Preliminary Design Report for the Midwest Rocketry Competition

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Executive Summary

Aquilla II, is a high-powered rocket that utilizes cold gas thrusters to both maneuver and stabilize itself on the roll axis. The design contained in this report is the culmination of months of research and planning toward creating safe, effective, well-implemented, and innovative launch vehicle.

The layout of this report begins with explaining the physical structure of our rocket, and it's intended mission profile. Within that section we will also explain why certain design decisions were made, the possible negative effects of some decisions, and how we negated those effects. We will also give a brief description of the construction procedure.

Aquilla II's avionics system are much more complex than those for a standard high-powered rocket. Consisting of four separate microcontrollers and a myriad of support hardware, they are designed to give the rocket as much redundancy as possible for the most mission critical elements. and to implement many of the necessary safety features. The pneumatics system, however, is the defining feature of Aquila II. Compressed air is stored in a high-pressure tank and then regulated down to a pressure compatible with commercial solenoid valves. Two valves control both clockwise and counterclockwise rotation, while the third valve serves as an emergency pressure release which channels all compressed gas out of the system without altering the attitude of the rocket.

This design also addresses the bonus challenge by implementing a bi-directional communications system between Aquilla II and the ground control system, This will allow real-time monitoring of all rocket instrumentation and computer data, the ability to program new roll orientation parameters while the rocket is on the pad, and the evaluation and transmission to ground of received arithmetic problems.

1. ~~Rocket Structure and~~ Mission Profile

~~1.1 Mission Profile - What it looks like from the outside.~~

Lift-off operations begin with the final pre-flight checks of the vehicle via radio link before sending any bonus objective data to the vehicle. Once all checks are completed and the bonus objective data is delivered, the vehicle is ready for launch. After ignition, the vehicle experiences a 1.7 second burn from its Cesaroni J760 motor, taking it to nearly mach .5 (approx 380 mph). Then, the vehicle has approximately 16 seconds of coast time to complete the mission instructions before apogee. At an estimated apogee of 3900 ft, ~~regardless of its completion of mission objectives,~~ the commercial altimeter will fire an ejection charge ~~will fire,~~ and the upper and lower sections of the vehicle will separate~~,~~ and deploy ~~begin falling under~~ an 18” drogue chute. Should the altimeter based ejection not fire, a charge built into the motor will fire 18 seconds after burnout.

Once the noncommercial avionics have detected that the vehicle is descending, they will open the high pressure dump valve ~~for the compressed gas system~~ and hold it ~~will be opened and remain~~ open for the remainder of the flight to eject excess compressed air . After falling from ~~our estimated~~ apogee ~~(3900 ft),~~ to a ~~our~~ recovery altitude of 700ft, a~~our~~ Jolly Logic Chute Release will open~~allow~~ the main parachute ~~to open~~ and slow the vehicle’s descent to an estimated 20 ft/s at landing. Recovery of the vehicle will be accomplished by a small radio transponder and a directional receiving antenna.

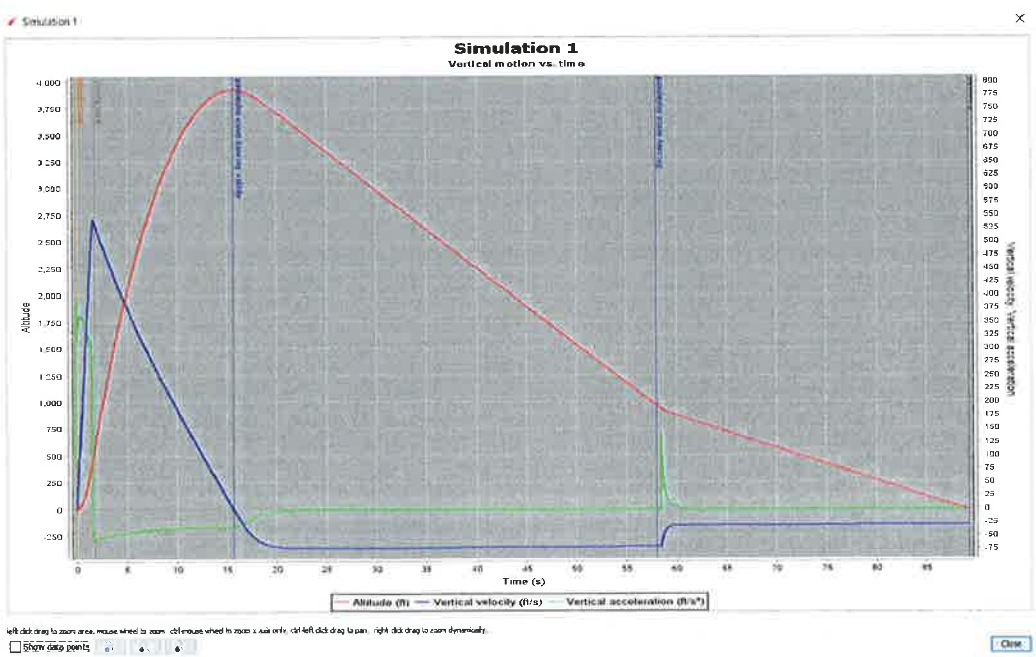


Figure 1. Open Rocket Simulation - Vertical Motion vs Time

After postflight inspection and data collection, the vehicle will be disassembled, inspected, refueled, repacked, and brought to Range Safety Officer (RSO) tent for inspection for its second flight ~~within an hour~~. Details of this process will appear in the Flight Readiness Report.

