ISS Space Grant Team

TRAPPIST-1

Illinois Space Society
University of Illinois at Urbana-Champaign

March 10, 2017

Faculty Advisor: Diane Jeffers
Team Lead: Connor Latham

Niharika Agrawal, Reisha Chellani, Gianna Ciaglia, Tori Colthurst, Matthew Dickinson, Aiden Dreher, Destiny Fawley, Brian Hardy, Elena Kamis, Jihyun Kim, Cameron Palte, Quentin Shaw, Zach Wang, Wesley Warton

Table of Contents

Executive Summary

The Illinois Space Society (ISS) team has designed the TRAPPIST-1 rocket to compete in the Space Grant Midwest High-Power Rocket Competition. The 2016-2017 competition requires participants to build an adaptable single-stage rocket that will be launched on either a combination of I and J motors or J and K motors, reaching the same highest possible apogee during both flights. Additionally, each team must design and manufacture a data collection package that is comprised of a velocity sensor that does not use pressure, accelerometer, or GPS data. This custom sensor will then compare its velocity readings against a standard, commercially-available altimeter. Finally, the vehicle must also be capable of verifying parachute deployment via an autonomous onboard system.

The ISS team is comprised of 14 freshmen students, with an additional junior team member acting as an advisor. Connor Latham, one of the freshmen students, is the active team lead responsible for organizing the team and managing the budget. Connor and the remaining 13 freshmen are split into two sub-teams that are each responsible for designing different velocity sensor prototypes, as well as a third sub-team that is prototyping the rocket's active drag system. In addition to sub-team-based work, the team collaborates as a whole regarding the structural design of the vehicle. Members attend weekly meetings hosted by the team lead, during which they can discuss the design of the rocket and update the entire team regarding sub-team progress.

The TRAPPIST-1 rocket will be adaptable between a J and K motor and feature a flap-based active drag system and either a pitot tube or anemometer-based velocity sensor. The rocket itself is primarily constructed from Blue Tube, with a 4" outer diameter and total length of 80". To determine the active drag system deployment time, an Arduino-compatible altimeter will be connected to an Arduino Mega board that will log velocity and altitude data from the J motor flight. In-flight data from the commercial altimeter during the K motor flight will be compared against the J motor flight data and determine if the drag system should be deployed at that time. OpenRocket was utilized to design the rocket and analyze the flight.

Vehicle Design

Mission Statement

The team's mission is to design a high power rocket that utilizes an active drag system to achieve the same highest possible apogee using two different class motors. In addition, this vehicle will record altitude and velocity data throughout flight using a combination of commercially-available altimeters and a custom-designed velocity sensor. Restrictions in motors and dimensions set by the Space Grant Midwest High-Power Rocket Competition provoke additional challenges in the design of the rocket.

From a team perspective, the design and build process will involve all student members and emphasize creativity, thoroughness, and confidence in the final design. At the end of the project, team members will have gained a greater understanding of rocketry fundamentals and the engineering design process, while also giving back to the community via educational outreach.

Primary Success Criteria

- The rocket must be recovered safely and in flyable condition for both launches.
- The static margin must be equal to or greater than 1, and less than or equal to 5, for the entirety of the flight.
- The rocket must obtain an apogee of at least 914.4 meters (3000 ft) on an I or J motor of the team's choosing.
- The rocket must reach a similar apogee as the I or J while flying with a J or K respectively.
- The descent speed cannot exceed 7.31 m/s (24 ft/s).
- The rocket must use a dual deployment scheme, with an altimeter triggering an ejection charge at apogee and a motor ejection charge as a backup.
- The external geometry of the rocket must be identical at both launch and apogee.
- The rocket must capture up and down video of the outside of the rocket.
- The rocket must sense and record velocity without direct measurement of pressure or acceleration or GPS data.
- The rocket must sense and log separation of the section of body tube holding the parachutes.
- The rocket must sense and log ejection of the parachutes.
- Each team must be prepared to fly within 1 hour and fly twice within a time span of 8 hours.

Airframe & Choice of Materials

A full view of the completed TRAPPIST-1 rocket can be seen in Figure 1 below. The nose cone, upper body tube, coupler, lower body tube, motor assembly, and tail cone are all pictured together, with additional descriptions of each component following. All rocket sections were recreated using Siemens NX 10.0 CAD software to allow for maximum understanding of the design process.

