RedShift

Team 111 Project Technical Report for the 2018 IREC

Ruqayya Toorawa[1] and Thomas White.[2]
Stanford University, Stanford, CA, 94305

Gabe Alvarez[3], William Alvero-Koski[4], Julea Chin[5], Chloe Glikbarg[6], Ben Goldstein[7], Tylor Jilk[8], Seth Liyanage[9], Jacob Meisel[10], Max Newport[11], Matthew Pauly[12], Sharon Platt[13], Daniel Shorr[14], Rayan Sud[15], Tori Thompson[16], Skye Vandeleest[17], Tim Vrakas[18], Winnie Xiao[19]
Stanford University, Stanford, CA, 94305

The Stanford Student Space Initiative (SSI) Rockets Team strives to build expertise in all aspects of rocketry with the ultimate goal of a launch to the 100km Karman Line. By teaching a new generation of students and furthering SSI's technical experience, the 2018 IREC entry accomplishes both of these goals. The rocket, RedShift, is 10.6 ft tall and 4 inches in diameter, and is aiming for a 30,000ft apogee using an N2900 commercial off the shelf solid motor. It also carries a significant advancement in custom radio technology within the avionics bay, a validated serial deployment recovery system, and a novel GPS experiment as a payload. In addition, although ultimately not included in the final rocket, the project developed a highly tested mechanical decoupling system for use next year, and automated the composite winding process, both of which will enable future projects by Stanford Rocketry.

[1] Co-Lead , Mechanical Engineering ('18), 531 Lasuen Mall, Stanford CA 94305
[2] Co-Lead, Aero/Astro ('20), 531 Lasuen Mall, Stanford CA 94305
[3] Member, Engineering Physics ('21), 531 Lasuen Mall, Stanford CA 94305
[4] Member, Mechanical Engineering ('19), 531 Lasuen Mall, Stanford CA 94305
[5] Member, Mechanical Engineering ('19), 531 Lasuen Mall, Stanford CA 94305
[6] Recovery Co-Lead, Electrical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[7] Structures Co-Lead, Engineering Physics ('19), 531 Lasuen Mall, Stanford CA 94305
[8] Launch Ops Lead, Engineering Physics ('19), 531 Lasuen Mall, Stanford CA 94305
[9] Member, Mechancial Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[10] Member, Electrical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[11] Staging Lead, Engineering Physics ('21), 531 Lasuen Mall, Stanford CA 94305
[12] Payload Lead, Electrical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[13] Avionics Co-Lead, Engineering Physics ('19), 531 Lasuen Mall, Stanford CA 94305
[14] Recovery Co-Lead, Philosophy ('21), 531 Lasuen Mall, Stanford CA 94305
[15] Member, Aero/Astro ('21), 531 Lasuen Mall, Stanford CA 94305
[16] Structures Co-Lead, Mechanical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[17] Recovery Co-Lead, Chemical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[18] Avionics Co-Lead, Electrical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305
[19] Member, Electrical Engineering ('21), 531 Lasuen Mall, Stanford CA 94305

I. Introduction

The Stanford Student Space Initiative (SSI) is a student organization founded in February 2013 with the mission of giving future leaders of the space industry the hands-on experience and broader insight they need to realize the next era of space development. The SSI Rockets Team is advised by Professor Hai Wang, Rockets Faculty Advisor and a Stanford Mechanical Engineering Professor; Professor Marco Pavone, a Stanford Aero/Astro Professor and James Dougherty, a rocketry expert with the Tripoli Rocketry Association. The team is led by Ruqayya Toorawa ('18) and Thomas White ('20), who are responsible for both administrative and systems engineering tasks. They interface with the Stanford administration and IREC officials, and are responsible for team management, general rocket health, proper systems integration, and risk mitigation. Tylor Jilk ('19) is the launch operator; he is responsible for launch logistics and launch operations. The team is split into five sub teams: payload, avionics, structures, staging, recovery, and launch ops.

Team management strategies take into account the fact that the students are volunteering their time and effort. The team uses self-made schedules with clear milestones to track progress on a week to week basis using Asana (a productivity and team management tool). All experimental work, meeting agendas and outcomes, and large design decisions are documented. Within these schedules we emphasized testing, documentation, and presentation practices that are common in industry and have become a part of SSI's culture. This attention to industry processes meant we gave both a PDR as well as a CDR for our project to professionals in industry, current members of the amateur rocketry world, professors, and past IREC team advisors as well as consulting with professionals on ways to test some of our custom components.

II. Systems Architure Overview

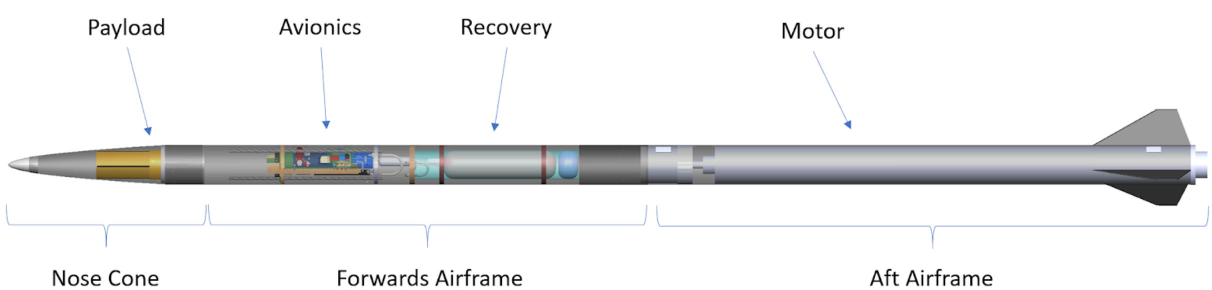


Figure 1. CAD of the fully integrated rocket

The rocket consists of three sections: nose cone, forward airframe, and aft airframe. Nosecone, forwards, and aft sections of the airframe are made of COTS fiberglass to ensure radio transparency, and the SRAD fins are made of carbon fiber for increased strength. The nose cone has an aluminum tip to protect against Mach heating and contains the payload assembly. The nose cone is bolted into the forward airframe and contains entirely SRAD components: the Avionics bay, parachute deployer, and main and drogue parachutes. The entire avionics and recovery systems are attached together via fiberglass rods and bolted into the airframe at a single bulkhead at the recovery hardpoint. The forward and aft sections are integrated using a 12in coupler with shear pins on the forward side and bolts on the aft side. The aft airframe contains the recovery backup deployer, the steel ballast mass, the SRAD motor retainer which also serves as the aft hardpoint, and the motor. Two 10-10 rail buttons are bolted into the aft section of the airframe. Spaces for competition-mandated tracking devices are provided above the payload and below the recovery backup deployer.

A. Propulsion

The final motor choice for the rocket was the N2900 by Cesaroni Technology. The N2900 is a reloadable 6-XL grain, 98mm diameter solid motor with average thrust of 2867.5 N, max thrust of 4164.5 N, total impulse of 17613.7 N-s and a 6.14 second burn time. With the N2900, the rocket is simulated to reach approximately 30,000ft with 73 lbs of loaded weight and worst case weather conditions. This gives us an additional 27% mass buffer from our predicted mass of 58lbs. The design decisions that informed this final choice are described below.

1. Simulations

We employed OpenRocket and RasAero for our trajectory analyses. OpenRocket was used to model precise layout, mass, and CG, but is less accurate with aerodynamics at supersonic speeds. Therefore, we used RasAero to model flight trajectory based on model input from OpenRocket and given flight conditions (altitude, weather, launch angle, launch rail length, etc.).

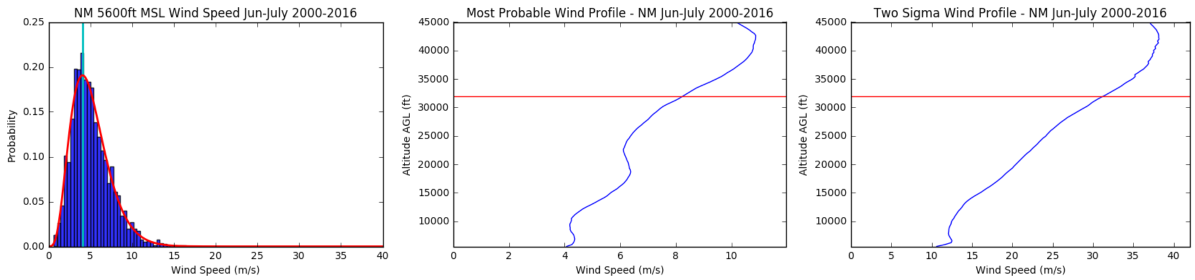


Figure 2. New Mexico Wind Profile in June

There were three main uncertainties that we attempted to account for in our simulations: mass, length, and weather. While we had an initial mass estimate based on CAD designs, most aerospace projects end up being 1.2-1.4 times heavier than initial estimates[20]. For this reason, we adopted a system of mass contingency and margin. We calculated "worst-case" maximum expected mass values to account for expected growth. We then used simulations to find the maximum possible mass that would still allow us to get us to 30,000 feet with the worst expected surface finish and weather conditions (44 mph wind, 75°F). Our design requirement was that the margin be at least 10% of the current mass estimate, guaranteeing that we could account for unforeseeable growth even with the worst possible scenario. One of those scenarios was a final mass considerably under our contingency/margin, and so we allocated space in the rocket for up to 15lbs of steel ballast. Using this system, we narrowed down our motor options to the N2900, as described below.

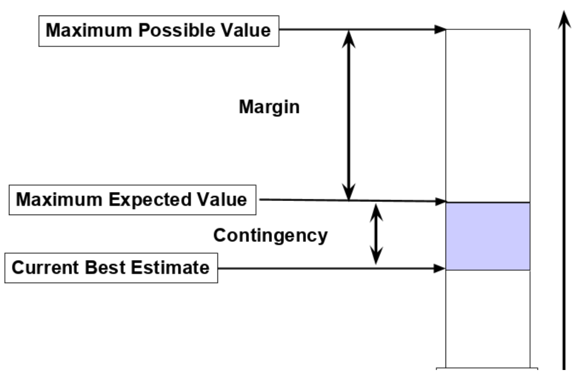


Figure 3 Description of Margin and Contingency System

2. Design Decisions

Given the constraint of using a solid COTS motor, our main choice was deciding which motor would get us to 30,000 ft with a reasonable margin. The first option we looked into was designing a two-stage boosted dart rocket that used drag separation to achieve a higher altitude using a smaller motor for the first stage. However, after mapping out the design and weight, we realized that the competition requirements would not allow us to optimize for a boosted dark system. Instead, we opted to pursue a single stage rocket with mechanical separation. We had two classes of motors to choose from: O and N. In order to limit weight and cost of our airframe, we limited our search to 98mm minimum diameter motors. Next, we ran a range of simulations to determine which motor would guarantee that we hit 30,000 ft in the case that our rocket was heavier than predicted, but also would also not require us to add more than 15lbs of ballast in the case that our estimates were accurate. From the initial list, we found that the N2900 and the N2540 met our criteria the best. . From our simulation results below, we found that the N2900 gave us both a higher max altitude and larger mass margin (under ideal conditions) for the same cost.

Motor	Impulse (N-s)	Max Altitude (ft)	Thrust to Weight	Mass Margin (% of initial)	Cost per reload
N2540	17907	36999	9.4	21	$850
N2900	17613	40635	10.7	35	$850

Figure 4. Motor Selection Matrix

20 NASA; Margins and Contingency Module: Space Systems Engineering, version 1.0

After finalizing motor choice, we began simulating the flight profile for our current rocket design. The flight profile for final mass with ballast and expected weather conditions (at time of documentation) is pictured below.

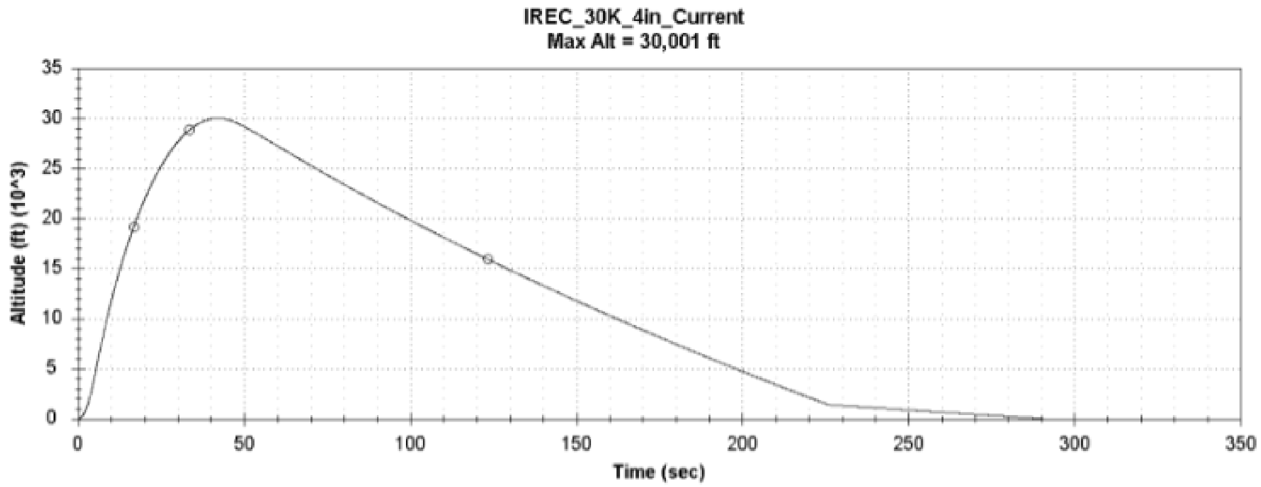


Figure 5. Flight Profile

3. Testing

While simulations were a good place to start for propulsion, we also needed to do several test launches to slowly increase motor size and improve simulation accuracy by comparing to flight data. We started with a subsonic test with basic subsystems to prove recovery system functionality using a K1620 to ~5kft. For the second test launch, the improved subsystem configurations were tested in flight using an L400. For the final test, we used a M2500 to do a supersonic test flight of all of our systems in the final configuration.

B. Aero-Structures

Structures is responsible for curating and assembling the airframe and all of its supporting parts, including the launch buttons, motor retention system, and fins. Although significant progress was made in fabrication of an SRAD airframe, a reliability assessment left the final flight configuration as COTS. The fins are laid up by hand using prepreg sheets of carbon fiber, and then secured on the rocket by epoxy and tip-to-tip layers of fiberglass. The motor is retained by a threaded rod terminating in a machined aluminum hardpoint, and a close friction fit with the airframe. It connects to the launch rail with 1010 buttons.

1. Design Decisions

Our airframe was chosen as entirely fiberglass because the process of creating radio-transparent sections for the avionics, payload, and two competition-mandated electronics packages was deemed overly complicated and not enough to compensate for the slightly higher strength of carbon fiber. Significant research and development work was put into the development of custom airframes, including the purchase of a desktop filament winder, and the process was validated with several test airframes. However, some integration issues remained prior to the last test launch, centering around the surface finish of the airframes - it was not clear that they would be able to fit snugly enough to prevent bending moments, or integrate all of the interior bulkheads comfortably. Given the tight schedule, and the necessity of flying the competition configuration on the final test launch, so as to gain useful simulations data, the decision was made to use commercial airframes at IREC.

Our fin shape was optimized for Mach flight. After careful accounting for boundary layer effects in a variety of simulations, and altering the fins after test flights, we have arrived at a shape to assure stability and minimize drag.

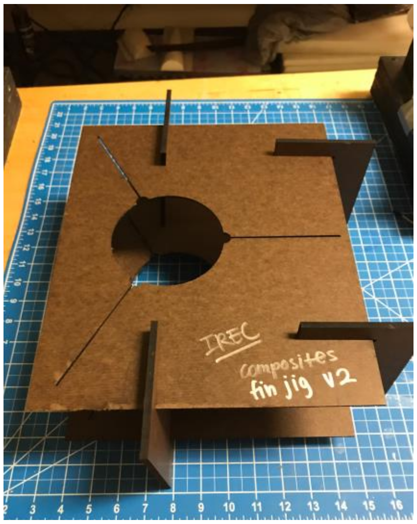


Figure 6. Fin jig

Our fins were made of carbon fiber to maximize strength and minimize weight, especially since our minimum diameter motor prevented through-wall fins. They were hand laid-up in a 0, -45, 45, 0, 90 | 90, 0, 45, -45, 0 degree pattern, and then secured in place with a tip-to-tip layup consisting of six layers of fiberglass and an epoxy fillet. The tip-to-tip was chosen for ease of use and because it conformed to the required shape more easily than carbon fiber. The fin thickness, 0.125", was determined using fin flutter analysis assuming the weakest fiberglass shear modulus and a factor of safety of 2. Several revisions of fin jigs were made to assure correct alignment.

Our coupler was primarily designed to minimize airframe bending. For our first test launch, we used a 6" phenolic coupler. It was too small and did not fit well in the airframe, so it was wrapped in layers of tape to provide a proper friction fit. However, due to the compressibility of the tape, the shortness of the coupler, and relative lack of strength of phenolic, the rocket experienced significant bending. In response, we both increased the length of the coupler to 12", the longest COTS length available, and switched to fiberglass. Thanks to the close tolerance between the COTS airframe and coupler, as well as the strength of the longer component, the bending problem was satisfactorily resolved.

In the first iteration we used rail guides to hold the rocket to the rail, but they had experienced issues scratching the rail as well as, in one case, falling off the rocket when it was under too much horizontal stress. To prevent these cases and increase our capacity to make launch site repairs if necessary, we moved to through-wall rail buttons of the standard 1010 size.

2. Techincal Specifications

Due to the constraints of our minimum diameter system, the long and thin recovery, which was designed to accommodate the decoupling project, and our need to leave space for the competition-mandated electronics, our rocket is comparatively long and thin: our forward airframe is 49" long, and our aft is 63".

Our fins have a root chord length of 10.5", a tip chord of 3.75", a height of 3", a sweep length of 5.55", and a sweep angle of 61.6 degrees. We laid them up by hand from carbon fiber using a stencil according to the following layer specifications: 0, -45, 45, 0, 90 | 90, 0, 45, -45, and 0 degrees. This combination gives us acceptable strength in all directions while simultaneously keeping the fin weight to a minimum.

Figure 7. Aluminum Motor Retainer and U-bolt

The motor retainer was machined out of solid aluminum, which can bear 88,000 psi of compressive force. It was lathed to the inner diameter of the airframe, and cut to a length of 2.5 inches. The center of the motor retainer was drilled and tapped with a ⅜ 16 tap to allow for the connection of a steel threaded rod to connect to the forward motor assembly and allow for fine linear location adjustments of the motor casing assembly.

Our payload bay is bolted through the nose cone coupler to the airframe. The avionics and recovery are secured by a bolted delrund bulkhead, and aligned by two unsecured PLA bulkheads on the avionics and one polycarbonate alignment ring on the recovery. The coupler is bolted into the aft airframe and held into the forwards by two nylon shear screws.

3. Testing

Our initial attempts to make an airframe were hand layups using pre-impregnated sheets of fiberglass. However, these test pieces had an unusably rough surface finish with large ridges running up and down the length of the airframe, and because of the extra layers required from fiberglass, took an impractical amount of manual labor to produce. Making matters worse, the rough surface made the sections very difficult to remove from the mandrels. Rather than try to make a better hand layup, we made the decision to purchase a small two axis filament winder.

The XWinder was put through a rigorous test program in the subsequent months, during which two primary issues were resolved: repeated software failures and difficulty removing the airframe from the mandrel. The first required some modifications to the winder to account for; the second proved particularly pernicious. Our 5” test layups slide off easily, but longer 10” airframes began to fail. Switching to a metal mandrel helped, but did not resolve the issue, and we had difficulty sourcing a metal mandrel of sufficient size. Our final attempt was to wind an airframe around a mandrel with the same inner diameter as our rocket, and then allow the epoxy to bond the fiberglass permanently to the mandrel. This approach promised to produce a very precise interior diameter, with applications to better motor retention and coupler stiffness. However, this method could not be fully validated in time, with only a forwards airframe produced. Had there been more time, we would have resolved the new integration challenges this presented and been able to test that the phenolic ID would have the same resistance to swaying as the fully fiberglass COTS airframe. However, in order to assure a final flight in full configuration we moved to our back up commercial airframe with COTS fins instead. All of our airframes also withstood a program of shock testing, starting with bending testing and ending with test launches under Mach conditions, to assure structural stability. All tests were passed with comfortable safety margin.

Figure 8. X-Winder Setup

Figure 9. Bad quality surface finish of first layup

C. Recovery

The recovery system consists of the serial deployment of a SRAD drogue and SRAD main parachute. The assembly was designed to ensure ejection of the parachutes by limiting the amount of pressurization volume using a recovery tube. The recovery tube also allows for a quicker, more efficient integration into the rocket and guaranteed ematches were neatly routed. Separation of the rocket body is triggered by both a COTS CO2 deployment system, and a black powder charge (3 grams) using shear pins to separate the forward and aft airframes. After the rocket separates, the drogue needs to be ejected from within the sealed recovery tube. The primary method for drogue deployment is a CO2 deployment system in which a small amount of black powder triggers the release of high-pressure CO2 into the recovery tube, thereby ejecting the end cap and allowing the drogue to exit the airframe.. A larger black powder charge (1 gram) is ignited afterwards as a backup drogue ejection mechanism. Main chute deployment is controlled by a COTS Recovery Tether system in which a small amount of black powder triggers the release of a retention shock cord at 1500 ft. We use a main parachute in conjunction with a drogue parachute in order to reach the target descent speed (main) while minimizing descent drift (drogue). The motivations for different aspects of this system are detailed below, along with technical specifications.

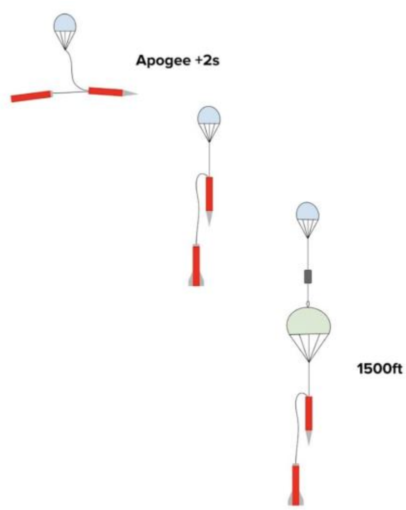


Figure 11. Decent Conops

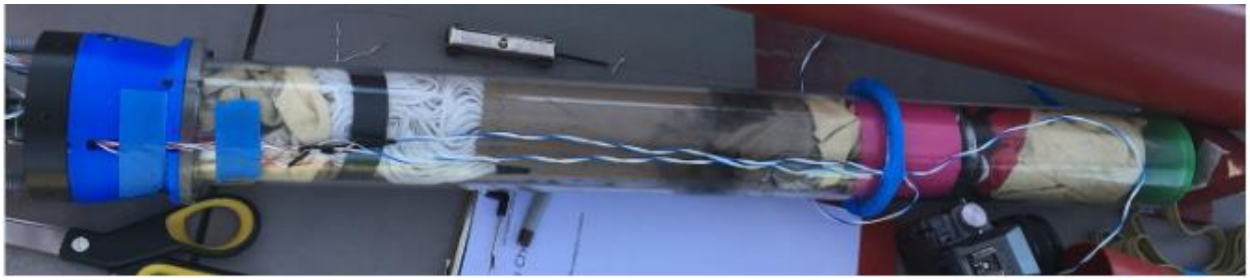


Figure 12. Integrated Recovery Assembly

Event 1: Separation at Apogee
-Black powder igniter triggered, CO2 igniter triggered

Event 2: Drogue deployment after 1 second
-Air from CO2 cartridge pressurizes parachute compartment
-Piston pushes drogue out and drogues deploys
-Main retention wire goes taught
-Backup black powder charge igniter triggered 2 seconds after apogee

Event 3: Main released at 1500 ft
- Black powder ignition releases the retention system
-Drogue tension force pulls main parachute out of deployment bag and inner tube
-The main chute begins to expand, slowing the rocket to approximately 28 ft/s

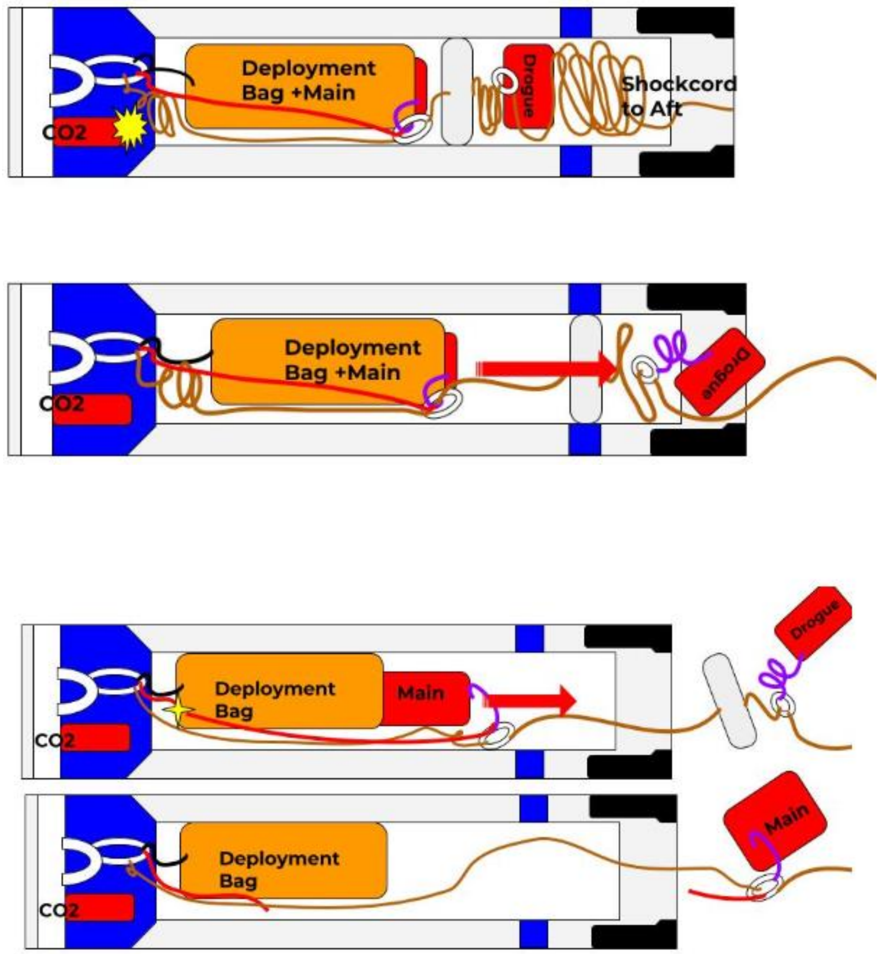


Figure 13. Recovery Mechanism Concept of Operations

1. Design Decisions

Based on IREC 2017 performance, the recovery team outlined six primary design decisions that are described at length below. The overall effect of these choices resulted in a system with far more redundancy, a lower likelihood of deployment/separation errors, cleaner parachute deployment, and modular design and transport that makes integration without airframe possible, thus vastly improving ease and assembly of system.

Figure 14. The disassembled recovery system ahead of a test launch.

Separation Method: The first design decision made was the use of a CO2 based deployment system that pressurizes the conjunction chamber between the forward and aft airframes, breaking shear pins in the coupler and thus causing separation (in conjunction with a black powder based system). This decision largely rested on two factors: the inherent variability of black powder, especially at high altitudes (low pressures), and the fact that we found the calculations for CO2 to be much more mathematically accurate than black powder systems. This method was originally seen as a backup to the mechanical separation mechanism. When the team later decided to not fly with the mechanical separation system (see staging mechanism section below), we promoted the CO2 system back to our primary separation driver. On top of this, given flight heritage, a 3 gram black powder charge is still prepared in order to ensure redundancy.

Figure 15. The CO2 ejection mechanism used to pressurize and break the shear pins in the coupler that attaches the airframes.

General Configuration: The second design decision is the choice of using serial deployment instead of a conventional dual separation configuration or parachute reefing because of its balance of efficiency and reliability. Furthermore, this means that there are less breaks in the airframe, vastly improving overall rigidity of the rocket system. For a more detailed comparison of the deployment methods, see appendix E.

Figure 16. Integrated recovery + AV system shows that serial deployment allows for a more elegant system that is far more compact and simple without need for multiple breaks in airframe.

Self-contained System: Rather than insert the recovery system directly into the forward airframe, we adopted a restricted diameter inner tube recovery bay system using 3D printed adapters and polycarb tubing. The design decision was initially made to accomodate the mechanical staging system, although we later decided not to fly with that mechanism. However, we discovered additional benefits to the new system that outweighed the space constraints of the smaller tube. The recovery bay can now be packed and wired independently from the main airframe, allowing for greater ease and speed of assembly, as the fully assembled system must only be slid into the airframe. The recovery system also simplifies testing. Although separation requires the entire airframe, deployment of drogue and main can be accurately tested with the recovery bay alone. Restricted diameter capabilities will give us greater flexibility for future design iterations as well.

Parachute Size: The third main design decision is the desired terminal velocities at various stages, which subsequently determines the necessary parachute sizes. We chose a maximum impact speed of 30 ft/s for the main parachute. We designed the drogue terminal velocity window to be between 75 and 100 ft/s to maximize falling rate without incurring critical damage in the unfortunate scenario of failed main deployment. A drogue falling at more than 100 ft/s would pose too great a risk for the rocket, and anything significantly slower than 75 ft/s would have too much dispersion, in addition to not being in the descent speed window designated by the competition rules..

Parachute Design: We chose to pursue SRAD parachutes to allow greater control over the technical details of the recovery system. With SRAD, we were able to construct parachutes of the exact diameter necessary to avoid excess material. This decision was also more cost effective than purchasing a comparable parachute. SRAD main parachute diameter was shrunk from last year to increase ease of deployment, hit target terminal speed, and fit within new inner tube dimensions. We decided not to make our own deployment bag due to noticeably high friction, variability, and system reliancy issues with our SRAD deployment bag last year; we transitioned back to COTS with no remaining issues.

Shock Cord Configuration: After tangling at competition last year and during the first test flight this year, we redesigned our shock cord system to consist of one intersection shock cord which is broken up into components (recovery bulkhead to main, main to drogue, drogue to motor retainer). This, in conjunction with swivels for both main and drogue parachutes, decreases the likelihood of tangling and thus increases the likelihood of successful deployment.

2. Techincal Specifications

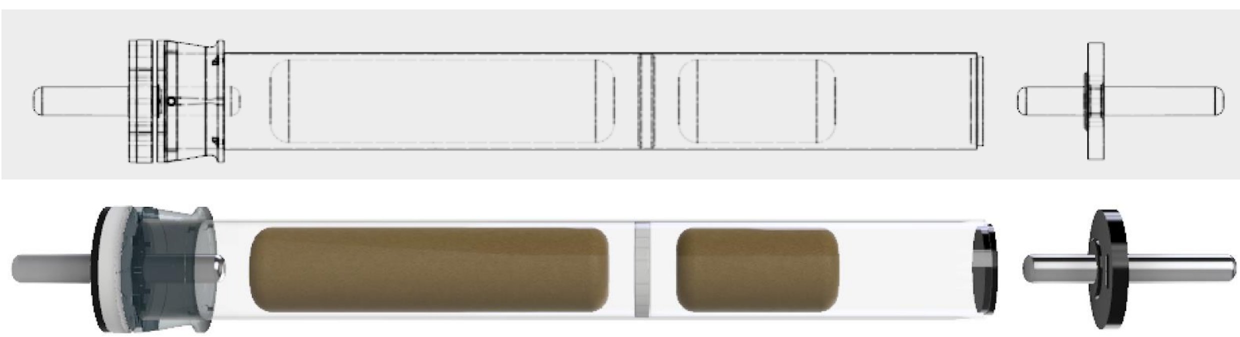


Figure 17. CAD layout of the system. See Appendix F for more detailed part drawings.

Parachutes and Descent Rates: The SRAD main parachute has a 90 inch diameter and was manufactured to slow down a 50 lb rocket to 28 ft/s. The SRAD drogue parachute has a 32” diameter, which will reduce the airspeed of the rocket to 78 ft/s, for a 50 lb rocket. Both calculations were done for a 4595 ft altitude; ground level for the launch site. The main parachute will deploy when the rocket is at 6000 ft above sea level, which corresponds to a descent speed of 81 ft/s at the moment of deployment. These descent rates do not take into account the drag caused by the rocket, which can be quite substantial. As a result, they represent the upper bound of the descent rates. The weights used were based on the expected rate of the rocket and the corresponding dry weight, where the approximately 18 pounds of fuel are no longer present.

The main parachute is hemispherical and constructed with lightweight calendered nylon and Spectra Nanoline shroud lines. All gores, seams, and rigging were cut and sewn by students. Contrasting thread color was used to enhance inspectability. This parachute was tested for sufficient drag on foot and during rocket flight. Damage incurred during the testing process was repaired using patching and assurance techniques detailed by the operational handbook developed

Figure 18. Sewing in process

by the FAA Airman Testing Standards Branch. A MATLAB program was constructed based upon "The Parachute Manual: A Technical Treatise on Aerodynamic Decelerators" by Dan Poynter (1984) as well as additional sources listed in the appendix.