2. Airframe Design

2.1. Overview

The most recent design (shown in figure 1) is constructed of 3” ID filament wound fiberglass tubing purchased from MadCow Rocketry. The total length is approximately 82” (2.04m) with an estimated pad weight is approx. 7.01kg.

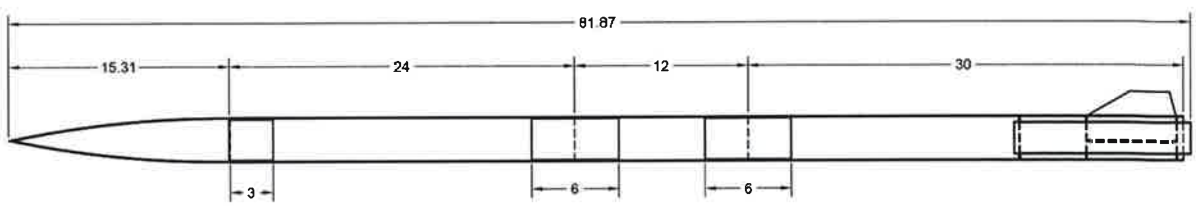


Figure 2. Full Airframe Schematic

The nose cone is a 5:1 ogive design and will be purchased from Madcow Rocketry as well. It contains 560 g of ballast in order to maintain stability of the rocket and counteract the effects of ~~with~~ the heavyweight pneumatics components mounted lower in the airframe. ~~Due to the nature of the rocket's recovery system, detailed later, it is not necessary to eject the nose cone during flight.~~

The body is split in two places, resulting in a three section airframe. The two forward sections are joined by a 6” coupler and secured together using 3mm machine screws, which prevent drag separation and excess flex. This forward joint exists solely for the purpose of servicing the pneumatic components of the rocket. ~~When joined together, the screws prevent drag separation and excess flex at the joint. Several of the high power fliers in the club have used this technique when joining payload sections to AV bays. It's like joining sections with shear pins, but they can't be blown apart. TWe plan to attach t~~he nose cone will be attached in a similar manner, as due to the nature of the rocket's recovery system, it is not necessary to eject the nose cone during flight~~.~~

~~as we will not be utilizing traditional dual deployment, which requires a forward payload bay to eject at lower altitude~~.

Throughout the structure, there are several 3d printed support plates that mate to the various subassemblies. ~~Several of these are still in design, but general concepts for them are already decided.~~ The propellant tank will be supported by a bowl-shaped ring that is epoxied to the airframe, and also rests on a centering ring for extra support. At peak thrust, the propellant tank will weigh in excess of twenty pounds, and during a severe, high-g ejection event (perfectly timed, premature, or even late) that number could increase by several orders of magnitude, so the extra support of the centering ring will definitely be necessary. Above the tank will be a~~, we are planning a~~ heavy-duty retainer system to ensure the tank stays in place. It is likely that this retainer system will be a screw in plug, similar to an aeropack retaining ring, but with threads on the inside.

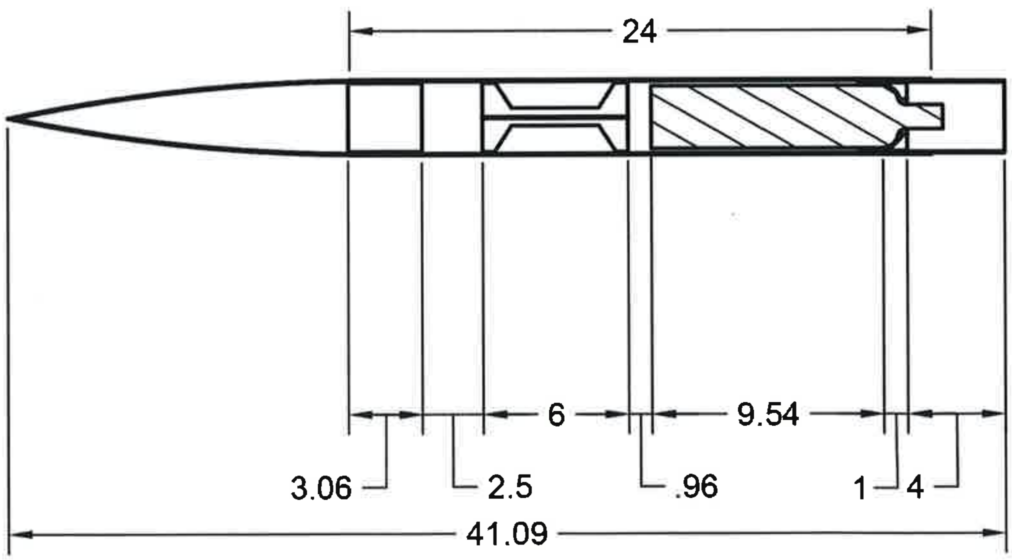


Figure 3. Nosecone/UAB/Propellant Tank Assembly

Above the propellant tank, held against a more narrow centering ring, is the non-commercial avionics package. The actual physical arrangement of the components within that subassembly will be examined in proceeding sections.

