OSU AIAA ESRA - Ramkoers

Team 68 Project Technical Report for the 2024 IREC

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Oregon State University's student Branch of the American Institute of Aeronautics and Astronautics (OSU AIAA) is an organization dedicated to aerodynamic education and research for all. As a team within the chapter, OSU AIAA's Experimental Sounding Rocketry Association team seeks to apply that education in the Intercollegiate Rocket Engineering Comeptition's (IREC) 10,000 ft Student Researched And Developed (SRAD) category. Equipped with the custom airbraking Blade Extending Apogee Variance System (BEAVS) to permit greater flight accuracy, Ramkoers is a 13 ft rocket merging custom built aluminum bulkheads, carbon fiber fins, and a fiberglass nose cone with a sponsor provided 6 inch carbon fiber main body. It will fly on a custom APCP motor, carrying a 3U payload capable of measuring UV flux and atmospheric gas concentrations, storing the data locally. The following report details the challenges, solutions, and specifications of the 2024 OSU AIAA ESRA Rocket Ramkoers.

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I. Nomenclature

G = shear modulus
t = thickness
C_r = root cord
C_t = tip cord
b = semi span
S = fin surface area
AR = aspect ratio
I = taper ratio
h_{vmax} = altitude at max velocity
P_{vmax} = air pressure at max velocity
T_f = temperature
a = speed of sound
V_f = fin flutter velocity

II. Introduction

Oregon State University's (OSU) American Institute of Aeronautics and Astronautics' (AIAA) Experimental Sounding Rocket Association (ESRA) is an undergraduate team in the OSU AIAA Chapter. OSU AIAA is a student-led organization founded in 2012 with the mission to introduce aerospace and aviation to a campus with no formal program for such studies. In 2024, OSU AIAA supported a total of 8 teams, serving more than 200 students. OSU AIAA ESRA has participated in the Intercollegiate Rocket Engineering Competition (IREC) for a decade and achieved 1st place at the competition in 2014. The team strives to uphold the legacy of the team after its absence from the competition in 2023.

OSU AIAA ESRA is a student-led team. This means that decisions are ultimately made by undergraduate team leadership. The team possesses a Team Lead, Team Treasurer, and divides itself into 5 subteams: Avionics, Payload, Propulsion, Recovery, and Structures. Each subteam possesses its own Subteam Lead. These positions encompass team leadership. The team is fortunate to have two faculty advisors, Dr. Roberto Albertani and Dr. Devin Roach. These advisors have provided invaluable insight and enabled the team to operate. The team is graciously supported by mentorship of the L3 flier, Mike Stewart.

Although the OSU AIAA ESRA team has substantial history in the IREC, none of the current team members have participated in IREC previously. Although previous OSU AIAA ESRA teams have competed in the 30,000 ft AGL SRAD category, the team recognizes this as a very challenging category beyond the current scope of abilities. However, with the support from adjacent rocket teams in the OSU AIAA Chapter, faculty advisors, gracious sponsors, and alumni the team will be competing in the 10,000 ft above ground level (AGL) student researched and developed (SRAD) category. The team wished to challenge themselves and concluded that the resources to produce an SRAD rocket were available. This year, the team proudly presents *Ramkoers*, the OSU AIAA ESRA rocket for the 2024 IREC.

III. System Architecture Overview

The System Architecture Overview provides a top-level view of the integrated rocket. The rocket is presented as if it will be flown in the competition. This section will first cover the overall rocket, then break into subsections detailing individual systems within the rocket. The purpose of the System Architecture Review is to present and justify the design. Design choice, reasoning, and manufacturing methods (if applicable) will be reviewed by this section. In some cases, components were commercial off the shelf (COTS). In these instances, justification for this choice is provided and the reasoning for this option is above an SRAD component. Technical drawings of subsystems can be found in APPENDIX F – ENGINEERING DRAWINGS.

A. Aero-Structures

The Aero-Structures Subsystem design is driven by the following IREC rules and regulations:

8.1 Adequate Venting
8.2 Overall Structural Integrity
8.3 Material Prohibitions
8.4 Load Bearing Eye Bolts And U-Bolts

8.5 Joints Implementing Coupling Tubes
8.6 Rail Buttons
8.7 Identifying Markings
8.8 Other Marking
10.2 Launch Stability
10.3 Ascent Stability
10.4 Over-Stability

1. Aero-Structures Overview

The goal of the Aero-Structures subteam is to design and manufacture the many structural components of the vehicle. All design decisions stem from restrictions put forth by the IREC rules and regulations, as well as restrictions on the team's ability to acquire and manufacture parts of the vehicle. The entirety of the vehicle is carefully designed to meet the goal of safely launching the payload to a target altitude of 10,000 ft and returning successfully.

The main structure of *Ramkoers* consists of two sections of 6.25 in diameter carbon fiber tube. These tubes are COTS, manufactured by Innovative Composites Engineering. These tube segments total a length of 128 in. Between these two tubes lies a 14 in long SRAD carbon fiber coupler that joins the two sections of the rocket together. On the bottom of the motor side (aft) body tube lies 4 G10 fiberglass core fins overlaid with a carbon fiber layup. A 3D-printed PA-6 nosecone mandrel with fiberglass layup is coupled to the fore body tube via an SRAD carbon fiber coupler. The body tube contains five 6061 bulkheads that separate sections of the rocket and secure different systems to the body tube.

In subsections 2-7 each aspect of the vehicle’s design will be covered.

Fig. 1

2. Body Tube

The purpose of the body tube is to both contain the internal components of the vehicle and transfer different loads throughout the length of the rocket. The main airframe consists of a COTS 6.25” diameter, 168” long carbon fiber tube provided by Innovative Composite Engineering (ICE). The tube was inherited from the OSU AIAA Chapter. Because of this, many design decisions were driven from the sizing of this pre-existing tube. The large diameter and length provided ample room to allow for a CubeSat formfactor payload. During the early stages of development this large size allowed for many routes to be explored such as differing motor diameters and payload designs. The long length of the body tube would later be instrumental, providing extra stability to the rocket meaning that less ballast would be needed to achieve an appropriate caliber of stability upon leaving the launch rail. The reason for working around this tube instead of ordering a custom sized one comes from the prohibitive cost and the lead time of getting a new tube. ICE graciously donated this tube to the OSU AIAA Chapter. This cost saving was necessary for the team to compete. Furthermore, the lead time required to order a composite tube meant that manufacturing of the vehicle would be greatly delayed.

IREC regulation 8.2.1 states that the rocket structure must be able to “withstand the operating stresses and retain structural integrity under the conditions encountered during handling and transportation and during rocket flight.” Carbon fiber is a great material to adhere to this regulation. Its structural qualities along with its density means that the body tube will remain light while maintaining the extreme structural stability necessary to undergo flight safely. Using carbon fiber also satisfies IREC regulation 8.3 as carbon fiber is one of the materials recommended for body tube use.

The singular 168” long tube was cut into two separate sections using a Dremel and sandpaper within the OSU Composites Lab. The tube was cut to allow for parachute deployment to take place in the middle of the vehicle. This allowed isolation of the rocket components that require hand integration to be within reach.

The aft tube (motor side tube) is 65.5” in length. The aft tube is where the main thrust load is transferred from the motor to the rest of the vehicle. Inside of the aft tube lies 3 bulkheads, one for transferring thrust, one to secure the BEAVS airbrake, and a final drogue parachute bulkhead. These bulkheads will be further discussed in subsection 4. Twelve holes were drilled for radial bolts using a bolt jig, hand drill, and shop vacuum. The 3D-printed bolt jig held the guide in place using set screws. Metal bushings aligned the drill to allow for 8 evenly spaced holes that allow radial bolts to interface with the bulkheads. This jig also allowed for accurate placement of pressure relief holes for all enclosed sections of the rocket. Along with the radial bolts and pressure relief holes, the bolt jig was used to create the holes used to attach the rail buttons. Although the team plans to bring a launch rail, the rail buttons are IREC regulation 8.6 compliant.

The fore tube (nosecone side) is 61" in length. This side of the tube contains two bulkheads, one for parachute attachment and another for payload attachment. The lower portion of the tube contains the main and drogue parachutes. Radial bolts and pressure relief holes are drilled in the tube using the same jig as the aft tube.

Fig. 2

3. Coupler Tubes

Ramkoers requires two couplers to assemble the rocket structure. The separation coupler, located at the point of separation between the fore and aft body tubes, is a critical component of the rocket. This coupler must withstand torsional loading from the reactionary forces exerted on the fins and translate that motion to the for section. This coupler will also undergo bending caused by reactionary forces exerted on the fins. This coupler must keep the fore and aft body tube sections colinear throughout the flight of the rocket before apogee.

To have the separation coupler succeed, it must be at least twice the length of the body tube diameter. This coupler must also possess low outer diameter tolerances such that the fit into the body tube is tight but not difficult to insert. The coupler must also be made a durable material to endure the anticipated loading.

Due to these design constraints, the team created an SRAD coupler. Because of the custom body tube donated from ICE, the inner diameter of the body tube is nonstandard, and a COTS option for this coupler would result in alteration of the coupler outer diameter. The team utilized its access to the OSU Composites Lab to design and manufacture a custom coupler. This coupler is constructed of Toray T830 Woven Carbon Fiber with a layup schedule of [0/45/0/45/0/45/0/45/0]. Plies were cut into rectangles and laid inside a cut section of the COTS body tube. The coupler is 14" in length such that it is greater than twice the diameter. Fig. 3 illustrates a few steps in this process.

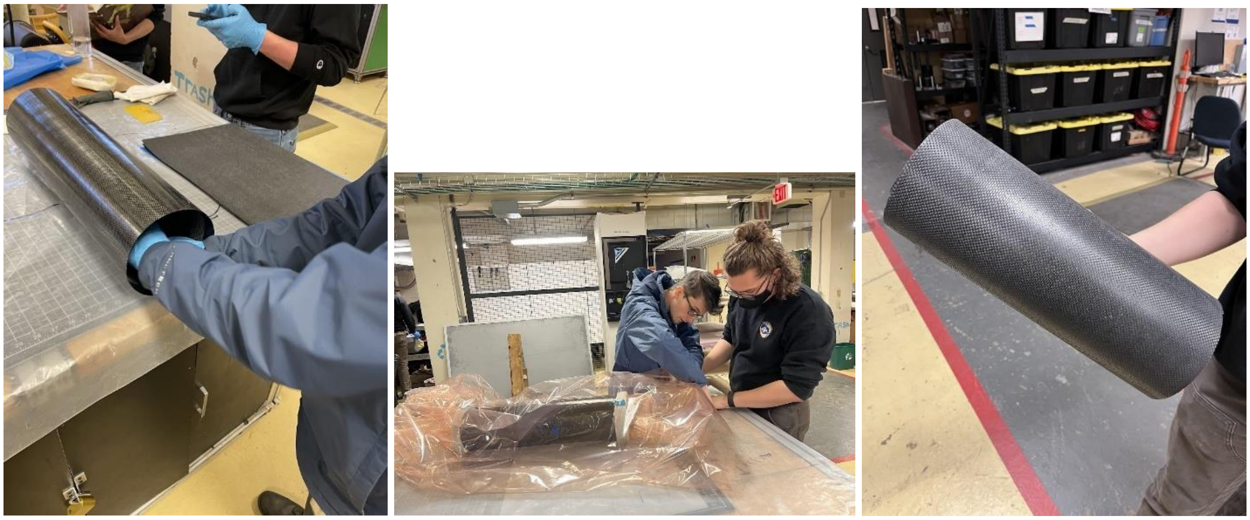


Fig. 3

This coupler is then epoxied into the fore body tube as a permanent joint. In addition to the separation coupler, there is a coupler required for the joining of the nosecone to the fore body tube. This joint must be removable for integration of the AV bay, payload, and main parachute bulkhead. However, this joint will not be utilized as a separation point during recovery and will remain as such throughout the entire event. Because of this, the nosecone coupler is not expected to endure as severe loading as the separation coupler. The design of this coupler is altered to have a layup schedule of [0/45/0/45/0/45/0/] and be 11” in length. This coupler is then used in the manufacturing process of the nosecone and is depicted in Fig. 4.

Fig. 4

4. Bulkheads

The purpose of the bulkheads within the rocket is to act as the interface between the body tube and internal structures. Within the vehicle there are three types of bulkheads that the Aero-Structures subteam is responsible for. This includes the thrust bulkhead, two parachute bulkheads, and the payload bulkhead. Because of the high stresses that the rocket will undergo, and the ease of manufacturing, aluminum was chosen as the bulkhead material.

Early in the design process it was decided that it would be best to implement radial bolt secured bulkheads into the rocket. This allows for the replacement of bulkheads as the result of damage and allows for much more versatility in how the team can integrate the vehicle. However, it was decided that for the thrust bulkhead, a stronger epoxy bond was needed to ensure that the bulkhead was able to transfer the load of the motor to the body tube without shearing bolts. Empirical data collected by another OSU AIAA team can be found in APPENDIX G – ADDITIONAL RESOURCES and was used to determine the strength of a carbon fiber to aluminum bond. Along with this, finite element analysis (FEA) using simulated motor data was used to validate that the motor bulkhead is capable of handling 150% rated load seen in Fig. 5.

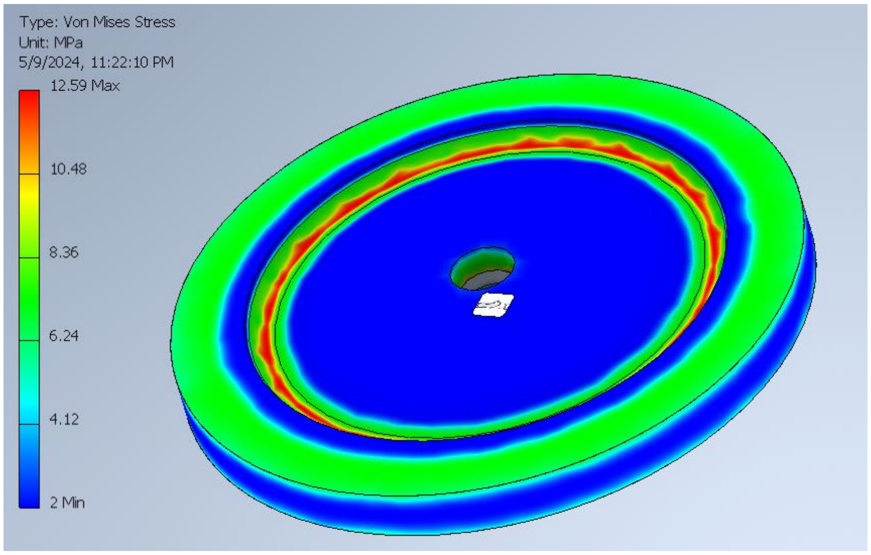


Fig. 5

The thrust bulkhead is a flat plate of aluminum with a diameter of 6.25 inches. The thrust bulkhead was cut out of a sheet of ½ in 6061 aluminum by Rosen Aviation, a sponsor. Once the round was delivered, the team could lightweight the part by removing material from the middle of the non-motor contacting side of the bulkhead. A ⅝" hole was drilled in the middle to allow for the motor retention bolt to screw into the forward enclosure of the motor.

The two parachute bulkheads were also cut from a sheet of ½" 6061 aluminum by Rosen Aviation. A center hole was drilled to allow for a ½" grade 9 bolt to secure the forged recovery eye-nut. Along with the ½" main bolt, a smaller ¼" eye bolt is used to prevent the main eye bolt from loosening.

Fig. 6

The last bulkhead is the payload bulkhead. It is similar in design to parachute bulkheads as it has eight radial bolts used to secure it to the body tube. The main purpose of the parachute bulkhead is to mate with the payload and secure it during flight. The fastening method can be seen in Fig. 7.

Fig. 7

5. *Nosecone*

The OSU AIAA ESRA team constructed an SRAD nosecone for *Ramkoers*. Due to the restriction imposed by the nonstandard size COTS body tube donated by ICE, the team designed and manufactured a custom nosecone. For simplicity and aerodynamic efficiency, a 1.0 Ogive nose cone was chosen. Design considerations include joint mechanism to the fore body tube, structural integrity, mass, manufacturability, aerodynamics, and mounting mechanism for the AV bay. OSU AIAA ESRA is fortunate enough to have access to documentation of previous OSU AIAA teams' nosecone construction. This design is inspired by and an improvement upon a design idea from a previous University Student Launch Initiative (ULSI) team. This past design used a hollow, 3D-printed, non-removable mandrel to layup dry woven fiberglass and a room-temperature cure resin. The nosecone was then finished with sandpaper and painted. To improve upon this design, the team used Fiberglast 7781 E-Glass prepreg instead of a wet layup. Prepreg composites mitigate common problems such as improper or inconsistent matrix-reinforcement ratios. However, manufacturing complications arise since 7781 E-Glass must be cured at 270 °F. Thus, PA-6 nylon filament infused with 30% fiberglass is used as material for the mandrel. This is critical as a filament with a very high transition temperature is required for the mandrel to hold shape during the cure cycle.

The mandrel is printed in 4 sections that slot together to form a single rigid body. The largest diameter section interfaces with the carbon fiber coupler detailed in *Coupler Tubes*. This section must also interface with the AV bay bulkhead. Detailed drawings can be found in APPENDIX F – ENGINEERING DRAWINGS and an illustration of the glue-up process can be found in Fig. 8.

Fig. 8

From this state, the 7781 E-Glass prepreg plies are laid onto the mandrel. The layup schedule is [0/45/0/45/0]. The laminate undergoes debulking between layers. To do this, a debulk bag is constructed and vacuum is pulled for 20 min. Once the final layer has been laid, the entire mandrel is vacuum bagged and cured in-house. This process is illustrated in Fig. 9.

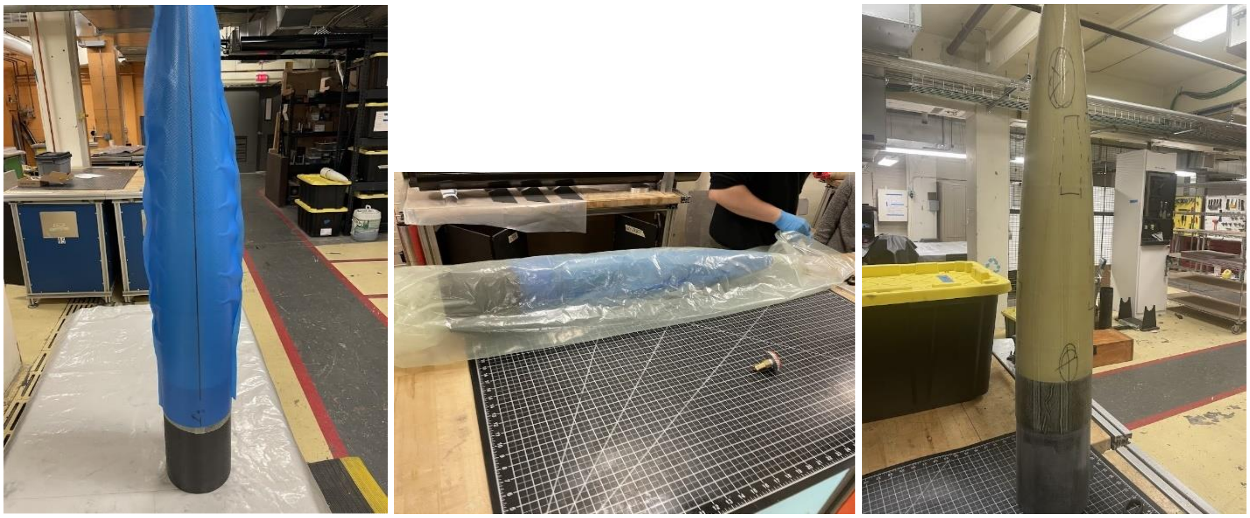


Fig. 9

After the nosecone is cured, finishing work is done to create a smooth surface finish and remove excess resin. The final product is primed and painted in the theme of the team's colors.