Small scale parachutes were constructed first from paper to verify the shape and design. Next, a small scale fabric parachute was made from heavyweight nylon. This was constructed primarily to confirm the viability of the manufacturing process. Both scaled parachutes were successful, so we moved into design of the final parachute. For our final design, calendered ripstop Nylon was used. This material was chosen because opening forces were well below design limits and the reduced porosity proportionally reduced canopy area without increasing weight. Flat felled seams were used as in the small scale model to provide strength. Although there are some concerns in using the less heat resistant Spectra lines justified by our testing, careful packing and kevlar placement should protect the lines from the black powder backup charge. The lines were looped between adjacent seams to promote integrity, then tied into a single loop around a metal quick link. A woven tape was sewn beneath the line attachments on parachute seams to provide additional stability and a better bind. The vent hole was line with bias tape for support against rapid air flow while the lower canopy edge was hemmed and reinforced with a double line of stitching.

Figure 19. Ground Test of SRAD Main

We observed desirable inflation and drag characteristics while testing the parachute through running. The full opening of the parachute under human force was filmed and documented from packed configuration to full expansion. Ejection testing of the SRAD parachute was successfully performed, but due to a misplaced charge, a small portion of the outer rim of the canopy was damaged. This portion was patched according to FAA Airman Testing Standards. The SRAD main parachute was also launched. It deployed, but due to a violent separation, became detached from the rocket, traveled for miles, and was lost. However, due to the success of the first iteration during both ground and flight tests, it was decided that a second SRAD main parachute identical to the first would be built. The drogue was also lost in the launch, so a SRAD drogue was built according to the same principles of design and construction as the original main SRAD parachute. In total, the parachute as-built shows good agreement between modeled and actual weight, drag, and volume characteristics. It meets our design specifications and needs.

Separation Method: A 25g CO_2 canister will be used for the separation event, in conjunction with 3 grams of black powder. The mathematical calculations for CO_2 were confirmed through testing of 12g, 16g, and 25g canisters. See <CO2 Separation Ground Test Report> for details of the 9 tests we conducted. The mathematical calculations for black powder were confirmed through testing of 3 gram, 3.5 gram, and 4 gram charges. See <Black Powder Separation Ground Test Report Phase 1> and <Black Powder Separation Ground Test Report Phase 2> in Appendix B for details of the 4 tests we conducted. See Figure 34 in Avionics for details on deployment timing and redundant e-match connectivity.

Parachute Deployment Method: A 25g CO_2 canister will be used for the drogue deployment event, in conjunction with 1 gram of black powder as a backup method. The mathematical calculations for CO_2 were confirmed through testing of 12g, 16g, and 25g canisters. See <CO2 Separation Ground Test Report> in Appendix B for details of the 9 tests we conducted. The main parachute is deployed using a black powder controlled retention system which keeps it inside the recovery inner tube until the charge is sent and the mechanism releases. See Figure 34 in Avionics for details on deployment timing and redundant e-match connectivity.

Connections: There will be 4 shock cords used, 3 of which will experience between 80 and 100 Gs of deceleration after the separation event, based on prior experience and the subscale tests. There will also be three quick links used to connect various shock cords. All of these connections are outlined below. The max opening force for the drogue was calculated assuming a horizontal velocity of 250 ft/s at apogee, which is the worst case scenario with high winds and low launch angle. Due to the serial nature of our system, all three quick links as well as the tender retention system take the full load of each shock force.

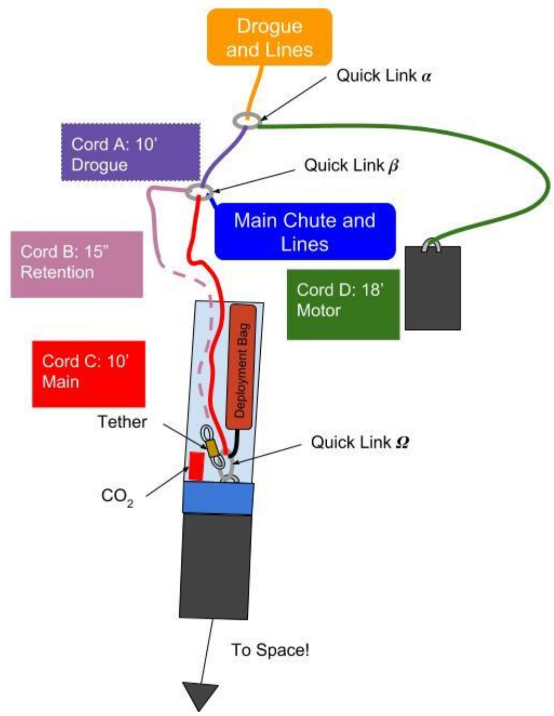


Figure 20. Shock cord configuration during descent

Shock Cord Designation	From/To	Estimated Load	Technical Specification
Main	Quick Link Omega to Quick Link Beta	Max @ 870N (195 lbf) of opening force	2200 lbf
Drogue	Quick Link Beta to Quick Link Alpha	Max @ 1050N (240 lbf) of opening force	2200 lbf
Retention	Tether to Quick Link Alpha	Max @ 1050N (240 lbf) of opening force	2200 lbf
Motor	Motor side hardpoint to Quick Link Alpha	80 - 100 Gs separation deceleration, 9 - 11 KN (2000 - 2400 lbf)	2200 lbf

Figure 21. Recovery Loadings

Other Connections	From/To	Estimated Load	Technical Specification
Quick Link Alpha (α)	Drogue shock cord, Retention shock cord, Deployment bag	Max @ 1050N (240 lbf) of opening force	1700 lbf
Quick Link Beta (β)	Drogue shock cord, Retention shock cord, Main shock cord, Main parachute	Max @ 870N (195 lbf) of opening force	1700 lbf
Quick Link Omega(Ω)	Tender retention, Main shock cord, Deployment bag	Max @ 870N (195 lbf) of opening force	2200 lbf
Tender Retention	Quick Link Omega, Retention shock cord	Max @ 1050N (240 lbf) of opening force	2000 lbf

Figure 22. Connector Loadings

We are conducting further testing of quick link tensile strength at the Blume Earthquake Center (see Tensile Test 20170522 for more information).

Shock Cord Lengths: The shock cords are proportioned to minimize the likelihood of the separated airframe halves colliding. They are also sufficiently long to allow time for the airframe to decelerate upon separation so that the airframe sections don't rebound into each other when they hit the end of the cord.

D. Payload

The payload subsystem is a GPS experiment with the goal of using a relatively inexpensive commercial software defined radio to capture GPS data and track a rocket's trajectory. Such a system has the advantage of being resistant to the high-dynamics often seen in rocket flight by using post processing and requiring less real-time computing resources. The system captures raw RF samples from the GPS L1 spectrum at 1.5 GHz and stores them onboard. All L1 signals from visible GPS satellites are recorded. After the flight, we use tracking algorithms to solve for the rocket's flight trajectory. The tracking algorithms we have used are GNSS-SDR and SoftGNSS.

The electronics of the payload consist of a lithium ion battery, an RTL-SDR dongle, a GPS antenna, an ESP8266 wifi chip, and a 3.7 to 5V voltage regulator. Below is a view of the system as it is packed into its 3P (3x PocketQube 5x5x5cm) sized plywood box.

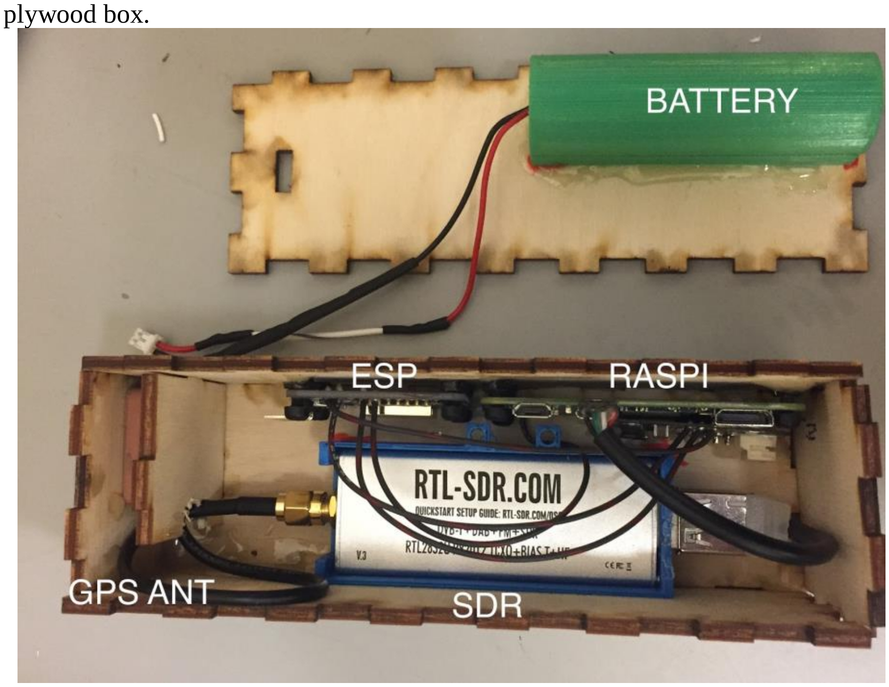


Figure 23. Unboxed payload with major components.

1. Design Decisions

The Raspberry Pi zero was selected as the flight computer due to its inexpensiveness ($5), compact form factor, and ability to run linux, which is important for package availability of the SDR drivers. While being sufficient for the task, the Raspberry Pi does not have much margin to spare. We conducted tests to determine what the maximum sampling rate the USB bus could handle was, and found that, of the sampling rates tested, our selected sampling rate of 2.048 MHz was the maximum rate that did not drop samples during capture.

Since the payload subsystem is integrated with the rest of the rocket long before launch, it was determined that a remote triggering system was necessary to turn on recording a few minutes before launch. This ensures that enough power and data storage space on the SD card is left for the flight. The remote triggering system uses the ESP8266 wifi chip to signal when to start recording data. When it is determined that it is time to start the payload, our ground operator sends a signal to the main avionics system through our SRAD long-distance radio system. Then, the avionics relay that triggering signal to the payload via its own ESP8266 chip.

To ensure that Raspberry Pi draws as little power as possible while idle, it is turned completely off by the ESP8266. This is done through the 3.7 to 5V voltage regulator that feeds power to the Pi. Its output is switched off by the ESP8266 until the triggering signal is received from the avionics system. The ESP8266 draws power directly from the battery. When the Raspberry Pi powers up, it immediately begins recording RF samples from the RTL-SDR onto its SD card. After the flight, a disarming signal is sent to the ESP8266. When this happens, the ESP8266 first signals to the Pi to initiate shutdown (this is necessary so that the SD card is not corrupted during writing), then waits a few seconds before cutting off power to it. In the event that the payload is not disarmed before running out of battery life, the Raspberry Pi will detect that the battery voltage is low and shut itself off.

2. Technical Specifications

To reduce feed line losses, the GPS antenna was selected to have a low-noise amplifier. To supply power to the LNA, the RTL-SDR's bias-t is enabled from software, which puts 4.5V DC on the core of the feedline.

To reach the required minimum weight of 8.8lbs, the system is attached to two steel disks which provide the majority of that weight. These steel disks attach the payload mechanically to the airframe via bolts. Below, the orange pieces are 3D printed components that constrain the plywood box containing the payload electronics. These pieces are attached on the bottom via a nut and washer to a threaded rod which threads into the steel blocks (shown as one block in the drawing).

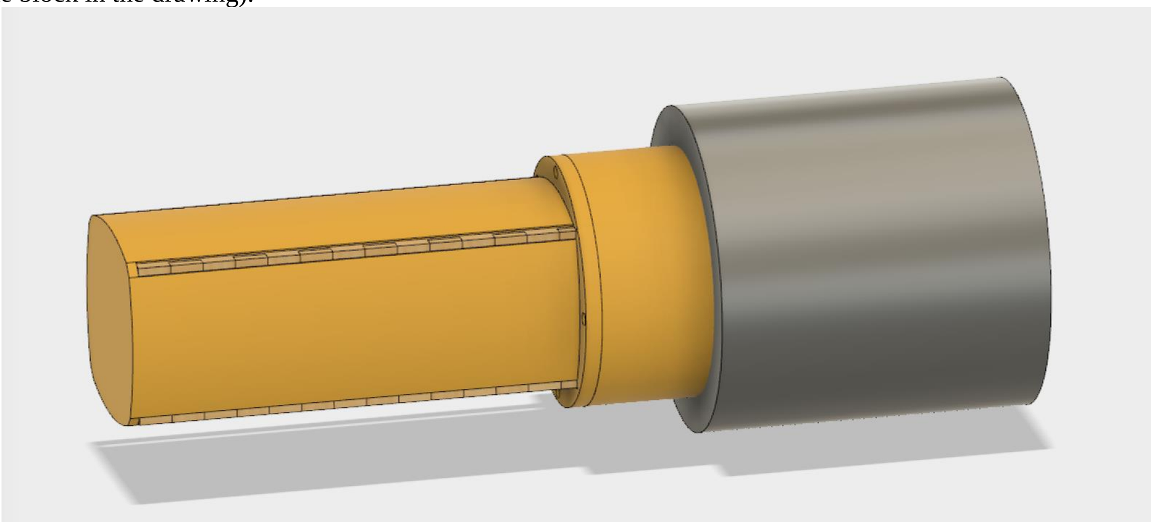


Figure 24. CAD render of the payload assembly

3. Testing

Tests of the entire system were conducted after assembly. To ensure that the Raspberry Pi was capable of recording samples at the rate provided by the SDR, sample drop rate tests were conducted used various sample rates. The sample rates tested were 2.048 MHz, 2.56 MHz, and 3.2 MHz. Of these, the Raspberry Pi dropped samples for the higher two sampling rates, but not the 2.048 MHz sampling rate. This has previously been determined as a sufficient for the payload, so this sampling rate was chosen.

Full system tests on the ground verified that the payload was capable of capturing signals from GPS satellites and recording them such that they could be post processed. In post processing, the position of the payload could be found and tracked with time. Unfortunately, no flight data our test flights has been recovered. The goal with this system is to fly it on a rocket and compare its ability to maintain tracking of the rocket throughout flight with conventional GPS units that track in real time. The unit that will be used for comparison is the NEO M8-N, mounted on the SkyBass custom altimeter in the avionics bay. Below are some plots from post processing of the data from a stationary ground test.

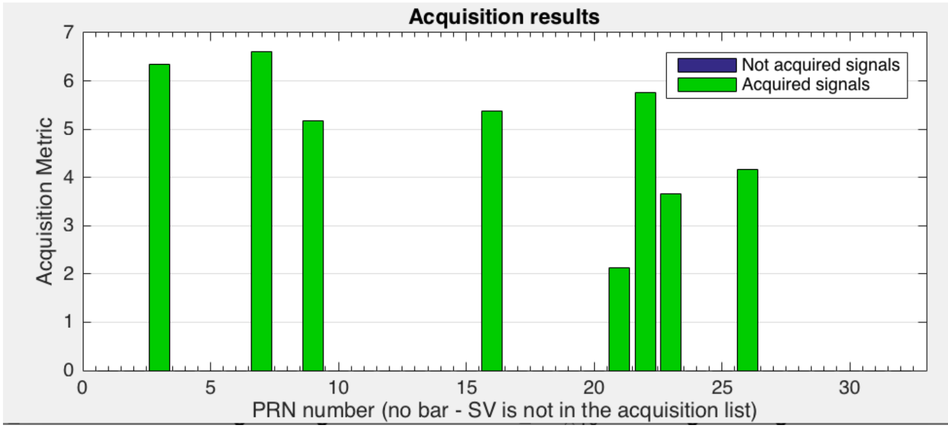


Figure 25. Visible satellites by PRN number, and the strength of acquisition. Eight satellites are easily visible in this test.

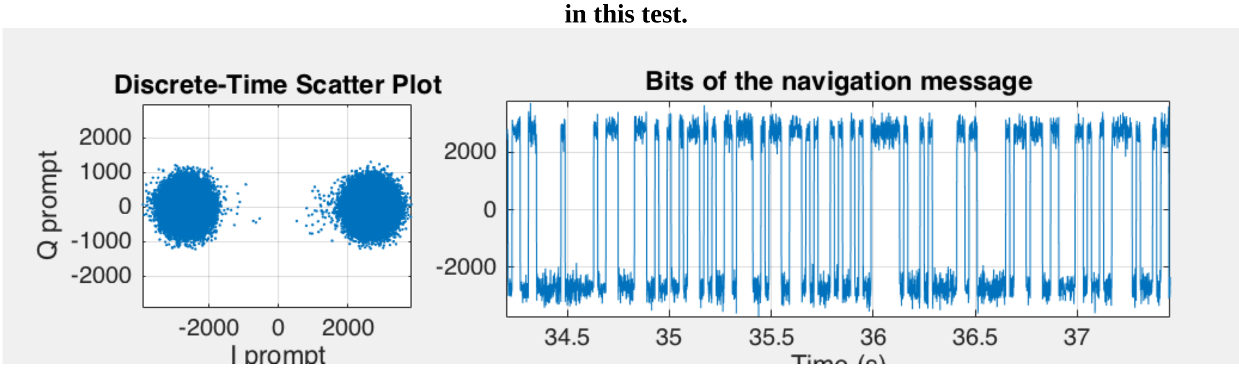


Figure 26. In-phase/quadrature and time series visualization of the bits of the navigation message from PRN 7. Here, the bits are easily distinguishable

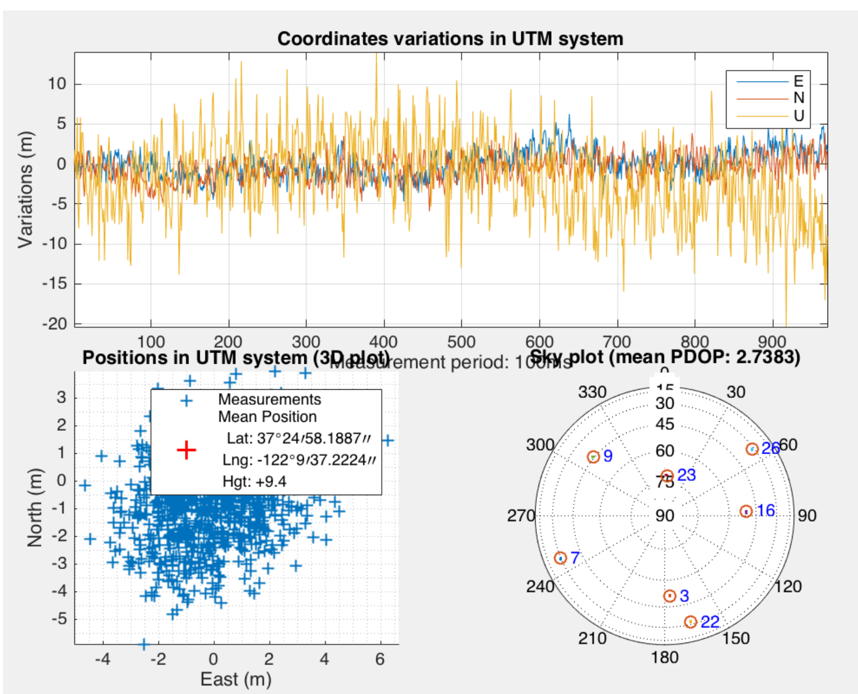


Figure 27. Coordinate plots. In the lower left, a plot of the all the solved locations. In the lower right, a plot of the sky and the satellites that are visible.

E. Avionics

The primary function of the avionics bay is to house and manage the redundant system of altimeters and flight computers, which detect flight conditions and trigger appropriate events. In addition, it houses the SRAD RF communications device (SRADio) for live telemetry and emergency RF beacon for finding the rocket after it lands.

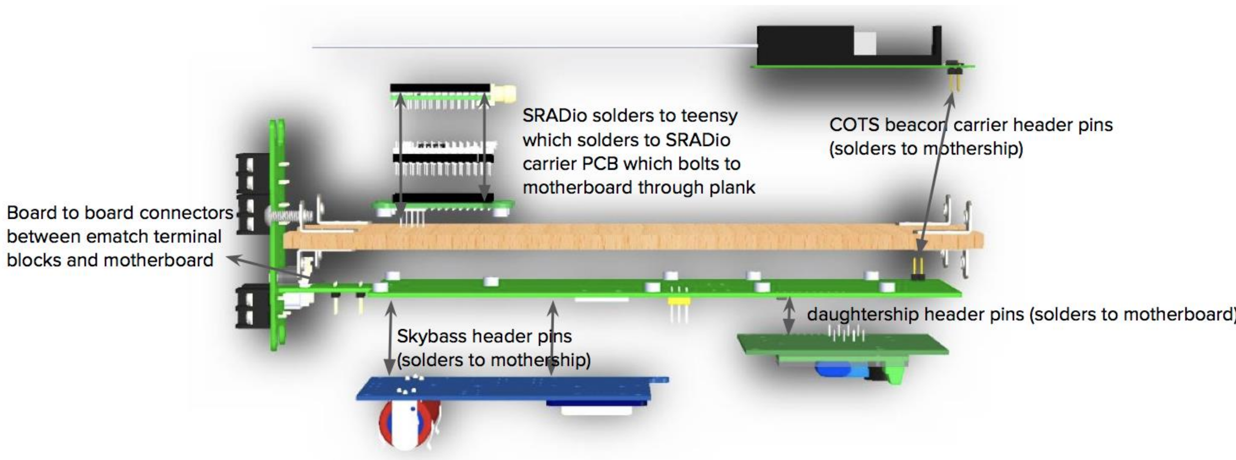


Figure 28. Exploded diagram of different avionics components

1. Design Decisions

The electrical design of the avionics bay is highly modular. It consists of a single Motherboard, into which each redundant system connects. The motherboard routes information between relevant systems. The Motherboard PCB was designed and assembled entirely by students. The PCB contains the power source for the COTS altimeters and the SRADio telemetry system, in four large battery holders. It houses the mechanical switches for the arming system, as well as an ESP8266 WiFi module and a magnetic switch, which allow wireless arming of the motherboard itself. The aft end of the motherboard has a high-reliability connector which connects to a PCB on the bulkhead. The ematches for recovery events are connected to this bulkhead PCB, and the signal for the ematches is sent through the Motherboard. Three modular systems are mounted on motherboard. The first of these is a Daughtership, which contains the two COTS altimeters, Stratologger and Raven. SkyBass, the student-designed and assembled flight computer, is also mounted here. Finally, the SRADio telemetry system and backup RF beacon are mounted on the back side of the board.

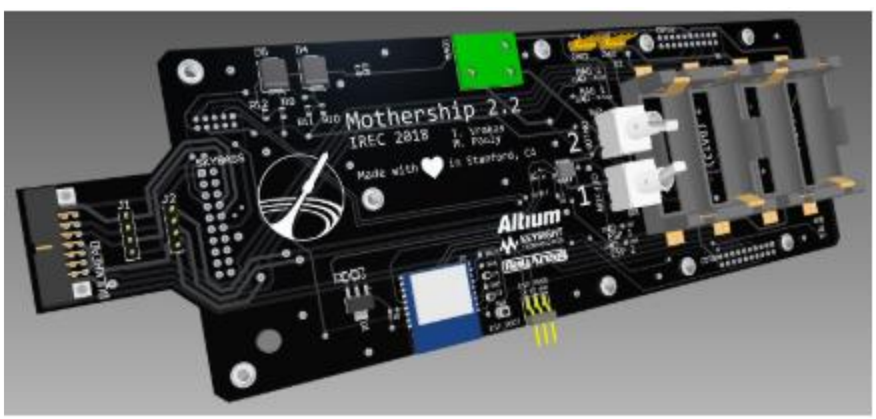


Figure 29. Motherboard PCB Design

Power Budget

The avionics system is designed to supply power to all systems even after ten hours on the pad, and with enough redundancy to allow the rocket to fly after even 50 hours on the pad. The long battery life of the telemetry systems also allows the rocket systems to stay on after the flight is compelte, so that recovery can take place up to 24 hours after landing.

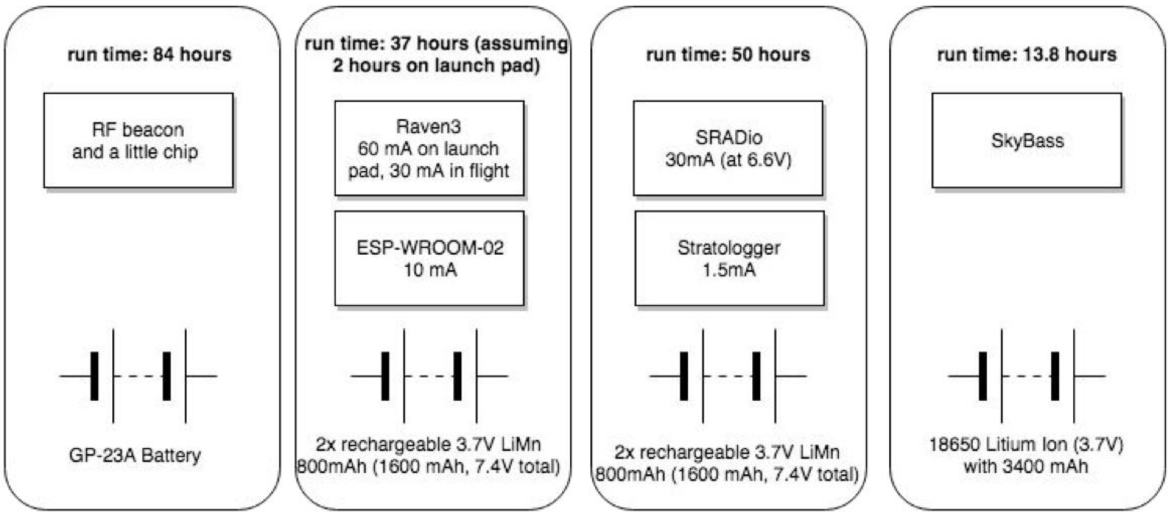


Figure 30. Power budget

Arming System

Pre-Arming (just before rocket integration)	Arming Method (after setup on pad)	Armed System
MilSpec Switch	Motherboard ESP 8266	Stratologger
MilSpec Switch	Magnetic Switch	Raven
MilSpec Switch	Skybass ESP 8266	SkyBass SRAD altimeter
-	Payload ESP8266	Payload Raspberry Pi

Figure 31. Arming diagram

The arming system is a critical safety feature that prevents accidental deployment of any events before the rocket is safely on the pad, as well as saving battery life. This highly-redundant arming system allows for all critical avionics systems to be turned off during assembly, integration, and setup on the pad, after which they can be armed over WiFi.

The first layer of the arming system involves mechanical switches, which interrupt power from the batteries. The second layer relies on the ESP8266 wireless chip and a magnetic switch. The ESP8266 chip is programmed as a web server. A client (such as a smartphone) can connect and arm the rocket, or use a variety of terminal commands, using a custom graphical user interface. As a backup, the magnetic switch can arm the rocket when it detects a magnetic field being passed over it the side.

The payload is armed over WiFi through a radio intermediate, because its power draw is high, so it is necessary to arm it just before launch from a safe distance. Thus, the payload ESP8266 is connected over WiFi to the ESP8266 of the SkyBass flight computer. The ground station sends an RF telemetry packet to the SRADio on the rocket, just before launch, and the SRADio sends this packet to the SkyBass Teensy. The Teensy then passes the packet on to the ESP8266, which sends it to the arming ESP8266 system on the payload.

Mechanical Design

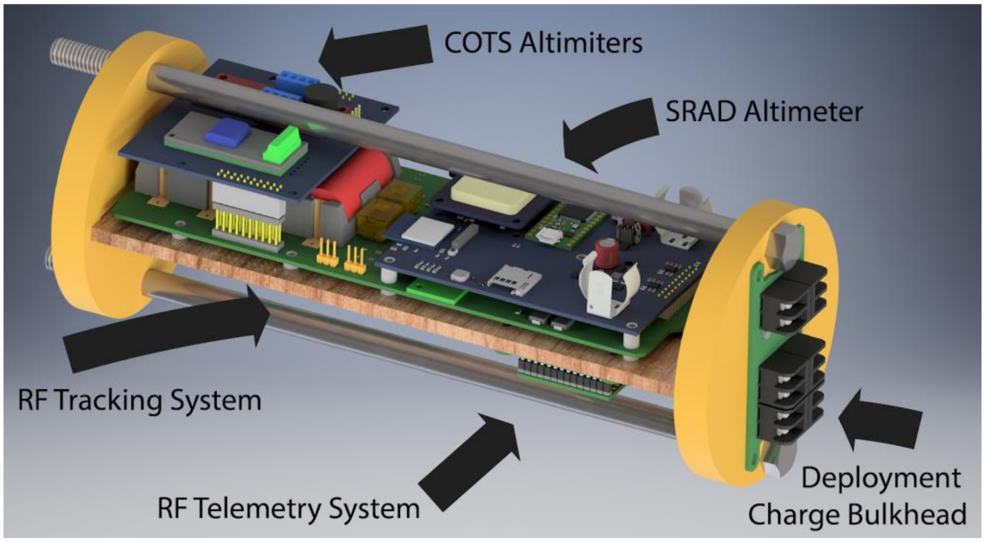


Figure 32. Labelled CAD of complete avionics bay (front view)

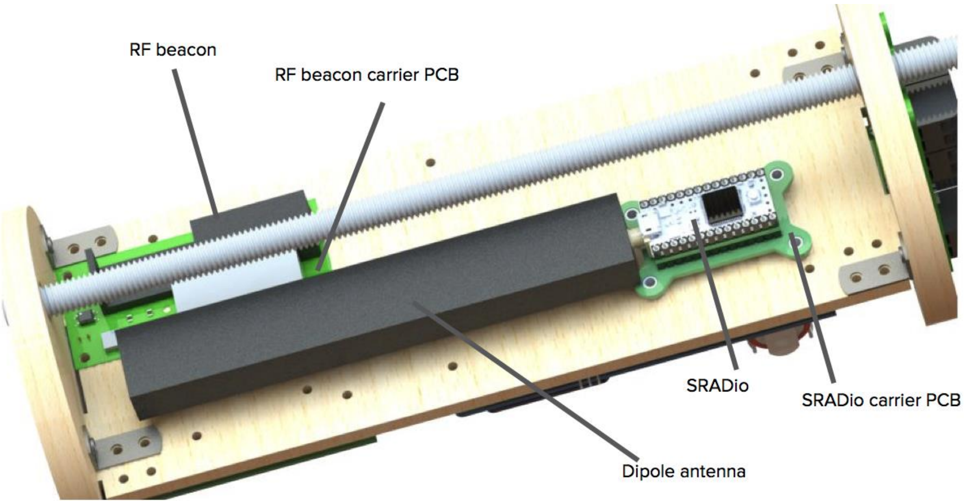


Figure 33. Labelled CAD of complete avionics (back view)

The mechanical design of the avionics bay is primarily driven by ability to survive launch, recovery, and landing conditions. It was designed to complete detail using CAD software, including all electrical components, fasteners, structural elements, and external connections. A main function of using CAD was to ensure all components fit properly.

The bay consists of two 3D printed PLA bulkheads, 10” apart. The bulkhead material was chosen for easy and quick manufacturing, as well as high strength. The bulkheads are connected by two fiberglass threaded rods to increase structural integrity. Between the bulkheads is a high-density fiberboard mounting plank, which was laser-cut to the design from CAD.

The overall design is easily modifiable, and highly modular. All parts are screwed into threaded inserts in the fiberboard, and all electrical connections are made with reliable pin headers.

2. Technical Specifications

The altimeters redundantly sense altitude of rocket, and using a single fault tolerant design, trigger e-matches for recovery events. The altimeter setup is triple-redundant. There are two COTS and one SRAD altimeter. The overall configuration, showing which altimeter triggers each event, is below.

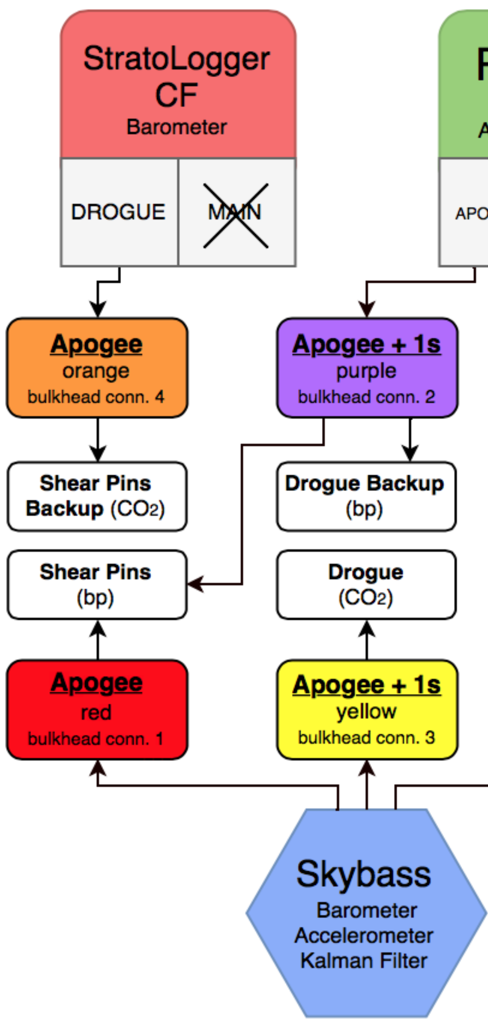


Figure 34. Recovery Event Ematch Diagram

The two commercial altimeters chosen were Raven and Stratologger, which have flight heritage on similar designs, as they flew on a similar rocket at IREC 2017. The Raven altimeter collects barometric and accelerometer data to detect conditions. The Stratologger uses only barometric data.

