Unexploded Ordnance Hybrid Rocket

Team 38 Project Technical Report for the 2018 IREC

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Unexploded Ordnance (UXO) is a hybrid rocket developed by Waterloo Rocketry for entry in the 10000 ft apogee with Student Researched & Developed (SRAD) hybrid/liquid propulsion system category at the 2018 Intercollegiate Rocket Engineering Competition. The UXO launch vehicle is powered by the Kismet engine, a nitrous oxide/hydroxyl-terminated polybutadiene SRAD hybrid engine, and features a deployable payload system designed for a 3U CubeSat. The primary objective of UXO is to attain an apogee of between 8000 ft and 12000 ft and achieve a non-hazardous descent, while the objective of the payload is to achieve successful deployment at apogee, followed by video documentation of payload descent and proper functionality of data acquisition electronics. In support of these objectives, the team has developed robust ground support equipment systems for safe and efficient management of rocket pre-launch activities and launch operations.

Nomenclature

AGL	=	Above Ground Level
ASL	=	Above Sea Level
CO_2	=	Carbon Dioxide
CONOPS	=	Mission Concept of Operations
COTS	=	Commercial Off-the-Shelf
DAQ	=	Data Acquisition
ESRA	=	Experimental Sounding Rocket Association
FOS	=	Factor of Safety
GSE	=	Ground Support Equipment
GPS	=	Global Positioning System
HTPB	=	Hydroxyl-terminated polybutadiene
I2C	=	Inter-Integrated Circuit
ID	=	Inner Diameter
IMU	=	Inertial Measurement Unit
IREC	=	Intercollegiate Rocket Engineering Competition
LiPo	=	Lithium polymer
NO	=	Normally Open
NOS	=	Nitrous Oxide
OD	=	Outer Diameter
PCB	=	Printed Circuit Board
PPE	=	Personal Protective Equipment
RLCS	=	Remote Launch Control System
SAC	=	Spaceport America Cup
SF	=	Static Fire
SPI	=	Serial Peripheral Interface
SRAD	=	Student Researched and Developed
UXO	=	Unexploded Ordnance

[1] All authors team members of Waterloo Rocketry

I. Introduction

WATERLOO Rocketry is an engineering student team representing the University of Waterloo, from Waterloo, Ontario, Canada. The team will be competing in the 2018 Intercollegiate Rocket Engineering Competition (IREC) at the 2nd Annual Spaceport America Cup (SAC) with the Unexploded Ordnance (UXO) rocket, which is entered in the 10000 ft apogee with Student Researched & Developed (SRAD) hybrid/liquid propulsion system category. The primary mission objective is to launch UXO to an apogee between 8000 ft and 12000 ft AGL, followed by successful recovery system operation and a non-hazardous descent. A secondary objective is successful operation of the payload module, although this objective is not essential for mission success.

The team comprises approximately 20 undergraduate students studying Mechanical, Mechatronics, Electrical, Computer, Chemical, Civil, Nanotechnology, and Systems Design Engineering. The Team Lead is responsible for overall project management and team direction, including overseeing all technical, administrative, and operational activities necessary to achieve team objectives. Technical projects are led by Project Leads, who are chosen based on past experience, skillset, and interest. Project Leads are responsible for coordinating and managing all aspects related to their projects, leading the design, manufacture, and testing of their systems, and ensuring the successful integration of their project with other vehicle and ground systems. Team members are welcome to work on any projects that interest them, and project teams often have significant overlap and collaboration. Although one team member takes on the role of Safety Captain and is responsible for development and maintenance of safety documentation and procedures, safety is the responsibility of every team member and is always the team's highest priority.

Team stakeholders include academic partners, advisors, sponsors, and team members. The team represents the University of Waterloo and owes much to the institutions and resources that the University makes available to student teams. The team's advisors, both from within the University and from industry, are hugely helpful in sharing knowledge and providing insight as the team continues to develop more complex and sophisticated systems. Team sponsors are additional stakeholders, as they have provided significant material and financial support essential for the team's operation. Finally, the team's most important stakeholders are the team members. The primary objective of the team is to provide students with opportunities to engage in hands-on learning through practical engineering challenges. Team growth and continuity is contingent on the team's ability to maintain this atmosphere of learning and collaboration while remaining competitive and improving year-to-year. Many past and present members have dedicated significant time and effort to the team, and continued success is a recognition of this commitment.

II. System Architecture Overview

UXO is a hybrid rocket measuring 178" in length and 6" in diameter. The vehicle can be divided into three major modules: the Kismet engine, the recovery system, and the payload. UXO was designed with modularity in mind; all major sections are self-contained and separable. In addition to vehicle systems, the team has developed ground support equipment (GSE) systems necessary for fill and launch operations. A full sectional view of UXO can be seen in Figure 1.

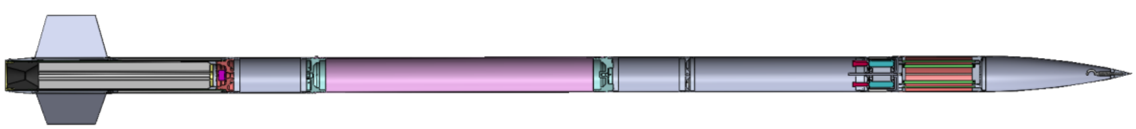


Figure 1. UXO sectional view. *UXO is a modular design permitting rapid assembly and disassembly of individual subsystems.Visible in this figure, from left to right: fin can, Kismet engine, recovery module, payload module, nose cone.*

A. Propulsion Subsystems

UXO uses the Kismet engine, an SRAD hybrid engine with liquid nitrous oxide (NOS) as the oxidizer and hydroxyl-terminated polybutadiene (HTPB) as the fuel. A cross section of the engine is shown in Figure 2. Kismet was initially designed to achieve a 30000 ft apogee; however, due to a low combustion efficiency (60%), the current revision of the engine will carry the rocket to approximately 10000 ft. Almost all of the components of the engine are manufactured by team members in the University of Waterloo's student machine shop. No CNC work was done on any of the engine components, in order to promote learning through hands-on manufacturing processes. All major structural components of the engine, including the tanks and bulkheads, are made of 6061-T6 aluminium alloy. This material was selected as it is relatively inexpensive, available in a variety of sizes and form factors, and easily machineable.

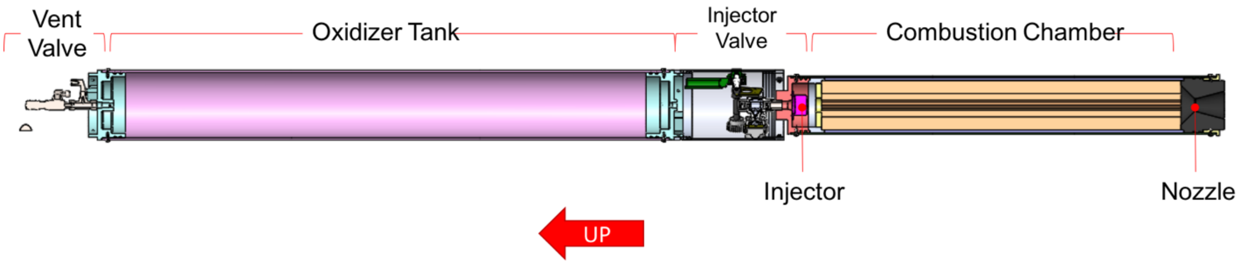


Figure 2. Kismet engine cross section. *A sectional view of the Kismet engine, including detail of the vent valve section, oxidizer tank, injector valve section, injector, combustion chamber, and nozzle. Exterior combustion chamber airframe section and electronics assemblies are not shown.*

1. Oxidizer Tank

The Kismet oxidizer tank has a 6” outer diameter (OD), 3/16” wall thickness, and is 48” long. The tank is sealed on both ends by bulkheads with two Buna-N o-rings. The bulkhead are joined to the tube with twenty-four 1/4”-28 bolts arranged radially, which results in a minimum factor of safety of 2.4 in bearing failure of the tank. A static structural finite element model was used to minimize the mass of the bulkheads, which resulted in the end wall thickness of 3/8”. The tank has been successfully hydrostatically tested to a factor of safety (FOS) of 1.5 times the maximum expected operating pressure of 1000 psi.

There are two SRAD electrically actuated ball valves on the rocket. The main components (the ball valves and DC motors) are commercial off-the shelf (COTS); however, the assembly coupling the motor to the valve is SRAD. This decision was made due to a lack of COTS solutions that adhere to the space requirements for UXO. Static and dynamic stress analysis has been performed for both valve assemblies. The valves both open in approximately 0.3 seconds. CAD of the assemblies can be seen in Figure 3.

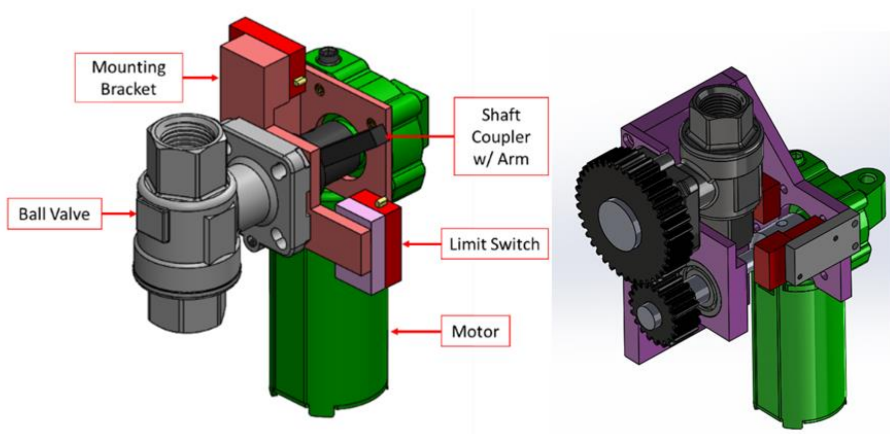


Figure 3. Kismet valve assemblies. *Shown on the left is the assembly for the vent valve, and on the right is the injector valve assembly.*

The first of the two valve assemblies is an SRAD vent valve (shown in Figure 3) located at the top of the oxidizer tank. This valve is used during filling and venting of the oxidizer tank. During fill procedures, the vent valve remains open, allowing air to escape the oxidizer tank as NOS is loaded. In order to limit the amount of NOS in the oxidizer tank, a dip tube is attached to the vent valve. When the liquid level reaches the bottom of the dip tube, a plume will be visible outside of the rocket indicating that the oxidizer tank is filled with liquid to that line. This provides visual confirmation that that the tank is filled to the desired level. Moreover, the dip tube prevents overfilling of the tank, which could result in dangerously high pressures as the NOS expands in desert temperatures. A COTS pressure relief valve set to 1000 psi is mounted to the top bulkhead of the oxidizer tank as a further safeguard against possible overpressurization. When the tank is full, the vent valve is closed. The valve is reopened to vent the tank of NOS in the event of an aborted launch attempt. Oxidizer is loaded into the tank through a port on the bottom bulkhead. This port is connected to fill hoses via a quick disconnect mechanism and has an internal check valve.

The second valve assembly is mounted between the oxidizer tank and combustion chamber, above the injector. It is opened after the primary ignition sequence is initiated, to allow flow of oxidizer into the combustion chamber. This assembly has a gearset, which is used in order to align the center of the valve with the center of the rocket, thereby reducing flow losses.

2. Combustion Chamber

The combustion chamber shell is a 1/8" thick, 5" OD cylinder. Both the top bulkhead and the nozzle are sealed with two Buna-N o-rings. The combustion chamber is insulated with a 1/8" thick G10 fiberglass tube and sealed with flame-resistant caulking on the top and bottom ends. The chamber has a FOS of 2.6 and has been hydrostatically tested to 2.1 times the maximum expected operating pressure of 500 psi.

The fuel used in Kismet is a mixture of 90% HTPB and 10% powdered aluminium by mass. The fuel grain has a pseudo-finocyl grain geometry (Figure 4), achieved through investment casting. Polystyrene is used to create a mould for the port while the fuel is cast inside the liner and is dissolved in acetone after the fuel has solidified.

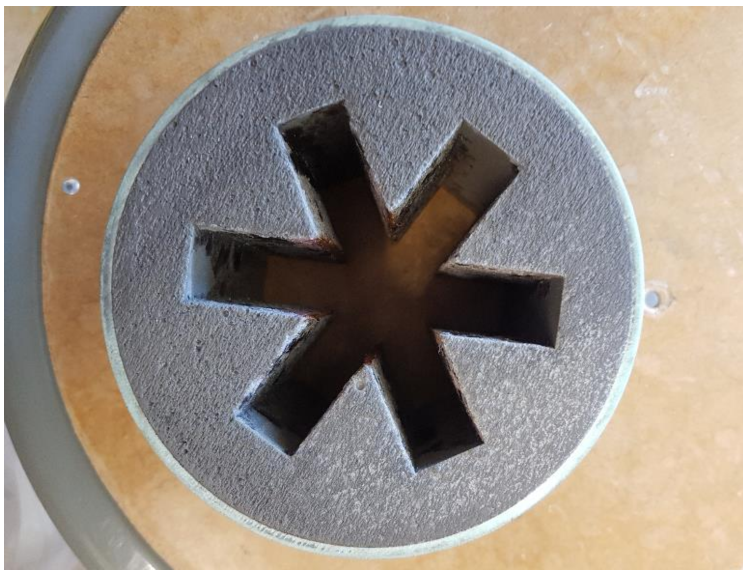


Figure 4. Kismet fuel grain. *The parameters for the pseudo-finocyl grain geometry were empirically determined by the team through numerous static fires.*

Previous combustion chambers designed by the team were lined with ABS, a common thermoplastic polymer. However, as ABS is a plastic, it can act as a fuel itself and is prone to being burned through. In two static fire tests of the team's older Vidar engine, sections of the liner were seen to burn through. Although the liner degradation did not result in damage to the combustion chamber, it was identified as an area in need of development. Research indicated that there were many alternative materials with better thermal properties that were more suitable as chamber liners. Also, by using a material with better properties, a thinner layer can be used for the liner, reducing the overall mass of the rocket.

The most common liners used in hybrid rockets by other teams and enthusiasts are laminate tubes. Laminates have a base material that are bound together with a resin system. Of these laminates, a popular choice is phenolic tubes. These tubes use phenol resin as a binding agent to the base material, which can be paper, cloth, or canvas. The most durable and the material with the best thermal properties is the canvas based phenolic tube, also known as Phenolic CE. Another popular laminate that is used is G10, where woven glass is mixed with epoxy resin. Both Phenolic CE and G10 tubes were tested to determine which material would serve as a better liner for the Kismet combustion chamber.

As both liner materials are ablative, it was necessary that sufficient material to shield the combustion chamber remain at the end of the burn. To test this, an oxy-acetylene torch was applied parallel to the surface of the tube. Both tubes were tested with this method, and had material remaining after 10 seconds. As the liner was not expected to be exposed to direct flame for more than 10 seconds, both materials were deemed sufficient. The second criterion considered was insulation quality. A material is better suited as a chamber liner if it can better insulate the chamber from heat. To test this, thermistors rated for 100 ºC were attached to the inner wall of the tubes, and heat was applied to the outer wall by holding the oxy-acetylene torch perpendicular to the tube. The data recorded is shown in Figure 5.

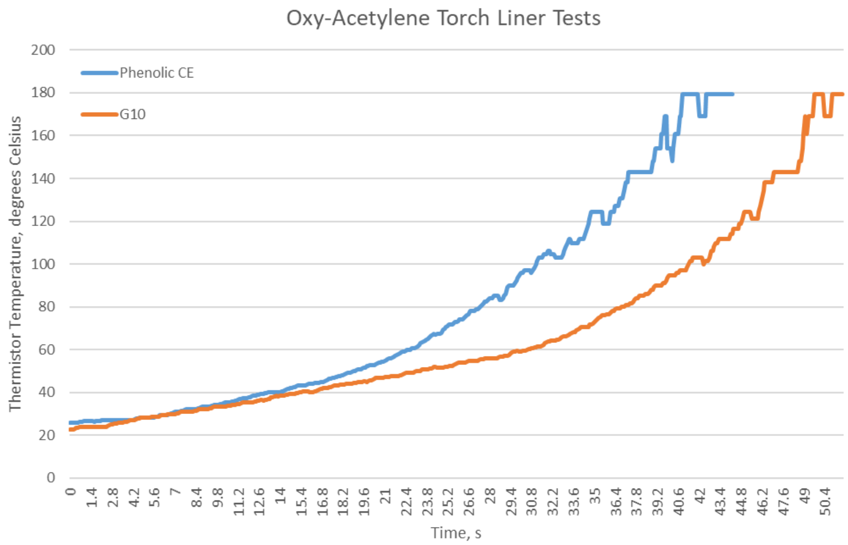


Figure 5. Oxy-acetylene torch liner tests. *This graph displays the recorded temperature at the inside of each liner sample while flame was applied using an oxy-acetylene torch.*

As observed in the graph, the G10 tube took longer to reach 100 ºC, indicating that it would be more effective at insulating the chamber during an engine burn. Therefore, the G10 tube was chosen as the better material for the liner, and was used in the first static fire test of Kismet. The primary objective of the static fire test was to evaluate the performance of G10 liner in a scaled engine burn. The engine burned successfully with the liner remaining intact after the burn (Figure 6). Based on the results of this test, G10 was demonstrated to perform well as a liner and was used for all subsequent fires of Kismet.

Figure 6. Kismet fuel grain after Static Fire 1. *The unburned remaining HTPB can be seen insulating the walls of the liner, while the liner itself remained intact and undamaged following the burn.*

One of the significant failure modes considered for Kismet was yield strength reduction of the 6061-T6 aluminium due to annealing. Annealing can occur due to high temperatures after the engine has been fired, causing a burst failure the next time the engine is used. To analyze this failure mode, temperature measurements of the combustion chamber were taken during each engine test, and hydrostatic testing to a FOS of 1.5 was conducted after each engine test to ensure the combustion chamber shell was re-useable. During the design phase, thermal analysis using ANSYS mechanical was conducted to determine the magnitude and duration of thermal loads on the combustion chamber. Based on the results of design analysis and empirical testing, it was determined that an aluminium boat-tail placed near the nozzle would act as a heat sink and reduce the temperature of the combustion chamber shell significantly enough to avoid annealing.

The nozzle is machined out of graphite and is a linear approximation of a Bell nozzle. It was designed to achieve an optimal expansion ratio, and in conjunction with the injector it was designed to achieve a sufficient pressure drop across the injector. Through testing, it was found that the pressure drop across the injector was approximately 50%. The injector of UXO was designed with the same methodology as the injector of the Vidar engine. To mitigate feed-system coupled combustion instabilities, which can lead to backflow of combustion gases to the oxidizer tank, the aspect ratio (L/D) of the injector orifices is 12. This design promotes vapour formation inside the injector, which chokes the flow of oxidizer across the injector and mitigates feed-system coupled instabilities.[1]

Engine ignition relies on two separate events: heat application via ignition of a puck of solid rocket fuel, and oxidizer flow initiation through opening of the injector valve. The ignition puck is a toroidal disc composed of 70% potassium nitrate (KNO_3) and 30% epoxy, and sits above the fuel grain at the top of the combustion chamber. The puck is cast with two embedded coils of nichrome wire, which connect to wires that exit the chamber through the nozzle. The puck is ignited when current passes through the nichrome coils, causing them to heat up. Once the puck successfully ignites, the nichrome coils break, and the change in current is displayed by the Remote Launch Control System (RLCS). The operator then sends the signal to open the injector valve. Once the valve opens and oxidizer flow begins, thrust ramp of the engine is immediate.