The SRAD nosecone tip is the final component of the nosecone. The tip is triangular conical as opposed to following the same curve used to define the nosecone. This is done to reduce manufacturing complexity. The nosecone tip is constructed of 6061-T6 aluminum and machined in-house on a manual lathe. The base of the nosecone tip is threaded 1/4"-20 for the purpose of AV bay assembly.

Fig. 10

6. Fins

The stability of the rocket is one of the most important numbers that the structures subteam must keep in mind during the design of the vehicle. Fin shape was determined by looking at past OSU AIAA ESRA teams to identify a fin shape that would suit the needs of a vehicle performing the same task of carrying a payload. Iterating on fin designs using OpenRocket led the team to the current fin design. Leveraging the length of the body tube the team can maintain a balanced caliber of stability satisfying IREC regulations 10.3 and 10.4. Immediately after leaving the launch rail, the vehicle has a caliber of stability of 1.6 cal and a dynamic in-flight stability of 3.38 cal, always remaining in the IREC window for stability.

The fins are made of a core of 0.1875" G10 Garolite from McMaster-Carr. These cores were cut to size and 2 layers of Toray T830 Woven Carbon Fiber in a [0/45] pattern were applied to each side. The fins were then chamfered to 78 degrees. After the chamfering, the surface of the tube was prepped for bonding using sandpaper. Using West Systems 105 epoxy, the fins were attached to the body tube with a fin jig to hold each fin straight.

Fig. 11

After each fin was secured straight to the tube, a filet of epoxy was added to the base of the fins to increase their strength. To further reinforce the fins and add the structural stability needed to survive flight, a layup of carbon fiber was applied to the fins. Toray T830 Woven Carbon Fiber was used in a [0/45/0]. To cure the resin, an envelope bag was used to pull a vacuum on the fins around the tube. After curing overnight, the bag was removed and the fins were sanded to their flight ready state.

Fig. 12

The fins are one of the most important components during flight and so it is immensely important that the fins are structurally sound. One of the main failure modes of fins is fin flutter. During a fin flutter event, the fins of a vehicle will shake themselves apart causing a catastrophic failure. To prevent this, the fins are designed to withstand immensely high velocities before fin flutter becomes an issue. Using equations derived from NACA Technical Note 4197, an equation can be found that gives a maximum velocity before fin flutter will occur for a fin of a certain geometry. Using a program developed by Oregon State University called OSULaminates, the shear modulus of the Toray T830 layup can be calculated.

Table 1

Number of Fins	4
Root Cord	13.25 in
Tip Cord	5.938 in
Height	4.5 in
Sweep Length	5.438 in
Thickness	0.25 in
Shear Modulus	12.448 GPa

$$V_f = a\frac{\sqrt{G\left(2(AR+2)\left(\frac{t}{C_r}\right)^3\right)}}{1.337(AR)^3(P_{vmax})(I+1)} \tag{1}$$

$$AR = \frac{b^2}{S}, \qquad S = \frac{1}{2}\,(C_r + C_t)b, \qquad I = \frac{C_t}{C_r}$$

$$a = \sqrt{1.4(1716.59)\big(T_f + 460\big)}, \qquad T_f = 59 - 0.00356(h)$$

Using fin geometry, the team was able calculate fin flutter velocity. With the vehicle's current fins, the fin flutter velocity is 4144 ft/s with an 80% safety margin. This 4144 ft/s boundary is well above the 938 ft/s maximum current velocity of the vehicle.

7. BEAVS

The Blade Extending Apogee Variance System (BEAVS) is the team's solution to hitting the target altitude regardless of the power of the motor. The purpose of BEAVS is to allow the team to focus on building a reliable motor and stable rocket without having to worry about cutting weight and adding additional ballast to hit the target altitude. If the motor is consistently over- powered BEAVS, can always lower the apogee. To do this, BEAVS uses two blades that protrude from the body of the rocket. During the coast phase, the system uses enabled and using on-board sensors and an active control system. Actuation of the blades causes the blades to be actuated to increased drag and slows the vehicle. The system is powered by a single high torque servo motor that rotates a pinion. Both blades run on linear guides and have a rack to interface with the pinion. This gives the system precise control of the position of the blades at any given time. When designing the system, the team reviewed previous attempts to make airbrakes at Oregon State University. Previous revisions were routinely underpowered and under-built for the forces they experience during flight.

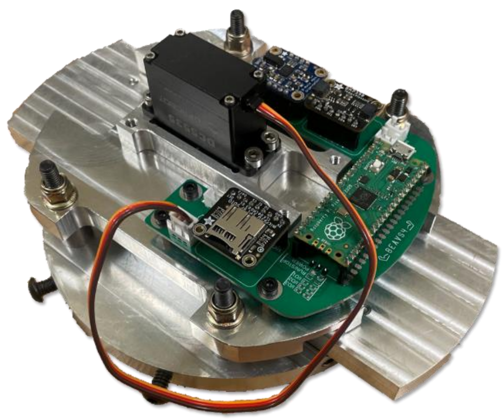
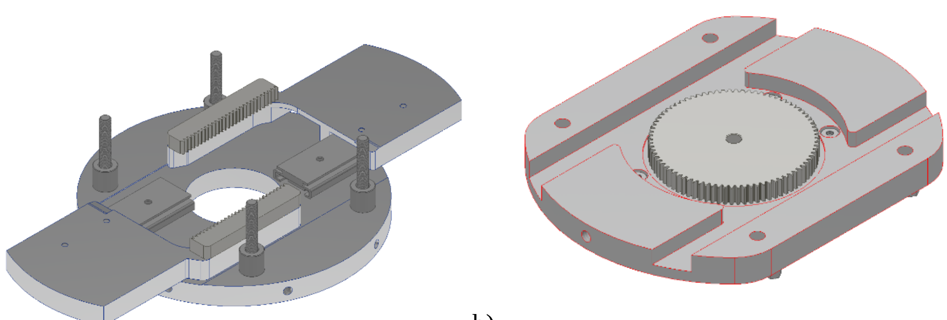


Fig. 13

BEAVS is assembled like a sandwich with the motor and electronics mounted and prepared on one side. The other side has linear guides mounted and tuned, blades attached, and hard stops mounted if needed. The two halves are then mated and secured together with through bolts and spacers to ensure alignment. The electronics powering BEAVS consists of an RP2040 microcontroller as the brain of the operation. The RP2040 is wired to a microSD card to store data. It is also equipped with a manual interrupt to assist with integration. For sensing the controller is wired to a BMP390 altimeter and BNO055 accelerometer/gyroscope. The control system only uses the altimeter to find vertical velocity and feeds that into the PID controller. Because the system is completely dissipative the controller was programmed and tuned to utilize its effectiveness of the blades based on the current velocity. With the blades being more effective at the beginning of the coast phase when the vehicle has the most speed. Then as the vehicle slows using the finer control at the end of the coast phase to hit the target apogee with greater accuracy.



a) b)

Fig. 14

B. Propulsion

1. Objective

The main objective of the propulsion subteam is to design and test an SRAD solid fueled rocket motor capable of supplying the team's rocket with enough impulse to achieve an altitude of at least 10,000 ft. This must be done while adhering to the safety rules and regulations outlined in the IREC documentation, as well as the policies of the local government and Oregon State University. Knowledge leading to the subteam's design choices has been acquired primarily through online research, faculty advisors, and documentation from previous OSU AIAA rocketry teams.

2. Main Structure

The main structure of the rocket motor consists of the outermost tube called the motor tube and the enclosure that seals off the front most end of said tube called the forward enclosure. These components are intended to contain the high temperatures and pressures produced in the combustion of the propellant. Hence, each needs to be adequately resilient to temperature and mechanically strong yet must also be lightweight to reduce any negative effects to overall flight characteristics such as stability and off the rail velocity. To meet these design requirements, both are made from 6061-T6 aluminum alloy; an alloy which is stronger and more resilient to high temperatures than other aluminum alloys, yet significantly more lightweight and cost effective than materials such as titanium or steel.

The motor tube measures approximately 36 in length, 3.5 in inner diameter, with a 3/16 in thickness at its thinnest and a 1/4 in thickness at its thickest. On each end it contains an inner groove 1/4 in deep into the tube machined to fit black phosphate interior retaining rings, one to secure the forward enclosure and one to secure the nozzle. The forward enclosure measures approximately 1.5 in in length with two different radii; one is slip fit into the motor tube and measures 1 in of the total length, and the other is slip fit to the phenolic and measures the remaining 0.5 in of the total length. The forward enclosure features 3 grooves machined to fit o-rings, allowing for a better seal against pressure. Two of the o-rings seal the motor tube, and one seals the phenolic. The o-ring in the phenolic is intended to prevent hot exhaust gas from traveling behind the phenolic and ablating it from both sides.

3. Thermal Insulation

The yield strength of the aluminum used for the motor tube reduces rapidly as its temperature increases. This, in addition to the high pressures the motor must contain, makes thermal insulation a major consideration for the motor. This problem is being solved by inserting a COTS phenolic tube between the propellant grains and the motor tube. The phenolic insulates the tube by ablating as it contacts the hot exhaust gas. The phenolic tubes are a significant budget item for the team, as such an attempt to produce the team's own thermal liners from paper and epoxy resin for future motor burns is underway.

4. Nozzle

The effects of nozzle geometry on the operation parameters of a rocket motor is a highly complex topic for which understanding is not within the reasonable scope of this subteams goals. As such the team has highly relied on previous teams' nozzle designs along with simulation software such as OpenMotor to decide on nozzle geometries. The team ended up designing a nozzle with a 15° divergence half-angle, a 55° convergence half-angle, a 1.05 in throat diameter, a 1/4 in throat length, and a 2.875 in exit diameter. Additionally, the nozzle would feature two o-ring grooves to prevent unwanted escape of exhaust gas and would be retained with an internal retaining ring. Regarding the nozzle, machinability and cost has been a much higher concern for the team.

Early in the year, OSU gave word that the machining of graphite and phenolic in university facilities would no longer be available to the team. This left 2 options for the team; externalize the production of graphite or phenolic nozzles or find another material or method capable of producing a working nozzle. The prior option would end up costing between $500 and $1000 per nozzle, a price the team could not justify. The team proceeded to find a material that would be cheap, available to machine in house, and able to withstand the high temperatures experienced by a nozzle. The decision was made to create a nozzle out of a 304 stainless steel. The nozzle was designed for the convergent section and throat to sit inside the motor tube, whereas the divergent section remained external.

Two nozzles were created this way, one was used during a full scale static fire and the other was used during the team's April launch in Brothers, Oregon. Both instances showed promising and successful results. Each of the nozzles experienced minor erosion at the throat in addition to varying tempering across the entirety of the nozzles. After the launch in Brothers, the team discovered that nozzles made of stainless steel would not be permitted at competition since Tripoli insurance is now required for IREC. Though highly successful in producing and utilizing stainless steel for the nozzle, the team is currently working on exploring other means of creating a nozzle for future launches including competition.

Fig. 15

5. Propellant Gains

The propellant being utilized is an Ammonium Perchlorate Composite Propellant (APCP) mixture formulated by previous students and faculty at OSU called Liquid Sand. Ideally, the propellant is 79% 200µ Ammonium Perchlorate (AP), 2% aluminum powder, 13% R45, 2.61% MDI, with the remaining percent being various binders. The mixed propellant is packed by hand into paper grain tubes using wooden dowels and 3D-printed molds. The result is five BATES grains, three at 7 in lengths and one at 6 in and 1 at 5 in. Additionally, each has a different core diameter, and are assembled with the largest core at the nozzle end and the smallest at the forward end of the motor. The result of burning this propellant along with the motor design outlined above is a total impulse of around 11,000 Ns, a maximum chamber pressure of around 800 psi, and a burn time of no less than 4 s.

Fig. 16

C. Recovery

1. Objective

The objective of the recovery subteam is to safely bring the vehicle to the ground after flight at a safe velocity, to a reasonable distance from the launch site. Using a dual deploy system the recovery team can bring the vehicle back to a location close to the launch site. Many systems are made redundant using multiple charges.

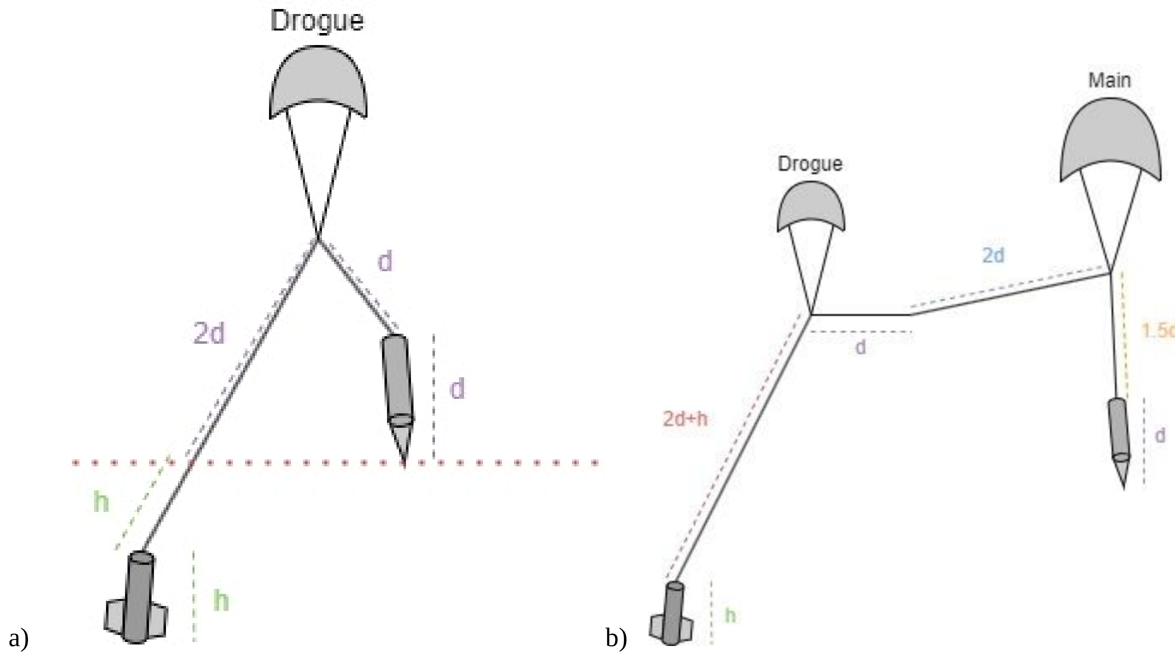


Fig. 17

Above are the line diagrams for the recovery system. When designing the parachute system, a high priority was ensuring that there was no possible way for the aft or fore sections of the rocket to collide with the parachutes after deployment. The chances of this and the fore and aft sections colliding during descent were minimized by using the specific lengths of line in the recovery system. The section of shock cord between the aft tube and drogue is 28.5 feet long, the section of cord between the drogue and main is 25 feet, and the length between main and the fore body tube is 15 ft.

2. Drogue Chute

The drogue parachute is the first parachute to deploy immediately following the rocket's apogee. It is intended to keep the rocket's recovery system inline during descent, and to slow the descent of the rocket to a speed where the main parachute can safely deploy. Ideally a drogue parachute experiences negligible shock loading when deployed at apogee. However, a mishap at takeoff can introduce horizontal velocity that can damage the drogue on deployment. It is for this reason a toroidal parachute was used as it distributes the load of the parachute across a greater number of shroud lines. Alongside this, a toroidal design has a theoretical maximum drag coefficient $C_d = 2.2$ compared to $C_d = 1.5$ for a conventional hemispherical parachute of the same canopy diameter. This higher drag coefficient allows for the use of a smaller parachute. The inflated drogue parachute is pictured in Fig. 18.

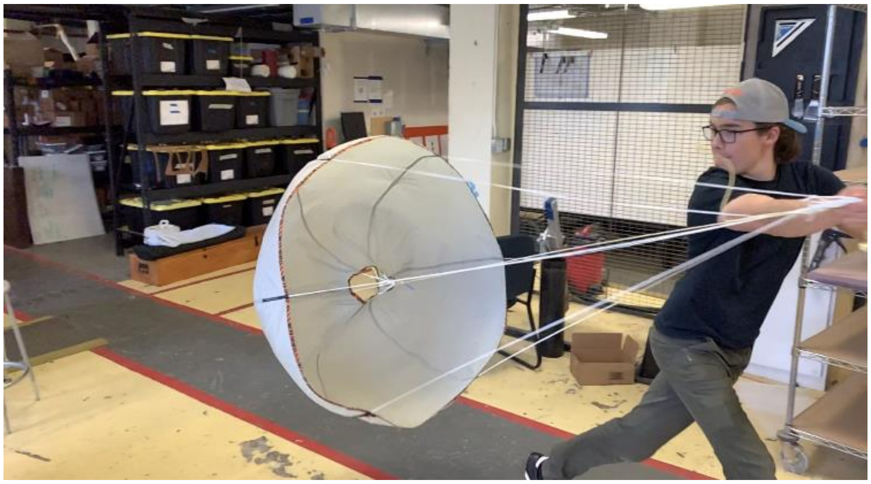


Fig. 18

The diameter of the canopy was determined by

$$V_{descent} = \sqrt{\frac{8mg}{\pi\rho C_d D^2}} \tag{2}$$

Where…

$$m = \text{Apogee Mass} = 29.8 \text{ kg}$$
$$g = \text{Gravitational Acceleration} = 9.8 \text{ m/s}^2$$
$$\rho = \text{Air Density} = 0.7775 \text{ kg/m}^3$$
$$C_d = \text{Drag Coefficient} = 2.2$$
$$D = \text{Canopy Diameter} = 4.5 \text{ ft} = 1.3716 \text{ m}$$

Both the test launch site in Brothers, Oregon and the competition launch site are roughly 4500 ft above sea level (ASL). This puts the team's apogee ASL at both sites around 15,000 ft. The parachute was designed around the lowest air density it would encounter, $\rho = 0.7775$ kg/m^3 at apogee. When solving for descent rate using Eqn. (2), the maximum theoretical descent rate of the drogue parachute was found to be 15.2 m/s or 49.9 ft/s. It was assumed that due to a lower drag coefficient, and manufacturing inconsistencies the drogue parachute would fall closer to the descent rate range of 75-150 ft/s outlined by IREC Rules and Restrictions.

The SRAD drogue parachute used in the first flight was a 4.5 ft toroidal canopy with 6 gores. The gores were cut on a ply cutter from .DXF files made using an online parachute designer called Chutemaker. The canopy was constructed from generic fabric store ripstop nylon and grosgrain webbing. The shroud lines along the perimeter of the parachute and the perimeter of the spill hole were made from 725 lbs Spectra flat braided cordage. The center shroud line connecting the bridle to the spill hole shroud lines was made from 1000 lbs Kevlar cordage. The perimeter and center shroud lines were tied off at a bridle made from a ¾" tubular Kevlar webbing dog-bone with COTS swivel. The grosgrain webbing used was tigerstripe to ensure that the drogue parachute stands out. The parachute has perimeter shroud line lengths 115% of the parachute diameter, and spill hole shroud line lengths 115% that of the spill hole diameter. The shroud line attachment to the parachute is pictured in Fig. 19.

Fig. 19

3. Main Parachute

The main parachute serves to slow the rocket down to a speed at which it can safely impact the ground. After descending under the drogue parachute from apogee the main parachute is deployed at 1500 ft AGL. For the first launch, a Fruity Chutes Iris Ultra 120” COTS parachute was used. A toroidal parachute was chosen for its smaller packed size compared to traditional hemispherical parachutes. Packed size was a serious consideration due to the large parachutes needed to support the weight of the rocket, and a toroidal parachute minimizes this packed size. Using Eqn. (2) and assuming a canopy diameter $D = 10\text{ ft} = 3.048\text{ m}$, a drag coefficient $C_d = 2.2$, and an air density at 6500 ft ASL of $\rho = 1.007\ \text{kg/m}^3$, the theoretical descent velocity becomes 19.72 ft/s. For future launches an SRAD main parachute is currently being constructed. The main parachute used at the time of this report is pictured in Fig. 20.