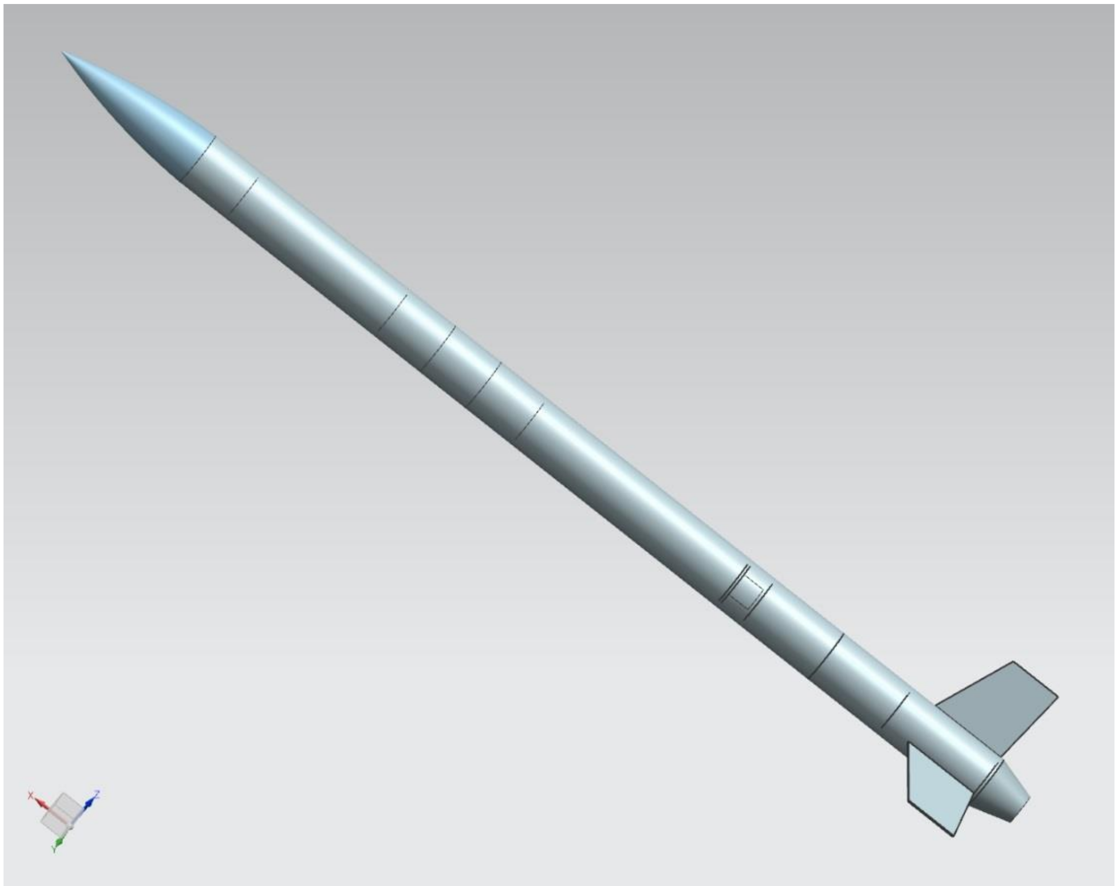


Figure 1: Full view of TRAPPIST-1

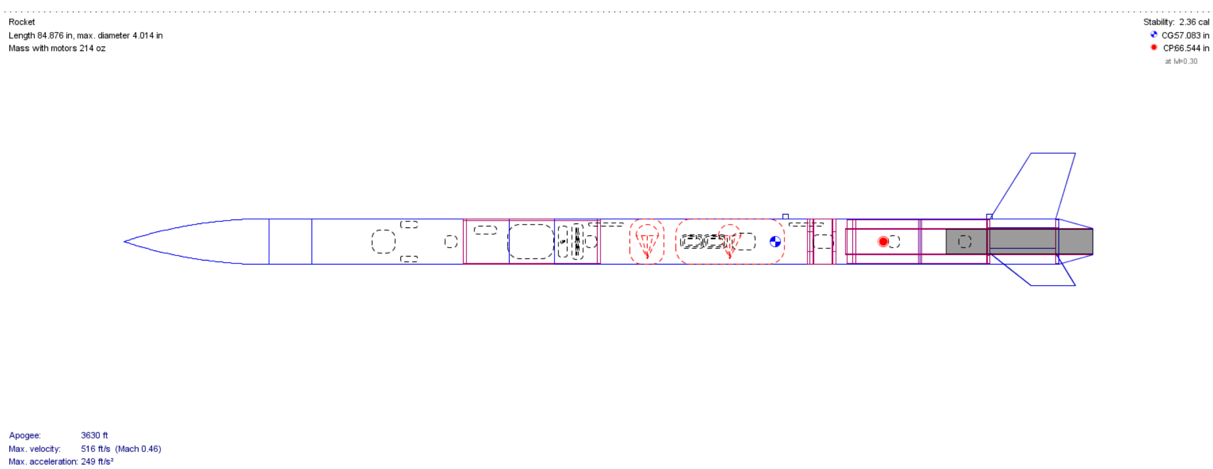


Figure 2: A diagram of the OpenRocket design with the J415W motor. CG and CP are labelled.

The uppermost component of the vehicle will be an ogive-shaped nose cone, as seen in Figure 3. This section will be made from polystyrene plastic, allowing it to be easily obtained as an off-the-shelf component.

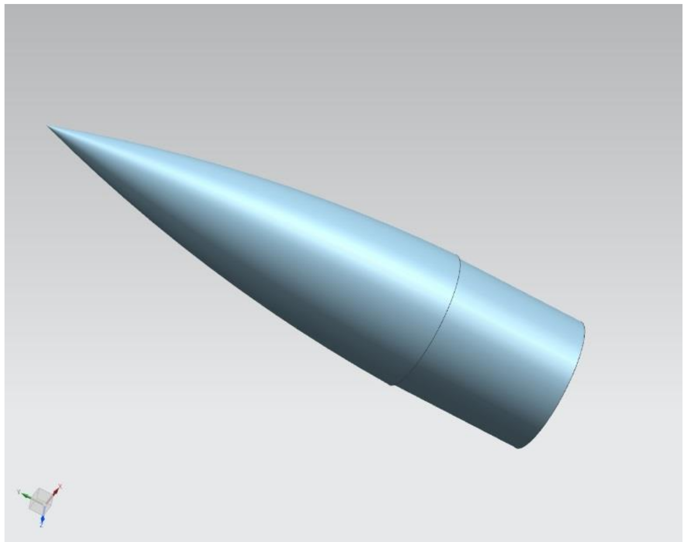


Figure 3: Nose cone

The upper body tube, depicted in Figure 4, will be fixed to the nose cone via three screws affixed to plywood-backed T-nuts on the inner edge of the tube. As with all tubular components on the vehicle, this section will be constructed from Blue Tube, a reinforced paper-based product that the Illinois Space Society has had success with in the past. Blue Tube is an ideal material for building rocket airframes, being abrasion-resistant, easy to work with, stronger than cardboard tubes, and lighter than fiberglass. The upper body tube will also house the team's custom velocity sensor, as well as two onboard cameras.

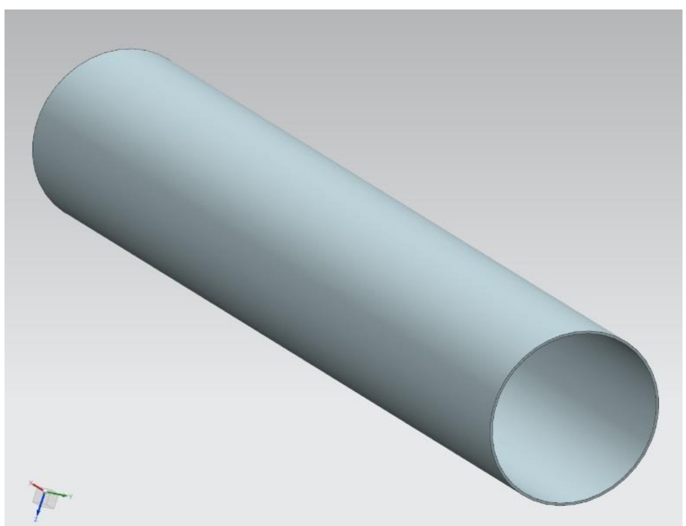


Figure 4: Upper body tube

Figure 5 depicts TRAPPIST-1's Blue Tube-based body coupler, which comprises the lower end of the rocket's upper section when separated. Not shown is a plywood bulkhead, which will protect the avionics and serve as a mounting point for the apogee ejection charge. In addition to both altimeters, this section will also house an Arduino Mega board and its associated light and pressure sensors.