3. Engine Instrumentation

The engine instrumentation system is comprised of three main units: valve control, sensors and instrumentation, and communication. Each unit is controlled by a central microcontroller. An Arduino Nano was selected as the microcontroller board for this project since it is small, simple to use, and has an extensive set of software libraries available. The entire system is powered by a single 2200 mAh lithium polymer (LiPo) battery. A block diagram of the engine instrumentation system can be seen in Figure 7.

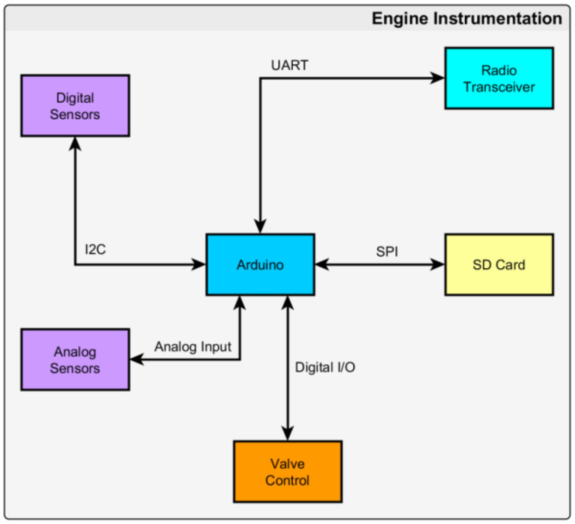


Figure 7. Engine instrumentation. *The engine instrumentation system comprises actuators used to control engine vent and oxidizer flow, sensors for monitoring the fill process, and additional sensors used for flight DAQ.*

There are two instances of the engine instrumentation system present in the rocket. The first is located in the vent section of the rocket and is responsible for controlling the oxidizer tank vent valve and logging oxidizer tank pressure. The second instance of the system is located in the injector section. It controls the injector valve between the oxidizer tank and combustion chamber. It also logs the combustion chamber pressure. Both instances communicate with RLCS and log sensor data.

The control Arduino drives the valves using an H Bridge circuit. The H Bridge provides power to the valve to let it rotate forward or backward depending on which inputs to the H Bridge are active. The current to the valve flows through a pair of limit switches that ensure that power to the valve is cut off when the valve reaches a fully open or closed position to prevent stalling the valve motor. The valve limit switch wiring is shown in Figure 8.

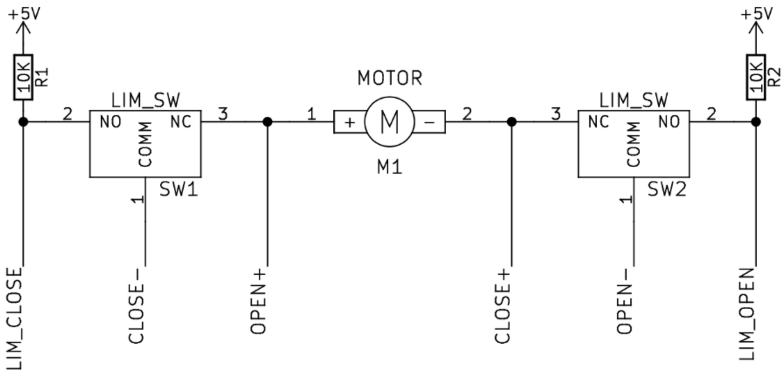


Figure 8. Engine valve limit switch circuit.

The normally open (NO) contacts of the switches are pulled up to 5 V to allow the status of the valve to be read. When the valve is fully open, the NO contact becomes shorted to ground and the valve no longer receives power. The inputs to the H Bridge are pulled up and down appropriately to ensure that the valve turns to reach a safe state if it is not actively driven (for example, if the Arduino becomes inoperational and leaves its digital outputs floating).

The H Bridge is equipped with flyback diodes to protect the circuitry from the inductive spike that occurs when the current path through the motor is cut off. To further protect the electronics, the control software is written so that transistors in series are not switched simultaneously. This prevents "shoot-through" conditions in which power and ground briefly become shorted together.

The instrumentation portion of engine instrumentation records the following sensor data:

- Combustion chamber pressure
- Oxidizer tank pressure
- Pitch, roll, and yaw of the rocket
- Acceleration of the rocket
- Barometric pressure
- Ambient temperature
- Temperatures of various surfaces inside the rocket

These readings are continuously logged and saved to a microSD card.

A variety of gyroscopes, accelerometers, barometers, and magnetometers were considered for the system's sensor suite. The primary consideration was whether the selected sensors would be able to capture enough information to construct a reasonable model of the rocket in flight. Ideally, the system would capture readings for altitude, velocity, acceleration, and attitude independently so that the error of each measurement could be reduced by comparing it to related measurements. Measuring velocity directly proved to be difficult since it required modifications to the airframe. As such, the system measures altitude (derived from barometric pressure and temperature), acceleration, and attitude. The system contains a barometric pressure sensor, an inertial measurement unit (IMU) containing an accelerometer and gyroscope, and an independent gyroscope.

Once the parameters to be measured were established, sensors were selected according to cost, communication mode, voltage level, and physical package. Sensors with analog outputs were avoided due to a shortage of analog inputs on the Arduino. Instead, the selected sensors all communicate over a single I2C bus. While all the selected sensors also have SPI capabilities, I2C was selected because it requires significantly fewer wires, which makes printed circuit board routing much easier. All the selected digital sensors have compatible input voltage ranges and were wired to run on a common voltage level of 3.0 V. The communication signals to and from the sensors pass through a bidirectional shifting circuit to allow the Arduino and sensors to communicate without problems. Finally, each sensor had to be available in a package that could reliably be soldered without industrial tooling.

B. Aero-structures Subsystems

The UXO airframe is constructed entirely from aluminium and fiberglass components. The recovery module, payload module, and combustion chamber are all contained within fiberglass tubes joined with aluminium couplers, while the oxidizer tank has a 6" OD and thus has no additional outer airframe section. The nose cone is a custom fiberglass part, and the fins are constructed from aluminium.

1. Nose Cone

The main purpose of the nose cone is to reduce the form drag of the rocket while protecting the payload and deployment systems. A tangent ogive nosecone with a 4:1 fineness ratio was selected as it minimized simulated drag during the design stage. The nose cone consists of three separate parts: the coupler, the body, and the tip. The coupler permits the nose cone to be attached to the rest of the rocket, while the body provides the main shape and structure and the tip provides an attachment point for the payload parachute.

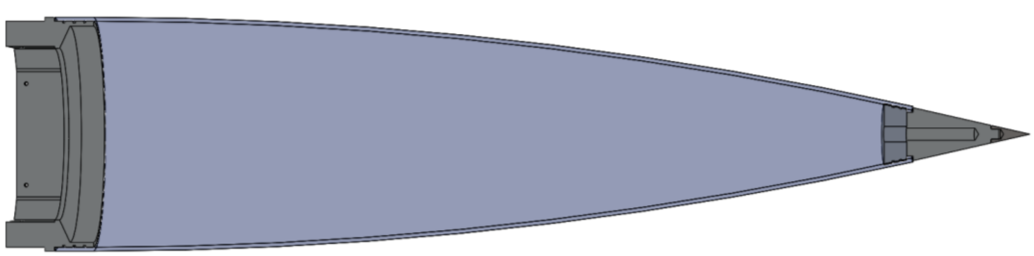


Figure 9. Sectional view of UXO nose cone. *From left to right, the coupler, body, and tip can be seen in this figure.*

The body of the nose cone was manufactured as a single fiberglass composite piece so that it would have the required rigidity and strength while being lightweight and hollow. This required the creation of a 2-part mold CNC-machined from medium-density fiberboard, which was then sealed and waxed. The fiberglass was then cut to shape, laid in the mold, and infused with resin before being vacuum bagged and cured. The final body was then trimmed and sanded to remove any surface imperfections. The tip of the nose cone was machined from 6061-T6 aluminium alloy and 303 stainless steel as it was infeasible to achieve the desired shape with the team's layup process. The coupler was also machined from 6061-T6 in order to attain the necessary strength and geometry required for integration with the rest of the rocket airframe.

The completed nose cone body was tested by applying 68 kgf of compressive force along the longitudinal axis, to simulate the aerodynamic forces during flight, which the nose cone withstood with no issues. The composite resin system is capable of withstanding the temperatures achieved during launch and flight. A drop test was also conducted on the nose cone tip to prove its durability. As a result, there are minimal concerns regarding the possibility of failure of the nose cone.

2. *Fins*

UXO uses a fin can assembly of three through-the-wall trapezoidal fins welded to 6" OD, 13" long, 1/4" thick cylindrical 6061-T6 stock. 6061-T6 was chosen as the material for the fin can components for its good weldability and strength. The fins have a 12" root chord, an 8" tip chord, and a semispan of 7.25". The semispan was constrained to be less than 18" to avoid interference with the launch tower. The fins have a trapezoidal cross-section measuring 1/8" in thickness, with a 45° chamfer on the leading and trailing edge to decrease drag and induce a roll rate. In order to validate that the chosen fin geometry was sufficient to ensure stable flight, simulation was conducted using OpenRocket software with data taken from static engine testing. At liftoff, UXO will have a stability margin of approximately 2.3 cal. This will slowly rise during the flight, reaching 4.5 cal at motor burnout. The rail departure velocity is predicted to be 76 ft/s.

Structural failure of fins caused by aeroelastic flutter is a concern on rockets approaching transonic and supersonic speeds because oscillations in the airflow can couple with the natural elastic properties of the fins to create a positive feedback loop of increasing oscillations in the fins themselves. A fin flutter analysis was performed on the chosen fin geometry by calculating the flutter velocity (the velocity above which the airflow will amplify rather than dampen oscillations in the fin) and comparing it to UXO's maximum predicted velocity. It was calculated that fin flutter would begin to occur at 1763 ft/s, well above the maximum velocity of 688 ft/s predicted by simulation.

The three fins are joined to the can using all-around concave fillet welds. From an aerodynamics perspective, concave fillet welds are preferable over bolted connections because they reduce interference drag by rounding out the sharp angles at the attachment point between the can and the fins. The choice of thickness was influenced by concerns about weld distortion along the fin can. The magnitude of warping in a part due to the thermal stresses created in the welding process depends on many factors, and the thickness of the material being welded is one of them. The 1/4" thickness of the can will reduce the amount of weld distortion, although weld distortion is difficult to quantify without knowledge of the exact welding process.

C. Recovery Subsystems

The UXO recovery system is housed in two adjacent fiberglass tubes joined by aluminium couplers. The lower tube houses UXO's parachutes and recovery lines and is secured to the top of the oxidizer tank vent section with radial bolts. The bottom coupler of the parachute section contains a plate into which an eyebolt is threaded. This eyebolt serves as the primary mounting point for recovery lines. The upper tube houses electronics used for recovery deployment and vehicle tracking. The two recovery sections are connected with mating aluminium couplers and secured with three nylon rivets. These nylon rivets act as shear pins and allow the sections to separate during recovery deployment.

UXO's recovery system uses dual deployment events, deploying a drogue parachute 5 seconds after apogee and a main parachute at 1500 ft AGL. A 5 second delay was selected for drogue deployment to ensure that this event does not interfere with payload deployment. As the payload deployment event occurs at apogee, the 5 second delay decreases the risk that any of the recovery lines will tangle. Drogue deployment is carried out using a carbon dioxide (CO_2) canister-based separation mechanism. A CO_2 canister is mounted into an ejection cylinder that contains an steel cylinder with a sharp point, a small amount of gunpowder, and an electric match. This cylinder is sealed with epoxy, and the electric match is connected to the drogue output terminals of the altimeter. When the altimeter sends the drogue signal, the electric match ignites, causing the gunpowder to detonate and shoot the steel cylinder forward into the CO_2 canister. The sharp point of the cylinder punctures the canister, causing it to eject CO_2 into the parachute section. The increasing pressure inside this section applies a force to the mating recovery electronics coupler, causing the nylon rivets to shear and separating the sections. As the electronics section is pushed away from the rest of the rocket, an attached line pulls the drogue parachute from the parachute section. The drogue parachute has a diameter of 37.5" and slows UXO's descent to a rate of 114 ft/s.

Prior to main parachute deployment, the parachute is secured by a two-ring release mechanism. The release mechanism consists of two interlocking rings secured together by a nylon cord. The cord is secured within a pyrotechnic cutter mechanism. This mechanism is similar to the CO_2 ejection mechanism used for drogue deployment, but uses the pointed cylinder to sever the nylon cord instead of puncture a CO_2 cylinder. Like the drogue ejection mechanism, the pyrotechnic cutter is actuated via electric match; this match is connected to the main output terminals of the altimeter. At 1500 ft AGL, the electric match is detonated, causing the cord to sever and allowing the rings to slip past one another. This allows the main parachute to be pulled from the airframe section by the drag force of the drogue parachute. The main parachute was tested in a wind tunnel at various speeds to determine the drag coefficient. Based on this experimentally determined drag coefficient, the size of the parachute was calculated for a ground hit speed of 29 ft/s. The resulting parachute has a diameter of 142".

UXO uses two COTS altimeters for recovery deployment. Two different altimeters, a PerfectFlite StratoLoggerCF and a Featherweight Raven3, were selected in order to decrease the risk of common mode failures and increase the reliability of the system. Each altimeter is powered by a 9 V battery and armed immediately prior to launch using a magnetic switch actuated from outside of the rocket. Dual redundancy of the deployment system is achieved using two altimeters, two CO_2 ejectors, and two pyrotechnic cutters. Each altimeter is capable of independently triggering each ejector and each cutter, and actuation of one ejector and one cutter is sufficient for deployment. This allows the system to tolerate failure of an altimeter, an ejector, and a cutter, while still resulting in safe recovery.

D. Payload Subsystems

The function of the payload subsystem is to carry a camera and instrument package to an altitude of 10000 feet, deploy it from the rocket, and recover it safely via parachute. The goal of the payload experiment is to evaluate the performance of the deployment mechanism in order to promote future iteration and development of scientific payloads.

The team elected to develop a deployable payload system this year in order to increase the variety of experiments that can be flown in future years. The advantages that a deployable payload has for scientific experiments include exposure to open air, increased time at high altitudes, clear line of sight to ground, and inability to damage launch vehicle in event of experiment failure.

Due to time constraints and uncertainty about deployment system performance, the team did not believe it was feasible or prudent to install a scientific payload in the CubeSat this year. Instead, a technology demonstration CubeSat was developed, and the data collected from it will be used to design scientific payloads to be used with the deployment system in future years.

In order to meet IREC minimum standards and qualify as a functional payload, the payload must:

- Weigh a minimum of 8.8 lb.
- Contain no more than 1/4 of the total payload mass as deadweight.
- Adhere to the CubeStat standard in a 3U form factor.
- Not contain any prohibited materials.
- Adhere to safety critical wiring standards for any recovery elements.
- Adhere to the "Payload Recovery" guidelines outlined in the design, test and evaluation guide.
- Adhere to the "Stored-Energy Devices" standard of the design, test and evaluation guide for our deployment electronics.
- Have a tracking system on board for location following recovery.

Additional constraints on the payload design were determined by UXO architecture. The payload must:

- Fit in a 6" OD airframe section.
- Not interfere with the main UXO recovery system.
- Have the deployment system fail safe.

For the purposes of this section, "fail safe" deployment indicates that a deployment failure does not place the rocket into an unsafe state; that is, if the payload does not successfully deploy, no components of the rocket are ejected without recovery systems or exceed the maximum speed for safe recovery under main parachute.

The payload subsystem consists of three parts: the CubeSat, the deployment system, and the ground system. The CubeSat is mounted in the deployer at the top of the rocket. At apogee, the deployer is triggered and releases the CubeSat from the rocket, where it deploys a parachute and falls back to earth. The arming of the deployment system and collection of payload data is handled by a handheld transponder. A render of the complete system can be seen in Figure 10, and a system block diagram for the payload electrical systems can be seen in Figure 11.

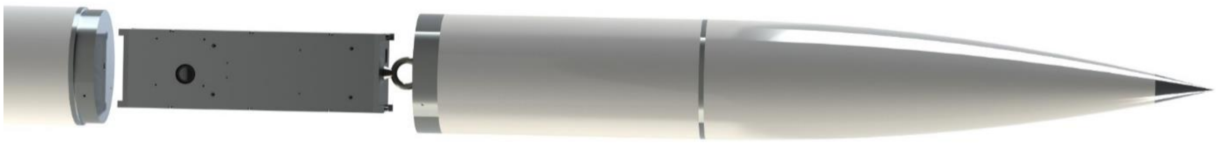


Figure 10. Render of complete payload system. *The CubeSat can be seen at the left of the image. Also visible is the deployment mount (center; airframe tube) and the nose cone.*

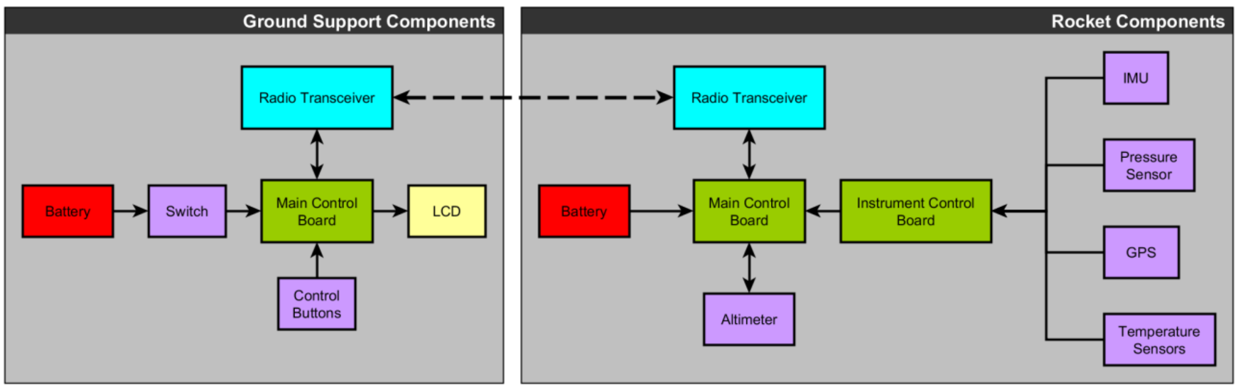


Figure 11. Payload block diagram. *The payload systems comprise a suite of on-rocket sensors and custom PCBs for control and data acquisition, along with a handheld transponder for arming of the payload display of data.*

1. CubeSat

The goal of the CubeSat is to demonstrate the safety and effectiveness of the deployment system in order to justify development of scientific payloads for deployment. To accomplish this, various sensors are installed in the CubeSat. These sensors are:

- Pressure sensor
- Temperature sensors
- Inertial Measurement Units (IMUs)
- GPS
- Ambient light sensor

The CubeSat sensor suite records data during the flight and logs recorded data to an SD card on the instrumentation board. Data is also transmitted once per second to the ground. From this data, the position, altitude, vertical velocity, deployment event characteristics, and landing characteristics can be determined. The CubeSat also contains a GoPro HERO4 Black camera, which records video documentation of the payload's deployment and recovery.

At the 2017 IREC, the team's payload also featured a GoPro camera. Unfortunately, the camera overheated prior to launch and no video footage of the flight was captured. It was theorized that this was a result of the transparent acrylic tube used for the payload airframe, which behaved similarly to the glass walls of a greenhouse. As the airframe for UXO's payload would be non-transparent, overheating was not identified as a major concern. To ensure that the camera could withstand ambient desert temperatures, thermal tests of the payload were conducted. The test procedure consisted of heating the air around the CubeSat housing to 60 °C and determining at what point the camera triggered a thermal shutdown. It was determined that the camera would be able to withstand temperatures of up to 56 °C, and as such was suitable for use in the desert.