Joining the middle section to the fin can is another coupler. This coupler is epoxied to the middle section and is bisected by a bulkplate in order to allow more room for the nozzle attachment points. The plan is to use the coupler to help reinforce the sections of the body pierced by nozzle hardware. Below this bulkplate, rests our commercial avionics package. In traditional form, the AV bay is sealed from the fin can by a pair of bulkplates and threaded rods. Our primary ejection charge(s) will rest upon these plates. We are planning to use the motor ejection only as a backup. Final release of the parachute will be accomplished using a Jolly Logic Chute Release.

To keep symmetry with the dual thruster pods of our design, we are using a four fin layout, and each will be custom milled on a CNC router. Due to the necessary length of the rocket in order to house our subsystems, the fin size required to maintain stability is quite small (see figure 4). This is greatly advantageous to us, as it leads to a more efficient airframe for vertical performance, and it limits the aerodynamic torque our thrusters are required to overcome. The root length of the fins is 6" and the height is only 1.75".

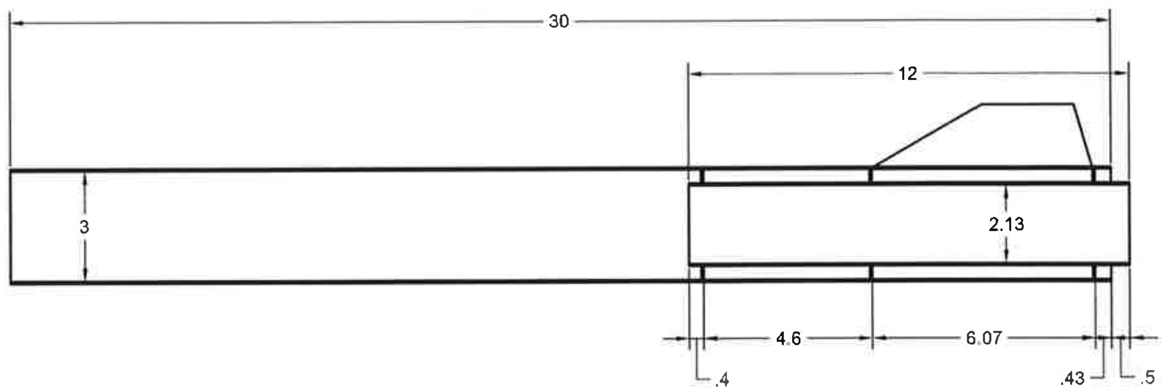


Figure 4. Fin Can/Motor Mount Assembly

Our fins are attached through-the-wall to our 54mm motor mount. 54mm was chosen for the larger selection of motors in the J range, and the ability to take full advantage of every Newton-Second of impulse the competition allows. The motor we have chosen is the Cesaroni J760. Its high initial/average thrust will allow us to leave the pad with greater stability, and its high impulse will allow us to loft the extremely heavy subsystem components to the required 3000+ feet in altitude. While not pictured in the diagram, the motor retainer we plan to use is the aeropack 54mm standard retainer.

When constructing the fin can, we will be utilizing a technique where, on each side of each fin, a single piece of fiberglass cloth will be used to fuse the motor tube, fin and body tube. This results in a single, continuous, internal fiberglass-reinforced fillet. See figure 5 for an example of this technique on a 4" rocket constructed by a team member. This technique gave incredible rigidity and strength to his entire fin can, and in our application, will allow us to launch with assurance that none of our three centering rings will fail during boost. After applying internal fillets, the aft centering ring is installed with epoxy, and then fiberglassed into place. The centering rings are made from 1/16" fiberglass, and are being purchased from MadCow Rocketry.

Figure 5. Continuous Fiberglass Reinforcement

Throughout the design process, Open Rocket was used to calculate stability information. As of our latest simulations, our center of gravity is 43.44" from the tip of the nose cone, and our center of pressure was calculated as 50.09" from the tip of the nose cone. According to OpenRocket, the stability margin when leaving the rail is just above 1 and never exceeds 3.2 calibers before apogee (figure 6 below).