For the competition an SRAD main parachute is being produced by the team. This main parachute will use the same construction techniques as used for the SRAD drogue parachute. The main parachute will be hemispherical and measure 15 ft in diameter with a 20% spill hole. Spectra 725 lb shroud lines will be run at 115% of the main canopy’s diameter. ¾ in Kevlar webbing will bridle with a COTS swivel joint.

Fig. 20

4. Ejection Charges & Shear Pins

The ejection charges and shear pins are what allow the rocket to separate at apogee and deploy its drogue parachute. The ejection charge is a 4 g black powder charge contained within zip tied surgical tubing. This charge creates the pressure necessary to break 8 radial M2 Nylon 6-6 shear pins that hold the two halves of the rocket together during launch. Prior to testing, calculations were done to estimate the amount of black powder necessary to shear different numbers and sizes of shear bolts. To do this, the force on the bulkhead from a given pressure in the compartment, and pressure within the compartment created per gram of black powder were calculated.

The force on the bulkhead from the charge was determined by Eqn. (3).

$$F = P\pi\left(\frac{D}{2}\right)^2 \tag{3}$$

Where…

$$P = \text{Pressure Within Compartment}$$
$$F = \text{Force on Bulkhead}$$
$$D = \text{Inner Diameter of Compartment} = 159.25\ \text{mm}$$

The pressure within the compartment for the charge was determined by Eqn. (4).

$$P = \frac{mR_cTg}{\pi H\left(\frac{D}{2}\right)^2} \tag{4}$$

Where…

$$P = P\text{ressure Within Compartment}$$
$$m = \text{Mass Black Power (g)}$$
$$R_c = \text{Combustion Gas Constant for Black Powder} = 12.1579\ \text{m/K}$$
$$T = \text{Temp} = 1739\ \text{K}$$
$$g = \text{Gravitational Acceleration} = 9.8\ \text{m/s}^2$$

$$H = \text{Compartment Height} = 884.9934 \text{ mm}$$
$$D = \text{Inner Diameter of Compartment} = 159.25 \text{ mm}$$

Equations (2) and (3) can be combined to solve for a linear relationship between the force on the bulkhead and mass of black powder within the charge. This force on the bulkhead is 232.96 N or 52.36 lb per gram of black powder in the charge.

Once a linear model for bulkhead force and black powder mass had been made, the shear strengths of different nylon 6-6 bolts were found. Table 11 has the shear failure force for different bolts. From this table and the linear model, the forces on the bulkhead and chamber pressures for different grams of black powder were calculated. This is depicted in Table 12. From the bulkhead forces, the minimum and maximum shear strength of different combinations of Shear bolts were tested. These different combinations are depicted in Table 13. The results of Table 13 informed how the first ejection charge testing was carried out. Further details on this test can be found in APPENDIX B - PROJECT TEST REPORTS. Fig. 21 depicts ejection charge testing.

Fig. 21

D. Avionics

1. Purpose

While the proposed rocket will not have actuated control surfaces, it will still require electronic control units to ensure mission success. Pyrotechnic events such as drogue parachute deployment, main parachute deployment, and payload deployment will be handled by an onboard digital module. Telemetry data such as altitude, time to apogee, and GPS coordinates is critical when evaluating a rocket's flight performance. The OSU AIAA ESRA team has chosen to use two AltusMetrum TeleMetrums as their primary and secondary flight computers. The avionics module also contains a standalone automated packet reporting system (APRS) transmitter that is capable of transmitting GPS data back to the ground station hardware even if power is lost to both flight computers.

2. Onboard Power

Both TeleMetrums are powered by 3300 mAh lithium polymer batteries. The APRS board is supplied power from a 1100 mAh lithium polymer battery. Both battery types conform with the guidelines stated by ESRA. Both flight computers, the APRS PCB, and their respective batteries are mounted to carbon fiber vertical plates. These plates are attached to one another with billet aluminum structural components (please refer to APPENDIX F – ENGINEERING DRAWINGS for visual context). The flight computers are not powered on until the rocket is in a vertical orientation and has been placed on the launch rail (please refer to APPENDIX E - ASSEMBLY, PREFLIGHT, LAUNCH, AND RECOVERY CHECKLISTS for integration checklists).

3. Flight Computer Operation

Pre-flight programming and in-flight communication with the flight computers is performed using AltusMetrum's provided software AltOS. Ejection charge deployment parameters have been set using simulation data. The drogue parachute will be deployed at apogee which is determined by a sign change in accelerometer data. The main parachute is deployed at a set altitude during descent using altimeter data. The secondary drogue and main parachute charges are delayed by two seconds compared to their primary counterparts. The ground station hardware consists of 3 laptops, 3 yagi antennas, 2 TeleDongles, and 1 radio-to-USB adapter. 2 laptops, with TeleDongles connected, will be running AltOS to monitor in-flight telemetry and will use the last recorded GPS coordinates to guide the recovery team once the rocket has landed. The sole purpose of the APRS board is to establish the landed rocket's location if both flight computers have lost power.

4. Design Process

When considering the design of the flight computer and APRS module, the avionics subteam first reviewed design choices made by past OSU AIAA teams. While these designs differed in materials and dimensions, they all incorporated a horizontally (perpendicular to the long axis of the rocket) oriented bulkhead to which vertical mounting plates were attached. A threaded rod would typically run along the center axis of the module to provide rigidity and additional integration points to the rest of the rocket.

The avionics subteam produced several iterations of the flight computer and APRS module. The first iteration was deemed too heavy and complex to manufacture. The use of ½" aluminum plate given to the team by a sponsor drove design decisions for the second iteration. The third and final iteration carried over most characteristics from the second iteration, but it strove to lightweight the components where possible.

Most components were able to be machined using manually-operated equipment. The carbon fiber vertical plates were cut on a bandsaw and drilled using a drill press. Aluminum components were machined from billet stock on a three axis milling machine. The part containing the most complex geometry was the avionics bay bulkhead. This was machined by cutting the aforementioned aluminum plate on a CNC ProtoMAX Waterjet (please refer to APPENDIX F – ENGINEERING DRAWINGS for visual context).

E. Payload

The OSU AIAA ESRA team will be participating in the Space Dynamics Laboratory (SDL) Payload Challenge. Utah State University's SDL presents judging criteria to evaluate the contending payloads. These judging criteria outline point allotments contributing to scientific or technical objective(s), payload construction and overall professionalism, readiness / turnkey operation, and execution of objective(s).

1. Objective

The OSU AIAA ESRA 2024 declares 2 scientific objectives for the payload to accomplish.

1. Detect levels of UV Flux
2. Measure atmospheric gas concentrations

The payload will collect the desired data during descent, creating an elevation map of UV and atmospheric data. The payload will also have various other requirements to fulfill beyond the objectives. The payload must weigh a minimum of 8.8 lbs per the IREC Rules and Requirements. The IREC Rules and Requirements also awards additional points for a payload that conforms to a Cube Unit form factor. For the integrity of the payload itself and to be awarded points for payload construction, the payload must be structurally sound. The payload must remain static within the airframe of the rocket during ascent. This requires a rigid structure and proper mounting mechanisms for the payload. It is also critical that integration of the payload is accounted for in the design. A simple integration procedure will minimize risk and streamline the overall integration process.

The payload's primary objectives are to collect scientific data in flight. To be a successful sensing device, the payload must meet requirements set by the team. A successful payload will log data locally to be accessed upon recovery. Acquisition of the data is critical. Without data, the payload is nonfunctional. The payload must also record a significant amount of data. Less than 10 data points during descent would be insignificant. There is a limited amount of time the rocket will be in descent; thus the payload must record data frequently enough to obtain significant data quantity.

2. Scientific Relevance

The OSU AIAA ESRA team takes interest in Mars exploration and research. The team wishes to design and construct a payload that could mimic a deployment to the Martian atmosphere to measure UV flux and atmospheric gas concentrations. Thus, the 'target environment' for the payload will be the Mars atmosphere. This target environment is chosen since it is a much larger area of research in aerospace than New Mexico, and thus the value of data from Mars is much higher. This distinction is important for sensor choice and context for the objectives.

3. Sensors

The European Space Agency (ESA) shows that the atmospheric composition of Mars is “95.32% carbon dioxide, 2.7% nitrogen, 1.6% argon, 0.13% oxygen”. From this information, the payload subteam generates the following priority table outlining what gasses are important to measure based on their concentration.

Table 2

CO_2	N_2	Ar	Ozone	CH_4	SO_2	CO	Ne	Kr	Xe
94.9%	2.6%	1.9%	0.174%	60ppb	0.2ppb	0.0747%	2.5ppmv	0.3ppmv	0.08ppmv

There are two considerations when choosing which gasses to sense. First, how high of a gas concentration does the payload expect to witness in the target environment? Gasses whose concentrations can be sensed will fill a larger percentage of the total real molecular composition of the atmosphere. Sensing all the high concentration gasses reduces the percentage of unknown gasses, giving a more accurate prediction. Secondly, sensors must be purchased and therefore must fit into a budget. This heavily restricts which sensors can be procured for the design. Table 2 is highlighted to show which gasses are to be chosen to sense. Green colored items are easy to sense and are low cost, yellow items are difficult to obtain but remain possible, whereas red items are unobtainable. The red items are noble gasses, which prove to be very difficult to sense concentrations of since they are inert.

The payload must also sense UV flux. D. C. Catling et al. published a conference paper Ultraviolet Radiation on the Surface of Mars describing what UV conditions are like on Mars. D. C. Catling et al. states that in general, UV conditions are comparable to Earth’s. However, on Mars shorter wavelengths contribute to a much greater portion of UV flux. This encouraged the payload subteam to choose an array of UV flux sensors that can discern between higher wavelength, lower energy UV flux (UVA) and lower wavelength, higher energy UV flux (UVC). This way, the payload would obtain a more insightful understanding of UV flux across the band.

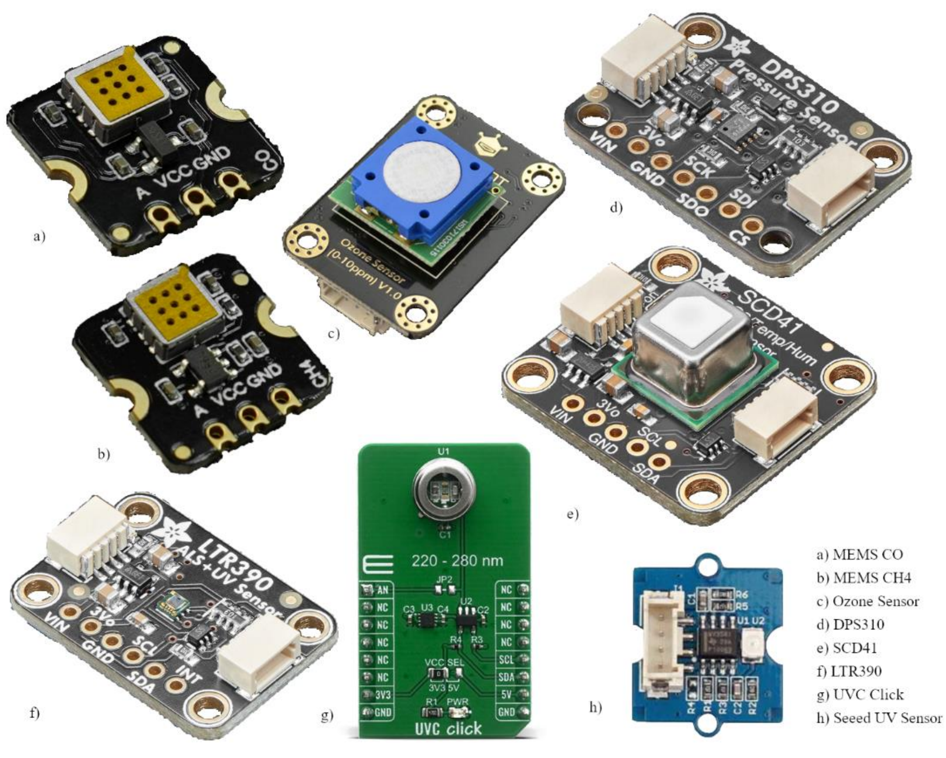


Fig. 22

Fig. 22 illustrates the 8 sensors chosen to be used by the payload. Full details on the sensor choice can be found in APPENDIX G – ADDITIONAL RESOURCES.

At the current state, the payload has only been developed to this state. The team intends to complete the payload for flight in Spaceport America. For the purpose of test flights, 12 lbs is allocated for payload mass, and aluminum round stock is used as substitute mass.

IV. Mission Concept of Operations Overview

Ramkoers will undergo 7 phases, taking the rocket from its fully integrated state on the launch pad, through flight, and to touchdown. The flight phase graphic is illustrated below in Fig. 23.

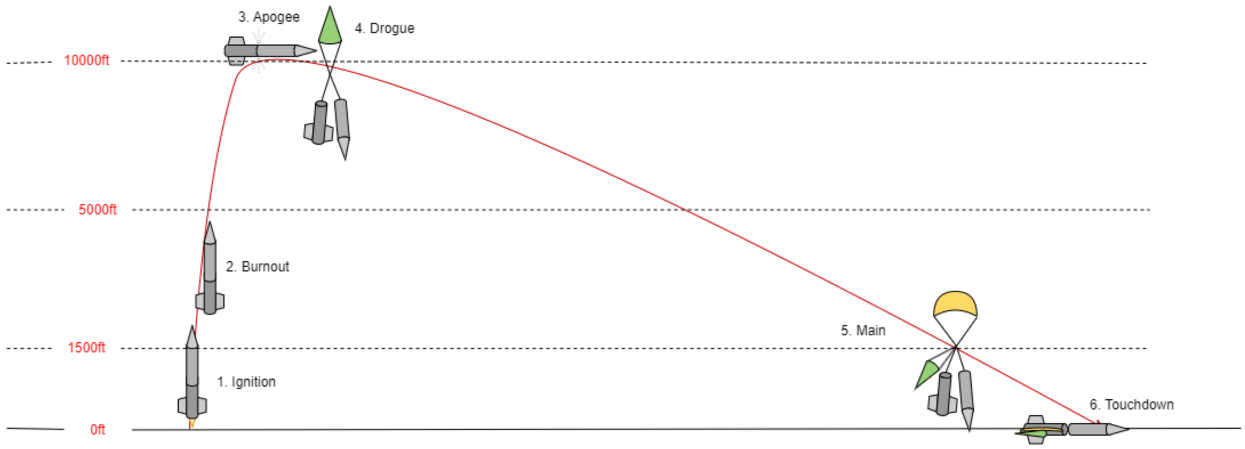


Fig. 23

A. Phase 0: Ground

All checklists have been completed and the rocket is fully integrated. The launch rail has been prepared and the rocket has been placed on it ready to launch. The launch box has been prepared and connected to ignition charges set inside the motor of the rocket. The rocket is awaiting a signal from the launch box for motor ignition.

B. Phase 1: Burn

Launch signal is sent from the launch box, causing igniters placed within the motor to initiate ignition. As the motor burns the rocket is accelerated along the launch rail and into the air as the motor burns for approximately 4.55 seconds. The rocket is experiencing thrust for the duration of this phase.

C. Phase 2: Coast

As the rocket approaches 2400 ft the motor stops exerting thrust on the rocket as it finishes its burn. At this point, BEAVS is expected to begin actuation. Throughout this phase, BEAVS routinely adjusts the degree to which it is deployed to lower the rocket's velocity until it achieves apogee.

D. Phase 3: Apogee

The vertical velocity of the rocket reaches zero and the rocket reaches the maximum height of its flight profile. BEAVS stops exerting control on the rocket during the remainder of the flight of the rocket.

E. Phase 4: Drogue Deployment

Briefly after apogee, the rocket ignites separation charges and has a separation event. Deploying the drogue parachute which will slow down the rocket to 150-75 ft/s.

F. Phase 5: Main Deployment

Slightly after the rocket reaches 1500 ft, the main parachute is deployed. This parachute slows the rocket down to at least 30 ft/s, preparing it for touchdown.

G. Phase 6: Touchdown

The rocket has made contact with the ground and is no longer in motion.

V. Conclusion and Lessons Learned

A. Lessons Learned

Upon the team's first test launch, there were several shortcomings and failures. The team was able to experience the process of full integration for the first time. At this event, the team found that they were not as prepared as intended. The team possessed all the tools and components necessary for integration however, items were not organized or easy to locate. Furthermore, the team became reliant on team members' personal tools, which is unfavorable. During integration, the team found that checklists were either not present or not used. This became a massive problem and caused integration to take significantly longer than planned. The team was barely able to launch the rocket before the event closed. For competition in Spaceport America, this problem must be resolved. The team has plans to continue developing checklists before the competition.

At this same launch, damage to the airframe was caused by a failure of the main parachute deployment. This failure mode has been identified as interference of the numerous ejection charge wires with the main parachute. Namely, these long wires that run the length of the rocket can become entangled with the main parachute and prevent it from successfully deploying. For future launches, the team will secure these wires to the inside of the rocket's body tube using foil tape. This will allow electrical current to be passed through the length of the rocket without interfering with recovery system deployment. The damage caused is depicted in Fig. 24.

Fig. 24

Due to the damage sustained during the first test flight, a 12 in section of the tube was cut from the top of the rocket. After performing acoustic testing no internal voids or deformations were found with the rest of the tube. A large portion of the stability came from the extra length of the rocket allowing us to reduce ballast. Because of the loss of length, a significant weight would have to be added to the ballast for stable flight. To counter this the team has developed a plan to increase the stability of the rocket by adding 4 strakes above each fin to the vehicle as seen in Fig. 25.

Fig. 25

These strakes would be long and short fins that would rest above the main fins. This long leading edge and short height would make them resistant to fin flutter while greatly increasing stability allowing us to reduce the ballast needed to maintain stability off of the launch rail. Whereas this is not an ideal solution to the stability problem, it is a solution seen in industry as many flight vehicles utilize streaks to increase lift and give directional stability. The strakes would be made of carbon fiber reinforced G10. The dimensions of the strakes are included in Table 3.