The altimeter used by the CubeSat is a PerfectFlite StratoLoggerCF. This altimeter was selected for its relatively inexpensive cost, small footprint, low power requirements, and versatility.

2. Deployment System

The CubeSat initially rests on the top coupler of the recovery electronics section and sits in between eight Delrin rails. Prior to deployment, it is held in place by these rails and the top coupler of the deployment mount section. Above the deployment mount is the nose cone, where the payload recovery system is stored. The deployment mount is attached to the recovery electronics top coupler with three nylon rivets. To trigger payload deployment, the altimeter stored on the CubeSat activates a CO_2 deployment mechanism identical to the one used for UXO drogue deployment. Once the deployment mount has separated from the main body of UXO, the CubeSat is unsupported and falls away from the rest of the rocket. As it falls, the CubeSat pulls the payload parachute from the nose cone. The parachute measures 47” in diameter and slows the CubeSat to a descent rate of 29 ft/s. It was determined that a redundant deployment system was not necessary for CubeSat recovery, as a failed deployment does not place the rocket into an unsafe state; the payload will simply remain attached to and be recovered with the rest of the rocket. UXO’s recovery system is sized such that the rocket will descend at an acceptable rate even if the payload fails to deploy.

During the initial design phase, alternative solutions were considered for the physical deployment mechanism, including the use of a powerful compression spring capable of exerting enough force to shear the nylon rivets. The spring would be held in a locked position by a pyrotechnic bolt that could be sheared using a gunpowder charge to allow the spring to release. This approach was not chosen for several reasons:

- Improper manufacturing of the pyrotechnic bolt could cause premature spring release
- The team was not confident in the ability to develop pyrotechnic bolts safely and reliably
- Compression of the spring for loading into the rocket could not be done in a safe manner

Overall, the team determined that the CO_2 ejection system was more reliable and safer to develop and operate.

In order to test the full payload deployment system, the payload and deployment mount were assembled on a testing rig. A vacuum pump was attached to the pressure equalization hole of the deployment mount and powered on, causing the pressure inside of the deployment mount to decrease. As the StratoLoggerCF is a barometric altimeter, this pressure drop registers as an increase in altitude. In order to simulate apogee, the vacuum pump was powered off, allowing the pressure inside the deployment mount to rise. The StratoLoggerCF interprets this pressure change as a change from increasing altitude to decreasing altitude, and therefore signals that apogee has occurred. All electronic components functioned as intended and the deployment system was actuated successfully.

3. Ground System

The ground system for payload takes the form of a handheld transponder (Figure 12). The transponder is responsible for collecting and displaying data recorded by the payload, as well as arming the payload deployment system prior to launch. The transponder has a radio transceiver, an SD card logger, an LCD screen, and three navigation buttons. The transponder can be used to view any data transmitted by the payload during flight and is used to locate the payload after landing.

Figure 12. Payload transponder. *The antenna for the radio transceiver, LCD, navigation buttons, and potentiometer for LCD contrast are visible.*

E. Ground Support Equipment Systems

The complexity of a hybrid rocket necessitates sophisticated ground support equipment in order to enable safe and efficient launch operations. GSE development makes up a significant portion of the team's activity and requires multiple dedicated members with diverse skillsets. GSE systems can be broadly classified into two categories: the launch tower, and the Remote Launch Control System. Systems that are only used for testing, such as the static engine test DAQ system, are not within the scope of this report.

1. Launch tower

The launch tower is a modular structure consisting of five sections of steel lattice mounted on a base of square steel tubing. When fully erected at an angle of 5° from vertical, the tower reaches a total height of 39 ft. The launch tower provides support for the 1515 aluminium extrusion launch rail, which guides the rocket during the first few seconds of unstable flight. The tower also acts as a mounting structure for other GSE subsystems, including RLCS components.

In order to raise the launch tower to a vertical position (Figure 13), a gin pole assembly is used. The gin pole is a steel arm that is mounted to the base of the tower, perpendicular to the tower axis. A steel cable runs from the end of the gin pole to a cross member midway up the tower, and a separate steel cable runs from the end of the gin pole to a motorized winch away from the tower. When the winch is powered, force is transmitted through tension in the steel cables to the cross member on the tower; this results in a moment about the tower base, causing it to rotate upwards. Once upright, the tower is secured with three guy wires to ensure that any unexpected forces do not cause it to tip. The gin pole assembly is a new system and replaces the previous raising technique, which relied on human operators to lift the tower. The new raising mechanism is significantly safer and faster than the previous technique.

Figure 13. Launch tower raising. *This photo depicts the launch tower as it is being raised. The gin pole can be seen at the base of the tower.*

The launch tower additionally provides mounting features for the remote disconnect mechanism. Due to the nature of hybrid fill operations, it is necessary that a mechanism exist to disconnect the fill line from the engine prior to launch. This is accomplished using a spring-loaded system secured with a two-ring release. The fill adapter, which connects the fill line to the fill port in the oxidizer tank bulkhead, is mounted to an aluminium arm that pivots around a bracket mounted to the tower; the other end of this arm is connected to two tension springs. During fill, the adapter is secured to the fill port with a fabric strap, which is in turn secured with the two-ring release. The release mechanism is locked with a pin that connects to a linear actuator under the control of RLCS. Once fill has concluded, the linear actuator pulls the pin from the mechanism, allowing the strap to release. Pulled by the tension springs, the fill arm pivots away from the rocket and pulls the fill adapter from the fill port.

2. Remote Launch Control System

The Remote Launch Control System is the system that controls all electrical components involved in propellant loading and other preflight actions required to launch the rocket. It allows the launch operations team to conduct launch procedures from a safe distance without placing any human operators in danger. The primary objective of RLCS is to allow the launch system to be operated at a minimum distance of 1 km from the launch tower. Once RLCS takes control of the launch operations, no human intervention should be required (in any possible error state) that requires a human to approach the system. In event of total failure, the system must safe all engine and fill systems so that personnel can approach the rocket without placing themselves in any danger.

RLCS controls the following actuators necessary for fill and engine start:

- The Remote Fill Valve, which controls the entry of NOS into the fill system
- The Line Vent Valve, which opens the fill system to atmosphere in order to vent NOS
- The linear actuator that triggers the remote disconnect mechanism
- Two nichrome coils inside the engine ignition puck
- The Injector Valve, which controls the flow of NOS into the combustion chamber
- The Tank Vent Valve, which allows the oxidizer tank to be vented of NOS

Moreover, RLCS must use sensors to collect the following data, and report that data back to the operator:

- The current state of all valves (open/closed)
- The amount of current flowing through each nichrome coil inside the ignition puck
- The current mass of the rocket, loaded on the rail
- The pressure of oxidizer in the rocket's oxidizer tank
- The pressure of oxidizer in the fill lines
- The pressure of oxidizer in the supply lines

A block diagram of the UXO launch system can be seen in Figure 14.

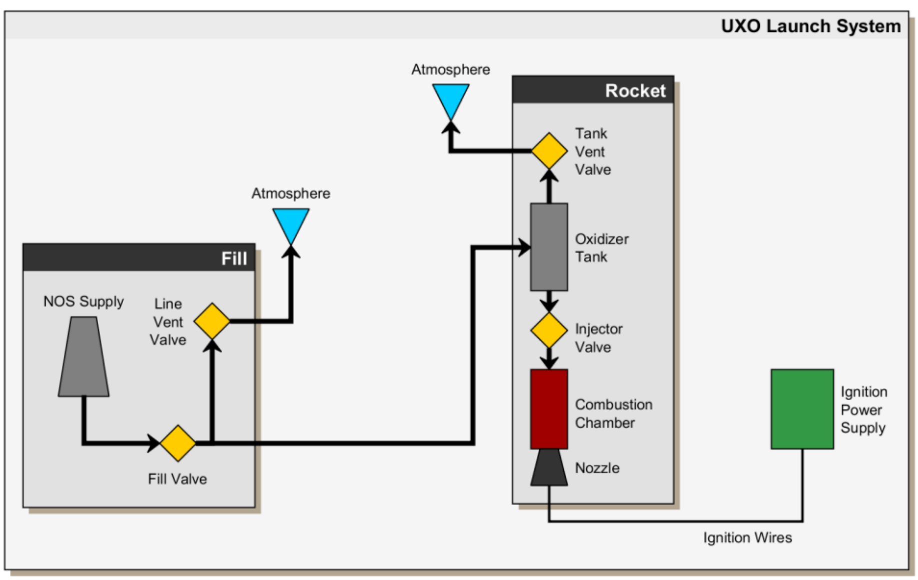


Figure 14. Block diagram of the UXO launch system. *This diagram does not include the manual backup valves on the fill system, the remote disconnect mechanism, or the numerous sensors present in the system.*

RLCS is composed of two parts: the client-side module and the tower-side module. The client-side module provides an operator interface with switches for actuator control and an LCD for displaying system data. The tower-side module controls all actuators necessary to launch the rocket. In addition to controlling the actuators, the tower-side communicates with the engine instrumentation system for control of engine actuators and DAQ. Both modules communicate over a pair of XBee Pro S3B transceivers, both using half dipole antennas with a gain of 3dBi. The tower-side module communicates with flight instrumentation using XBee Series 1 transceivers with small whip antennas. The Pro transceivers operate at 900 MHz while the Series 1 transceivers communicate at 2.4 GHz.

The client-side module LCD, radio transceiver, and switches all connect to an Arduino Mega which runs the core system logic. All switches are connected in series with a key switch to allow the system to be disabled whenever personnel are nearby the rocket. The ignition switch is in series with a momentary pushbutton to remove the possibility of a switch being left in the the "fire" position when the system is first started. The client-side also uses a custom power regulation board. This board is a switching regulator which drops the 11.1 V supply from the battery to 5 V, which can be used by the microcontroller.

The tower-side module controls external actuators through relay boards, which are cutomed designed PCBs that feature a DPDT relay, for changing direction of valves or swapping between ignition circuits, and an SPST relay, for interrupting current to the actuator when it is set to off. The boards also feature current sensors on all actuator outputs, and logic level shifting for the limit switch signals coming off of the valve, dropping the signal from 12 V to 5 V, which the microcontroller can read. The batteries in this module are fused to prevent a fire in the event of a short circuit.

During the design phase of this system, the team considered using higher-powered radio transceivers instead of the 500mW XBee transceivers that were available. By using higher powered transceivers, the risk of communication loss could have been decreased. However, the team elected to continue using XBee Pro transceivers since the safe operating distance of 3000 ft is well within their operational range. Higher-powered transceivers would have required extensive testing and debugging, as well as significantly more power than the system was designed to use.

RLCS is powered by several 2200 mAh LiPo batteries designed for use in RC cars. These batteries were selected due to their low cost, size, and very high energy density. Because of their low cost, the team was able to purchase enough replacements to have a spare for every battery in the system, which relieves the problem of long charge times.

The previous version of RLCS used hand-assembled Veroboard to mount all electrical components. For this revision, all functionality has been moved to custom designed PCBs. This decision was made to ensure higher reliability, increased modularity, and to allow use of components available only in surface mount packages, such as the current sense amplifiers.

III. Mission Concept of Operations Overview

The UXO CONOPS can be divided into eight phases, as seen in Figure 15.

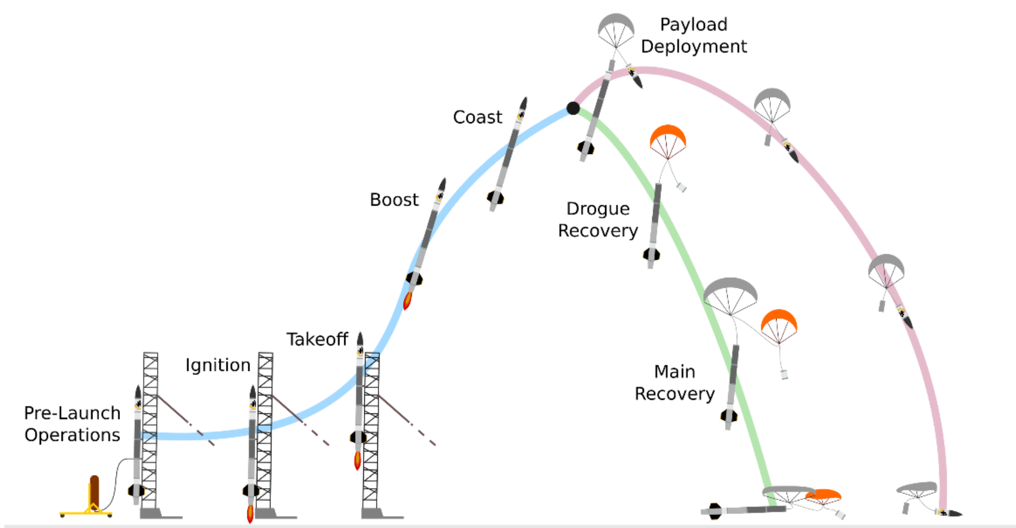


Figure 15. UXO Mission Concept of Operations. *The blue path indicates phases that are common to the main vehicle and the payload, while the green path traces the vehicle's activities after apogee and the pink path traces the payload's activities after deployment.*

The Pre-Launch Operations Phase begins when the launch tower is raised to the vertical position and the launch operations team begins final launch preparations. This phase encompasses payload and recovery system arming, oxidizer fill procedures, and fill arm disconnect. During this phase, RLCS is expected to operate nominally and provide continuous feedback of oxidizer pressure and rocket mass. This phase ends when the fill arm is disconnected and permission is given to proceed to ignition.

The Ignition Phase encompasses ignition procedures of the Kismet engine. It begins when the ignition signal is sent to the primary ignition puck. The puck must ignite successfully. Once puck ignition is confirmed, the injector valve is opened. This phase ends when Kismet ignites and UXO begins to move.

The Takeoff Phase begins at first vehicle motion. UXO begins accelerating along the launch rail and departs the rail with a velocity of 76 ft/s and a static stability margin of 2.3 cal.

The Boost Phase begins once UXO departs the launch rail. The engine continues burning for approximately 16 seconds, accelerating the rocket to approximately 678 ft/s and climbing to an altitude of approximately 10500 ft. At burnout, the stability margin of the rocket is approximately 4.5 cal.

The Glide Phase begins following burnout and lasts for the remainder of UXO's ascent. As the engine is no longer producing thrust, the rocket begins to decelerate. UXO reaches an apogee of 12480 ft at 10 seconds after burnout and 36 seconds after engine ignition. The peak stability margin reached during this phase is 4.6 cal.

The Payload Deployment Phase begins at apogee. The payload altimeter detects that apogee has been reached, and triggers the payload deployment mechanism. The payload module becomes detached from the rest of the vehicle and begins to descend under its own parachute, falling at a rate of 29 ft/s.

The Drogue Recovery Phase begins 5 seconds after apogee. The recovery altimeters detect that the 5 second apogee delay has been completed, and trigger the first deployment event. The parachute section is pressurized with CO_2, causing the nylon rivets to shear and detach the recovery electronics section at the mating coupler. The drogue parachute is pulled out by the force of the deployment event, and inflates, slowing descent rate to 114 ft/s. The main parachute remains restrained by the two-ring release mechanism. The payload continues to descend independently.

The Main Recovery Phase begins when UXO descends to 1500 ft AGL. The recovery altimeters detect that the preset altitude has been reached, and trigger the second deployment event. The pyrotechnic cutters are actuated, severing the strap retaining the main parachute release mechanism. This allows the drag force on the drogue to pull the main parachute out of the airframe. As the main parachute inflates, it slows UXO's descent speed to 29 ft/s. The payload continues to descend independently. This phase concludes once both UXO and the payload have landed.

IV. Conclusions and Lessons Learned

A. Team Management

As the team continues to take on challenging projects and develop increasingly sophisticated systems, the importance of strong project management cannot be overstated. For all current team members, UXO was the first rocket they had worked on that was not an iteration of the Vidar series. The team's approach to development while iterating on Vidar had been to freeze design on most of the rocket's systems and choose only a few per design cycle for focused development. This approach worked very well for iteration and allowed the team to progressively fix issues with Vidar over the course of multiple years. However, when building a new rocket almost entirely from scratch, this is clearly not a feasible approach. In order to ensure that all of the systems and projects being worked on were progressing, not blocked, and would integrate well with each other, the team needed to place more effort on structure and planning than in previous years. Although the team had not previously held weekly meetings, these became necessary to ensure that all Project Leads were aware of the expectations for their project and were progressing well. It became evident midway through the year that meetings alone were not sufficient and a more detailed plan was necessary if UXO were to be completed in time for the 2018 IREC. These changes reflect that Project Leads, as well as the Team Lead, must take increasing responsibility for project management in addition to technical work. Delays that may have only been inconveniences for simpler projects can now mean milestones are missed and other systems begin to fall behind, and every Project Lead must ensure that they are able to communicate effectively with other team members if issues begin to appear.

An additional important lesson is the necessity of always having a team member that is designated as having and is able to take on an overall leadership role. Due to the University of Waterloo's co-op program, engineering students alternate between 4 month academic terms in Waterloo and 4 month work terms across a wide variety of locations. In previous years, Team Leads have retained overall team leadership if they are on work terms that take place outside of Waterloo. However, it became clear over the course of this year that it can be dangerous to assume that the Team Lead will be able to dedicate as much time and effort during their work term as when they are on academic term. In order to ensure that there is always a leader that can keep the team moving and resolve any issues necessary, Team Leads (and Project Leads to a lesser extent) should plan for their work terms as if they will not be able to contribute much to the team during the term.

In developing UXO, all team members maintained an awareness of the importance of knowledge transfer and documentation of work. Senior team members took on fewer critical projects than in previous years, and instead acted in more advisory roles to allow more junior members to develop their technical and project management skills. Frequent design reviews were held for all projects, both to ensure that there were no significant technical issues and to allow junior members to become more familiar with the work the team was conducting.

B. Technical Development

As this year was the team's first in recent memory developing many new systems in parallel, the importance of frequent testing at the component and system level was reinforced. It is essential to test every system for functionality prior to integration testing in order to ensure that preliminary issues are identified before they can affect other systems. However, exhaustive testing at a system level is no substitute for proper integration testing, as there will always be interactions between systems that cannot be characterized without testing.

After static engine testing, the thrust produced by the Kismet engine was originally characterized as significantly higher than in reality. This was due to a calibration error on the load cell used to measure thrust. The importance of proper calibration cannot be overstated, as an incorrect calibration can lead to a major misunderstanding of a system's characteristics. In the case of Kismet, the error was caught soon enough that the team was not prevented from completing design on UXO; however, this will not always be the case. Testing is only significant if there exists a reliable way to characterize test results.

