Aquila: WPI High Power Rocketry Club

Team 81 Project Technical Report for the 2022 IREC

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This report, written by the Worcester Polytechnic Institute (WPI) High Power Rocketry Club (HPRC), details the technical specifications of 2022 Spaceport America Cup project Aquila. Project Aquila consists of a 10,000 ft COTS Propulsion sounding rocket and a folding quadcopter payload. The rocket has five major systems which were designed by the team this year. One system, couplings and motor retention, was responsible for designing and fabricating an aluminum coupling mechanism to replace standard coupling tubes. The other systems consisted of a composite fin-can, custom airbrakes, a new CO2 ejection system, and a custom electronics package. The payload team set out to build a vehicle to complete a search and rescue mission. The payload consists of a retention mechanism and a quadcopter. When the payload lands a distance away from the rocket, the retention mechanism will orientate and deploy a folding quadcopter. This quadcopter will then autonomously or manually locate the lower airframe section. This is to simulate a search and rescue mission profile. The 135-person team has designed, built, and tested these systems throughout the academic year and hope to demonstrate their capabilities at competition in New Mexico. While it may be the first year that WPI HPRC is competing at the Spaceport America Cup, we hope to demonstrate our capability to be a competition winning team.

1. Nomenclature

\begin{itemize}
\item \(a\) = speed of sound
\item \(AR\) = fin aspect ratio
\item \(c\) = fin root chord
\item \(G\) = shear modulus
\item \(ID\) = inner diameter
\item \(i\) = time index during navigation
\item \(j\) = waypoint index
\item \(M\) = bending moment
\item \(OD\) = outer diameter
\item \(P\) = atmospheric pressure
\item \(t\) = fin thickness
\item \(V_f\) = fin flutter velocity
\item \(\lambda\) = fin taper ratio
\end{itemize}

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II. Introduction

HE Worcester Polytechnic Institute (WPI) High Power Rocketry Club (HPRC) is a 135 member strong club on campus. The team was founded in 2018 as a group of students entered NASA’s University Student Launch Initiative (USLI). Prior to 2018, students at WPI had competed in the Battle of The Rockets (BOR). This year, the team has chosen to compete in the Spaceport America Cup as an effort to further push our engineering skills. We hope to prove ourselves as a formidable competitor at this year’s launches.

The team is comprised of mostly undergraduate team members. The team is structured with three executive board members, Team Captain, Rocket Division Lead, and Payload Division Lead. The Team Captain is responsible for all team activities and oversees the team’s ten-person officer board. The officer board consists of the: Treasurer, Safety Officer, Logistics Officer, Engagement Officer, Public Relations Officer, Documentation Officer, Sponsorship Officer, and the executive board. Each division lead oversees the various subteam leads that manage an individual system. Each subteam lead oversees general team members who complete the design, construction, and testing of each system. The following sections will detail the team’s technical systems.

III. System Architecture Overview

The Aquila project consists of the launch vehicle, Altair, and payload, Tarazed. Altair stands at 134 inches tall with a 6.17-inch diameter airframe and is expected to reach an apogee of 10,000 feet. The rocket weighs 38.7 pounds unloaded and without payload and 68.1 pounds at liftoff. The vehicle uses a COTS CTI M1800 solid rocket motor for propulsion.

![Launch vehicle livery](image1)

**Figure 1. Launch vehicle livery.**

![Diagram of launch vehicle sections](image2)

**Figure 2. Diagram of launch vehicle sections.**

The vehicle is split into multiple sections; the nosecone and upper airframe contain the payload. The middle airframe contains the drogue and main parachutes, and recovery hardware. The electronics bay contains the recovery electronics, GPS tracker, and telemetry antenna. The lower airframe contains the airbrake system, avionics stack, and vibration datalogger. Finally, the tailcone holds the motor retention system. The vehicle makes use of several innovative systems, including a single end deployment recovery system, actively controlled airbrakes, and a novel new airframe attachment method.

The payload consists of a recovery bay, a piston, and a retention system. The sides of the payload retention system contain the stabilization system, with the inside containing the quadcopter, a gripper mechanism, an arm deployment mechanism, parachute release mechanism, plus batteries and electronics.

A. Propulsion

1. Motor Selection

Before the start of the competition year, the team purchased a CTI 98mm 4G motor casing for use on this year’s launch vehicle. This casing was selected for a variety of reasons; the team has had significant experience using Cesaroni motors, so this manufacturer was preferred over others. Based on first order estimates of the vehicle size, the 98mm 4G reloads available could deliver the launch vehicle to the target apogee with even the lower impulse reloads, while the higher impulse reloads offered the ability to fly heavier rockets in the future.

With the casing selected, flight simulations determined that the CTI M1800 would be capable of launching the vehicle just above 10,000 feet, allowing the airbrakes to reduce the apogee to the target.
2. Flight Simulations

The flight environment was estimated from historical data from Spaceport America. The nominal flight was simulated with a ground temperature of 95 F, with an atmospheric pressure of 12.8 psi. The elevation of the launch site was determined to be 4595 ft MSL. The vehicle will fly off a 17ft launch rail, but given that the vehicle can rotate once the forward rail button disengages, the rail length was set to 161 in. The launch was simulated with a launch angle of 7 degrees.

OpenRocket was used to conduct the flight simulations. For the nominal case, the vehicle is expected to reach an apogee of 10,353 ft without the use of the airbrakes. In the worst-case simulation, with 20 mph wind and a 10-degree launch angle, the vehicle is expected to reach 10,219 ft. Given that the airbrakes are expected to be capable of reducing the apogee by over 500 ft, the target apogee is within the range of the vehicle.

![Figure 3. Nominal flight simulation results.](image)

3. Vibration Datalogging

To better understand the vibration environment experienced by the launch vehicle during its flight, the team has integrated a vibration datalogger system onto the forward closure of the motor casing. For data collection, the team is using an enDAQ S5-E100D40 Shock & Vibration sensor. The sensor uses piezoelectric accelerometers to record vibrations at a sampling rate of up to 20,000 Hz. Additionally, the sensor includes a gyroscope and magnetometer, as well as pressure and temperature sensors which can be used to supplement the data. With a battery life of 17 hours of continuous recording at the highest data rate, the sensor is more than capable of operating throughout a launch day.

The sensor is attached to the forward closure of the motor using a machined aluminium plate. The team decided to install the sensor directly onto the motor casing as during burn most of the vibrations on the vehicle will be produced by the motor. When the motor is not burning, the motor casing is rigidly attached to the vehicle, so any buffeting vibrations will be captured.
B. Aerostructures

The aerostructures was responsible for the selection of the nosecone and airframe tubes, as well as the design and construction of custom fiberglass fin can and tailcone.

1. Nosecone and Airframe Tubes

The choice to purchase a COTS nosecone and airframe tube was selected to reduce the amount of composite manufacturing the team needed to do, allowing a focus on development of the fin can and tailcone. Each airframe section is made of G12 fiberglass body tubes, with an inner diameter of 6 in and outer diameter of 6.17 in. The body tubes for the airframe sections were purchased from Composite Warehouse.

The upper airframe is 36 1/8 in, the middle airframe is 26 19/32 in, the electronics bay is 10 in, the lower airframe is 18 29/32 in, and the fin can is 10 in. The launch vehicle also includes a filament wound fiberglass nosecone with a metal tip. The nosecone, which had previously been purchased from Madcow Rocketry, is a tangent ogive with a length of 24 in. The upper and middle airframe are attached with a 12 in section of fiberglass coupler tube, also purchased from Composite Warehouse. Each of the remaining launch vehicle sections are attached to each other using the couplings, as described in Section C.

2. Fin Can

The fin can was manufactured as a tip-to-tip layup using 6oz S-glass fiberglass fabric. Since this was the team’s first experience using this technique, multiple prototype fin cans were manufactured to gain experience.

Through the development of these prototypes, the team learnt important lessons regarding fin alignment, filleting methods, and surface preparation procedures to ensure the fin can would be capable of withstanding flight loads.

For the final product, four trapezoidal fin cores were routed from 1/8 in G10/FR4 fiberglass plate and epoxied along their root chord onto the fin can. To ensure alignment, a fin alignment jig was manufactured to align each of the fins vertically along the body tube. The root chords were attached using Loctite EA9460 due to its excellent composite bonding characteristics. With the fins attached, 0.8 in radius fillets were built up at the root chord using G5000 RocketPoxy, chosen for its long work time and flight heritage.

With the fillets completed and cured on all fins, 3 layers of plain weave 6oz fiberglass were laid between the tips of each fin pair. The layers were oriented at 90/45/90 to give the fin stiffness both in torsion and bending, and the size of each layer was staggered to avoid delamination at the fin edge and give a slight taper to the fin surface.
Before each layup was conducted, the team sanded the fins and airframe until the surfaces passed a water break test, where water spreads into a thin film rather than beading up. This test indicates that the surface energy of the fiberglass is sufficient to achieve a chemical bond with the epoxy resin, rather than simply a mechanical bond.

The fiberglass was wet with PRO-SET LAM-125/LAM-226 laminating epoxy, selected for its high strength and temperature resistance, as well as its relatively low cost compared to similarly performing epoxy resins such as Aeropoxy PR2032/PH3660. The layups were allowed to cure without the use of a vacuum bag, as the prototype fin cans demonstrated that with proper surface prep the extra adhesion force is unnecessary. Once all the layups were completed, the excess fiberglass was cut off and the fin can was sanded and painted, as seen in Figure 7.

An Ansys Composite PrepPost (ACP) static structural simulation was used to verify the fin can design. The tip-to-tip layup with three layers was verified to withstand the expected impact force on landing, which resulted in a maximum deformation of 0.00013 in and a maximum stress of 320.25 psi.

The fin flutter velocity was calculated with Equation 1, which considers the fin geometry, fin material, and atmospheric properties at the rocket’s maximum velocity [1]. The fin has a root chord of 10 in, tip chord of 4 in, semispan of 6.5 in, and thickness of 0.15 in. The maximum velocity of the rocket will occur at 2800 ft AGL. Although the fins are made of G10 fiberglass, they will also be attached to the rocket body under three layers of fiberglass layups and will have a different shear modulus than just G10 plates. The shear modulus of G10 fiberglass with a fiberglass layup can be approximated conservatively to 1,766,600 psi [2]. These parameters result in a fin flutter velocity of 1652 ft/s, providing a factor of safety over the recommended 1.2 in the newsletter.
\[ V_f = a \sqrt{\frac{g}{1.337AR^2 P(\lambda+1)}} \]  
\[ \frac{2(AR+2)}{(C_d)^3} \]  

(1)

3. Tailcone

The tailcone is a tangent ogive, with a length of 4 ¾ in, forward diameter of 6.17 in, and aft diameter of 5.3 in. These dimensions were selected based on an optimization of the tailcone within OpenRocket for the highest possible altitude. The tailcone reduces the base drag of the rocket, a phenomenon where airflow separates at the sharp end of an airframe, and becomes turbulent, creating a low-pressure zone behind the rocket. The optimization of the tailcone requires balancing this reduction in base drag, with the higher mass and skin friction drag associated with a longer tailcone.

The tailcone was custom-made using 6oz fiberglass sleeve laid up over a 3D-printed mold. As with the fin can, this manufacturing technique had never been attempted by the team before, so multiple prototype tailcones were manufactured and tested before the final tailcone was constructed.

![Figure 9. Prototype tailcone manufacturing.](image)

A mold for the tailcone was printed out of PLA, and six fiberglass sleeves were wet with PRO-SET LAM-125/LAM-226 laminating epoxy and laid over the mold. Once the epoxy was cured, the mold was heated until it released, and the excess fiberglass was cut off both ends and sanded down to be flat. Additionally, a bulkhead was made from 1/8 in G10 fiberglass and was attached inside the forward end of the tailcone using RocketPoxy as shown in Figure 10. The bulkhead is mounted to the thrust coupling, which attaches it to the fin can section.