SkyBass is a custom altimeter and flight computer, designed, built, and programmed in-house. It uses a GPS module, pressure sensor, and two Inertial Measurement Units (IMUs) to detect flight conditions such as velocity, altitude, orientation, and acceleration. It has software allowing for customised firing times, and can fire up to 4 ematches. It collects data and sends it to the RF telemetry system. It also contains an integrated ESP8266, allowing for wireless WiFi arming after the rocket is set up on the pad. Additionally, it serves as the relay WiFi station for RF arming of the payload system. The design is centered around an ARM Cortex M4 processor provided by a Teensy 3.2.

The board integrates two different types of inertial measurement units (IMU), after extensive research into existing units used on commercial altimeters such as the Altus Metrum TeleMega. We use a “High G IMU” from NXP Semiconductors (MMA65XX) that is used in automotive airbag and crash detection systems to measure high acceleration events during takeoff, separation, and ground impact. However, this IMU has a lower resolution than other IMUs rated for lower acceleration. To achieve higher resolution at lower accelerations, we have included a second high resolution 9-axis IMU from Bosch (BNO055) that provides increased accuracy.

For barometric pressure, we use two Bosch pressure sensors (BMP280). We selected this sensor due to its low cost, high resolution, and because members of our organization have extensive experience using it well beyond its rated limits on high altitude, long duration latex balloon flights. For GPS Tracking, we use a uBlox NEO-M8N GPS module with an integrated patch antenna.For Data Logging, we use a Standard Micro-SD card for low latency, high frequency data logging over SPI. Our setup allows at up to 60MB/s with a maximum frequency of each individual write at 2 kHz. This allows us to log data at the full rate of our sensors. To learn more about the software that runs these sensors, refer to Appendix 6.

Tracking/Telemetry

To use the data from the altimiters, a telemetry system was developed to processes data from the flight computers such as rocket location, altitude, velocity, battery voltages, e-match connectivity status, barometric pressure, etc. and relays the information to a ground station during flight. After landing, a redundant tracking beacon is activated, providing a redundant method of tracking and recovery.

SRADio (the SRAD radio system) uses a commercial packet radio transceiver, the SiLabs 4463, to provide telemetry in the 433Mhz UHF band. This radio hardware was designed by our team, and tested on balloon flights to a range of 100km. For IREC, we qualified reliable communication to 50km, at a data rate of 5kbps. This data rate provides useful telemetry logs in the event the rocket fails catastrophically. We successful used this data to determine the cause of early deployment in a test flight. The radio controller uses context-aware truncation code to compress the data for transmission.

The telemetry data is received and processed by a ground telemetry station, consisting of a rugged laptop computer, a radio receiver module, and a large dipole antenna. The computer logs all telemetry data plots the live position of the rocket during flight in Google Earth 3D mapping software.

3. Testing

Using detailed simulation data, extracting temperature, pressure, orientation, acceleration, velocity, and altitude, we ran a Software-in-the-Loop (SITL) test on the SkyBass altimetry system. It successfully detected apogee as well as the recovery events, and triggered the appropriate ematch charges. A detailed set of test reports is attached. The Daughtership unit, which houses the two COTS altimeters, has been tested extensively, at IREC 2017 as well as on test launches this year.

F. Staging

The primary motivation of this project was set to be to develop an easily-reusable, scalable staging mechanism which separates linearly while minimizing shock. For testing purposes, on this year’s rocket the system would just be used to separate the two airframes in lieu of the CO2 deployer and coupler.

After multiple rounds of design iteration and prototyping, a clamp-based design was selected for its strength, durability, and low-shock separation. The final mechanism consists of two flanges, a PCB with integrated motor drivers and power management, and a radially-symmetric three-clamp system, actuated by a stepper motor with a threaded output shaft.

After a variety of tests (with varying levels of success), the staging system was prepared for a flight test in a subscale test launch. However, due to complications with the mechanism’s software and a failed test launch that caused extensive damage in other components, the flight test was postponed. After a thorough analysis of our risk management profile and the accelerated nature of the testing schedule, the staging mechanism was removed from the final rocket layout, to be continued as a separate project with hopes for test flights later in the year.

1. Design Decisions

The design of the staging system began last year and relied on solenoid-actuated pins locking the stages. However, the design had difficult actuating while loaded and confidence in the structural integrity of the pins was not assured. Our revised design, based loosely on a published specification attributed to the University of Portland, used side clamps to reduce load-induced friction and creating loads less likely to break parts. We also focused on space efficiency, and used a threaded rod as a driver to distribute torque away from the motors in flight. The mechanism was created in SolidWorks, and designed for manufacturability, as we worked closely with suppliers through several iterations.

For redundancy purposes, the upper flange was designed to be held in place with shear pins, so that a pyrotechnic charge placed between the two airframes can separate the rocket should the staging system fail.

The prototype mechanism was created using Form2 SLA printers. This allowed us to rapidly prototype part tolerances, fit and functionality through several iterations. After final parts were machined, it was found that the upper flange did not properly redistribute a high axial load to the airframe, and instead broke the shear pins. We redesigned a new upper flange to properly distribute the load through the flange, to the airframe. This design modification, along with the entire final mechanism (rightmost image), can be seen in the images below.

The staging avionics was designed to actuate the staging system on command. We designed a PCB for this to minimize footprint and maximize resistance to stress. At apogee, the main avionics would send both a wired and a wireless signal to the staging PCB, which would drive the stepper motor to separate the airframe. To determine whether or not separation was successful, a photoresistor circuit could sense the light of the opened airframe. If successful, the avionics would send a Wi-Fi response signal to the main avionics bay so that parachutes could be safely ejected from the separated airframe. If separation was unsuccessful or if no response signal was sent, the backup pyrotechnic charge would be ignited, breaking the shear pins of the forward staging mechanism flange and separating the airframe.

A prototype of the staging avionics was created using a breadboard and breakout boards of the various components to be eventually assembled on the PCB. After using this method to determine which components would be best for the mechanism, we continued to use the breadboard prototype to run full tests of the system.

2. Technical Specifications

The PCB was printed at Bay Area Circuits. Electrical components include the Wi-Fi enabled microprocessor (ESP-WROOM-02), which received and sending all signals; the stepper motor driver chip (L298 PowerSO20), capable of driving the NEMA bipolar stepper motor with 2A/phase; a 1000mAh LiPo battery; voltage regulators; switches; a photoresistor; and various other auxiliary circuitry.

All of the flight software was contained on the ESP-WROOM-02, the Wi-Fi enabled microprocessor on the PCB. Code was written to the chip using the Arduino IDE. The software initially utilized the Stepper class from Arduino, but after it failed in testing, we decided to write our own stepper motor driving signal sequences. Additionally, the ESP-WROOM-02 hosted a Wi-Fi network, and could connect to the Wi-Fi from the main avionics bay to communicate wirelessly. It also hosted multiple HTTP websites, allowing another device (such as a smartphone or computer) to connect to it and browse these specific websites in order to open, close, tighten, and loosen the stepper motor before launch. The code was written such that the mechanism could receive multiple inputs yet only open once during flight.

The flanges, clamps, and vertical linkages are made from Aluminum 6061, CNC-machined and bead-blasted for a smooth finish. The center piece and horizontal linkages are made from Form2 Tough V4 resin, printed on a Form2 printer and UV-cured. Similarly, the vertical uprights, pivots, and base plates were printed on the Form2 using High-Temp V5 resin. The clevis pins at the joints were 3/16” steel pins with grooves for retaining clips (varying in length; ⅝”, ⅞”, and 1 ⅛” pins were used), ordered from McMaster-Carr. The carriage nut is brass, and the output shaft is stainless steel with TR8x8 threads. The shaft was cut to length from its original 28cm to ~12cm.

Motor: The stepper motor is a NEMA 17-size hybrid stepper (Bipolar, 200 Steps/Rev, 42×38mm, 2.8V, 1.7 A/Phase). Ordered online from Pololu, the motor was supplied with the appropriate 4-wire input. With the TR 8x8 threaded output shaft and carriage nut, a precision of 40 micrometers per step could be achieved (finer resolution is possible with micro-stepping as well). The carriage nut moves 8mm per full rotation, indicating a maximum speed of 30 cm/s with no load. The motor has a maximum torque of 3.8 kg-cm.

III. Mission Concept of Operation Overview

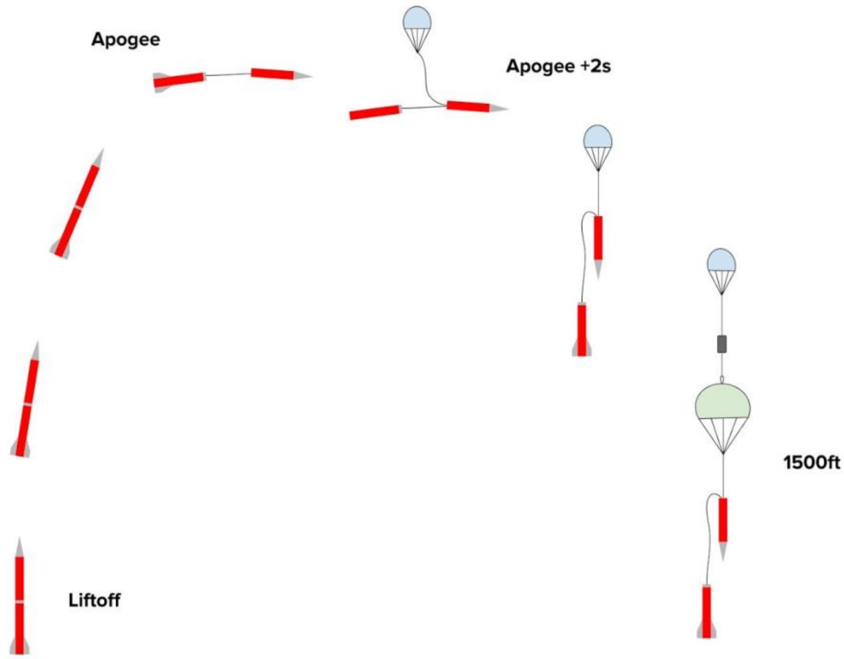


Figure 35. Conops Diagram

Phase 1: Preflight

Begins after the rocket is on the pad. The COTS altimeters are armed with a magnetic switch, and the SRAD avionics and the payload system are armed with a wireless signal. The ground station begins receiving telemetry. The igniter is installed. This phase ends on ignition.

Phase 2: Powered flight

Powered flight begins after ignition of the motor and ends when the motor is no longer firing. During this phase, the payload and avionics are armed and collecting data; the avionics is transmitting live telemetry to the ground station, which is displaying it in real time. The recovery system awaits deployment. Propulsion is providing thrust to the rocket.

Phase 3: Ballistic flight

Ballistic flight begins once the motor is no longer on and ends once the rocket reaches apogee. During this phase, all systems but propulsion function identically to Powered Flight.

Phase 4: Recovery deployment

Recovery deployment begins at apogee and ends at full drogue deployment. The avionics system fires the e-matches which trigger rocket separation. This causes Recovery to puncture a CO2 canister, deploying the parachutes from the recovery tube, as well as a CO2 canister and backup black powder charge designed to pressurize the recovery bay, shear the nylon screws and seperate the forwards and aft airframes. The drogue is released and inflates while the main parachute is retained by a tether. Otherwise all systems continue to function as in Ballistic Flight.

Phase 5: Descent on drogue

Descent on drogue begins after the drogue is deployed from the rocket. The drogue brings the rocket to a descent speed of 78 feet per second. The motor retainer retains the motor. All other functions continue as before.

Phase 6: Descent on main parachute

Descent on main parachute occurs at 1500 feet above ground level, when another charge from the avionics bay operates a cordcutter that severs the tether retaining the main. The drudge pulls out the main. The main brings the rocket to its final descent velocity of 26 feet per second. The motor is still retained in the rocket. All other functions continue.

Phase 7: Landing

Landing begins once the entirety of the rocket is at rest on the ground. The avionics transmits telemetry and beacon signal. The recovery system and propulsion are still retained by the rocket. All other functions continue.

IV. Conclusion

Our largest lessons learned from the previous year were in the realms of preventing premature optimization and facilitating coordination and communication among the subteams. In order to keep a trade space open, we spent a longer time in a planning phase, with more iterations of prototyping and subscale modeling to settle on final designs for our subsystems. This was particularly important for the staging system, which required a number of highly-toleranced parts, but also was relevant for all other components of our system. In addition, we created new roles and a centralized document set to track the size and configuration of the rocket persistently - this helped make sure that the team was kept on the same page, and sudden changes from one subteam would not adversely impact another.

One great challenge this year was the temptation of schedule slip. Some systems had ill-defined requirements that made it difficult to determine when we ought and ought not to launch. Combined with our long prototyping phase and testing schedule focused on prototyping - which required the fabrication of several complete rocket systems - we in a few cases found ourselves launching systems which were not flight ready at the time. After a test flight failure attributed primarily to scheduling and integration errors, we instituted significant reforms, including institutional build freezes, pre-integration sessions, full systems testing prior to flight, and carefully designed standard requirements for launch.

Since we had some deeply speculative components on this year's rocket, we also found it difficult to set deadlines and schedule work in a way that got parts done on time. This is in part because of the nature of a volunteer organization, but in part because of a lack of systemization in the way that work tasks were broken down and distributed often placed uneven loads on team members, sometimes overloading the leadership of a sub-team while leaving others on the team with little to do. In the future, individual training of subteam leads in a variety of techniques from past SSI projects surrounding subteam inclusion, delegation and design will help mitigate this problem.

We have only a single graduating senior on this team, but there are a number of concrete knowledge transfer steps we have and will continue to take. The first is by ensuring that no group has solely upperclassmen - there will be returning students who have worked on every subsection, and every system has a designed 'bus factor' so that expertise can be replicated even if team members were to suddenly leave. The second is our extensive locally available documentation, which covers everything from individual projects to launch day procedures. Last, at the end of the competition, our team will be compiling a list of lessons, impressions, and advice. The document will include organization management guideline, teams specific advice, and technical suggestions moving forward.

Appendix

A. System Weights, Measures, And Performance Data

Current System Weights and Measures

Airframe	Nose Cone	Forward	Aft + Fins
Length (in)	16.00	49	63
Weight (lbs)	1.4	2.6	4

Components	Payload		AV Bay	Recovery Bay	Recovery Tube	Coupler		Ballast	Retaining Rod + Motor Retainer	Motor + Casing
Length (in)	4	4	10.5	3.75	30	6	6	6	1.5	51.5
Weight (lbs)	9.5		1.6	1	4	0.4		TBD	1.5	32

Total Length (In)	128.00
Total Weight (lbs)	58

Current Performance Data

Stability Calibers	CG Location	CP Location	Time to Apogee	Max Velocity	Max Acceleration	Velocity off Rod
2.9	75 in	86 in	43s	2081 ft/s Mach 1.85	471 ft/s^2 15 Gs	275 ft/s

B. Project Test Reports

SSI Test Report - Redshift

Team Testing: Recovery			
Name of Test: First Subscale Flight Test w/ Restricted 3” Diameter - Launch 1 (LUNAR) 20180		Version: 1	Date: 2/17/18
Names of testers: Daniel Shorr, Matthew Pauly			
Successful?	~Y/N	Location: The TCC Launchsite in Riverdale, CA	

Purpose:

Flight test the new restricted 3” diameter configuration to put theory to practice -- specifically looking at pressurization, successful ejection, and finally, the avoidance of tangling.

Note: Descent rate is also critical, though it will not be determined at this launch due to the subscale motor.

Materials list:

4” Fiberglass airframe & 3” phenolic innertube w/ 3D printed adapter	4” Fiberglass Coupler
Recovery bulkhead & Pyrotechnic components	COTS drogue, new COTS 76” ultra compact main, 3” deployment bag for main
Relevant Shockcords & Quicklinks	Kevlar sheets

CO2, BP charges, & relevant ematches	Remote detonator & set of airframe stands

Procedure:

1. Configure the new IREC recovery bay following the revised instructions (see recovery assembly procedure), notably:
    a. Install the brand new restricted 3" diameter via the threaded adaptor and centering ring
    b. Replace main with Fruity Chutes 76" ultra-compact + 3" dia 9" length deployment bag
2. The complete configuration should be as follows:

3. Arrive at the outside loading bay and set the recovery cannon atop the airframe holders, minding the ricochet
4. Clear the area and connect the leads of the remote ignitor to the drogue CO2 Charge
5. Ignite the CO2 system, observe and record the results
6. With someone pulling on the drogue (applying relatively constant force), ignite the main retention system
7. Much like before, observe and record the results

Note: This time around, the pressurization was provided by a duck tape enclosed coupler, which simulates the flight pressurization volume.

Data:

Criterion\Deployment Event	Drogue	Main
Successful Pressurization/Separation	Yes	No
Correct Connections w/ Shock-cord	Yes	Yes
Minimal Tangling/Damage	Yes	No

Results:

First subscale flight test to 10,000 ft with our new 3” restricted diameter mechanism. Integration was mostly successful with some pressure sealing issues -- addressed with tacky-tape, will be fixed next time with better manufacturing tolerances. During launch, drogue deployment successful, pressurized ejection successful. Drogue shock-cord and intersection shock-cord tangling, however, preventing main from deploying. This ultimately resulted in a rocket impact speed at approx. 70 ft/s.

As evident in the photo above, the intense separation force due to CO2 ejection likely caused the inner-tube to deform, further increasing chance of entanglement in chute deployment. To address this, we will switch to quantum tubing with support rings that runs the length of the inner tube.

Also, note:

Storing used pyrotechnic components in a cup of hot water really helps clean out the various pieces.

SSI Test Report - Redshift

Team Testing: Everyone			
Name of Test: Launch 2		**Version: 1**	**Date:** 4/14/2018
Names of testers: Chloe Glikbarg, Skye Vandeleest			
Successful?	N	**Location: LUNAR**	

Recovery:

Did not experience ejection due to ballistic flight and no signals sent from avionics. Upon finding the rocket, we were able to pull out both drogue and main in the correct order and confirm that they unfolded properly. All charges appeared to be positioned correctly, although no signals were sent to those charges.

Conclusion and Steps To Be Taken:

SEPARATION
Good: system set up correctly

DROGUE
Good: drogue came out after flight and was packed properly

MAIN
Good: main came out after flight and was packed properly

OVERALL IMPROVEMENTS
Practice integration ahead of time to expedite on-site process

Pictures (w/ captions):

Manual deployment of parachutes


Drogue CO2 system still correctly set up post flight

Intersection shock cord correctly attached to motor retainer, all holes plugged for pressurization

SSI Test Report - Redshift

Team Testing: Everyone			
Name of Test: Launch 3		**Version:** 1	**Date:** 5/18/2018
Names of testers: Chloe Glikbarg			
Successful?	Y/**N**	**Location:** TCC	

Recovery:

Experienced early separation due to premature signals sent from avionics. The CO2 separation charge effectively separated the rocket, confirming in-flight effectiveness. Main SRAD parachute (and likely drogue, although it was not visible at the given altitude) was ripped out prematurely due to violent separation, visibly deployed, and slowly descended separate from the system. Intersection shock cord between motor retainer and drogue ripped. Drogue, SRAD main parachute, portions of shock cord, and some kevlar sheets were permanently displaced.

Conclusion and Steps To Be Taken:

SEPARATION

Good: system set up and fired correctly from the recovery point of view

DROGUE

N/a

MAIN

Good: main came out and deployed successfully during flight

OVERALL IMPROVEMENTS

Replace older shock cord with newer, stronger, less used pieces. Rebuild SRAD main parachute and replace COTS drogue parachute with SRAD drogue parachute. Perform testing on quick links to minimize future problems with greater than expected forces.

Pictures (w/ captions):

Fully assembled bay

Aft frame with intersection shock cord ripped

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: CO2 Drogue Deployment Ground Test		Version: 1.0	Date: 4/5/18
Names of testers: Chloe Glikbarg, Daniel Shorr, Skye Vandeleest, Seth Liyanage			
Successful?	**Y**/N	Location: Stanford	

Purpose:

Confirm reliability of CO2 drogue deployment on system redesign.

Materials list:

- Test rig
  - 2 - ¾” diameter phenolic main tube (30” long)
  - ¾” thick delrin recovery bulkhead
  - 3D printed bulkhead adapter
  - U-bolt (attached to recovery bulkhead)
- Real parachutes (drogue and main - same as planned for final use)
- Main parachute deployment bag
- 25g CO2 canister
- CO2 deployment system
- Piston
- Fuse box
- E-matches
- Black powder
- Safety glasses
- Test stand
- Tools
  - Drill and bits/driver bits
  - Scissors
  - Extra screws
  - Extra shear pins

Procedure:

Set up

1. Put in CO2 canister with properly connected ematches and black powder.
2. Put parachutes into inner tube and link system together with intersection shock cord.
3. Attach recovery bulkhead to inner tube.
4. Attach e-matches to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
5. Put pin in fuse box.

Test Variables

- New recovery bay system redesign

Test Rig Specs

- 30” from bulkhead to end of inner tube

Results and Conclusions

- Successful test! Drogue deployed with piston and CO2 deployment charge functioned as intended.

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: Main Deployment Ground Test		**Version: 1.0**	**Date: 4/5/18**
Names of testers: Chloe Glikbarg, Daniel Shorr, Skye Vandeleest, Seth Liyanage			
Successful?	**Y**/N	**Location: Stanford**	

Purpose:

Confirm reliability of main deployment on system redesign.

Materials list:

- Test rig
  - 2 - ¾" diameter phenolic main tube (30" long)
  - ¾" thick delrin recovery bulkhead
  - 3D printed bulkhead adapter
  - U-bolt (attached to recovery bulkhead)
- Main and drogue parachutes
- Main parachute deployment bag
- 25g CO2 canister
- CO2 deployment system
- Retention system
- Piston
- Fuse box
- E-matches
- Black powder
- Safety glasses
- Test stand
- Tools
  - Drill and bits/driver bits
  - Scissors
  - Extra screws
  - Extra shear pins

Procedure:

Set up

1. Put in CO2 canister with properly connected ematches and black powder.
2. Put in retention system with properly connected ematches and black powder.
3. Put parachutes into inner tube and link system together with intersection shock cord.
4. Attach recovery bulkhead to inner tube.
5. Attach e-matches to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
6. Put pin in fuse box.

Test Variables

- New recovery bay system redesign

Test Rig Specs

- 30” from bulkhead to end of inner tube

Results and Conclusions

- Successful test! Main deployed with black powder retention charge functioning as intended.

<Main deployment bag stayed in place>

<Main deployed properly>

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: Separation Ground Tests (9 individual tests)		Version: 1.0	Date: 1/24/17 through 2/24/17
Names of testers: Saylor Brisson, Derek Phillips			
Successful?	**Y**/N	Location: Stanford	

Purpose:

Determine if basic separation system design works and what size CO_2 cartridge to use (on ground).

Materials list:

- Test rig
  - 4” diameter phenolic main tube (36” long)
  - Phenolic coupler (7” long)
  - 2 - ¾” thick plywood bulkheads
  - 2 U-bolts (each attached to one bulkhead)
  - Coupler bulkhead is epoxied (15-minute 2-part epoxy) into coupler
  - Main bulkhead screwed into main tube with 4 wood screws
- Testing parachutes (drogue and main - old parachutes not planned for final use)
- Real parachutes (drogue and main - same as planned for final use)
- Parachute deployment bags (drogue and main - same as planned for final use)
- CO_2 canisters (12g, 16g, 25g, 38g)
- Fuse box
- E-matches
- Pyrodex
- Safety glasses
- Test stand
- Tools
  - Drill and bits/driver bits
  - Scissors
  - Extra screws

  - Extra shear pins
  - Awl

Procedure:

Set up
1. Put in CO_2 canister with properly connected ematches and black powder.
2. Attach 2 shock cords to main bulkhead and 1 shock cord to coupler bulkhead.
3. Put parachutes into main tube.
4. Screw in main bulkhead.
5. Attach coupler with shear pins.
6. Attach e-matches to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
7. Stand back from test rig at least 30 feet.
8. Put pin in fuse box.

Test Variables
- Shear pin size
- CO_2 canister size
- Parachute number/size/type

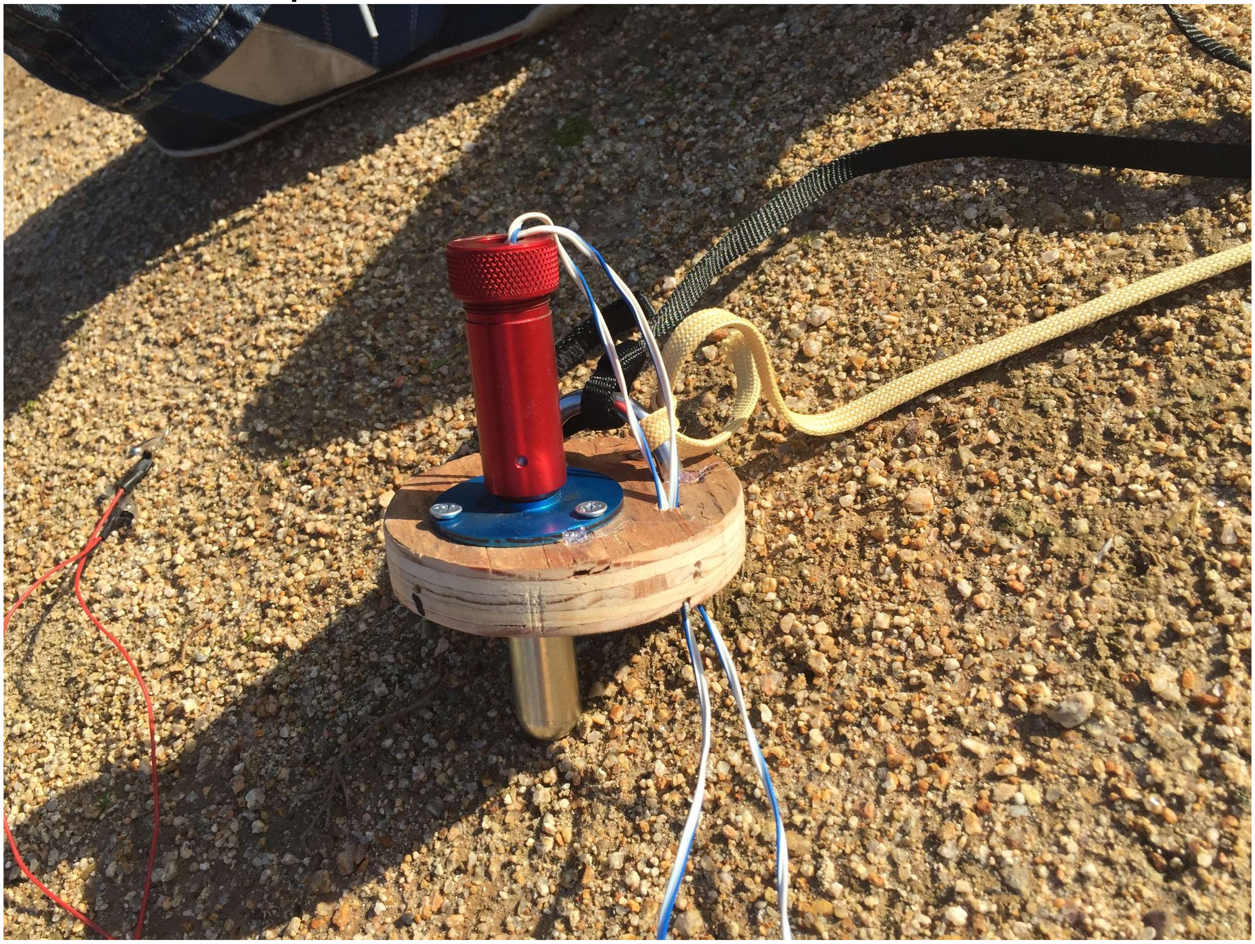
Test Rig Specs
- 30” from bulkhead to bulkhead

Notes
- 9/64” drill bit for 8-32 shear pin

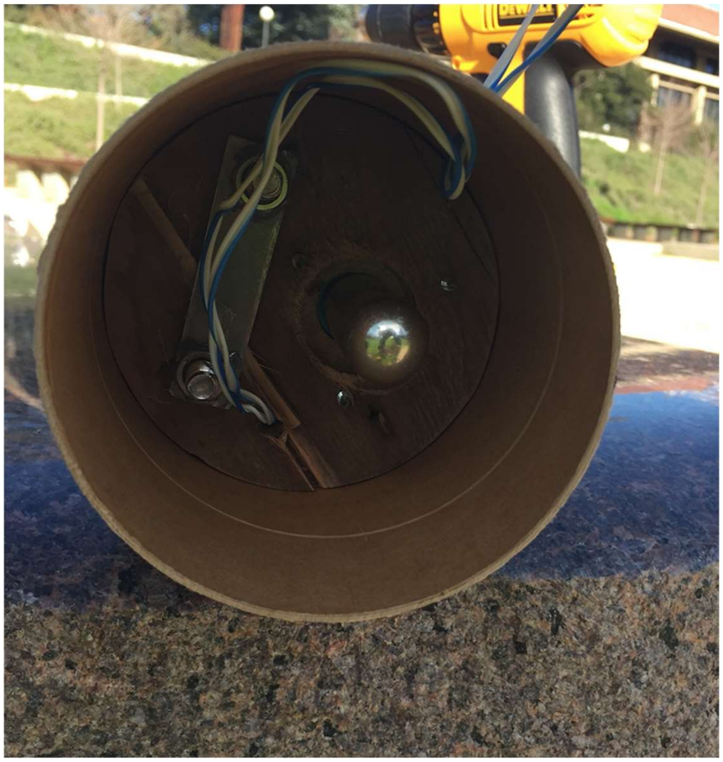
Results and Conclusions
- 1st test
  - Didn’t ignite ematches at first - have to press yellow button on fuse box
- 2nd test
  - (only connected one ematch to fuse box because of trouble with gator clips - note for future: make sure we have good alligator clips
  - When ematch ignited, plunger didn’t pierce co2 canister (12 g)
  - Noticed that the canister did have a small indent from the tip of the plunger, so we concluded that the plunger did hit the canister with some force, but not enough to pierce it
- 3rd test
  - Ematch ignited, but plunger still didn’t pierce co2 canister (12 g)
  - Continued to make a bigger indent in the co2 canister
- 4th test
  - Used same co2 canister (12g)
  - Used 1 ematch, placed paper towel wadding in other hole

- Used black powder instead of pyrodex
    - Successfully punctured co2 canister!
    - Didn't eject parachutes
    - On analysis of video and markings on main tube, we concluded that the co2 leaked out on the bottom instead of pushing the parachutes through.
- 5th test, 2/10
    - Used 12g co2 canister
    - Sealed main tube bulkhead with duct tape and hot glue
    - Air escaped around co2 canister
- 6th test
    - Used 16g co2 canister
    - Sealed main tube bulkhead and co2 hole with hot glue
    - Air escaped screw holes
- 7th test, 2/11
    - Used 12g co2 canister
    - Sealed main tube bulkhead and co2 hole and screw holes with tacky tape
    - Did not use shear pins
    - Successful ejection of coupler, very weak
- 8th test, 2/12
    - Used 25g co2 canister
    - Sealed main tube bulkhead and co2 hole and screw holes with tacky tape
    - Used 2 #6 shear pins
    - Successful ejection of coupler and parachutes, very forceful, one sheared pin, the other ripped through airframe. Will reinforce in the future.
- 9th test, 2/24
    - Used 25g co2 canister
    - Same as 8th test, with reinforced airframe.
    - Successful.