Overall, the body coupler will have a total length of 30.5 cm (12 in), with one third affixed to the upper body tube via screws, one third inserted into the lower body tube, and one third covered by a switch-band.

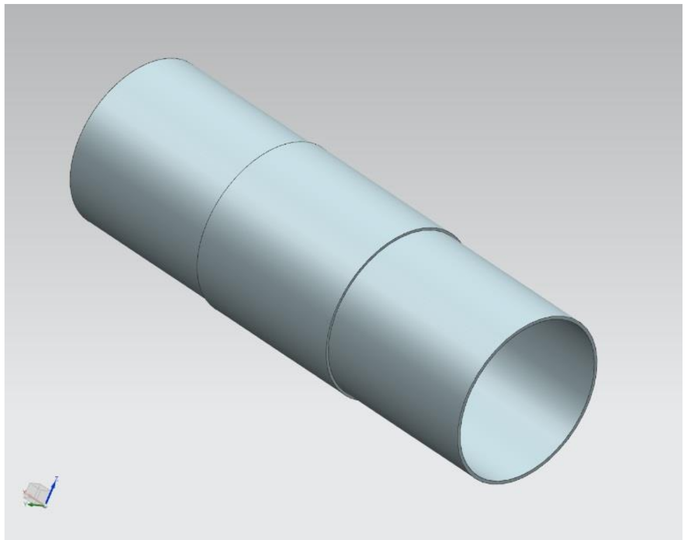


Figure 5: Body coupler

The lower body tube, shown in Figure 6, will interface with the body coupler above it via sheer pins designed to break off under the force of the ejection charge. This section will house both the drogue and main parachutes, as well as a mass equalizer, wires, and the active drag deployment system. As with the other airframe sections on the vehicle, the lower body tube will be constructed from Blue Tube.

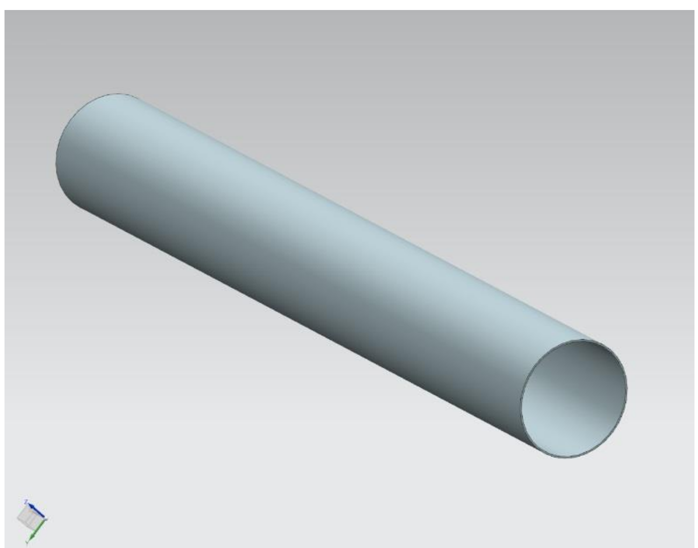


Figure 6: Lower body tube

The vehicle's motor assembly tube contains the fin system, presented in Figure 7, as well as all motor mounting hardware. To ensure rigidity of the fin system, the team will be constructing each fin from

3.175 mm (1/8 in) fiberglass. Fiberglass, though not as strong as carbon fiber, is less brittle and more prepared for unpredictable collisions during either flight or transport.

A complete model of the motor assembly tube is provided in Figure 8. A 30.5 cm (12 in) coupler piece is used to connect the lower body tube and motor assembly tube, with half of its length in each component. The assembly tube itself is made of Blue Tube, with three plywood centering rings positioned at the ends of the fins as well as near the top of the motor mount tube.