System Weights, Measures, and Performance Data Appendix

Vehicle Parameter	Measurement
Airframe Length (inches):	178
Airframe Diameter (inches):	6
Fin-span (inches):	20.5
Vehicle weight (pounds):	94
Propellent weight (pounds):	40
Payload weight (pounds):	9
Liftoff weight (pounds):	143
Number of stages:	1
Strap-on Booster Cluster:	No
Propulsion Type:	Hybrid
Propulsion Manufacturer:	Student-built
Kinetic Energy Dart:	No

Predicted Flight Data	Measurement
Launch Rail:	Team-Provided
Rail Length (feet):	36
Liftoff Thrust-Weight Ratio:	5.7
Launch Rail Departure Velocity (feet/second):	76
Minimum Static Margin During Boost:	2.3
Maximum Acceleration (G):	3.9
Maximum Velocity (feet/second):	678
Target Apogee (feet AGL):	10000
Predicted Apogee (feet AGL):	12480

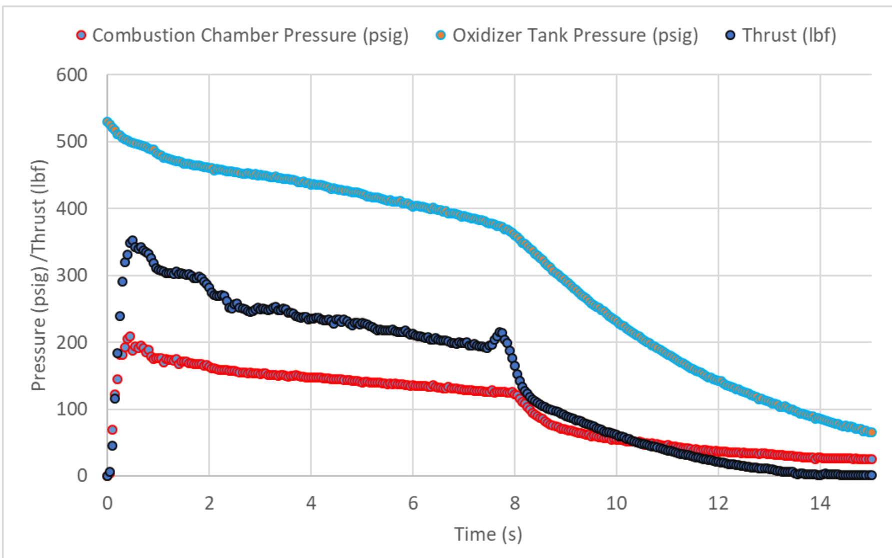
Date	Type	Description	Status	Comments
1-20-18	Ground	Cold flow engine test	Successful	Injector validation with CO_2
2-25-18	Ground	Static Fire	Successful	Scaled burn for functional test
3-17-18	Ground	Payload deployment test	Successful	Test of deployment mechanism
3-17-18	Ground	Static Fire	Successful	Full length burn for performance test
5-26-18	Ground	Wet Dress Rehearsal	Minor Issues	Propellant loading/off-loading test; minor issues with launch control system
5-30-18	Ground	Recovery deployment test	TBD	Ground test of deployment mechanism
6-2-18	Ground	Wet Dress Rehearsal	TBD	Validation of launch operations

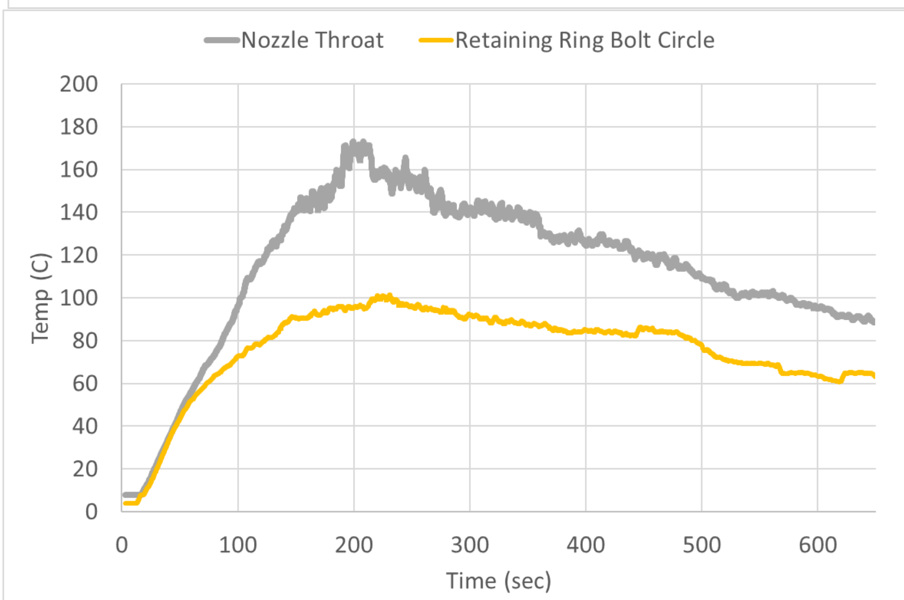
Project Test Reports Appendix

The oxidizer tank was hydrostatically tested to 1500 psi for 2 hours. Since the pressure relief valve on the tank will be set to 1000 psi at competition, this corresponds to a hydrostatic test at a FOS of 1.5 times the maximum operating pressure. The maximum operational time of the oxidizer tank was identified as 1 hour, which is the amount of time it would take to vent the oxidizer if the launch attempt had to be aborted. For this reason, the tank was hydrostatically tested for 2 hours, which is equal to twice the maximum operational time.

A hydrostatic test was performed on the combustion chamber to 1050 psi (FOS of 2.1) for 2 minutes. Since the tank is not able to be hydrostatically tested with the nozzle in place, an end cap was made to sit in the nozzle's position and seal the tank. During engine testing, the measured pressure drop across the injector was 50%; therefore, the maximum operating pressure of the combustion chamber was determined to be 500 psi. The combustion chamber is in operation for less than 1 minute, during the engine burn, so the tank was hydrostatically tested for 2 minutes, which is equal to twice the maximum operational time.

Static Fire 1 of the Kismet engine was conducted on February 17, 2018. For this test, the oxidizer tank was filled half full. The purpose of this test was to obtain data on the engine's performance while limiting the risk of failure due to thermal loading. The results are shown below:

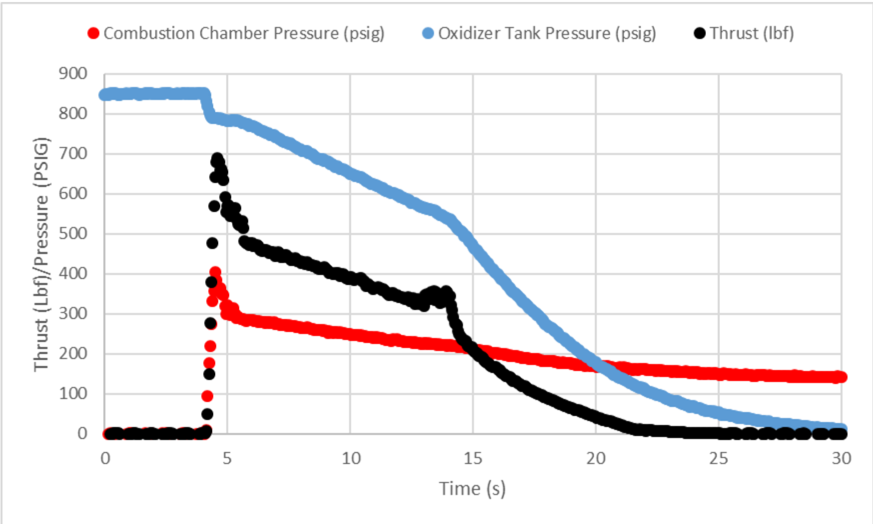


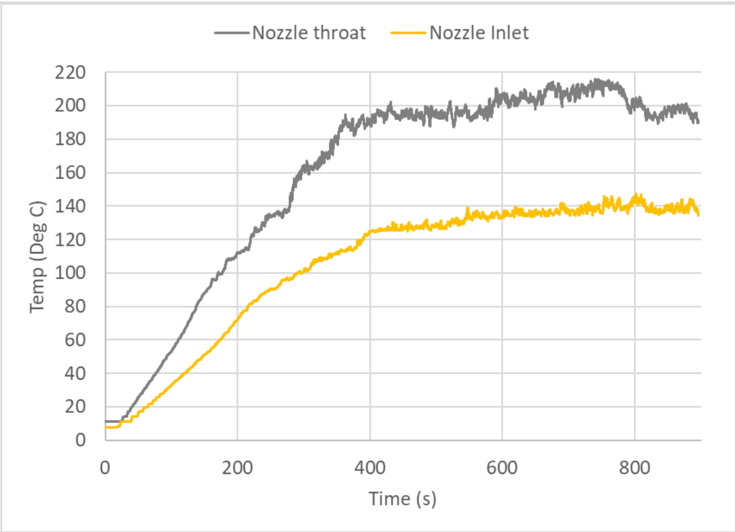


It is apparent that the combustion chamber pressure tap became clogged sometime during the test; however, it is realistic to assume that the pressure at the start of the burn was correctly measured. Since this test was conducted at low temperature, the oxidizer pressure and also the thrust are lower than expected at competition. Changes that were made based on this test were:

- Modification of the fuel grain geometry to achieve a higher peak thrust and lower the O/F ratio
- Addition of an aluminium boat-tail in order to reduce the post firing temperature of the combustion chamber shell at the nozzle throat (in order to avoid annealing)

Static Fire 2 was conducted on March 24, 2018. For this test, the oxidizer tank was fully filled, and was heated to 25 °C via a water jacket to simulate the tank temperature expected at competition. The purpose of this test was to validate the engine design, and to obtain thrust and oxidizer mass flow measurements for flight simulation. The results are shown below. It should be noted that similar to SF1, the combustion chamber pressure tap became clogged sometime during the test.

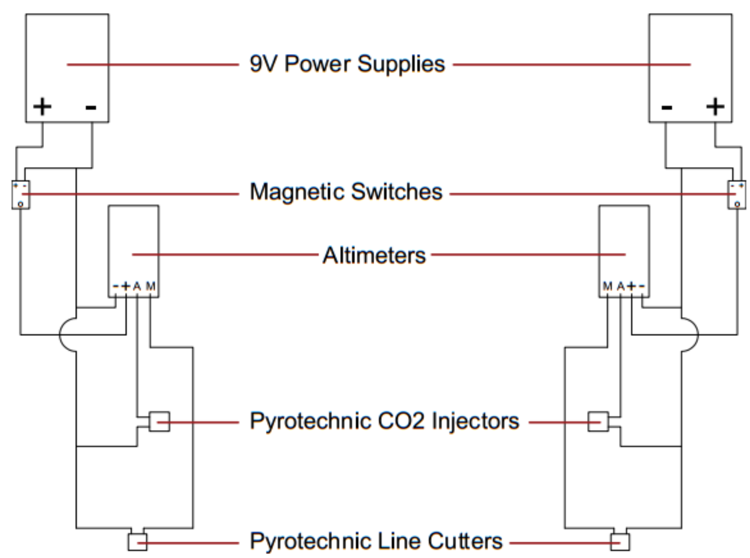




A summary of the important measured parameters from the two tests is shown below. The engine's combustion efficiency was very low, and this was discovered after the two tests had been performed, when the team properly calibrated the load cell that measures the thrust of the engine. The calibration was performed with an Instron compression testing machine and a setup as close to static fire configuration as possible.

Parameter	SF1	SF2	Target
Oxidizer/Fuel ratio	3.7	4.3	2.5 - 4
Pressure drop across injector	50 – 60%	50 – 60%	> 30%
Peak thrust	350 lbf (@ 7°C)	700 lbf	> 700 lbf
Fuel burnt	40% of grain	70% of grain (6.7lbs used, 3.0 lbs left)	N/A
Oxidizer used	47% of full tank	100% of full tank	N/A
Impulse	28% of target (2210 lb*s or 9830 N*s)	63% of target (4950 lb*s or 22040 N*s)	35000 N*s
Efficiency $(\frac{isp_{actual}}{isp_{ideal}})$	60%	60%	90%

Ground tests of the recovery mechanisms were performed on June 1, 2016, in Vidar recovery configuration. The recovery module was assembled, complete with pyrotechnics and parachutes, and laid out horizontally. The Raven altimeter was programmed through Featherweight software to simulate an ascent, apogee, and descent. At 5 s after simulated apogee, the CO_2 canisters were punctured, separating the avionics module from the recovery module. At a simulated altitude of 1500 ft AGL, the pyrotechnic cutters were actuated, allowing the three-ring release to deploy. The drogue chute was pulled away from the recovery module, pulling the main parachute from the fiberglass tube and thus verifying successful pyrotechnic actuation. A further test was performed on May 19, 2017, confirming that both the CO_2 canisters and pyrotechnic cutters were functional. A full deployment test in UXO configuration is planned for May 29, 2018.



The controller used for the recovery system are commercial Featherweight Raven and PerfectFlite StratoLoggerCF altimeters. These units are used in parallel to control recovery deployment mechanisms. The two controllers use independent circuits with separate power supplies and switches. Each controller is capable of actuating both CO_2 canisters and both pyrotechnic line cutters even if the other controller fails.

A payload recovery system deployment test was conducted on March 17, 2018. This was a ground test using a vacuum pump to lower the pressure of the module, simulating an increase in altitude for the barometric altimeter. Removing the vacuum and allowing the pressure to increase simulated a decrease in altitude, thus causing the altimeter to send the drogue deployment signal. This was connected to a CO_2 ejector mechanism, and resulted in successful separation of the payload module from the rest of the rocket.

Hazard Analysis Appendix

Kismet uses nitrous oxide as a liquid oxidizer. Among the commonly used hybrid oxidizers, NOS is usually regarded as the safest. However, NOS is a general anesthetic and can be dangerous to personnel if inhaled. Moreover, evaporating NOS can result in significant low temperatures, potentially causing frostbite or other injury. It is therefore of the utmost importance that personnel not come into contact with liquid or gaseous oxidizer. To mitigate the dangers posed by NOS, the team takes significant precautions whenever oxidizer must be handled.

Nitrous oxide is stored in the team's workspace, kept in the original supply cylinders. These cylinders are stored upright and chained to mounts on the wall. They are never removed from these mounts unless required for a test fire or for weighing. Supply cylinders are secured to a wheeled cart using chains for localized transportation between storage and the team's static test location. The team does not transport NOS to remote test locations.

As the cylinders used by the team are non-siphoning, they must be inverted in order to decant liquid NOS. For this purpose, the team has designed a tank inversion fixture, made from welded steel tube. The NOS supply cylinder is moved from the wheeled transport cart, laid horizontally in a frame on the tank inverter, and secured using a steel bracket and a ratchet strap. Once the cylinder is secured, the frame is lifted, rotating the cylinder 90° to invert it. The frame is secured using two locking pins.

Any personnel that will be near NOS supply lines during fill procedure are required to wear Personal Protective Equipment (PPE). For NOS, this includes safety glasses, face shields, and shop coats to protect any exposed skin. In addition, any personnel operating valves for NOS are required to wear cold-resistant gloves.

As HTPB is non-toxic, no special procedures or equipment are required for handling Kismet's solid fuel. However, during the fuel casting process, the presence of aluminium powder requires precautions. Aluminium is kept in an ammunition box, which is only opened after the required safety criteria are met. Fuel casting is always performed in a well-ventilated area, and personnel are required to wear safety glasses, respirators, and gloves. In addition, a Class D fire extinguisher is always present, in order to extinguish any fires resulting from accidental ignition of aluminium powder.

The pyrotechnic materials used in the ignition, recovery, and payload subsystems also require precautions to be taken. Gunpowder and KNO_3 are both stored in separate ammunition boxes to prevent accidental spills or exposure. As gunpowder is not absorbed through the skin, gloves are not necessary. However, personnel are required to wear safety glasses and thoroughly wash their hands after handling gunpowder. KNO_3, used in the ignition puck, fuse, and pellet, requires personnel to wear safety glasses, gloves, and respirators, and can only be used if a fire extinguisher is present.

Due to the danger inherent in firing a rocket engine, the team takes significant precautions during static tests. Prior to beginning fill procedure, a perimeter around the test location is established and secured, to prevent others from accidentally coming too close to the engine. Additionally, two blast shields are erected to protect all personnel involved. The first blast shield is placed around the combustion chamber in case of accidental explosion, while the second is placed a distance away from the engine and used for cover by the primary and secondary technicians during testing. All personnel witnessing the test are required to remain a safe distance away and to wear safety glasses and industrial hearing protection.

Risk Assessment Appendix

Waterloo Rocketry Team	UXO	28-May-18		
Failure Mode	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Pre-Launch Operations				
Rocket ignites during launch preparations, causing injury to surrounding personnel	Premature activation of ignition circuit	Low; solid rocket fuel requires presence of liquid oxidizer to ignite.	Ignition circuit requires activation of an emergency stop, manual depression of ignition button for several seconds, and independent actuation of injector valve.	Low
			Rocket and power supply are not connected to the ignition circuit until immediately prior to fill.	
Rocket falls from launch rail during launch preparations, causing injury to surrounding personnel	Stopping mechanism fails to support the weight of the rocket	Low; rail stops are rated for >200 lb load compared to rocket weight of approximately 100 lb. Rail buttons are not load-bearing.	Tower is raised with rocket on top, with the tower structure and gin pole supporting the rocket during erection.	Low
	Rail buttons rip out of bulkhead		Launch rail is kept level to avoid stress on rail buttons.	
			All personnel involved in launch tower erection are to wear hard hats.	
Recovery system deploys during launch preparations, causing injury to surrounding personnel	E-matches fire prematurely	Low; carbon dioxide canisters only rupture under significant force from the recovery bullet.	Avionics are only to be armed using magnetic switches once final assembly and launch preparations are complete.	Low
	Carbon dioxide canisters are ruptured			
Nitrous oxide escapes from the supply plumbing during fill procedure, causing freezing of body parts, unconsciousness, or other bodily harm	Leaks in valves, fittings, or hoses	Low; all plumbing components have been tested without failure and have adequate factors of safety. Check valve is rated to well over expected operating pressure.	Visually inspect all plumbing components during assembly.	Low
	Premature activation of remote disconnect system		Remote disconnect system requires power supply connection and activation of arming switch.	