Pictures (w/ captions):



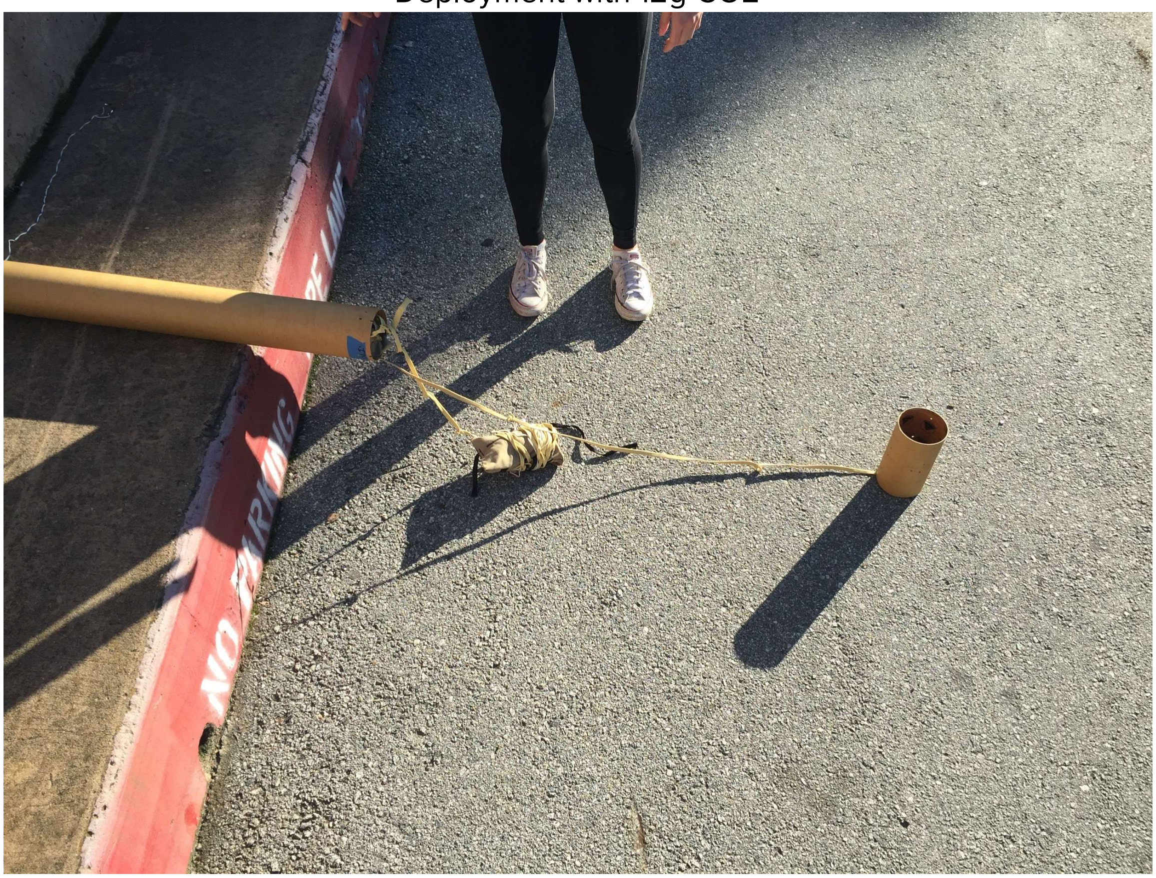
<CO2 system in test bulkhead>



<CO_2 system in test airframe, early tests>

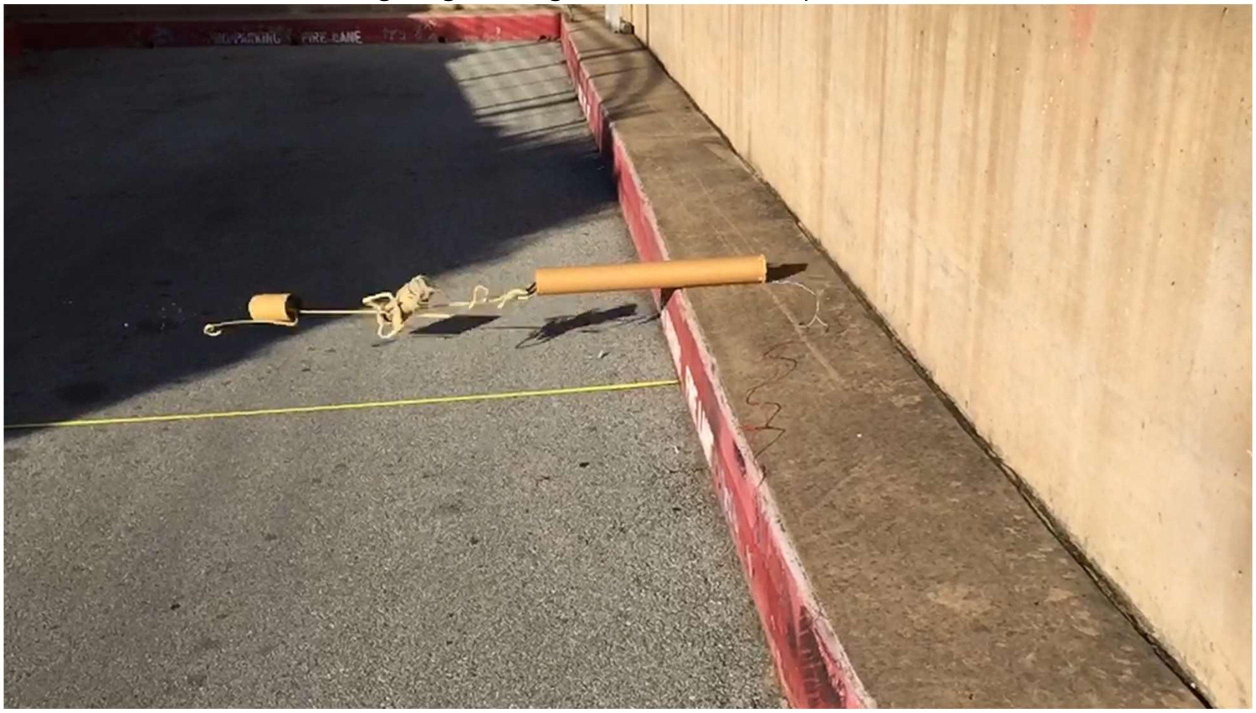
<CO_2 system with tacky tape in test airframe, later tests>

<Deployment with 12g CO2>



<Airframe post-deployment of 12g CO2>

<During 25g CO2 ignition with shear pins, test 8>



<Test 9, 25g CO2 ignition with shear pins>

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: Separation Ground Tests (2 individual tests)		Version: 1.0	Date: 4/13/17
Names of testers: Chloe Glikbarg, Skye Vandeleest, Max Newport, Matthew Pauly			
Successful?	Y/**N**	Location: Stanford	

Purpose:

Test black powder separation of airframes with new staging mechanism.

Materials list:

- Airframe (forward and aft)
- Main and drogue parachutes
- Main parachute deployment bag
- Coupler (12" long)
- Fuse box
- E-matches
- Shear pins (#6)
- Black powder (2 gram, 3 gram, and 4 gram charges)
- Safety glasses
- Test stand
- Tools
    - Drill and bits/driver bits
    - Scissors
    - Extra screws
    - Extra shear pins

Procedure:

Set up

1. Put in black powder charge with properly connected e-matches.
2. Attach intersection shock cords to recovery bulkhead, main parachute, drogue parachute, and motor retainer.

3. Put parachutes into inner tube.
4. Screw in recovery bulkhead.
5. Attach coupler with shear pins.
6. Attach e-matches to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
7. Stand back from test rig at least 30 feet.
8. Put pin in fuse box.

Test Variables

- Black powder charge quantity (3 and 4 grams, respectively)

Results and Conclusions

- 1st test
  - Didn't break shear pins, explosion did not seem violent
  - Decided to try using more black powder
- 2nd test
  - Didn't break shear pins, explosion seemed semi-violent
  - Decided to try using more black powder
- 3rd test
  - Didn't break shear pins, explosion seemed too violent
  - Re-examined pressurization techniques and decided to pursue a more aggressive pressurization approach

Pictures (w/ captions):

<3 gram separation attempt>

<3.5 gram separation attempt>

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: Black Powder Drogue Deployment Ground Test		Version: 1.0	Date: 5/4/18
Names of testers: Chloe Glikbarg, Skye Vandeleest, Saylor Brisson			
Successful?	**Y**/N	Location: Stanford	

Purpose:

Confirm reliability of black powder drogue deployment on system redesign.

Materials list:

- Test rig
    - 2 - ¾" diameter phenolic main tube (30" long)
    - ¾" thick delrin recovery bulkhead
    - 3D printed bulkhead adapter
    - U-bolt (attached to recovery bulkhead)
- Real parachutes (drogue and main - same as planned for final use)
- Main parachute deployment bag
- 1 gram black powder charge
- Piston
- Fuse box
- E-matches
- Safety glasses
- Test stand
- Tools
    - Drill and bits/driver bits
    - Scissors
    - Extra screws
    - Extra shear pins

Procedure:

Set up

1. Put in black powder charge with properly connected e-match.
2. Put parachutes into inner tube and link system together with intersection shock cord.
3. Attach recovery bulkhead to inner tube.
4. Attach e-match to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
5. Put pin in fuse box.

Test Variables

- Integration of piston into system

Results and Conclusions

- Successful test! Drogue deployed with piston, and black powder charge functioned as intended.

<Drogue deployed due to black powder charge>

Ground Tests

COTS Components Verification

The first tests we ran were just evaluating advertised values for the COTS components of the system. For this, we tested the coefficient of drag for our backup drogue parachute and the backup COTS main parachute. We also tested other values, such as mass and volume, of the components. An additional round of testing involved running empirical tests on specimens of shock cords to determine the minimum breaking strength observed. This was consistently about 40-60% of the advertised technical specifications.

<Cd test = “12-16 Parachute Testing”>

SRAD Components Verification

We tested the coefficient of drag for our primary drogue parachute and primary main parachute using vehicle, on foot, and in flight tests. We also tested other values, such as mass and volume, of the components.

Separation Tests

In addition to the above general tests we ran a number of tests to evaluate the three critical objectives of the system: separation, drogue deployment, and retention cutting. We ran over 20 independent separation tests, evaluating a number of aspects of the system. We tested to confirm that 25g of CO_2 (see <CO2 Separation Ground Test Report>) and 3 grams of black powder (see <Black Powder Separation Ground Test Report Phase 1>, <Black Powder Separation Ground Test Report Phase 2>) would each be enough to separate the rocket with the designated number of shear pins. Due to the concern about improper installation of the CO_2 system, we opted to include a black powder backup system to force separation of the rocket should the CO_2 system fail. For this, we place 3g of black powder in the coupler between the airframes, with kevlar lining inserted in front of the drogue parachute.

Drogue Deployment Tests

We successfully tested drogue deployment and confirmed that the CO_2 system has a fairly high degree of reliability, with no noted failures thus far. Our only concern is a lack of flight testing. We also tested black powder drogue deployment and confirmed that it will be effective as a backup mechanism.

<CO2 Drogue Deployment Ground Test Report>

<Black Powder Drogue Deployment Ground Test Report>

Retention System Tests

We successfully tested the retention system and confirmed that the tether system has a fairly high degree of reliability, with no noted failures thus far. We ran a number of tests with this system, with only the Launch 3 test posing a concern. However, we have diagnosed the premature release of the main parachute to be due to the increase in force on the drogue given early separation of the airframes.

<Main Deployment Ground Test Report>

Flight Tests

Launch 1 (TCC)

First subscale flight test to 10,000 ft with our new 3” restricted diameter mechanism. Integration was mostly successful with some pressure sealing issues -- addressed with tacky-tape, will be fixed next time with better manufacturing tolerances. During launch, drogue deployment successful, pressurized ejection successful. Drogue shock-cord and intersection shock-cord tangling, however, preventing main from deploying. This ultimately resulted in a rocket impact speed at approx. 70 ft/s.

<see Launch 1 (LUNAR) 20180>

Launch 2 (LUNAR)

The first flight test was a low launch to a few thousand feet, which was intended to help us verify many of our load numbers. Due to complications, we were unable to test the recovery system in flight. However, post flight analysis showed a successful set-up of the system and correct deployment on ground after the flight.

<see Launch 2 (LUNAR) 20180414>

Launch 3 (TCC)

In this flight test, the CO2 separation charge was sent early, confirming the success of that system but subsequently causing the main and drogue parachutes to deploy prematurely. The SRAD main parachute fully and visibly deployed, and came down at a what appeared to be a very safe speed.

<see Launch 3 (TCC) 20180518>

Future Tests

We plan to perform tensile strength tests at the Blume Earthquake Center on the various quick links we use to confirm COTS accuracy. We also plan to use NASA Ames’ wind tunnels to verify SRAD coefficients of drag and opening force rates.

Main and Drogue parachute Coefficient of Drag testing 12/16

Method

Used a standard automobile to pull the parachute at constant speed and allow full inflation of the parachutes, measure force on force gauge attached to parachute and held within vehicle. Vehicle drives approximately 100 yards at the constant test speed, measured forces averaged.

Specifications

Main Parachute

96” FruityChutes Iris Ultra Standard Parachute
Shape: half-torus
Shroud lines length: 10 feet
Frontal area: 7,200 in^2, 4.668 m^2 (96/2)^2*\pi Should actually measure diameter
Surface area:

Drogue

48” Spherachutes heavy duty drogue parachute
Shape: Standard hemisphere
Shroud line length: 3 feet
Frontal area: 48” is half circumference ⇒ r = 15.27 ⇒ a = 732.5”^2 = 0.471m^2

Experimental Measurements

Main

Speed: 14 mph = 6.25 m/s (/ 110% = 5.67 m/s)
Drag Force: 50-55lb average (222 - 244 N)

Drogue

Speed: 25 mph = 11.17 m/s (/ 110% = 10.15 m/s)
Drag Force: 10 lb average (44.5 N)

Points of error

Speed measured by car speedometer, generally imprecise speed + 10%
Force measured by hand as the car was driving. Much variation observed over time. Average of results measured during constant vehicle speed phase is presented.
Vehicle Draft: Main held approximately 10 feet behind car.
Drogue held out of the side of the car (window) to limit drafting effects

Calculations:

$$F = \frac{1}{2}\rho v^2 C_d A \rightarrow C_d = \frac{2F}{\rho v^2 A}$$

Assuming air density at 15°C and sea level - approximately correct - 1.225 kg/m^3

Cd_Main

Drag Force [N]	Speed [m/s]	Cd
222	5.67	2.41
244	5.67	2.65
222	6.25	1.98
244	6.25	2.18

Cd_Drogue

Speed [m/s]	Cd
10.15	1.49
11.7	1.12

At a constant drag force of 44.5 N
(2 * 44.5) / (1.225*10.15^2*.471) = 1.49
(2 * 44.5) / (1.225*11.7^2*.471) = 1.27

Conclusions

Due to likely lower than measured speed and non-full exposure to air velocity, measurements are likely underestimates. However, both lower and upper bounds of the resultant drag coefficients are within margin, for both drogue and main parachutes.

SSI Test Report - Redshift

Team Testing: Recovery			
Name of Test: IREC 2018 w/ Restricted 3” Diameter Ground Ejection Test w/ Live CO2 & BP Charges		Version: 1	Date: 2/16/18
Names of testers: Daniel Shorr, Derek Phillips			
Successful?	Y/N	Location: Outside ESIII Garage (Loading-bay)	

Purpose:

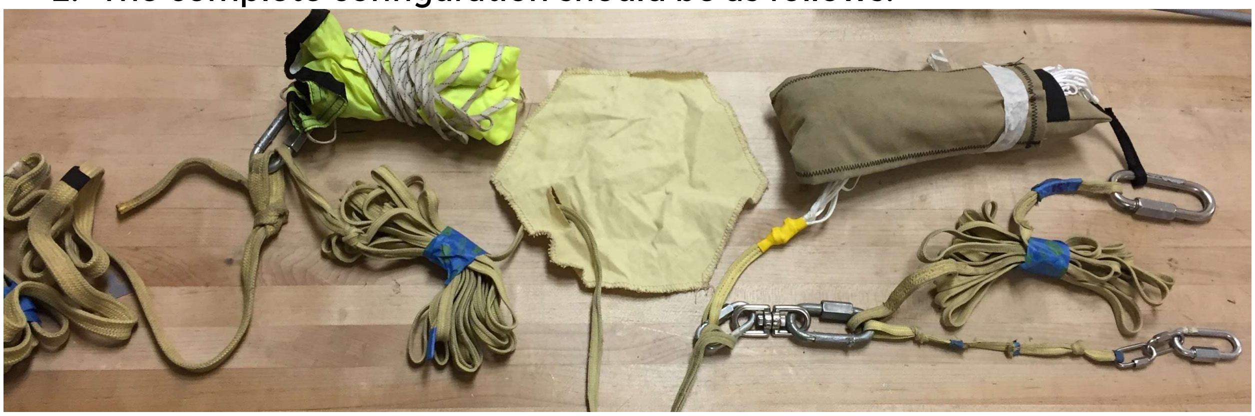
Confirm that the new restricted 3” diameter configuration (to accommodate the introduction of staging mechanism) for recovery operates as expected, including pressurization and ejection sequence.

Materials list:

4” Fiberglass airframe & 3” phenolic innertube w/ 3D printed adapter	4” Fiberglass Coupler
Recovery bulkhead & Pyrotechnic components	COTS drogue, new COTS 76” ultra compact main, 3” deployment bag for main
Relevant Shockcords & Quicklinks	Kevlar sheets
CO2, BP charges & relevant ematches	Remote detonator & set of airframe stands

Procedure:

1. Configure the new IREC recovery bay following the revised instructions (see recovery assembly procedure), notably:
    a. Install the brand new restricted 3” diameter via the threaded adaptor and centering ring
    b. Replace main with fruitychutes 76” ultra-compact + 3” dia 9” length deployment bag
2. The complete configuration should be as follows:



3. Arrive at the outside loading bay and set the recovery cannon atop the airframe holders, minding the ricochet
4. Clear the area and connect the leads of the remote ignitor to the drogue CO2 Charge
5. Ignite the CO2 system, observe and record the results
6. With someone pulling on the drogue (applying relatively constant force), ignite the main retention system
7. Much like before, observe and record the results

Data:

Criterion\Deployment Event	Drogue	Main
Successful Pressurization/Separation	Yes	Yes
Correct Connections w/ Shock-cord	Yes	Yes
Minimal Tangling/Damage	Yes	Yes

Results:

Ground testing suggests that our new inner tube configuration is valid! Drogue came out under CO_2 pressurization and main was retained appropriately. It appears that all components were performing to spec and we look forward to implementing the system for our flight test!!! One thing to note, however, is that the packing of the assembly is integral to how the system performs. With that, following packing instructions will be really important.

SSI Test Report - Redshift

Team Testing: Recovery			
Name of Test: Revised IREC 2017 Ground Ejection Test w/ Live CP2 & BP Charges		Version: 1.5	Date: 2/1/18
Names of testers: Daniel Shorr, Derek Phillips			
Successful?	Y/N	Location: Outside ESIII Garage (Loading-bay)	

Purpose:

Confirm that pressurization and ejection sequence are still correct after incorporating feedback from the previous IREC configuration.

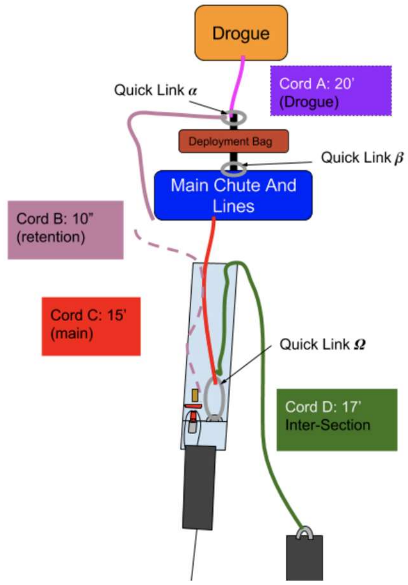
Materials list:

4" Phenolic airframe	4" OD plastic nosecone
Recovery bulkhead & Pyrotechnic components	COTS drogue, COTS main, deployment bag for main
Relevant Shockcords & Quicklinks	Kevlar sheets
CO2, BP charges & relevant ematches	Remote detonator & set of airframe stands

Procedure:

1. Configure the IREC recovery bay following instructions from the year prior with 2 notable exceptions

   a. Instead of the SRAD main, use the COTS 96" Fruity Chutes counterpart
   b. Do not install the backup kevlar cutter system for main retention
2. The complete configuration should be as follows:



3. Arrive at the outside loading bay and set the recovery cannon atop the airframe holders, minding the ricochet
4. Clear the area and connect the leads of the remote ignitor to the drogue CO2 Charge
5. Ignite the CO2 system, observe and record the results
6. With someone pulling on the drogue (applying relatively constant force), ignite the main retention system
7. Much like before, observe and record the results

The exploded set-up prior to installation within the mock airframe:

Note: Pressurization was provided by the plastic nosecone attachment (see the image at the bottom)

Data:

Criterion\Deployment Event	Drogue	Main
Successful Pressurization/Separation	Yes	Yes
Correct Connections w/ Shock-cord	Yes	Yes

Results:

Conclusion:

The verification of last year's recovery set-up was successful! With the exception of what's featured in the photo above -- the deployment bag for the main chute is visibly charred from the BP actuation. We will take care to protect main with appropriate kevlar sheeting in the future as we transition to a restricted diameter set-up.

SSI Test Report - Redshift

Team Testing: IREC Recovery			
Name of Test: Separation Ground Tests (3 individual tests)		Version: 1.0	Date: 4/14/17
Names of testers: Chloe Glikbarg, Skye Vandeleest, Max Newport			
Successful?	**Y**/N	Location: Stanford, LUNAR	

Purpose:

Confirm black separation of airframes with new staging mechanism.

Materials list:

- Airframe (forward and aft)
- Main and drogue parachutes
- Main parachute deployment bag
- Coupler (12" long)
- Fuse box
- E-matches
- Shear pins (#6)
- Black powder (3 gram charge)
- Safety glasses
- Test stand
- Tools
  - Drill and bits/driver bits
  - Scissors
  - Extra screws
  - Extra shear pins

Procedure:

Set up

1. Put in black powder charge with properly connected e-matches.

2. Attach intersection shock cords to recovery bulkhead, main parachute, drogue parachute, and motor retainer.
3. Put parachutes into inner tube.
4. Screw in recovery bulkhead.
5. Attach coupler with shear pins.
6. Attach e-matches to wire from fuse box - BE CAREFUL AT THIS STEP - do not put pin in hole at all.
7. Stand back from test rig at least 30 feet.
8. Put pin in fuse box.

Test Variables

- Black powder charge quantity (3 grams)

Results and Conclusions

- Successful separation! Pressurization using a standoff ring on the recovery inner tube and tacky tape in the motor retainer holes dramatically decreased the size necessary to pressurize, and 3 grams of black powder proved to be the appropriate amount.

Pictures (w/ captions):

STANFORD STUDENT SPACE INITIATIVE

SSI Test Report - Redshift

Team Testing: Staging			
Name of Test: Airframe Separation Test		Version: 1	Date: 3/6/18
Names of testers: Gabe Alvarez, Max Newport, Tylor Jilk, Daniel Shorr			
Successful?	Y	Location: ESIII Basement	

Purpose:

Determine how actuation of the staging mechanism impacts airframe separation through simulation of the relative rocket motions near apogee.

Materials list:

Two fiberglass airframes (upper and lower)	2x Loading-bay dollies
Staging mechanism (completed)	2x Rocket airframe holders
Laptop	Electronics, Battery

Procedure:

1. Bolt the upper ring into the upper airframe. Bolt the lower ring and staging mechanism to the lower airframe.
2. Actuate the staging mechanism (i.e. clamps on), solely tightening with the power of the motor.

3. Place one airframe holder on each dolly, and seat the rocket horizontally between them. The two dollies should be immediately adjacent to one another.
4. Keeping the dollies together, begin accelerating the system to approx. 1 m/s and attempt to maintain speed.
5. Actuate the mechanism, giving airframes time and space to passively separate.
6. Observe trajectory and measure both time for separation and final distance between.
7. Repeat 3 times, then switch the two dollies and repeat another set.

Note:

Data:

Test #	Separation (Y/N)	Misaligned (Y/N)	Notes
1	N	N/A	Dropped Dolly Handle*
2	Y	Y**	
3	n/a	n/a	

Additional Notes:

*First test failed, likely not due to issues with the separation mechanism, but because the high friction of the handle on the ground caused the front dolly to rapidly slow with respect to the back dolly
**At release, the sections appeared to be misaligning rapidly, although they were stopped from doing so by the retaining straps that we placed to protect the wires that spanned the interface

Results:

The first test failed to fully separate because the dolly's handle quickly stopped the front dolly (which actually resulted in the airframes being pushed back together). However, in the second test, the airframe separated extremely quickly after electromechanical release, with significant misalignment. The airframes continued to separate after release, and likely would have continued to do so, had we not placed retention straps between the dollies (necessary because our electrical configuration spans the airframes.

Conclusion:

While we were unable to run a third test due to battery constraints, we feel from this level of testing that the mechanism is capable to seperate freely while in motion, as long as some differential force on the upper and lower airframes is present. More simulations are required to ensure that enough force difference is present to allow this separation to occur on a reasonable time scale when we are flying slowly near apogee. However, in all, this test provides confidence in the system's ability to separate and misalign such that the drogue can be deployed without interacting with the lower airframe.

Pictures (w/ captions):

Below: Airframe after Trial 1. Slight misalignment, clamps fully retracted, but the airframes

did not separate (see note in Data).

Below: Airframe shortly after separation, beginning to misalign (the retaining strap on the bottom stopped further misalignment).

SSI Test Report - Redshift

Team Testing: Staging		
Name of Test: Functional Test	Version: 1	Date: 2/11/18
Names of testers: Max Newport, Tylor Jilk		
Successful? No		Location: Dragon

Purpose:

To verify the basic functionality of the final version of the staging mechanism. Success will be determined if the ring for the upper airframe falls freely after the staging mechanism is actuated.

Materials list:

Staging Mechanism (complete)	
Laptop	
Battery for motor	
Electronics	

Procedure:

1. Holding motor assembly upside-down, as if rocket's nose cone is pointing downward, actuate the staging mechanism as if releasing the rocket for decoupling.

2. The ring that mounts to the upper airframe should separate, falling away from the mechanism relatively unhindered by the clamps.
3. Repeat three times.

Data:

Test Number	Success (Y/N)
#1	N
#2	N
#3	N

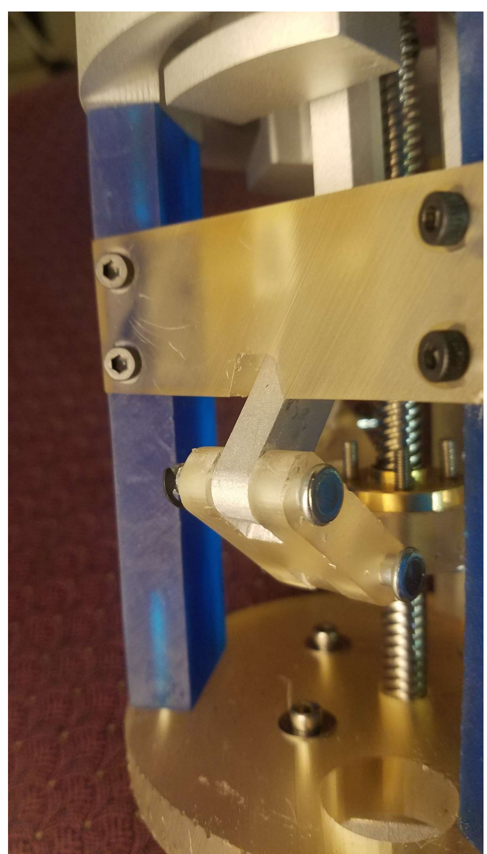
Results:

There is too much friction to fully actuate the arms, such that the upper flange cannot disengage entirely from the mechanism. Specifically, where the pivots slide into slots in the supporting structure needs to have a higher tolerance.

Conclusion:

More tolerance required at a critical intersection point between the pivots and supporting structure. It is possible, however, to open the mechanism by hand, at which point the upper flange falls off with no resistance.

Pictures (w/ captions):



A close-up photo of the intersection point which needs more tolerance (right):

SSI Test Report - Redshift

Team Testing: Staging		
Name of Test: Battery Test	Version: 1	Date: 3/14/18
Names of testers: Max Newport, Tylor Jilk, Gabe Alvarez		
Successful? Y		Location: ISS Destiny

Purpose:

To verify the battery life of our power supply and measure the current through the motor as a function of time to test the longevity of the electronics.

Materials list:

Staging Mechanism (complete)	Multimeter
Laptop	
Battery for motor	
Electronics	

Procedure:

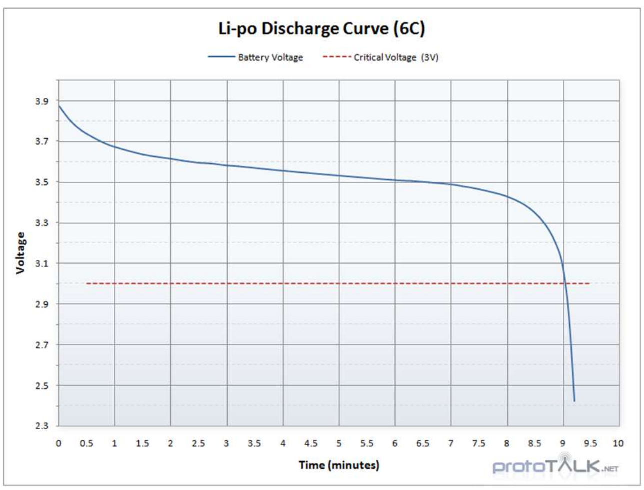
1. Connect electronics to staging mechanism with multimeter in series.
2. Actuate clamps.
3. Measure current through the stepper motor as a function of time.

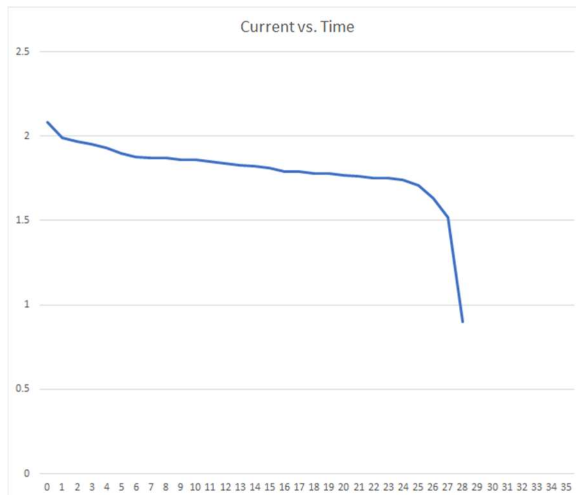
Data:

Time (min)	Current (A)
0	2.08 (7.4 V)
1	1.99
2	1.97
3	1.95
4	1.93
5	1.9
6	1.875
7	1.87
8	1.87
9	1.86
10	1.86
11	1.85
12	1.84
13	1.83
14	1.82
15	1.81
16	1.79
17	1.79
18	1.78
19	1.78
20	1.77
21	1.76

22	1.75
23	1.75
24	1.74
25	1.71
26	1.63
27	1.52
28	0.9 (6.5 V)

Results:





Conclusion:

The battery discharge curve closely mirrored the expected curve! We can run a holding current for about 25 minutes. However, we expect to need longer holding-times for our system, so we need to look into higher-power batteries or (long-term) more current-efficient motors.

Pictures (w/ captions):

See above.

SSI Test Report - Redshift

Team Testing: Staging		
Name of Test: Axial Bending	Version: 1	Date: 2/27/18
Names of testers: Gabe Alvarez, Max Newport, Tylor Jilk, Daniel Shorr		
Successful?	N	Location: ISS Destiny

Purpose:

To determine how well the staging mechanism can hold the upper and lower airframes together when an axial load is applied. I.e. bending test.

Materials list:

Two fiberglass airframes (upper and lower)	
Staging mechanism (completed)	
Laptop	
Electronics, Battery	

Procedure:

1. Bolt the upper ring into the upper airframe. Bolt the lower ring and staging mechanism to the lower airframe.

2. Actuate the staging mechanism (i.e. clamps on), solely tightening with the power of the motor. Apply Holding torque.
3. Hold the lower airframe horizontally, release,and measure how wide of a gap develops between the upper and lower airframes as a result of the gravitational load on the upper airframe, as well as the angle of declination with respect to the lower airframe. For this test, we will be placing a 10.78lb weight at ~1m from the interface to simulate a fraction of the load of the actual rocket.
4. Repeat three times.

Note: The fiberglass coupler prepared for launch #2 (without any tape) has a bend of 0.7 degrees, with unloaded forward airframe and a 10.78lb weight placed atop the airframe at ~1m. We will use this as a benchmark for our success, accepting anything less than or equal to 1 degree of declination as adequately small bend.

Data:

Test #	Upper Gap (mm)	Angle of Declination (deg)	
1	1.79*	1.0*	
2	**	**	
3	***	***	

Additional Notes:
*This test was done with no load, simply as a metric to compare with the loaded measurements. Also, no holding torque was applied on the motor.

** Upon applying the weight to the airframe, the center piece (see Pictures section) fractured at the edge of where the clevis pins interfaces with the horizontal linkage. The horizontal linkage also fractured. This fracture may have resulted from a pre-existing crack in the plastic, but either way it indicates an inability of the material to withstand the necessary axial load. We will likely re-design the center piece (and the horizontal linkages) with thicker walls around the clevis pins to reduce the likelihood of fracture. Prior to fracture, there was significant bending, on the order of multiple degrees. The test was stopped in order to prevent further damage and to await a new center piece (and/or other improved components).

***After replacing the broken components with new pieces (identical to previous pieces), we repeated another trial to see if we could repeat the break. No parts fractured- instead, about when the full weight of the 10.78lb was given to the airframe to support, the shear pins broke just below the head. While this doesn't indicate system failure, it still shows that the mechanism cannot withstand extreme bending. Further tests and evaluations of possible axial load are necessary.

The electronics also had some issues with heating up and maintaining the proper voltage.