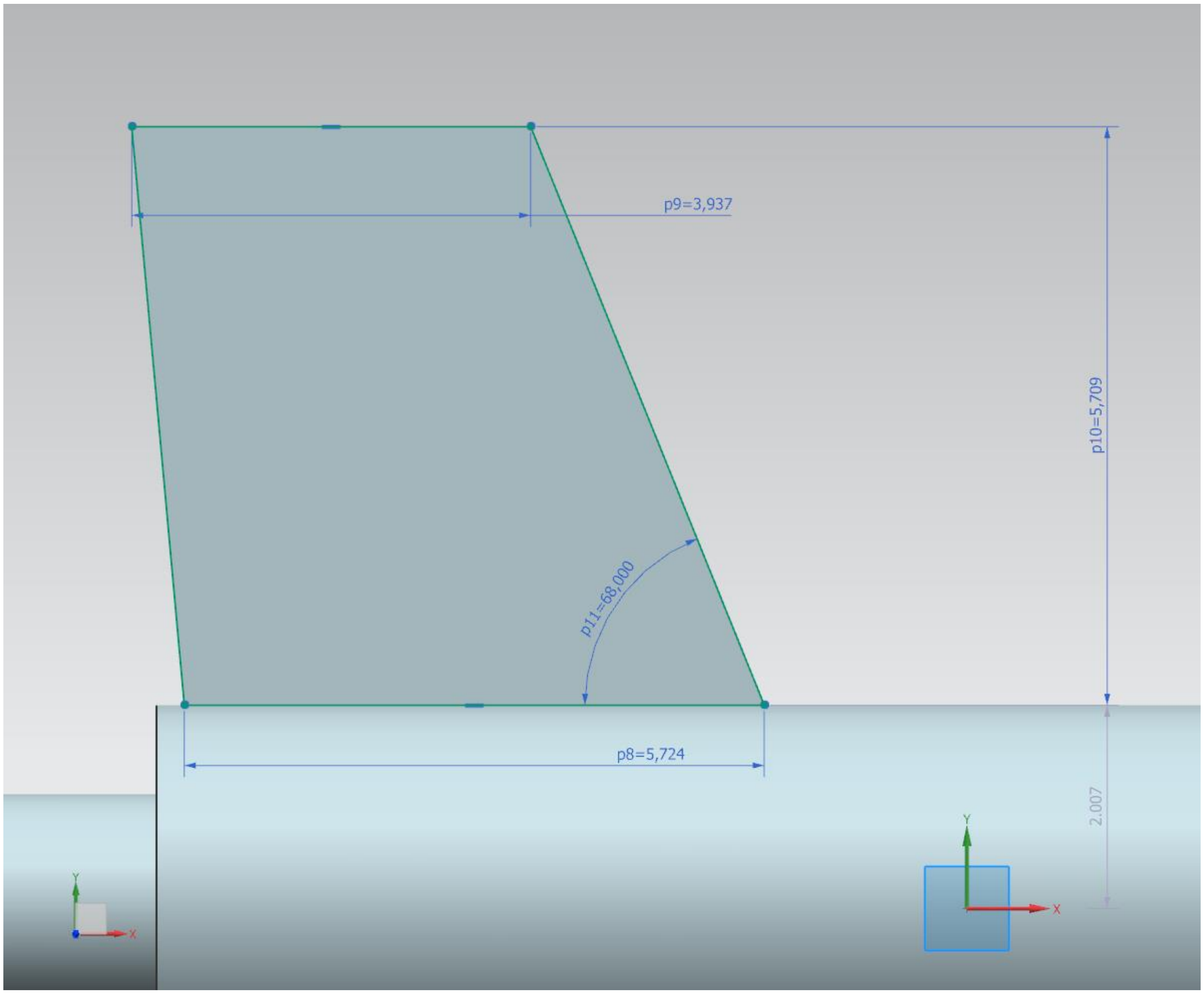


Figure 7: Fin Dimensions (in)

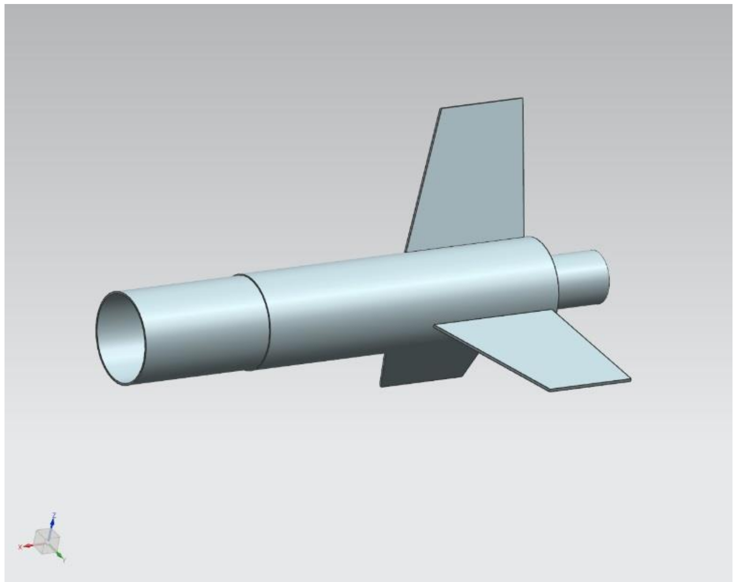


Figure 8: Motor assembly tube

Finally, the lowermost component of the rocket will be an aluminum tailcone, shown in Figure 9 below. This tailcone will screw onto a threaded piece attached to the bottom of the 54 mm (2.13 in) Blue Tube motor mount tube and stretch to meet the bottom of the 10.2 cm (4 in) body tube, helping to reduce drag on the overall rocket during flight.

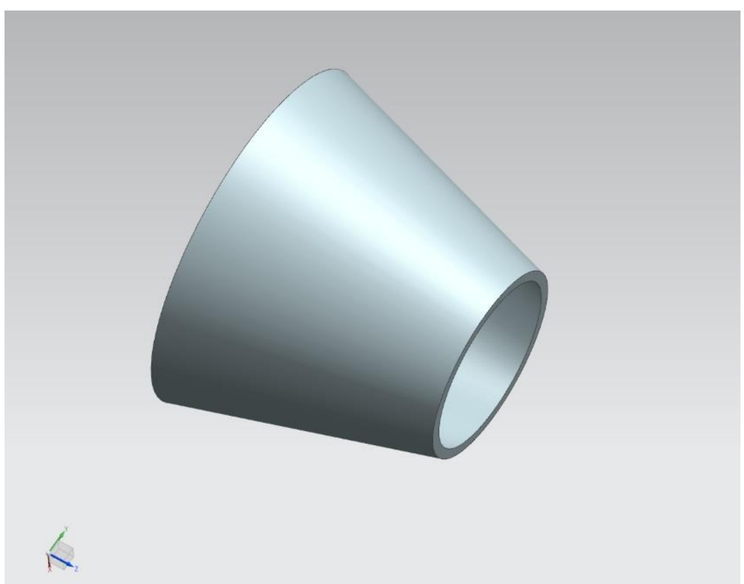


Figure 9: Tailcone

Dimensions & Weights

The dimensions and weight of each component were carefully examined and tabulated to maximize efficiency for the design. Specific information can be viewed below in Table 1 and Table 2.