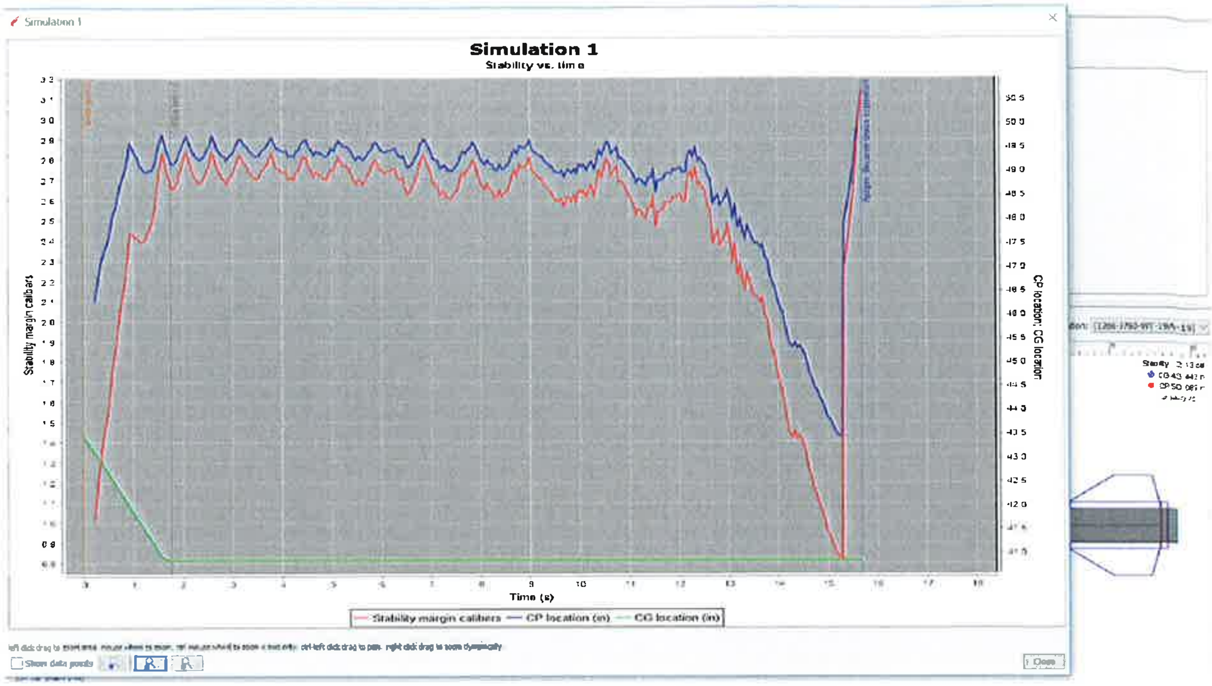


Figure 6. Stability vs Time

In order to separate the sections of the rocket in a well-timed manner, our current plan is to use our commercial altimeter to detonate a black powder ejection charge at apogee and allow the system to descend under a drogue until 700 feet in altitude. As mentioned before, we also plan to utilize the Jolly Logic Chute Release system to keep our parachute from deploying at apogee. The parachute will be a six foot, four line canopy from rocketman parachutes. We will also be utilizing 30' of tubular nylon as a shock cord which is secured to the motor mount using a forged eye bolt. All hardware will be at least ¼" stainless steel.

2. Avionics Systems

2.1. Commercial Altimeter

A StratoLoggerCF will be used as the rocket's commercial altimeter. It will record the rockets peak altitude and maximum velocity after flight as well as take 20 samples of altitude, temperature, and battery voltage per second. The information can be downloaded to a computer with a DT4U USB interface. It also has a telemetry output for real-time data in flight with an RF link. The StratoLoggerCF will serve as the primary means of parachute deployment, as discussed in Section 1.1. Mission Profile.

2.2. Noncommercial Package

2.2.a. Teensy Flight Controllers (TFC)

Aquila II uses three separate but identical Teensy 3.6 control boards (TFCs) to read information from our IMUs. Each controller will work both independently and together with each other. Each TFC will have its own IMU and will read data from the IMU and send it the other two TFCs. Once the prioritized TFC has received data from the other two TFCs, it will average the IMU readings from all three IMUs. Then it will process this data though its control algorithm, opening or closing the valves necessary to adjust the rocket's roll to the desired angle. If one TFC fails then the other two TFCs will be alerted via a break in communication and will be capable of performing exactly the same tasks. Thus using three independent flight controllers provides redundancy to the control system and a higher accuracy from the IMU readings.

2.2.b. Teensy Flight Recorder (TFR)

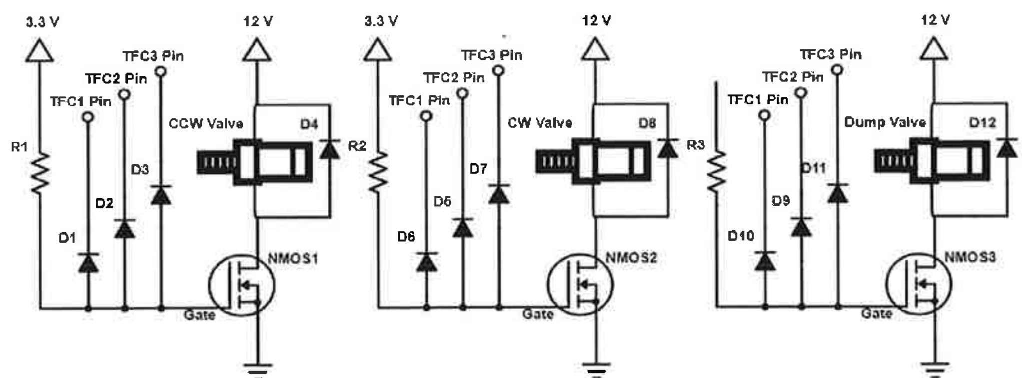
A fourth Teensy 3.6 will be used as the rocket's flight recorder and as the communications computer. All flight data (the data from all three TFC IMU's, all other data received from the TFC's, and any information conveyed from the grounstation) will be recorded to the SD card plugged into the Micro SD card slot on the Teensy board at a rate of 10 Hz. A UART connection will be used to connect the Teensy board to the XBee communications module and provide power to the XBee, requiring a total of four pins. The Teensy will also be connected to each of the three flight controlling Teensy boards via a transmitting and receiving line, requiring a total of six connecting lines.

2.2.c. Inertial Measurement Units (IMUs)

Aquila II uses three Prop Shield IMUs, which have prewritten libraries designed to work specifically with the Teensy 3.6. Testing with alternative IMUs such as the L3G4200D and MPU9250 has shown that their accuracy and library compatibility are not sufficient for our use. The Prop Shield has a 6-Axis Linear Accelerometer, 3-axis linear magnetometer, 3-Axis Digital Angular Rate Gyroscope and a Precision Altitude and Temperature sensor. The three IMUs will be mounted as evenly throughout the rocket as possible to provide the maximum accuracy: One will be mounted in the nose cone; one will be mounted as close to the tale of the rocket; and one will be mounted in the middle of the rocket.

