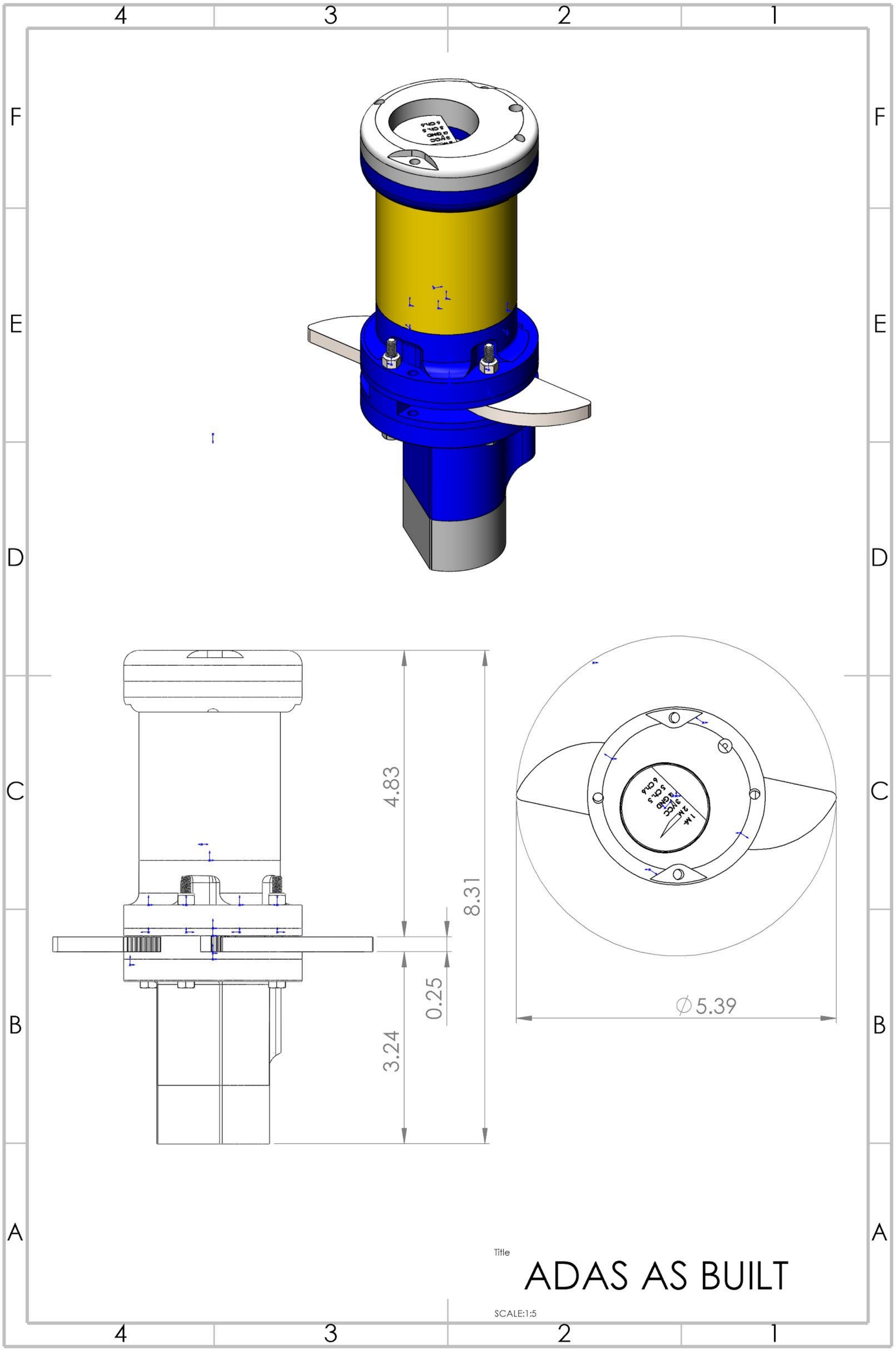
The data recording software implements interrupt-based launch detection via the digital motion processor in the

Arduino 101 Curie IMU. The sensors are polled and a data frame is constructed from all sensor data. Ten data frames are collected contiguously. The accelerometer data is also filtered using the Madgwick sensor fusion algorithm to produce rocket orientation data. To prevent SD card corruption, interrupts are disabled while the data is written.