![Figure 10. Fiberglass tailcone with epoxied bulkhead.](image)

An ACP static structural simulation was used to verify the tailcone design and whether the six fiberglass layers would be able to withstand landing forces. A load was applied to a single node to simulate the tailcone landing on a sharp edge. The maximum deformation was 0.005 in, and the maximum stress was 8614.1 psi at the node, as shown in Figure 11.
C. Couplings and Motor Retention

Traditionally, high power rockets utilize coupler tubes to provide a stiff joint between airframe sections. While couplers are flight proven, easy to manufacture, and the default choice for most in the hobby, they do offer some disadvantages. They can be frustrating to assemble, particularly when internal components are mounted inside, as three degrees of alignment are necessary to bolt through the airframe, coupler, and into the component. The stiffness of a coupler joint is also highly dependent on the diameter tolerance and length of the tube, with longer tubes required for stiffer joints. To overcome some of these issues, the team developed a machined airframe joint known internally as a coupling.

1. Couplings

The couplings operate similarly to the captive nut found on the end of a garden hose, with a freely rotating nut attached to one airframe screwing into a fixed threaded coupling on the opposite airframe, as shown in Figure 12. The couplings offer several advantages over coupler tubes; they are lighter and take up less volume in the airframe. They include standardized mounting flanges, which allow for internal components such as the airbrakes and electronics bay to be easily installed and removed. Finally, because tightening the couplings provides a preload to the airframe joint, the joint can be made much stiffer than coupler tubes and removes the need for bolts loaded in shear to hold the coupler in place.

Figure 11. Ansys simulation of von-Mises stress for tailcone.

Figure 12. Coupling assembly rendering.
Throughout the launch vehicle, there are 3 coupling joints located between the middle airframe and electronics bay, electronics bay and lower airframe, and lastly lower airframe and fin can. Each joint consists of 4 SRAD CNC machined parts made of aluminium. The fiberglass body tubes are attached to the top and bottom couplings via 3M DP8407NS methyl-methacrylate structural adhesive. This adhesive was chosen for its high shear and peel strength and superior heat resistance and ability to bond dissimilar materials compared to a two-part structural epoxy such as the Loctite EA9460 used on the fin can.

Such a design allows for guaranteed rotational alignment with the use of an alignment boss on the coupling, which only allows the airframes to be assembled in one orientation. In addition, any rolling moments the vehicle may experience throughout flight are transferred to the alignment boss rather than the threaded connection which could potentially disassemble the joint.

At 10 mph winds (nominal launch) and 20 mph winds (absolute worst case launch condition), Aquila will experience 3 and 3.25G’s of lateral acceleration respectively. This results in a maximum bending moment of 2667 in-lb for a nominal launch and 2890 in-lb for a worst-case launch, located 66 inches below the top of the nosecone. By using a discrete bending moment solver, developed by the team, a bending moment diagram was created along the rocket body.

**Figure 13. Bending moment diagram with 10 and 20 mph winds.**

We are assuming a constant bending moment value throughout the entire length of the launch vehicle equal to the maximum bending moment. Since this novel design is in its first iteration and OpenRocket, has limited accuracy, an engineering safety factor higher than normal was chosen. To counteract the bending moments and prevent the airframe joints from separating an axial preload is applied by the threaded connection. By applying a compressive preload stress equal to the maximum tensile bending stress, any tensile stresses (and thus separation) within the joint will be eliminated. This allows for a rigid and stiff joint that doesn’t deflect under bending loads. Mathematical derivations result in this relationship between preload, bending moment (M), coupling outer diameter (OD), and coupling inner diameter (ID).

\[ \text{Preload} = 8M \times \frac{OD(OD^2-ID^2)}{OD^4-ID^4} \] (2)
The launch vehicle’s ability to remain straight and resist bending throughout flights allows us to disregard aeroelastic effects, satisfying the assumptions of our flight simulations.

The couplings can be assembled to a torque specification to provide the proper preload using a torque wrench, breaker bar, and 2 custom collet wrench attachments. This airframe joint design actively prevents joint separation due to lateral loads as opposed to the standard coupler tube which offers little joint rigidity. Standardized mounting flanges allows for simple integration with internal subsystems such as the electronics bay and airbrakes module. This allows for our modular subsystems to be swapped out or moved around different parts of the rocket. Lastly, the couplings are more mass and volume efficient compared to coupler tubes, weighing 70% of its predecessor and takes up 80% less length in the rocket.

Using Ansys Mechanical solid structural, the coupling design was verified to withstand 5.34 the expected load with its failure mode being bending of the inner retaining ring flange. Since the design is in its first iteration and was already significantly lighter than the coupler tube design, a higher than desired safety factor of 5.34 was accepted. Further verification was completed by running a 3-point flexural test to expected operational loads. At the time of the test, Aquila was expected to experience 3700 in-lb of bending moment, higher than the moment for the final vehicle. The test revealed that the retaining ring had plastically deformed, and the entire joint had deflected 0.1mm when unloaded because the coupling was only torqued to only 30% of the required spec. The torquing mechanism used at the time was unable to provide the desired torque because the strap wrench used for torquing was friction based and often slipped on the coupling’s smooth surface. Faced with this deformation, the material for the retaining ring was swapped to a stronger 7075 aluminium alloy. With this change, and considering the coupling was not properly torqued we are confident in the ability of the couplings to withstand flight loads.
The team identified and overcame numerous challenges during the development of the couplings. Machining large parts like these required significant time and the development of multiple fixturing techniques to successfully achieve all the operations. Tolerancing and creating large diameter custom threads also proved to be challenging, with initial prototypes seizing due to poor surface finish, though this problem was solved with improved surface finish and the use of anti-seize grease. After the couplings were first assembled, the team discovered that the launch vehicle was not straight, due to slightly angled cuts on the airframes. To solve this issue, the airframes and couplings were strapped to a known straight spine before epoxying to ensure the concentricity of all airframes.

2. **Motor Retention System**

The motor retention system withstands thrust exerted by motor burn and retains its position throughout flight. It consists of a thrust coupling, hex standoffs, and a COTS Aero Pack motor retainer. The thrust coupling is similar in form to the airframe couplings, but without any threading. During motor burn the hex standoffs transfer the load to the flanges on the thrust coupling while being loaded in compression. These standoffs are capable of withstanding 22.4 times the peak thrust of the motor before buckling. The thrust coupling is made of aluminum 6061-T6 which has a tensile yield strength of 38,000 psi at 200 °F. The maximum stress experienced by the thrust coupling is 12,000 psi at peak thrust, resulting in a safety factor of 3.2.
Figure 18. Rendering of motor retention system.

Figure 19. Completed motor retention assembly inside tailcone.

D. Airbrakes

In 2020, the team began the research and development of a design for an airbrake mechanism that allows the rocket to accurately achieve a 10,000 ft apogee by controlling the rocket’s drag. For this year’s competition, the team iterated upon previous work by prototyping, refining, simulating, and testing the design.
4. Mechanical Design

The airbrakes are located at the top of the lower airframe and attach via the standardized coupling mounting pattern. The structure is made from machined, and waterjet cut aluminium plates, to simplify manufacturing. The upper plate holds the servo and provides the attachment point to the couplings. The central plate is rotated by the servo. Curved bearing raceways push the fins outward, sliding along linear rails attached to the lower plate.

The use of these curved slots allows for a significant degree of control over the opening characteristics of the airbrakes. By decreasing the angle of the slots, the torque required by the motor is reduced. Alternatively, the angle can be increased to result in a faster opening time. The angle of the slot can also be varied along its length to provide more torque when the airbrakes are fully extended, and a higher actuation speed when the airbrakes are closed. Due to difficulties in the mathematical modeling of the system, an equiangular slot geometry was chosen for simplicity, but a new actuator plate can be easily swapped out if desired.

The airbrakes are driven by a single GoBilda SuperSpeed Servo. The use of a single servo makes it impossible for the airbrakes to deploy asymmetrically, which could produce moments on the vehicle and cause it to go unstable. The servo hub is supported with a pillow block to prevent flight loads from causing the servo to bind. With a no-load speed of 0.035 sec/60° (290 rpm) and stall torque of 5.4 kg-cm (75 oz-in) when operating at 7.4 V, this servo met the team’s requirements for the necessary speed and torque for actuation.

The airbrake fins were machined from an aluminium plate. They include press fit bearings which fit freely into the actuator plate slots. The fins are mounted onto 7mm linear rails. These rails provide smooth movement with no binding and are more than capable of withstanding the bending moment produced by the drag on the fins during flight.
5. **Simulation**

To verify that the airbrakes would be capable of effectively controlling the apogee of the vehicle, we began by simulating a nominal flight using OpenRocket. From this trajectory, we selected a series of points that were representative of the full range of dynamic pressures the launch vehicle will experience during flight. At each of these points, we used Solidworks Flow Simulation to conduct a Computational Fluid Dynamics (CFD) analysis to determine the drag on the vehicle at multiple airbrake extensions. Using results from the simulations, we used MATLAB to determine the relationship between dynamic pressure, airbrake extension, and drag on the vehicle. The SolidWorks Flow Simulation data yielded the following final drag equation with 95% confidence bounds, with \( x \) as dynamic pressure and \( y \) as extension.

\[
D = -0.1503 + 3.646x + 0.07924y - 10.17x^2 + 2.217xy + 6.642x^3 + 2.31x^2y
\]  

(3)

Ultimately, the team determined that at maximum velocity and full extension, the airbrakes will have the capability to produce an additional drag force of about 23 pounds to the launch vehicle. The drag produced at various airbrake extensions and dynamic pressures is shown on the surface fit plot in Figure 22.

![Surface Fit of Airbrake Extension vs Dynamic Pressure vs Drag Force](image)

**Figure 22.** Surface fit of airbrake extension vs dynamic pressure vs drag force.

![Air Velocity Contour Plot of 100% Airbrake Extension](image)

**Figure 23.** Air velocity contour plot of 100% airbrake extension.

6. **Testing**

The MATLAB simulations conducted by the team showed that each fin of the airbrakes needed to withstand a maximum of about 5.6lbs of force per fin at full extension immediately after motor burnout. The team needed to determine if the servo motor could actuate the airbrakes with the maximum amount of force applied to them. The test consisted of four equal weights suspended from each airbrake using fishing wire. To prevent the wires from hitting anything below the airbrakes, the entire airbrakes mechanism was suspended on a beam of wood that was secured into a vice. Water jugs were used for weights so an exact weight of 6.72lbs per airbrake could be achieved, giving us a
20% safety margin. With the weights suspended the entire mechanism was actuated to and from full extension in 0.3 second intervals. The servo motor was successfully able to actuate the airbrakes at maximum force without stalling, verifying our design.

Figure 24. Airbrake actuation test.

7. Controls
The goal of the airbrakes controls system is to actuate the airbrakes to change the drag coefficient over the rocket to reach the target apogee of 10,000 ft. Our control system compares the drag coefficient that airbrakes produce in real-time to the drag coefficient that airbrakes need to produce to reach an apogee of 10,000 ft. A PID was chosen as a controller to take in the error between two drag coefficients and output a value of extension of the airbrakes. This way, the control system aims to converge the values of real and target drag coefficients. The control systems subteam wrote a MATLAB flight simulation to test different conditions and obtain optimal PID coefficients before the flight. CFD information was used as a source of force data to simulate the flight. The simulation also considers the system dynamics of the goBILDA Super Speed servo. For this, a transfer function of a motor is obtained through the System Identification MATLAB toolbox. Consideration of the system dynamics of an actuator improves the accuracy of a flight simulation, and therefore ensures the optimal tuning of PID coefficients.