2.2.d. Electronics-Pneumatics Interface (EPI)

Each of valve (CW, CCW, and Dump) will be be connected directly to the 12V power supply and will be switched on and off with a PSMN4R2-30MLDX N-channel MOSFET (NMOS). All three TFCs will have an output pin connected to each valve NMOS gate pin; to turn a valve on, the active TFC will write 0 volts to the that NMOS gate. Diodes will be placed in between each output and its corresponding NMOS gate and pull up resistors will tie each gate to 3.3 V. These additional components will ensure that only the prioritizedTFC can affect the valve switching. Finally, a flyback diode will be placed in parallel with each valve solenoid in order to prevent high voltage spikes when the valve solenoids are switched off. These circuits will be included on the PCBs mounted on the electronics sled.



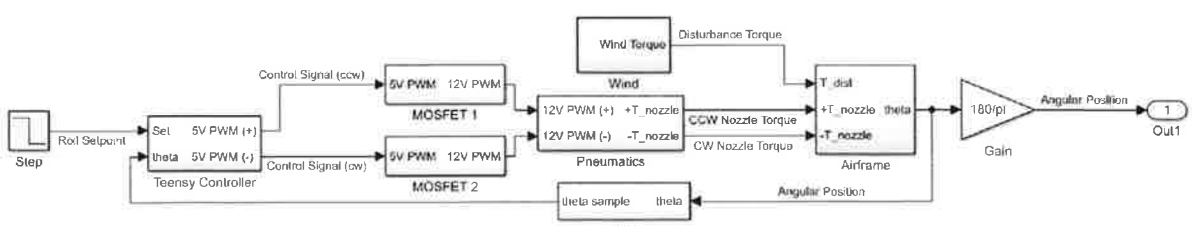
2.2.e. Power System

Aquila II is powered bysing two lithium polymer batteries. Each battery is a 3 cell providing 11.1 volts and are rated at 450mAh. Both batteries will be connected to a Smart-Fly BatShare, a commercial device that allows operation of both batteries at once but switches to a single battery if one is to fail. An eBoot Mini MP1584EN DC-DC Buck Converter is used to convert the 11.1 volts down to 5 volts to power our TFCs, and TFR, and IMUs.With both batteries fully operational the power system will have a total rating of 900mAh, and if one battery fails it will drop to 450mAh. With our expected current draw, and a rating of 450mAh, the avionics system operation time exceeds any expected flight time and stand-by time.

2.2.f: Control Algorithm

The prioritized TFC will be responsible for incorporating the IMUs and EPIs in a closed-loop control algorithm. The X and Y axes magnetometer readings from all three IMUs will be taken at a frequency of 10 Hz and averaged to correct for sensor error and obtain data that is more accurate for the entire airframe. The magnetic heading will then be determined by finding the angle of the magnetic field with respect to the X and Y axes. As in a standard control loop, the sensor reading will be subtracted from the target value to calculate the error.

A control signal with a value between -100% and 100% will be generated by applying Proportional, Integral, and Derivative (PID) gains to the error. The exact values of these gains will be tuned using a simulation of the rocket built in Simulink, and it is likely that different sets of gains will be used for the separate challenges of actuating the rocket and of holding it steady. If the control signal is a less than 0, the TFC will send an inverted pulse width modulated (PWM) signal to the switching MOSFET for the clockwise-facing valve with a frequency of 5 Hz and a duty cycle equal to the absolute value of the control signal. If the control signal is greater than 0, the TFC will send a similar signal to the switching MOSFET for the counterclockwise-facing valve. This has the net effect of constantly creating a torque on the rocket airframe that drives the error to zero. Current simulations indicate that Aquila II will be able to complete any given roll command in under 2 seconds. A high level block diagram of the control algorithm is shown below.



2.3. Hardware Interface

2.3.a. **Avionics Bays**

For the upper avionics bay (UAB), a removable sled design will allow for easy separation for maintenance of the avionics payload from the rocket even after full assembly. The shape of the bay follows a spool like design, with two circular bulkheads connected in the center by a rectangular prism. Each face of the rectangular prism is where the microcontrollers will be mounted. The batteries will be secured on the top circle and will be shielded from temperature, pressure, and physical damage. The external switches to turn on the avionics will also be located on the top circle on opposite sides of the center prism. To connect to the electronics that are not located in the avionics bay, regular pin headers will connect the IMU's, and TX30 connectors will connect the solenoid valves. These connections will be secured by electrical tape during flight, but will allow for easy disassembly during the manufacturing and launch preparation stages.