The deployment of ADAS is controlled by a PID loop. The PID algorithm compares the velocity profile of the rocket to a constructed model and takes the difference between the rocket's current velocity and the model's velocity in addition to the rate of change of this difference in order to determine the degree to which the aerobraking fins should be deployed. This value is then passed to the motor control code and physically executed by the rocket.

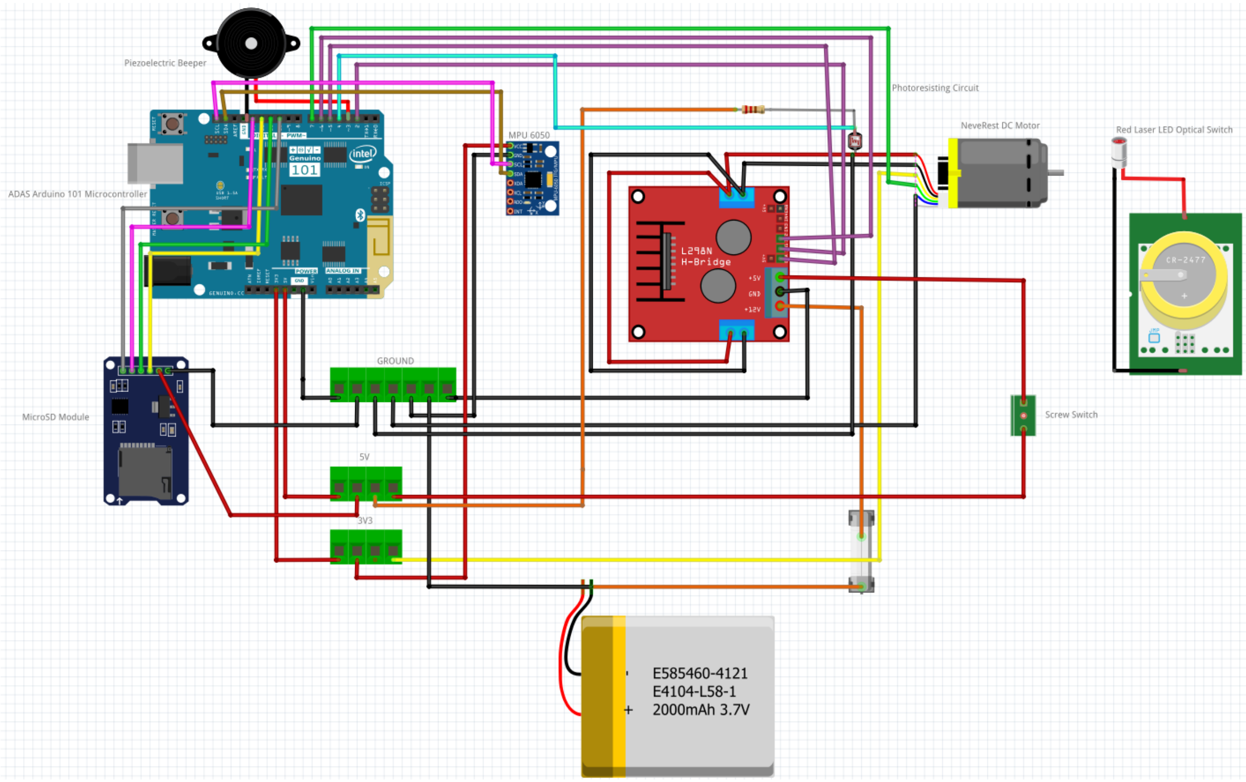
5.2.4 Drawing AS BUILT

The following is a drawing of ADAS as built. Note the additional segment added to the base to align the fins with the slits cut into the airframe.