E. Electronics
The avionics system is in the lower airframe, mounted on top of the airbrakes. The purpose of the avionics system is to gather sensor data, transmit data to the ground station, and actuate the airbrakes. The avionics system is composed of four custom made circuit boards arranged in a vertical stack. This same system will also be used in the payload self-righting mechanism.
Figure 25. A render of the avionics system structure.

These boards were designed by the electronics team using Altium Designer and manufactured by JLC PCB. Every board has four copper layers, these being a front and back signal layer, as well as a power and ground plane. The four boards in the system are the Power Board, the Telemetry Board, the Sensor Board, and the Controller Board. The Power board is responsible for regulating the battery power and distributing power to the other three boards. All boards are connected to 5V and 3.3V rails from the power board. The power board also delivers power to the airbrake servo. The Telemetry Board is designed to store and transmit data from the rocket. The board has a flash memory chip for recording data locally, and a 915MHz LoRa module for transmission to the ground station. The Sensor Board contains all the sensors for measuring the rocket’s motion. The three sensors on the board are a barometric pressure sensor, a 6 axis IMU, and a GPS module. The Controller board is tasked with the computation of the rocket’s apogee and running the control system given the sensor data. For this we are using the MicroMod modular Teensy 4.0 processor, which connects to the controller board via an M.2 connector.
Figure 26. The four avionics boards in altium (Top left - Telemetry Board, Top right – Controller Board, Bottom left – Sensor Board, Bottom right – Power Board).

The four boards in the system communicate over a Controller Area Network (CAN). Each board contains a CAN transceiver and controller chip, as well as an ATMega328 processor except for the controller board. The CAN system provides reliable communication over any number of connected nodes, allowing the system to be expanded upon with additional boards.

The boards were assembled by electronics team members using SMD reflow soldering techniques with hot air guns and a reflow oven. Key functionality of the boards such as programming the ATMega chips and CAN communication has been tested, and further testing is underway.
F. Ground Station

The ground station is primarily responsible for being able to quantify, visualize, store, and parse telemetry data live as it comes from Aquila. Along with the primary responsibilities, the ground station team is also responsible for dealing with anything and everything RF whether it be on the rocket or on the ground. The ground station will allow the team to be able to track the rocket as it progresses through its flight and as each vital state is reached. To achieve this, the ground station team has developed a fully custom front end application and backend server to feed data to multiple ground station computers.

8. Data Flow

![Data Flow Diagram]

Figure 28. Ground station data process.

Seen above in Figure 28, the flow chart details the process the ground station goes through as soon as it receives data from the rocket. As soon as a packet is received by the EByte E32 LoRa, it is sent via the USB protocol to the Teensy 4.0 Microcontroller which sends a serial stream of data to the Raspberry PI which is running the back-end.
server. The back-end server then stores the data it parses into a telemetry struct, saves that struct to a CSV file, and pushes the data as a JSON (JavaScript Object Notation) over the WebSocket for the front-end to parse.

![Figure 29. Serial data stream.]

Figure 29 shows an example of a serial packet sent by the Teensy 4.0 microcontroller to the backend server of the ground station. At the beginning and end of each packet, a 32-bit ascii sequence of “BEGB” and “ENDB” respectively are sent to guarantee a full packet is sent. In the packet itself, a three-character ascii identifier is sent before each packet of data such as “ALT” for altitude. These specific identifier sequences provide a helpful human interpretation of a serial stream and helps greatly when debugging on a large scale. All floats follow the IEEE 754 standard, and all integer values are signed following the twos complement standard.

9. Front-End

The front-end application has been developed using the power of JavaScript, Node.JS, Electron and React. With JavaScript and the tools/libraries previously mentioned, a fully functional and custom ground station has been developed to meet all the following goals set out for it! JavaScript and the Electron API were used specifically for the ease of development, as well as the multi-platform functionality they provide. The ground station application can be built and deployed for Windows (x64, x86), Mac, and Linux (x86, x64, ARM64).

![Figure 30. Ground station front-end application.]

Seen above in Figure 30, the Ground Station front-end application can scale to multiple display sizes to be as flexible as possible. The application can display the most vital information to us such as battery, temperature, rocket uptime, altitude, calculated velocity, acceleration in the $<x, y, z>$ coordinate frame of reference, and a timeline as the rocket progresses through each stage of flight. All the data on the dials or graphs, can be swapped between graph and dial with the press of a button depending on what the user would like to see. All data can be zeroed with the “zero” command in the console to display data in the reference frame of the rocket instead of earth’s frame. The ground station also comes bundled with an offline map with detailed Map Data included for New Mexico and Massachusetts.
10. Back-End

The ground station backend was developed with expansion and flexible use in mind in Java. Java was chosen for the backend due to its flexibility with machine architecture and software. Java can be used on most machines and is easily compilable to a single file which can be easily run. The backend takes advantage of object-oriented programming enabling the software to be used in any scenario, with any rocket, with any system, etc. The backend can be easily configured and re-deployed for any task requiring serial data to be parsed and used in a flexible and easy to read format. The backend server will be hosted on a Raspberry PI 4 computer which will host its own network for ground station users to connect to. Once connected, the user will initiate the WebSocket connection on the front end and telemetry data will begin to flow over the WebSocket connection. The backend server uses threaded programming to complete the tasks smoothly and continuously without any hiccups. Through thorough testing and optimization, the transmitter on the rocket can transmit at a rate of 10Hz or every 100ms and the ground station logs a datapoint at an average of every 101ms.

11. Antenna Design

The ground station team was also responsible for designing receiver and transmitter antennas to be used on the rocket and on the rocket. The ground station team eventually chose a Quadrifilar helicoidal antenna for the receiver and a blade dipole antenna for the transmitter.

The ground station team has used MATLAB for all antenna simulation and design. MATLAB has proven to be such a useful tool for dealing with antennas allowing us to analyze the theoretical standing wave ratio (SWR) as well as the theoretical gain. Figure 31 shows a picture of our vector network analyzer (VNA) connected to the transmitter antenna tuned for 915MHz. The Tx antenna was specifically chosen due to its omnidirectional nature at any and every angle to it. At all orientations, except for right at the top, this blade dipole has a gain of approximately -6dBi. Figure 32 is a picture of our prototype receiver antenna. The MATLAB Analysis of this antenna’s resonance is shown in Figure 33. It was important that the receiver antenna be resonant and wide-banded across the frequency span of 900MHz-930MHz to be able to move the radios center frequency around the 33cm band to avoid interference.
G. Recovery

The recovery system is responsible for returning the launch vehicle to the ground safely after launch. Aquila utilizes a single ended dual deployment recovery system to reduce the space taken up in the airframe and the number of separation points on the vehicle. The airframes are separated using a COTS CO₂ ejection system.

12. Parachutes and Lines

The only previous experience the team had developing a single ended ejection system was utilizing a Jolly Logic Chute Release. This system proved to be unreliable, and is disallowed at IREC, so a different solution was investigated. The team settled on a system using two redundant Tender Descenders to hold and then release the main parachute from a deployment bag.

At apogee, the airframe separates and releases the drogue parachute. The load from the drogue parachute is routed through the tender descenders, bypassing the main parachute, which remains inside its deployment bag. The drogue parachute is a 42-inch heavy duty hemispherical parachute manufactured by Spherachutes LLC and stabilizes the descent of the vehicle.

At 1500 feet, the Tender Descenders fire and allow the drogue to pull the main parachute out of its bag, and it inflates. The Tender Descenders are connected in series, such that even if one fails to separate, the main will still be able to release. The main parachute is a 120-inch toroidal parachute manufactured by The Rocketman. The main parachute slows the vehicle to a safe speed for landing and utilizes a reefing ring to reduce the opening shock load. This opening shock was estimated using a 1-DOF numerical simulation based on the opening time calculations provided in T.W. Knacke’s Parachute Recovery Systems Design Manual [5]. The maximum expected loading was calculated to be approximately 500 lb, well within the capabilities of the shock cord, quick links, and bulkheads.

Figure 36 and Figure 37 show the shock cord line diagram, and lengths used. The shock cord is sized such that with the lines taught, each connection point allows the parachute or body section to rotate through 180 degrees without impacting another component. This method results in a total shock cord length of 594 inches, comfortably above the recommended length of 3x the rocket body length.

Figure 34. Recovery system deployment stages.

Figure 35. Acceleration during main parachute deployment.
13. Ejection System

The launch vehicle uses two COTS altimeters for altitude recording and controlling recovery events. The primary altimeter is an Altus Metrum EasyMini, and the Backup altimeter is a Featherweight Raven 4. Dissimilar altimeters were chosen so that a design fault in one altimeter would not affect the operation of the other. In addition to being manufactured by different companies, the Raven includes a unique method of apogee detection, using an onboard accelerometer in addition to the more traditional barometer. As such, the redundancy of the system is improved.

Both altimeters are connected to independent power and arming circuits so that a fault in one will not impact the other. Missile Works Screw Switches are used to arm the system, as they are easy to actuate, and the action of tightening the screw protects the switch from opening during flight. Both altimeters are connected to 2S LiPo batteries, which can deliver plenty of current to fire the MJG Firewire Initiators used to ignite the Eagle CO₂ ejection systems and Tender Descenders.
The Eagle CO₂ ejection system was chosen over just black powder as a separation method for cleanliness and to reduce the exposure of recovery hardware to high temperature gases that degrades them with time. The Eagle CO₂ system can accommodate any CO₂ canister with a ¼ or 3/8-inch thread, so is used on both the payload and rocket ejection systems. Additionally, the system has proved reliable, never failing to fire in any tests. The Rocket uses a 23g cartridge for its primary charge, and a 35g cartridge for its backup, sizes validated through ejection testing.

14. Electronics Bay

In order to house the electronics needed to perform the recovery tasks, an electronics bay was designed. The bay consists of two main parts: the bulkhead and the sled. It also houses a directional antenna for the avionics system to transmit live data back to the ground station. The bulkhead, depicted in Figure 39 attaches to a couplings system and creates a seal to protect the electronics from the ejection gases.
The plate contains the attachment points for the CO₂ system, eye nut, and sled, as well as sealed through holes for wires. The bulkhead is CNC milled out of 6061-T6 aluminum for strength as all parachute lines attach to the eye nut on the bulkhead. In order to optimize the topology of the plate and reduce weight, SOLIDWORKS Simulation was used to determine where pocketing could occur.

![Figure 39. Electronics bay bulkhead.](image)

The sled was designed in a semi-hexagonal shape in order to maximize space and have several flat surfaces to mount the recovery electronics to. The Big Red Bee GPS and antenna are mounted on the front center section of the plate. On each side of it is a recovery electronics system, almost identical aside from a different primary and backup altimeters, the Raven 4 and EasyMini 2.0 respectively. Both electronics systems have a screw arming switch and connect to their two cell LiPo battery via XT30 connectors. Each battery is housed on the back slide of the sled by sliding it in through a slot within the bottom support where an endcap screw can be removed and replaced for easy access.

![Figure 40. Machined electronics bay bulkhead in coupling.](image)
The sled is 3D printed out of polycarbonate as it is not a structural piece but needs to withstand a range of extreme temperatures. The two supports that slot into the back of the sled are made of CNC routed G10 fiberglass. The sled and supports are epoxied together, and heat set inserts are added to secure all the electronic components. To connect the sled to the bulkhead, two four-inch standoffs go through the top and bottom support and bolts on either side secure them at each end.