Table 1: Design Dimensions

Part	Dimensions (cm)	Dimensions (in)
Nose Cone	Length: 30.5, Diameter: 10.2, Thickness: .2, Shoulder Diameter: 9.91 Shoulder Length: 9.52	Length: 12.0, Diameter: 4.014, Thickness: 0.079, Shoulder Diameter: 3.90, Shoulder Length: 4.00
Upper Body Tube	Length: 53.3, Outer Diameter: 10.2, Inner Diameter: 9.91	Length: 21.0, Outer Diameter: 4.014, Inner Diameter: 3.90
Tube Piece on Coupler	Length: 10.16, Outer Diameter: 10.2, Inner Diameter: 9.91	Length: 4.00, Outer Diameter: 4.014, Inner Diameter: 3.90
Coupler	Length: 30.5, Outer Diameter: 9.91, Inner Diameter: 9.53	Length: 12.0, Outer Diameter: 3.90, Inner Diameter: 3.750
Lower Body Tube	Length: 78.7, Outer Diameter: 10.2, Inner Diameter: 9.91	Length: 31.0, Outer Diameter: 4.014, Inner Diameter: 3.90
Motor Assembly Coupler	Length: 30.48, Outer Diameter: 9.91, Inner Diameter: 9.53	Length: 12.0, Outer Diameter: 3.90, Inner Diameter: 3.750
Motor Assembly Tube	Length: 30.48, Outer Diameter: 10.2, Inner Diameter: 9.91	Length: 12.0, Outer Diameter: 4.014, Inner Diameter: 3.90
Motor Mount Tube	Length: 53.3, Outer Diameter: 5.74, Inner Diameter: 5.4	Length: 21.0, Outer Diameter: 2.260, Inner Diameter: 2.135
Centering Ring	Length: .635, Outer Diameter: 9.91, Inner Diameter: 5.75	Thickness: 0.250, Outer Diameter: 3.90, Inner Diameter: 2.265
Tailcone	Length: 7.62, Outer Diameter: 10.2, Inner Diameter: 5.75	Length: 3.00, Outer Diameter: 4.014, Inner Diameter: 2.265
Fin	Root Chord: 14.5, Tip Chord: 10.01, Height: 14.5, Sweep Angle: 32 degrees, Thickness: .3175	Root Chord: 5.72, Tip Chord: 3.94, Height: 5.71, Sweep Angle: 32 degrees, Thickness:0.125
Camera	Length: 3.81, Width: 1.27, Height: 1.27	Length: 1.50, Width: 0.500, Height: 0.500
Altimeter	Length: 4.83, Width: 1.78, Height: 1.45	Length: 1.90, Width: 0.700, Height: 0.570
StratoLogger	Length: 6.99, Width: 1.91, Height: 1.27	Length: 2.75, Width: 0.750, Height: 0.500
Arduino	Length: 10.1, Width: 5.33	Length: 3.98, Width: 2.10
Servo	Length: 4.00, Width: 2.00, Height: 4.00	Length: 1.57, Width: .787, Height: 1.57

Table 2: Design Weights

Part	Mass (kg)	Weight (oz)	Part	Mass (kg)	Weight (oz)
Nose Cone	.200	7.05	Chute Release 2x	.034	1.2
Upper Body Tube	.317	11.2	Main Parachute	.227	~8.00
Tube Piece on Coupler	.060	2.12	Drogue Parachute	.142	~5.00
Coupler	.230	8.13	Battery	.060	2.12
Lower Body Tube	.483	17.0	Linkage Hardware	.075	2.65
Motor Assembly Coupler	.126	4.44	Motor Casing	.318	11.3
Motor Assembly Tube	.132	4.64	Mass Equalizer	.244	8.60
Motor Mount Tube	.132	7.01	J415W-14 Motor	1.17	41.3
Centering Ring 3x	.056	1.96	K1103X-14 Motor	1.46	51.5
Tailcone	.112	3.95	Total Mass	6.08	218
Fin 3x	.366	12.9			
Camera 2x	.170	~8.00			
AltimeterTwo	.010	.350			
Stratologger	.013	.450			
Arduino	.037	1.30			
Servo 3x	.276	9.74			
Velocity Sensor	.227	~8.00			
Epoxy	.570	~12.0			
Quicklinks	.072	2.54			
I Bolt 2x	.060	2.12			

Recovery System

The recovery system will consist of a 0.91 m (36 in) SkyAngle drogue parachute with a drag coefficient of 1.34, as well as a 1.52 m (60 in) Fruity Chutes main parachute with a drag coefficient of 2.2. Both parachutes are constructed of ripstop nylon. Both the drogue and main parachutes will be located inside the lower body tube, attached to the same shock cord at a sufficient distance from one another to ensure unravelling. Each parachute will be tethered to the rocket using a swivel to reduce parachute tangling, followed by a small quicklink attached to a loop in the Kevlar shock cord. This shock cord will then be connected to forged steel eyebolts, which will be screwed and epoxied into the bottom bulkhead of the avionics coupler and the upper area of the motor assembly tube.

An onboard StratoLogger altimeter will deploy an ejection charge at apogee, estimated to be about 1100 m (3600 ft), separating the body coupler from the lower body tube and pulling both parachutes out of the rocket. Once the rocket is more well-defined, an estimation of black powder needed for the electronic charge will be calculated. The motor ejection charge will remain in place as a back up to the electronic deployment. This ejection charge has a delay of 14 seconds, making the motor ejection event occur about 1.5 seconds after apogee, ensuring that even if the StratoLogger fails, the drogue parachute and bundled main parachute can be deployed in a sufficiently short time-span. The drogue parachute will be free to deploy almost instantly, while a series of redundant Jolly Logic Chute Releases in series will keep the main parachute bundled until deploying at an altitude of 230 m (750 ft) or less, depending on the conditions of launch day. Simulations in OpenRocket indicate that drogue deployment will slow the rocket to 10.36 m/s (34 ft/s) during descent. Following deployment of the main parachute, the simulation predicts descent speeds around 4.27 m/s (14 ft/s) for both the J-class and K-class motors. This final descent speed was also confirmed by hand calculations to be around 3.1 m/s (10.2 ft/s). This discrepancy is well within the margin of error, considering the hand calculations assumed the use of a perfectly circular parachute and sea level atmospheric density.

An onboard parachute verification system will use an Arduino-based light sensor, attached to the bottom of the body coupler, to detect the separation of the rocket body and the extraction of the drogue and main parachutes from the rocket body. These stages in the recovery system will be also documented by an external video system. Two cameras will be positioned on the rocket, aimed outward toward two mirrors that will ensure video coverage aimed both upward and downward the external rocket airframe. This dual camera system should ensure that the video footage captures both the drogue and main parachute ejection and deployment events.

Finally, a small radio based tracker will also be integrated in the rocket to locate it after landing. This tracker will be secured to the shock cord close to the booster tube, but far enough out so that the antenna can achieve an adequate line of sight.