Table 3

Number of Fins	4
Root Cord	24 in
Tip Cord	18 in
Height	2.8 in
Sweep Length	3 in
Sweep Angle	47°
Shear Modulus	12.448 GPa

B. Conclusion

Although the team has faced many roadblocks and failures, the most important thing is that the team learned from the failures. The rocket that will fly over the skies of New Mexico during competition would be very different if the team knows what it does now. The team believes that they have identified solutions to all the major lessons learned during the development and that the rocket will be safe and ready to fly very soon once the final solutions have been implemented. A final secondary test flight will occur before the competition to validate all changes made to the vehicle. The team looks forward to competing at the IREC in Spaceport America, 2024

APPENDIX A - SYSTEM WEIGHTS, MEASURES AND PERFORMANCE DATA

A. Basic Rocket Information

Table 4   Basic Rocket Information

Parameter	Value	Unit
Number of Stages	1	-
Vehicle length	166	in
airframe diameter	6.35	in
number of fins	4	-
fin semi-span	4.5	in
fin tip chord	5.938	in
fin root chord	13.25	in
fin thickness	0.25	in
vehicle weight	51.7	lb
propellent weight	12.8	lb
empty motor case/ structure weight	65.3	lb
payload weight	9.5	lb
liftoff weight	78.1	lb
center of pressure	122	in
center of gravity	101	in

B. Propulsion Information

Table 5   Propulsion Information

Parameter	Value	Unit
Motor Type	SRAD	-
Motor letter classification	N	-
Average thrust	2604	N
total impulse	11,861	Ns
motor burn time	4.55	s

C. Predicted Flight Data

Table 6 Predicted Flight Data

Parameter	Value	Unit
Launch rail length	34	ft
liftoff thrust-weight ratio	7.5:1	-
rail departure velocity	129.21	ft/s
minimum static margin	1.6	
maximum acceleration	8.28	G
maximum velocity	938	ft/s
fin flutter velocity	5180	ft/s
target apogee	10,000	ft
predicted apogee	10469	ft

D. Flight Profile Graph

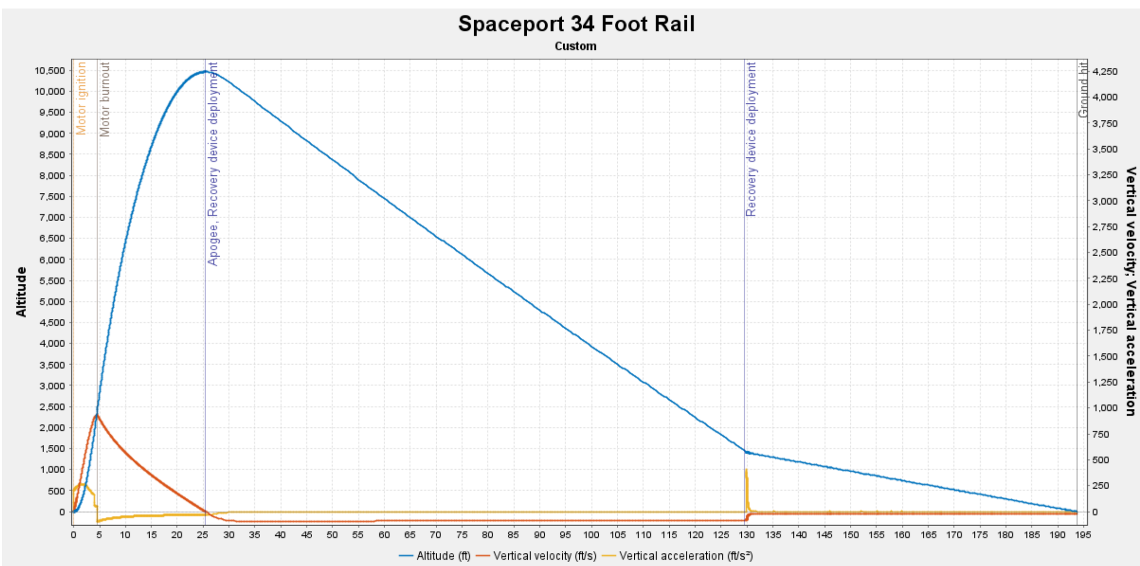


Fig. 26 Flight Profile Graph

E. Recovery Information

Table 7   Recovery Information

Parameter	**Value**	**Unit**
Primary Altimeter	Altus Metrum TeleMetrum	-
Secondary Altimeter	Altus Metrum TeleMetrum	-
drogue primary charge	4	g
drogue backup charge	6	g
drogue deployment altitude	apogee - 10,000ft	ft
drogue decent rate	-85.11	ft/s
main decent rate	-22.08	ft/s
shock cords	Aft To Drouge: 342 Drouge To Main: 300 Main To Fore: 180	in
mechanical links	35kN swivel joints, 0.25” screw carabiners	-

APPENDIX B - PROJECT TEST REPORTS

A. Avionics: Testing Communication Range of AltusMetrum TeleMetrum

The avionics subteam of the OSU AIAA ESRA team conducted a series of tests to verify the communication range of the AltusMetrum TeleMetrum rocket flight computer. The objective was to ensure reliable communication between the TeleMetrum and ground station hardware over a minimum distance of 10,000 feet (the competition target altitude).

The testing took place near Corvallis, Oregon, with the ground station set up on the OSU campus. The team chose Bald Hill for the remote location due to its elevation and proximity to the campus. The setup involved three team members: two stationed on Bald Hill and one at the OSU campus.

Equipment Used:

1. AltusMetrum TeleMetrum rocket flight computer
2. Yagi antenna
3. Laptop running AltOS (flight computer software)
4. Handheld radios for team communication
5. Handheld GPS devices for coordinate data

Procedure:

1. The team members established communication via handheld radios. One team member remained at the OSU campus with the ground station hardware, including the yagi antenna and laptop. The other two team members proceeded to Bald Hill.

2. Upon reaching Bald Hill, team members positioned themselves at a vantage point with a clear line of sight to the OSU campus.

3. The team member at the OSU campus initiated the communication test by activating the AltOS software and configuring it to establish communication with the TeleMetrum. The team on Bald Hill used handheld radios to coordinate their positions and movements.

4. The team member at the OSU campus monitored the AltOS software for successful communication with the TeleMetrum. The distance between the ground station and the TeleMetrum was continuously recorded using GPS devices.

5. Upon successful communication establishment, the recorded distance was noted. The team cross-referenced the GPS data to verify the distance achieved during the test.

During the communication test, the AltusMetrum TeleMetrum successfully established communication with the ground station hardware at a distance of 2.65 miles, equivalent to approximately 13,992 feet. This exceeded the minimum requirement of 10,000 feet. The test results demonstrate the capability of the TeleMetrum to maintain reliable communication with ground station hardware over extended distances, crucial for monitoring and controlling rocket flights.

B. Recovery: Ejection Charge Testing

The recovery team conducted ejection charge testing to ensure that the two sections of rocket will successfully separate when the charges go off at apogee. This involves setting off the black powder charges at a distance and then observing the separation event. The team's ejection charge testing standard operating procedure (SOP) is below detailing the procedures and safety measures.

The ejection charge testing proved successful as seen in Fig. 27. The ejection charge sizing was determined to be correct after reviewing ejection charge testing footage.

Fig. 27

Standard Operating Procedure

[Mixing and Processing *Liquid Sand* Solid Rocket Propellant]

Department:	OSU ESRA 2023-24
Date Approved By Faculty Advisor:	
ESRA Faculty Advisor:	Roberto Albertani
ESRA Team Lead:	Collin Hale-Brown
ESRA Safety Officer:	Jackie Caynon caynonJ@oregonstate.edu
Emergency Contact:	Faculty Advisor: Roberto Albertani Phone Number: (541) 737 7024 Email: roberto.albertani@oregonstate.edu
Locations Covered By SOP:	OSU Propulsion Lab

Purpose

The purpose of this SOP is to outline the process for testing ejection charges for the 2023-24 OSU ESRA team.

Training Requirements

- OSU EH&S Laboratory Safety Training (required every 3 years)
- Safety Data Sheet / Right to Know (Read and do GHS Training/quiz) (required every 3 years)
- Hazardous Waste Training (required annually)
- Noise and Hearing Conservation (required annually with additional requirements)
- Chemical Storage
- Eye and Face Protection
- OSU Fire Extinguisher Training

Personal Protective Equipment (PPE)

- **Eye Protection**
- Safety Glasses - 4+

- **Ear Protection**
- Ear Plugs - 4 sets+

- **Skin and Body Protection**
- Long Sleeve Shirts
- Jeans/Thick Pants
- Closed-toed Shoes

- **Face Protection**
- Face Shields

- **General Safety Supplies**
- First-Aid Kit - 1+

Engineering Controls

- Be in a large open space
- Be sure the space is completely flat
- Be far away from any buildings, trailers, cars, etc

Supplies Checklist

- **Chemicals**
- Ejections charges in Ammocan

- **Tools and General Supplies**
- Tarp 2+
- Fire Extinguisher
- Pliers
- Drill and Drill bits
- Shear pins
- Flathead Screwdriver (for Telemega and shear pins)
- Adjustable wrench
- Wire strippers
- Laptop, TeleMega, and antenna
- E Matches

Procedure

- 1. Arriving at Propulsion Lab
  - 1.1 Reserve time at Propulsion Lab (1 week in advance)
  - 1.2 Set up barricades outside the Propulsion Lab
  - 1.3 Lay out tarp
  - 1.4 Set up body tube stands

- 2. Assembly
  - 2.1 Ensure all personnel move at least 25 feet away from ejection test area
  - 2.2 All flight computers and arming switches set to off
  - Mount drogue to corresponding location
  - Connect AV bay wires
  - Add drogue charge
  - Mount main parachute to corresponding location
  - Pack parachute, recovery cord, and drogue
  - Align shear holes and insert shear bolts
  - Attach all parts of the rocket body

- 3. Ejection Charge Testing
  - 3.1 All personnel move 25 feet away from ejection test area
  - 3.2 Connect flight computers and verify continuity
  - 3.3 Countdown and announce when triggering Echarges

- 4. Post Charge Testing
  - 4.1 Ensure that all charges are fired
  - 4.2 If a charge does not fire, wait at least 10 minutes before approaching the rocket
    - When approaching the rocket, DO NOT face either end of the rocket, approach the rocket from the side
  - 4.3 One individual approaches rocket powering off and disarming flight computers
  - 4.4 Individual checks for all charges deployed
  - 4.5 If charge does not deploy, have individual remove charge, shunt leads, and place in ammunition canister
  - 4.6 All other participants approach testing area and pack up area

- 5. Congratulations On A Successfully Ejection Charge Test!

First Aid Procedures

If an accident happens, complete the Safety Incident Reporting Form at the end of this SOP.

If inhaled:
Move to fresh air. If the person is not breathing, give artificial respiration. Avoid mouth to mouth contact. Call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.

In case of skin contact:
Immediately (within seconds) flush the affected area for at least 15 minutes. Remove all contaminated clothing. Call 911 immediately. Call EH&S at 541-737-2273.

In case of eye contact:
Use eye wash to flush eyes for 15 minutes. Call 911. Follow safety instructions for further assistance:
http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/eyewash_and_safety_shower_si.pdf

If ingested:
Do not induce vomiting. Contact 911 and/or poison control center if swallowed: +1(800)-222-1222.

Special Storage & Handling Requirements

Black powder and ejection charges need to be stored in an ammunition canister

Handling:
Wear safety glasses, long sleeve shirts and long pants when handling black powder

Storage:
Stored in ammunition canister in Graf Recovery Cabinet

Other Emergencies

Medical Emergency: Dial 911

Life Threatening Emergency, After Hours, Weekends and Holidays: *Dial* ***911*** *(This will connect you to Good Samaritan Hospital Corvallis where they will be able to treat the victim).*

Non-Life Threatening Emergency:
If needed, call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.

Decontamination/Waste Disposal Procedure

General hazardous waste disposal guidelines:

Label Waste

- *Affix an EH&S hazardous waste label on all waste containers (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/hwlabelfull.pdf) as soon as the first drop of waste is added to the container.*

Store Waste

- *Store hazardous waste in closed containers, in secondary containment and in a designated location. (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/waste_hazardous_disposal_si.pdf).*
- *Double-bag dry waste using transparent bags*
- *Waste must be under the control of the person generating & disposing of it*

Dispose of Waste

- *Dispose of regularly generated chemical waste within 90 days*
- *Put in a waste request at: http://ehs.oregonstate.edu/waste*

Faculty Advisor SOP Approval

By signing and dating here the designee certifies that the Standard Operating Procedure (SOP) for Mixing Liquid Sand Solid Rocket Propellant is accurate and effectively provides standard operating procedures for laboratory personnel.

Signature *Printed Name/Title* *Date*

I have read and understand the contents of this SOP:

Name	Signature	Date
Hannah Thompson	Hannah Thompson	1/31/2024

C. Propulsion: Fullscale Static Fire Test

The propulsion team completed a fullscale static fire test with the objective of gaining thrust, pressure, and temperature data. The team's fullscale test fire standard operating procedure (SOP) is below detailing procedure and safety measures.

Standard Operating Procedure

[Mixing and Processing *Liquid Sand* Solid Rocket Propellant]

Department:	OSU ESRA 2023-24
Date Approved By Faculty Advisor:	
ESRA Faculty Advisor:	Roberto Albertani
ESRA Team Lead:	Collin Hale-Brown
ESRA Safety Officer:	Jackie Caynon caynonJ@oregonstate.edu
Emergency Contact:	Faculty Advisor: Roberto Albertani Phone Number: (541) 737 7024 Email: roberto.albertani@oregonstate.edu
Locations Covered By SOP:	AIAA Lab
	AP Storage Facility
	Mixing Lab

Purpose

The purpose of this SOP is to outline the process for mixing and processing the *Liquid Sand* solid rocket propellant used by the 2021-22 OSU ESRA team.

Training Requirements

- OSU EH&S Laboratory Safety Training (required every 3 years)
- Safety Data Sheet / Right to Know (Read and do GHS Training/quiz) (required every 3 years)
- Hazardous Waste Training (required annually)
- Noise and Hearing Conservation (required annually with additional requirements)
- Chemical Storage
- Gas Cylinder Safety
- Filtering Facepiece Training (if needed, i.e. mixing rocket fuel)
- Eye and Face Protection
- Enrolled in or completed ME 250 (if not, Shop Safety is required)
- OSU Fire Extinguisher Training

Personal Protective Equipment (PPE)

- **Hand Protection**

- Nitrile Gloves - 2 boxes+
- Hand Warmers (Recommended) - 8+

- **Eye Protection**
- Safety Glasses - 4+
- Safety Goggles - 4+

- **Ear Protection**
- Ear Plugs - 4 sets+

- **Skin and Body Protection**
- Long Sleeve Shirts
- Jeans/Thick Pants
- Closed-Toed Shoes
- Aprons/Fire Retardant Coats (Recommended) - 4+

- **Respiratory Protection**
- Respirators (And Clean Filters) - 4+

- **General Safety Supplies**
- First-Aid Kit - 1+
- Space Heaters (Recommended) - 2+

Engineering Controls

- Open window(s) in the lab.
- Keep the door partially or completely open.

Supplies Checklist

- **Chemicals - See Formulation and Mix Sheets for Amounts**
- Acetone
- Grease
- AP (200 microns)
- IDP
- Aluminum (10 microns)
- R45/HX752
- Castor Oil
- Lecithin Oil
- MDI

- Silicone Oil

- **Tools and General Supplies**
- Digital Timers - 2+
- Mixing Bowl - 2+
- Spatula - 1
- Packing Sticks or Dowels - 2 +
- Scale (Higher Precision Strongly Recommended) - 2+
- Industrial Stand Mixer - 1
- Kitchen Stand Mixer - 1
- Vacuum Pump - 1
- Gaskets - 2
- Paper Towels - 2 rolls+
- Garbage Bags - 2+
- Disposable Cups (Preferably Solo For Liquid Resistance) - 10+
- Popsicle Sticks - 10+
- Casting Tubes - 1 per grain
- Coring Rods (Composite/3D Printed/Wood) - 1 per grain
- Threaded Rods - 1 per grain
- Nuts - 2 per grain
- Base/End Caps - 2 per grain
- Desiccant Packs - 2+
- Pen/Pencil - 2+
- Mix Sheet - 1
- Bluetooth Speaker - 1 (Optional For Music)

Procedure

- 1. Preparation And Organization Before Mix Day
  - 1.1 Organize casting tubes, thermal liners, coring rods, end caps, and any other needed packing materials (1 to 2 weeks in advance)
  - 1.2 Procure and organize all other needed supplies for mixing (1 week in advance)
  - 1.3 If necessary, cut casting tubes to length (do not cut thermal liners to the same length)

- 2. AP Handeling
  - 2.1 Put on appropriate PPE including respiratory protection

- 2.2 Fill plastic 2 kg AP containers from the barrel and take them into the mix lab (wear PPE when handling AP)
- 2.3 Weigh and record the amount of AP used
- Return AP to its original location (wear PPE when handling AP)

- 3. Open Up The Propulsion Lab And Prepare To Mix
  - 3.1 Put on safety glasses, nitrile gloves, and fire retardant coats, make sure long hair is tied back and out of the way (use respirators when adding solid powders to propellant)
  - 3.2 Wipe down surfaces with acetone if there is residue from previous mixes
  - 3.3 Turn on and zero the scale (with a piece of plastic on it)
  - 3.4 Take out consumables like cups, paper towels, popsicle sticks, etc
  - 3.5 Store bins with supplies under the table to keep them out of the way
  - 3.6 Set up garbage bags
  - 3.7 Open doors

- 4. Mix The Inhibitor (Can be done simultaneously with Propellant Mix)
  - 4.1 Weigh each inhibitor ingredient in a cup and add it to the mixing bowl (Including the Curative)
  - 4.2 Write down the actual amounts of inhibitor ingredients added on the mix sheet
  - 4.3 Mix the inhibitor until uniform in color (About 15 minutes)
  - 4.4 Place vacuum seal on the mixing bowl making sure red seal is in place
  - 4.5 Pull a vacuum on the inhibitor until the mixture stops bubbling (About 5 minutes)
  - 4.6 Release the vacuum
  - 4.7 Use fingers to apply a thin coat of inhibitor to the inside of each casting tube (wearing gloves)
  - 4.8 Clean the bowl and paddle with acetone before the epoxy cures
  - 4.9 Excess inhibitor can be put in a cup in the regular garbage

- 5. Mix The Propellant (Can be done simultaneously with Inhibitor Mix)
  - 5.1 Weigh each liquid ingredient in a cup and add it to the mixing bowl (Except the Curative)
  - 5.2 Write down the actual amounts of liquid ingredients added on the mix sheet
  - 5.3 Mix the liquid ingredients (About 5 minutes)
  - 5.4 Place vacuum seal on the mixing bowl making sure red seal is in place
  - 5.5 Vacuum the liquid ingredients mix (About 5 minutes)
  - 5.6 Put on respirators and goggles if not on already before adding solid ingredients
  - 5.7 Weigh and add aluminum powder, wet aluminum powder by mixing with the mixer paddle manually to avoid putting aluminum dust into the air (DO NOT ALLOW ALUMINUM POWDER AND AP POWDER TO COME INTO CONTACT AS THEY WILL SPONTANEOUSLY COMBUST UPON CONTACT)
  - 5.8 Write down the actual amount of aluminum powder added on the mix sheet
  - 5.9 Mix liquids and powder well ensuring an even color throughout (About 15 minutes)
  - 5.10 Place vacuum seal on the mixing bowl making sure red seal is in place
  - 5.11 Vacuum the liquid ingredients and solid aluminum powder mix (About 5 minutes)

- 5.12 Weigh and add AP to the mix in 3 stages (Mix about 20 minutes after each addition for a total mix time of 60 minutes)
    - 5.12.1 Optionally sift the AP to eliminate any clumps (Strongly recommended)
    - 5.12.2 Scrape sides of mixing bowl to prevent clumping (Every 5-10 minutes)
    - 5.12.3 Write down the actual amount of AP added on the mix sheet (Each stage)
- 5.13 Place vacuum seal on the mixing bowl making sure red seal is in place
- 5.14 Pull a vacuum on the liquids, aluminum, and AP mix, watching carefully to see if it bubbles up to the top, firmly tap bowl on ground to help pop bubbles (About 15 minutes - critical step)
- 5.15 Add the curative to the mix
- 5.16 Write down the actual amount of curative added on the mix sheet
- 5.17 Mix everything together, scrape down sides at least every 15 minutes through to help grains set later (About 45 minutes)
- 5.18 Vacuum everything again (About 10 minutes)
    - 5.18.1 While waiting, weigh the empty (with inhibitor) casting tubes, and subtract this value from the measured grain weight during post-processing
- 5.19 Release vacuum and begin packing propellant mix into casting tubes

- 6. <u>Pack The Propellant</u>
  - 6.1 Wipe down coring rods, end caps, threaded rods, and nuts with acetone
  - 6.2 Spray molds and cores with mold release
  - 6.3 Thread a nut on one end of a threaded rod, insert the rod through one end cap and slide a coring rod over the threads til it is flush with the end cap, and then place a casting tube into the end cap groove
  - 6.4 Pack the propellant into the casting tubes with one end cap on the bottom and a coring rod in the middle, use your hands or a dowel/stick to push handfuls of propellant around the rod (Minimize air gaps and pack the propellant as tightly as possible)
    - 6.4.1 For subscale, each person packs their own grains, for full scale, one person rolls larger clumps of propellant into balls while another pushes them down with a stick or dowel
  - 6.5 Add a second end cap and apply a nut to the other end, ensuring a clamped fit (Try to keep the casting tube as perpendicular to the end caps as possible to ensure straight grain)
  - 6.6 Place packed grains in a secure metal ammo box with a desiccant inside for storage, upright if possible to ensure better curing, ensuring that the box is stored in a dry place
  - 6.7 After packing all of the casting tubes, weigh out the excess propellant left in the bowl, then place excess propellant and propellant-contaminated items into a bag

- 7. <u>Clean Up The Mixing Lab</u>

- 7.1 Wipe down all surfaces
- 7.2 Clean all tools with alcohol
- 7.3 Once the lab is cleaned up and reasonably organized, turn off the lights, lock the lab, and return all borrowed equipment and supplies to their original locations

- 8. Congratulations On A Successfully Completed Mix!