Results:

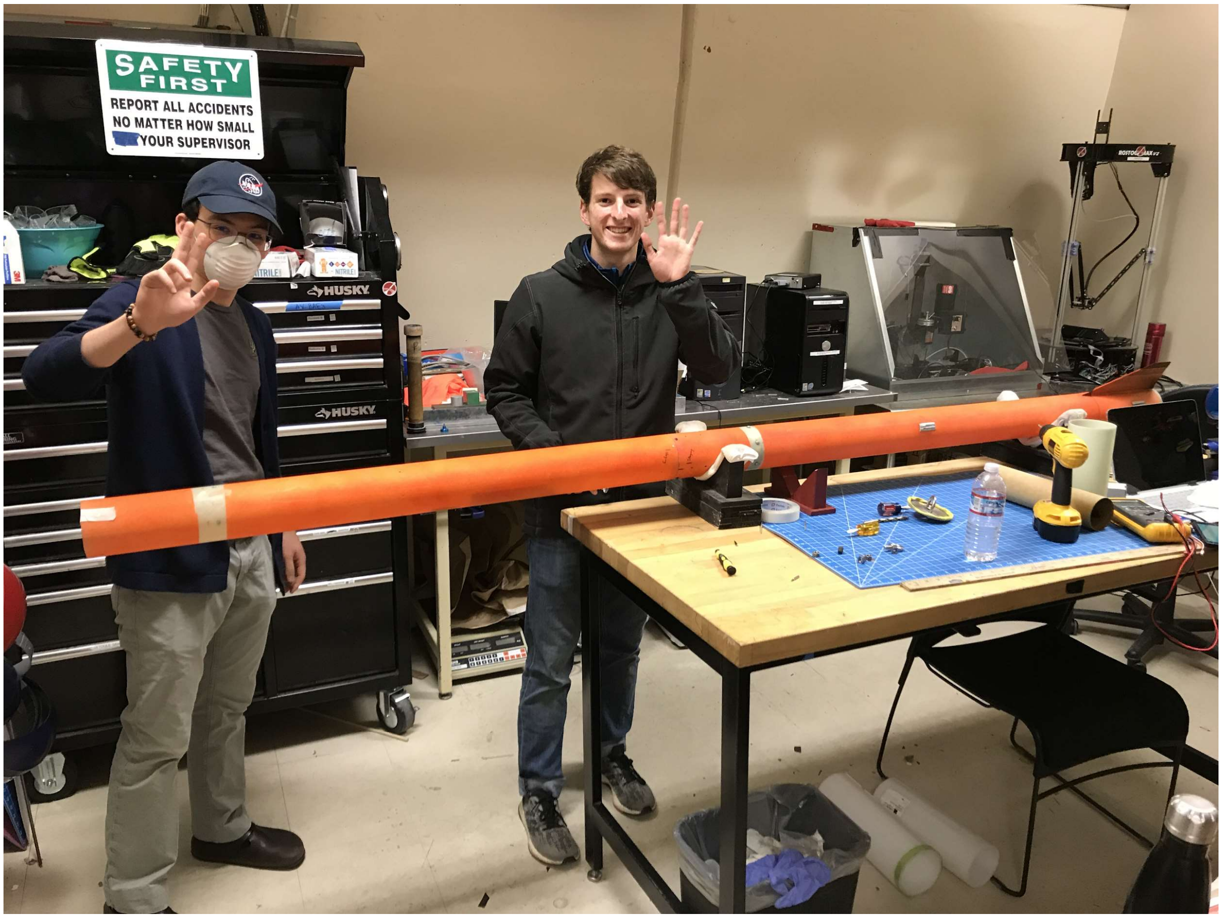
The test was stopped, after a component of the mechanism fractured while applying load. Without load, the mechanism performed exceptionally well, but under high duress, it began to bend significantly before breaking at a failure point. When not fracturing a piece, high axial load caused the shear pins to break preemptively.

Conclusion:

The failure points of the mechanism need to be considered and improved to have higher load tolerance before fracture. Without holding torque and with the current design, the system is unable to adequately prevent axial bending.

Pictures (w/ captions):

Below: The staging mechanism supporting the (empty) forward airframe, unsupported. Bending is imperceptible in the photo. Here, no weight has been applied yet.


SAFETY FIRST
REPORT ALL ACCIDENTS
NO MATTER HOW SMALL
YOUR SUPERVISOR
HUSKY
HUSKY

Below: The fractured components from the second trial. The horizontal linkage fractured at the end where it connected to the center piece.

SSI Test Report - Redshift

STANFORD STUDENT SPACE INITIATIVE

Team Testing: Staging			
Name of Test: Functional Test		Version: 1	Date: 2/11/18
Names of testers: Max Newport, Tylor Jilk, Gabe Alvarez, Daniel Shorr			
Successful?	Y	Location: Dragon	

Purpose:

To verify the basic functionality of the final version of the staging mechanism. Success will be determined if the ring for the upper airframe falls freely after the staging mechanism is actuated.

Materials list:

Staging Mechanism (complete)	
Laptop	
Battery for motor	
Electronics	

Procedure:

1. Holding motor assembly upside-down, as if rocket's nose cone is pointing downward, actuate the staging mechanism as if releasing the rocket for decoupling.
2. The ring that mounts to the upper airframe should separate, falling away from the mechanism relatively unhindered by the clamps.
3. Repeat three times.

Data:

Test Number	Success (Y/N)
#1	Y
#2	Y
#3	Y

Results:

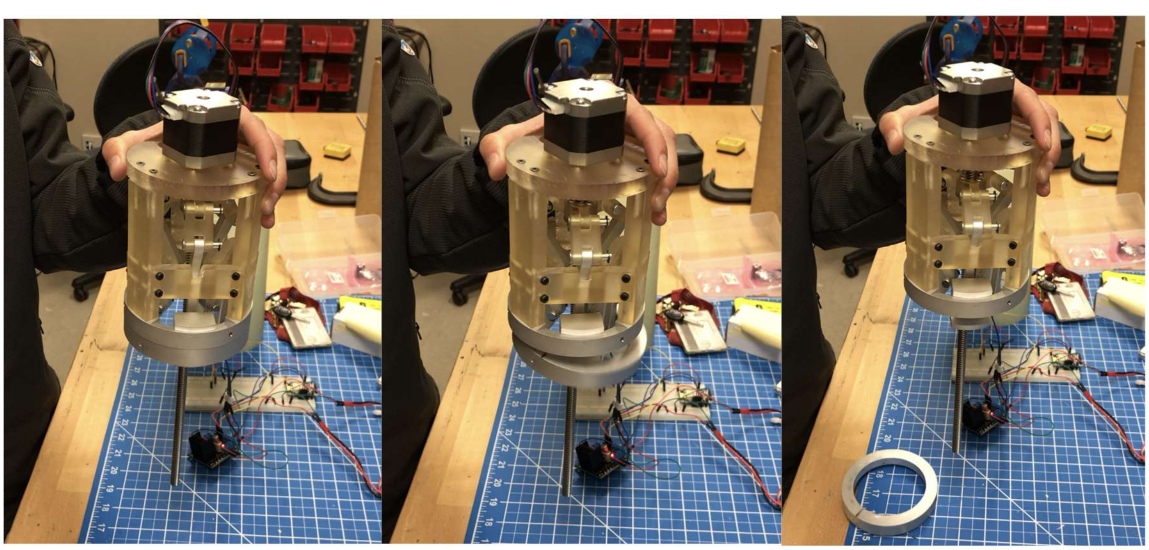
The mechanism successfully achieved full release, allowing the upper flange to drop freely. This success was repeated thrice.

Conclusion:

The mechanism is able to adequately "stage" under very basic, low stress scenarios. This allows us to continue to more high stress testing, now that we have demonstrated the system's basic functionality.

Pictures (w/ captions):

Below is the mechanism as the mechanism opens and releases the ring to fall.



STANFORD STUDENT SPACE INITIATIVE

SSI Test Report - Redshift

Team Testing: Rockets - Structures			
Name of Test: X-Winder Initial Test		Version:1	Date:4/10/2018
Names of testers: Ben, Marie			
Successful?	N	Location:Dragon	

Purpose:

Preliminary Experimentation with the X-Winder

Materials list:

() = planned on using but didn't get there

Fiberglass Reel	X-Winder (and software)
Epoxy (209 Hardener)	Packaging Tape
Cash Register Tape	(heat gun)
(shrink wrap tape)	Mandrel (the test one)

Procedure:

1. Pre-wrap(PW) layer 1: Extend the ends in the G-Code a little
    a. To open up G-Code files, go to Build->Launch Executor w/o G-Code and then open the G-Code file from within the executor

   b. By Hand: Max RPM ~8 for human use
2. Pre-Wrap Layer 2: Extended as in pre-wrap layer 1
   a. For Future use, PW layer 1 should extend a few inches past PW later 2
   b. By Hand: Max RPM ~8 for human use
3. Winding of the filament
   a. 40 degree angle
   b. 5" tube
   c. Standard filament characteristics as given by supplier

Results:

While we did somewhat manage to get the pre-wrap layers on, the actual filament did not work. It seemed to go over a small ~2" section of the mandrel over and over again and didn't actually go to the ends. This led to a large buildup there and not an actual nice layout on the mandrel as we wanted.

Additionally, we also forgot to use rubber bands to hold down the wiper blade, so the epoxy ran out quickly and dripped from the mandrel extensively (but paper towels were in place to catch it)

Conclusion:

We need to figure out how to properly do the prewrap layers, but I think our plan for how to do it is solid.

On the other hand, we aren't exactly sure what went wrong with the winding itself, so that will be investigated in the next test.

Pictures (w/ captions):

STANFORD STUDENT SPACE INITIATIVE

SSI Test Report - RedShift

Team Testing: Overall			
Name of Test: Test Launch 3		Version:	Date: 5/18/18
Names of testers: Full Team			
Successful?	N	Location: TCC	

Purpose: Full configuration test launch.

Materials list:

Procedure:

1.

Data: (modify this section to suit your needs)

Results:

- Nominal rocket takeoff.
- Shortly after Mach transition, premature deployment event.
- Aft and middle airframe recovered. Parachutes, nose and AV Bay lost.

Conclusions:

- Full systems test drastically increased efficiency and ease of on-site assembly
- Place “return to” messages on crucial parts of the system that could get lost

Pictures (w/ captions): (see attached drive).

STANFORD STUDENT SPACE INITIATIVE

SSI Test Report - Redshift

Team Testing: Rockets - Structures			
Name of Test: X-Winder 10 Inch Test 1		Version:1	Date:4/14/2018
Names of testers: Ben, Tori			
Successful?	No	Location: Dragon	

Purpose:

Attempt to make a 10" tube on the XWinder

Materials list:

Fiberglass Reel	X-Winder (and software)
West System Epoxy (209 Hardener)	Packing Tape
Cash Register Tape	Heat Gun
Heat Shrink Tape	Mandrel (4" OD phenolic tube)

Procedure:

1. Pre-wrap(PW) layer 1: Extend the ends a little beyond the intended winding area, Width 2.25"
    a. Do this by hand by adding distance on both ends in the software
2. Pre-Wrap Layer 2: Extended as in pre-wrap layer 1, width 1.8"

   a. PW layer 1 extends a few inches past PW later 2
   b. By Hand: Max RPM ~8 for human use
3. Winding of the filament
   a. 2 layers at 40 degree angle
   b. Speed: fast
   c. 10” tube
   d. Standard filament characteristics as given by supplier

Results:

The surface finish was significantly better on this piece than the previous piece. The edges have large bumps on them that will likely need to be cut off.

This piece did not slide off the mandrel easily. We were able to move it to the end of the mandrel, but then had to destroy the mandrel to get the piece out.

Conclusion:

The uneven surface finish on the first piece was most likely caused by the buildups on the edges that we saw on the this test piece. For the real airframes we will most likely need to cut off about 2” on each end to remove these buildups.

We are unsure why this test piece got stuck when the last piece did not. We think it may have been caused by winding it on fast mode rather than on medium. More testing will need to be done.

Pictures (w/ captions):

SSI Test Report - Heart of Steel

Team Testing: Recovery			
Name of Test: **Textile Tensile Testing**		**Version:** **1.0**	**Date:** **2017-05-22**
Names of testers: Thomas White, Logan Herrera			
Successful?	**Y**	**Location:** **Blume Earthquake Engineering Center Stanford**	

Purpose:

This test will establish a lower bound on the tensile strength of shock cords and shroud lines. It will also verify shock cord is sufficient for deployment loading conditions and inform whether larger shock cords are required for the forward airframe - aft airframe connection. Results will also verify shroud line type and count is sufficient for parachute loading conditions.

Materials list:

5x shroud lines, sewn end loops
5x medium kevlar shock cords, sewn end loops
5x think kevlar shock cords, tied end loops
2x dowel pin grips for tensile testing machine

Procedure:

1. Set load rate to 2" per 3 minutes. Beware 5 inch max displacement
2. Place sample loops on dowel pins
3. Tighten collets to secure dowel pins
4. Take before photos

5. Point video camera, start video
6. Verbally announce start of test to synchronize video with data trace
7. Pull until failure
8. Stop video
9. Remove sample from tester
10. Uniquely label sample according to filename

Data:

Each sample was tested to ultimate failure. Rated underlying material strengths were:

- Shroud line - UHMWPE - 550 lbs
- Thin Kevlar - Kevlar - 2,000 lbs
- Thick Kevlar - Kevlar - 6,000 lbs

Shroud Line	**Thin Kevlar**	**Thick Kevlar**
210.9808	1176.655	2595.345
250.0693	1207.374	2564.191
237.3044	1656.056	2706.257
246.873	1388.887	2844.791
	1165.477	
Mean:	Mean:	Mean:
236.306875	1318.8898	2677.646
Minimum:	Minimum:	Minimum:

210.9808	1165.477	2564.191

Results:

1. Shroud line failure was gradual. The threads failed and stitches pulled out of the line one by one.
2. Stitched kevlar failure was sudden (brittle). Every stitch failed simultaneously. No threads pulled out. Both kevlar and nylon thread failed the same way.
3. Knotted kevlar failure was gradual. All failures were at knots.

Conclusion:

All specimens failed at approximately 40%-60% of the underlying material strength. This test shows significant derating is required when designing with rope and cord.

The stitched Kevlar shock cords failed suddenly and each stitch failed simultaneously and independently. Therefore increasing the number of stitches will increase strength at failure, potentially up to the strength of the underlying material. All future shock cords will be sewn in this manner.

Pictures (w/ captions):

Representative test setup: Double sewn loop shock cord specimen tensile loaded between dowel pins

SSI Test Report - Redshift

Team Testing: Avionics			
Name of Test: AV Bay Quanta Labs Vibration Test		Version: 2.2	Date: 4/9/2018
Names of testers: Rayan Sud, Chloe Glikbarg			
Successful?	Y	Location: Quanta Labs, Santa Clara	

Purpose:

To verify that the avionics bay of the rocket will hold up to random vibrations during flight at IREC

Materials list:

6x ⅜” bolts
8x 3/16” bolts
IREC AV Bay 2.2
Delrin vibe test jig
Misc. washers

Procedure:

1. Slide the AV Bay into a test airframe, with the PCB plane parallel to the shaker table

2. Orient the airframe with the thrust axis parallel to the axis of vibration
3. Secure the bottom part of the vibe test jig into the Quanta shaker table using the ⅜" bolts and washers (note: washers are critical as the Delrin is too soft to screw into tightly)
4. Place the four vibe jig fasteners on top of the airframe, aligning them with the holes in the bottom part of the jig, and screw them in with 3/16" bolts.
5. Run 10 G rms vibration for 20 seconds
6. Disassemble the jig, and rotate it 90° so the thrust axis is perpendicular to the vibration axis
7. Run 7.8 G rms vibration for 20 seconds
8. Rotate the AV bay inside the airframe, so that the PCB plane is normal to the shaker table
9. Run 7.8 G rms vibration for 20 seconds

Results:

Test successful - no systems were damaged in any way

Conclusion:

The avionics bay holds up to NASA sounding rocket vibration standards, and is ready to be flown at IREC.

Pictures:

Fig. 1 - The shaker table, with the bottom half of the vibe jig pictured before being fixed

Fig. 2 - The fully installed jig in the thrust-axis orientation, with top fastening blocks, being tightened

Fig. 3 - Fully installed jig, looking down the airframe to the bay

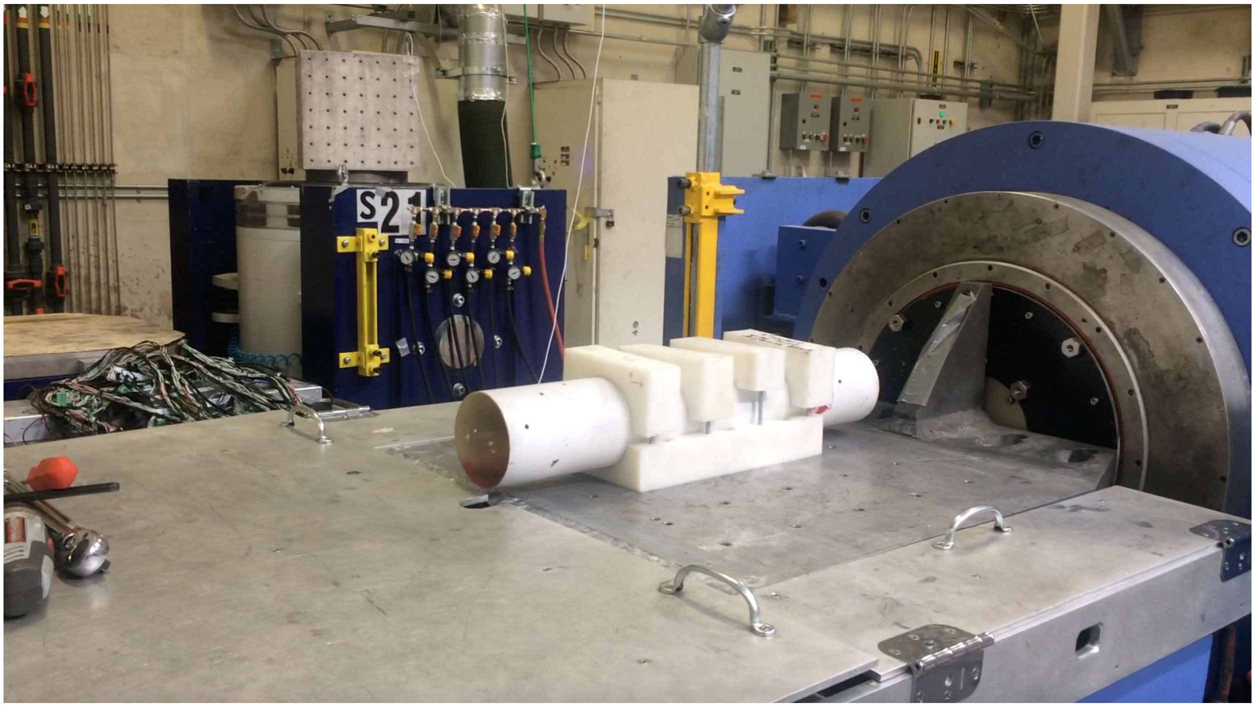


Fig. 4 - Picture of the jig fixed on the vibration table, undergoing 10G rms vibration

SSI Test Report - Redshift

Team Testing: Avionics			
Name of Test: SRADio Skyline Test		Version: S6B	Date: 01-13-18
Names of testers: Sasha, Sharon, Joan, Matthew			
Successful?	Y	Location: Skyline	

Purpose: To validate and test the limits of long range operation of the SRADio (Student Researched And Designed Radio) system. This system will be used to downlink live telemetry from the IREC rocket to a ground station. This test was important because short range tests with more attenuation have a greater potential for RF to leak off of or be picked up on the traces on the the board themselves, bypassing the attenuation.

Materials list:

1. Two SRADio units
2. Carbon fiber airframe tubes
3. Ground station antenna
4. Flight antenna

Procedure:

1. One team drove up to a vantage point on Skyline Blvd, while the other team drove up to the Stanford radio shack, near the dish. This distance is about 10km.
2. The team on Skyline used the flight antenna and airframe pieces to simulate the environment that the system operates in.
3. The team at the radio shack used the ground station antenna.

The following steps were repeated under varying conditions of added attenuation and bitrate.

4. Bitrate and amount of attenuation to add to the receiver are agreed upon.
5. Receiving is started.
6. Transmission is started.
7. The Skyline team counts out 20 packets, while the radio shack team counts the number of packets received during the same interval of time.
8. The difference between 20 and the number of packets received as well as longer delays between individual packets being received are used to determine the number of packets received.

Data: (modify this section to suit your needs)

The physical distance between the transmitter and receiver for each test was 10km. Each test was conducted with 20 packets, each spaced by about 1 second apart.

We solve for the simulated distance using the following formula, where A is attenuation in dB, P1 is the power density without attenuation, P2 is the power density with attenuation, D1 is the physical distance, and D2 is the simulated distance.

$$\frac{P2}{P1} \sim \frac{1}{\left(\frac{D2}{D1}\right)^2}$$

$$\frac{P2}{P1} = 10^{\frac{-A}{10}}$$

Therefore $\frac{1}{\left(\frac{D2}{D1}\right)^2} \sim 10^{\frac{-A}{10}}$

Therefore $D2 = D1\sqrt{10^{\frac{\;}{10}}}$

Added attenuation (dB)	Bitrate (kB/s)	Simulated distance (km)	HCTX	Results
10	0.5	31	n	All errors corrected successfully if present
10	5	31	n	Some errors, all corrected successfully

10	50	31	n	Errors present, all corrected successfully
10	150	31	n	Nothing received
0	150	10	n	About half of the packets dropped, but those received were corrected successfully
0	0.5	10	y	All packets received without errors
20	0.5	100	y	All packets received without errors
30	0.5	310	y	Almost all packets dropped
26	0.5	200	y	Most packets received and errors corrected successfully, but some packets dropped

Results:

The SRADio system performed well at 5 and 50 kB/s at a simulated distance of 31 km. This is approximately the maximum distance that the rocket will fly away from the ground station, and these are the bitrates and we are interested in using for data transmission. Few packets were dropped, and those that were received with errors were successfully corrected.

Conclusion:

The test was successful because the SRADio system was validated at and beyond the distances that will be experienced during the IREC launch.

Pictures (w/ captions):

STANFORD STUDENT
SPACE INITIATIVE

SSI Test Report - Redshift

Team Testing: Rockets - Structures			
Name of Test: X-Winder 10 Inch Test 2		Version:1	Date:4/16/2018
Names of testers: Ben, Tori			
Successful?	No	Location: Dragon	

Purpose:

Attempt to make a 10” tube on the XWinder that can be slid off the end of the mandrel.

Materials list:

Fiberglass Reel	X-Winder (and software)
West System Epoxy (209 Hardener)	Packing Tape
Cash Register Tape	Heat Gun
Heat Shrink Tape	Mandrel (4” OD phenolic tube)

Procedure:

1. Pre-wrap(PW) layer 1: Extend the ends a little beyond the intended winding area, Width 2.25”
    a. Do this by hand by adding distance on both ends in the software

2. Pre-Wrap Layer 2: Extended as in pre-wrap layer 1, width 1.8”
   a. PW layer 1 extends a few inches past PW later 2
   b. By Hand: Max RPM ~8 for human use
3. Winding of the filament
   a. 2 layers at 40 degree angle
   b. Speed: medium
   c. 10” tube
   d. Standard filament characteristics as given by supplier

Results:

The surface finish of this piece was comparable to the previous 10” piece we attempted. However, the piece still got stuck on the end of the mandrel.

Conclusion:

The winding speed was not the cause of the inability to remove the piece from the mandrel. We think the additional friction caused by the increased length of the tube is what is causing our problems. To rectify this we are going to run our next test on a metal mandrel which should have less friction than the phenolic mandrel.

Pictures (w/ captions):

SSI Test Report - Heart of Steel

Team Testing: Avionics		
Name of Test: SkyBass Continuity Test	Version:1	Date:6/2/2018
Names of testers: John Dean, Rayan Sud		

Successful?	Y	Location: ISS

Purpose:
Verify electrical connections on SkyBass board

Materials list:

Assembled SkyBass board
DC power supply
Laptop + USB Cable
Multimeter

Procedure:

1. Pull MCU_EN pin high from DC power supply
2. Plug in

Results:
Test successful - all

Conclusion:

Preliminary SkyBass functionality is verified, and further testing with code can be done

STANFORD STUDENT SPACE INITIATIVE

SSI Test Report - Redshift

Team Testing: Rockets - Structures			
Name of Test: X-Winder 10 Inch Test 3		Version:1	Date:4/16/2018
Names of testers: Ben, Tori			
Successful?	No	Location: Dragon	

Purpose:

Attempt to make a 10" tube on the XWinder that can be slid off the end of the mandrel.

Materials list:

Fiberglass Reel	X-Winder (and software)
West System Epoxy (209 Hardener)	Packing Tape
Cash Register Tape	Heat Gun
Heat Shrink Tape	Mandrel (4" OD aluminum)

Procedure:

1. Pre-wrap(PW) layer 1: Extend the ends a little beyond the intended winding area, Width 2.15"
    a. Do this by hand by adding distance on both ends in the software
2. Pre-Wrap Layer 2: Extended as in pre-wrap layer 1, width 1.7"

   a. PW layer 1 extends a few inches past PW later 2
   b. By Hand: Max RPM ~8 for human use
3. Winding of the filament
   a. 1 layer at 90 degrees (hoop)
   b. 2 layers 40 degrees (Add'l end angle of 360)
   c. 1 layer at 90 degrees (hoop)
   d. Speed: fast
   e. 10" tube
   f. Standard filament characteristics as given by supplier

Results:

This piece was not completed. The final hoop layer was not completely run. This caused a decrease in the quality of the surface finish.

Initially, we were unable to slide the piece on the mandrel at all. After allowing the mandrel to come to room temperature, we were able to slide the piece to the end of the mandrel where is got stuck on the uneven edges of the mandrel. We then attempted to use dry ice to cause the mandrel to contract further and while this did work, the piece was still stuck on the end of the mandrel. We ended up cutting the piece off of the mandrel.

Conclusion:

Decreasing the temperature of the mandrel appears to be an effective way to loosen the test piece from the tube. However, the edges of the tube will need to be sanded to prevent any snagging as the test piece is removed from the tube.

Pictures (w/ captions):

STANFORD STUDENT
SPACE INITIATIVE

SSI Test Report - Redshift (Work in progress)

Team Testing: Avionics			
Name of Test: Telemetry		Version:1	Date:4/1/2018
Names of testers: Tim Vrakas			
Successful?	Y	Location: ES3, Engr Quad	

Purpose:

Develop, Debug, and test the telemetry link. This included GPS, Skybass Processing, Serial Communication Protocols, SRADio encoding, RF link, Ground Station Code, Google Earth Visualization.

Materials list:

AV Bay 2.1
Ground Station RX
Gnd Antenna
Laptop

Procedure:

1.

Data: (modify this section to suit your needs)

Results:

Conclusion:

It works.

Pictures (w/ captions):

Need to take

SSI Test Report - Redshift

Team Testing: Rockets - Structures		
Name of Test: X-Winder 5 Inch Test	Version:1	Date:4/12/2018
Names of testers: Ben, Tori		
Successful? Y		Location: Dragon

Purpose:

Attempt to make a 5” tube on the XWinder

Materials list:

Fiberglass Reel	X-Winder (and software)
West System Epoxy (209 Hardener)	Packing Tape
Cash Register Tape	Heat Gun
Heat Shrink Tape	Mandrel (4” OD phenolic tube)

Procedure:

1. Pre-wrap(PW) layer 1: Extend the ends a little beyond the intended winding area
    a. Do this by hand by adding distance on both ends in the software
2. Pre-Wrap Layer 2: Extended as in pre-wrap layer 1

    a. PW layer 1 extends a few inches past PW later 2
    b. By Hand: Max RPM ~8 for human use
3. Winding of the filament
    a. 2 layers at 40 degree angle
    b. 5” tube
    c. Standard filament characteristics as given by supplier

Results:

While the surface finish was not very smooth, the XWinder successfully made a 5” tube. The pre-wrap went on with minimal difficulty, and the software ran the test piece as expected.

The test tube was fairly easy to remove from the mandrel after curing it with a heat gun for 30 minutes.

Conclusion:

So far the XWinder seems to be working as it should. The next step will be to start attempting to make longer pieces with more layers of fiberglass.

Pictures (w/ captions):

C. Hazard analysis

Hazards	Potential Cause	Risk (Likelihood and Severity) of Hazard and Rationale for Risk Assessment	Risk Mitigation Approach	Risk of Failure After Mitigation Approach
Fiberglass dust from machining	Insufficient precautions while drilling.	Medium - easy to do when hurried - proper venting can be difficult to assure outdoors.	Bring vacuum cleaner. Enforce use of it.	Low.
Fiberglass splinters	Handling of broken fiberglass.	Medium - difficult to handle even with safety precautions.	Prevent creation of splintered fiberglass. SOP to deal with it, including storage and disposal concerns.	Low
Transportation of black powder	No precautions taken	Low - repeated practice of transporting in ammo box	Team policy	Low
Transportation of motor grains	Static or other charge.	Low - motors are well qualified for safety.	Use of steel explosives box for handling. Team SOPs.	Very low.
Epoxy skin contact	Hurry, lack of precautions, insufficient safety equitment.	Medium - epoxy environment is cluttered and hurried.	Education. Simplification of environment. Reduction of time pressure.	Low
Transportation of e-matches	No precautions taken	Low - repeated practice of transporting in ammo box	Team policy	Low
Deployment during testing.	Avionics failure triggers ematches while being handled.	Medium - AV failues happen.	Comprehensive AV testing before hookup.	Low.
Fire hazard during ground testing.	Overloading of black powder, placement on flamable location, simultaneous deploy of all charges.	Medium - near fire has occured.	Fire retardants available. Charge concentrations carefully analyzed and kept low.	Low.
Machine tool risks.	Hurried use of tools, improper use of SOPs.	Low - SOPs are common.	Organizational safety culture. Oversight by several members. Safety procedures (like safety glasses) are made as convenient as possible.	Very low.