Flight Control & Data Systems

Avionics

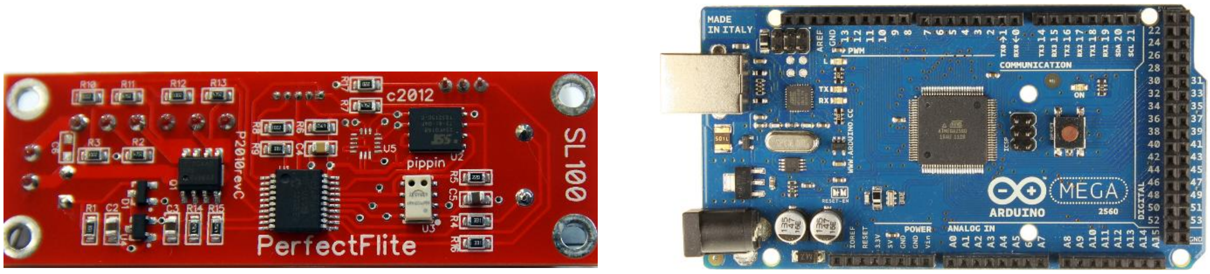


Figure 10: Onboard flight computers

The avionics bay inside the body coupler contains a number of systems critical to the gathering and analysis of flight data. At the heart of this system is an Arduino Mega, which has substantially more processing power than previous models. At 10.1 cm (3.98 in) by 5.3 cm (2.1 in), the Arduino will be small enough to fit inside the avionics bay while providing the power necessary to manage incoming data from the active drag, velocity measurement, and light sensor systems. Data from an Arduino-compatible altimeter unit will feed into the Arduino Mega, and the system will analyze this information to pass the appropriate commands down to the active drag servos in the lower body tube. Data transfer to the lower section will take place via a breakaway wire, which will still allow the upper and lower sections to separate after the active drag system's task is completed. This breakaway will be securely attached to the body tubes to ensure it does not separate from the rocket in flight. Finally, parachute deployment will be directly detected by a light sensor mounted on the lower end of the body coupler. When the parachute ejects, the sensor will record a substantial increase in oncoming light, indicating a successful deployment.

A StratoLogger SL100 altimeter will gather data that will be compared to the noncommercial velocity sensor. In addition to satisfying the requirement that altitude be measured consistently throughout the ascent, the StratoLogger was chosen because of its accuracy, size, and ease of use. Despite weighing less than half an ounce, the StratoLogger can record data up to 100,000 feet with 0.1% accuracy. This StratoLogger will be on its own circuit to ensure interference from the Arduino system does not cause deployment issues. A basic wiring diagram of electronic components, including all components connected to the Arduino Mega and StratoLogger, is shown in Figure 11 on the following page.

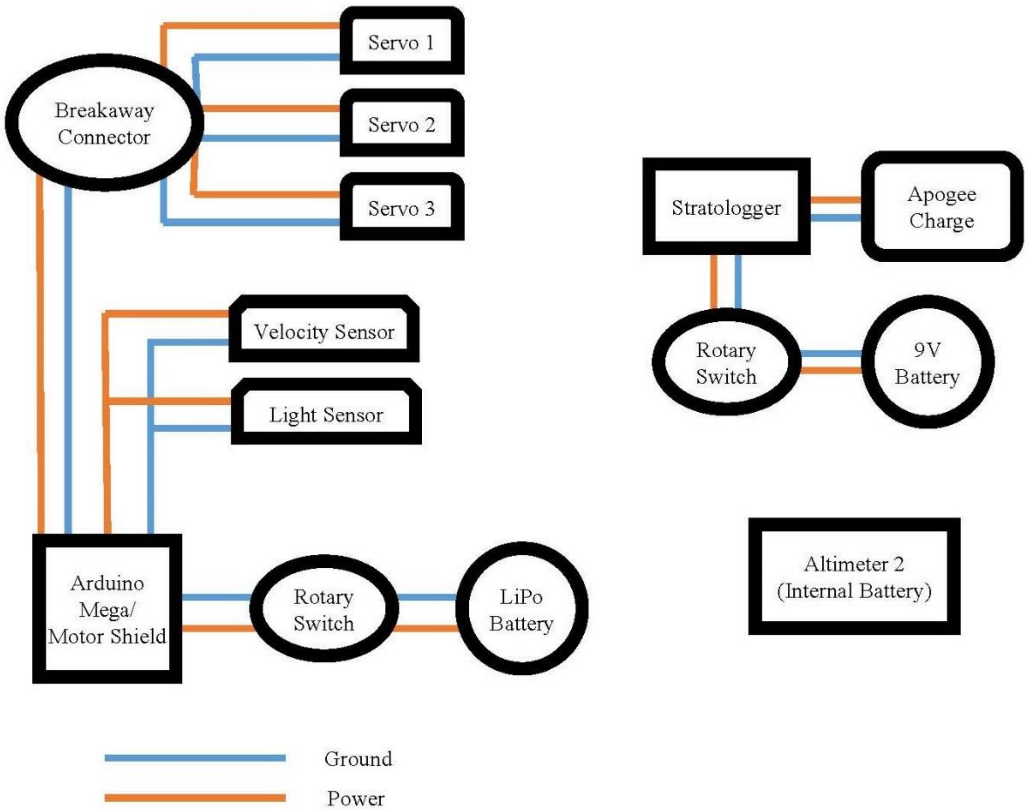


Figure 11: Electrical diagram for onboard electronics

Active Drag

The active drag system will accomplish the goal of achieving similar altitudes on each flight by way of actuating flaps. There will be three flaps spaced equally between the fins of the rocket. By putting them between the fins, they do not disrupt the flow around the fins themselves as much, providing greater stability to the rocket if they were otherwise in line with the fins. These flaps will be 3.81 cm (1.5 in) square and protrude out from the rocket at 90 degrees, perpendicular to the airframe and flow around the rocket.

The flap size was determined by a MatLab simulation written to provide an alternative to OpenRocket due to OpenRocket's inability to model flaps effectively. The rocket was modelled using estimations of mass provided by OpenRocket and coefficient of drag from various internet sources. Motor thrust data was input from ThrustCurve.org. The coefficient of drag for a square in three dimensional flow was found to be about 1.5, a figure used in the simulation. After all data was accounted for, the simulation was run. It uses an algorithm to define when to deploy flaps based on current altitude and the comparison of velocity between the J-motor and K-motor flights. If at the same altitude, the velocity on the K-motor flight is higher than the velocity from the J-motor flight (uploaded to the Arduino as a part of the pre-flight procedures), the flaps will be deployed. It follows reasonably that if the velocity is similar at the same altitude, the final apogee will be similar for both flights. The simulation is able to come to this conclusion as well, providing final apogees with a difference of 1.5 m (4.9 ft).