4.83
8.31
0.25
3.24
Ø5.39
Title
ADAS AS BUILT
SCALE:1:5

5.2.5 Schematics AS BUILT



5.3 Reliability

The full scale launch revealed to the team that the ADAS system needs a greater redundancy and robustness to ensure proper operations. From the available data and an initial inspection, it appears that the ADAS SD card became dislodged during assembly and only recorded data for approximately 12 seconds. Plans have been made to include a redundant SD card and improve the securement of the card into place.

5.4 Construction

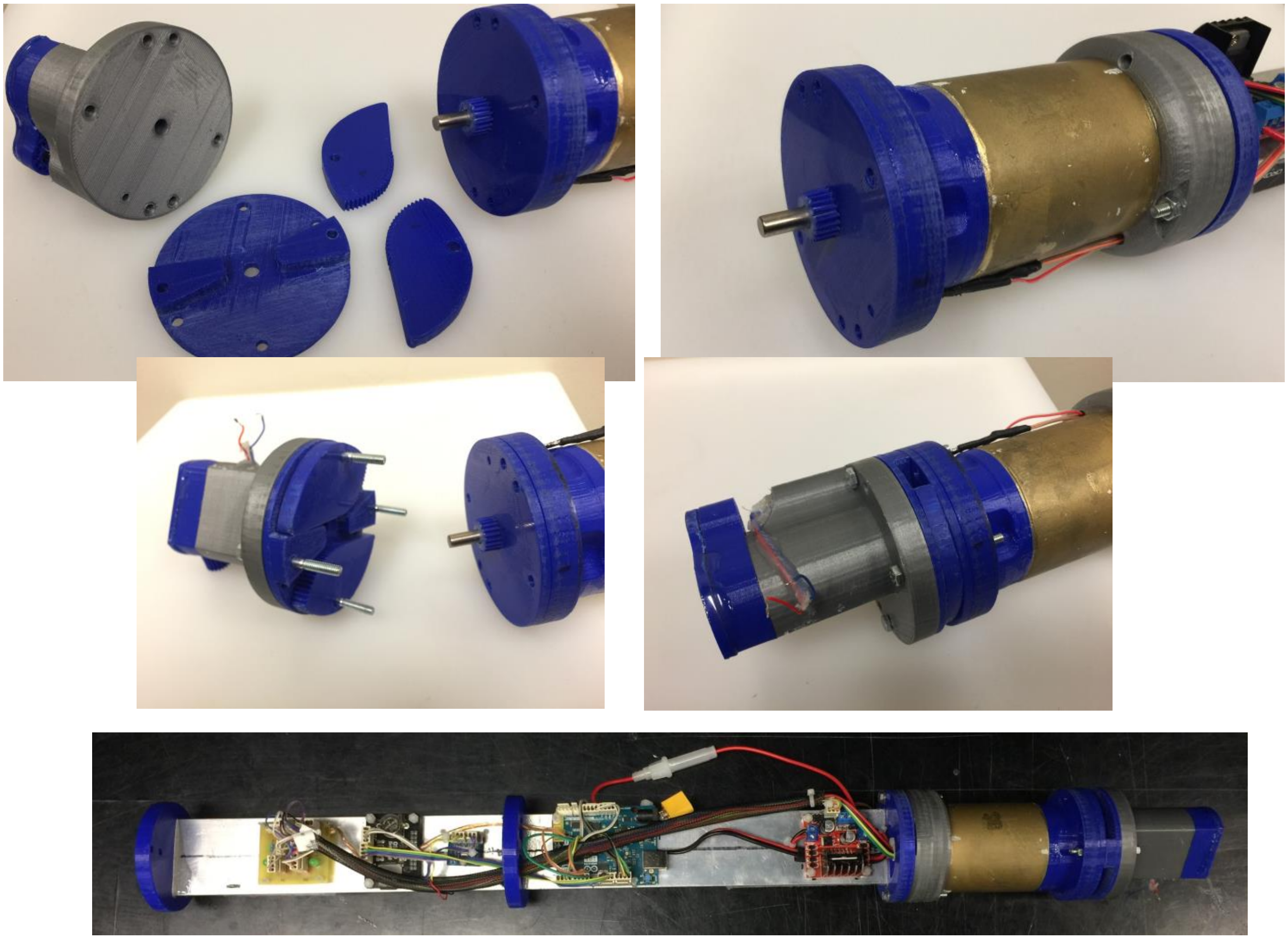


Figure 5.4.1 ADAS components and full assembly

5.5 Differences in the constructed payload

As the rocket's design mass required ballast, it was decided that rather carry dead weight, the batteries for the electrical systems would be improved. The new Lipo battery added 128 grams to the overall mass of the rocket.

6 Safety

6.1 Personnel Hazard Analysis

Hazard	**Cause**	**Effect**	**Likelihood and**	**Mitigation**	**Verification**

			Severity (RAC)		
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 (CATO)	Damage to motor or improper motor assembly	High-velocity shrapnel and debris injuring team and spectators.	3E	The team will follow the NAR Code when conducting all launches including the minimum distance guidelines in Appendix B. NOTE: The NAR minimum distances will be used,	Motor assembly procedures in section 4.1.2 help prevent a CATO.

				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.	
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.

6.2 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

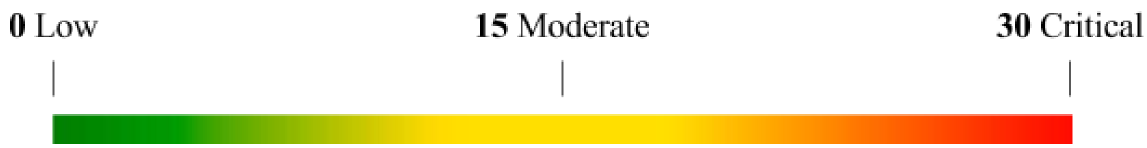
Each phase of flight has its own table of failure modes, sources of that failure, effects that the failure is predicted to have in addition the likelihood, severity, and preventability of that failure rated on a scale from 1 to 10. The likelihood, severity, and preventability ranking system is clarified 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	Design stress analysis and physical tests shall be performed to verify the security of the rail buttons' attachment to the rocket.

									launch	