	Failure of oxidizer tank check valve		During remote fill procedure, all personnel are to remain well away from supply plumbing. Manual fill procedure (if necessary) is to be performed by only two technicians clothed in appropriate PPE.	
	Fill line does not adequately depressurize upon disconnect		Personnel are to remain well away from fill line following disconnect and prior to launch.	
Explosion of oxidizer tank during fill procedure with blast or flying debris causing injury	Overpressurization due to clogging of the vent	Low; permanent vent hole provides pressure relief.	Cover all open ends of plumbing during assembly, only uncovering before launch.	Low
	Oxidizer tank fails to hold normal operating pressure		Oxidizer tank is designed to rupture laterally instead of radially, minimizing flying debris.	
			Oxidizer tank is pressure tested to 1.5x expected maximum operating pressure.	
Rocket ignites during fill procedure, causing injury to nearby personnel	Premature activation of ignition circuit	Low; ignition circuit is designed to minimize the possibility of accidental ignition.	All personnel are to remain well away from the rocket during fill procedure.	Low
			Ignition circuit requires activation of a key switch and an emergency stop button prior to arming.	
			Ignition circuit is not armed until launch personnel receive confirmation from range safety personnel.	
Ignition Phase				
Rocket does not ignite when command is given ("hang fire"), but does ignite when team approaches to troubleshoot	Primary igniter is activated, but gives no visual confirmation	Low; rocket ignition relies on continuous delivery of current over several seconds. Primary igniter produces a great deal of smoke for visual confirmation of successful ignition.	LCD on RLCS indicates that ignition circuit is active; personnel are not to approach the rocket during this time.	Low
	Electrical ignition signal is delayed		All ignition control systems are to be disarmed prior to approach by launch personnel.	
Takeoff Phase				
Rocket deviates from nominal flight path at takeoff and comes into	Failure of launch tower components	Low; simulated off-the-rail velocity is 78 ft/s,	Thoroughly inspect all launch tower	Low

contact with personnel at high speeds		resulting in acceptable stability.	components before assembly.	
	Unexpectedly low off-the-rail velocity resulting in low stability		Direct launch tower away from the campsite.	
Explosion of combustion chamber or oxidizer tank during engine burn with blast or flying debris causing injury	Backflow of gases from the combustion chamber into the oxidizer tank	Medium; engine has not been tested in flight or static tested in Spaceport America New Mexico weather conditions. Backflow, nozzle clogging, or fuel grain inhomogeneity have not been observed during static test fires. Engine components are designed with high factor of safety.	Injector has been designed for 50% pressure drop to minimize the chances of backflow.	Low
	Clogging of the nozzle due to bundled ignition wires		Use minimal, thin, ignition wires.	
	Fuel grain inhomogeneity, causing breach of ABS tubing or clogging of nozzle		Adhere to fuel casting procedure and visually inspect fuel grain prior to assembly.	
	Failure of hex bolts used to connect bulkheads, oxidizer tank, and combustion chamber		All personnel should remain well away from the launch pad during launch procedures.	
			Oxidizer tank and combustion chamber are designed to rupture laterally instead of radially, minimizing flying debris.	
	Failure of O-ring seal		Two O-rings are used for redundancy.	
Boost Phase				
Explosion of combustion chamber or oxidizer tank during engine burn with blast or flying debris causing injury	Identical to entry in *Takeoff Phase*			
Rocket deviates from nominal flight path during engine burn and comes into contact with personnel at high speeds	Unexpectedly high winds	Low; simulated rocket flight with high winds did not experience significant deviation.	Design fins to maintain a stability margin of between 2.3-4.5 cal throughout flight.	Low
	Damaged tail fins		Ensure the tail fins are unobstructed during ascent on the tower.	
			Ensure all participants are aware of the launch and can take cover if necessary.	
Coast Phase				

Rocket deviates from nominal flight path during engine burn and comes into contact with personnel at high speeds	Identical to entry in *Boost Phase*			
Payload Deployment Phase				
Payload parachute fails to deploy, payload comes in contact with personnel	Tangling or catching of payload parachute on structural systems	Low; minimal lines are used, ground testing has been performed on deployment system	Ground test all decoupling systems prior to launch.	Low
			Ensure all participants are aware of the rocket’s position and are able to avoid it if necessary.	
Drogue Recovery Phase				
Drogue chute fails to deploy, rocket comes in contact with personnel	Failure of altimeters	Low; altimeters are commercial components, and two are used for redundancy.	Ground test all decoupling systems prior to launch.	Low
	Insufficient pressure in the recovery bay to break shear bolts		Ensure all participants are aware of the rocket’s position and are able to avoid it if necessary.	
Main parachute deploys at or near apogee, rocket drifts into unexpected area	E-matches fire unintentionally	Low; avionics have been thoroughly tested in a vacuum chamber, 2-ring system is rated to well above expected stress	Ground test all decoupling systems prior to launch.	Low
	2-ring system breaks under load when the drogue is deployed		Check rings for signs of wear prior to launch.	
Main Recovery Phase				
Main chute fails to fully deploy, rocket comes in contact with personnel	Failure of altimeters	Medium; line tangling has not been tested, outcome is uncertain	Ground test all decoupling systems prior to launch.	Low
	2-ring system fails to decouple the avionics bay and booster, main chute does not deploy		Use a commercial pyrotechnic cutter to decouple the 2-ring system	
	Drogue chute lines tangle with main chute lines		Ensure all participants are aware of the rocket’s position and are able to avoid it if necessary.	
Rocket airframe separates into multiple assemblies, components come into contact with personnel	Failure of recovery lines, resulting in component freefall not slowed by main parachutes	Low; all recovery lines used are designed for use with parachutes	Ensure all participants are aware of the rocket’s position and are able to avoid it if necessary.	Low

Assembly, Preflight, and Launch Checklists Appendix

The following pages contain checklists for assembly, preflight setup, and launch operations.

Sanitation Procedures

<u>Equipment and Materials</u>

- Hand tools for component disassembly
    - Screwdrivers
    - Tweezers
    - Cups
    - Small, clean trays
- Toothbrush for small components
- Larger pipe brush for oxidizer tank
- Deionized water
- Simple Green cleaning solution
- Ziploc bags (both large and small)
- Clean plastic cups (for cleaning solution and water)
- Aluminium foil
- PPE equipment as noted above
- Hose and component plugs/caps
- Table cover (plastic or parchment sheet to prevent dust)
- Paper towel
- Sieve
- Storage Box lined with plastic drop sheet (for storage of cleaned components)

<u>Cleaning Procedure by Component Type:</u>

Oxidizer Tank

1. Rinse loose dirt/dust off of outside and inside of oxidizer tank using tap water.
2. Prepare 1/3 to 1/2 bucket of diluted cleaning solution, as per manufacturer instructions.
3. Using pipe brush and bucket of Simple Green cleaning solution placed inside the sink, scrub the inside of the oxidizer tank for 15 minutes. Be mindful of even coverage and use a cup or similar to frequently coat the inside of the tank with cleaning solution.
4. Rinse the tank, bucket, and brush thoroughly with tap water for at least 5 minutes. The tank should receive the most care.
5. Use a small quantity of deionized water to rinse the inside of the oxidizer tank.
6. After previous step (rinsing with deionized water), the inside of the tank should NOT contact any other material (i.e. paper towel). Shake the tank to remove excess water.
7. Dry interior of tank with compressed air.
8. Place covering on either end of the oxidizer tank and the hose (ie Ziploc bag or similar), and secure using rubber bands or similar.
9. Store tank in a safe location.
10. Attach label to the tank indicating date/time of cleaning, and by whom.

Hoses

1. Remove residual Teflon tape or other debris from hose ends.
2. Prepare 1 cup of Simple Green cleaning solution.
3. Pour cleaning solution through hose, catching at the other end with another cup.
4. Repeat three times.
5. Repeat step 3 with deionized water until the water is clear when exiting the hose.
6. Use compressed air to flush hose of excess water for 5 minutes.
7. Cap/plug hose ends, label hose (date/time cleaned and by whom), and store safely.

Valves

1. Rinse away loose surface dust/dirt using tap water.
2. Prepare roughly a cup's worth of cleaning solution as per manufacturer instructions.
3. Disassemble valve with reference to the manufacturer specifications, being careful to document reassembly instructions and to not lose components.
4. Clean each component thoroughly using a toothbrush and cleaning solution.
5. Rinse components in tap water using a sieve.
6. Rinse components in a small quantity of deionized water.
7. Dry components with compressed air.
8. Reassemble component.
9. Cover open ports on component with aluminium foil.
10. Place component in Ziploc bag. Label (date/time cleaned and by whom), and store safely.

Fittings and Miscellaneous small components

1. Rinse away loose surface dust/dirt using tap water.
2. Prepare roughly a cup's worth of cleaning solution as per manufacturer instructions.
3. Clean each component thoroughly using a toothbrush and cleaning solution.
4. Rinse components in tap water using a sieve.
5. Rinse components in a small quantity of distilled water.
6. Dry components with compressed air.
7. Wrap components with aluminium foil.
8. Place component in Ziploc bag. Label (date/time cleaned and by whom), and store safely.

Sensors / Gauges

1. Ensure that the sensor can be cleaned using the materials prescribed (sensor dependent). Modify following procedure accordingly.
2. Prepare roughly a cup's worth of cleaning solution as per manufacturer instructions.
3. Rinse away loose surface dust/dirt using tap water.
4. Clean each component thoroughly using a toothbrush and cleaning solution.
5. Rinse components in tap water using a sieve.
6. Rinse components in a small quantity of deionized water.
7. Cover open ports on component with aluminium foil.
8. Place component in Ziploc bag. Label (date/time cleaned and by whom), and store safely.

Bulkheads

1. Rinse away loose surface dust/dirt using tap water.
2. Prepare roughly a cup's worth of cleaning solution as per manufacturer instructions.
3. Clean each component thoroughly using a toothbrush (or other appropriate tool) and cleaning solution.
4. Rinse components in tap water.
5. Rinse components in a small quantity of deionized water.
6. Use compressed air to remove large water droplets.
7. Wrap component with aluminium foil.
8. Place component in Ziploc bag. Label (date/time cleaned and by whom), and store safely.

Engine Assembly Procedures

Ignition Wiring

- Connect a 2' length of 24-gauge speaker cable to each nichrome wire embedded in the ignition puck
- Secure the connection with heat shrink (**not** electrical tape)

- Ensure continuity in each circuit with a multimeter

Combustion Chamber

Notes:

- Do not assume anything is sanitized
- Ensure tools used to handle sanitized parts are also sanitized
- Use clean gloves for installation to avoid contamination
- Keep all parts and assemblies clean throughout the assembly process

Procedure:

- Remove any old o-rings
- Ensure injector and upstream portion of bulkhead is sanitized (ref. Sanitation Procedure)
- Install injector o-ring on injector bulkhead
- Bolt injector to bulkhead
- Install external o-rings on injector bulkhead
- Install o-rings on nozzle
- Place nozzle on retaining ring
- Wrap o-rings securely with painter's tape to keep clean
- Apply caulking to female lip of fuel grain
- Apply a small amount of caulking to male end of nozzle
- Join fuel grain and nozzle
- Clean excess caulking
- Remove tape
- Place bolt hole plugs into the nozzle end of combustion chamber tube, ensuring they protrude to the surface of the tube. Secure into place with rubber band
- Slide combustion chamber tube over fuel grain assembly and bolt into place, checking for ripped o-rings
- Slide ignition wiring down the fuel grain and out the nozzle
- Caulk male end of fuel grain and female end of spacer
- Attach spacer to fuel grain
- Loop the ends of the ignition wire to the surface of the tube and tape
- Cover the nozzle end of the assembly
- Place bolt hole plugs into the injector end of combustion chamber tube, ensuring they protrude to the surface of the tube. Secure into place with rubber band
- Caulk male end of spacer and female end of injector bulkhead
- Slide injector bulkhead onto combustion chamber assembly
- Remove bolt hole plugs, and install bolts, checking for ripped o-rings

Oxidizer Tank

Notes:

- Do not assume anything is sanitized
- Use gloves for installation to avoid contamination

Procedure:

- Sanitize everything that will contact oxidizer (ref. Sanitation Procedure)
- Put check valve on bottom oxidizer bulkhead, make sure the arrow on it is pointed upwards to allow the flow going inside the oxidizer tank
- Record the dip tube length and insert it on top oxidizer bulkhead
- Install o-rings
- Place bolt hole plugs into one bottom of tank, secure into place with rubber band

- Ensure that the plugs do not protrude into the tank
- Slide bottom oxidizer bulkhead into place, ensuring the holes align while inserting
- Remove plugs and bolt injector bulkhead into place, checking for ripped o-rings
- Place bolt hole plugs into holes on the top side of the tank, secure and check for protruding plugs
- Align top bulkhead such that the vent port is aligned with the fill port
- Slide top bulkhead into place, ensuring the holes align
- Remove plugs and bolt vent bulkhead into place, checking for ripped o-rings

Recovery System Setup Procedures

Inspection

- Ensure all components are undamaged
- Ensure that all pyrotechnics and batteries are disconnected and shorted before starting

Wiring

- Ensure that all pyrotechnics and batteries are disconnected and shorted before wiring
- Check that all circuit components are properly mounted to the sled with proper spacers, screws, and nuts
- Ensure all switches are in the energized position
- Check continuity between batteries and altimeters
- Turn all switches to the non-energized position
- Check batteries for full capacity (nominal 9 V)
- Install batteries correctly in battery holders

CO_2 System Installation

- Ensure all ejection device wires and batteries are disconnected from the electronics bay before proceeding
- Ensure the two CO_2 ejection devices are installed into the bulkhead
- Install two 38 gram CO_2 cylinders into the ejection devices, using two washers to ensure CO_2 vent holes are unobstructed. Use Teflon tape on the threads of the CO_2 cylinder when connecting

GPS System

- Ensure GPS battery is fully charged
- Ensure GPS is functional after connecting battery
- Turn GPS system off by waving magnet over the magnetic switch

Sled Installation

- Ensure all wires are tucked away to prevent pinching during installation
- Ensure the CO_2 cylinders are installed into the CO_2 ejection device
- Ensure that the batteries are installed in the battery holder
- Slide the sled onto the central threaded rod
- Connect the altimeters to the circular connectors using the screw terminals
- Check continuity between recovery bay connector pins and altimeters

CO_2 Ejector Setup

- Place igniter and wires inside igniter cylinder and center igniter in cylinder using tissue paper
- Place epoxy on igniter wires so that when the igniters are pulled, the wires do not pull out of the igniter cylinder
- Ensure igniter is placed so that it is flush with the rim of the cylinder that touches the puncturing cylinder
- Place aluminium foil on the working surface
- Place a separate piece of aluminium foil on the working surface for holding and pouring the gunpowder
- Place avionics assembly on the first aluminium sheet with the injector body opening upwards such that the entire body is grounded
- Place O-ring on puncturing cylinder and lightly lubricate with spray silicone lubricant making sure to wipe off excess lubricant
- Place puncturing cylinder in injector body
- Fill puncturing cylinder to the rim with FFFF gunpowder
- Ensure igniter leads remain shorted
- Place O-ring on igniter cylinder and lubricate
- Place igniter cylinder on top of puncturing cylinder and push down until igniter cylinder is flush with injector body
- Ensure gunpowder vent holes are clear of obstructions and cover lightly with masking tape
- Run igniter wires through body cap and screw cap on tightly
- Check for movement of the igniter wires
- If moving, take apart and reseat igniter so that it is seated firmly in place

Pyrotechnic Cutter Setup

- Slide an O-Ring into the bottom of the cutter to act as a bumper for the piston
- Insert recovery dual ring rope through the hole of the cutter
- Trim excess rope
- Insert shearing piston
- Insert black powder
- Insert E-match
- Install o-rings to act as seal
- Slide hex screw over E-match leads and screw into cutter

Parachute Section Assembly

- Ensure that all recovery lines are free and not tangled
- Ensure that the 9 V batteries are disconnected
- Fold the main parachute, gore by gore, in an accordion-style pattern
- Fold the main parachute vertically in half
- Roll the main parachute from the top towards the main parachute lines
- Pack the rolled parachute into the parachute bag so that the main parachute lines extend from one of the open corners
- Secure the main parachute lines over the parachute bag cover using the elastics
- Use the carabiner to connect the main parachute line to the main coupling line
- Connect the two-ring release mechanism and secure using the dual ring rope

- Secure the pyrotechnic line cutters to the primary recovery line using electrical tape
- Connect the pyrotechnic leads to the connectors on the primary recovery line
- Secure the drogue parachute line to the base of the avionics module
- Pack the parachute bag into the recovery module and push it towards the engine end
- Fasten the eyebolt to the top of the vent bulkhead with a lock washer and Loctite
- Wrap a fireproof cloth around the pyrotechnic line cutters to protect main parachute and recovery lines from the black powder burn
- Apply a thick layer of grease to the coupler at the base of the recovery tube and a thin layer of grease on the vent bulkhead
- Insert the vent bulkhead into the recovery module
- Secure the vent bulkhead to the recovery module coupler using 6x 1/4"-28 (1/2") screws
- Connect the circular connector from the primary recovery line to the avionics module
- Pack the drogue parachute and the remaining recovery lines into the recovery module
- Confirm that the altimeters are off
- Make all appropriate electrical connections at the avionics terminals
- Insert the 9V batteries into their mounts
- Slide the fiberglass airframe section over the sled
- Thread the top coupler onto the avionics threaded rod until it mates with the airframe section
- Tighten the nut on the bottom of the lower avionics coupler
- Wrap a fireproof cloth around the igniter cylinders to protect recovery lines and parachutes from the black powder burn
- Apply a layer of grease to the avionics and recovery couplers
- Place the avionics module coupler over the recovery module coupler
- Secure the avionics and recovery modules together with shear pins

Payload Setup Procedures

Assembly

- Ensure all components are undamaged
- Ensure the CubeSat is fully assembled
- Assemble one CO_2 ejector as per the instructions in the Recovery System Setup Procedures and secure it to the payload recovery strap
- Connect the e-match to the payload deployment electronics
- Connect the payload recovery strap to the CubeSat
- Slide the CubeSat into the deployment mount
- Connect the base coupler of the deployment mount to the top coupler of the recovery avionics section and secure it with three shear pins

Launch Tower Procedures

<u>Assembly Checks</u>

- Ensure all ¼” cable clamps are torqued to 4 ¾ lbs.ft (57 lbs.in) minimum
- Ensure all 3/16” cable clamps are torqued to 3 ¾ lbs.ft (45 lbs.in) minimum
- Ensure that there are a minimum of 2 threads sticking sticking out the end of the turnbuckles

- Ensure that cable assemblies are at least the lengths specified in the "Gin Pole Mechanism Drawings"
- Ensure that the "Connecting Wire ASY" and "Puller Wire ASY" are assembled onto the long gin pole. A section of the "Puller Wire ASY" will not be connected to the winch; this is what should be on the gin pole
- Have the hand drill set on low speed. Max rpm on low speed is 600 rpm, which is also the rpm rating of the winch
- Ensure there is sufficient lubrication on winch gears

Launch Pad Installation Procedure

Estimated time: 10 min

Technicians Required: 2

Tools Required:
- Sledgehammer
- Strike plate
- Level measurement device

1. Identify a fairly flat piece of land, unobstructed by plants
2. Place the launch pad on the ground. If the ground is soft, place several 2x4's underneath the pad, evenly spaced
3. Level the launch pad by adding/removing ground as required. Max of 2deg tilt is acceptable
4. Drive stakes through each corner of the launch pad legs, leaving about 1"-2" sticking out

Gin Pole Installation

Estimated Time: 1 min

Technicians Required: 3

Tools Required
- Adjustable wrench/ratchet wrench x2
- Long Gin Pole section

1. Ensure the pad is rotated to "tower vertical" position
2. Disassemble the bolt and nut on the Short Gin Pole (already installed on the pad)
3. Slide the Long Gin Pole onto the Short Gin Pole
4. Use the bolt and nut to fasten the sections together, and tighten with wrenches

Ground Anchor Installation

Estimated Time: 25 (5 min per anchor). Time is reduced with more technicians and hammers

Technicians Required: 1 (per sledgehammer)

Tools Required

- Sledgehammer
- Short stake
- Medium stake
- Long stake
- Strike plate
- Measuring tape (at least 22')
- 5x ground anchors

PPE

- Safety glasses (per sledgehammer)

1. Locate a point 18' away from the pivot point of the launch tower. Line up this point with the gin pole (installed on the tower)
2. Use the short stake, strike plate, and sledgehammer to drive two anchors vertically down at this location. Switch to the medium, then long stake when there is insufficient length of rod
3. Leave 2" of cable sticking out of the ground, close enough that they can be routed to attach at a single point
4. Pull on the cable to lock the anchor in the ground
5. Locate three points 16' away from the pivot point of the launch tower, in the geometry shown in "Guy Wire Schematic"
6. Drive at one anchor at each point.