The flaps will hinge on a small bracket mounted to the rocket body itself. There will be rectangular holes about 2.54 cm (1 in) by 1.27 cm (0.5 in) in size, cut out from the body of the rocket in order for the connecting rods from the servo to attach to the mount point on the flap. In order to achieve maximum torque output from the servo, and therefore achieve greater drag by higher deployment angle, the mount position on the flap will be as far from the hinge as the clearance between the body tube and motor mount tube provides. The connecting rod on the servo will be mounted such that it makes full use of the servos range to provide the flap with 90 degrees of rotation. Using SolidWorks flow simulation and a simple 3.81 cm (1.5 in) square, the maximum torque applied in the X or Z direction was 1.56 Nm, or 16 kg-cm. The servos being used will have a maximum output of 20 kg-cm at a voltage of 7.4 V, ensuring safe operation of the servos in flight. If a servo does fail, the system shall ensure that the two other servos are retracted promptly to ensure safety of the rocket launch. If the system fails to retract the servos, the fins should provide a reasonable amount of counter-force to maintain a similar path to the rocket's original trajectory.

The system will be controlled by an Arduino and Arduino-compatible pressure sensor to determine the velocity and altitude of the rocket

The servos will be securely mounted inside a coupler that holds the lower body piece and motor assembly together. They will be removable and adjustable. This is such that any issues with a servo or connection can be corrected. A fourth servo will be ordered in the event a servo burns out and must be replaced. The mounting assembly should be a combination of plywood, blue-tube and fiberglass.

Custom Velocity Sensor

Multiple types of velocity sensors were researched and prototyped. Four designs were then chosen for further discussion: an anemometer, a pitot tube, a friction-based sensor, and a hot-wire. A design matrix was used to narrow down these four choices to three: the anemometer, pitot tube, and hot-wire. All of these designs were then prototyped. However during the prototyping phase, the hot-wire was dropped due to the complexity of the project.

During discussions, the anemometer was found to be less complex than the pitot tube, less expensive, as accurate, yet less durable than the pitot tube. However, durability was an important characteristic, due to the high speeds the rocket will be traveling at. Both parts are being 3D printed initially to run a sub-system test on the mid-power rockets, and may need to be redesigned later with parts capable of withstanding the 25G+ forces encountered on takeoff.

Both the anemometer and pitot tube are commonly used to measure velocity in different settings. The anemometer uses wind to produce potential in a DC motor, which then maps out to and calculates velocities. This has been a proven method of velocity calculations, the concern rises for the high velocity the rocket will be traveling at. After the prototype is built, it will be tested at high velocities in a wind tunnel to see if the speed will cause the motor to generate more voltage than the Arduino can handle. The pitot tube measures changes in fluid flow velocity, and uses the dynamic pressure to inflate or deflate a membrane upon which a strain gauge is secured. This strain gauge then reports the amount of resistance through the circuit to determine velocity. Here, the team was concerned as to the complexity of the sensor. As prototyping continues, the prototyping team has found the design to be simpler than previously expected. Once both sensors are complete, they will be tested on mid-sized rockets the team has already built to test their accuracy.

Camera System

The cameras will be placed in the rocket such that they capture incoming light from two mirrors placed on the side of the rocket. These cameras will record in 720HD and have internal memory storage and batteries capable of filming for two hours minimum. The batteries do not need to store any information of the Arduino or take battery life from the main system battery.

Flight Predictions & Analysis

Stability Analysis

The stability margin of the rocket must stay between 1 and 5 throughout its flight in order for the rocket to remain stable. If the margin is below 1, the rocket will be unstable, and if it is above 5, the rocket will be overstable. If the rocket is unstable, it may not fly completely upwards throughout its flight, and if overstable, it may rotate whilst in flight. For the rocket to maintain stability, the center of pressure (Cp) must remain behind the center of gravity (Cg) by a certain distance inversely proportional to the diameter of the body tube (Dbody tube). The drag system must be placed at or below the center of pressure, at a minimum distance determined by the following equation:

$$Stability\ Margin = \frac{X_{Cp} - X_{Cg}}{D_{body\ tube}}$$

$$Stability\ Margin_{J\ motor} = \frac{168 - 145}{10.2} = 2.25$$

$$Stability\ Margin_{K\ motor} = \frac{168 - 147}{10.2} = 2.05$$

Minimum distance the active drag flaps must be deployed from the center of gravity to maintain Stability Margin >= 1: 10.2 cm (4.02 in)

Finally, the velocity off the rail for the J-motor launch is 17.98 m/s (59.1 ft/s), which exceeds the 13.72 m/s (45 ft/s) safety minimum in the guidelines. The velocity off the rail for the K-motor launch is 32.04 m/s (105 ft/s), exceeding the guideline as well.

Flight Predictions

The primary method used to model the rocket's overall flight profile was the simulation software OpenRocket. The software allows users to model the rocket in great detail, allowing for almost every design aspect to be included in some way. OpenRocket can also model a rocket's flight and provides key predictions and simulations, such as thrust curve data, predicted altitude curves, time to apogee, and burnout time. OpenRocket is widely used and well respected, and proved to be very successful in making predictions with the subscale rockets the team built and flew.

The team was able to model every aspect of the rocket before even beginning to build it. This provided knowledge on whether the chosen design would be aerodynamically stable, how much it would weigh, and how high it was predicted fly. This allowed for simple and easy design changes that could be made early on to the rocket if the design did not meet the competition criteria, or if changes had to be made to ensure the rocket would fly successfully. This was very useful as many design changes were made throughout the design period. Having predicted simulations on the rocket's performance from the beginning was a very powerful tool for the team. It allowed for an initial successful general design to be created, and then gradually improved and revised while still maintaining stable and consistent rocket properties.

OpenRocket proved to be very useful to the team in predicting how the rocket would perform. However, there were some limitations, primarily when factoring in the active drag system that would be implemented on the rocket. OpenRocket does not allow for predictions to be made with an active drag system, so any results were only relevant to flights where the system was not deployed. As a result of the limitations of the software, the drag system had to be modeled and tested separately.

The program modelling the flap system and its subsequent activation and retraction was just as or more useful than OpenRocket in understanding how the rocket will fly. It also allows for further analysis if the design changes or other factors come up. It does have a low cycle rate, yet this will be improved upon as time goes on.