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.	The team's experienced mentor shall inspect the fin connections to ensure proper attachment.

Drogue Deployment FMEA

Source	Failure Mode	Hazard	Cause	Effect	L	S	P	R	Mitigation	Verification
StratoLogger CF Altimeter	Primary drogue altimeter failure only	-None- (Redundant system)	Improper wiring or manufacture r 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	Rocket segments	Insufficient design	The rocket will separate	2	4	2	8	Stress simulations were performed to verify that	A checklist item is included to verify that the U Bolts are properly mounted and

	from rocket	falling at higher then planned velocities		into unplanned segments.					the design of the rocket was sufficient to handle the yank of parachute deployment	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	Insufficient design	The rocket will separate	2	4	2	8	Stress simulations were performed to verify that the design of the rocket was	A checklist item is included to verify that the U Bolts are properly mount and bonded into place with locktight.

		higher then planned velocities		into unplanned segments.					sufficient to handle the yank of parachute 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.	Segments of the rocket will be recovered separately	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.

6.3 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 precipitation	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.

7 Launch Operations Procedures

7.1 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*****

7.2 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)

7.3 Avionics Bay Integration

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

- ❏ Ensure that all avionics boards and batteries are firmly mounted in place

- ❏ 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
- ❏ 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*****

7.4 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.

7.5 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*****

7.6 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

7.7 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.

7.8 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.