H. Payload

The 11-pound Tarazed payload is a functional and deployed folding-arm quadcopter designed to complete the mission of autonomously locating the launch vehicle after landing. The quadcopter is stowed in a retention system in the upper airframe of the launch vehicle during ascent, attached to the nosecone for deployment.
15. Payload Retention and Deployment

The structure of the payload retention system consists of a spine of 6061-T6 aluminum T bar extrusion with #8 clearance holes drilled every inch for retention system mounting. Aluminum bulkheads are attached to both ends of the spine using pairs of aluminum brackets. To verify that this system could withstand landing forces we utilized SolidWorks Simulation to ensure a factor of safety of at least 2. To increase overall rigidity, two 3D printed polycarbonate brackets were also added to either end of the spine to limit bending even further. This skeleton was chosen for the payload to have a significant amount of open room and adaptability to place our different sub-systems. This design allowed us to design and construct each module separately and then mount them independently to the spine.

The payload ejects from the rocket at 1,400 ft, after the main parachute has deployed. The payload ejection system consists of a recovery bay similar to the main rocket recovery bay, where the altimeters (a PerfectFlite StratoLogger CF and a Featherweight Raven 4), the Eagle CO₂ system, and an eye nut are mounted to a 1/8th in fiberglass bulkhead plate. A 35g CO₂ cartridge is used as the primary deployment charge and a 45g CO₂ cartridge is used as a backup to ensure successful deployment. Above the payload recovery bay is a piston consisting of a cut fiberglass coupler tube epoxied to a fiberglass bulkhead plate. The piston helps form a seal, providing a more constant ejection force on the payload while also protecting the payload electronics from ejection gases. To prevent the piston from separating from the rocket, shock cord is mounted from an eye bolt on the piston to the eye bolt on the payload recovery bay.
A 9 ft Rocketman Ultra-Light Parabolic Parachute is used to slow the payload down to its descent rate of 15ft/s. It is packed between the piston and the payload retention system. The shock cord runs through a slot across the top of the payload retention system to just under the nosecone, where it is attached to a parachute release mechanism. To reduce the risk of the payload dragging or an improper deployment, a quick link attached to the parachute’s shock cord is attached to a removable pin. This system consists of a milled 6061-T6 aluminum U bracket and turned pin along with 3D printed polycarbonate servo mount and servo horn adapter. This ¼ inch diameter pin will be manipulated by an HS-5087MH servo. To translate rational motion to linear motion a slider-crank mechanism was created using a combination of 3D printed polycarbonate and machined aluminum links. Upon detection of landing, the payload will actuate the servo and detach the parachute. There are currently implementation issues with this mechanism and other designs such as COTS rotary latches are being researched.

**Figure 45. Payload parachute release mechanism.**

A payload stabilization system is implemented with two main objectives: lock the payload retention bay during ascent and provide a stable base for the quadcopter. Once ejected from the rocket, four legs on either end of the payload retention bay spring from a locking position into one perpendicular to the rest of the payload. These eight legs are made from 1/8" in CNC routed G10 fiberglass measuring 5 inches in length. The legs are mounted to 3D printed polycarbonate bases with 6061-T6 aluminum shafts and dowel pins to accommodate the torsion springs used to actuate the mechanism. One base is modified to house a rocker switch to power on the payload electronics once deployed from the airframe.

**Figure 46. Payload stabilization leg assembly.**

Once landed safely on the ground, the stabilization system is capable of rotating the quadcopter to a level position for takeoff. The self-righting mechanism of the stabilization system consists of two sets of CNC milled 6061-T6 aluminum bulkheads on either side of the payload retention system, connected with a custom D-shaft. Thrust bearings between the plates are used to reduce friction and provide consistent rotational motion for the mechanism. One side
is powered by a goBILDA Super Speed servo coupled to the D-shaft, driving the rotational motion with feedback from a microcontroller.

Figure 47. Payload stabilization rotation assembly.

An arm deployment mechanism holds the quadcopter’s arms in place during ascent and descent and unfolds them once visual confirmation of a safe landing is made. The mechanism works with two identical modules, each unfolding two arms of the quadcopter. Each module consists of two steel 8mm REX (rounded hex) shafts, a HS-311 servo, and four linear extension springs. This is in addition to 3D printed polycarbonate parts including a two-sided rack and pinion, two lever arms, and an upper and lower retaining plate. During ascent, the servo is in the locked position with an aluminum servo horn retaining the rack. When the microcontroller signals, the servo rotates, releasing the rack and allowing the springs to pull it towards the center of the payload. This causes the pinion gears to turn the shafts and lever arms, pulling out the quadcopter arms until the rack hits hard stop on the upper plate and the arms are locked in place by pins on the quadcopter. All bolts are screwed into the plastic using brass heat-set threaded inserts.

The final component of the quadcopter arm deployment is the quadcopter gripper. This system’s purpose is to hold the body of the quadcopter steady throughout ascent. The system utilizes a goBILDA Torque servo, and an assortment of polycarbonate 3D printed parts, including an idler gear, drive gear, and two geared gripper arms. The ratio between the idler gear and the drive gear is a ratio of 18:23. All but the driven gear are mounted with shoulder screws, sleeve bearings, and washers for precision rotation and limited friction. The driven gear is connected directly to servo via a screw and heat set bronze gear servo horn. The quadcopter is further held in place by the bolt heads protruding from the bottom of the quadcopter into the gripper base. These two features make it such that the quadcopter is retained in

Figure 48. Top view of payload arm deployment mechanism with gears and rack shown in yellow.
all axes of motion. Once the arms of the quadcopter unfold and the quadcopter boots up, the gripper releases the quadcopter to complete the mission.

![Section view of quadcopter gripper.](image)

**Figure 49. Section view of quadcopter gripper.**

16. **Quadcopter**

The quadcopter consists of a frame made from two main sections of carbon fiber plates. The first section is the bottom plate sandwich, with two identical 2mm carbon fiber main plates on the outside and the 3mm carbon fiber quadcopter arms laser cut wood spacer mid plate on the inside. The other section is the 2mm carbon fiber top plate and is attached to the bottom plate sandwich with seven 4-40 threaded aluminum standoffs. The quadcopter’s main flight electronics are housed in the space between these two sections, with the battery being attached to the top plate using VELCRO pads and straps.

![Quadcopter in the Unfolded Configuration.](image)

**Figure 50. Quadcopter in the Unfolded Configuration.**
The size of the quadcopter was determined using eCalc, an online unmanned aerial vehicle (UAV) flight simulation tool. This tool allowed us to simulate flight time with different quadcopter sizes and specifications, helping us choose our vehicle size and powertrain. Using this tool, the best option allowing the quadcopter to fold up inside of the rocket used 6.7 in folding propellers and a 6s 1800 mAh LiPo battery.

The quadcopter arms fold inward to fit inside the launch vehicle’s airframe. A shoulder bolt was used as a vertical pivot at the base of the arm, allowing for smooth and reliable arm deployment. To lock the arms in place once deployed, three machined aluminum pins are pushed by a spring into matching holes in the quadcopter arms and main body plates. The pins are epoxied into a 3D printed polycarbonate pin carrier that retains the pins and distributes the force of the spring onto the pins, creating the desired locking motion.

Other prominent features of the quadcopter include electronics mounts, with 30.5 mm and 20 mm square hole patterns to mount common COTS UAV electronics found with such hole pattern. A 3D printed camera mount is on the front of the quad and slides over the standoffs, allowing for a RunCam Hybrid 2 to be angled for various viewing angles. 3D printed antenna mounts are affixed on the front and back of the quadcopter for the GPS, LoRa receiver antenna, and FrSky receiver antennas. The LoRa receiver antenna is a directional antenna that receives the rockets telemetry transmission. Because it is directional, it is used for finding the relative direction to the rocket and provides a basis for our navigation algorithm.

IV. Mission Concept of Operations Overview

The vehicles flight is split into 8 phases described here.
Figure 52. Flight profile diagram.

**Phase 1:** In phase 1 the vehicle is on the launch rail before motor ignition. In this phase the avionics system has been activated, the rocket and payload altimeters have been armed, and the ignitor has been installed into the motor and connected. The vehicle is ready for launch.

**Phase 2:** In phase 2 the motor has been ignited and the vehicle is flying under thrust. This phase will last approximately 5.5 seconds, until the motor burns out. During this time, the altimeters and avionics system will detect launch and begin recording data. The airbrakes will not be activated during this phase.

**Phase 3:** In phase 3 the motor has burnt out and the vehicle is coasting to apogee. During this phase, the altimeters will continue to record flight data. The avionics system will be analyzing sensor data to estimate the state of the vehicle and use this data to control the airbrakes.

**Phase 4:** In phase 4 the vehicle has reached apogee and the altimeters have detected apogee. The primary rocket altimeter will fire to separate the vehicle and release the drogue, with the backup altimeter firing 1 second after apogee is detected. The airbrakes will fully retract at this stage to avoid tangling the lines.

**Phase 5:** In phase 5 the vehicle is descending under drogue parachute. The altimeters are continuing to record data to prepare for main parachute deployment.

**Phase 6:** At 1500 ft the vehicle reaches phase 6, where the main parachute is deployed. The primary and backup altimeters fire both Tender Descenders with no delay to allow the drogue to pull the main parachute from its deployment bag.

**Phase 7:** At phase 7 and 1400 feet, the payload altimeters fire to release the payload. The payload and nosecone drop away completely from the rocket.

**Phase 8:** In phase 8, the rocket and payload are descending separately under their own parachutes.

**Phase 9:** In phase 9, both the rocket and payload have landed. All altimeters cease data recording and begin reporting apogee using beep codes. When the recovery teams arrive, they will activate the payload system, which will carry out its autonomous mission. Once complete, the team will recover the rocket.
V. Conclusions and Lessons Learned

For knowledge transfer from more experienced members to new team members, the team takes various approaches to continue the education of its members. The first resource team members can use is the team’s prior technical documents and technical resources found in the team’s shared file system. This file system contains years of competition documents, technical reports, and information that can be used. The team has also created a team wiki where team members have written short posts about the work they have done and the lessons they learned in the process. In the summer, the team regularly runs a series of team workshops based upon team interests. Last summer, the team ran workshops on CAD, CNC, and FEA software. The workshops are multi-day sessions which provide the basic information required to use a desired skill. The team also runs more basic workshops during the beginning of the school year intended to help bring new students up to speed on the team’s resources. As an organizational structure, subteam leads, who are usually second year students and older, act as experienced members to teach newer members.

Many of the lessons the team learned this year were a result of a large growth in team size. At our first interest meeting of the year, we had over 250 students attend. Over the consecutive meetings we slowly lost more team members as most clubs at our school do but we still had too many team members for the work at hand. Subteam leads often had to lead teams of 20 students which is too large for adequate education and available tasks. While we must remain inclusive as a club on campus to receive institutional funding, we are looking for ways to better manage large engineering groups and still provide a quality education to any student who wants to participate. We are hoping to include some early design projects such as Level 1 rockets and small machining operations to new students so they can work on skills which can be applied to the rocket and payload at a later date. We have also been struggling to find a good classification for our electronics groups in the team structure. The issue is that electronic systems are a key part of mechanical components and yet they also have standalone components such as the PCB boards and ground station equipment. We are currently investigating better ways to manage our electronics groups in conjunction with our mechanical design.

Appendix

A. System Weights, Measurements, and Performance Data

Rocket Information:

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<td>Center of Gravity [inches]</td>
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<td>Maximum Acceleration [G]</td>
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<td>Maximum Velocity [ft/s]</td>
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<td>PerfectFlite StratoLogger CF Backup</td>
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<td>45g CO$_2$ Backup</td>
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Recovery Information:

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<th>Altus Metrum EasyMini</th>
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<td>Redundant Altimeter</td>
<td>Featherweight Raven 4</td>
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<td>Drogue Primary &amp; Backup Deployment Charges [g]</td>
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<td>Main Primary &amp; Backup Deployment Charges [g]</td>
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<td>Drogue Decent Rate [ft/s]</td>
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<td>Main Decent Rate [ft/s]</td>
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B. Project Test Reports

Full-Scale Ground Test

Conducted by: Cameron Best, Thierry de Crespigny, Henry Lambert, Troy Otter, Terence Tan, Aunika Yasui

Date: 4/30/2022

Objective: To test the amount of CO$_2$ needed to separate the middle and upper airframes for the first recovery event.