- 9. Post-Processing (To Be Done 24 Hours After Completing Mix)
  - 9.1 Repeat Step 3 (Open Up The Mixing Lab And Prepare To Mix)
  - 9.2 Take out grains from their secure storage container
  - 9.3 Remove the nuts holding to the end caps to the grain
  - 9.4 Carefully use a popsicle stick to remove any excess propellant that is directly over the coring rod end to prevent tearing when pushing the rod with the drill press, then measure the excess propellant and put it into the burn bag
  - 9.5 Set up the grain so that it is lying flat on the base of the drill press and extend the collet down to push out the coring rod (with drill press off)
    - 9.5.1 If the entire coring rod cannot be removed with a drill press, use the collet to push the coring rod out partially, then place the grain in a vise and gently twist the coring rod back and forth until it easily slides out of the grain (DO NOT YANK THE CORING ROD OUT AS THIS WILL DAMAGE THE GRAIN)
  - 9.6 Measure the grains to make sure they are the required length to fit into their liner, taking into account the nozzle lip and forward enclosure lip which will take some space
    - 9.6.1 If the grains are too long cut them down to size with a hand saw, then measure the excess propellant and put it into the burn bag
  - 9.7 Use the belt sander to provide the grain ends with a smooth finished face
  - 9.8 Label each grain with the following information:
    - 9.8.1 Formula Name Abbreviation (Ex: Liquid Sand = LS)
    - 9.8.2 Mix Session # / Batch # (Ex: Mix 0 or Batch 0)
    - 9.8.3 Length (inches)
    - 9.8.4 Weight (grams) (Make sure to subtract casting tube, electrical tape weights)
  - 9.19 Repeat Step 7 (Clean Up The Mixing Lab)

First Aid Procedures

If an accident happens, complete the Safety Incident Reporting Form at the end of this SOP.

If inhaled:
Move to fresh air. If the person is not breathing, give artificial respiration. Avoid mouth to mouth contact. Call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.

In case of skin contact:
Immediately (within seconds) flush the affected area for at least 15 minutes. Remove all contaminated clothing. Call 911 immediately. Call EH&S at 541-737-2273.

In case of eye contact:
Use eye wash to flush eyes for 15 minutes. Call 911. Follow safety instructions for further assistance:
http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/eyewash_and_safety_shower_si.pdf

If ingested:
Do not induce vomiting. Contact 911 and/or poison control center if swallowed: +1(800)-222-1222.

Special Storage & Handling Requirements

Ammonium Perchlorate (AP) is stored in a special unit behind the Coastal Range Facility. AP over 1 lb is required to be stored in a H-occupancy building due to fire code. Respiratory equipment and gloves must be worn when handling AP, safety glasses, and a lab coat are also preferred to minimize contact. Have everyone not wearing a respirator leave the area when AP is being used.

Handling:
Wear the nitrile gloves, safety glasses, and a lab coat while handling all chemicals and packing the mix. Wear a respirator when handling solid powdered chemicals.

Storage:
AP is stored in the small room attached to the mixing lab

Transporting:
Refer to the 'Transport of Rocketry Motors with Propellant' SOP.

Chemical Spills

OSU Chemical Spill Safety Instructions:
http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/spill_response-chemicals_si.019.pdf

General Guidelines:
Ensure employees have adequate Personal Protective Equipment and spill control materials before attempting to clean up a spill.

For spills less than 1 gallon in size or low hazard chemicals:

- *1. Assess the magnitude of the spill and the associated hazards (broken glass, toxic fumes, risk of fire, etc.).*
- *2. If the hazards can be safely mitigated with available personal protective equipment (PPE), do so. This includes informing co-workers of the spill, removing ignition sources, and moving equipment that may be damaged by the spilled chemicals. (Note: If the spill is more than 1 gallon of liquid or 1 pound of solid, contact Public Safety at 541-737-7000 and ask them to notify EH&S.)*
- *3. Once all hazards have been assessed, put on appropriate PPE (respiratory protection, goggles, body protection, gloves, impervious shoes/boots, etc).*
- *4. Apply Pig Pads to the spill and give the pads time to absorb the chemical.*
- *5. Use gloves and cardboard to move the used Pig Pads to a garbage bag.*
- *6. Seal the garbage bag with a zip tie and label the bag with a Hazardous Waste Label.*
- *7. Place the garbage bag in a secondary containment (a cardboard box or plastic tote/bin) labeled "Hazardous Waste." Place the box in a location in the laboratory where EH&S personnel will easily find it.*
- *8. Request a Hazardous Waste Pickup (http://oregonstate.edu/ehs/waste).*
- *9. Replenish your spill kit's contents immediately.*

For spills greater than 1 gallon in size, high hazard chemicals:

- *1. In general, if a chemical spill is greater than 1 gallon in volume or is a particularly hazardous material (strong acid or base, carcinogen, highly reactive chemical, etc.), call Public Safety (541-737-7000), and tell them to contact the on-call EH&S personnel to respond to the spill.*
- *2. Provide the following information:*
    - *Your name and contact phone number*
    - *Location of the spill (Building and room number)*
    - *Approximate volume of spilled liquid*
    - *Name of chemical*
- *3. Do not attempt to clean up large and/or hazardous chemical spills.*
- *4. Notify all other workers who could be affected by the spill and vacate the laboratory/floor/building, particularly if the chemical produces hazardous fumes or poses other potential health hazards.*
- *5. Wait at the building entrance for EH&S personnel.*

- *6. Serve as a point of contact and provide information about the spill, as requested by EH&S personnel.*

Personal precautions:
If you need to clean a spill, always make sure you're wearing safety glasses, nitrile gloves, a lab coat, and clothes that cover the arms and legs. Use non-slip shoes when approaching the spill.

Environmental precautions:
Rocket propellant is an explosive and it can do substantial damage to the surrounding environment if it is placed near a source of heat.

Methods and materials for containment and cleaning up:
- *A hard copy of this Safety Instruction*
- *A hard copy of the Pink Pig Absorbent Pad Chemical Compatibility Chart* *http://www.newpig.com/wcsstore/NewPigUSCatalogAssetStore/Attachment/documents/ccg/HAZMAT.pdf*
- *Bucket with screw-on lid*
- *6 Pink Pig Absorbent Pads (Item number MAT301 at www.newpig.com)*
- *Heavy duty black plastic garbage bags 🎬 Zip ties (to seal garbage bags)*
- *Hazardous Waste Labels (available at http://oregonstate.edu/ehs/waste)*
- *Cardboard rectangles/squares for handling used Pig Pads, if necessary*
- *Appropriate lab-specific PPE, such as lab coats, goggles, gloves, etc.*

Other Emergencies

Medical Emergency: Dial 911

Life Threatening Emergency, After Hours, Weekends and Holidays: *Dial **911** (This will connect you to Good Samaritan Hospital Corvallis where they will be able to treat the victim).*

Non-Life Threatening Emergency:
If needed, call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.

Decontamination/Waste Disposal Procedure

General hazardous waste disposal guidelines:

Label Waste

- *Affix an EH&S hazardous waste label on all waste containers (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/hwlabelfull.pdf) as soon as the first drop of waste is added to the container.*

Store Waste

- *Store hazardous waste in closed containers, in secondary containment and in a designated location. (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/waste_hazardous_disposal_si.pdf).*
- *Double-bag dry waste using transparent bags*
- *Waste must be under the control of the person generating & disposing of it*

Dispose of Waste

- *Dispose of regularly generated chemical waste within 90 days*
- *Put in a waste request at: http://ehs.oregonstate.edu/waste*

Documentation of Training *(signature of all users is required)*

- *Prior to conducting any work with Liquid Sand Solid Rocket Propellant, designated personnel must provide training to his/her laboratory personnel specific to the hazards involved in working with this substance, work area decontamination, and emergency procedures.*

- *The Principal Investigator must provide this SOP and a copy of the SDS (can be available online) available to all laboratory personnel.*
- *The Principal Investigator must ensure that his/her laboratory personnel have attended appropriate laboratory safety training or refresher training.*

Faculty Advisor SOP Approval

By signing and dating here the designee certifies that the Standard Operating Procedure (SOP) for Mixing Liquid Sand Solid Rocket Propellant is accurate and effectively provides standard operating procedures for laboratory personnel.

Signature *Printed Name/Title* *Date*

I have read and understand the contents of this SOP:

Name	Signature	Date

During this static fire, our data acquisition (DAQ) failed to write any data points. We were able to collect high-quality video footage that we used to analyze components of the test fire. Data and video from previous static fires, and conversations with alumni and another OSU solid propellant rocket team were used to help analyze our test fire. Our team has come to several conclusions regarding this test fire. Firstly, our team has plans to upgrade the DAQ to resolve the errors that caused the data to not be collected. Secondly, our team believes the motor experienced higher chamber pressure than expected. In the video, a high-pressure wave can be seen expanding from the motor tube. This is consistent with the fact that our propellant grain cores were slightly off-center, which the team has quantified through subscale static fire tests. Next, our burn time was shorter than simulated. The team believes this to be a characteristic of the propellant we use as well as an effect of over-pressurization. Lastly, a small flame burns for several seconds after the pressurized burn is completed. The team believes this to be due to off-center grain cores causing left over propellant to burn slowly and un-pressurized.

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APPENDIX C – HAZARD ANALYSIS

Team RECOVERY - OSU AIAA ESRA			**Rocket/Project Name** *Ramkoers*	**Date** May 9, 2024
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Ejection Charges	Mishandling	Low	Transporting and storage in closed ammunition canister	Low
			Wait ten minutes before approaching charges if they do not deploy during testing or launch	
Black Powder	Mishandling	Low	Transportation and storage in closed ammunition canister	Low
			Wear face shield, safety glasses, and long sleeve garments	
			Handle in area that is clear of other objects	

Team PROPULSION - OSU AIAA ESRA			**Rocket/Project Name** *Ramkoers*	**Date** May 9, 2024
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Chemical Exposure	Inappropriate handling and storage of chemicals	High due to the toxicity of propellant chemicals	Chemicals are stored in a flame cabinet or separate room and are always handled with gloves and appropriate clothing. Respirators are worn when necessary. Team members also take required chemical, fire, and respirator training	Low
Accidental Ignition	Accidental spark from mishandling motor/grains during integration or transportation	Low due to the stability of the team's propellant mix used. Liquid Sand is not pressure ignited and needs a consistent flame to cause ignition.	The motor is integrated in an area with non-sparking materials and is transported in a motor casket. The propellant is stored in a canister in the flame cabinet until integration occurs.	Low
Graphite Particulate Inhalation	Improper ventilation	High, graphite produced a lot of dust when machined	Proper respiratory PPE as well as room ventilation	Low
Graphite Particulates in Machinery - can cause electrical malfunction	Improper ventilation	High, graphite produced a lot of dust when machined	Sufficient ventilation to remove dust before it encounters the machine	Medium

APPENDIX D – RISK ASSESSMENT

Team RECOVERY - OSU AIAA ESRA	Rocket/Project Name *Ramkoers*	Date May 9, 2024

Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Total Recovery Failure (A total failure of the recovery system means that the whole or part of the rocket falls with no parachute.)	Drogue ejection charges fail to cause separation	Low: Ejection charges need to break sheer pins and cause the fore and aft sections to separate	Ejection charge testing helped hone in on the right amount of black powder and the main charges have some extra.	Low
	Main and drogue parachutes both become tangled	Medium: Toroidal parachutes which are more prone to tangling	Methodical folding of the parachutes and installation of recovery prevent tangling	Low
	Fore or aft sections of the rocket are separated from the recovery system	Low: A connective line or link could break causing either section to enter free fall	The forces that could cause a break are less than the tolerances of the materials used	Low
	Tandem failure of main and drogue to deploy	Low: Both the main and drogue could have independent failures outlined in other sections	Careful precautions of the recovery system and redundant design reduce the likelihood of failures	Low
Partial Recovery Failure (A partial failure means that the rocket descends under only one parachute, or there is a failure causing one of the parachutes to be partially or totally ineffective.)	Main or drogue has failure to deploy	Low: The main or drogue could have failures caused by: tangling, failure of ejection charges, or if either is damaged during deployment	Careful precautions of the recovery system and redundant design reduce the likelihood of failures	Low
	The main or drogue is detached from the recovery system	Low: A connective line or link could cause the main or drogue to be disconnected from the recovery system	The forces that could cause a break are less than the tolerances of the materials used	Low
	Tandem failure in both tender descenders	Medium: Both the tender descenders could fail to have there charges activate	The use two tender descenders so that it would require two separate failure events	
Minor Recovery Failure (Minor failures in the recovery system do not interfere with the efficacy of the parachute system and do not affect the	Redundant connective line or link failure.	Low: A connective line or link that would not lead to separation of anything from the system could fail	The forces that could cause a break are less than the tolerances of the materials used	Low
	One of the redundant tender descenders fails	Medium: One of the two tender descenders	Methodical preparation and	Low

descent rate of the rocket.)		could fail to have their charges activate	installation of the tender descenders into the recovery system mitigates the difficulty of proper usage	
	Aft and fore sections collide during descent	Low: The rocket system could develop a spin allowing the fore and aft sections to collide	The lengths of cordage used in the recovery system do not allow the fore and aft sections to be close enough to collide	Low
	Deployment of main at apogee	Medium: The main could be prematurely pulled out of the fore section and deploy	The proper installation of the main parachute removes the likelihood of it being pulled out of the body prematurely	Low

Team PROPULSION - OSU AIAA ESRA		**Rocket/Project Name** *Ramkoers*		**Date** May 9, 2024
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Accidental Ignition	Improper handling, spark	Low due to the stable nature of the team's propellant	The motor remains in the casket until ready to be integrated with non-sparking tools	Low
Failure to Ignite	Faulty igniter, poor electrical connection, dead batteries in launch box	Medium due to the multiple areas of failure	Electrical connections and igniters are checked. Multiple igniters are used for redundancy. Batteries are charged the night before and spares are packed.	Low
CATO	Overpressure, improper mixing, structural failure	High due to SRAD motor	Proper procedure, machining, and integration are performed to prevent CATO	Low
Motor Pushes Through Bulkhead	Structural failure	Low due to strength of epoxy	Bulkhead is epoxied into the body tube and fillets are added as well as the integrity is checked before motor is integrated into the body tube.	Low
Motor Falls out of Rocket Body	Improper motor retention	Medium due to the single retention point	The motor retention bolt is torqued correctly to ensure retention	Low

APPENDIX E - ASSEMBLY, PREFLIGHT, LAUNCH, AND RECOVERY CHECKLISTS

Recovery Tools Checklist		
	Item	Reasoning
	Fiber Insulation	necessary for parting parts from burning or moving in flight
	Shear Pins	necessary for construction of the rocket
	Quick Links	attachment method of lines
	Swivel Locks	attachment method for main parachute
	Painters Tape	used in taping shock cords and remove before launch pieces
	Shock cords	absorbs shock for the parachute
	Main Parachute pre-folded in bag	our main parachute
	Drogue parachute pre-wrapped in heat blankets	our drogue parachute
	Ejection Charges	necessary for ejection of the parachute
	E matches	necessary for ejection of the parachute

Recovery Pre-Integration Checklist	
Main Parachute	
	Verify the integrity of the main by checking for tears, and cord entanglement, and if all seams are intact
	Secure swivels to the main parachute
	Attach fasteners to the shock cords
	how to attach from bulkhead - add
Drogue Parachute	
	Verify integrity of drogue by checking for tears, cord entanglement, and if all seams are intact
	Secure swivels
	Attach fasteners to shock cord
	Attach Drogue Flame Bag To Fasteners
Shock Cords	
	Verify integrity
	Tape shock cord together by z folding the main shock cord and zippering the other

Recovery Integration Checklist	
Main Parachute	
	Verify shock cord integrity
	Connect Bag to Tender Descenders
	Connect drogue to the main parachute shock cord
	Connect free end of main shock cord to forward bulkhead swivel link via quick link
Drogue Parachute	
	Verify shock cord integrity
	Ensure fasteners are attached to shock cords
	Attach connection to swivel links
	Insert shear pins
Ejection Charges	
	Inspect the integrity of the ejection charge
	Inspect the integrity of the e-matches
Shock Cords	
	Wrap in fireproof material

Recovery Post Flight Checklist	
Main and Drogue Parachutes	
	Check for tears, cord entanglement, and if seams are intact
	Refold parachutes
	Repack parachutes
Shock Cords	
	Pack up what is possible
	Transport back to Corvallis
Ejection Charges	
	Check if ejection charges went off
	If ejection charges did not go off wait ten minutes before approaching
	Dispose of ejection charge parts as needed

Recovery Failed Landing (ejection charge failure)	
Safety	
	Try to best identify where the rocket will land
	Clear area as much as possible
If the Rocket is Burning	
	Verify if the blaze is spreading
	If spreading call 911
	If contained put out with fire extinguisher
If Not Burning	
	Wait ten minutes before approaching to ensure no charges will go off
After ten minute wait or containing the blaze	
	Approach rocket from the side
	Take photos of the damage
	Take out any avionics hardware and nosecone if salvageable
	Pull out all remaining parachutes and shock cords while remaining out of line of fire of any ejection charges
	Check for black powder residue on the recovery components

Recovery Failed Landing (parachute failure)	
	Identify where the rocket will land
	Clear area as much as possible
If the Rocket is Burning	
	Verify if the blaze is spreading
	If spreading call 911
	If contained put out with fire extinguisher
If Not Burning	
	Wait ten minutes before approaching to ensure no charges will go off
After ten minute wait or containing the blaze	
	Approach rocket from the side
	Take photos of the damage
	Remove avionics hardware and nosecone whilst standing over the rockets

	Remove remaining recovery material whilst staying out of line of fire
	Check for any black powder residue on what remains of the recovery system
	Safely transport back to site

Avionics Components Checklist		
	Item	Notes
	Flight computer & APRS module	Charge all three LiPo cells prior to integration
	2 x Yagi antennas	
	2 x TeleDongle modules	
	3 x Laptops	All charged, 2 will run AltOS, 1 will run DireWolf
	Foil tape	
	Small flat-blade screwdriver	Fits interrupt switches
	1/4-20 Nut & washer	
	Torque wrench, 12” extension, & 5/8” socket	

Avionics Pre-Integration Checklist	
Before nose cone has been attached	
	Verify that primary TeleMetrum, secondary TeleMetrum, and APRS PCB are connected to their respective batteries
	Verify that APRS PCB antenna is attached and pointing upwards
	Verify that all ejection charge leads are attached to primary and secondary TeleMetrums
	Align Flight computer & APRS module with threaded nose cone rod and insert into nose cone until bottom plate makes contact with interior nose cone lip
	Secure flight computer module onto threaded rod with washer and 1/4-20 nut, torque to 20 ft-lbs
	Connect all ejection charge leads to their respective wires, secure to inside of body tube with foil tape
After nose cone has been attached	
	Verify that all ejection charge wires are secured to inside of body tube
	Connect all ejection charge wires to their respective e-matches
	Proceed to avionics post-integration checklist

Avionics Post-Integration Checklist
Once rocket is vertical on launch rail

	Turn primary and secondary apogee interrupt switches to on position
	Turn primary and secondary main parachute interrupt switches to on position
	Turn primary and secondary TeleMetrum power interrupt switches to on position
	Confirm that both flight computers have powered on by listening for a 4 kHz and 3 kHz beep once every 5 seconds
	Retreat to ground control station
	Establish communication with both TeleMetrums and APRS PCB using their respective laptops
	Inform team lead that communication with onboard avionics has been established
After rocket has launched	
	Monitor in-flight telemetry from both TeleMetrums, paying specific attention to when ejection charges fire
	Note GPS coordinates from TeleMetrums listed when acceleration values reach 0 (signaling that rocket has landed)
	Compare GPS coordinates to latest APRS packet data
	Once given all clear by launch pad staff, travel to recorded GPS coordinates to recover rocket

Propulsion Component Checklist	
	Item
	O-rings
	Snap Rings
	Snap Ring Pliers
	Grease
	Motor Tube
	Forward Enclosure
	Nozzle
	Propellant Grains
	Phenolic Liner
	Centering Rings
	Superglue
	Wood Glue
	Igniters
	Dowels
	Electrical Tape