<u>Winch Installation</u>

Please see drawings for details

Estimated Time: 30 sec

Technicians Required: 1

1. Ensure the cable on the winch is fully retracted
2. Snap the carabiner on the winch frame to the both ground anchors. Ensure the winch cable is facing the pad
3. Ensure the carabiner is twist locked
4. Extend the winch cable until it reaches the "Puller Wire ASY", which is installed on the gin pole
5. Snap the carabiner from the "Puller Wire ASY" onto the winch cable
6. Ensure the carabiner is twist locked

<u>Tower Installation Procedure</u>

Estimated Time: 30 min

Technicians Required: 3

Tools Required

- Hand drill with ⅝" socket and adapter
- Winch handle

PPE

- Gloves x1 pair (for holding the wire on the winch)

1. Locate the turnbuckle on the "Connecting Wire ASY" closest to the gin pole. Leave 2 inches of threads sticking out either end
2. Place technician #1 at the winch. This technician should have the hand drill/handle
3. Place technician #2 between the winch and the gin pole. This technician should hold the winch wire with gloves
4. Place technician #3 at the pad, holding the gin pole
5. Unwind the winch, and rotate the gin pole until it hits the launch pad
   - Technician #1: Use the hand drill/winch to unwind the winch cable
   - Technician #2: Keep tension on the winch cable
   - Technician #3: Rotate the gin pole to keep tension on the wire
6. Install the tower (see "Tower Assembly Procedure") onto the launch pad
7. Install any other GSE required for the tower before it is lifted
8. Snap the carabiner from the "Connecting Wire Assembly" to the "Cable Mount Assembly" on the tower
9. Tighten the turnbuckle on the connecting wire assembly to prevent slack

<u>Tower Raising Procedure</u>

Estimated Time: 2 min (based on test)

Technicians Required: 6

Tools Required

- Hand drill with ⅝" socket and adapter for the socket
- Winch handle
- Wooden rod (for adjusting wire)

PPE

- Gloves x4 pairs (for handling the wire)
- Hard hat x2
- Safety glasses x7

1. Place technicians #1 to #2 at each guy wire, pulling with the tower rotation direction. Gloves should be worn
2. Place technician #3 at the guy wire, pulling against the tower rotation direction. Gloves should be worn
3. Place technician #4 and #5 at the launch pad. Hard hats should be worn
4. Place technician #6 and #7 at the winch. Technician #6 should have the hand drill. Technician #7 should have gloves and the wooden rod
5. **Ensure there are no people under the tower**
6. Lift the tower
   - Technicians #1 to #2: Keep light tension on the guy wires to prevent the tower from swaying side to side. Walk towards the ground anchors. **Do not wrap the wire around your back. If**

the tower falls, you will be dragged along with it. Keep the wire in front of you. Hold it and the turnbuckle with two hands

- Technician #3: Hold the wire, do not pull
- Technician #4 and #5: Keep your hands on the rocket and watch for any hoses/wires. Make sure they are secure
- Technician #6: Use the hand drill/handle to wind the wire on the winch
- Technician #7: Use the wooden rod to correct the fleet angle on the winch, ensuring the wire is winding neatly

7. Observe the tower as it approaches the vertical position
   - Technicians #1 to #3: Hook your turnbuckle into the ground anchors if possible
   - Technicians #4 and #5: Get ready to support the tower as it lands
   - Technician #6: Slow down
   - Technician #7: Keep correcting the fleet angle
8. The tower is vertical
   - Technicians #1 and #2: Tighten your turnbuckles. Check that the tension is at least 5lbf using the spring gauge
   - Technician #3: Tighten your turnbuckle. Check that the tension is at least 2lbf using the spring gauge
   - Technician #6: Remove your drill/handle from the winch. Install the locking bracket on the gin pole. Then, locate the turnbuckle on the end of the gin pole (part of the "Connecting Wire Assembly") and loosen it. Bring the cable to the launch pad and secure it there, away from the rocket and surrounding systems
   - Technician #4, #5, #7: You are on standby.

Unexploded Ordnance Hybrid Rocket
2018 IREC

Launch Operations Procedures

Compiled on 2018-05-28

Background and Reference

Contents

This document contains two nominal procedures:

- **N1**, *Final Setup and Pre-Launch Checks*, comprises the final checks and tests performed on the Remote Launch Control System (RLCS) prior to rocket launch, as well as avionics systems arming.
- **N2**, *Fill and Launch Operations*, comprises steps for oxidizer fill and rocket launch.

Additionally, this document contains five abort procedures:

- **A1**, *Abort Procedure - Leak At Supply Plumbing*, is used if a plumbing leak is detected when the supply cylinder is initially opened.
- **A2**, *Abort Procedure - Low Supply Pressure*, is used if the oxidizer pressure is below the acceptable limit for launch.
- **A3**, *Abort Procedure - High Supply Pressure*, is used if the oxidizer pressure is above the acceptable limit for launch.
- **A4**, *Abort Procedure - Leak At Fill Plumbing*, is used if a plumbing leak is detected during manual fill leak checks.
- **A5**, *Abort Procedure - Remote Disconnect or Ignition Failure*, is used if the remote disconnect or ignition systems fail, necessitating a full vent of the oxidizer tank.

Personnel Required

The launch operations team consists of four personnel:

1 ☐ The **Operations Director [OPS]** is stationed at Launch Control. **OPS** directs operations procedures and communicates with the other launch personnel.

2 ☐ The **Control System Operator [CONTROL]** is stationed at Launch Control and is responsible for operation of RLCS, including remote fill, disconnect, and ignition.

3 ☐ The **Primary Fill Operator [PRIMARY]** is initially stationed at the Launch Tower and carries out all tasks occurring at the Launch Tower. **PRIMARY** engages the remote disconnect system, arms the vehicle recovery deployment system, connects the ignition wires to the rocket, and operates all manual valves during the manual portion of fill.

4 ☐ The **Secondary Fill Operator [SECONDARY]** is the backup for **PRIMARY**, and communicates with **OPS**. If **PRIMARY** becomes incapacitated, **SECONDARY** is responsible for removing them from danger.

Sign-Off

To be completed by all test personnel after reading and familiarization with procedures

1 ☐ **Operations Director [OPS]** ________________ ________________

2 ☐ **Control System Operator [CONTROL]** ________________ ________________

3 ☐ **Primary Fill Operator [PRIMARY]** ________________ ________________

4 ☐ **Secondary Fill Operator [SECONDARY]** ________________ ________________

[N1] Final Setup and Pre-Launch Checks

Prior to Start

1 ☐ Ensure that the following procedures are complete:

2 ☐ Rocket Assembly procedure
3 ☐ RLCS Setup procedure
4 ☐ Launch Tower Setup procedure

5 ☐ Ensure that all personnel as defined above are available and have completed the sign-off.

6 ☐ Ensure that the following personnel have walkie-talkies and communication is functional:

7 ☐ **OPS**
8 ☐ **CONTROL**
9 ☐ **PRIMARY**
10 ☐ **SECONDARY**

11 ☐ Ensure that **OPS** is in possession of the system control key.

12 ☐ Ensure that the locations of Launch Control, Launch Tower, and the Minimum Safe Distance are clearly defined.

Nominal Procedure

1 ☐ **PRIMARY**: Confirm that the following valves are initially closed:

2 ☐ Cylinder Valve
3 ☐ Remote Fill Valve
4 ☐ Parallel Fill Valve
5 ☐ Series Fill Valve
6 ☐ Line Vent Valve
7 ☐ Parallel Vent Valve

8 ☐ **PRIMARY**: Confirm that the ignition connectors are disconnected from the rocket.

9 ☐ **CONTROL** and **SECONDARY**: Confirm that all actuators fail to move while the system control key is removed:

10 ☐ Remote Fill Valve
11 ☐ Line Vent Valve
12 ☐ Remote Disconnect
13 ☐ Tank Vent Valve
14 ☐ Injector Valve

15 ☐ **SECONDARY**: Confirm that the voltage across the ignition connectors is 0 V.

16 ☐ **OPS**: Give the system control key to **CONTROL**.

17 ☐ **CONTROL**: Confirm that all actuator controls are in the off state:

18 ☐ Remote Fill Valve

19 ☐ Line Vent Valve
20 ☐ Remote Disconnect
21 ☐ Tank Vent Valve
22 ☐ Primary Ignition
23 ☐ Secondary Ignition
24 ☐ Injector Valve

25 ☐ **CONTROL**: Engage the key switch and enable actuators.

26 ☐ **CONTROL** and **SECONDARY**: Confirm that all actuators actuate as intended:

27 ☐ Remote Fill Valve
28 ☐ Line Vent Valve
29 ☐ Remote Disconnect
30 ☐ Tank Vent Valve
31 ☐ Injector Valve

32 ☐ **CONTROL** and **SECONDARY**: Confirm that the ignition voltage is 12 V when the ignition button is fired:

33 ☐ Primary Ignition
34 ☐ Secondary Ignition

35 ☐ **CONTROL**: Confirm that all DAQ readings are displaying appropriately.

36 ☐ **CONTROL**: Remove the system control key and give it to **OPS**.

37 ☐ **PRIMARY**: Arm the payload using the transponder.

38 ☐ **PRIMARY**: Arm recovery avionics using the magnetic switches

39 ☐ **PRIMARY**: Arm remote disconnect by connecting the springs, fill adapter, and strap.

40 ☐ **PRIMARY**: Connect the ignition connectors to the rocket.

[N2] Fill and Launch Operations

Prior to Start

1 ☐ Ensure that the following procedure is complete:

2 ☐ **N1**, *Final Setup and Pre-Launch Checks*

3 ☐ Ensure that all personnel are available and have completed the sign-off.

4 ☐ Ensure that the following personnel have walkie-talkies and communication is functional:

5 ☐ **OPS**

6 ☐ **CONTROL**

7 ☐ **PRIMARY**

8 ☐ **SECONDARY**

9 ☐ Ensure that **PRIMARY** and **SECONDARY** are wearing face shields and have no exposed skin.

10 ☐ Ensure that **PRIMARY** is wearing thermal gloves.

11 ☐ Ensure that **OPS** is in possession of the system control key.

Nominal Procedure

1 ☐ **SECONDARY**: Confirm that no personnel other than **PRIMARY** and **SECONDARY** are within the Minimum Safe Distance.

2 ☐ **OPS**: Confirm that the actuator key switch is disabled and that only **OPS** is in possession of the system control key.

3 ☐ **OPS**: Confirm that the Range Safety Officer and Launch Control Officer have given clearance to proceed with fill procedures.

4 ☐ **CONTROL**: Confirm that the RLCS client-side box is on and displaying DAQ information.

5 ☐ **PRIMARY**: Confirm that the following valves are initially closed:

6 ☐ Cylinder Valve

7 ☐ Remote Fill Valve

8 ☐ Parallel Fill Valve

9 ☐ Series Fill Valve

10 ☐ Line Vent Valve

11 ☐ Parallel Vent Valve

12 ☐ **OPS**: Confirm that the Tank Vent Valve is initially open.

13 ☐ **OPS**: Confirm that the Pressure Relief Valve is initially closed.

14 ☐ **OPS**: Confirm that the Injector Valve is initially closed.

15 ☐ **PRIMARY**: Slowly open the Cylinder Valve through $\frac{3}{4}$ of a turn.

- If leaks are observed:

16 ☐ **OPS**: Proceed to procedure A1.

17 ☐ **PRIMARY**: Communicate the supply line pressure as visible on the Pressure Gauge.

- If the supply line pressure is below 800 psi:

18 ☐ **OPS**: Proceed to procedure **A2**.

- If the supply line pressure exceeds 1050 psi:

19 ☐ **OPS**: Proceed to procedure **A3**.

20 ☐ **CONTROL**: Confirm that the supply line pressure as read by **PRIMARY** agrees with the supply line pressure measured by the DAQ system.

21 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

- If leaks are observed:

22 ☐ **OPS**: Proceed to procedure **A4**.

23 ☐ **CONTROL**: Confirm that the pressures in the fill lines and in the oxidizer tank are increasing.

24 ☐ **PRIMARY**: Close the Parallel Fill Valve.

25 ☐ **PRIMARY**: Open the Series Fill Valve.

26 ☐ **PRIMARY** and **SECONDARY**: Retreat to the Minimum Safe Distance.

27 ☐ **SECONDARY**: Confirm that **PRIMARY** and **SECONDARY** are at the Minimum Safe Distance.

28 ☐ **PAUSE POINT**

29 ☐ **OPS**: Give the system control key to **CONTROL**.

30 ☐ **CONTROL**: Confirm that all actuator controls are in the off state:

31 ☐ Remote Fill Valve
32 ☐ Line Vent Valve
33 ☐ Remote Disconnect
34 ☐ Tank Vent Valve
35 ☐ Primary Ignition
36 ☐ Secondary Ignition
37 ☐ Injector Valve

38 ☐ **CONTROL**: Engage the key switch and enable actuators.

39 ☐ **CONTROL**: Open the Remote Fill Valve.

40 ☐ **CONTROL**: Monitor the RLCS display for rocket mass and oxidizer tank pressure.

41 ☐ **OPS**: Proceed only when the following is true:

42 ☐ Rocket mass plateaus
43 ☐ Oxidizer tank pressure is within the acceptable limits

44 ☐ **CONTROL**: Close the Tank Vent Valve.

45 ☐ **CONTROL**: Close the Remote Fill Valve.

46 ☐ **CONTROL**: Open the Remote Vent Valve.

47 ☐ **CONTROL**: Confirm that the fill line pressure is atmospheric.

48 ☐ **CONTROL**: Actuate Remote Disconnect.

- If Remote Disconnect fails to actuate:

49 ☐ **OPS**: Proceed to procedure **A5**.

50 ☐ **PAUSE POINT**

51 ☐ **OPS**: Perform pre-launch checks:

52 ☐ Request clearance for launch from the Launch Control Officer.

53 ☐ Confirm that all members are aware of launch.

54 ☐ **PRIMARY**: Perform engine startup procedure:

55 ☐ Arm the Primary Ignition switch.

56 ☐ Hold down the Fire button until the Primary current reading drops to 0 A.

- In the event of a failed ignition (current drop not observed within 1 minute):

57 ☐ **PRIMARY**: Disarm the Primary Ignition switch.

58 ☐ **PRIMARY**: Arm the Secondary Ignition switch.

59 ☐ **OPS**: Revisit ignition procedure.

- In the event of a second failed ignition (current drop not observed within 1 minute):

60 ☐ **PRIMARY**: Disarm the Secondary Ignition switch.

61 ☐ **OPS**: Proceed to procedure **A5**.

62 ☐ **PRIMARY**: Start the engine by opening the Injector Valve.

63 ☐ **ALL**: Observe the rocket during takeoff, ascent, and recovery:

64 ☐ First vehicle motion

65 ☐ Launch rail departure

66 ☐ Engine burnout

67 ☐ Payload deployment

68 ☐ Drogue parachute deployment

69 ☐ Main parachute deployment

70 ☐ Approximate recovery area/direction

71 ☐ **CONTROL**: Disarm RLCS:

72 ☐ Disable actuator control by removing the system control key.

73 ☐ Give the system control key to **OPS**.

74 ☐ **OPS**: Confirm that RLCS is disarmed and **OPS** is in possession of the system control key.

75 ☐ **OPS**: Proceed only when clearance is received from the Launch Control Officer to approach the Launch Tower.

76 ☐ **PRIMARY** and **SECONDARY**: Approach the Launch Tower.

77 ☐ **PRIMARY**: Close the Cylinder Valve.

78 ☐ **PRIMARY**: Open the Parallel Vent Valve.

79 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

80 ☐ **PRIMARY** and **SECONDARY**: Retreat 20 ft from the fill system.

81 ☐ **OPS**: Give the master key to **CONTROL**

82 ☐ **CONTROL**: Engage the key switch and enable actuators.

83 ☐ **CONTROL**: Open the Remote Fill Valve.

84 ☐ **CONTROL**: Confirm that the supply line pressure is atmospheric.

85 ☐ **PRIMARY**: Disconnect the fill line from the supply cylinder.

86 ☐ **PRIMARY**: Replace the cap on the nitrous oxide supply cylinder.

87 ☐ **OPS**: Proceed with teardown and disassembly.

Abort Procedures

[A1] Abort Procedure - Leak At Supply Plumbing

1 ☐ **PRIMARY**: Close the Cylinder Valve.

2 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

3 ☐ **PRIMARY**: Slowly open the Parallel Vent Valve.

4 ☐ **CONTROL**: Confirm that the fill and supply pressures are atmospheric.

5 ☐ **PRIMARY**: Disarm the system:

6 ☐ Disconnect the ignition leads from the rocket.

7 ☐ Detatch the torsion springs from the disconnect mechanism.

8 ☐ Disarm the recovery electronics system using the magnetic switches.

9 ☐ Disarm the payload using the transponder.

10 ☐ Disconnect the fill line from the supply cylinder.

11 ☐ Replace the cap on the nitrous oxide supply cylinder.

12 ☐ **OPS**: Revisit plumbing setup.

[A2] Abort Procedure - Low Supply Pressure

1 ☐ **PRIMARY**: Close the Cylinder Valve.

2 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

3 ☐ **PRIMARY**: Slowly open the Parallel Vent Valve.

4 ☐ **CONTROL**: Confirm that the fill and supply pressures are atmospheric.

5 ☐ **PRIMARY**: Allow the supply cylinder to warm up.

6 ☐ **OPS**: Revisit **N1**.

[A3] Abort Procedure - High Supply Pressure

1 ☐ **PRIMARY**: Close the Cylinder Valve.

2 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

3 ☐ **PRIMARY**: Slowly open the Parallel Vent Valve.

4 ☐ **CONTROL**: Confirm that the fill and supply pressures are atmospheric.

5 ☐ **PRIMARY**: Disarm the system:

6 ☐ Disconnect the ignition leads from the rocket.

7 ☐ Detatch the torsion springs from the disconnect mechanism.

8 ☐ Disarm the recovery electronics system using the magnetic switches.

9 ☐ Disarm the payload using the transponder.

10 ☐ Disconnect the fill line from the supply cylinder.

11 ☐ Replace the cap on the nitrous oxide supply cylinder.

12 ☐ **OPS**: Revisit cylinder cooling methods.

[A4] Abort Procedure - Leak At Fill Plumbing

1 ☐ **PRIMARY**: Close the Parallel Fill Valve.

2 ☐ **PRIMARY**: Close the Cylinder Valve.

3 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

4 ☐ **PRIMARY**: Slowly open the Parallel Vent Valve.

5 ☐ **CONTROL**: Confirm that the fill and supply pressures are atmospheric.

6 ☐ **PRIMARY**: Disarm the system:

7 ☐ Disconnect the ignition leads from the rocket.
8 ☐ Detatch the torsion springs from the disconnect mechanism.
9 ☐ Disarm the recovery electronics system using the magnetic switches.
10 ☐ Disarm the payload using the transponder.
11 ☐ Disconnect the fill line from the supply cylinder.
12 ☐ Replace the cap on the nitrous oxide supply cylinder.

13 ☐ **OPS**: Revisit plumbing setup.

[A5] Abort Procedure - Remote Disconnect or Ignition Failure

1 ☐ **CONTROL**: Open the Tank Vent Valve.

2 ☐ **CONTROL**: Monitor the RLCS display for rocket mass and oxidizer tank pressure as the oxidizer tank vents.

3 ☐ **OPS**: Proceed only when the following is true:

4 ☐ Rocket mass is equal to the pre-launch recorded mass
5 ☐ Oxidizer tank pressure is atmospheric
6 ☐ The Launch Control Officer has given clearance to approach the Launch Tower.

7 ☐ **PRIMARY** and **SECONDARY**: Approach the Launch Tower.

8 ☐ **PRIMARY**: Close the Cylinder Valve.

9 ☐ **PRIMARY**: Open the Parallel Vent Valve.

10 ☐ **PRIMARY**: Slowly open the Parallel Fill Valve.

11 ☐ **PRIMARY** and **SECONDARY**: Retreat 20 ft from the fill system.