D. Risk assessment

reference: http://www.soundingrocket.org/uploads/9/0/6/4/9064598/example_risk_assessment.pdf					
Phase	**Hazards**	**Potential Cause**	**Risk (Likelihood and Severity) of Hazard and Rationale for Risk Assessment**	**Risk Mitigation Approach**	**Risk of Failure After Mitigation Approach**
Preflight	Separation of the rocket while transporting causes injury to handlers	Avionics inadvertently set off the ematch charges, while handlers of the rocket fail to avoid aligning the ends of the rocket with team members	Medium - With focus on handling and transporting the rocket, team members can be unaware of where the rocket is pointing and ematches can fire unexpectedly	One team member, not holding the rocket, is assigned to making sure the rocket is never pointed at a person and the pin switch is disarming the rocket until the launch pad	Low
	Rocket lifts off when pin is pulled and causes harm to team members at the pad	Igniter is ignited early	Low	do not wrap igniter wires around leads until after pin has been pulled	Very Low
	Explosions from black powder harm those in vicinity	Inadvertent impact to black powder charges or ematch firings while assembling the rocket	Medium - Black powder is extremely combustible	Team members are trained to handle black powder with care and once ematches are set, avionics responsible for firing are kept off until the launchpad	Low
	Rocket motor ignites prematurely and causes harm to bystanders	igniter fails	Low	only one member inserts and wraps igniter round leads and others stand 10 ft back	Very Low
Powered Flight	Rocket explodes off the pad and debris endangers viewers	The airframe is not structurally capable of handling an N-motor and it shreds on lift off	Medium - CATOs are a relatively common occurrence with high powered rockets	The composite airframe design and build were tested on five separate launches -- two of which attained supersonic flight with equivalent motor power to airframe ratio	Very Low
	Rocket falls off launch pad/rail tips and severely injures handlers	Launch lugs break once the rocket is stood up, allowing the rocket to tip	Medium - It is possible that if the weight of the rocket generates a shear force on the lugs when the rocket is stood up, the lugs will fail	Ensure that connection between railguides and rocket is as strong as possible. Safety officer is also responsible for keeping a watchful eye on the rocket at all times during set up	Very Low
	Motor does not ignite initially but fires when team approaches to troubleshoot	igniter issue or propellant issue	Medium	The team follows NAR protocol on procedure and time as to when the rocket is safe to approach	Very Low
	Deviates from flight path and comes into contact with personnel at high speed	Severe inertial roll coupling	Medium - Inertial roll coupling and play at airframe joints have been observed during previous test launches. Creating misalignment in the fins is a possibility during rigorous assembly of the rocket	The team will implement lessons learned to prevent inertial roll coupling (shim to maintain concentric thrust and robust retention system to hold the motor)	Very Low
		Damage to fins cause significant spiraling during powered flight		The team has a checklist to verify that the fins are undamaged and the rocket's condition does not pose a threat during lift off	
	Early separation and contents of rocket comes into contact with personnel at high speed	avionics trigger ematches early	Low	run avionics tests multiple times and gain flight heritage	Very Low
	Motor is not retained, breaks through rocket, and harms viewers	Improper assembly and install of the motor retention system	High - When motor retention systems are not able to be inspected visually, they are susceptible to failure	The team has designed a retention system that allows for clear visual inspection that the motor is being retained per the intended design	Very Low
Ballistic Flight	Deviates from flight path and comes into contact with personnel at high speed	Severe inertial roll coupling	Medium - Inertial roll coupling and play at airframe joints have been observed during previous test launches. Creating misalignment in the fins is a possibility during rigorous assembly of the rocket	The team will implement lessons learned to prevent inertial roll coupling (shim to maintain concentric thrust and robust retention system to hold the motor)	Very Low
		Significant wobble at the joints of the airframe create extreme instability		The team will hold multiple integration sessions to ensure that the combination of shear pins, bolts, and tape applied will minimize any potential wobble at the joints of the airframe	
		Damage to fins cause significant spiraling during powered flight		The team has a checklist to verify that the fins are undamaged and the rocket's condition does not pose a threat during lift off	

	Early separation and contents of rocket comes into contact with personnel at high speed	avionics trigger ematches early	Low	run avionics tests multiple times and gain flight heritage	Very Low
	Motor is not retained, falls out, and comes into contact with personnel at terminal velocity	Improper assembly and install of the motor retention system	High - When motor retention systems are not able to be inspected visually, they are susceptible to failure	The team has designed a retention system that allows for clear visual inspection that the motor is being retained per the intended design	Very Low
Recovery Deployment	Main parachute deploys prematurely and drifts to unsuspecting areas (highways, crowds, etc.)	High winds combined with early deployment of the main parachute	Medium	Shortented retention cord to keep the main parachute inside the forward airframe until it is cut at 1500 feet will prevent early deployment	Low
Descent	Parachute failed to deploy, and rocket falls at dangerous velocity and comes into contact with someone	Main parachute is tangled and unable to open	Low, while the main parachute failing to open has been observed, the risk of the rocket falling back down to the launch site without a visual to alert personel is low	Shorten retention cord to prevent shroud lines from tangling by keeping the parachute bag inside the rocket until deployment	Very Low
		Retention cord fails to be cut thereby preventing the main chute from opening		Redundant cord cutting systems to increase probability of cutting the lines	
		Failure to observe the descent of the rocket		Specially assinged team members who observe telemetry data and observe the rocket as it descends	
Recovery	Rocket charges go off unexpectedly while handling	Rocket fails to separate during flight but avionics fires a signal once the rocket is being recovered	Low, the separation charges would first need to fail during flight and then accidentally fire at the moment of recovery	Mandated procedure to inspect for the three sections of the rocket, disarm the avionics upon arrival, and stay clear of unseparated stages	Very Low

E. Assembly, preflight, and launch checklists

STANFORD STUDENT
SPACE INITIATIVE

Master Checklist

The Day Before Launch printed

- ❏ Conduct Launch Readiness Review and complete the configuration checklist
- ❏ Packing checklists
    - ❏ Structures
    - ❏ Avionics
    - ❏ Recovery
    - ❏ Aft / Propulsion
    - ❏ Payload
    - ❏ Tools Packing

At the Launch Site

- ❏ Sub-team assembly, if needed
    - ❏ Structures
    - ❏ Avionics and RF
    - ❏ Recovery
    - ❏ Payload
    - ❏ Aft/Propulsion assembly - do not integrate yet
- ❏ System Configuration and Launch Readiness Checklist
- ❏ Integration Checklist
- ❏ Weigh entire rocket - do not allow anyone to stand in front
- ❏ Weight: _______
- ❏ Run Simulation for Stability

All Sub-Teams Final Safety Checks

Located in assembly documents

- ❏ Structures
- ❏ Avionics
- ❏ Ground Station
- ❏ Recovery
- ❏ Aft / Prop
- ❏ Integration
- ❏ Staging

Launch Procedure

- ❏ Double check Launch Readiness Checklist
- ❏ Team Photo with rocket (of course)
- ❏ Split into teams: establish roles
- ❏ Bring to launch site: Masking tape, igniter, cameras, magnet, phone
- ❏ Load rocket onto launcher. Another optional photo.
- ❏ Arm the rocket
    - ❏ Slide magnet past mag switch to hear beeping
    - ❏ Use phone, connect to esp wifi

        SSID is ESP-'some other number'

        Go to this website: 192.168.4.1/arm to arm rocket

        To check status, go to #/status

        To disarm, go to #/disarm
- ❏ Check that leads don't spark, i.e. no voltage difference
- ❏ Attach leads to ignitor
- ❏ Collect and record anemometer readings
- ❏ Launch

Post-Launch Procedure

- ❏ Do not run carelessly at the rocket
    - ❏ Remain out of the direction of potential live charges (i.e. nose cone)
- ❏ Take many pictures of the rocket without touching anything
- ❏ Verify that all parachutes were ejected
    - ❏ If not, check out the next option below (Live Charge Remaining)
- ❏ If they were, carefully disarm the avionics bay
    - ❏ Using the phone, connect to esp and go to 192.168.4.1/disarm
    - ❏ Using a magnet, slide it past the mag switch to turn off altimeter
- ❏ It is now safe for everyone to approach
- ❏ Disassemble rocket
- ❏ Get the data
- ❏ Pack up tools into their respective boxes
- ❏ Pull out motor and clean
- ❏ Take down tents and tables and pack cars
- ❏ Send out post-launch survey to people who came

Live Charge Remaining

- ❏ Do not run carelessly at the rocket
    - ❏ Remain out of the direction of live charges (i.e. nose cone)
- ❏ Have someone who knows what they are doing disarm the avionics bay
    - ❏ Using the phone, connect to esp and go to 192.168.4.1/disarm
    - ❏ Using a magnet, slide it past the mag switch to turn off altimeter
- ❏ Disconnect wires that connect to e-matches
- ❏ Treat the charges as live still, just don’t light the rocket on fire
- ❏ It is now safe for everyone to approach

Integration Checklist

Check the box next to each item as it is completed, and write the time of completion on the line next to the box. The first section must be completed first, but after that, the sections may be completed in any order, unless otherwise noted in the instructions.

Get out that scale printed

1. ☐ ______ Weigh each component of the rocket and record below

Nose Cone	Fwd Airframe	Aft Airframe	Motor	Payload	Avionics	Recovery

Recovery + Avionics

2. ☐ ______ Thread ematches through 1 hole in recovery bulkhead.
3. ☐ ______ Wire the ematches to avionics / recovery as needed (see diagram)
   a. Remember problems with wires not being long enough to slide the AV bay onto the threaded rods connecting to the recovery bay!

Bulkhead connectors	
AV Connector	**Recovery Connector**
Bulkhead 1	Shear pins (bp) (red)
Bulkhead 2	Shear pins (CO2) (orange)
Bulkhead 3	Drogue CO2 (yellow)
Bulkhead 4	Main - tender retention (green)

Bulkhead 5	Main - backup tender retention (blue)
Bulkhead 6	Drogue backup black powder (purple)

4. ☐ ______ Bolt AV bay to recovery bay forward bulkhead (using 2 threaded rods and nuts)
5. ☐ ______ Screw recovery main section into forward recovery bulkhead
6. ☐ ______ Make sure space side of AV bae is actually towards space!!
7. ☐ ______ Tie shock-cord into aft side of aft airframe
8. ☐ ______ Slide this assembly into the aft side of the rocket
    a. Double check the location of the mag switch so we know where it is
9. ☐ ______ Bolt the recovery bulkhead into the airframe

Mid-Section

Coupler

10. ☐ ______ Insert coupler. Tape coupler appropriately.
11. ☐ ______ Make sure holes in bulkheads are properly sealed
12. ☐ ______ Take off tape. Put shock cord in aft airframe.
13. ☐ ______ Slide the forward and aft airframes together
14. ☐ ______ Screw in shear pins to coupler on Recover side (not motor side)

Propulsion + Aft Section

15. ☐ ______ Slide in motor and screw tight
16. ☐ ______ Test bending in between coupler and body tubes. If bending exceeds 2 degrees (use inclinometer), de-integrate. Apply packing tape to coupler until fit is better. Re-fit screws retaining coupler.

Payload and the Nose

17. ☐ ______ Slide payload into nose cone
18. ☐ ______ Slide nose cone into upper airframe - space side
19. ☐ ______ Bolt payload, upper airframe, and nose cone together w/#10 bolts

---

STANFORD STUDENT SPACE INITIATIVE

Avionics Pre-Flight

Pre-Flight Checklist: printed

This list combines both assembly and pre-flight checks.
Note: Only critical designations (SWITCH 1) get to be all caps... other acronyms get italicised (apo)

PART 1: PRE-INTEGRATION

	Done?	Timestamp	Description
1.	☐	______	Ensure E-Matches DISCONNECTED
2.	☐	______	Turn ON motherboard SWITCH 1 and SWITCH 2
a.	☐	______	check that MAG LED 1 ON
b.	☐	______	check that ESP LED 1 ON
3.	☐	______	ARM magswitch and motherboard ESP (*ssid:* Motherboard *pw:* redshift http://192.168.4.1/arm)
a.	☐	______	check that MAG LED 2 ON
b.	☐	______	check that ESP LED 2 ON
4.	☐	______	Check that you hear the following from Strato (red *cots*):

a. Low beep
b. 7 beeps (corresponding to preset 7 (0 second apogee delay, 1500 ft main deploy))
c. 1 beep, 5 beeps, 10 beeps, 10 beeps (corresponding to main deploy altitude of 1500 ft)
d. low beep
e. Some string of beeps for last flight's apogee
f. low beep
g. AT LEAST 6 beeps, 6 beeps (representing battery voltage of 6.6 V)
h. low beep
i. Continuity chirps continuously reported every .8 seconds
    i. silence = no continuity - should be this one
    ii. 1 chirp = drogue continuity
    iii. 2 chirps = main continuity
    iv. 3 chirps = main + drogue continuity

5. ☐ ______ Check that you hear the following from Raven (green cots):
    a. ☐ AT LEAST 6 beeps (corresponding to battery voltage of 6.6V rounded down to nearest volt)
    b. ☐ Low, single beep every 2 seconds if no charges are detected (the one we want), if the accelerometer does not read a near-vertical orientation, or if the battery voltage is below 3.85V
    c. ☐High beep, beep, beep, high beep (corresponding to *apo* continuity, Main no continuity, 3rd no continuity, 4th continuity)
6. ☐ ______ Confirm Telemetry Transmission to Ground Station
7. ☐ ______ Turn OFF motherboard SWITCH 2
8. ☐ ______ DISARM magswitch
9. ☐ ______ DISARM motherboard ESP
    a. *ssid:* Motherboard *pw:* redshift http://192.168.4.1/disarm
10. ☐ ______ Turn ON skybass red switch
11. ☐ ______ Ensure SD card is in SkyBass
12. ☐ ______ ARM Skybass
    a. *ssid:* Skybass *pw:* redshift http://192.168.4.1/arm
13. ☐ ______ Hold Skybass upright and steady
14. ☐ ______ Check that Skybass has GPS lock by ensuring that LED 2 is bright
15. ☐ ______ Check that Skybass does not have ematch continuity by ensuring that LED 3 is OFF
16. ☐ ______ Listen for the following set of beeps:
    a. 1,2 - warnings
    b. 3 - High - flight mode
    c. 4 - High - GPS lock
    d. 5 - low - no ematch 1 continuity
    e. 6 - low - no ematch 2 continuity
    f. 7 - low - no ematch 3 continuity
17. ☐ ______ Turn OFF skybass red switch

PART 2: PRE-ASSEMBLY

Done?	Timestamp	Description
18. ☐	______	Connect e-matches, 6 total
	a.	See E-Match Connector in Integration Checklist
19. ☐	______	Ensure motherboard SWITCH 1 is ON
20. ☐	______	Turn ON motherboard SWITCH 2
21. ☐	______	Turn ON skybass RED SWITCH
22. ☐	______	Ensure ALL Systems Disarmed
23. ☐	______	Ensure wifi networks active
24. ☐	______	Proceed with assembly

PART 3: PRE-LAUNCH (On Launch Rail)

Done?	Timestamp	Description
25. ☐	______	ARM motherboard ESP
	a.	*ssid:* Motherboard *pw:* redshift http://192.168.4.1/arm
26. ☐	______	Verify Strato ematch continuity through beeps
27. ☐	______	Set motherboard magswitch to armed
28. ☐	______	Verify Raven ematch continuity through beeps
29. ☐	______	ARM skybass ESP
	a.	*ssid:* Skybass *pw:* redshift http://192.168.4.1/arm
30. ☐	______	Verify Skybass ematch continuity through beeps
31. ☐	______	Confirm Skybass armed via groundstation
32. ☐	______	Confirm Skybass in flight mode via groundstation
33. ☐	______	Confirm Stratologger and Raven armed via groundstation

STANFORD STUDENT
SPACE INITIATIVE

Post - Flight Checklist

1. ☐ ______ Set motherboard ESP to disarmed. Confirm strato disarmed via groundstation
2. ☐ ______ Set skybass ESP to disarmed. Confirm skybass disarmed via groundstation
3. ☐ ______ slide magnet across tube to disarm raven. Confirm disarmed via groundstation vsense
4. ☐ ______ Cut ematch wires
5. ☐ ______ Save data from SD card to laptop

STANFORD STUDENT SPACE INITIATIVE

People Assembly

It's not rocket science really

- ❏ Set up tent (4 people)
- ❏ Set up tables + chairs (2 people)
- ❏ Put sub-team boxes in segregated stacks (sub-teams)
- ❏ Put coolers and food stuff in segregated stack
    - ❏ Spagooters
- ❏ Team breakout session before rocket assembly
    - ❏ Pep Talk + Rally

STANFORD STUDENT SPACE INITIATIVE

People Packing

General / L1 Launch

❑ **THING**	**LOCATION**
❑ Cooler for drinks	Dragon
❑ Cameras	
❑ Inverters and power strips for power from car	Dragon
❑ Sharpies and pens	Unity
❑ First aid kits	Outside Unity
❑ Tent	Dragon
❑ Chairs	Dragon
❑ Folding tables	Garage
❑ Trash bags	Tranquility
❑ Table cloth	??
❑ Tarp	Garage
❑ Extension Cord (Orange)	Garage
❑ Pre-filled out documentation	

Buy on the way there or the night before

- ❑ Food - both sustenance and snacks
- ❑ Cases of water

STANFORD STUDENT SPACE INITIATIVE

Avionics No SkyBass Pre-Flight

Pre-Flight Checklist: printed

This list combines both assembly and pre-flight checks.
Note: Only critical designations (SWITCH 1) get to be all caps... other acronyms get italicised (apo)

PART 0: CONFIGURE BAY TO LAUNCH WITHOUT SKYBASS

1. ☐ ______ Remove SkyBass PCB and screws that held SkyBass to bay
2. ☐ ______ Connect Strato Drogue to Bulkhead 3
   a. Cut solder jumping R22 and solder jumping R23
   b. Solder jump R20 and jump R21
3. ☐ ______ Connect Raven 3rd to bulkhead 1
   a. Drill hole into bulkhead
   b. Connect ematch wire from outputs on daughtership to bulkhead
   c. 5 minute epoxy wire to side of bay
4. ☐ ______ Connect Raven Main to bulkhead 5
   a. Drill hole into bulkhead
   b. Connect ematch wire from outputs on daughtership to bulkhead
   c. 5 minute epoxy wire to side of bay
5. ☐ ______ Use double sided tape to attach GPS SPOT in place of SkyBass

PART 1: PRE-INTEGRATION

	Done?	Timestamp	Description
6.	☐	______	Ensure E-Matches DISCONNECTED
7.	☐	______	Turn ON motherboard SWITCH 1 and SWITCH 2
a.	☐	______	check that MAG LED 1 ON
b.	☐	______	check that ESP LED 1 ON

8. ☐ ______ ARM magswitch and motherboard ESP

   (*ssid:* Motherboard *pw:* redshift http://192.168.4.1/arm)

   a. ☐ ______ check that MAG LED 2 ON
   b. ☐ ______ check that ESP LED 2 ON

9. ☐ ______ Check that you hear the following from Strato (red *cots*):
   a. Low beep
   b. 7 beeps (corresponding to preset 7 (0 second apogee delay, 1500 ft main deploy))
   c. 1 beep, 5 beeps, 10 beeps, 10 beeps (corresponding to main deploy altitude of 1500 ft)
   d. low beep
   e. Some string of beeps for last flight's apogee
   f. low beep
   g. AT LEAST 6 beeps, 6 beeps (representing battery voltage of 6.6 V)
   h. low beep
   i. Continuity chirps continuously reported every .8 seconds
      i. silence = no continuity - should be this one
      ii. 1 chirp = drogue continuity
      iii. 2 chirps = main continuity
      iv. 3 chirps = main + drogue continuity

10. ☐ ______ Check that you hear the following from Raven (green *cots*):
    a. ☐ AT LEAST 6 beeps (corresponding to battery voltage of 6.6V rounded down to nearest volt)
    b. ☐ Low, single beep every 2 seconds if no charges are detected (the one we want), if the accelerometer does not read a near-vertical orientation, or if the battery voltage is below 3.85V
    c. ☐High beep, beep, beep, high beep (corresponding to *apo* continuity, Main no continuity, 3rd no continuity, 4th continuity)

11. ☐ ______ Confirm Telemetry Transmission to Ground Station
12. ☐ ______ Turn OFF motherboard SWITCH 2
13. ☐ ______ DISARM magswitch
14. ☐ ______ DISARM motherboard ESP
    a. *ssid:* Motherboard *pw:* redshift http://192.168.4.1/disarm

PART 2: PRE-ASSEMBLY

Done?	Timestamp	Description
15. ☐	______	Connect e-matches, 6 total

a. See E-Match Connector in Integration Checklist

Done?	Timestamp	Description
16. ☐	______	Ensure motherboard SWITCH 1 is ON
17. ☐	______	Turn ON motherboard SWITCH 2
18. ☐	______	Ensure ALL Systems Disarmed
19. ☐	______	Ensure wifi network active
20. ☐	______	Proceed with assembly

PART 3: PRE-LAUNCH (On Launch Rail)

Done?	Timestamp	Description
21. ☐	______	ARM motherboard ESP

a. *ssid:* Motherboard *pw:* redshift http://192.168.4.1/arm

Done?	Timestamp	Description
22. ☐	______	Verify Strato ematch continuity through beeps
23. ☐	______	Set motherboard magswitch to armed
24. ☐	______	Verify Raven ematch continuity through beeps
25. ☐	______	Confirm Stratologger and Raven armed via groundstation

STANFORD STUDENT
SPACE INITIATIVE

Post - Flight No SkyBass Checklist

1. ☐ ______ Set motherboard ESP to disarmed. Confirm strato disarmed via groundstation
2. ☐ ______ slide magnet across tube to disarm raven. Confirm disarmed via groundstation vsense
3. ☐ ______ Cut ematch wires

Aft / Prop Assembly

The Day Before: printed

1. ☐ Clean all motor parts thoroughly. Baby wipes!

Assembly:

1. ☐ Insert and screw in motor retainer
2. ☐ Screw in threaded rod from the bottom of the airframe through the motor retainer until it is through the entire motor retainer
3. ☐ Insert the bulkhead that holds the threaded rod center
4. ☐ Hold rocket vertically and screw in motor casing
5. ☐ Attempt to pull motor casing out of rocket to ensure the casing has been screwed in

Final Safety Check

1. ☐ ______ Motor fit: is the motor secured? Is the bottom flange resting against airframe?
2. ☐ ______ All required bolts (see below)
3. ☐ ______ General inspection: are there noticeable chips or cracks in the airframe? Is the rocket rigid and well constructed?
    a. *If not, consult mission lead, possibly substitute alternate airframe components depending on damage or scrub mission.*
4. ☐ ______ Are the fins chipped? Bent? Damaged?
5. ☐ ______ Is the core body section chipped? Bent? Damaged?
6. ☐ ______ Front section chipped? Bent? Damaged?

7. ☐ ______ Nose cone chipped? Bent? Damaged?
8. ☐ ______ Seam alignment along launch rail
9. ☐ ______ #12 bolts - all holes tapped
10. ☐ ______ Check the aft coupler wobble

Holes List

1. ☐ Nose Cone holes
2. ☐ Recovery bulkhead
3. ☐ Vent holes
4. ☐ Staging/Coupler Holes (Forward and Aft)
5. ☐ Motor retainer

Payload Assembly

Pre-Flight Checklist (at bench)

printed

	Done?	Timestamp	Description
1.	☐	______	Plug in battery to power up payload
2.	☐	______	Look inside to see if red light on ESP breakout is on
3.	☐	______	Connect to the ESP wifi hotspot and check that there is a response at 192.168.4.1/status
4.	☐	______	Screw payload together
5.	☐	______	Bolt payload into rocket airframe

Final Safety Check (at pad)

	Done?	Timestamp	Description
1.	☐	______	Verify disarmed status at 192.168.4.1/status
2.	☐	______	Arm payload by visiting 192.168.4.1/arm
3.	☐	______	Verify that the payload is armed at 192.168.4.1/status

STANFORD STUDENT SPACE INITIATIVE

Avionics Packing

The Day Before

- ❏ Charge daughtership batteries
- ❏ Charge USB battery pack (Thomas has one)

Non-RF Packing:

- ❏ Intellicharger (charges Skybass batteries and daughtership batteries)
- ❏ Extra batteries
    - ❏ 18650 - skybass x1
    - ❏ 18350 - daughtership x4
- ❏ Micro SD Card
- ❏ The Bay - Already fully integrated (daughtership, SRADio stack, beacon, SkyBass, bulkhead PCB all attached)
- ❏ Arming magnets
- ❏ Imperial Hex key set, AKA Allen Wrenches
- ❏ Strato programming USB Cable
- ❏ Raven programming USB cable
- ❏ Micro-USB cables
- ❏ Mini-USB cables
- ❏ FTDI - USB 3.3V cable (this is also for the ESP programming)
- ❏ Jumpers: male-male, male-female, female-female
- ❏ Soldering Iron & extra AA batteries
- ❏ Leaded Solder
- ❏ Multimeter
- ❏ Tweezers

- ❑ Zip Ties, all 3 sizes
- ❑ Dedicated precision screwdriver set (blue)
- ❑ Dedicated small snips
- ❑ Thomas' USB Battery Pack
- ❑ Flux
- ❑ Mini oscilloscope

RF Packing:

- ❑ Ground station antenna, usb cable
- ❑ 2+ Baofeng radios
- ❑ N type - SMA connector and cable
- ❑ BNC - BNC cable
- ❑ SMA - BNC (has red cap !donotlose!)
- ❑ Assorted extra antenna connectors/attenuators
- ❑ Ground station computer
- ❑ Ground station computer charger
- ❑ SPOT GPS module
- ❑ Directional antenna for beacon (and connector to SMA (for baofeng)

Structures Assembly

Assembly Checklist printed

- ❑ Attach Launch Buttons
- ❑ Bolt in motor retainer and attach threaded rod
- ❑ Bolt Payload into the nose cone
- ❑ Bolt nose cone to forward airframe
- ❑ Bolt in AV/Recovery
- ❑ Bolt coupler to aft airframe
- ❑ Attach forward airframe to coupler with shear pins

Final Safety Check

- ❑ No joint deflects more than 2 degrees. Use inclinometer.
- ❑ Coupler sliding is smooth. Rocket can actually separate when needed.
- ❑ Rail buttons are firmly attached.
- ❑ Shear pins are slotted in.
- ❑ Ensure that motor casing is firmly attached to threaded rod.

Structures Packing

Packing list:

- ❏ #8 0.5''-long bolts (like 50 of them)
  Especially the ½" ones, not ¾"
- ❏ Shear pins (like 20 of them) + extra shear pins!
- ❏ Aft airframe with fins
- ❏ Forward airframe
- ❏ Coupler
- ❏ Nose cone
- ❏ Motor retainer
- ❏ Retaining rod
- ❏ Spare retaining rod (that is at least 10" longer than the one you are planning on using)
- ❏ 4 Cradles for Rocket
  - ❏ Make sure they all have towels on them so they don't scratch the rocket
- ❏ Motor Casing
- ❏ Blue Tape strips for drilling holes (4&6)
- ❏ Tap handle and taps (specifically check for the 8-32 or size 29 tap)
- ❏ Make sure there is an 11/64 Drill Bit
- ❏ Bring nuts that match the bolts
- ❏ Proper motor assembly tools, including the wrench
- ❏ Spare Rail Buttons
- ❏ Size 6, 8, and 10 bolts
- ❏ Nuts for all the bolt sizes

Staging Assembly

At the Launch Site

1. ☐ ______ Make sure everything is bolted together properly
2. ☐ ______ Using a phone, actuate the mechanism while not in the rocket to verify functionality
3. ☐ ______ Turn off all electronics and get ready for integration

STANFORD STUDENT SPACE INITIATIVE

RF Telemetry

Pre-Flight: printed

1. ☐ ______ Set up Antenna
2. ☐ ______ Verify receiving transmissions from Beacon/Sradio
3. ☐ ______ Run Grounstation.py
4. ☐ ______ Verify receiving telemetry/GPS transmissions
5. ☐ ______ Arm Payload by typing “ARM” at terminal
6. ☐ ______ Ensure Payload Arming Feedback

Emergency Charges:

7. ☐ ______ Type “BOOM” at Terminal

STANFORD STUDENT
SPACE INITIATIVE

Recovery Packing

Packing Checklist:

- ❏ Main Parachute (SRAD + COTS)
- ❏ Main Deployment Bag
- ❏ Main swivel x2
- ❏ Main shock cord (15')
- ❏ Main retention shockcord (<2')
- ❏ Recovery Tether System
- ❏ - 2 quick links, tender descender (delrin cap is part of system)
- ❏ Drogue Parachute (and backup)
- ❏ Drogue swivel
- ❏ Drogue shock cord (20')
- ❏ Inter-section shock cord (17')
- ❏ Thermal Protections (2 kevlar sheets)
- ❏ 25g CO2 canisters (two in CO2 system case, backups in box)
- ❏ CO2 system
    - ❏ Plunger, 2+ o-rings, e-match holder (plastic thing), and threaded cylinder (with top) , baseplate, screws and any backups
- ❏ Black Powder
- ❏ 6 e-matches (and ~2 backup e-matches)
- ❏ Black Powder measuring containers
- ❏ Electrical tape for black powder backup
- ❏ Glove for black powder backup
- ❏ Shear pins (#6 shear pins)
- ❏ 3 large quick links - 2700#, 1200#, 1200#
- ❏ 4 Nuts for fiberglass rods for AV Bay connection (P3/8 '' hex nuts) (and backups)

- ❏ Lube (for CO2 system plunger)
- ❏ Screws for CO2 (should be assembled in forward coupler)
- ❏ Long cardboard tube to push stuff out of airframe
- ❏ Forward Bulkhead (with u-bolt and CO2 plate assembled)
    - ❏ Aft pressure bulkhead should already be assembled on inner tube
- ❏ Ignition Box for testing charges
- ❏ Rubber bands
- ❏ Forward bulkhead adapter
- ❏ Restricted inner tube
- ❏ Restricted inner tube aft support rings
- ❏ Masking Tape
- ❏ Black Sharpie
- ❏ Colored sharpies for e-match labeling
- ❏ Tacky tape
- ❏ Screws and nuts to secure inner tube onto adapter

Here's the exploded assembly in picture form:

STANFORD STUDENT SPACE INITIATIVE

Tools Packing

General / L1 Launches

Loaded?	Description	Location
☐	Screwdrivers (‘+’ and ‘-’)	Unity
☐	Adjustable spanner (aka crescent wrench) (2)	Unity
☐	Allen Wrenches (imperial)	Unity
☐	Precision Screwdriver	Unity
☐	8/32 fasteners - lots, should be bought	Unity
☐	Small needle-nose pliers	Unity
☐	Power Drill	Unity
☐	Impact Driver	Unity
☐	Correct drill bits and heads - $\frac{9}{64}$, $\frac{5}{32}$, ¼.	Unity
☐	Drill Batteries (not all of them)	Unity
☐	Drill chargers (2) Make sure that ISS is left w/ at least one functional power drill	Unity
☐	Hot Glue Gun	Unity
☐	Hot Glue	Unity
☐	Scissors	Unity
☐	Zipties - NEED BOTH LARGE AND SMALL Do not take ziptie gun unless coordinated with Balloons	Unity
☐	Dremel	Unity
☐	Dremel Bits	Unity

	Item	Whee it might work?
☐	Clamps - large ‘C’ ones and small ones	Unity
☐	Flashlights (3)	Unity
☐	Strap Wrench	Unity
☐	Masking and duct tape	Unity
☐	Sandpaper (120 grit)	Unity
☐	Measuring tape	Unity
☐	Calipers	Unity
☐	Paper towels	Tranquility
☐	Weight Scale - large and small	Unity
☐	Rubber Gloves	Unity
☐	Motor retaining rings	Should be in black box with yellow handles
☐	Black powder	Tranquility (Ammo box)
☐	Grease for motor cases	
☐	Motors - all that we would reasonably use	
☐	Spare rocket components	
☐	Ruler	Unity
☐	Inclinometer	Tranquility
☐	Portable soldering iron (blue and yellow)	Harmony
☐	Solder wick and actual solder	Harmony
☐	Multimeter	Harmony
☐	File for filing things	Unity
☐	Baby wipes! Important for cleaning motor	
☐	Motor time delay tool	
☐	Surgical masks	

STANFORD STUDENT SPACE INITIATIVE

Recovery Assembly

The Day Before:

- ❏ Order of recovery bay:
    - ❏ Intersection shock cord
    - ❏ Kevlar
    - ❏ Drogue parachute
    - ❏ Drogue swivel and quicklink
    - ❏ Piston
    - ❏ Kevlar and backup drogue charge (e-match)
    - ❏ Intersection shock cord
    - ❏ Main swivel and quicklink (to retention shock cord and main intersection shock cord)
    - ❏ Main parachute
    - ❏ Retention system and kevlar
    - ❏ Main intersection shock cord
    - ❏ CO_2 black powder system (CO_2 canister on to-space side)
- ❏ Order of coupler bulkhead
    - ❏ E-match
    - ❏ CO_2 black powder system
- ❏ Connect top loop of main parachute to shock cord of deployment bag using quick link
- ❏ Connect main shock cord to swivel on main parachute
- ❏ Fold main parachute and stuff into deployment bag
- ❏ Fold main parachute shroud lines and tuck into deployment bag, using bands on bag to help secure
- ❏ Connect drogue to the drogue swivel using a quick link
- ❏ Prepare the 4 separate black powder charges (1.0g for behind piston, 3.0g for coupler/shear pin separation, 0.2g for retention system, 0.5g for CO_2 system)

- [ ] Make multiples if more than one launch, blowout tests, etc.
- [ ] Prepare the 6 e-matches (CO2 + backup charges, retention system main + backup charges, coupler/shear pins main and backup charges) by labeling each with their intended purpose
  - [ ] Look at the color-coded chart for more detail
- [ ] Submerge all pyrotechnic components in hot water to clean them out/prevent rust

Launch Day

- [ ] Insert e-matches into black powder
  - [ ] Put both main e-matches into retention system from the bottom up and fold the ends of both e-matches back down into the black powder
    - [ ] Put tacky tape on bottom of e-match hole to plug system
  - [ ] Put lube on o-rings in both red CO2 black powder systems
- [ ] Wire the 6 e-matches (CO2 + backup charges, retention system main + backup charges, coupler/shear pins main and backup charges) through the bulkhead and bulkhead adapter

AV (no skybass)	Purpose	Color	Color
1 (3)	Shear pins (black powder)	Red	
2	Shear pins backup (CO2 canister)	Orange	
3 (1)	Drogue (CO2 canister)	Yellow	
4	Main (tender retention)	Green	
5	Main backup (tender retention)	Blue	
6	Drogue backup (black powder)	Purple	

jank		Black	[redacted]

System Configuration and Launch Readiness Checklist

Simulations printed

General

- ❏ Rocket is simulated to a reasonably accuracy
    - ❏ Subsystems and components weighed after construction and their masses put in the sim
    - ❏ Airframe construction and fins match physical rocket geometry

Calculate the TWR

- ❏ Motor average thrust: ____
- ❏ Rocket mass: ____
- ❏ Rocket weight (mass x10): ____
- ❏ Rocket TWR (thrust / weight): ____
- ❏ **Rocket TWR is at least 5**

Stability

- ❏ Rocket stability at Mach 0.3: __________________________________
- ❏ Stability at Mach 0.3 is at least 1.5 calibre
- ❏ Launch rod height is correct in simulation (go to “Edit Simulation”)
- Plot the stability of the rocket during the flight in OpenRocket by clicking “Plot / Export” the selecting “Stability vs. Time” under “Preset Plot Configurations.” Make sure that “Launch rod clearance” is checked under the list of flight events. Zoom into the plot and look at the stability curve right when the rocket clears the launch rail.
- ❏ **Rocket stability at launch rod clearance is at least 1, and increases during the immediate period of time afterwards**

Launch Readiness Review

- ❏ At least one IREC co-lead, and two other IREC team members with L1 certs are present
- ❏ If the launch will be under the supervision of someone with an L2 who is available, make sure they are in attendance
- ❏ Attendees have reviewed the simulation on their own or review it now
- ❏ Motor configuration and rocket weight have not changed since TWR calculations
- ❏ Weight distribution in the rocket and airframe/fin geometry has not changed significantly since completion of the stability section of the checklist
- ❏ Attendees verify that the rocket TWR and stability are at reasonable values for launch
- ❏ **Attendees sign below to verify that the rocket is ready to be launched in this configuration, and that if there are significant changes to the flight configuration, that this process is repeated before launch**

Attendee Signature 1 ____

Attendee Signature 2 ____

Attendee Signature 3 ____

Attendee Signature 4 ____

Attendee Signature 5 ____

E. Additional Design Documentation

Conventional Dual Deploy:
A conventional dual separation deployment involves one separation event for the drogue, and a second event for the main chute, requiring two CO_2 ejection systems, thereby increasing the overall mass and volume of the recovery system.

Reefing:
A reefing option would involve only one full-size parachute whose surface area would initially be limited by a reefing cord or ring, reducing the surface area and producing drogue-levels of drag until the reefing is removed and the parachute is allowed to fully inflate. This saves space by eliminating the need for a drogue, but adds complexity due to the reefing mechanism, which creates more risk. Given this, we have begun designing and testing subscale reefing mechanisms for future launches. However, the mechanism still has some issues with reliability and consistency, leading us to not include it in our current system.