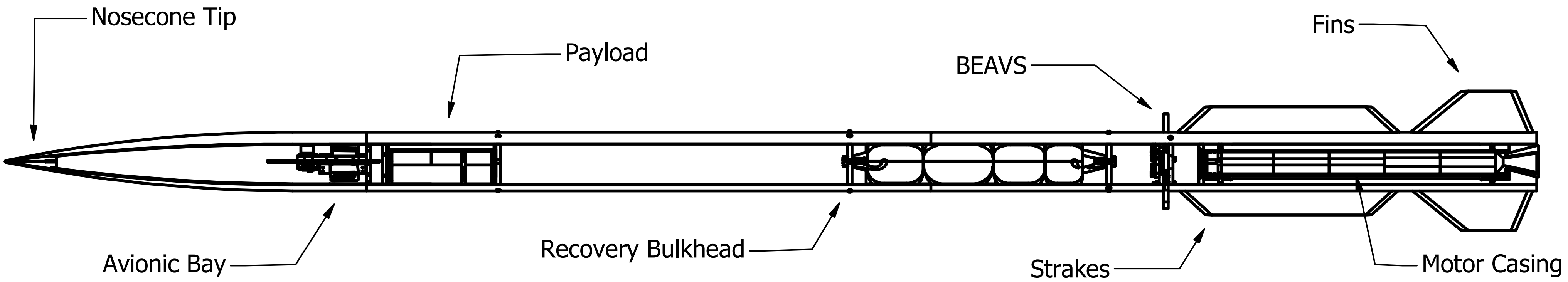
	Ignition System/Launch Box
	Motor Retention Bolt and Washers
	Socket Wrench and Extension

Propulsion Motor Assembly Checklist	
Completed Before Travel	
	Before assembly, wood glue propellant grains into the phenolic liner
	Grease o-rings and place them in appropriate grooves in the nozzle and forward enclosure
	Slide forward enclosure with o rings into tube stopping once slightly past the snap ring groove
	Clean grease out of the snap ring groove and place the snap ring in the groove with snap ring pliers
	Slide grains/phenolic into the motor tube
	Slide the nozzle with o rings into the tube stopping once slightly past the snap ring groove
	Clean grease out of the snap ring groove and place the snap ring in the groove with snap ring pliers
	Superglue centering rings onto the motor tube one inch from either end of the tube
	Place motor in casket once the superglue is dried

Propulsion Integration Checklist	
	Remove the motor tube from the casket
	Insert the motor tube into the rocket body flush with the thrust bulkhead
	Insert motor retention bolt and washer, tighten

Propulsion Launch Checklist	
	Attach ignitors to dowel using electrical tape
	Place ignitors on the dowel into the motor once the rocket is on the launch rail
	Set up the launch box by attaching the box antenna and screwing in the ignition alligator clip wire
	Essential team members wearing face shields complete the following steps
	Attach the igniters to the alligator clips
	Power on and arm the launch box

APPENDIX F – ENGINEERING DRAWINGS



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MFG					
APPROVED					
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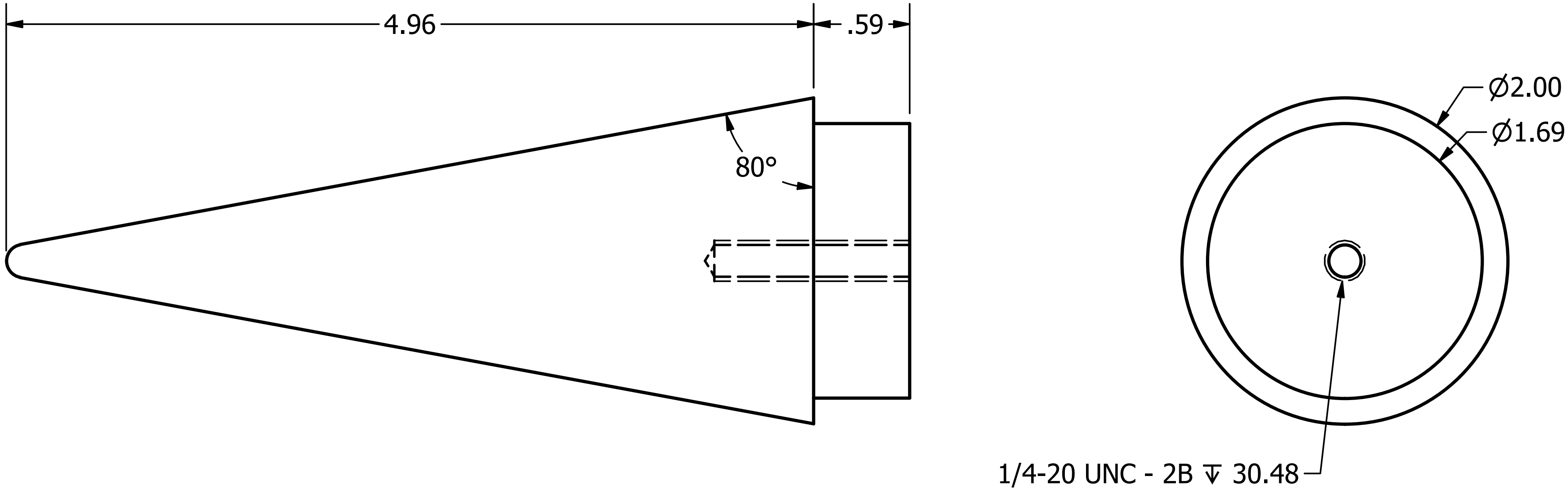

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MFG						
APPROVED						
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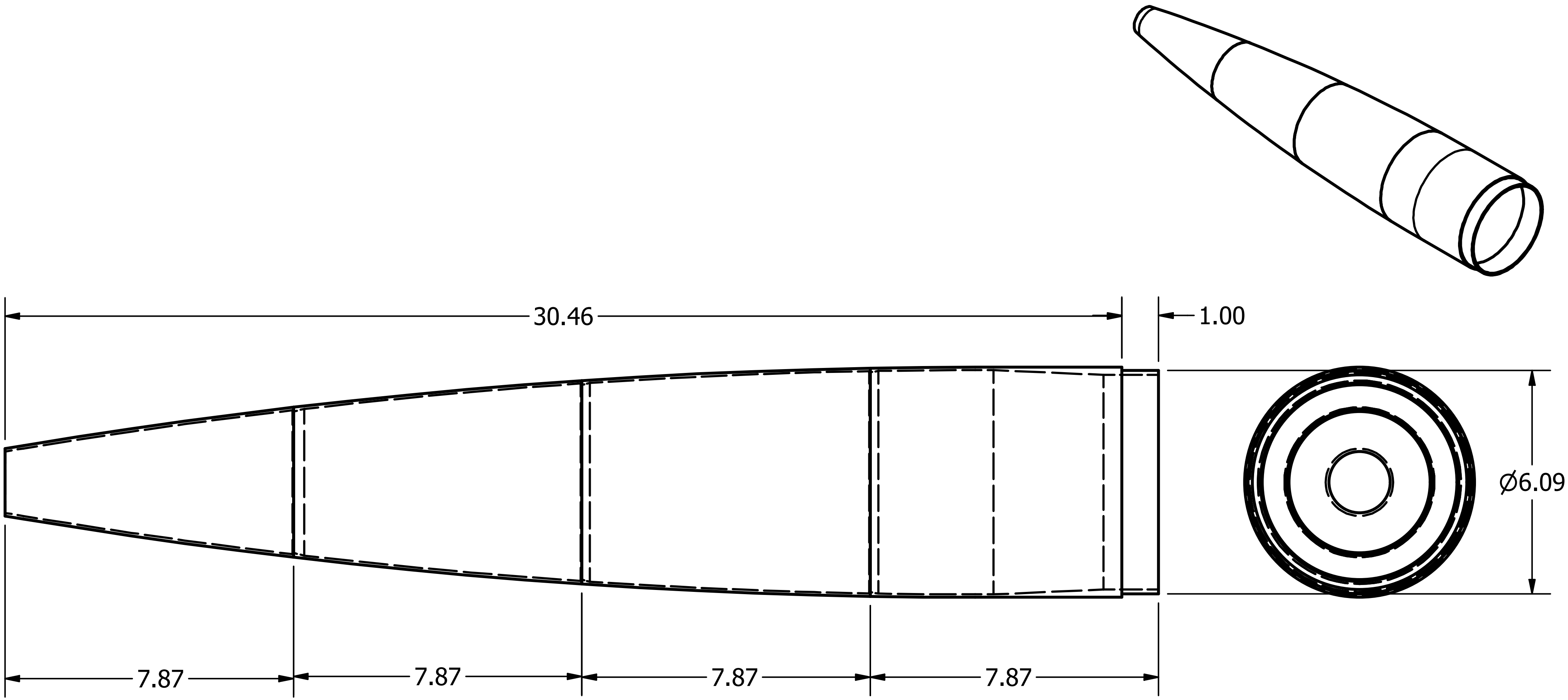
		SCALE 1 : 1			SHEET 2 OF 11	



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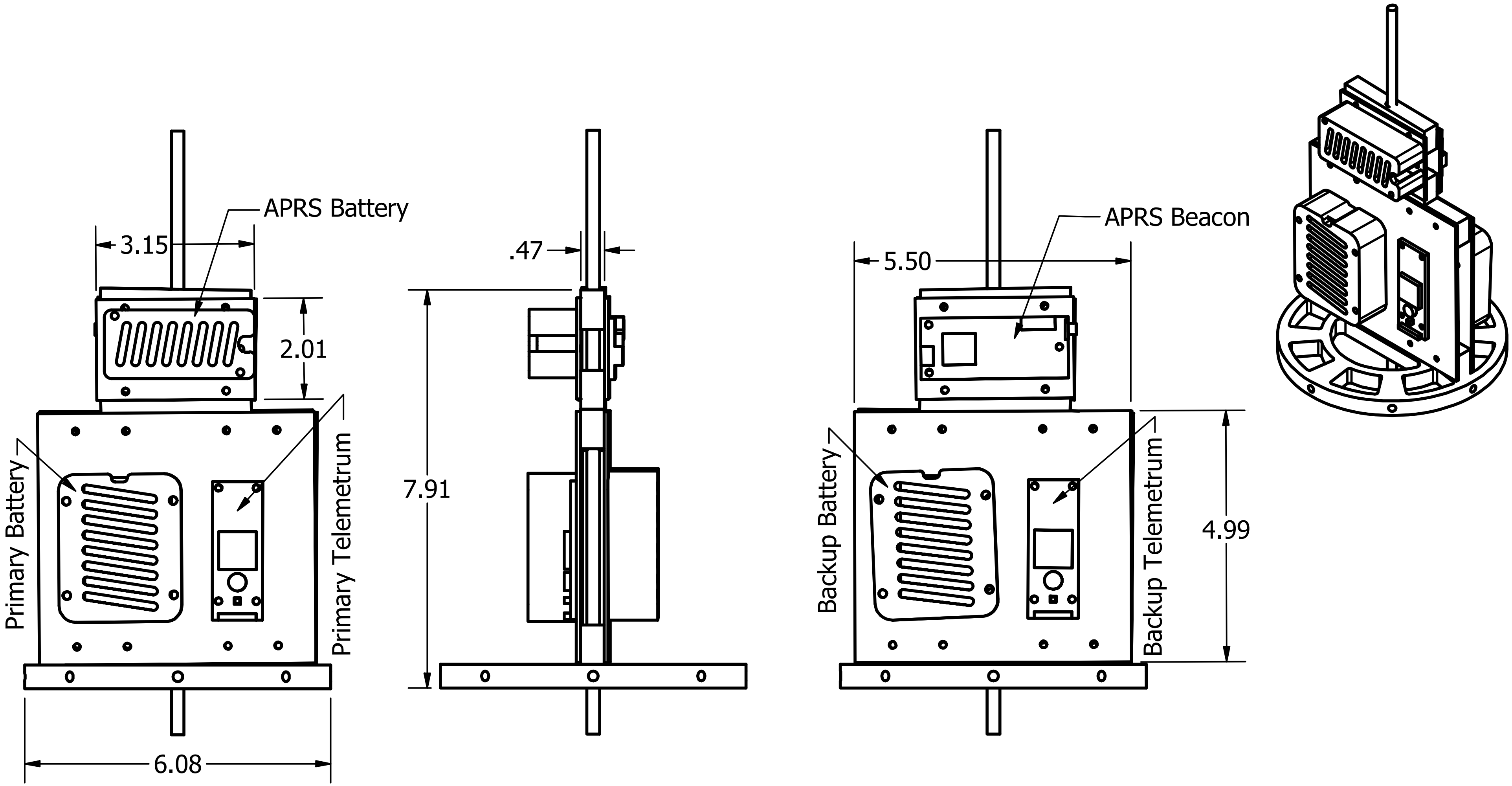
QA		TITLE [5.8.3] Nosecone_Mandrel		
MFG				
APPROVED				
Unit	inch	SIZE A4	DWG NO [0.0.0] CompleteAssembly	REV
		SCALE 1 / 4		SHEET 3 OF 11



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QA		
MFG		
APPROVED		
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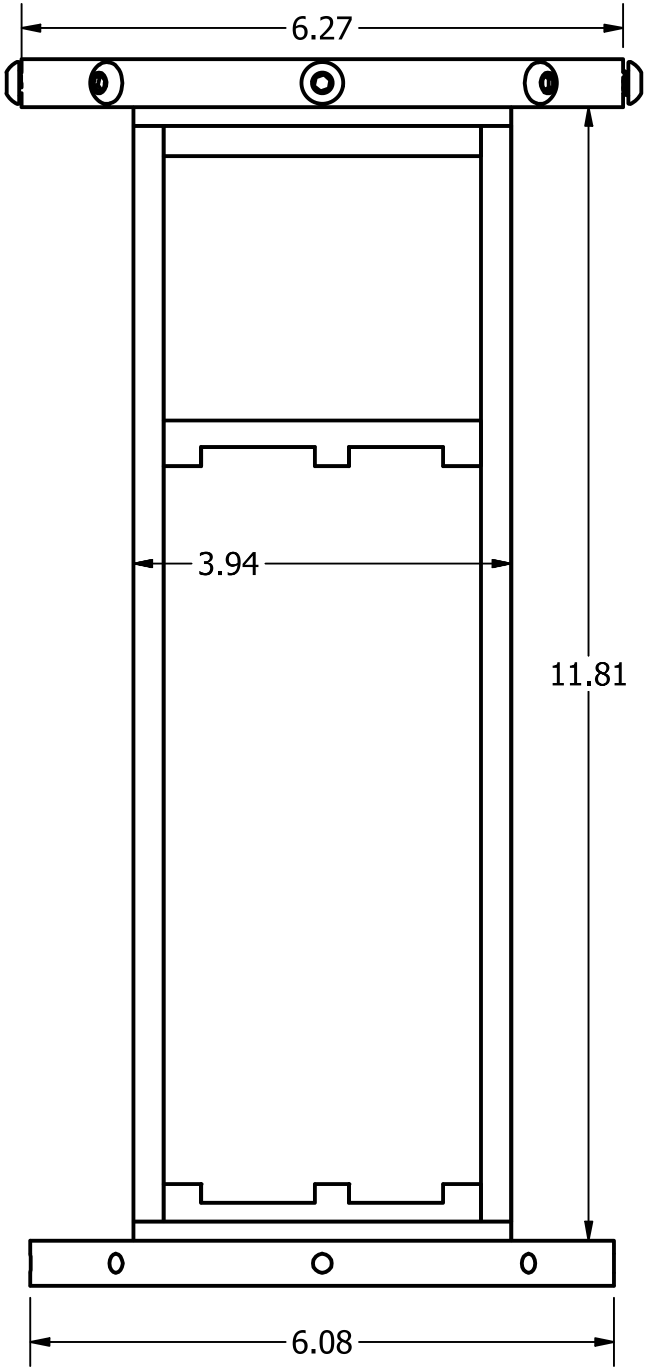
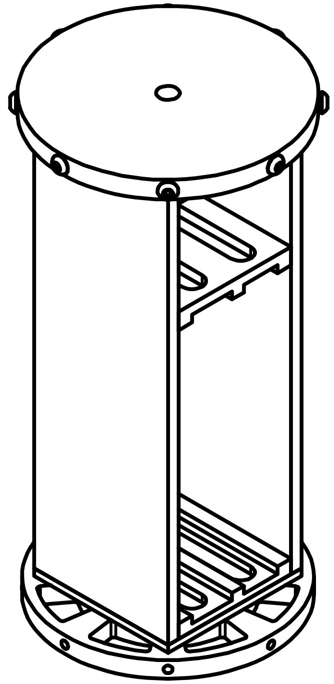
		SCALE 1 / 3 · SHEET 4 OF 11





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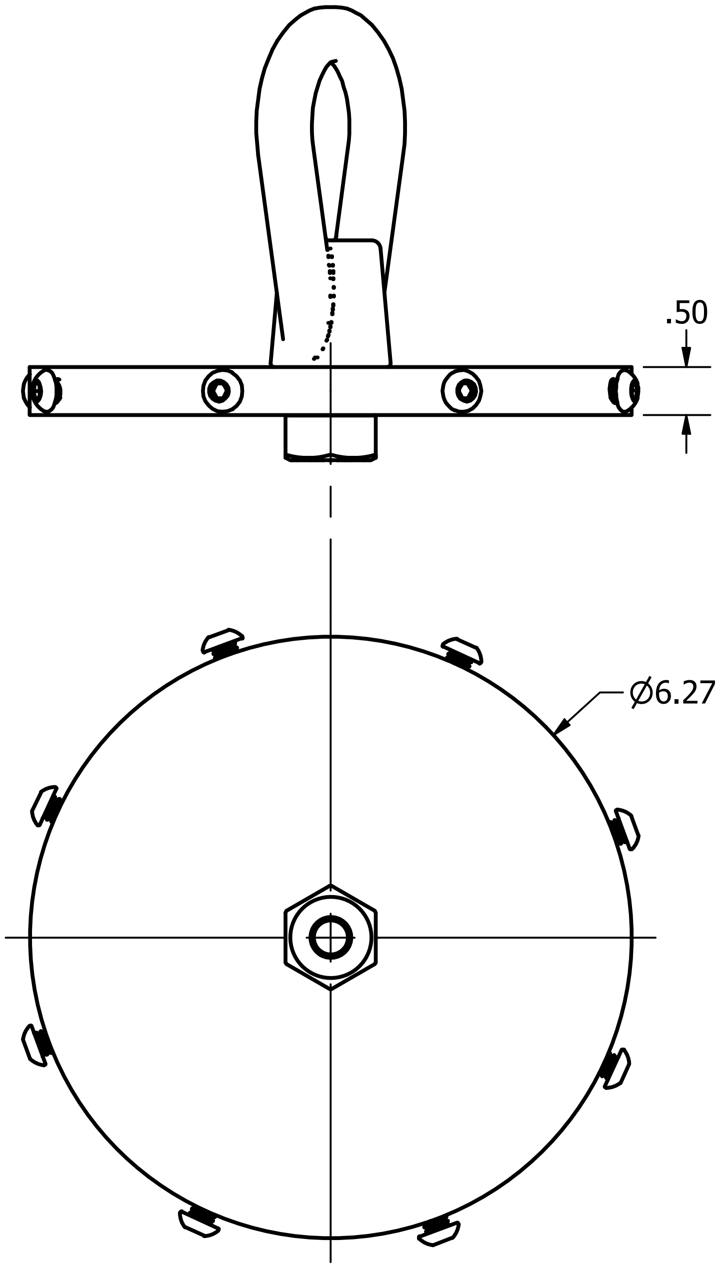
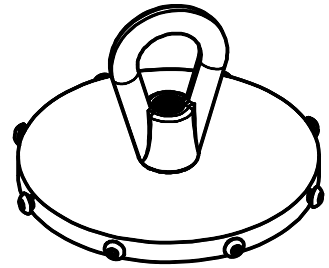
CHECKED				
QA		TITLE [2.0.20] Payload_Assembly		
MFG				
APPROVED				
Unit	inch	SIZE A4	DWG NO [0.0.0] CompleteAssembly	REV
		SCALE 1 / 2		SHEET 5 OF 11