Test Variable: Success or failure of rocket separation.

Methodology: The Eagle CO$_2$ is manually triggered causing the rocket to separate between the middle and upper airframes.

Success Criteria: The rocket separates between the middle and upper airframes and drogue is pulled out with no damage.
**Procedure:**
1. Load CO\textsubscript{2} system with black powder
2. Assemble the recovery bay into the avionics bay airframe
3. Connect a LiPo battery to the black powder e-match and detonate from a far distance
4. If the rocket does not separate, increase the amount of CO\textsubscript{2} and repeat

**Data:**
23g cartridge: Successful

**Success Criteria Met:** Yes

**Impact:** The minimum size CO\textsubscript{2} cartridge needed to separate the rocket was chosen

**Full-Scale Flight Test**

**Conducted by:** Henry Lambert, Aunika Yasui, Kevin Shultz, Cameron Best, Terence Tan, Kelli Huang, Haggay Vardi, Peter Detch, Daniel Pearson, Abby Hyde, Brad Miller, Max Schrader, Cameron McAfee, Max Friedman, Evan Mandel

**Date:** 4/2/2022

**Objective:** To test the single end dual deployment parachute system.

**Test Variable:** Success or failure of drogue and main parachute deployment.

**Methodology:** The new parachute ejection system is put onto last year’s rocket and triggered at apogee and 1,000 ft with a StratoLogger and Raven 4 altimeter.

**Success Criteria:** Both the drogue and main parachute are deployed at the correct altitudes.

**Procedure**
1. Load 5g primary black powder charge and 6g backup black powder charge
2. Load 0.3g of black powder in primary tender descender and 0.8g of black powder into backup tender descender
3. Assemble the recovery bay into the airframe
4. Load the parachutes and their lines
5. Assemble the rocket and mount onto the launch rod
6. Arm the avionics and recovery systems
7. Launch the rocket and observe for parachute deployment
8. Retrieve the rocket

**Data:**
Drogue deployment at 5715 ft and main deployment at 1000 ft.
Success Criteria Met: Yes

Impact: The new single end dual deployment system worked, allowing us to move forward with the design.

Payload Ejection Test

Conducted by: Cameron Best, Thierry de Crespigny, Henry Lambert, Troy Otter, Terence Tan

Date: 4/30/2022

Objective: To test the amount of CO2 necessary to eject the payload from the upper airframe.

Test Variable: Success or failure of payload ejection

Methodology: Eagle CO2 system is manually triggered, causing the payload to eject without damaging any components.

Success Criteria: The payload ejects without damage to any of the components.

Procedure:
1. Load CO2 system with black powder
2. Assemble upper airframe and payload horizontally
3. Manually detonate CO2 system using a LiPo battery. Ensure nobody is too close to the rocket to ensure safety.
4. If payload does not eject, increase the amount of CO2 and try again

Data:
16g cartridge: Unsuccessful
23g cartridge: Unsuccessful
35g cartridge: Successful

Success Criteria Met: Yes

Impact:
The necessary mass of the CO2 system was chosen, allowing us to move forward with more accurate mass estimates.
C. Hazard Analysis

### Hazard Probability Definitions

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<th>Description</th>
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<td>The condition is probable if it is not mitigated.</td>
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<tr>
<td>B</td>
<td>The condition may occur if it is not mitigated.</td>
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<tr>
<td>C</td>
<td>The condition is unlikely to happen if it is not mitigated.</td>
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<tr>
<td>D</td>
<td>The condition is highly unlikely to happen if it is not mitigated.</td>
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### Hazard Severity Definitions

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<tbody>
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<td>I</td>
<td>The condition may cause death or permanent disability to personnel or loss of the system.</td>
</tr>
<tr>
<td>II</td>
<td>The condition may cause major injuries or significant damage to the system.</td>
</tr>
<tr>
<td>III</td>
<td>The condition may cause injury or minor damage to the system.</td>
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<tr>
<td>IV</td>
<td>The condition may cause minor injury or negligible damage to the system.</td>
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### Hazard Analysis

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<th>Hazard Analysis</th>
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<td>C - Unlikely</td>
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</tr>
<tr>
<td>D – Highly Unlikely</td>
<td>DI</td>
</tr>
<tr>
<td>Section</td>
<td>Hazard</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Construction</td>
<td>Hand Tool Injury</td>
</tr>
<tr>
<td>Fire</td>
<td>Human error, short circuit amongst any other event that could cause a fire to start.</td>
</tr>
<tr>
<td>Objects from potential fire hazards.</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Electric Shock</strong></td>
<td></td>
</tr>
<tr>
<td>Member coming in contact with an exposed wire.</td>
<td></td>
</tr>
<tr>
<td>Burns, and in extreme cases, death from electrocution.</td>
<td></td>
</tr>
<tr>
<td><strong>DII</strong></td>
<td></td>
</tr>
<tr>
<td>Members will inspect all wires before working with them and not deal with live wires often, if at all.</td>
<td></td>
</tr>
<tr>
<td><strong>HPRC</strong></td>
<td></td>
</tr>
<tr>
<td>Members will perform an analysis of wires.</td>
<td></td>
</tr>
<tr>
<td><strong>Chemical Exposure to epoxy</strong></td>
<td></td>
</tr>
<tr>
<td>Improper PPE worn during construction.</td>
<td></td>
</tr>
<tr>
<td>Eye and skin irritation; prolonged and repetitive skin contact can cause chemical burns.</td>
<td></td>
</tr>
<tr>
<td><strong>BIV</strong></td>
<td></td>
</tr>
<tr>
<td>During work with epoxy, members will wear proper PPE including safety goggles, gloves, and clothes that protect the skin from encountering the material.</td>
<td></td>
</tr>
<tr>
<td><strong>MSDS</strong></td>
<td></td>
</tr>
<tr>
<td>Sheet for epoxy will be consulted and members will be wearing proper PPE.</td>
<td></td>
</tr>
<tr>
<td><strong>Exposure to carbon fiber/ fiberglass dust and debris</strong></td>
<td></td>
</tr>
<tr>
<td>Sanding, using a Dremel tool, machining carbon fiber/ fiberglass.</td>
<td></td>
</tr>
<tr>
<td>Eye, skin and respiratory tract irritation.</td>
<td></td>
</tr>
<tr>
<td><strong>CII</strong></td>
<td></td>
</tr>
<tr>
<td>During work with carbon fiber/ fiberglass members will wear proper PPE including safety goggles, gloves, long pants and long sleeve shirt, as well as a mask to protect their lungs.</td>
<td></td>
</tr>
<tr>
<td><strong>MSDS</strong></td>
<td></td>
</tr>
<tr>
<td>Sheet for each material will be consulted to make sure members are wearing proper PPE.</td>
<td></td>
</tr>
<tr>
<td>Exposure to black powder</td>
<td>Loading charges for stage separations or any other contact with black powder.</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Exposure to LiPo battery leakage.</td>
<td>Chemical burns if contacts skin or eyes.</td>
</tr>
<tr>
<td>Exposure to APCP motor damage.</td>
<td>Eye irritation, skin irritation.</td>
</tr>
<tr>
<td>Launch Injuries due to recovery system failure</td>
<td>Parachute or altimeter failure</td>
</tr>
<tr>
<td>Injuries due to the motor ejection from launch vehicle</td>
<td>Motor installed and secured improperly.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Injuries from premature ignition of separation charges</td>
<td>Improper installation of igniters, stray voltage.</td>
</tr>
<tr>
<td>Injuries due to a premature motor ignition</td>
<td>Improper storage of the motor, damage of the motor or</td>
</tr>
</tbody>
</table>
Injuries due to unpredictable flight path  
Wind, faulty parachute, or instability in thrust.  
If the rocket goes in unexpected areas, it could injure personnel or spectators.  
The rocket will not be launched during strong winds, the rocket design will be tested through simulations to make sure that it is stable during flight.  
Weather conditions will be assessed, the rocket will be launched only if the RSO considers the weather safe. Multiple simulations will be run to ensure that the rocket is stable.

### D. Risk Assessment

**Risk Probability Definitions**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The failure is probable if it is not mitigated.</td>
</tr>
<tr>
<td>B</td>
<td>The failure may occur if it is not mitigated.</td>
</tr>
<tr>
<td>C</td>
<td>The failure is unlikely to happen if it is not mitigated.</td>
</tr>
<tr>
<td>D</td>
<td>The failure is highly unlikely to happen if it is not mitigated.</td>
</tr>
</tbody>
</table>

**Risk Severity Definitions**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Complete loss of the item or system.</td>
</tr>
<tr>
<td>II</td>
<td>Significant damage to the item or system. Item requires major repairs or replacement before it can be used again.</td>
</tr>
</tbody>
</table>
### III
Damage to the item or system which requires minor repairs or replacement before it can be used again.

### IV
Damage is negligible.

#### F. Risk Analysis

<table>
<thead>
<tr>
<th>Severity</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - Irrecoverable</td>
<td>A – Probable</td>
</tr>
<tr>
<td>II - Significant</td>
<td>B – May Occur</td>
</tr>
<tr>
<td>III - Minor</td>
<td>C - Unlikely</td>
</tr>
<tr>
<td>IV – Negligible</td>
<td>D – Highly Unlikely</td>
</tr>
</tbody>
</table>

#### G. Risk Analysis: Launch Vehicle

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Probability/ Severity</th>
<th>Mitigation &amp; Controls</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle does not separate at apogee</td>
<td>Insufficient ejection charge, altimeter failure</td>
<td>The rocket would descend at a dangerous terminal velocity. If the main parachute deploys at this speed, the airframe will most likely be severely damaged and the payload cannot safely deploy.</td>
<td>CI</td>
<td>Calculate appropriate ejection charge sizing, and ensure the correct quantity of CO2 is used</td>
<td>Testing of the recovery system. Ground Ejection Test.</td>
</tr>
<tr>
<td>Drogue parachute does not inflate</td>
<td>The parachute may not be packed properly, or it might be too tight of a fit in the airframe.</td>
<td>The rocket would descend more rapidly than anticipated velocity. If the main parachute deploys at this speed, the airframe and vehicle will most likely sustain minor damage</td>
<td>CII</td>
<td>The drogue parachute will be properly sized and have a redundant system to deploy it.</td>
<td>Testing of the recovery system using last year’s rocket.</td>
</tr>
<tr>
<td>Parachute detaches from launch vehicle</td>
<td>Improper installation of the recovery system</td>
<td>This would result in the probable destruction of the rocket and its components upon ground</td>
<td>DII</td>
<td>Proper installation of the recovery system and select correct sizes of hardware to</td>
<td>Testing of recovery system including a ground ejection test and a full-scale test using</td>
</tr>
<tr>
<td>Issue</td>
<td>Description</td>
<td>Solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main parachute does not deploy</td>
<td>The parachute may not be packed properly, or it might be too tight of a fit in the airframe.</td>
<td>CII The main parachute will be properly sized and also have multiple systems to deploy it. Testing of the recovery system including a full-scale test using last year’s rocket.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melted or damaged parachute</td>
<td>The parachute bay is not properly sealed, or the parachutes are not packed correctly.</td>
<td>DII Proper protection and packing of the parachutes. Testing of recovery system including a full-scale launch using last year’s rocket.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shock cord tangles</td>
<td>Parachutes are not packed properly.</td>
<td>CII Properly pack the parachutes.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics bay is not secured properly</td>
<td>Electronic bay does not fit tightly into the airframe.</td>
<td>DII Manufacture the electronics bay to fit accurately within the airframe. Design Physical testing of the couplings to ensure tight fit of the airframes with minimal...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident</td>
<td>Cause</td>
<td>Recommendation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor ejected from launch vehicle</td>
<td>The motor is secured improperly.</td>
<td>The motor will be installed by a certified mentor. The motor retention system will also be inspected prior to launching the rocket. Conduct a thorough Finite Element Analysis of the motor retention system. Combine commercial retainers with the manufactured parts to increase the safety factor.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fins break off during ascent</td>
<td>Large aerodynamic forces or poor fin design</td>
<td>Mount fins properly onto the airframe.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail buttons fail during launch</td>
<td>Unexpected forces, damage to attachment components</td>
<td>Calculate expected loads on rail buttons &amp; attachment hardware, conduct qualitative “hang” test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch rail/tower fails</td>
<td>Poorly maintained equipment, improper setup</td>
<td>Launch tower will be setup and maintained by a responsible person at the launch club, and inspected by the ERS equipment, so no prior testing will take place</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Couplings to allow a simple, reliable installation of the electronics bay.**