2.3.b. External Switching

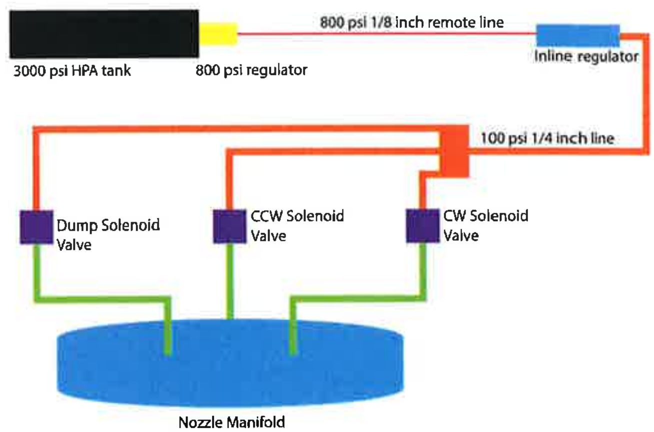
Three Apogee 09128 rotary switches will be used to turn the power on and off; one to the valves, one to the controllers and IMUs, and one to the StratoLoggerCF commercial altimeter. The first two switches will be mounted near the top of the rectangular prism at the center of the UAB, opposite from each other and offset 90° from the batteries. The third will be mounted in the LAB with the StratoLoggerCF. Each switch will be clearly labelled and externally accessible with a screwdriver through small "breathing holes" in the airframe.

2.3.c. Camera

A RunCam 2 will be used as the rocket's mounting camera. It has high definition recording capabilities, and will be equipped with a 64G Micro SD Card. The camera will be mounted internally above the UAB, and will be pointed at a small mirror mounted externally at 45 degrees to the surface of the rocket. This allows the camera image to be downward facing while still maintaining a clean aerodynamic profile.

3. Pneumatics System

The pneumatics design consists of three solenoid valves. One for clockwise rotation (CWSV), one for counterclockwise rotation (CCWSV), and a final "Dump" valve to evacuate all gas in the system in the event of an emergency (EDSV). Feeding these valves is the propellant tank, a 30.5 cubic inch high pressure air cylinder commonly used in paintball applications. A paintball tank was chosen for its durability and reliability~~. Paintball is an inherently high-impact sport where~~ as paintball tanks are routinely bumped, jostled, and held in ~~extremely~~ close proximity to the human body and ~~while in use. Tanks~~ are therefore manufactured with safety as the foremost concern. The tank will rest in a cradle of PETG plastic, that is backed by a fiberglass centering ring. The whole assembly is attached to the airframe, so the total epoxied area will be in excess of 14 square inches.

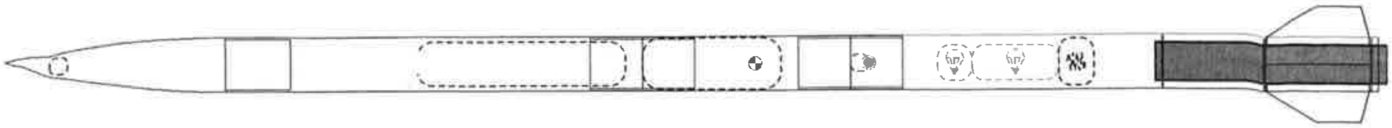


The propellant tank regulates its own output down to 850psi, but this pressure is still far too high for any the solenoid valves or piping ~~, or our plumbing~~ to be able to withstand. A ~~To remedy this, we are installing a~~ high-flow inline regulator will ~~to~~ bring the pressure down to the ~~our required~~ 100psi operating pressure required by these components. The inline regulator is also a paintball accessory and will be easy to secure inside of the airframe.

After the regulator, the air tubing is forked in three separate directions: two lines feeding the roll control solenoids, and one line feeding the EDSV~~emergency dump solenoid~~. The control solenoids are pulsed at 5hz and use PWM to control the total force applied. The Solenoids are quite large, but will fit inside of the airframe with enough space for support brackets.

The outputs of the control solenoids are then fed into a cylindrical manifold consisting of four converging-diverging supersonic nozzles. Two nozzles will be pointed in either direction but offset 180 degrees from each other so that they will apply no net torque in around the pitch or yaw axes of the rocket.

Rocket Design



Rocket

Stages: 1

Mass (with motor): 7096 g

Stability: 2.09 cal

CG: 110 cm

CP: 127 cm

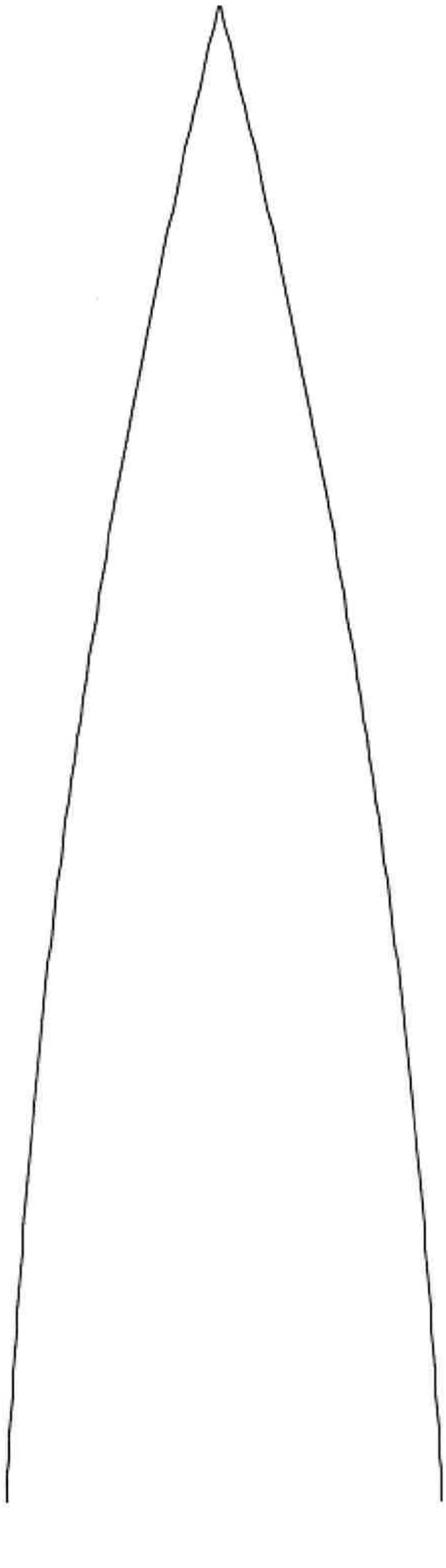
Altitude	1195 m
Flight Time	89.3 s
Time to Apogee	15.7 s
Optimum Delay	14 s
Velocity off Pad	23 m/s
Max Velocity	165 m/s
Velocity at Deployment	21.6 m/s
Landing Velocity	9.22 m/s