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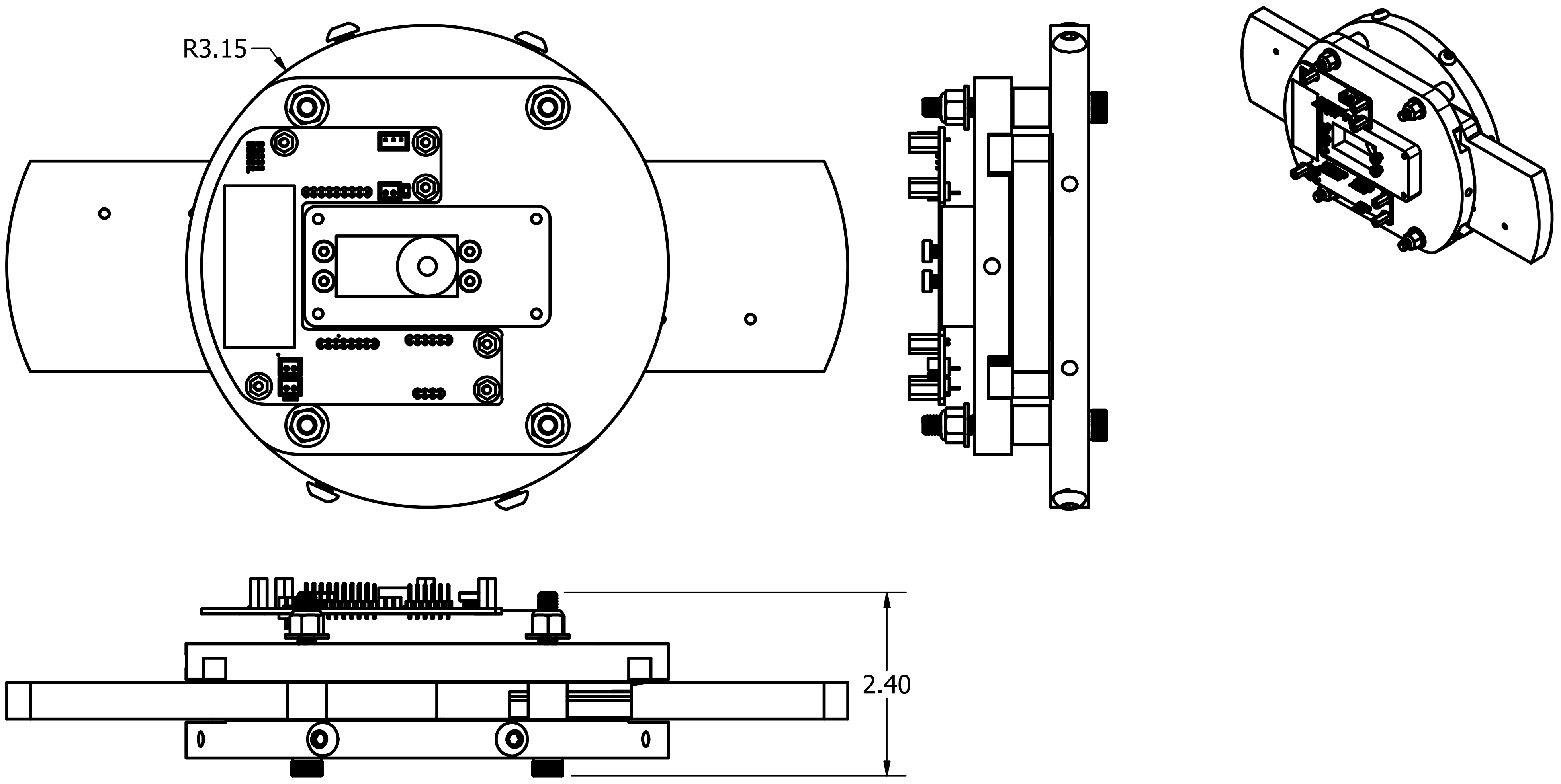
QA		TITLE [5.9.8] Parachute_Bulkhead_Assembly
MFG		
APPROVED		
Unit	inch	SIZE A4 · DWG NO [0.0.0] CompleteAssembly · REV
		SCALE 1 / 2 · SHEET 6 OF 11



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QA		TITLE [5.8.1] BEAVS_Assembly			
MFG					
APPROVED					
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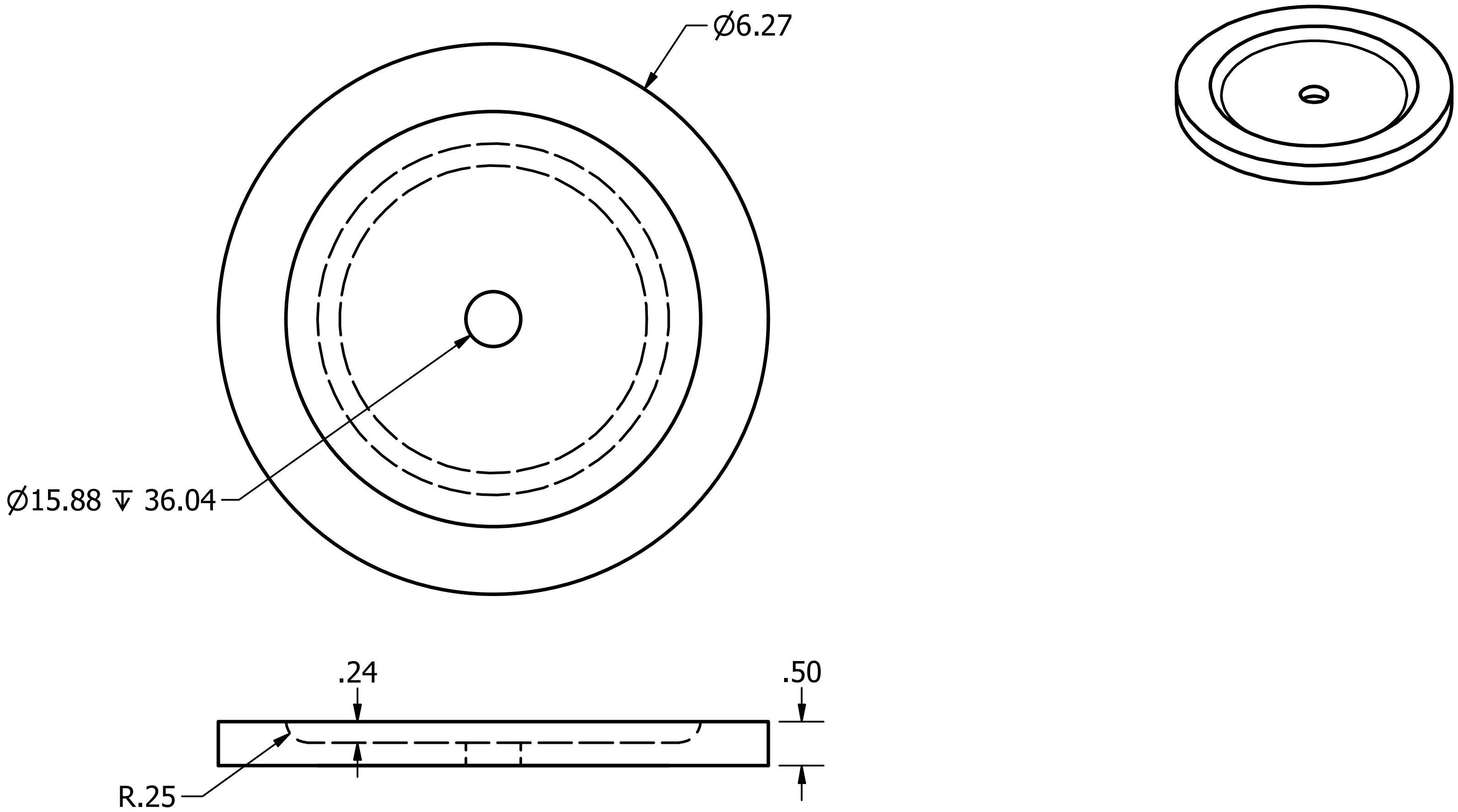

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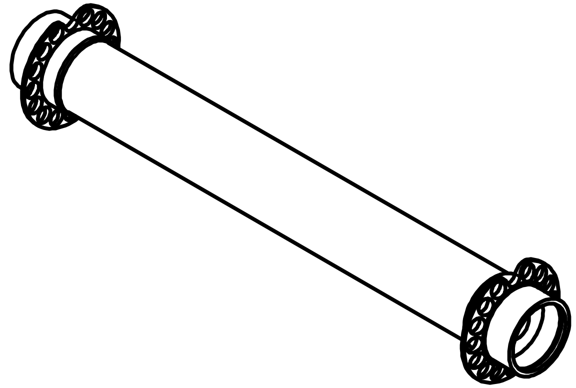
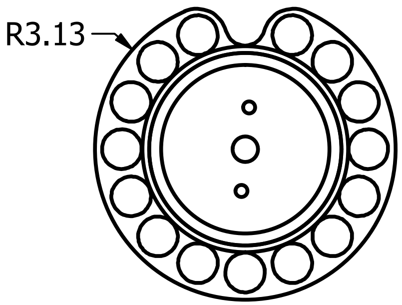
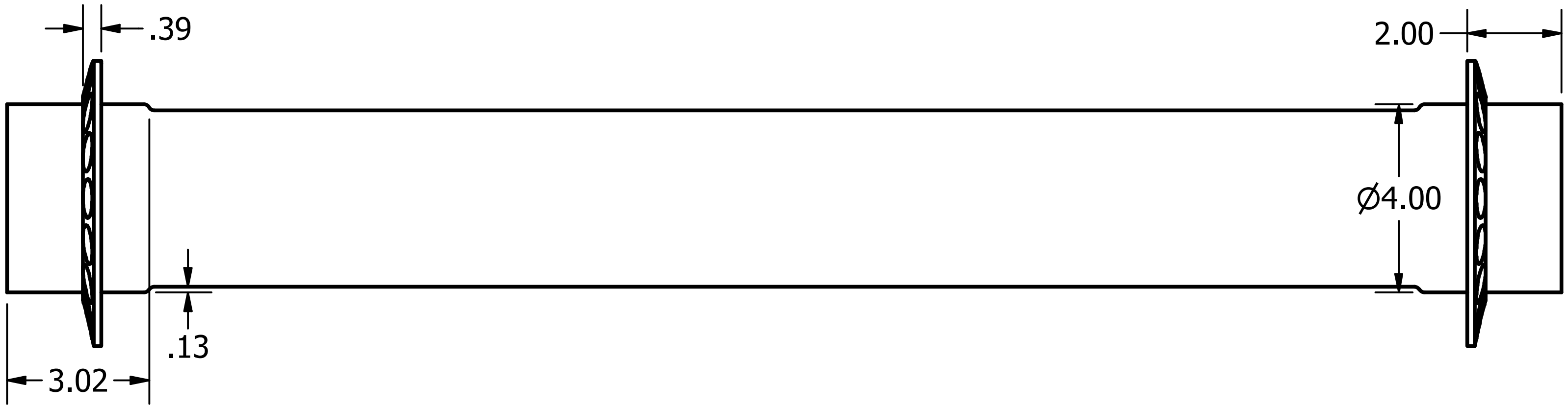
QA		TITLE [5.9.13] Thrust_Bulkhead			
MFG					
APPROVED					
Unit	inch	SIZE A4		DWG NO [0.0.0] CompleteAssembly	REV
		SCALE 1 / 2		SHEET 8 OF 11	







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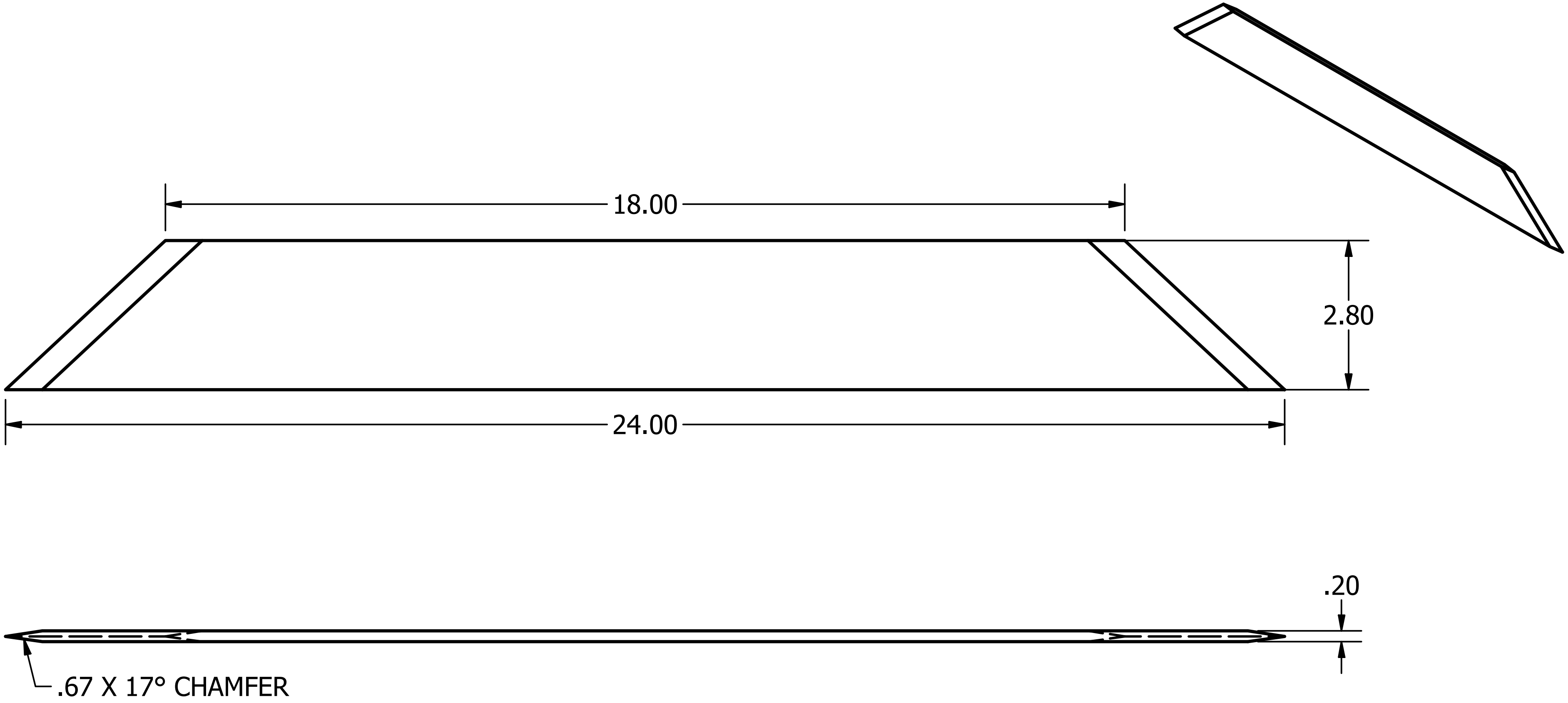
MFG		
APPROVED		
Unit	inch	SIZE A4 — DWG NO [0.0.0] CompleteAssembly — REV
		SCALE 1 / 4 — SHEET 9 OF 11



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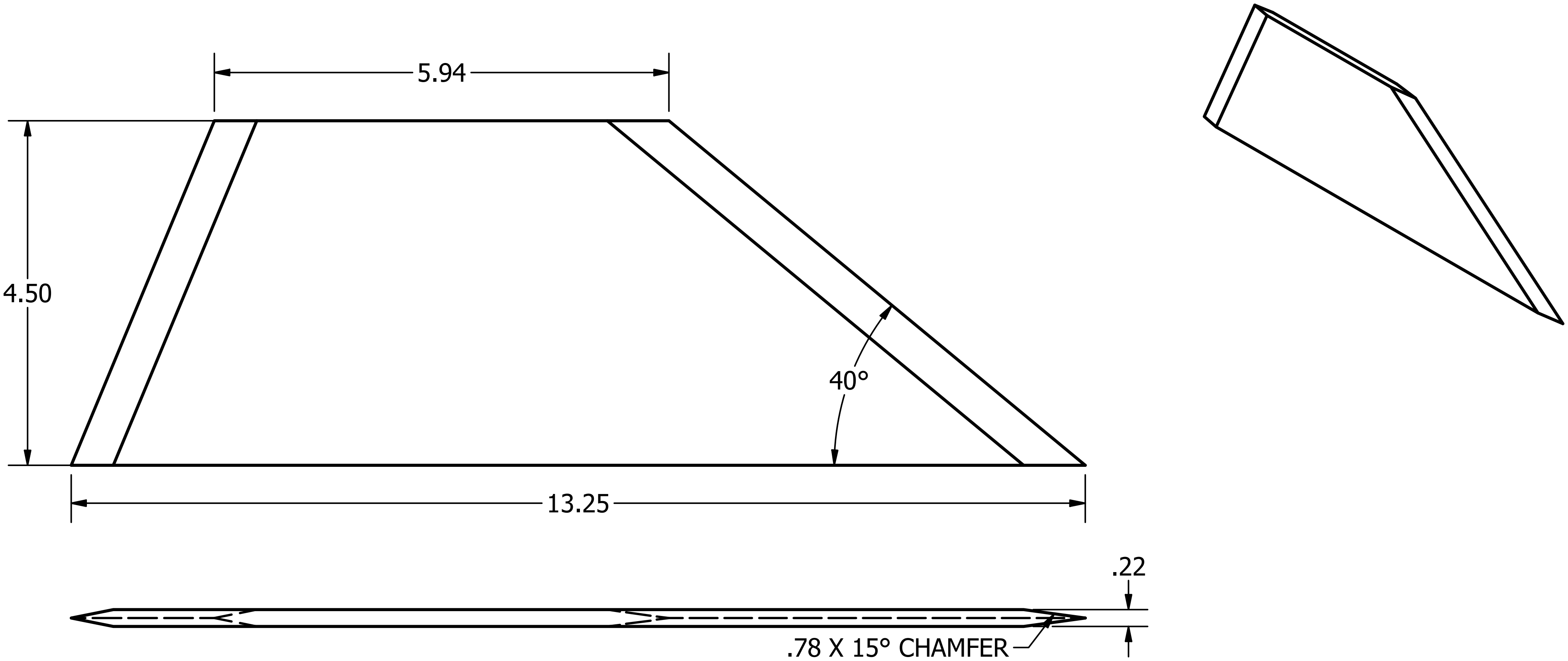
MFG		
APPROVED		
Unit	inch	SIZE A4 / DWG NO [0.0.0] CompleteAssembly / REV
		SCALE 1 / 3 / SHEET 10 OF 11



DRAWN colinhb	5/10/2024	OSU AIAA 2024 ESRA			
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QA		TITLE [5.5.3] Fin_V3			
MFG					
APPROVED					
Unit	inch				
		SIZE A4		DWG NO [0.0.0] CompleteAssembly	REV
		SCALE 1 / 2		SHEET 11 OF 11	