Serial:
Serial deployment balances complexity and space savings. allowing for the use of only one CO_2 separation system for the recovery bay itself, while limiting complexity. The main challenge of the serial deployment method is effective retention of the main parachute. We accomplish this by including a retention shock cord which keeps the main parachute inside of the airframe during the separation event. Then, for the main event at 1500 ft, we release this retention cord by severing the connection between the shock cord and the airframe using a quick link retention system (Recovery Tether). This allows for the drogue and intersection shock cord to pull the main chute out of the deployment bag.

Skybass Software

Flight States

The altimeter operates in discrete states that dictate the majority of the actions of the processor. However it is not in statemachine as the entirety of the unit is not determined solely by state and input.

States

1. Pre-Launch
   a. Startup
   b. Idle
   c. Armed
2. Launch

. Liftoff
a. Coast
b. Descent under Drogue
c. Descent under Main

3. Landed

. Awaiting Recovery
a. Recovered

Transitions

This details all of the flight transitions and what the criteria are for passing through.

- 1a => 1b: Transition occurs once startup is complete and all sensors initialized. Deterministic.
- 1b => 1c: The altimeter arms when it determines that it is pointing upwards and has been stable for a set amount of time. Non deterministic, and will likely be determined by set thresholds for both being stable and pointing upwards.
- 1c => 2a: Transition will occur when the altimeter undergoes an acceleration above a set threshold for a set amount of time. Thresholds will be determined from previous flight data.
- 2a => 2b: Transition occurs when acceleration transitions from positive to negative for a set amount of time.
- 2b => 2c: Occurs when the altimeter determines that altitude has reached it's maximum and is now starting to decrease. On this transition, an ejection charge is triggered for the drogue chute.
- 2c => 2d: Occurs when the altimeter has fallen to a set altitude where the main should be deployed (nominally around 700ft). On this transition, an ejection charge is triggered for the main chute.
- 2d => 3a: Occurs after the altimeter sees a sharp acceleration spike, followed by minimal movement.

Events

The processor manages multiple tasks without the implementation of a full RTOS through the use of events that are triggered by interrupts.

Events are stored in the `uint8_t events` variable. Each bit of the `events` variable can flag an event that signals a task to be processed in the next iteration of the main loop. Each event is enumerated as a single byte with a 1 in a position corresponding to the flagged bit. For example, the rightmost bit of `events` signals to execute the main update loop, which is named `EVENT_UPDATE` and enumerated as `0b00000001` After a task is processed, it is unscheduled.

The main event flags are triggered interrupt timers. These timers interrupt on constant intervals, and call a function that simply edits the interrupt bit in the `events` variable.

Code Organization

Classes

`Altimeter` - this is the primary class for the board and contains all of the other classes as members. Everything is initialized in this class

`Flight_Data` - this class stores the raw data values that are read from each sensor. It also also contains the methods for logging to SD card and has a member object that is the Kalman Filter object. Supports reading sensors at different frequencies. Does not store history, but probably will be updated in the future so that maybe the past 100 or so values are kept in ram.

`Flight_Sensors` - this class is used for accessing all of the sensors and reading GPIO inputs. Is kept separate from Flight_Data class, as use of this object can be easily swapped out for one for a Hardware-In-The-Loop test object

`Flight_Events` - Object of this class contains the 4 internal interrupt timers, as well as any other pin-driven interrupts, that can be used to time events properly.

`Altitude_Kalman_Filter` - Custom Kalman filter class for determining altitude. Stores all the relevant constants for the filter as well as the previous filter value. Contains all methods needed for filter update.

Members of `Altimeter` class

flight_data: Object of type Flight_Data that stores all of the relevant data values for the flight. flight_sensors: Object of type Flight_Sensors that interfaces with all sensors flight_events: Object of type Flight_Events that contains the 4 interrupt timers

flight_state: Integer that contains the enumerated flight state values *more to add below*

Non-Class Files

`S-ALT_REV0.h` - header file for the board. Contains all pin definitions and any pcb layout specific values`Flight_Configurations.h` - header file that defines enumerated list and structures or various things within the project.

Implementation Details

SD Data storage

In the root directory of the SD card, a new folder should be generated to store files for each flight, numbered incrementally as `flight_[number]`. So, if the altimeter boots up and sees that the folders `\fight_1` and `\flight_2`, it should create a folder `flight_3` to log data in.

Within the folder for the flight, the altimeter shall create a single `data.csv` file to log data into. It shall then write lines to the CSV file in the form: `[time stamp], [sensor enum], [data field 1], [data field 2], ...`. All possible sensor sources shall be enumerated as integers making the `sensor enum` field, so that for each line it can be identified what the following data fields represent. Sensor readings are written in separate lines to support writing sensor data at different frequencies.

For normal operations the altimeter should not log data to the SD card until after it reaches the `liftoff` state (to prevent excessive folder generation when the altimeter is simply just powered on). However, in the testing phase for data collection purposes, it should start logging data immediately.

RAM data storage

To keep a history of sensor information in the RAM, each sensor should have a circular array of variable length so store readings in. The storage should support the following functionality:

- Changing the length of the array for each sensor
- Store data at a fraction of the frequency it is sampled at (so if the accelerometer is sampled at 50Hz, it can be stored in ram at only say 10Hz, so that a longer history can be kept without taking up too much memory). However it should still be able to store at the same frequency that it is sampled if desired
- Methods for retrieving data given the sensor, and the nearest number of milliseconds/microseconds in the past it was logged.

Table of Contents


```
clear
close all
```

Parachute constants

```
%Cd = 1.75;  %From Fruity Chute specs for comparable parachute and
 other research
Cd = 1.5;   %Conservative Cd used in design

%p = 1.225;  %Sea level
p = 1.00;   %For altitude of site ~4600 ft
%p = .95;    %For altitude at main deployment ~6000 ft -> speed after
 main deployment

m = 50;     %lb
g = 9.8;    %m/s^2
```

Parachute size

```
v = 80;                 %Target velocity ft/s

v = v*12*2.54/100;      %m/s
m = m/2.2;              %kg
S = 2*m*g/(p*(v^2)*Cd); %Area of crossection at opening
R = sqrt(S/pi);         %Radius (m)
R = R*100/2.54          %inches
```

R =

15.6979

Size to velocity

```
R = 16;                     %Parachute radius in

R = R*2.54/100;             %m
```

```
S = pi*(R^2);                  %Area of opening
v = sqrt(2*m*g/(p*S*Cd));      %Velocity m/s
v = v*100/(12*2.54)            %ft/s


v =

   78.4897
```

Pattern design inputs

```
%Parachute radius inches
R = 16;
%Percent of area for vent
Per = 2;                       %Can be anywhere from 1 to 10
%Seam allowance
add = .5;

%Points plotted
numpoints = 50;
%Num of sections
numS = 8;
```

Shroud lines

```
Ls = numS*(1.1*2*R/36 + .25) %yds total needed


Ls =

    9.8222
```

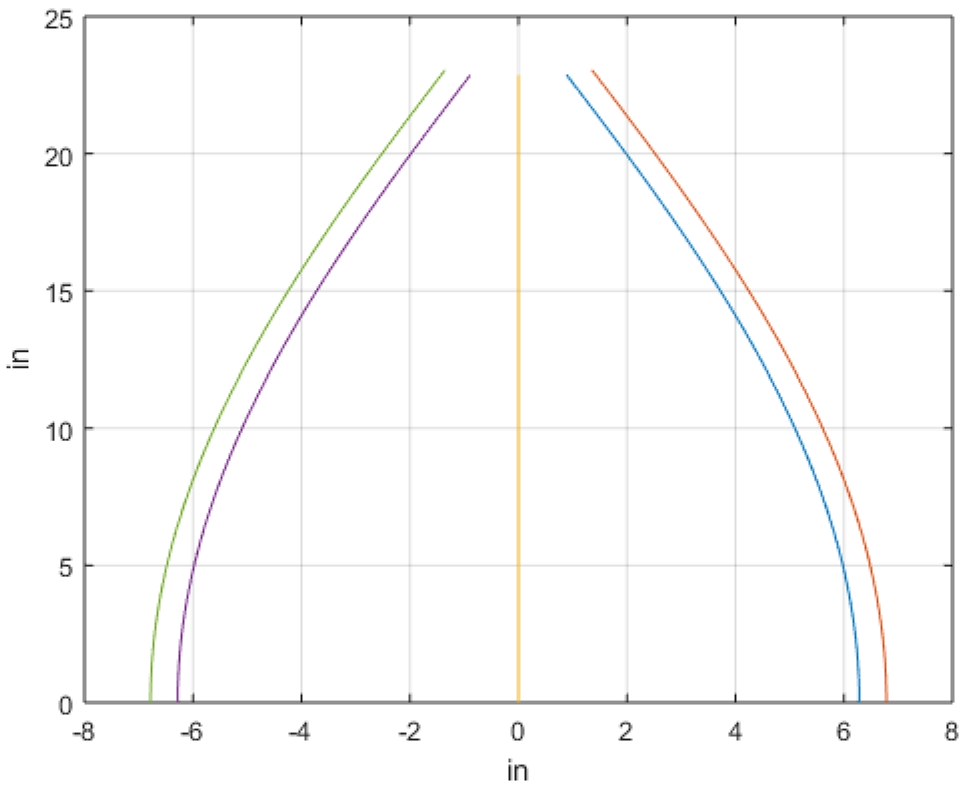
Parachute design

```
%Calculate vent area
So = 2*pi*(R^2);
Av = So*Per/100;
rmin = sqrt(Av/(2*pi))

%Map segment
angmax = acos(rmin/R);
angle = linspace(0,angmax,numpoints);
x = (1/numS)*pi*R*cos(angle);
y = angle*R;

%Seam allowance
dx = gradient(x, angle);
dy = gradient(y, angle);

magnitude = sqrt(dx.^2 + dy.^2);
```

```
xnew = x + add*(dy./magnitude);
ynew = y - add*(dx./magnitude);

plot(x,y,xnew,ynew,zeros(size(y)),y,-x,y,-xnew,ynew)
grid on
xlabel("in")
ylabel("in")
```

rmin =

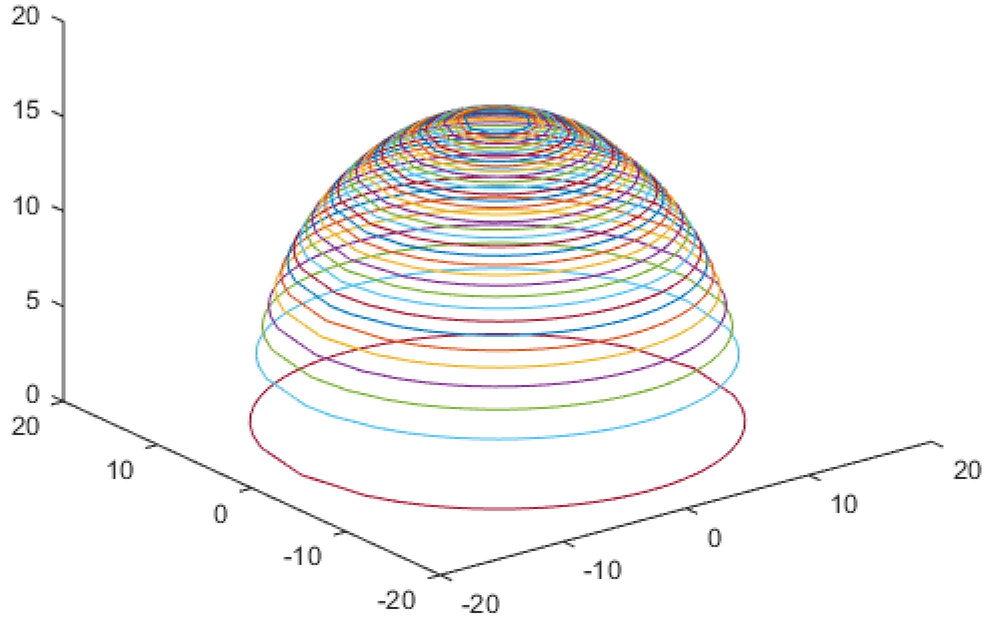
2.2627



Parachute image

```
N = 35;                          %Number of contour lines
step = (R - rmin)/(N - 1);

for r = rmin:step:R
    x = (-r):1:r;
    y = sqrt(r^2 - x.^2);
    X = [x,-x,x(1)];
    Y = [y,-y,y(1)];
    z = sqrt(R^2 - r^2)*ones(size(X));
```

```
    figure(2)
    plot3(X,Y,z)
    hold on
end
```



Published with MATLAB® R2017b

Table of Contents


```
clear
close all
```

Parachute constants

```
%Cd = 1.75;  %From Fruity Chute specs for comparable parachute and
 other research
Cd = 1.5;   %Conservative Cd used in design

%p = 1.225;  %Sea level
p = 1.00;   %For altitude of site ~4600 ft
%p = .95;    %For altitude at main deployment ~6000 ft -> speed after
 main deployment

m = 50;     %lb
g = 9.8;    %m/s^2
```

Parachute size

```
v = 30;                 %Target velocity ft/s

v = v*12*2.54/100;      %m/s
m = m/2.2;              %kg
S = 2*m*g/(p*(v^2)*Cd); %Area of crossection at opening
R = sqrt(S/pi);         %Radius (m)
R = R*100/2.54          %inches
```

```
R =

   41.8612
```

Size to velocity

```
R = 45;                     %Parachute radius in

R = R*2.54/100;             %m
```

```
S = pi*(R^2);                 %Area of opening
v = sqrt(2*m*g/(p*S*Cd));     %Velocity m/s
v = v*100/(12*2.54)           %ft/s
```

```
v =

   27.9074
```

Pattern design inputs

```
%Parachute radius inches
R = 45;
%Percent of area for vent
Per = 2;                      %Can be anywhere from 1 to 10
%Seam allowance
add = .5;

%Points plotted
numpoints = 50;
%Num of sections
numS = 16;
```

Shroud lines

```
Ls = numS*(1.1*2*R/36 + .25) %yds total needed
```

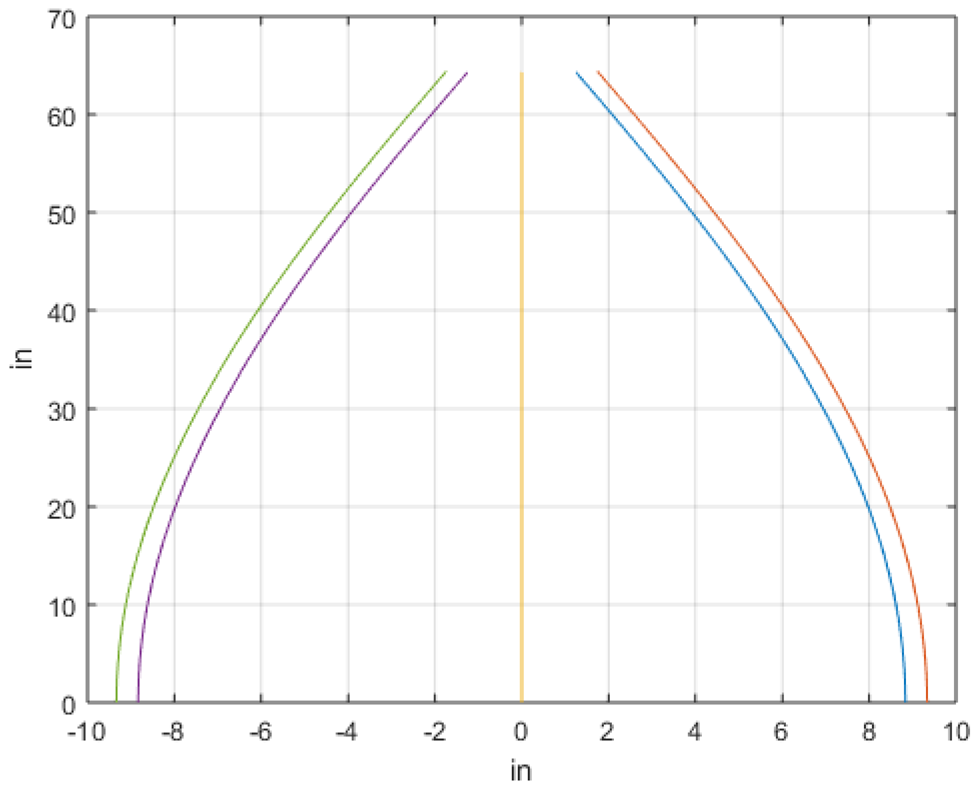
```
Ls =

   48.0000
```

Parachute design

```
%Calculate vent area
So = 2*pi*(R^2);
Av = So*Per/100;
rmin = sqrt(Av/(2*pi))

%Map segment
angmax = acos(rmin/R);
angle = linspace(0,angmax,numpoints);
x = (1/numS)*pi*R*cos(angle);
y = angle*R;

%Seam allowance
dx = gradient(x, angle);
dy = gradient(y, angle);

magnitude = sqrt(dx.^2 + dy.^2);
```

```
xnew = x + add*(dy./magnitude);
ynew = y - add*(dx./magnitude);

plot(x,y,xnew,ynew,zeros(size(y)),y,-x,y,-xnew,ynew)
grid on
xlabel("in")
ylabel("in")
```

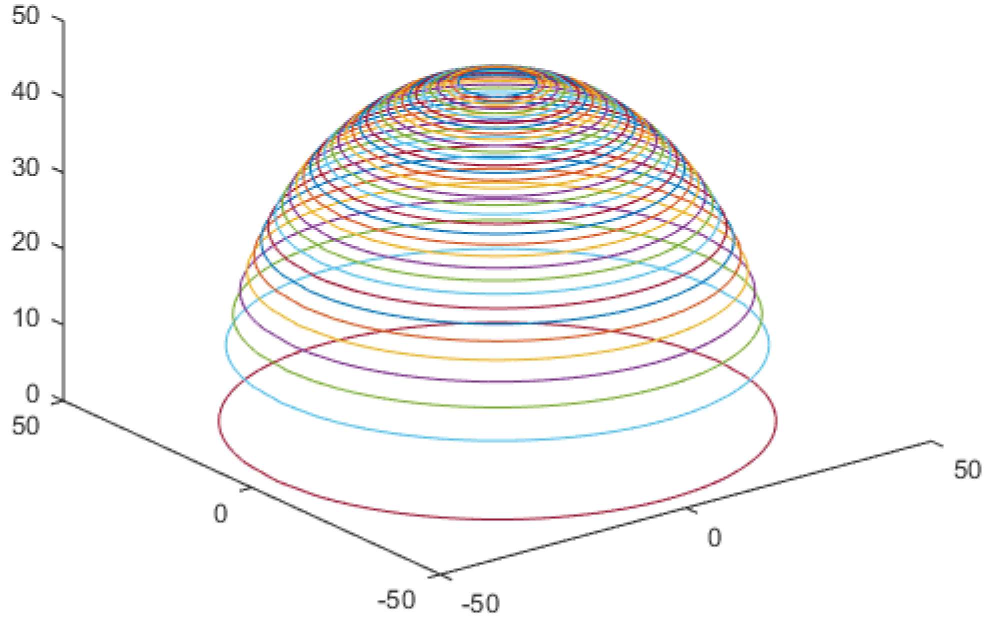
```
rmin =

    6.3640
```



Parachute image

```
N = 35;                            %Number of contour lines
step = (R - rmin)/(N - 1);

for r = rmin:step:R
    x = (-r):1:r;
    y = sqrt(r^2 - x.^2);
    X = [x,-x,x(1)];
    Y = [y,-y,y(1)];
    z = sqrt(R^2 - r^2)*ones(size(X));
```

```
    figure(2)
    plot3(X,Y,z)
    hold on
end
```



Published with MATLAB® R2017b

F. Engineering Drawings

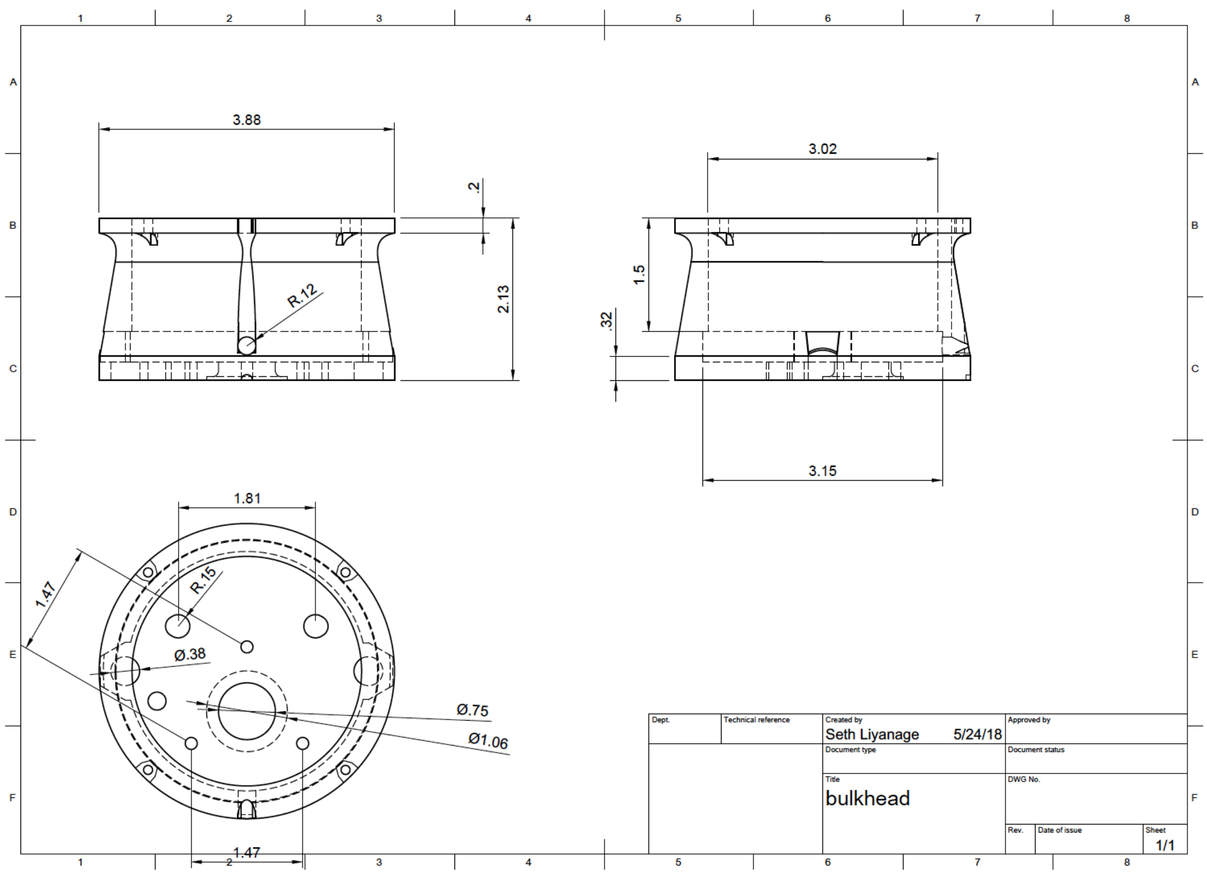


Fig. Bulkhead Coupler Part Drawing

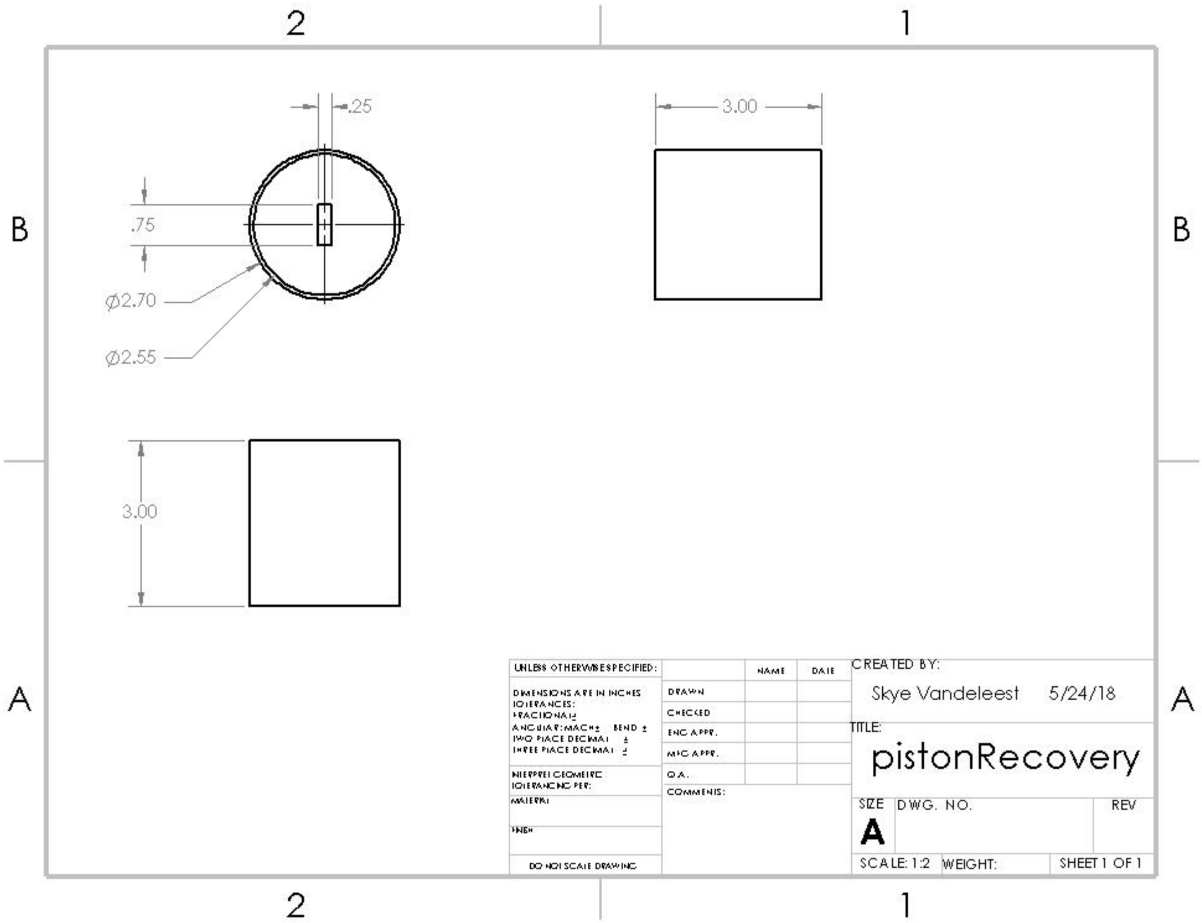
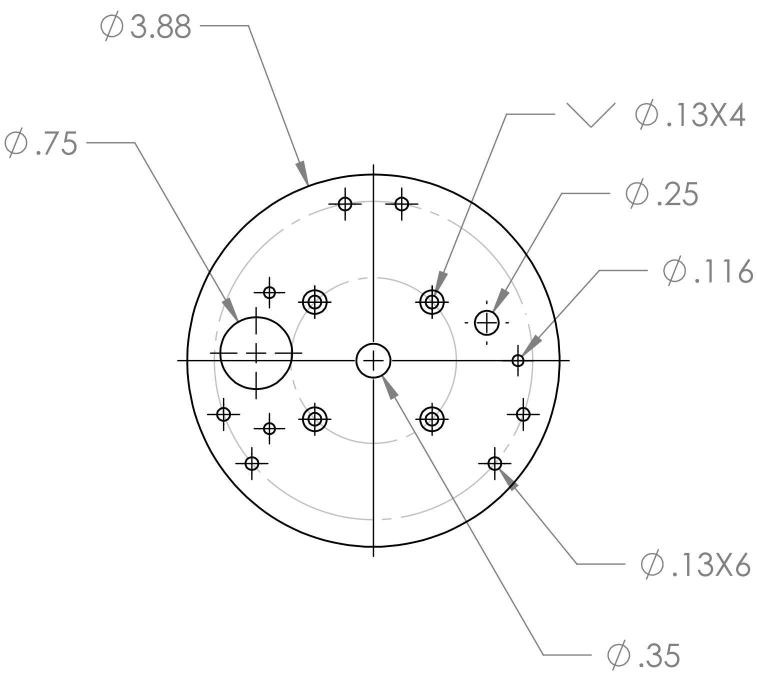
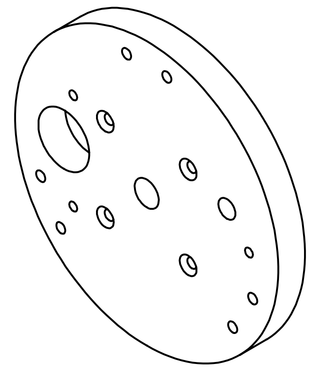
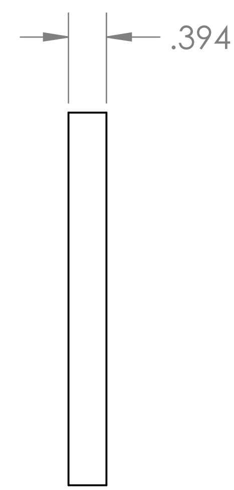


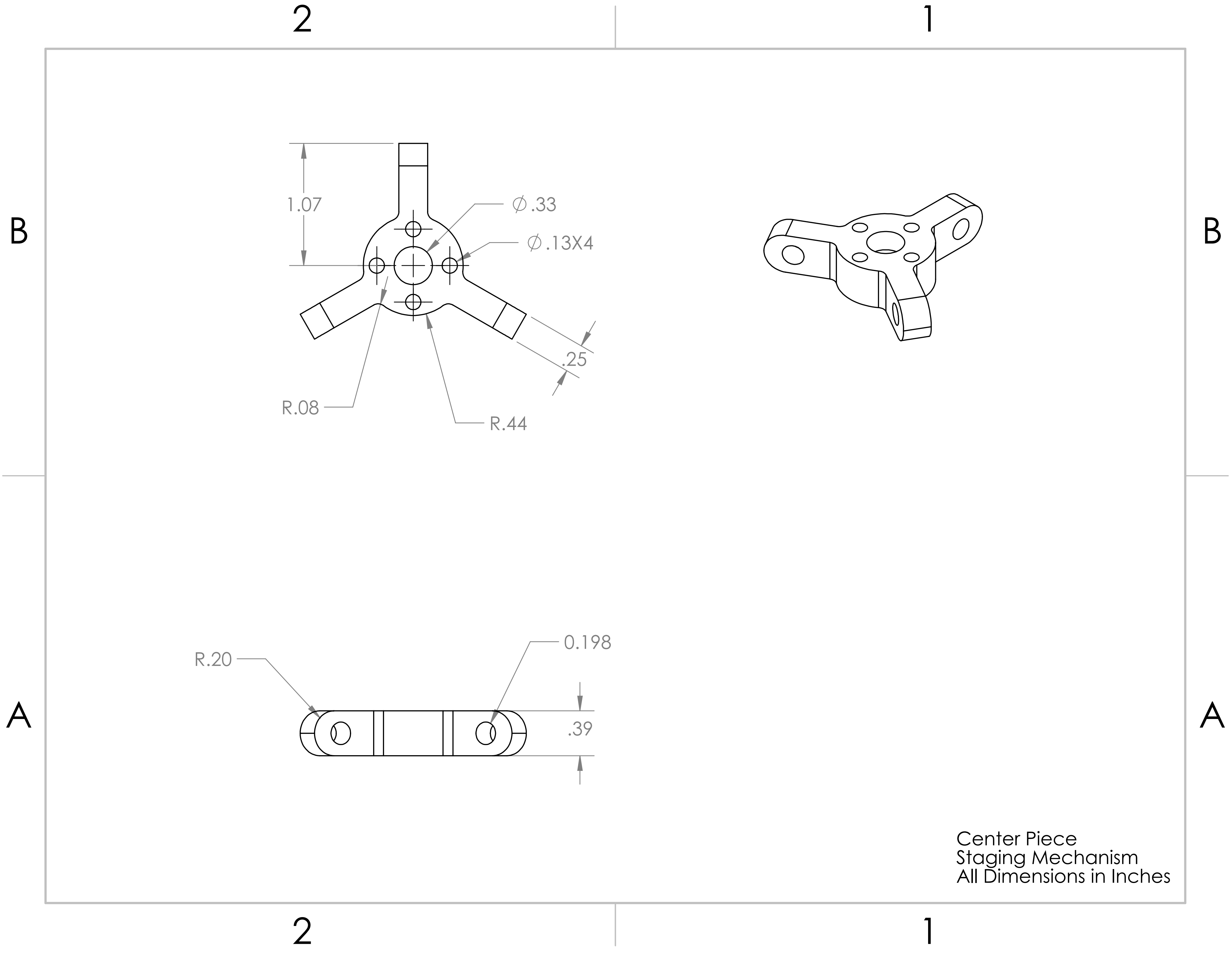
Fig. Piston Part Drawing



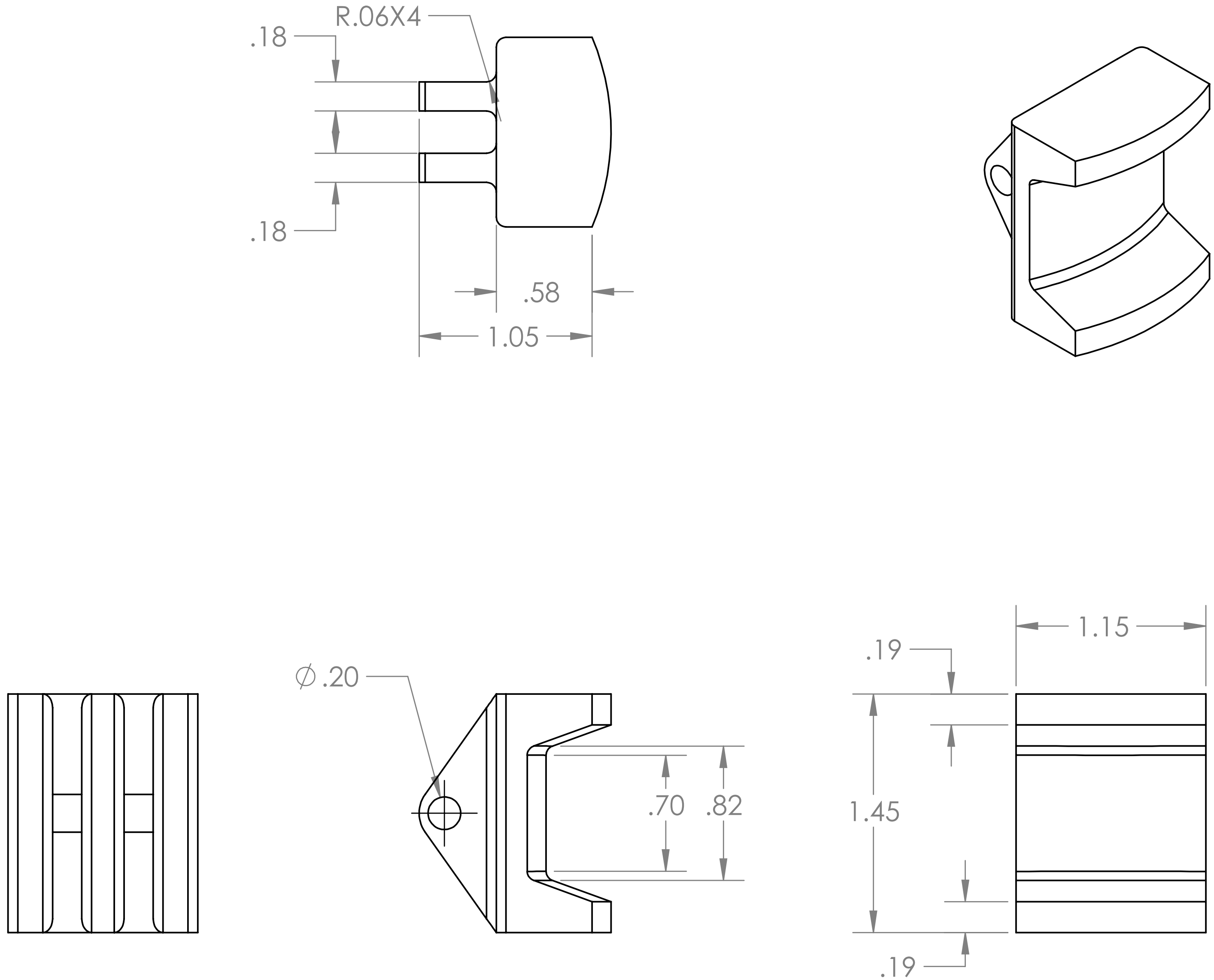




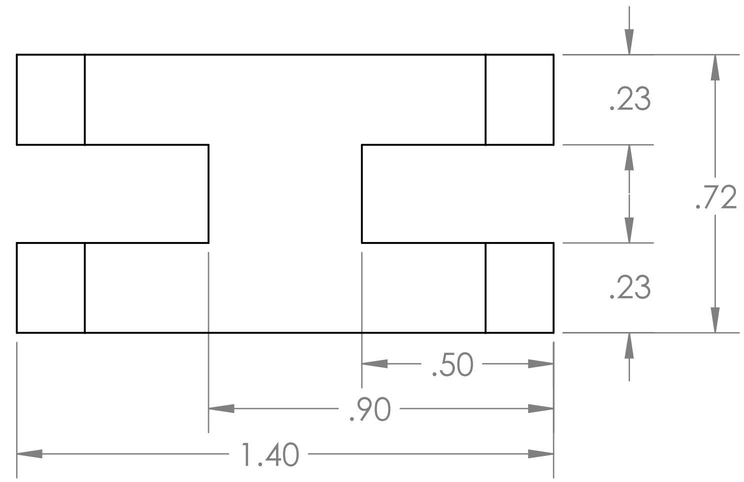
Base Plate for Motor Mount
Staging Mechanism
All Dimensions in Inches