8 Project Plan

8.1 Testing

Test Name	Completed on	Expected Result	Actual Result	Success/Unsuccessful
Blue Tube Coupler/Window Crush Test	2/24/18	The blue tube coupler, window section and the bond between them will withstand the load.	The blue tube coupler, window section would and the bond between them withstood the load.	Success

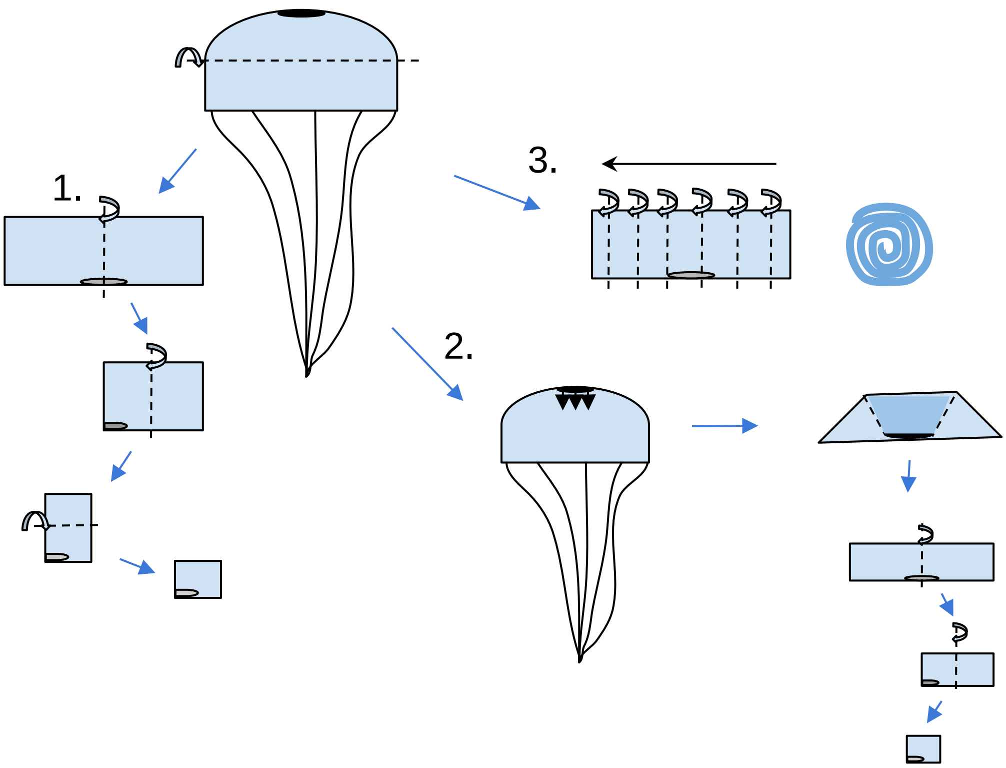
Methodology: In order to simulate the maximum load that the vehicle could experience, two masses (of 60 kg (132 lb) each) yielding a 1176 N (264.37 lbf) load to simulate the 852 N (246.55 lbf) force (calculated in 3.1.2.1) were placed on top of the test article. A secondary window section and coupler, identical to the ones used on the full scale rocket were bonded using the devcon plastic welder in the same method used on the full scale rocket. Then in teams of two, observing the proper safety precautions, the test masses were loaded onto a platform supported by the test piece. Once the article was found to withstand the load, the masses were removed slowly, again in teams of two, observing proper safety procedures. (Crush test pictured left).
Results: The test article proved to handle the load and was found to be undamaged and without any noticeable deformations.
Differences in predicted outcome: None

Test Name	Completed on	Expected Result	Actual Result	Success/Unsuccessful
Slotted Blue Tube Crush Test	2/24/18	The Blue Tube was expect to withstand the axial load	The Blue Tube withstood the axial load	Success