APPENDIX G – ADDITIONAL RESOURCES

A. Structures

Table 8 OSU AIAA HART Empirical Bonding Data

Data Table	Test	Material	Adhesive	Temp (F)	Failure Strength (kgf)	Failure Type	Contact Width (mm)	Contact Length (mm)	Contact Area (mm^2)	Stress (MPa)	Stress (Psi)	Average
10	28	Aluminum/CF	Aeropoxy ES2032/PH3630	68	356.0	Al Bond	19.2	10.2	195.8	17.8	2583.1	2213.4
	29	Aluminum/CF	Aeropoxy ES2032/PH3630	68	218.0	Al Bond	19.1	10.0	191.0	11.2	1621.9	
	30	Aluminum/CF	Aeropoxy ES2032/PH3630	68	365.7	Al Bond	19.4	11.0	213.4	16.8	2435.1	
11	31	Aluminum/CF	West System 105 Resin 206 Hardner	68	117.9	Al Bond	19.0	10.0	190.0	6.1	881.8	1618.3
	32	Aluminum/CF	West System 105 Resin 206 Hardner	68	208.1	Al Bond	19.1	10.0	191.0	10.7	1548.2	
	33	Aluminum/CF	West System 105 Resin 206 Hardner	68	341.3	Al Bond	20.0	10.0	200.0	16.7	2424.9	
16	45	Aluminum/CF	JB Weld	68	189.5	Cohesive	19.5	10.5	204.8	9.1	1315.2	1315.2
12	34	Aluminum/CF	Loctite EA-120HP Epoxy	68	481.6	Cohesive	19.4	10.3	199.8	23.6	3424.9	3327.4
	35	Aluminum/CF	Loctite EA-120HP Epoxy	68	465.9	Cohesive	19.2	10.7	205.4	22.2	3222.6	
	36	Aluminum/CF	Loctite EA-120HP Epoxy	68	477.6	Cohesive	19.2	10.6	203.5	23.0	3334.7	

B. Payload

Table 9 Atmospheric Sensor Suite Choice

Sensor Name	Price	Measuring	Communication Protocol
Adafruit DPS310 Precision Barometric Pressure / Altitude Sensor	$6.95	P, T, Alt	I2C, SPI
Adafruit MS8607 Pressure Humidity Temperature PHT Sensor	$14.95	P, T, Humidity	I2C
Adafruit Sensirion SHT45 Precision Temperature & Humidity Sensor	$12.50	T, Humidity	I2C
Adafruit SCD-41 - True CO2 Temperature and Humidity Sensor	$49.95	CO2	I2C
Gravity: Electrochemical Ozone Sensor	$49.00	Ox	I2C
Fermion: MEMS Methane CH4 Gas Detection Sensor	$4.90	CH4	Analog
Gravity: Factory Calibrated Electrochemical SO2 Sensor	$152.90		I2C, UART
Gravity: PM2.5 Air Quality Sensor	$39.90		I2C
Gravity: Electrochemical Oxygen / O2 Sensor	$53.90		I2C
Fermion: MEMS Carbon Monoxide CO Gas Detection Sensor	$4.90	CO	Analog

Table 10 UV Flux Sensor Suite Choice

Sensor Name	Price	Measuring	Range	Accuracy	Communication Protocol
Analog UV Light Sensor Breakout	$6.50	UV	240-370nm		Analog
Adafruit LTR390 UV Light Sensor	$4.95	UVA	300-350nm		I2C
Gravity: VEML6075 UV Sensor	$6.95	UVA	315-375nm		I2C
MIKROE-4144	$45.00	UVC	220-280nm	0-9.3mW/cm^2	I2C

[Seeed Grove - UV Sensor]	$10.90	UV	200-370nm		I2C

C. Recovery

Table 11 Shear Pin Sizing Chart

Screw Size	Min Shear Strength (N)	Max Shear Strength (N)
M2	120.102	173.481
2-56	137.895	204.618
4-40	222.411	338.065
M3	298.031	404.788
6-32	333.617	507.097

Table 12 Ejection Charge Sizing Chart

Charge Mass (g)	Bulkhead Force (N)	Pressure in Chamber (Pa)	Pressure In Chamber (psi)
0.25	58.39901334	2931.951259	0.4252286091
0.5	116.7980267	5863.902519	0.8504572181
0.75	175.19704	8795.853778	1.275685827
1	233.5960534	11727.80504	1.700914436
1.25	291.9950667	14659.7563	2.126143045
1.5	350.3940801	17591.70756	2.551371654
1.75	408.7930934	20523.65882	2.976600263
2	467.1921067	23455.61008	3.401828872
2.25	525.5911201	26387.56133	3.827057481
2.5	583.9901334	29319.51259	4.252286091
2.75	642.3891468	32251.46385	4.6775147
3	700.7881601	35183.41511	5.102743309
3.25	759.1871735	38115.36637	5.527971918
3.5	817.5861868	41047.31763	5.953200527
3.75	875.9852001	43979.26889	6.378429136
4	934.3842135	46911.22015	6.803657745
4.25	992.7832268	49843.17141	7.228886354
4.5	1051.18224	52775.12267	7.654114963

4.75	1109.581254	55707.07393	8.079343572
5	1167.980267	58639.02519	8.504572181
5.25	1226.37928	61570.97645	8.92980079
5.5	1284.778294	64502.92771	9.355029399
5.75	1343.177307	67434.87897	9.780258008
6	1401.57632	70366.83023	10.20548662

Table 13 Shear Pin Quantity Chart

3 Bolt Shear max strength (N)	3 Bolt Shear min strength (N)	4 Bolt Shear max strength (N)	4 Bolt min Shear strength (N)	5 Bolt Shear max strength (N)	5 Bolt Shear min strength (N)	6 Bolt Shear max Strength (N)	6 Bolt Shear min Strength (N)	8 Bolt max Shear Strength (N)	8 Bolt min Shear Strength (N)
520.443	360.306	693.924	480.408	867.405	600.51	1040.886	720.612	1387.848	960.816
613.854	413.685	818.472	551.58	1023.09	689.475	1227.708	827.37	1636.944	1103.16
1014.195	667.233	1352.26	889.644	1690.325	1112.055	2028.39	1334.466	2704.52	1779.288
1214.364	894.093	1619.152	1192.124	2023.94	1490.155	2428.728	1788.186	3238.304	2384.248
1521.291	1000.851	2028.388	1334.468	2535.485	1668.085	3042.582	2001.702	4056.776	2668.936

Standard Operating Procedure

[Fullscale Static Fire Test]

Department:	OSU ESRA 2023-24
Date SOP was approved by Faculty Advisor:	
ESRA Faculty Advisor:	Roberto Albertani
ESRA Team Lead:	Collin Hale-Brown
ESRA Safety Officer:	Jackie Caynon caynonJ@oregonstate.edu
Emergency Contact:	Faculty Advisor: Roberto Albertani Phone Number: (541) 737 7024 Email: roberto.albertani@oregonstate.edu
Location(s) covered by this SOP:	Corvallis Airport

Type of SOP: x Process ☐Hazardous Chemical ☐Equipment

Purpose

- To ensure the safety of all members and mitigate damage.
- To conduct a successful static fire of a subscale rocket motor to gather vital temperature, thrust, and pressure information while maintaining the safety of all involved.

Training Requirements

- OSU EH&S Laboratory Safety Training (required every 3 years)
- Safety Data Sheet / Right to Know (Read and do GHS Training/quiz) (required every 3 years)
- Hazardous Waste Training (required annually)
- Noise and Hearing Conservation (required annually with additional requirements)
- Chemical Storage
- Gas Cylinder Safety
- Filtering Facepiece Training (if needed, i.e. mixing rocket fuel)
- Eye and Face Protection
- Enrolled in or completed ME 250 (if not, Shop Safety is required)
- OSU Fire Extinguisher Training

STATIC FIRE TEST AT CORVALLIS AIRPORT

Contact Airport Manager for permission to test at the airport (1 week in advance)

- Contact Andrew Schomberg (andrew.schomberg@corvallisoregon.gov)

Pack Equipment

- All necessary materials and test equipment are in the static fire pack list in the drive

Inform Dispatch (Call before and after testing)

- Call 541-766-6911, speak with operator, inform dispatch of test times, location, and contact information

Check DAQ & Fernando (Before heading to the test site, at the AIAA Lab)

- Verify DAQ and Igniter batteries are fully charged, if needed charge them in advance using the Lipo battery charger.
- Make sure you have some backup 9V batteries.
- Download the Igniter Installer zip file which can be found on the AIAA drive.
- Open the lid of the DAQ and insert a new micro-SD card into the micro-SD card breakout board
- Connect batteries to the system
- Power on the system
- Power off quickly
- Power on quickly
- Record sample data with or without sensors to ensure the system boots and records data properly
- Double-check that a micro-SD card is in Dinosaur and the battery is plugged in **before** heading to the test site
- Close the lid

Determine Safety Distance

- Before setting up the tent, and assembling the motor, choose a location that's far enough from the test stand, with a minimum safety distance specified by the National Rocket Association (NAR) High Power Rocket Safety Code, this safety distance depends on the installed total impulse of the assembled motor (rocket). The current ESRA rocket is considered to be a non-complex rocket, for the fact that it is not multi-staged or propelled by two or more rocket motors, if this ever changes in the future make sure to refer to the complex rocket distance values on the last column (Figure 1).

MINIMUM DISTANCE TABLE

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

Figure 1: National Association of Rocketry (NAR) High Power Rocket Safety Code minimum distance table.

Assemble Test Stand

- The test stand is placed on the designated cement platform test spot.
  - The stand is made as close to level as practical.
- Sandbags are added to the legs of the test stand, one bag on each leg.
- Secure the test stand with ratchet straps
- Fix the load cell base into place in between the middle two legs of the test stand.
- Place the load cell in between the load cell plates

DAQ, Sensors, and Igniter Check (At the test pad, before integrating the motor)

- Set the DAQ on the concrete of the test pad near the edge as far away from the test stand as possible.
- Attach sensors to the testing setup following motor standard operating procedure
- Plug in the sensors required for the specific test
  - Load cell
  - Pressure transducer
  - Thermocouples
- Power on
- Power quickly off
- Power quickly on, and ensure the green power LED is on and the red LED turns off a. If not, clean off the DAQ of any dust, combustion products, or other debris.
  - Bring under cover from rain and open the lid
  - Ensure there is a micro-SD card installed and the battery is connected
  - If the red LED never turns off, start troubleshooting and prepare to abort the test
- Turn off the system.
- Verify that the Igniter Installer program runs well without issues on the laptop.

Motor Assembly

- ❏ All members are wearing safety glasses.
- ❏ The motor is placed securely in the v-cut brace or firmly held on a table.
- ❏ Heavily grease snap ring groove.
- ❏ Grease and install o-rings into the forward enclosure.
- ❏ Insert the forward enclosure into the forward end of the motor so that the top is past the snap ring groove.
- ❏ Degrease the snap ring groove and install the forward snap ring.
- ❏ The fuel assembly is inserted into the motor casing from the aft end and slid in until it sits flush on the forward enclosure and the forward enclosure sits flush with the snap ring.
- ❏ Grease and install o-rings onto the nozzle.

- ❑ Insert the nozzle from the aft end, pushing the end of the nozzle until it is flush with the thermal liner.
- ❑ Remove all grease from the snap ring groove.
- ❑ Install thrust ring.
- ❑ All personnel are clear of the nozzle end of assembly.
- ❑ Install the aft snap ring.
- **The motor is now live.**

Placing Motor Assembly in the Test Stand

- ❑ At this time, all non-essential personnel are relocated to the safe personnel distance for the motor.
- ❑ All personnel assembling the test stand are wearing face shields.
- ❑ Bring the motor assembly to the test stand.
- ❑ Position the assembly so that the aft (nozzle) end is toward the sky.
- ❑ Place the transfer tube between the motor and the load cell and make sure the pressure transducer hose is positioned in the cut-out.
- ❑ Ensure that the motor is sitting centered on top of the load cell.
- ❑ Connect the pressure transducer to the DAQ.
- ❑ Secure thermal transducers to the motor tube using electrical tape
    - ❑ For subscale only use two of the four
- **The motor assembly is ready to be armed.**

Arming Motor Assembly: Launch Control System and Igniter

- ❑ All but two evacuate the test site.
- ❑ The system is <u>not armed</u>. The system is on SAFE.
- ❑ Turn on the DAQ (left switch)
- ❑ Turn it off quickly
- ❑ Turn it on again quickly
- ❑ Check LEDs (ensure that the power switch is green and the red LED on the right is off)
- ❑ Turn on the DAQ's write switch (right switch)
- ❑ The member inserting igniters is wearing a full face shield.
- ❑ One (1) member will insert the igniter into the motor.
    - ❑ Ensure it is inserted to the bottom and the casing has been cut off.
- ❑ Wires to igniters are connected to the alligator clips, which are connected to the power supply from the igniter module.
- ❑ Turn on the Ignition system (Fernando), and arm it using the switches. The system is armed.
- ❑ Both members evacuate the test site. Get away the **<u>Minimum Personnel Distance</u>** (ft.) obtained on Page 9 of this document.

- **The motor assembly is armed and ready to fire.**

Ignition:

- ❏ Ping Fernando
- ❏ All members are accounted for
- ❏ Visual Clearance check.
    - ❏ Surrounding test site
    - ❏ Road
    - ❏ Airspace
    - ❏ Ensure Dispatch has been notified (see number on pg. 2)
- ❏ Launch control is ARMED.
- ❏ Final Clearance Check
    - ❏ Surrounding test site
    - ❏ Road
    - ❏ Airspace
- ❏ Countdown from five (5) seconds.
- ❏ Ignition (Launch).
- ❏ Disarm immediately.

Successful Fire

- ❏ Wait for **three (3) minutes** before approaching the test site.
- ❏ Approach the test site.
- ❏ Give assembly time to cool down. Assembly is HOT.
- ❏ Upon reaching a cool enough temperature, disassemble the test stand assembly.

Hang Fire

- ❏ Wait for **five (5) minutes** before approaching the test site.
- ❏ Launch control is SAFE.
- ❏ Two (2) members approach the test site with one (1) vehicle.
- ❏ Both members have full face shields.
- ❏ One member approaches the assembly. Approach cautiously. The motor could fire at any time.
    - ❏ Render the Ignition system SAFE.
    - ❏ Stop Data collection.
    - ❏ Remove alligator clips from igniter wires.
    - ❏ Remove igniters from the motor assembly.
- ❏ Troubleshooting.

CATO

- [ ] Wait for **ten(10) minutes** before approaching the test site.
- [ ] Launch control is SAFE.
- [ ] Approach the test site.
- [ ] The ignition system is DISARMED.
- [ ] Stop data collection.
- [ ] Take photos of components for failure documentation.
- [ ] Move all large pieces from the test site.
- [ ] Form a search pattern and comb the surrounding field for fire/shrapnel.
- [ ] Store all unburnt propellant in a paper/plastic bag.

Approaching the test site

- Turn off DAQ write (right) switch first
    - Failure to do so will result in data being lost
- Turn off the power switch (left)
- Disconnect sensors from the forward enclosure and motor tube
    - Motor tubes are hot after testing, remove sensors from DAQ first to stay clear of hot parts.
- Do not open the enclosure until it has been cleaned and is clear of weather.

Safety Data Sheet (SDS) Location

Online SDS can be accessed at (http://oregonstate.edu/ehs/sds). A hard copy can be found at Oak Creek Building with Environmental Health & Safety.

First Aid Procedures

If an accident happens the Safety Incident Reporting Form at the end of this SOP must be completed.

If inhaled
Move to fresh air. If the person is not breathing, give artificial respiration. Avoid mouth-to-mouth contact. Call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.

In case of skin contact
In case of burn injury, call 911 immediately.

In case of eye contact

Use eye wash to flush your eyes for 15 minutes. Call 911. Follow safety instructions for further assistance:
http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/eyewash_and_safety_shower_si.pdf

If ingested
Do not induce vomiting. Contact 911 and/or poison control center if swallowed:
1(800)222-1222

Special Storage & Handling Requirements

Storage:

Store motor grains in a cool dry location, and place desiccant inside the motor case to absorb moisture.

Transporting:

Motor grains must be transported in an ammo can by a certified driver

Personal precautions

Always wear the necessary PPE, face protection, eye protection, and gloves when interacting with all motor assembly and test stand components as described in the Procedure section.

Environmental precautions

Rocket propellant is an explosive and it can do substantial damage to the surrounding environment if it is placed near a source of heat. In the case of CATO, form a search pattern and comb the surrounding area for fire/shrapnel, and store all unburnt propellant in a paper/plastic bag.

Other Emergencies

Medical Emergency Dial 911

Life Threatening Emergency, After Hours, Weekends and Holidays – Dial **911** (This will connect you to Good Samaritan Hospital Corvallis where they will be able to treat the victim).

Non-Life Threatening Emergency – *If needed, call 911 from a phone. Call EHS at 541-737-2273 after emergency services have been contacted to report the incident.*

Decontamination/Waste Disposal Procedure

General hazardous waste disposal guidelines:

Label Waste

- Affix an EH&S hazardous waste label on all waste containers (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/hwlabelfull.pdf) as soon as the first drop of waste is added to the container.

Store Waste

- Store hazardous waste in closed containers, in secondary containment and in a designated location. (http://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/si/waste_hazardous_disposal_si.pdf).
- Double-bag dry waste using transparent bags
- Waste must be under the control of the person generating & disposing of it

Dispose of Waste

- Dispose of regularly generated chemical waste within 90 days
- Put in a waste request at: http://ehs.oregonstate.edu/waste

References

National Association of Rocketry (NAR) High Power Rocketry Safety Code:
https://www.nar.org/safety-information/high-power-rocket-safety-code/

Documentation of Training

- Before conducting any work with the Static Fire Test, designated personnel must provide training to his/her laboratory personnel specific to the hazards involved in working with this substance, work area decontamination, and emergency procedures.

- The Principal Investigator must provide this SOP and a copy of the SDS (which can be available online) to all laboratory personnel.

- The Principal Investigator must ensure that his/her laboratory personnel have attended appropriate laboratory safety or refresher training.

Faculty Advisor SOP Approval

By signing and dating here the designee certifies that the Standard Operating Procedure (SOP) for the **Static Fire Test** is accurate and effectively provides standard operating procedures for laboratory personnel.

Signature	Printed Name/Title	Date

I have read and understand the content of this SOP:

Name	Signature	Date

Date		Room Temp	
Recipe	Liquid Sand	Room Humidity	
Batch Number		Target Weight (g)	
Location		Grain Quantity	

Inhibitor	Target Weight (g)		Actual Weight (g)	

Ingredient	Percentage	Target Weight (g)	Actual Weight
R45	68.38%	0	
Castor Oil	1.05%	0	
Lecithin	1.05%	0	
IDP	15.79%	0	
Silicone Oil	0.00%	1 drop	
MDI	13.72%	0	

Mix Start Time		Mix End Time		Target (min)	15	Start this simultaneously with the propellant mix
Vacuum Start Time:		Vacuum End Time		Target (min)	5	

Liberally apply to the inside of the casting tubes with small paint brushes to prevent burning on the outside of the grain.
Flip the casting tubes periodically as the inhibitor runs and cures.
Inhibitor will likely not be fully cured by the time of packing.

Batch Start Time	

Propellant Liquids

Ingredient	Percentage	Target Weight (g)	Actual Weight
R45	12.99%	0	
IDP	3.00%	0	
Castor Oil	0.20%	0	
Lecithin	0.20%	0	
Silicone Oil	0.00%	1 drop per 1000 g	

Mix Start Time		Mix Stop Time		Target (min)	5	Start this simultaneously with the inhibitor mix
Vacuum Start Time		Vacuum Stop Time		Target (min)	5	Watch it while under vacuum!
Apply Electric Blanket						

Propellant Solids Fuels

Ingredient	Percentage	Target Weight (g)	Actual Weight
Aluminum	2.00%	0	

Mix Start Time		Mix Stop Time		Target (min)	15	
Vacuum Start Time		Vacuum Stop Time		Target (min)	5	Watch it while under vacuum!

Propellant Solids Oxidizers

Ingredient	Percentage	Target Weight (g)	Actual Weight
AP (200µ)	79.00%	0	

1st Mix Start Time		Mix End Time		Target (min)	20	
2nd Mix Start Time		Mix End Time		Target (min)	20	
3rd Mix Start Time		Mix End Time		Target (min)	20	Watch it while under vacuum!
Vacuum Start Time		Vacuum End Time		Target (min)	15	Run vacuum for 15 minutes.

Propellant Curative

Ingredient	Percentage	Target Weight (g)	Actual Weight
MDI	2.61%	0	

Mix Start Time		Mix End Time		Target (min)	45
Vacuum Start Time		Vacuum End Time		Target (min)	10

Packing Start	
Packing End	

Total Batch Time (hrs)	

NOTE: The coring rods are best removed the day after casting. Once cores are removed, cover ends in plastic wrap and store in a container with dessicant.

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