**Movement of any attachable part.**
<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Preventive Measure</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airframe separates during ascent</td>
<td>Improper connection of airframe sections; large aerodynamic forces cause the airframe to separate</td>
<td>Rocket cannot be relaunched, damage to airframe or internal components</td>
<td>Complete analysis of coupling and material strength testing. Conduct a physical static load test to simulate expected in-flight loads.</td>
</tr>
<tr>
<td>Altimeter failure</td>
<td>Loss of power, low battery, disconnected wires, destruction by black powder charge, or burnt by charge detonation</td>
<td>Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload not deploying from rocket.</td>
<td>There will be a backup altimeter with a second power source in case the main altimeter fails. There will also be a set of backup CO2 charges connected to the backup altimeter. Both altimeters will also be tested before launch.</td>
</tr>
<tr>
<td>Altimeter switch failure</td>
<td>Switch comes loose or disarms during launch or component failure</td>
<td>Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload not deploying from rocket.</td>
<td>Test switches before launch. Altimeter testing included in full-scale testing of last year’s rocket.</td>
</tr>
<tr>
<td>Recovery electronics bay failure</td>
<td>Loss of power, disconnected wires, destruction by black powder or CO2 charge, or burnt by charge detonation</td>
<td>Altimeter or recovery system failure</td>
<td>Test the electronic bay and altimeter before launch. Full-scale test of electronics on last-year’s rocket.</td>
</tr>
<tr>
<td>Descent too fast</td>
<td>Parachute is too small</td>
<td>Potential damage or loss</td>
<td>Properly size parachute; test. Testing of recovery system.</td>
</tr>
</tbody>
</table>

**Notes:**
- **DI** indicates a thorough analysis and testing to ensure the system’s capability to withstand expected loads.
- **DII** indicates supplementary testing and validation measures to ensure reliability.
<table>
<thead>
<tr>
<th>Incident</th>
<th>Description</th>
<th>Severity</th>
<th>Precaution</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Misfire</td>
<td>Damaged motor or damage to ignitor prior to launch.</td>
<td>DI</td>
<td>The motor is only handled by a certified team mentor. If there is a misfire, the team will wait at least 60 seconds before approaching the launch vehicle and will follow the instructions of the RSO.</td>
<td>There will be no prior verifications or testing.</td>
</tr>
<tr>
<td>Premature motor ignition</td>
<td>Damaged motor or accidental early ignition.</td>
<td>DII</td>
<td>The motor will be replaced. It will be properly installed by a certified mentor and inspected by the RSO.</td>
<td>There will be no prior verifications or testing.</td>
</tr>
<tr>
<td>Motor fails to ignite</td>
<td>Ground support equipment failure, faulty or damaged motor</td>
<td>DIII</td>
<td>The ground support equipment will be maintained by responsible persons from the launch site club. The motor will be stored according to specified guidelines.</td>
<td>Igniters testing in launch site.</td>
</tr>
<tr>
<td>Premature ejection charge detonation</td>
<td>Inadvertent arming, recovery electronics failure</td>
<td>DII</td>
<td>Arming switches will be locking, and detailed instructions will be kept and followed pertaining to the arming process.</td>
<td>Full scale testing</td>
</tr>
<tr>
<td>Shock cord is severed</td>
<td>Faulty shock cord, weak cord from repeated testing, destruction by</td>
<td>DI</td>
<td>The shock cord will be properly sized to handle ejection loads. It</td>
<td>Testing of recovery system including a full-scale test using</td>
</tr>
</tbody>
</table>

**Experiment**

al Sounding Rocket Association
<table>
<thead>
<tr>
<th>Issue</th>
<th>Cause/Description</th>
<th>Mitigation</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fins do not keep the rocket stable</td>
<td>Black powder charge, or burnt by charge detonation</td>
<td>Payload could potentially still deploy.</td>
<td>Will also be inspected before the parachutes are packed. A Nomex blanket will protect the shock cord from fire damage and the black powder charges will be measured carefully.</td>
</tr>
<tr>
<td>Fins break off during landing</td>
<td>High impact during landing; point stresses on fins</td>
<td>Rocket cannot be relaunched</td>
<td>Avoid fin designs with weak points and test fins with forces of final descent velocity</td>
</tr>
<tr>
<td>Descent too slow</td>
<td>Parachute is too large</td>
<td>Properly size parachute; test recovery system before launch.</td>
<td>Material testing of the fins.</td>
</tr>
<tr>
<td>Pressure not equalized inside airframe</td>
<td>Vent holes are too small</td>
<td>The vent holes will be drilled according to recommendations determined by external testing</td>
<td>Inspection and verification by Rocket and Aerostructure team leads.</td>
</tr>
<tr>
<td>Airbrakes fail to deploy or deploy incorrectly</td>
<td>Electrical or software failure, mechanical parts become stuck</td>
<td>The airbrake system will be tested prior to launch using simulated flight data, and hardware in the loop testing. Mechanical actuation will be tested for the first time during launch.</td>
<td>Airbrakes performance will not be verified prior to the competition, and will be tested for the first time during launch.</td>
</tr>
</tbody>
</table>
### Airbrakes deploy asymmetrically

**Driving plate or fin pins fail in one section but not others**

**Vehicle experiences unexpected loads and flight forces, causing an unpredictable trajectory or damage to other components**

**DII**

- Conduct analysis of part mechanical strength.
- Airbrake system is designed to force all fins to deploy evenly when there is no damage to parts.

Airbrakes performance will not be verified prior to the competition, and will be tested for the first time during launch.

### Rocket Catches on Fire

**High temperatures, short circuits, physical damage**

**Significant damage to vehicle, danger to personnel in vicinity due to energetics or harmful gases**

**DII**

- Temperature monitored during launches, components tested independently, electronics protected from damage.

No way to verify, but will be monitored and safety precautions will be taken as necessary.

### Avionics systems fail

**Damaged components, faulty power system**

**Vehicle overshoots expected apogee, flight data is not recorded. GPS positions are not transmitted, causing possible loss of vehicle**

**CIII**

- Test avionics systems before launch, verify functionality.

Avionics systems testing and full-scale testing using last year’s rocket.

### Payload comes loose in payload bay

**Damaged components, improperly designed retention system**

**Minor damage to vehicle, alteration of flight path**

**CIII**

- Perform analysis of payload retention system under expected flight loads, and test strength prior to launch.

Independent payload testing.

### Risk Analysis: Payload

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Probability /Severity</th>
<th>Mitigation &amp; Controls</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Causal</td>
<td>Effect</td>
<td>Probability /Severity</td>
<td>Mitigation &amp; Controls</td>
<td>Verification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Probability /Severity</th>
<th>Mitigation &amp; Controls</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Causal</td>
<td>Effect</td>
<td>Probability /Severity</td>
<td>Mitigation &amp; Controls</td>
<td>Verification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Probability /Severity</th>
<th>Mitigation &amp; Controls</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Causal</td>
<td>Effect</td>
<td>Probability /Severity</td>
<td>Mitigation &amp; Controls</td>
<td>Verification</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Payload retention failure</th>
<th>Incorrect programming of the altimeters, or severe damage to the upper airframe and retention pins</th>
<th>Payload deploys prior to apogee</th>
<th>DI</th>
<th>Inspection of upper airframe and retention pins prior to flight. Verification of the altimeter programming by team leads</th>
<th>WPI HPRC will create a payload inspection checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retention system becomes insecure</td>
<td>Damage to retention pins</td>
<td>Payload rattles within upper airframe and causes damage to itself</td>
<td>DII</td>
<td>Inspection of upper airframe and retention pins prior to flight</td>
<td>WPI HPRC will create a payload inspection checklist</td>
</tr>
<tr>
<td>Payload Ejection failure</td>
<td>Incomplete separation of upper airframe</td>
<td>Potential launch vehicle tumbling that could affect proper decent</td>
<td>DI</td>
<td>Inspection of CO2 charges and wiring and reduce friction between payload and upper airframe</td>
<td>Payload ejection test using expected CO2 charges.</td>
</tr>
<tr>
<td>Payload becomes damaged during ejection process</td>
<td>Excessive forces on shock cord during deployment</td>
<td>Payload is damaged</td>
<td>DII</td>
<td>Inspection of shock cord and computed simulations.</td>
<td>Recovery system full-scale test using last year’s rocket</td>
</tr>
<tr>
<td>Battery catches fire</td>
<td>Overheating of the internals of the payload during launch or outside temperature, faulty battery, incorrect wiring leading to an ignition, ignition within rocket that impacts the security of the payload</td>
<td>The rocket catches on fire and burns during launch, the rocket becomes ballistic and could hurt the environment or people in the crowd, the drone is destroyed and unable to complete its mission</td>
<td>DI</td>
<td>WPI HPRC will design the quadcopter and retention system to be well ventilated to prevent overheating. The payload recovery bay and GPS will be the only batteries turned on during launch to minimize overheating possibilities</td>
<td>The quadcopter will be run at acceptable levels to not overexert the battery's</td>
</tr>
</tbody>
</table>

I. Assembly, Pre-Flight, Launch and Recovery Checklists
**Lower Airframe Assembly Checklist**

<table>
<thead>
<tr>
<th>#</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inspect the tailcone, fin can, and lower airframe for damage.</td>
</tr>
<tr>
<td>2</td>
<td>Connect the tailcone to the lower airframe via the coupling. Torque the coupling.</td>
</tr>
<tr>
<td>3</td>
<td>Ensure the 3S LiPo battery for the avionics system is fully charged using a LiPo tester. The voltage should be around 12.6V. A battery measuring less than 12.3V should be charged before use.</td>
</tr>
<tr>
<td>4</td>
<td>Install the battery to the battery mount. Secure with the Velcro strap.</td>
</tr>
<tr>
<td>5</td>
<td>Connect the battery to the avionics stack. Power on the stack to confirm operation.</td>
</tr>
<tr>
<td>6</td>
<td>Power off the avionics stack.</td>
</tr>
<tr>
<td>7</td>
<td>Install the airbrakes into the lower airframe via the coupling. Ensure the fins can freely extend.</td>
</tr>
</tbody>
</table>

**Vehicle Assembly Checklist**

<table>
<thead>
<tr>
<th>#</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Lower Airframe, Payload, and Recovery Systems Assembly Checklists should have been completed before beginning this checklist.</td>
</tr>
<tr>
<td>2</td>
<td>Connect the recovery quick link to the upper airframe coupler bulkhead</td>
</tr>
<tr>
<td>3</td>
<td>Connect the upper airframe and payload to the middle airframe via the coupler tube. Install 2 #2 shear pins.</td>
</tr>
<tr>
<td>4</td>
<td>Activate the vibration datalogger</td>
</tr>
<tr>
<td>5</td>
<td>Install the assembled motor and secure the motor retention system.</td>
</tr>
</tbody>
</table>