12 ☐ **OPS**: Give the system control key to **CONTROL**

13 ☐ **CONTROL**: Engage the system control switch and enable actuators.

14 ☐ **CONTROL**: Open the Remote Fill Valve.

15 ☐ **CONTROL**: Confirm that the supply line pressure is atmospheric.

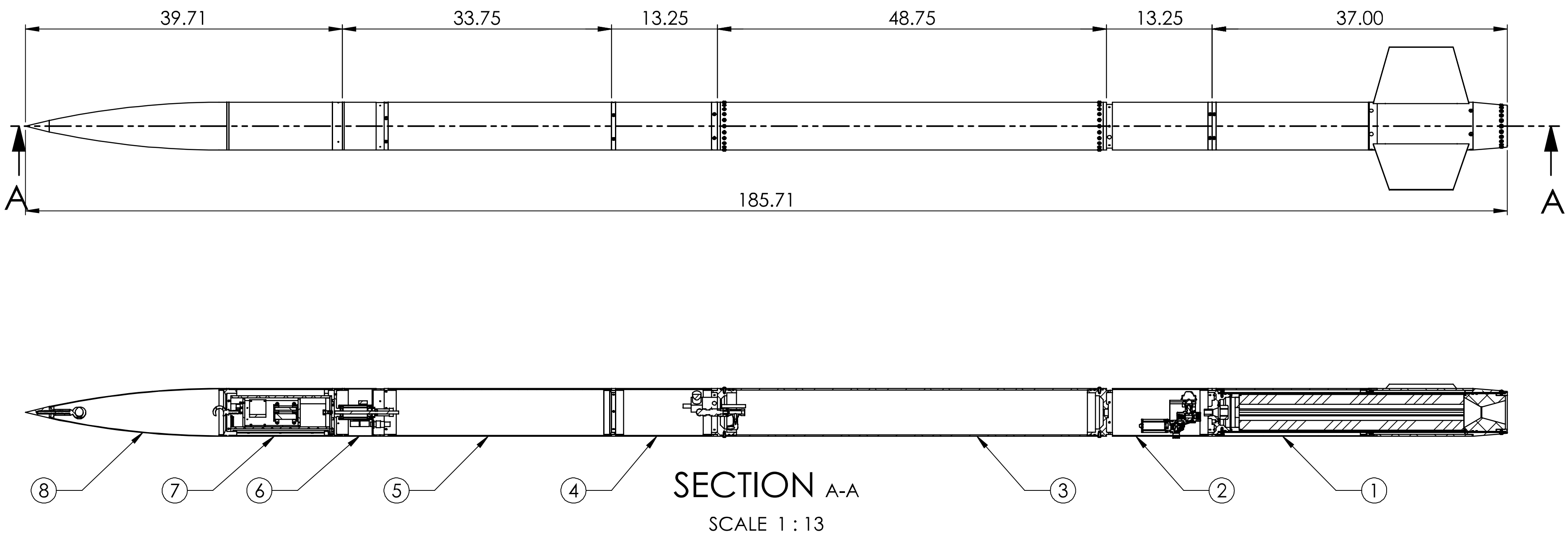
16 ☐ **PRIMARY**: Disarm the system:

17 ☐ Disconnect the ignition leads from the rocket.
18 ☐ Detatch the torsion springs from the disconnect mechanism.
19 ☐ Disarm the recovery electronics system using the magnetic switches.
20 ☐ Disarm the payload using the transponder.
21 ☐ Disconnect the fill line from the supply cylinder.
22 ☐ Replace the cap on the nitrous oxide supply cylinder.

23 ☐ **OPS**: Proceed with teardown and disassembly.

Engineering Drawings Appendix

The following pages contain engineering drawings of significant UXO components and assemblies.



Item No	Qty	Description
1	1	Combustion Chamber
2	1	Injector Valve Assembly
3	1	Oxidizer Tank
4	1	Vent Valve Assembly
5	1	Recovery Module/Parachute Bay
6	1	Avionics Module
7	1	Payload Module
8	1	Nosecone

QUANTITY	#	UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**WATERLOO ROCKETRY TEAM**
PROJECT	00_UXO	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.015 THREE PLACE DECIMAL ±0.005	DRAWN	INITIAL	YY-MM-DD	TITLE: UXO - Entire Rocket
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL MATERIAL	COMMENTS:			SIZE A DWG. NO. REV 01
NEXT ASSY	USED ON	FINISH				
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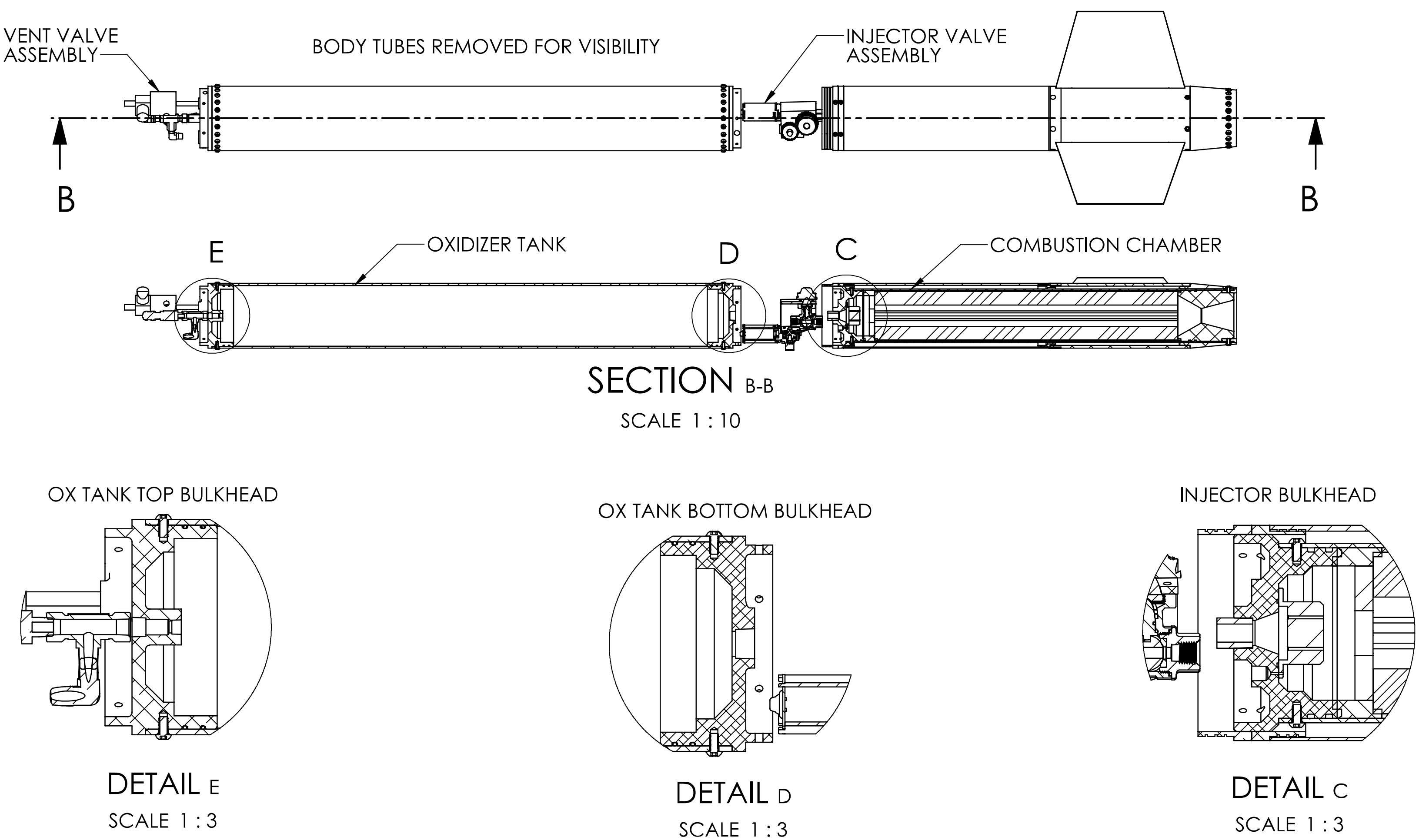

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QUANTITY	#
PROJECT	00_UXO
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	INITIAL	YY-MM-DD
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

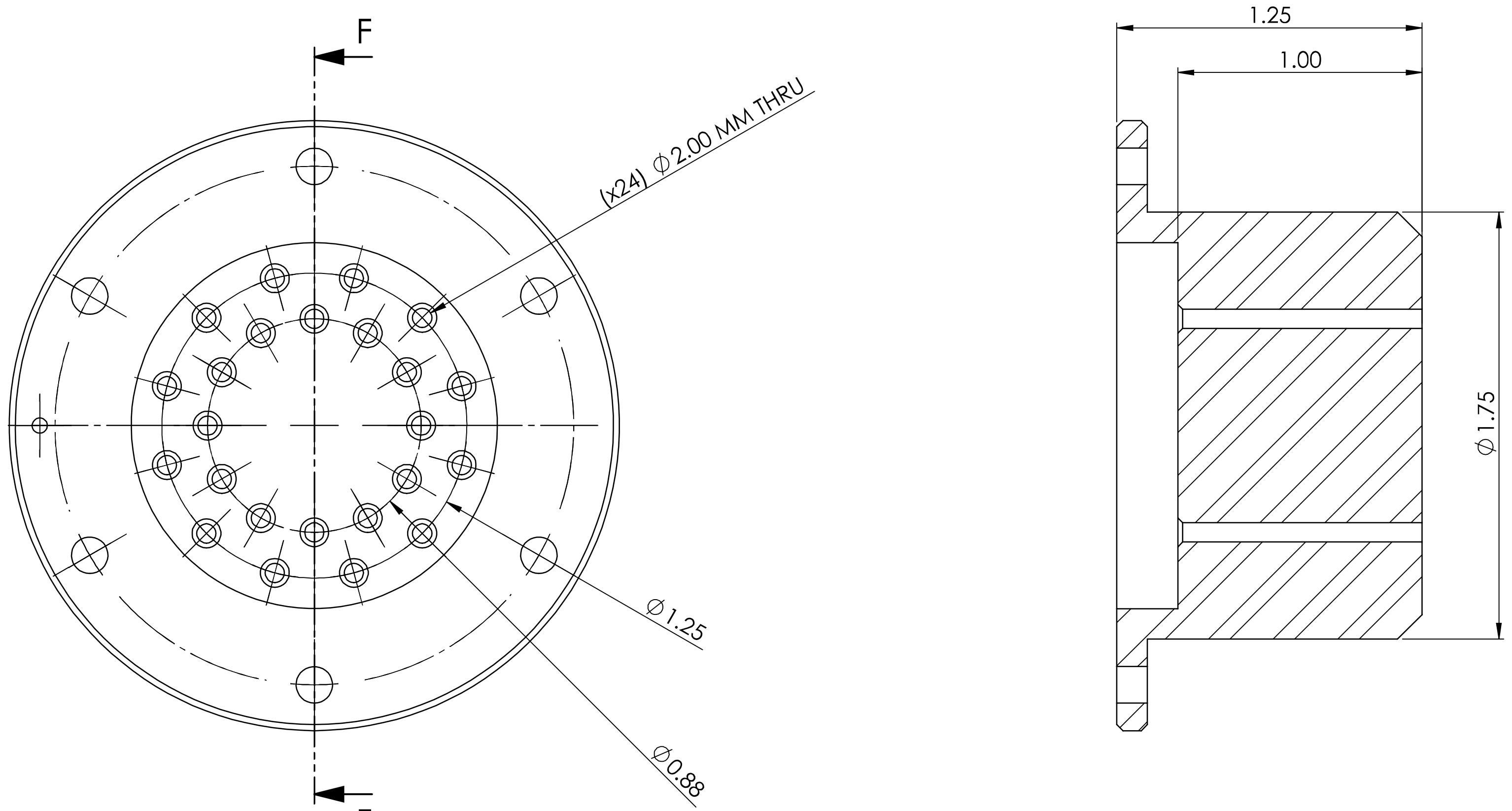
COMMENTS:

WATERLOO ROCKETRY TEAM

TITLE:
UXO - Engine (Assembly)

SIZE A DWG. NO. REV 01

SCALE: 1:20 WEIGHT:# SHEET 2 OF 10



SECTION F-F
SCALE 2 : 1

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QUANTITY	#
PROJECT	00_UXO
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

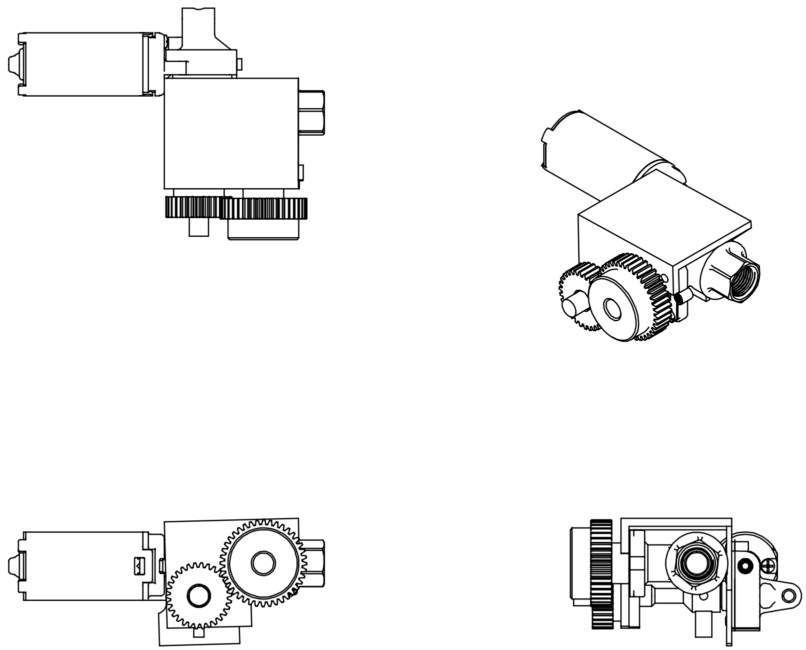
	NAME	DATE
DRAWN	INITIAL	YY-MM-DD
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

WATERLOO ROCKETRY TEAM

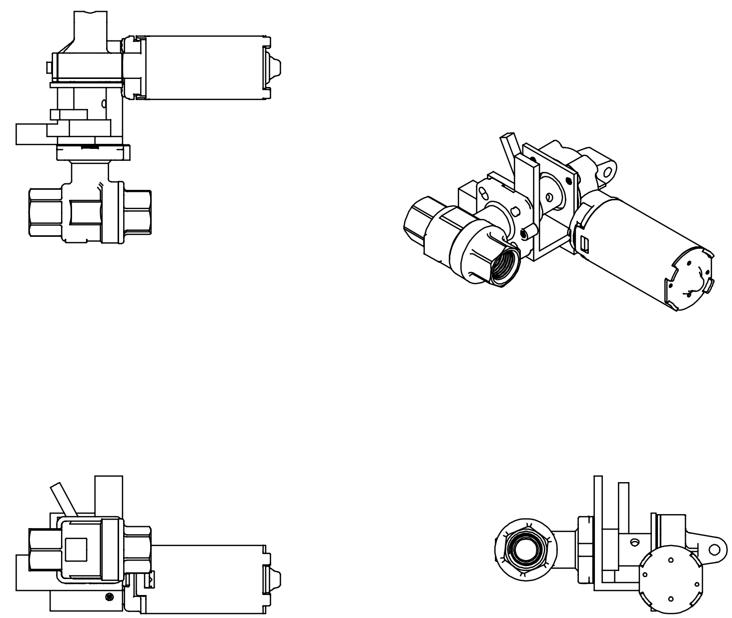
TITLE:
UXO - Injector Plate

SIZE A | DWG. NO. | REV 01

SCALE: 1:1 | WEIGHT:# | SHEET 3 OF 10



INJECTOR VALVE ASSEMBLY



VENT VALVE ASSEMBLY

PROPRIETARY AND CONFIDENTIAL

QUANTITY	#
PROJECT	00_UXO
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

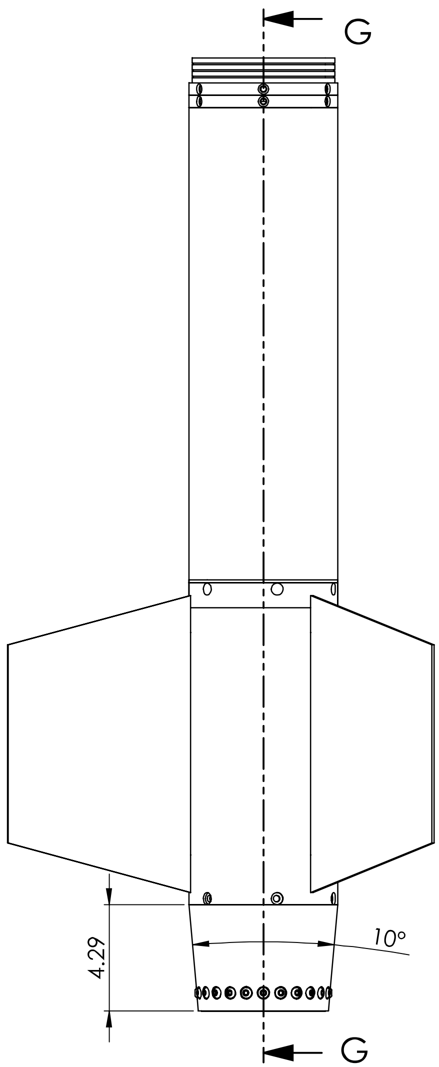
	NAME	DATE
DRAWN	INITIAL	YY-MM-DD
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

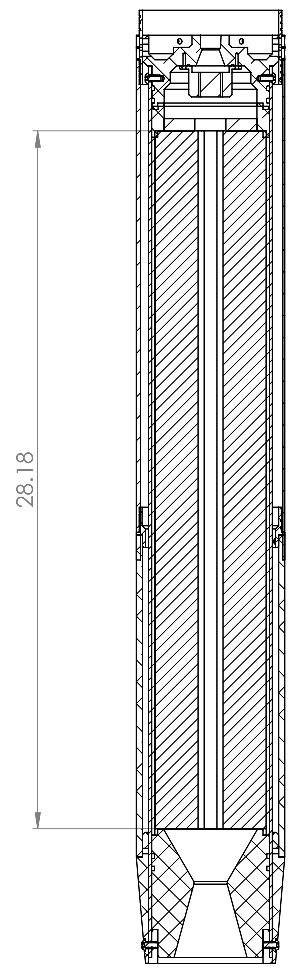
WATERLOO ROCKETRY TEAM

TITLE:
UXO - Engine - Injector and Vent Valve Assembly

SIZE A | DWG. NO. | REV 01

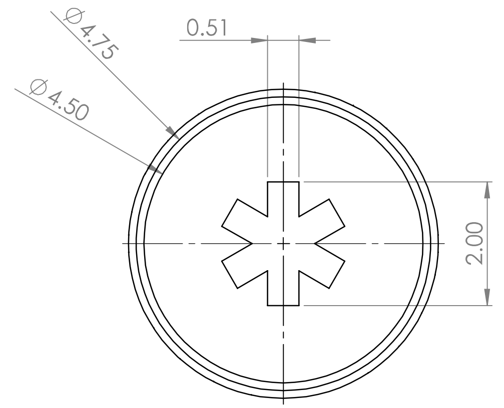
SCALE: 1:5 | WEIGHT:# | SHEET 4 OF 10





SECTION G-G

SCALE 1 : 5



FUEL GRAIN
(FUEL CASTED IN FIBERGLASS LINER)