Methodology: The possibility of the slotting of the Blue Tube undermining the structural integrity of the airframe was under investigation in this test. Spare airframe material was slotted identically to the slots in the full scale rocket. In order to simulate the maximum load that the vehicle could experience, two masses (of 60 kg (132 lb) each) yielding a 1176 N (264.37 lbf) load to simulate the 852 N (246.55 lbf) force (calculated in 3.1.2.1) were placed on top of the test article. (The test article is pictured left)
Results: The test piece did not buckle under the load and thus, fully withstood the load without deformation.
Lessons: While cutting the Blue Tube it was observed to be a plastic-like material in addition to being fibrous, thus cuts in it don't undermine the material's structural integrity as much as say cutting fibers in a carbon fiber cloth would.
Differences in predicted outcome: None

Test Name	Completed on	Expected Result	Actual Result	Success/Unsuccessful
Main parachute deployment test	1/29/18	It was expected that the traditional full-length triangle folding scheme would be most effective at quickly deploying the parachute.	The best technique found was folding along the center of the toroidal shape rather than over the full length of the chute. This technique allowed the parachute to deploy in less than 20 feet of descent	Success

Methodology: Different folding methods were tested to find the shortest possible unfurl timescale for the main chute. Deployment reliability was also tested to ensure that tangling effects were minimized. Three methods were tested: a full-length fold, a full-length fold with a spiral, and a half-length fold. The fold length is characterized by the vertical extent of the parachute before its horizontal folds are made.



Test Name	Completed on	Expected Result	Actual Result	Success/Unsuccessful
GPS Egg hunt test	2/10/18	Sub-meter precision on the GPS location	GPS precision was highly dependent on surroundings. Buildings at close proximity limited precision to ~10 m. Open field tests yielded precision of < 1 m	Success

8.2 Requirement Compliance

8.2.1 Handbook Requirements

8.2.1.1 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	In the days leading to the submission of a major document the team discusses

documents to the website prior to their due dates	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

8.2.1.2 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	The vehicle is planned to carry two such altimeters, the Stratologger CF and

commercially available barometric altimeter for apogee judging	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	The design of the rocket was done with this in mind. Verification of this

external circuitry or special ground equipment to launch	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-	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.

flights; not first-time flights	
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.

8.2.1.3 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 launch vehicle, will also carry an active electronic tracking device.	The rocket design consists of two sections, tethered to one another. This can be verified through the rocket schematics.
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	Extensive ground testing has been done on the subscale to verify that this is the case; testing will continue on the full scale rocket.

adversely affect the proper operation of the recovery system electronics.	

8.2.1.4 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	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

will be within 600 ft. of the launch pads.	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.

8.2.1.5 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	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

recovery activities	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.

8.2.2 Team Requirements

8.2.2.1 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.

8.2.2.2 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.

8.2.2.3 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.

8.2.2.4 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.

8.2.2.5 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.

8.3 Budget and Timeline

8.3.1 E-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**

8.3.2 Team Operations Budget

The team's operational costs are primarily for travel and the cost of motors.

Event	**Travel Cost**
Subscale motor	80
First subscale launch attempt	230
Subscale launch	130
Full scale motors (2)	270
First full scale launch attempt	130
Full scale launch (travel to San Diego)	480
Total:	1320

The team has also selected to appropriate some funds to subsidize team jackets

Jacket subsidy	310

8.3.3 Total Budget

Item	**Cost**
Sub scale rocket	1622
Effective 1 rocket	1816
Team operations	1630
Total	5068

8.3.4 Funding

The team acquired a number of funding sources

Source	**Amount**
Gene Haas Foundation	2000
GoFundMe	1550
UCSC Giving Day	3660
Total	7210

The remaining funds will be distributed to team members with financial difficulty to off set travel expenses for the competition in Alabama and any remaining funds will then set aside for next year.

8.3.5 Remaining Timeline

Due to the failures of the full scale launch and pending permission for a reflight, the team has until March 28th to complete another flight of the E-1 rocket. The only launch window available at the local range is on March 10th, and targeting this date, the team has a week to make the necessary repairs to refly the rocket. As a backup, there is a launch hosted by Tripoli Central California on March 17th which the team could attend.