**Preflight Checklist**

<table>
<thead>
<tr>
<th>#</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The launch vehicle should be installed on the rail and vertical before beginning this checklist.</td>
</tr>
<tr>
<td>2</td>
<td>All vent holes and airframes should be inspected for damage</td>
</tr>
<tr>
<td>3</td>
<td>The avionics system should be activated via the screw switch on the lower airframe.</td>
</tr>
<tr>
<td>4</td>
<td>The pad team should confirm with the ground station team that telemetry is being received from the GPS tracker and avionics board.</td>
</tr>
<tr>
<td>5</td>
<td>The payload altimeters should be armed sequentially, confirming and noting down the beep sequence for each altimeter.</td>
</tr>
<tr>
<td>6</td>
<td>The rocket altimeters should be armed sequentially, confirming and noting down the beep sequence for each altimeter.</td>
</tr>
<tr>
<td>7</td>
<td>Verify the continuity of the motor ignitor, and that the launch system is inactive.</td>
</tr>
<tr>
<td>8</td>
<td>Install the ignitor into the motor.</td>
</tr>
<tr>
<td>9</td>
<td>Connect the ignitor to the launch system and confirm continuity.</td>
</tr>
<tr>
<td>10</td>
<td>Exit the pad area.</td>
</tr>
<tr>
<td>#</td>
<td>Instructions</td>
</tr>
<tr>
<td>----</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Confirm the preflight checklist was completed and review beep sequence data from the altimeters.</td>
</tr>
<tr>
<td>2</td>
<td>Notify RSO of launch readiness</td>
</tr>
<tr>
<td>3</td>
<td>Launch when approved</td>
</tr>
</tbody>
</table>

**If the vehicle fails to launch**

<table>
<thead>
<tr>
<th>#</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inform RSO of failure to launch</td>
</tr>
<tr>
<td>2</td>
<td>If ignitor is still continuous, attempt launch again.</td>
</tr>
<tr>
<td>3</td>
<td>If unsuccessful, return to pad when approved to do so.</td>
</tr>
<tr>
<td>4</td>
<td>Replace ignitor. Confirm if ignitor fired or not.</td>
</tr>
<tr>
<td>5</td>
<td>Re-verify preflight checklist.</td>
</tr>
<tr>
<td>6</td>
<td>Restart launch checklist</td>
</tr>
</tbody>
</table>

## Recovery Checklist

<table>
<thead>
<tr>
<th>#</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>This checklist should be completed when the rocket and payload are located.</td>
</tr>
<tr>
<td>2</td>
<td>Report the location and status of the recovery team to the MCC.</td>
</tr>
<tr>
<td>3</td>
<td>Before disturbing the landing site, take photos of the site, launch vehicle, and payload.</td>
</tr>
<tr>
<td>4</td>
<td>Record the beep codes of the altimeters.</td>
</tr>
<tr>
<td>5</td>
<td>Safe the altimeters.</td>
</tr>
<tr>
<td>6</td>
<td>Verify that all energetics are spent.</td>
</tr>
<tr>
<td>7</td>
<td>Inspect the airframe for damage.</td>
</tr>
<tr>
<td>8</td>
<td>Inspect the recovery system for damage or tangling.</td>
</tr>
<tr>
<td>9</td>
<td>Once approval is given to activate the payload, complete the payload mission.</td>
</tr>
<tr>
<td>10</td>
<td>Return the vehicle to the team setup area.</td>
</tr>
<tr>
<td>11</td>
<td>Disassemble the electronics bay and lower airframe couplings</td>
</tr>
<tr>
<td>12</td>
<td>Disconnect all batteries</td>
</tr>
<tr>
<td>13</td>
<td>Download flight data from the altimeters and avionics.</td>
</tr>
<tr>
<td>14</td>
<td>Inspect internal components for damage</td>
</tr>
<tr>
<td>15</td>
<td>Remove and clean the motor casing, CO2 ejection systems, and Tender Descenders</td>
</tr>
<tr>
<td>16</td>
<td>Remove and clean the motor casing, CO2 ejection systems, and Tender Descenders</td>
</tr>
</tbody>
</table>

J. Engineering Drawings
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ± 1/32
ANGULAR: ±1
BEND: ±1
TWO PLACE DECIMAL: ± 0.01
THREE PLACE DECIMAL: ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G12 Fiberglass

TMO
NJ
5/10/2022

FIN CAN

A U22-1-1-002

HPRC

SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

5/12/2022
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1°
BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G10 Fiberglass

TITLE: FIN

SIZE DWG. NO. REV
A U22-1-1-003

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

CHECKED
TMO 5/12/2022

DRAWN
NJ 5/10/2022
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL: ± 0.01
THREE PLACE DECIMAL: ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL
ALUMINUM 6061

TMO

DRAWN TT 5/10/2022
CHECKED TMO 5/12/2022

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

DATALOGGER MOUNT

A U22-1-1-006

5/12/2022

SOLIDWORKS Educational Product. For Instructional Use Only.
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<td>U22-1-1-101</td>
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<td>2</td>
<td>U22-1-1-102</td>
<td>RETAINER PLATE</td>
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<tr>
<td>3</td>
<td>U22-1-1-103</td>
<td>TAILCONE</td>
<td>1</td>
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<tr>
<td>4</td>
<td>U22-1-1-104</td>
<td>TAILCONE BULKHEAD</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>98mm Retainer Flange</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>98mm Retainer Cap</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>#8-32x0.500</td>
<td>Female Threaded Hex Standoff</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>#8-32x0.375</td>
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<td>8</td>
</tr>
<tr>
<td>9</td>
<td>93505A032</td>
<td>Male-Female Threaded Hex Standoff</td>
<td>4</td>
</tr>
</tbody>
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4X 8-32 UNC THRU

DIMENSIONS ARE IN INCHES

TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

UNLESS OTHERWISE SPECIFIED:
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
ALUMINUM 6061

THRU

COUPLING

SCALE: 2:3

WEIGHT:

SHEET 1 OF 1

A22-1-1-101

TIMEDRAWN
5/10/2022
5/12/2022

HPRC
WPI AIAA

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
ALUMINUM 6061

UNLESS OTHERWISE SPECIFIED:

DRAWN TT 5/10/2022
CHECKED TMO 5/12/2022

SIZE A
DWG. NO. U22-1-1-102
REV

SCALE: 2:3
WEIGHT:

SHEET 1 OF 1

TMO

RETAINER PLATE
5.30

6.17

4.76

5.30

TITL: TAILCONE

SIZE: A

DWG. NO: U22-1-1-103

REV: A

SCALE: 1:4

WEIGHT: SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1
BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: S-Glass

DRAWN: NJ 5/10/2022
CHECKED: TMO 5/12/2022

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G10 Fiberglass

SCALE: 1:2
WEIGHT: 
SHEET 1 OF 1
**INITIALS**

**TITLE:** UPPER BODY TUBE

**SIZE** A

**DRAWN** 5/10/2022

**CHECKED** 5/12/2022

**NAME** 5/10/2022

**DATE** 5/12/2022

**DIMENSIONS ARE IN INCHES**

**TOLERANCES:**
- FRACTIONAL ± 1/32
- ANGULAR: MACH ± 1°, BEND ± 1°
- TWO PLACE DECIMAL ± 0.01
- THREE PLACE DECIMAL ± 0.005

**INTERPRET GEOMETRIC TOLERANCING PER:** ASME Y14.5

**MATERIAL** G12 Fiberglass

**SCALE:** 1:12

**WEIGHT:**

**REV** SHEET 1 OF 1

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL:
G12 Fiberglass

TITLE: UPPER AIRFRAME COUPLER

SIZE: A
DWG. NO.: U22-1-3-003

SAFETY FIRST MICROBRUSH CLEANING SOLUTION

DATE: 5/10/2022
DRAWN: NJ
CHECKED: TMO

5/12/2022

REV: A

DRAWN BY: NJ
CHECKED BY: TMO

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
ALUMINUM 6061

TITLES:
PAYLOAD COUPLING
STANDARD CONFIGURATION

SIZE DWG. NO. REV
A U22-1-3-005

SCALE: 2:3 WEIGHT:

DRAWN: TT 5/10/2022
CHECKED: TMO 5/12/2022

5/12/2022
5/12/2022

HPRC
WPI AIAA

5.755

5.10

5.99

5.50

4x 8-32 UNC THRU

.125

.75
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<td>U22-1-4-001</td>
<td>(THREADED COUPLING)</td>
<td>1</td>
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<tr>
<td>2</td>
<td>U22-1-4-002</td>
<td>(BARE COUPLING)</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>U22-1-4-003</td>
<td>(RETAINING RING)</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>U22-1-4-004</td>
<td>(ROTATING NUT)</td>
<td>1</td>
</tr>
</tbody>
</table>
BARE COUPLING
RECOVERY CONFIGURATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

UNLESS OTHERWISE SPECIFIED:

MATERIAL:
ALUMINUM 6061

NAME DATE
TT 5/10/22
TMO 5/12/22

SCALE: 2:3
WEIGHT: SHEET 2 OF 2
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ± 1/32
ANGULAR: MACH: 1° BEND: ±1°
TWO PLACE DECIMAL: ± 0.01
THREE PLACE DECIMAL: ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: ALUMINUM 7075

TITLE: RETAINING RING

DRAWN: TT 5/10/2022
CHECKED: TMO 5/12/2022

SIZE: A
DWG. NO.: U22-1-4-003
REV.

SCALE: 2:3
WEIGHT: SHEET 1 OF 1

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH 1 ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
ALUMINIUM 6061

TITLE: COUPLING MOUNTING PLATE

DRAWN: TE 5/10/2022
CHECKED: TMO 5/12/2022

SIZE DWG. NO. REV
A U22-1-5-001

SCALE: 1:2 WEIGHT: SHEET 1 OF 1
HUB SEPARATOR

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL: ± 1/32
- ANGULAR: MACH ± 1°
- BEND: ± 1°
- TWO PLACE DECIMAL: ± 0.01
- THREE PLACE DECIMAL: ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL:
POLYCARBONATE

UNLESS OTHERWISE SPECIFIED:
SCALE: 1:1
WEIGHT:

TITLE:
HUB SEPARATOR

SIZE DWG. NO. REV
A U22-1-5-002

DRAWN CHECKED
JS TMO
5/11/2022 5/12/2022

DATE

SOLIDWORKS Educational Product. For Instructional Use Only.
The arc of each slot is defined by the parametric equations:

\[
x = 0.825 \exp(1.023 \cos(t)) \\
y = 0.825 \exp(1.026 \cos(t))
\]

\[t_0 = 0 \quad t_1 = 0.87266\]
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1°
BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL

AL6061-T6

THERE ARE NO STOCK PREFERENCES

HPRC
WPI AIAA

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ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
POLYCARBONATE

NAME DATE
DRAWN js 5/10/2022
CHECKED TMO 5/12/2022

TITLE: BATTERY GPS MOUNT

SIZE DWG. NO. REV
A U22-1-5-006

SCALE: 1:2 WEIGHT: SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1
BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G12 Fiberglass

SOLIDWORKS Educational Product. For Instructional Use Only.
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G10 Fiberglass

TITLE: TOP SLED SUPPORT

SIZE DWG. NO. REV
A U22-1-6-202

SCALE: 1:1 WEIGHT: 0.02 lbs SHEET 1 OF 1
2X Ø.18 THRU

63.29°

40.9°

.58

.89

.13

.75

.63

1.75

.50

.43

R.10

G10 Fiberglass

BOTTOM SLED SUPPORT

SHEET 1 OF 1

SCALE: 1:1 WEIGHT: 0.02 lbs

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G10 Fiberglass

REVDWG. NO.
A U22-1-6-203

SIZE DWG. NO. REV
A U22-1-6-203

NAME DATE
JHL 5/11/2022
TMO 5/12/2022

5/12/2022

5/11/2022

5/12/2022
2X \( \Phi .12 \) THRU .36

1.15

45°

.50

.18

.14

.30

.30

.30

.07

Polycarbonate

XT30 MOUNT

U22-1-6-205

SHEET 1 OF 1

TMO

JHL

UNLESS OTHERWISE SPECIFIED:

SCALE: 2:1 WEIGHT:

DIMENSIONS ARE IN INCHES TOLERANCES:

FRACTIONAL: \( \pm \frac{1}{32} \)

ANGULAR: MACH 1 BEND \( \pm \frac{1}{1} \)

TWO PLACE DECIMAL: \( \pm 0.01 \)

THREE PLACE DECIMAL: \( \pm 0.005 \)

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL Polycarbonate

5/12/2022

5/11/2022

DRAWN JHL

CHECKED TMO

TITLE: XT30 MOUNT

SIZE DWG. NO. A U22-1-6-205 REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

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<td>1</td>
<td>U22-2-1-100 (NOSECONEN STABILIZATION ASSEMBLY)</td>
<td>1</td>
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<td>2</td>
<td>U22-2-1-001 (PAYLOAD SPINE)</td>
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<td>3</td>
<td>U22-2-1-002 (PAYLOAD SPINE BRACKET)</td>
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<td>4</td>
<td>U22-2-1-200 (COUPLER STABILIZATION ASSEMBLY)</td>
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<tr>
<td>5</td>
<td>U22-2-1-400 (QUAD GRIPPER ASSEMBLY)</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>U22-2-1-300 (STABILIZATION ASSEMBLY)</td>
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<tr>
<td>7</td>
<td>U22-2-1-300 (STABILIZATION ASSEMBLY)</td>
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<td>8</td>
<td>U22-2-1-300 (STABILIZATION ASSEMBLY)</td>
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<tr>
<td>9</td>
<td>U22-2-1-500 (ARM DEPLOYMENT ASSEMBLY)</td>
<td>2</td>
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<tr>
<td>10</td>
<td>U22-2-2-300 (PARACHUTE RELEASE ASSEMBLY)</td>
<td>1</td>
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<tr>
<td>11</td>
<td>U22-2-1-003 (BATTERY MOUNT)</td>
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<td>12</td>
<td>18650 Battery</td>
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<td>15</td>
<td>U22-2-1-004 (BACK 90 DEGREE BRACKET)</td>
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<td>16</td>
<td>U22-2-1-309 (STABLIZATION SLEEVE CUTOUT)</td>
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<td>U22-2-1-005 (FRONT 90 DEGREE BRACKET)</td>
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<td>18</td>
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<td>4</td>
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<tr>
<td>19</td>
<td>#8-32x0.500</td>
<td>8</td>
</tr>
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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Polycarbonate

TITLE: Battery Mount

DRAWN: CB 5/10/2022
CHECKED: JR 5/12/2022

SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL ± 1/32
ANGULAR: MACH: ± 1 BEND: ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Polycarbonate

---

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL ± 1/32
ANGULAR: MACH: ± 1 BEND: ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Polycarbonate

---

TITLE:
Back 90 Degree Bracket

DRAWN: CB  5/10/2022
CHECKED: JR  5/12/2022

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
Front 90 Degree Bracket

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: Polycarbonate

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<th>PART NUMBER</th>
<th>QTY.</th>
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<td>U22-2-1-101 (NOSECONE FORE BULKHEAD)</td>
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<tr>
<td>2</td>
<td>#8-32x0.375</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>#4-40x0.250</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>#6-32x0.250</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>U22-2-1-102 (NOSECONE AFT FIXED BULKHEAD)</td>
<td>1</td>
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<tr>
<td>6</td>
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Nosecone Aft
Rotating Bulkhead

U22-2-1-103

DIMENSIONS ARE IN INCHES
SURFACE FINISH: DEBURR AND BREAK SHARP EDGES
TOLERANCES: LINEAR:

FINISH: UNLESS OTHERWISE SPECIFIED

SOLIDWORKS Educational Product. For Instructional Use Only.
Nonecone PCB Bracket

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: Polycarbonate

DRAWN: CB 5/10/2022
CHECKED: JR 5/12/2022

A U22-2-1-106

SCALE: 1:1
WEIGHT: SHEET 1 OF 1
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<td>(STABILIZATION ROTATIONAL SHAFT)</td>
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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH 1 BEND ±1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
### Stabilization Dowel Pin

**Title:** STABILIZATION DOWEL PIN

**Drawing:** U22-2-1-304

**Scale:** 2:1

**Material:** 6061-T6

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<td>BEND ±</td>
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<td>INTERPRET GEOMETRIC</td>
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<td>TOLERANCING PER:</td>
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**Application:**

- **Finish:**
- **Do Not Scale Drawing:**

**Drawing Notes:**

- **Proprietary and Confidential:** The information contained in this drawing is the sole property of [Insert Company Name Here]. Any reproduction in part or as a whole without the written permission of [Insert Company Name Here] is prohibited.

**Dimensions:**

- **∅ .0787**
- **∅ .25**
- **.90**
- **1.125**

**Comments:**
**Title:** LEFT-HANDED TORSION SPRING  
**Drawing No.:** U22-2-1-306  
**Scale:** 1:1  
**Material:** Music-Wire Steel

### Dimensions

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<tr>
<td>0.95±0.1</td>
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### Tolerances

- Fractional
- Angular: Mach ± Bendl ±
- Two Place Decimal ±
- Three Place Decimal ±

### Interpret Geometric Tolerancing

- Machined
- Angular

### Notes

- Proprietary and Confidential
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SOLIDWORKS Educational Product. For Instructional Use Only.
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<td>U22-2-1-402 (Gripper Spring Mount)</td>
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<td>2000-0025-0004 (GoBILDA Super Speed)</td>
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<td>U22-2-1-405 (Gripper Servo Gear)</td>
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<td>U22-2-1-406 (Gripper Idler Gear)</td>
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<td>6</td>
<td>U22-2-1-404 (Gripper Idler Arm)</td>
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<td>U22-2-1-403 (Gripper Servo Arm)</td>
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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL:

Quad Gripper Assembly
A U22-2-1-400

SHEET 1 OF 1
Gripper Idler Gear

0.38in

18 Teeth

0.34in THRU
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<td>U22-2-1-512 (STANDOFF)</td>
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<td>#8-32x0.375</td>
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Bottom Plate

Unless otherwise specified:

Dimensions are in inches

Tolerances:
Fractional: ± 1/32
Angular: MACH: ± 1°
Two place decimal: ± 0.01
Three place decimal: ± 0.005

Interpret geometric tolerancing per: ASME Y14.5

Material: Polycarbonate

Check: JR 5/12/2022

Drawn: CB 5/10/2022

Size: A

Drawing Number: U22-2-1-501

Scale: 1:1.5

Weight:

Sheet 1 of 1
Hex Profile Pinion

Material: Polycarbonate

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH 1  ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

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Top Plate

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: Polycarbonate

UNLESS OTHERWISE SPECIFIED:
NAME DATE
DRAWN CB 5/10/2022
CHECKED JR 5/12/2022

POLYCARBONATE

SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.
Standoff

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Polycarbonate

A U22-2-1-512

SCALE: 2:1
WEIGHT:

SHEET 1 OF 1

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<td>U22-2-2-200 (PAYLOAD PISTON ASSEMBLY)</td>
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**Payload Recovery Assembly**

**Title:** Payload Recovery Assembly

**DRAWN:** CB 5/10/2022

**CHECKED:** JR 5/12/2022

**DIMENSIONS ARE IN INCHES**

**TOLERANCES:**
- FRACTIONAL: ± 1/32
- ANGULAR: MACHINE ± 1
- BEND: ± 1
- TWO PLACE DECIMAL: ± 0.01
- THREE PLACE DECIMAL: ± 0.005

**INTERPRET GEOMETRIC TOLERANCING PER:** ASME Y14.5

**MATERIAL:**

- SOLIDWORKS Educational Product. For Instructional Use Only.
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TOLERANCES:

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INTERPRET GEOMETRIC TOLERANCING PER:

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APPLICATION | DO NOT SCALE DRAWING |

SCALE: 1:1

WEIGHT: 

REV 

SIZE | DWG. NO. |
|------|----------|

TITLE: U22-2-2-101 (BULKHEAD) 

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Polycarbonate

TITLE: Raven Mount

DRAWN | CB | 5/10/2022
CHECKED | JR | 5/12/2022

SIZE | DWG. NO. | REV
A | U22-2-2-102 | 

SCALE: 1:1  WEIGHT: 
SHEET 1 OF 1
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**Parachute Release Assembly**

**UNLESS OTHERWISE SPECIFIED:**
- **SCALE:** 1:5
- **WEIGHT:**
- **REV:** A

**DIMENSIONS ARE IN INCHES**

**TOLERANCES:**
- **FRACTIONAL:** ± 1/32
- **ANGULAR:** MACH ±1 BEND ±1
- **TWO PLACE DECIMAL:** ± 0.01
- **THREE PLACE DECIMAL:** ± 0.005

**INTERPRET GEOMETRIC TOLERANCING PER:** ASME Y14.5

**MATERIAL:**

**DRAWN:** CB 5/10/2022

**CHECKED:** JR 5/12/2022
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL
Polycarbonate

3X Ø .15 THRU ALL
Ø .31 X 82°
2X Φ .14 THRU
Φ .31 X 82°

2X

.23
.40
.13

.75

.255

.48
.35
.85
.65

Pin Holder

A

U22-2-2-302

5/10/2022

5/12/2022

CB
JR

6061-T6 Aluminum

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

HPRC WPI AIAA

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24T Servo Spline

20T Servo Spline

8.00
.31

4.00
.16

2.00
R.08

R.20

1.50
R.06

4.00
R.16

[8.00]
.31

[4.00]
.16

[7.75]
.31

[4.00]

Aluminum

Servo Horn

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1°
BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: Aluminum

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Aluminum

FINISH

UNLESS OTHERWISE SPECIFIED:

NAME DATE

DRAWN LE 4/11/22

CHECKED

ENG APPR.

MFG APPR.

Q.A.

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

SCALE: 2:1
WEIGHT:

SHEET 1 OF 1

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<td>U22-2-3-001 (QUAD MAIN PLATE)</td>
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Quad Main Plate

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Quad Mid Plate

**Material:** Plywood

**Dimensions:**

- 9.19
- 1.00
- 1.64
- 1.73
- 2.93
- 3.59
- 3.93
- 5.13
- 6.49
- 6.97
- 8.17
- 8.95

**Tolerances:**

- Fractional: ± 1/32
- Angular: Mach 1, Bend ±1
- Two place decimal: ± 0.01
- Three place decimal: ± 0.005

**Interpret Geometric Tolerancing PER:** ASME Y14.5

**Checked:** JR 5/12/2022

**Drawn:** CB 5/10/2022

**Scale:** 1:1

**Weight:**

**Title:** Quad Mid Plate

**Size:** U22-2-3-003

**Sheet:** 1 of 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1°
BEND ± 1°
TWO PLACE DECIMAL ± 0.005
THREE PLACE DECIMAL ± 0.0005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL
Polycarbonate

TITIE: Runcam Split 4 Mount
SIZE DWG. NO. A U22-2-3-005
SCALE: 2:1
REV

DRAWN CB 5/10/2022
CHECKED JR 5/12/2022

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Quadcopter Arm Locking Assembly

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:
- FRACTIONAL: ± 1/32
- ANGULAR: MACH ± 1 BEND ± 1
- TWO PLACE DECIMAL: ± 0.01
- THREE PLACE DECIMAL: ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

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Acknowledgments

The team’s authors and members would like to thank the team’s sponsors, Curtis Heisey our rocketry advisor, and the various WPI administrators that have given their time and resources to the team.

References