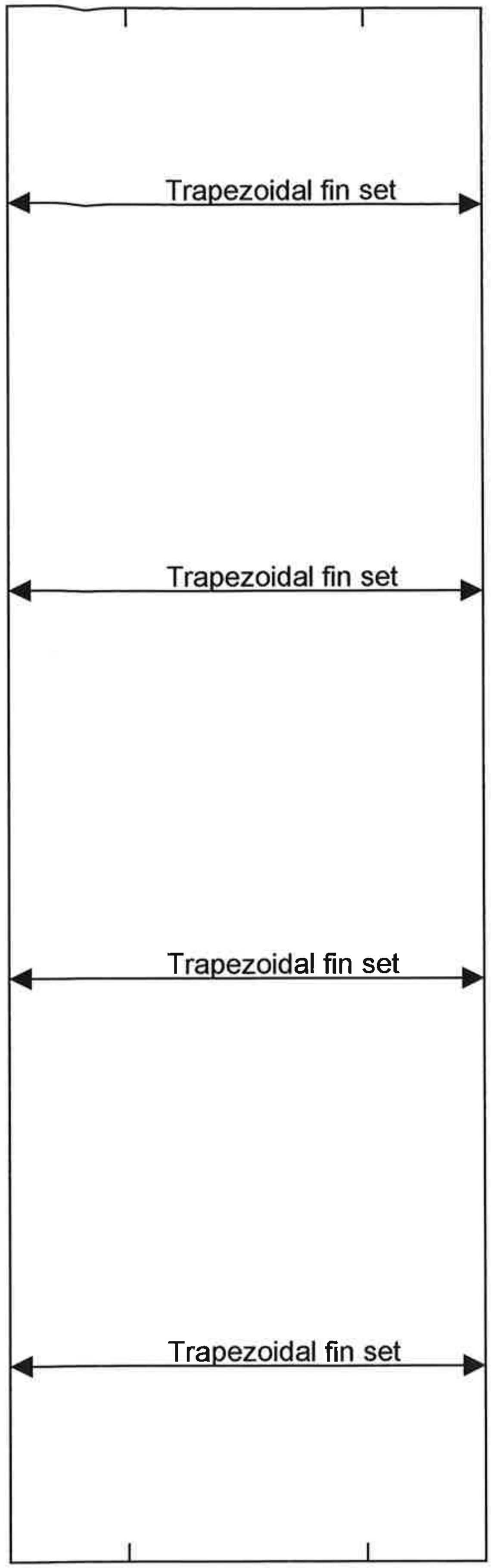
Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
1266-J760-WT-19A	758 N	1.67 s	939 N	1267 Ns	10.89:1	576 g	54/329 mm

Parts Detail

Sustainer

Nose cone	Fiberglass (1.85 g/cm³)	Ogive	Len: 32.5 cm	Mass: 155 g
balance_weight		Dia_{out} 2.5 cm		Mass: 567 g
Body tube	Fiberglass (1.85 g/cm³)	Dia_{in} 7.62 cm Dia_{out} 7.94 cm	Len: 61 cm	Mass: 438 g
Tube coupler	Fiberglass (1.85 g/cm³)	Dia_{in} 7.22 cm Dia_{out} 7.62 cm	Len: 15.2 cm	Mass: 132 g
Tank		Dia_{out} 6.35 cm		Mass: 794 g
Avionics		Dia_{out} 7.58 cm		Mass: 454 g
Body tube	Fiberglass (1.85 g/cm³)	Dia_{in} 7.62 cm Dia_{out} 7.94 cm	Len: 30.5 cm	Mass: 219 g
Tube coupler	Fiberglass (1.85 g/cm³)	Dia_{in} 7.22 cm Dia_{out} 7.62 cm	Len: 15.2 cm	Mass: 132 g
Valves and Nozzles		Dia_{out} 7.58 cm		Mass: 1500 g
Epoxy Weight (estimated)		Dia_{out} 2.5 cm		Mass: 454 g
Body tube	Fiberglass (1.85 g/cm³)	Dia_{in} 7.62 cm Dia_{out} 7.94 cm	Len: 76.2 cm	Mass: 547 g
Inner Tube	Fiberglass (1.85 g/cm³)	Dia_{in} 5.45 cm Dia_{out} 5.85 cm	Len: 33 cm	Mass: 218 g
Centering ring	Carbon fiber (1.78 g/cm³)	Dia_{in} 5.85 cm Dia_{out} 7.62 cm	Len: 0.2 cm	Mass: 6.66 g
Centering ring	Carbon fiber (1.78 g/cm³)	Dia_{in} 5.85 cm Dia_{out} 7.62 cm	Len: 0.2 cm	Mass: 6.66 g
Centering ring	Carbon fiber (1.78 g/cm³)	Dia_{in} 5.85 cm Dia_{out} 7.62 cm	Len: 0.2 cm	Mass: 6.66 g
Trapezoidal fin set (4)	Fiberglass (1.85 g/cm³)	Thick: 0.3 cm		Mass: 141 g
Parachute LOC/Precision LP-50	[material:Rip stop nylon] (66.8 g/m²)	Dia_{out} 127 cm	Len: 12.7 cm	Mass: 84.7 g
Shroud Lines LOC/Precision LP-50	[material:3/8 in. tubular nylon] (0 g/m)	Lines: 16	Len: 135 cm	
Shock cord	Tubular nylon (14 mm, 9/16 in) (16 g/m)		Len: 914 cm	Mass: 146 g
Drogue Public Missiles, Ltd. PML PAR-24R	Rip stop nylon (66.8 g/m²)	Dia_{out} 61 cm	Len: 5.04 cm	Mass: 19.5 g
Shroud Lines Public Missiles, Ltd. PML PAR-24R	Thin poly (0 g/m)	Lines: 8	Len: 50.8 cm	