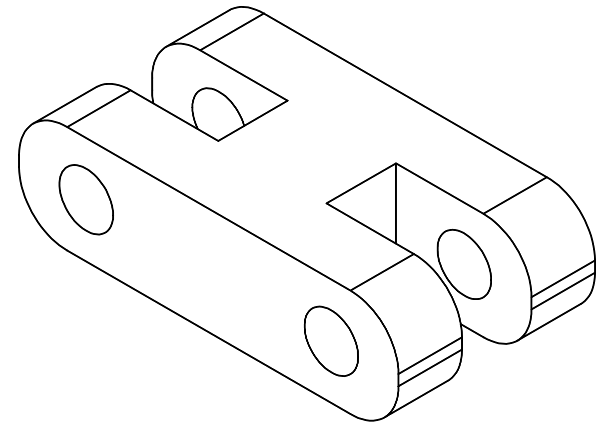


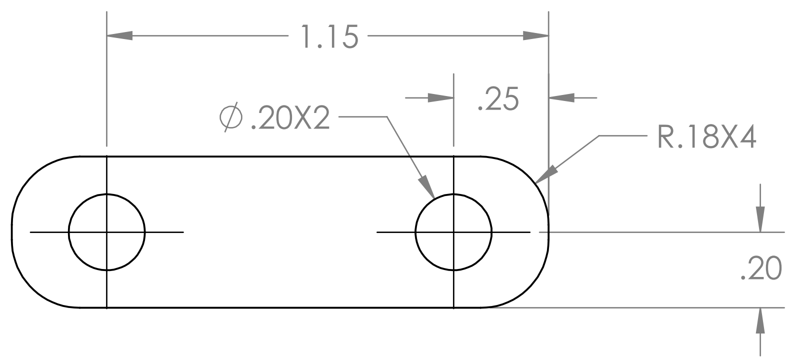
Center Piece
Staging Mechanism
All Dimensions in Inches

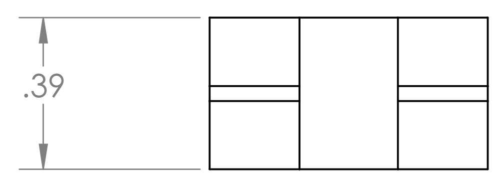


Clamp
Staging Mechanism
All Dimensions in Inches

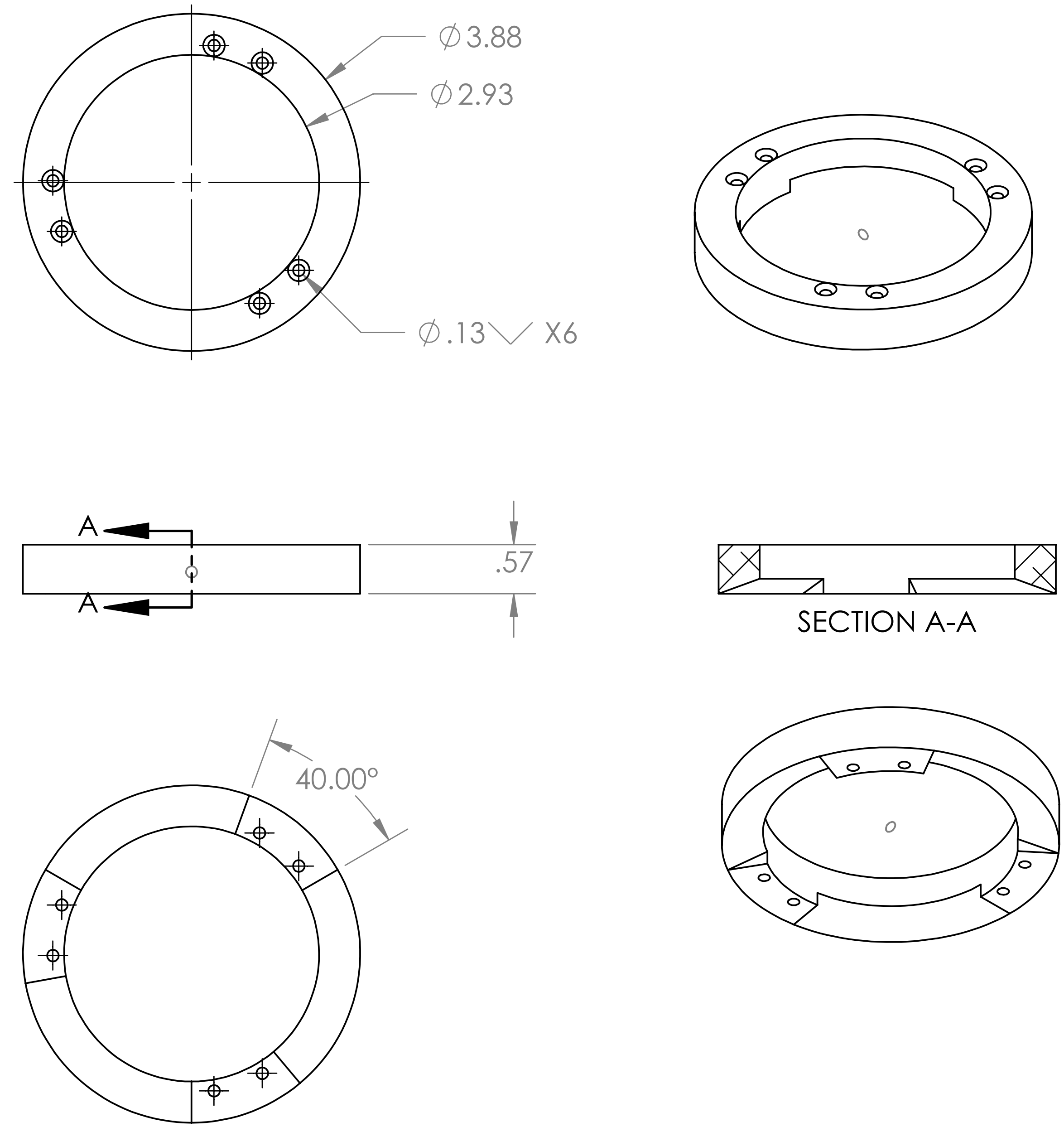




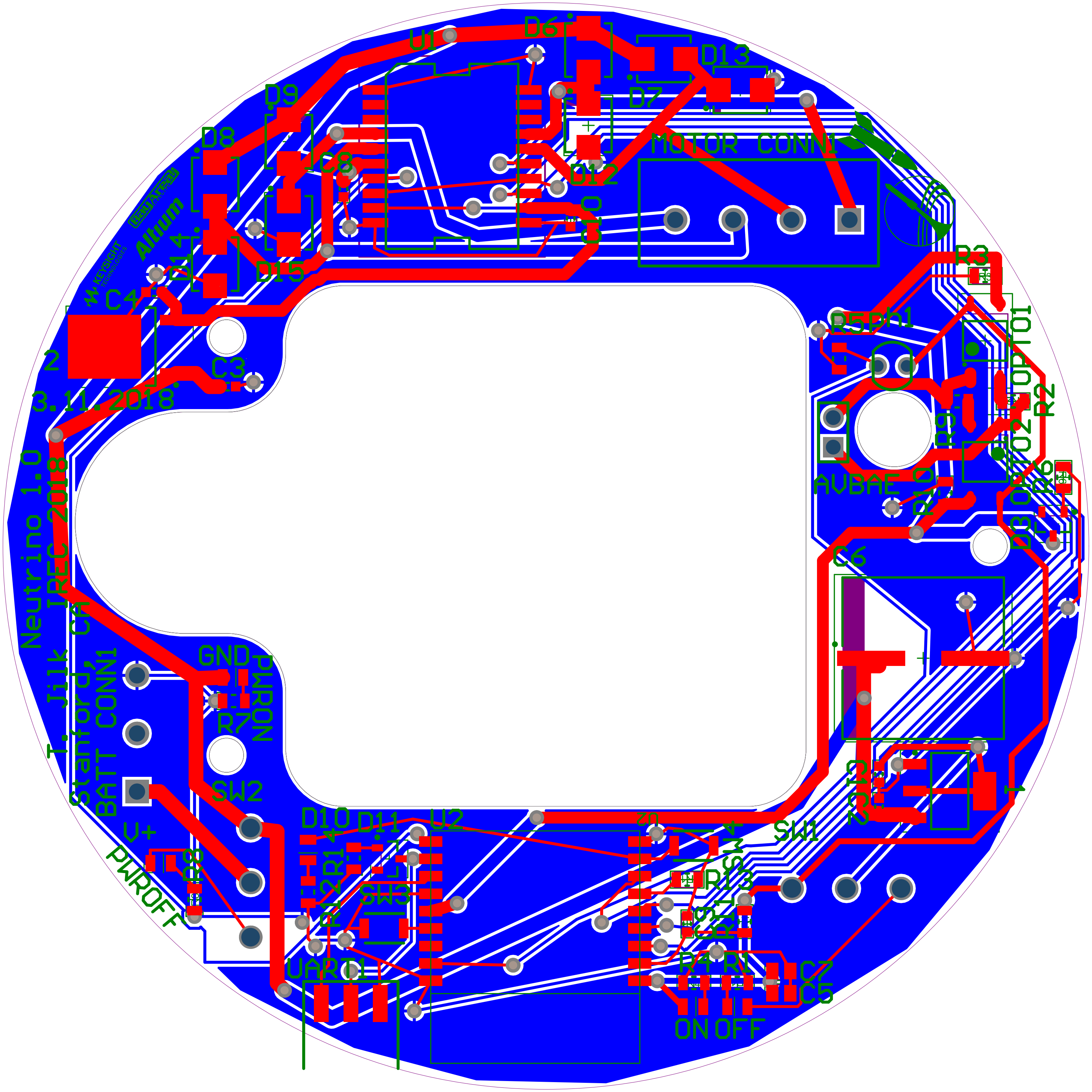


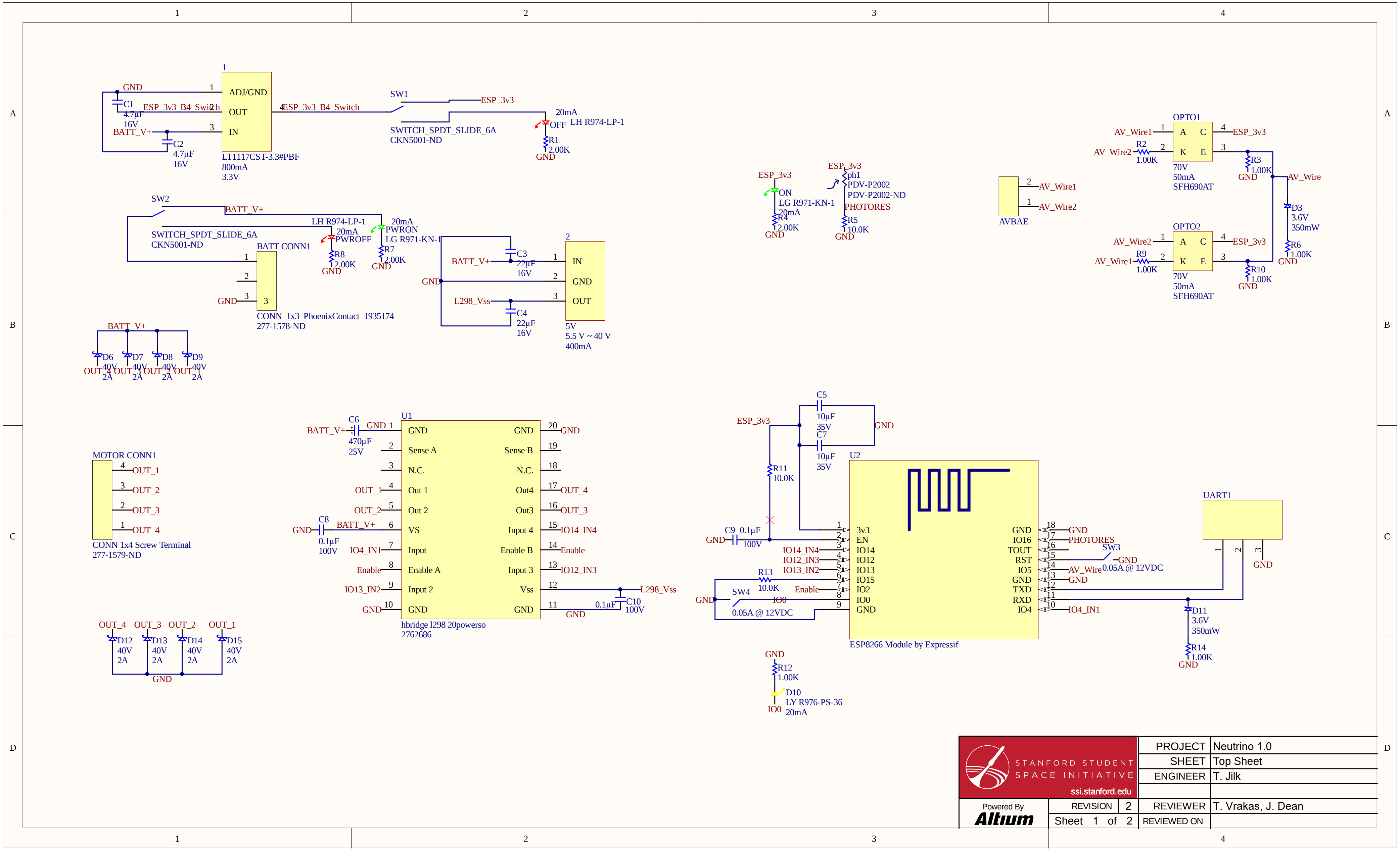


Horizontal Linkage
Staging Mechanism
All Dimensions in Inches



Lower Flange
Staging Mechanism
All Dimensions in Inches

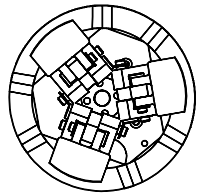

Neutrino 1.0
T. Jilk, IREC 2018
Stanford, CA
3.11.2018
U1
D6
D13
D7
D9
D8
C8
D12
D14
D15
C4
C3
MOTOR CONN1
R3
R5
Ph1
OPTO1
R2
R9
C6
Q1
SW1
SW2
GND
PWRON
R7
BATT CONN1
V+
PWROFF
D10
D11
U2
SW3
UART1
R13
R4
R1
C7
C5
ON
OFF

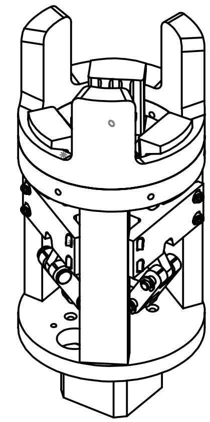


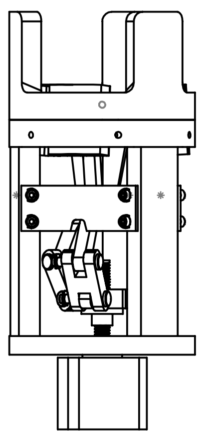
LT1117CST-3.3#PBF
800mA
3.3V
ADJ/GND
OUT
IN
ESP_3v3_B4_Switch
SW1
SWITCH_SPDT_SLIDE_6A
CKN5001-ND
ESP_3v3
20mA
OFF
LH R974-LP-1
R1 2.00K
GND
C1 4.7µF 16V
C2 4.7µF 16V
BATT_V+
SW2
SWITCH_SPDT_SLIDE_6A
CKN5001-ND
BATT CONN1
CONN_1x3_PhoenixContact_1935174
277-1578-ND
PWROFF
PWRON
LG R971-KN-1
R8 2.00K
R7 2.00K
C3 22µF 16V
C4 22µF 16V
L298_Vss
IN
GND
OUT
5V
5.5 V ~ 40 V
400mA
D6 D7 D8 D9 40V 2A
OUT_4 OUT_3 OUT_2 OUT_1
ON
LG R971-KN-1
R4 2.00K
ph1
PDV-P2002
PDV-P2002-ND
PHOTORES
R5 10.0K
AVBAE
AV_Wire1
AV_Wire2
OPTO1
OPTO2
70V
50mA
SFH690AT
R2 1.00K
R9 1.00K
R3 1.00K
R10 1.00K
AV_Wire
D3 3.6V 350mW
R6 1.00K
MOTOR CONN1
CONN 1x4 Screw Terminal
277-1579-ND
U1
hbridge l298 20powerso
2762686
C6 470µF 25V
C8 0.1µF 100V
C10 0.1µF 100V
GND
Sense A
N.C.
Out 1
Out 2
VS
Input
Enable A
Input 2
Sense B
Out4
Out3
Input 4
Enable B
Input 3
Vss
IO14_IN4
IO4_IN1
IO12_IN3
IO13_IN2
Enable
D12 D13 D14 D15 40V 2A
U2
ESP8266 Module by Expressif
C5 10µF 35V
C7 10µF 35V
C9 0.1µF 100V
R11 10.0K
R13 10.0K
SW4
0.05A @ 12VDC
IO0
3v3
EN
IO14
IO12
IO13
IO15
IO2
IO16
TOUT
RST
IO5
TXD
RXD
IO4
SW3
UART1
D11 3.6V 350mW
R14 1.00K
R12 1.00K
D10
LY R976-PS-36
20mA
STANFORD STUDENT SPACE INITIATIVE
ssi.stanford.edu
Powered By Altium
PROJECT Neutrino 1.0
SHEET Top Sheet
ENGINEER T. Jilk
REVISION 2
REVIEWER T. Vrakas, J. Dean
Sheet 1 of 2
REVIEWED ON

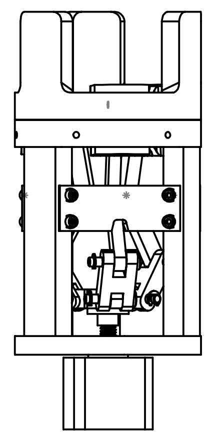
2 1

B B



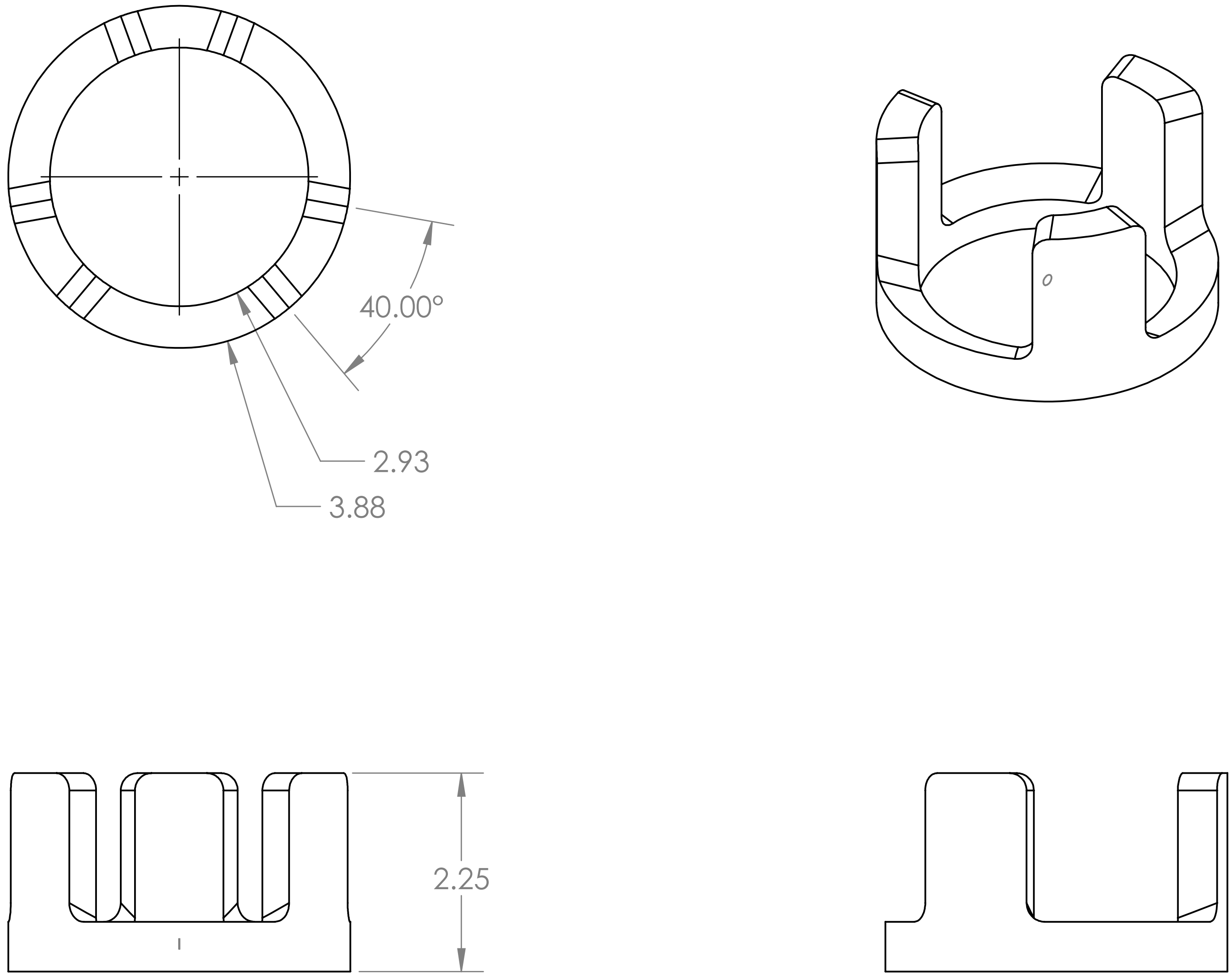




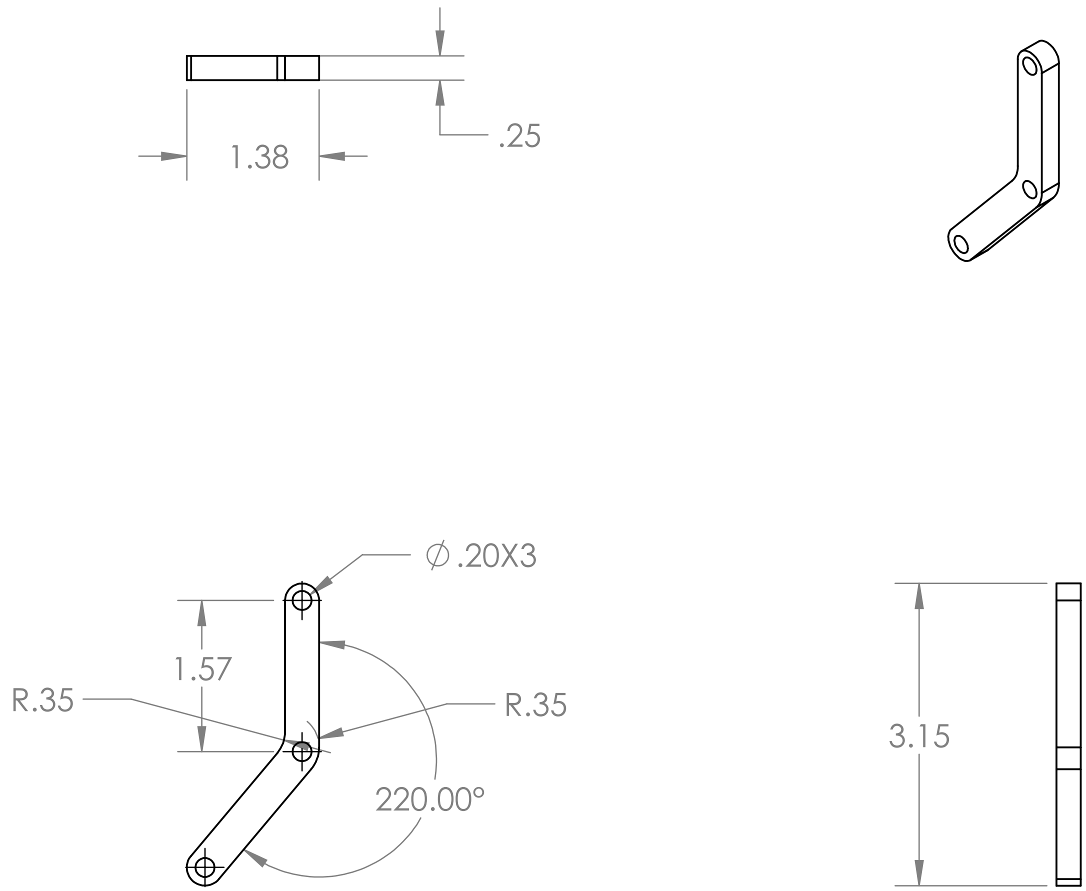


A A

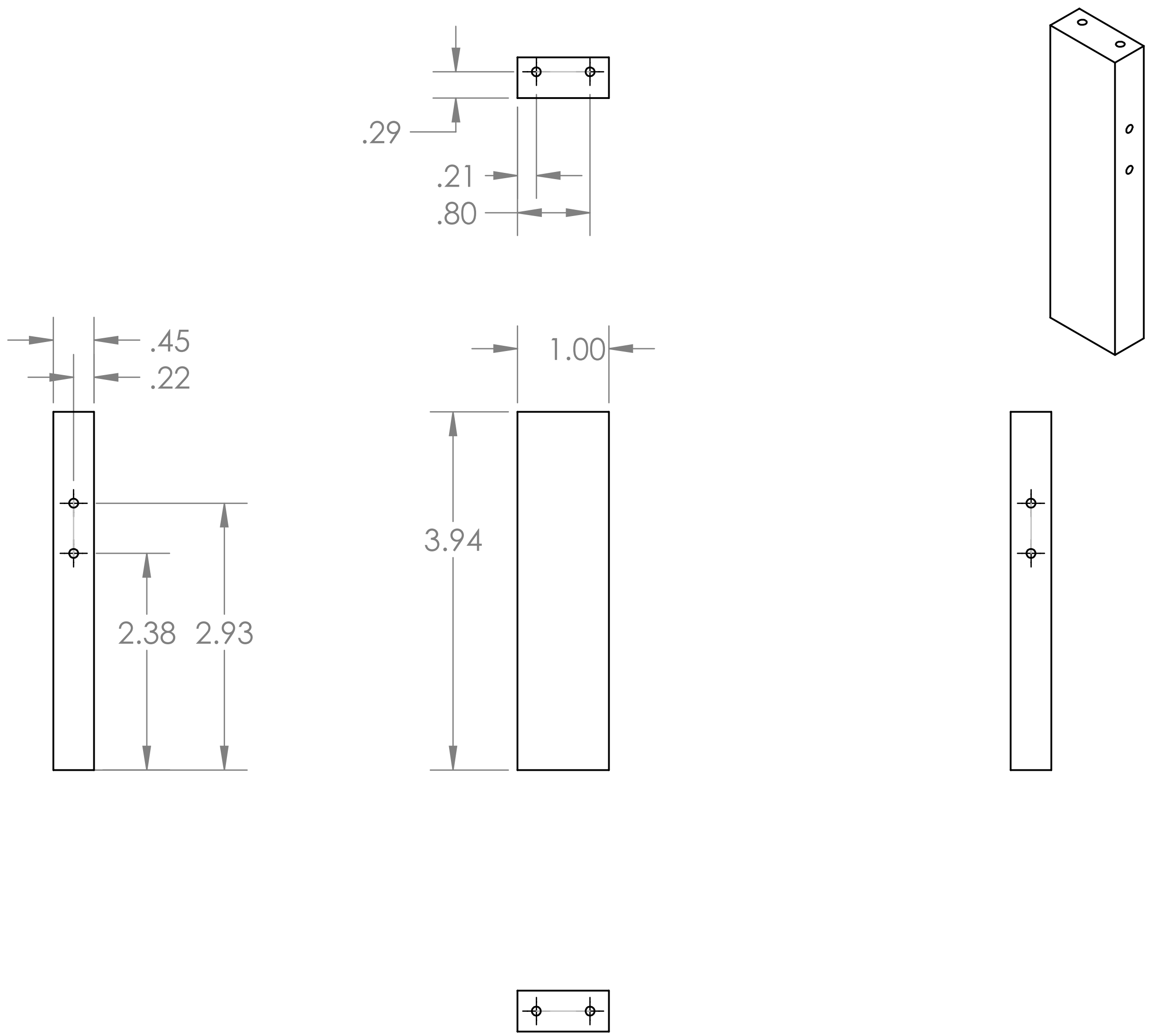
2 1



Upper Flange
Staging Mechanism
All Dimensions in Inches



Vertical Linkage
Staging Mechanism
All Dimensions in Inches



Vertical Upright
Staging Mechanism
All Dimensions in Inches

Acknowledgments

The team would like to thank…

Edward Conger for donating our IREC motor
Professor D'Amico and Vince Giarlo for lending their signal simulator to the payload team
Bloom Earthquake Center for letting us use their hydraulic test setup
Quanta Labs for allowing us to use their shock and vibe equipment
Hai Wong for his unwavering support
James Doughtery for advice and launch support
Our alumni for offering their technical expertise
Our PRD and CDR attendees for their valuable feedback
All of our generous sponsors for their donations to the team

References

Presentations

[20] NASA; Margins and Contingency Module: Space Systems Engineering, version 1.