QUANTITY	#
PROJECT	00_UXO
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

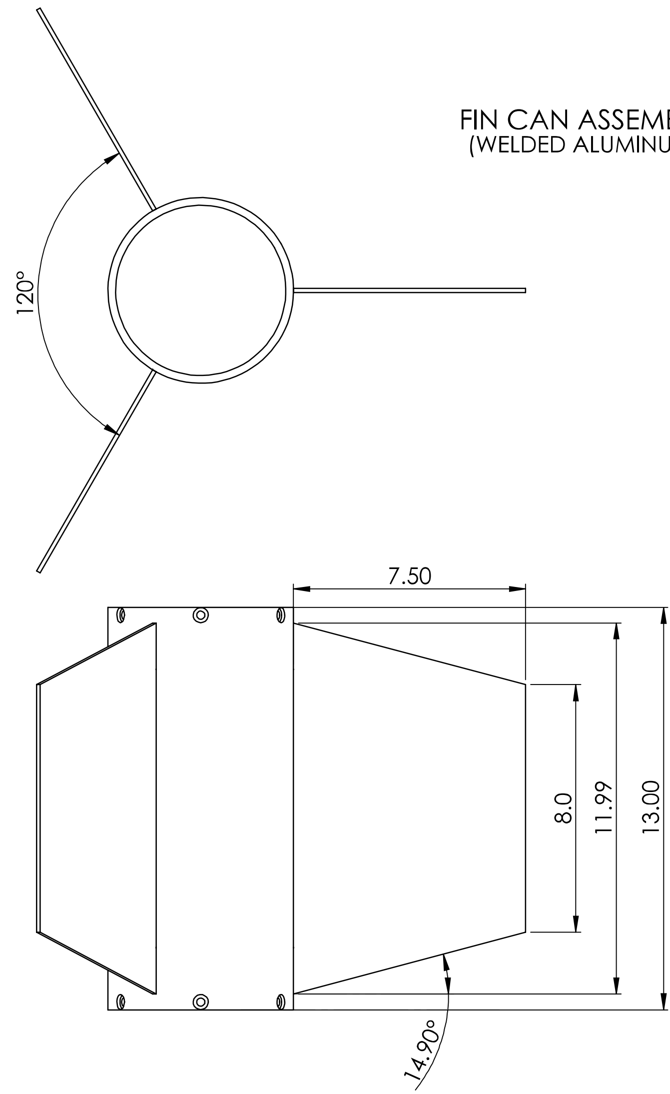
	NAME	DATE
DRAWN	INITIAL	YY-MM-DD
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

WATERLOO ROCKETRY TEAM

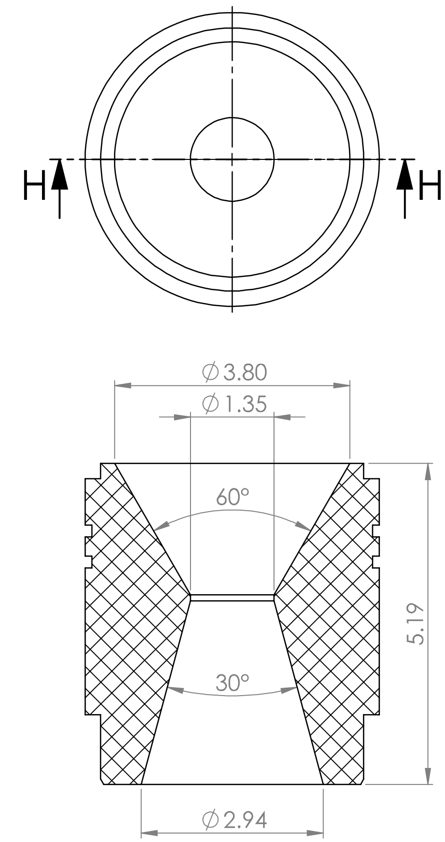
TITLE:
UXO - Combustion Chamber

SIZE	DWG. NO.	REV
A		01
SCALE: 1:10	WEIGHT:#	SHEET 5 OF 10

FIN CAN ASSEMBLY
(WELDED ALUMINUM)



NOZZLE



SECTION H-H
SCALE 1 : 2

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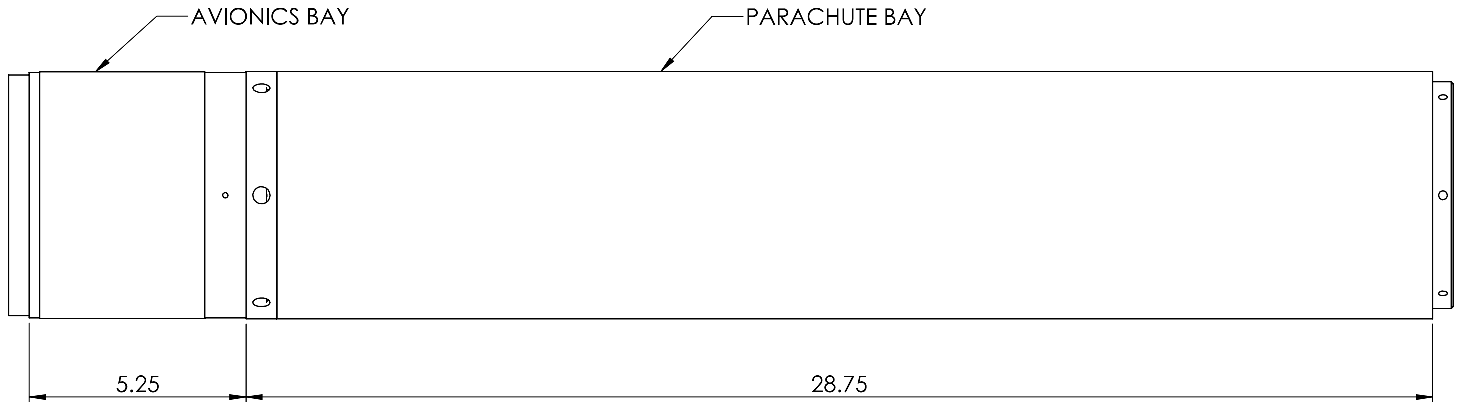
QUANTITY	#	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
PROJECT	00_UXO	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.015 THREE PLACE DECIMAL ±0.005	DRAWN	INITIAL	YY-MM-DD
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

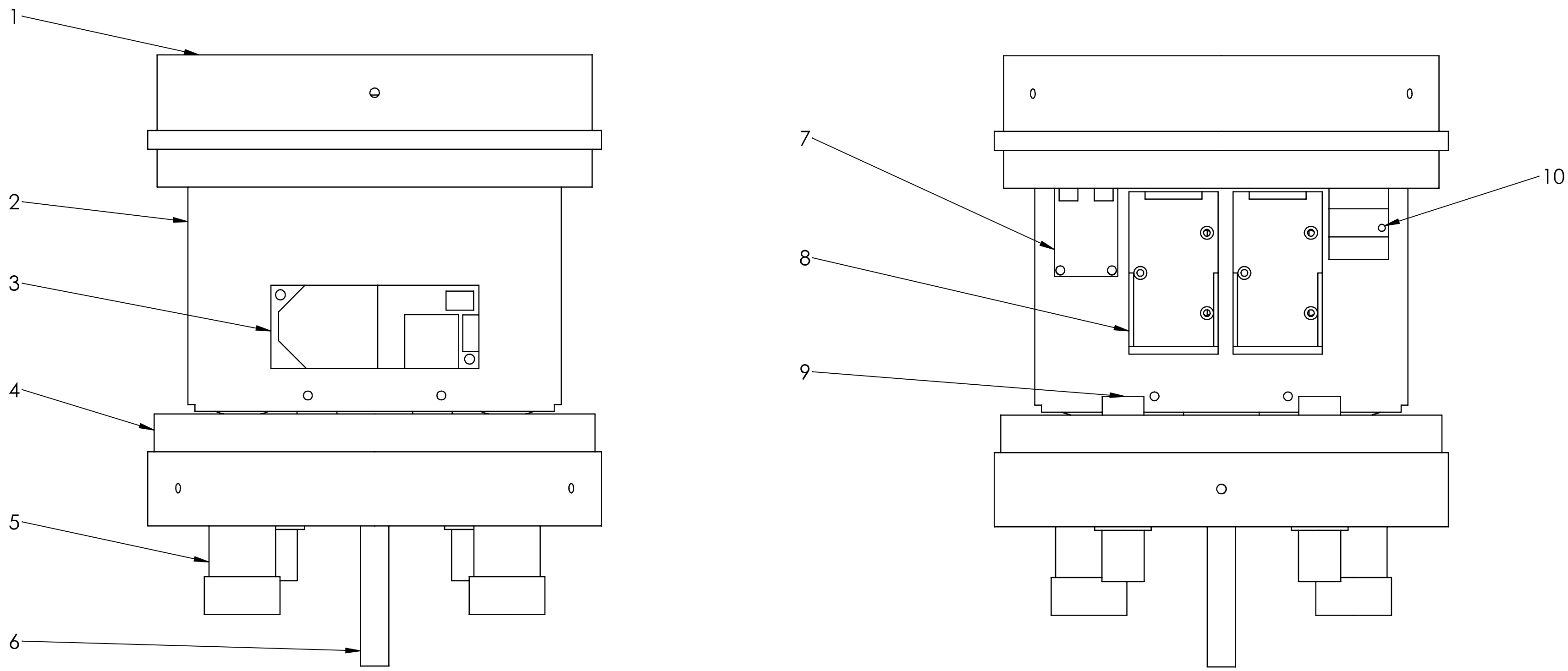
WATERLOO ROCKETRY TEAM

TITLE:
UXO - Fin Can and Nozzle

SIZE	DWG. NO.	REV
A		01
SCALE: 1:5	WEIGHT:#	SHEET 6 OF 10



QUANTITY	#	UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WATERLOO ROCKETRY TEAM
PROJECT	00_UXO	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.015 THREE PLACE DECIMAL ±0.005	DRAWN	INITIAL	YY-MM-DD	TITLE:
			CHECKED			UXO - Recovery
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL MATERIAL	COMMENTS:			SIZE A DWG. NO. REV 01
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT:# SHEET 7 OF 10



Item No	Qty	Description
1	1	TOP COUPLER
2	1	GPS SLED
3	1	GPS TRANSMITTER
4	1	BOTTOM COUPLER
5	2	CO2 CANISTER
6	1	THREADED ROD
7	1	STRATOLOGGER ALTIMETER
8	2	9V BATTERY HOLDER
9	2	CO2 EJECTOR
10	1	RAVEN ALTIMETER

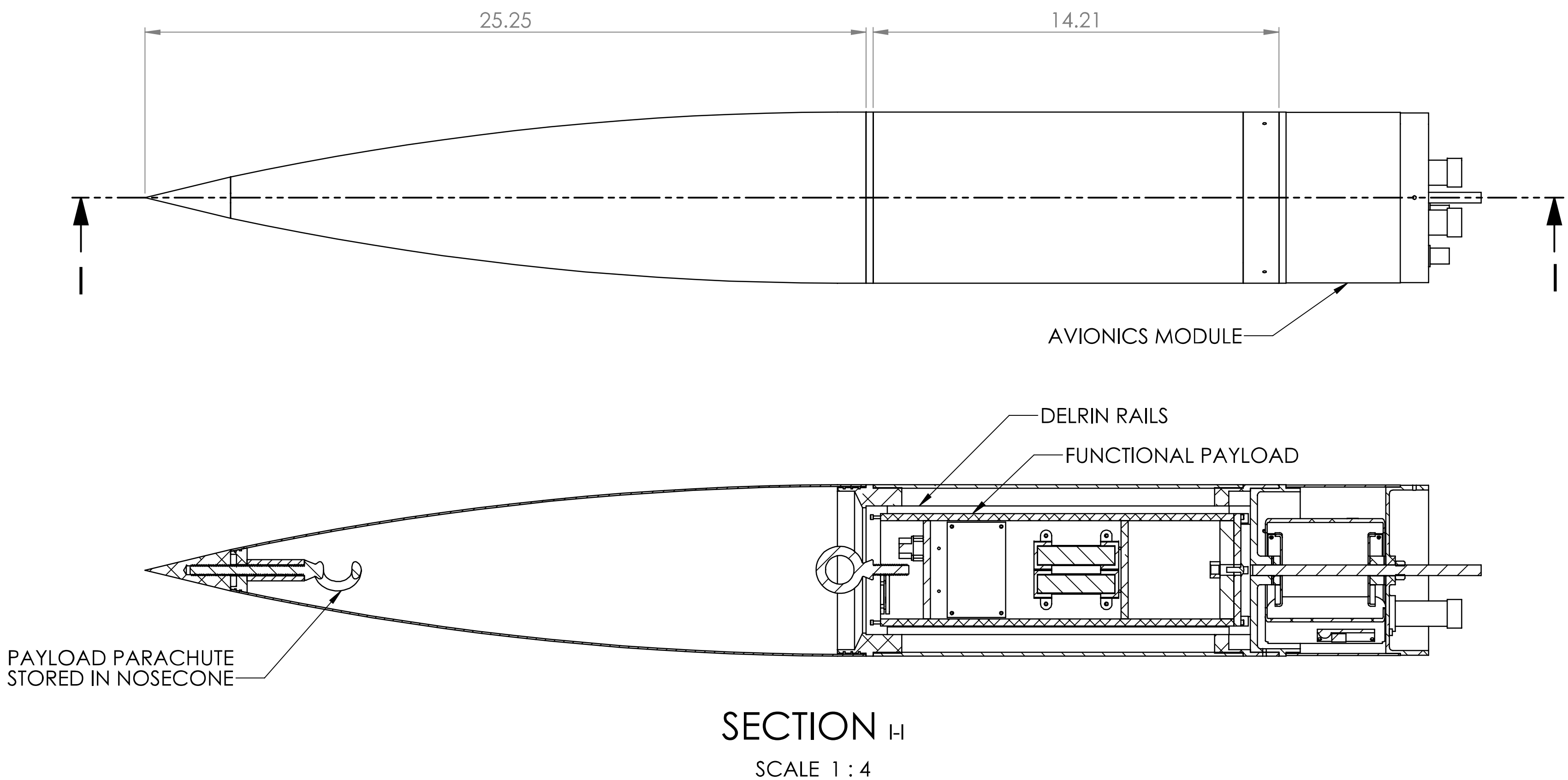
QUANTITY #
PROJECT 00_ROCKET
NEXT ASSY — USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

WATERLOO ROCKETRY TEAM
TITLE:
UXO - Recovery Avionics
SIZE A DWG. NO. REV 01
SCALE: 1:1.5 WEIGHT:# SHEET 8 OF 10



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QUANTITY	#	UNLESS OTHERWISE SPECIFIED:
PROJECT	00_ROCKET	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.015 THREE PLACE DECIMAL ±0.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL MATERIAL
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

WATERLOO ROCKETRY TEAM

TITLE:

UXO - Nosecone and Payload Bay

SIZE A | DWG. NO. | REV 01

SCALE: 1:10 | WEIGHT:# | SHEET 9 OF 10

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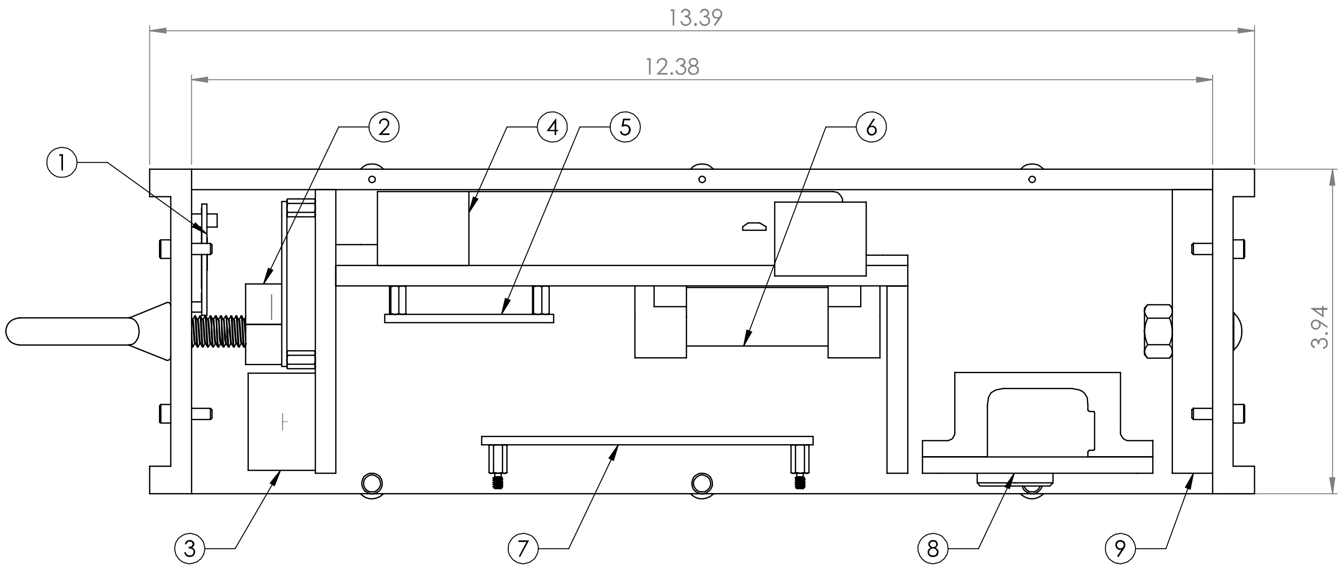

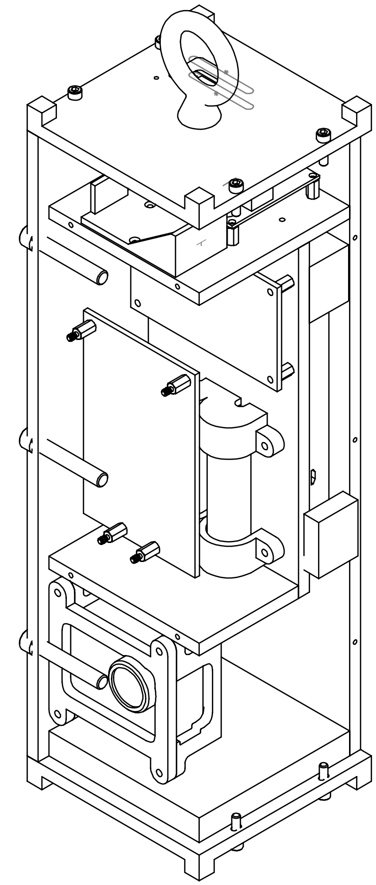

Item No	Qty	Description
1	1	AdaFruit GPS
2	1	Stratologger
3	1	9V Battery Holder
4	1	Battery Pack and Holder
5	1	Anything But Kismet Board
6	1	LiPo and LiPo Holder
7	1	Just Read the Datasheet Board
8	1	GoPro Assembly
9	1	Dead Weight

QUANTITY #
PROJECT 00_ROCKET
NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/32
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

WATERLOO ROCKETRY TEAM
TITLE:
UXO - Functional Payload

SIZE A | DWG. NO. | REV 01
SCALE: 1:5 | WEIGHT:# | SHEET 10 OF 10

Acknowledgments

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References

[1]Waxman, B. S. "An Investigation of Injectors for use with High Vapor Pressure Propellants with Applications to Hybrid Rockets," Ph.D. Dissertation, Department of Aeronautics & Astronautics, Stanfort Univ., Stanford, CA, 2014.