Trapezoidal fin set
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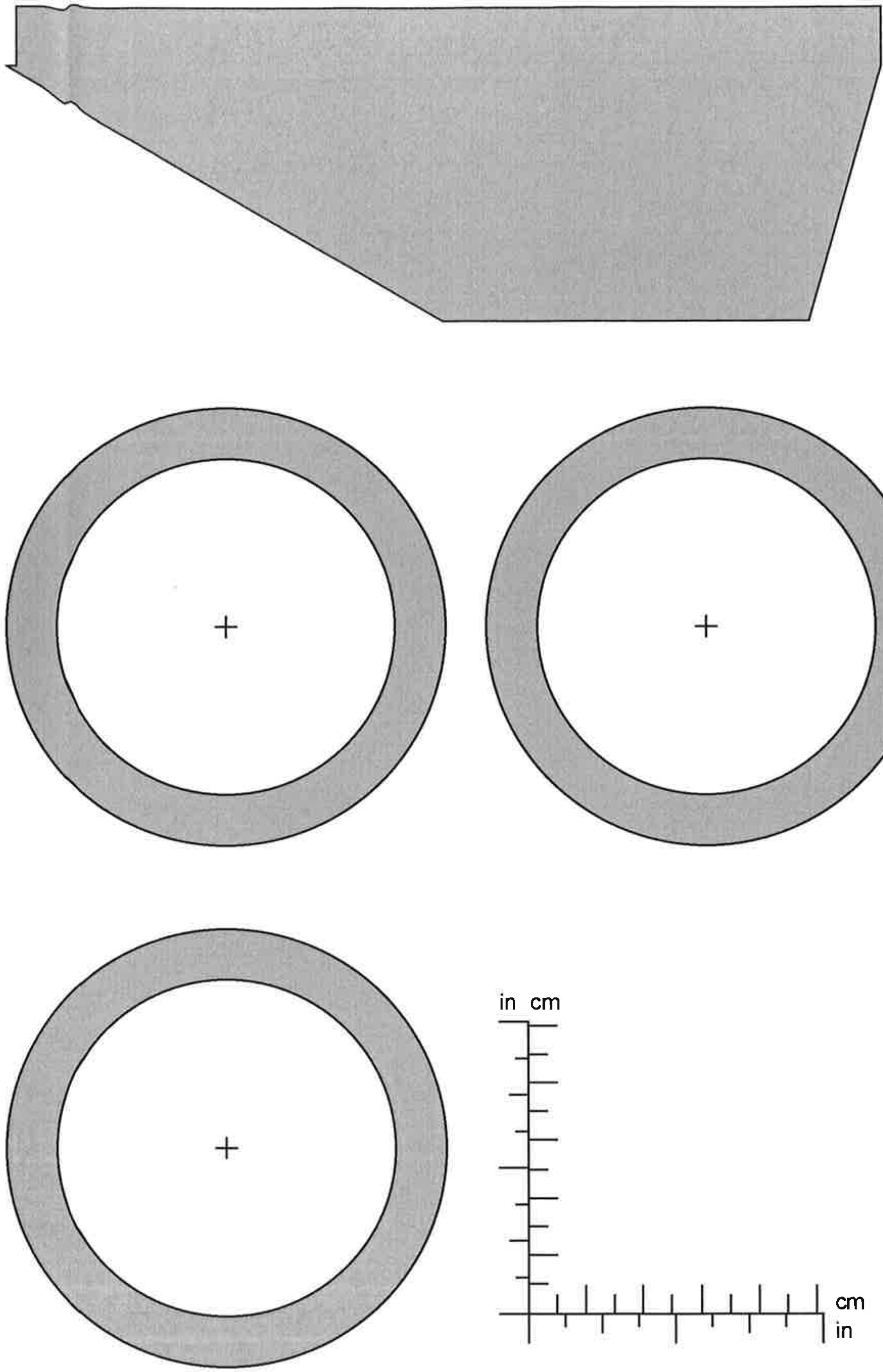
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