Active Drag Analysis

To model the active drag system, a custom MATLAB simulation program was written by team members to predict how the system would behave during flight. Inputting different motor types into the program allowed data for the flight to be predicted. Utilizing the simulation values could be determined for the drag system components that would cause the rocket to achieve the same predicted altitude on both flights. It was determined through the simulation that three 3.81 cm (1.5 in) square deployable flaps, actuated by 16 kg-cm torque servo motors or greater would achieve desired results. This program compensated for OpenRocket's inability to model the drag system. Using it, the team was able to model and optimize the system in order to achieve desired results, still ensuring that the design was consistent with the overall rocket structure and dimensions determined from the OpenRocket model. The simulation considered many various factors such as fluid flow conditions around the system while deployed, atmospheric data based on what predicted conditions the rocket would launch in, rocket trajectory, etc. Using the 3.81 cm (1.5 in) square flaps, and an algorithm for determining to have the flaps be deployed or not, an altitude difference of 1.5 m (4.9 ft) was achieved. This algorithm is explained more in the Active Drag section. The program allowed not only for the drag system to be modeled, but to ensure that while the system was deployed the rocket would still be stable. Using OpenRocket and the custom program, nearly every aspect of the rocket was able to be predicted or simulated in some manner.

Launch & Flight Analysis

Flight simulations were performed using OpenRocket 15.03. Launching with a K1103X-14 motor, the rocket reaches a projected maximum altitude of 1746 m (5730 ft) without flaps deployment in 17.7 seconds. It will achieve a velocity of 32.9 m/s (108 ft/s) before leaving the rail. The rocket has a predicted maximum velocity of 270 m/s (886 ft/s) and maximum acceleration of 246 m/s^2 (809 ft/s^2). Touchdown speed is estimated to be 3.96 m/s (13 ft/s). Total flight time is estimated to be 212 s. A visualization of the rocket's flight is provided in Figure 12.

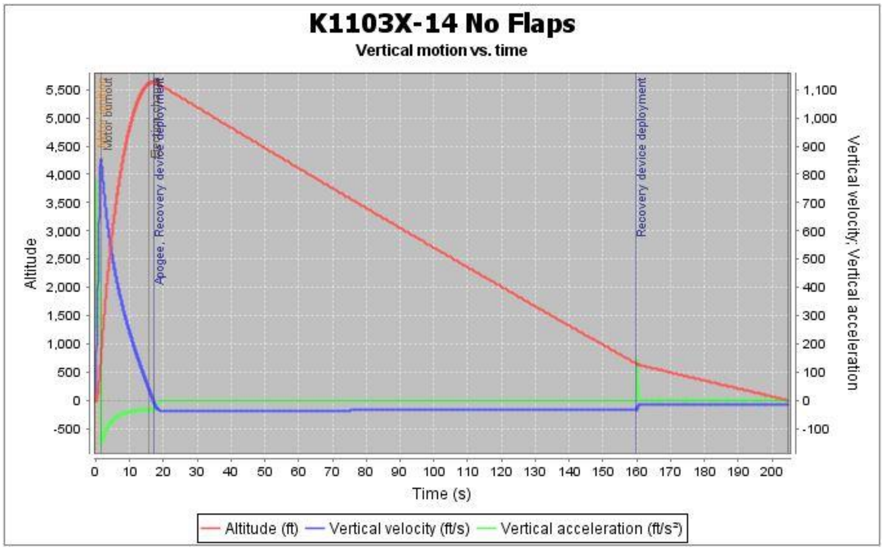


Figure 12: OpenRocket simulation for K1103X-14

With a J415W-14 motor, the rocket is predicted to reach an altitude of 1100 m (3610 ft). The rocket will reach a velocity of 18 m/s (59.1 ft/s) as it leaves the rail. The ascent will take 15.1 seconds. During ascent, the rocket will reach a peak acceleration of 74.68m/s^2 (245 ft/s^2) and a maximum velocity of 155m/s (509 ft/s). The estimated ground hit velocity is 4.27 m/s (14 ft/s). Total flight time is estimated at 148 seconds. A visualization of the rocket's flight is provided in Figure 13.

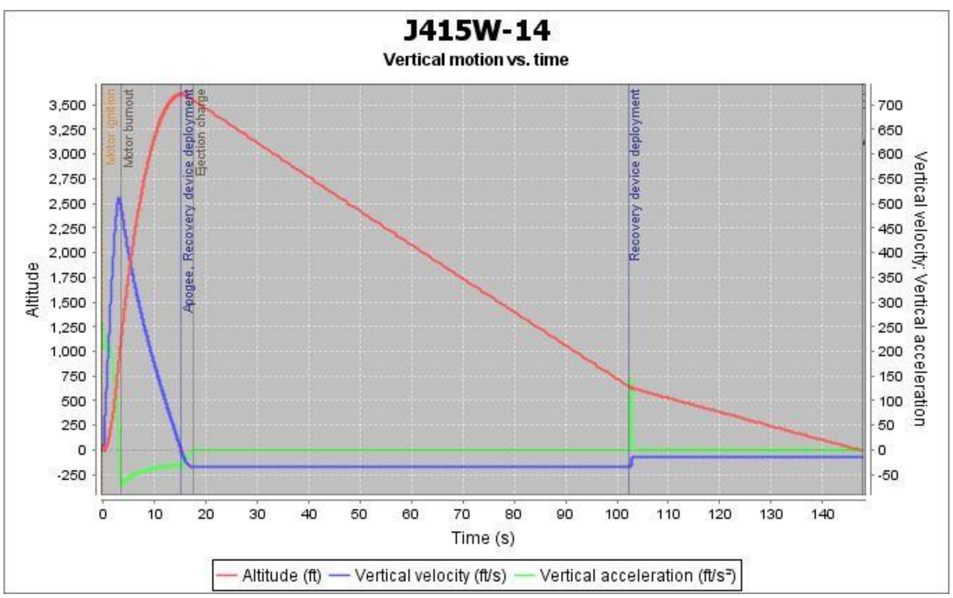


Figure 13: OpenRocket simulation for J415W-14

Center of Gravity and Center of Pressure Data

	J415W-L Installed	K1103X-14A Installed
Center of Gravity	145 cm (57.08 in)	148 cm (58.27 in)

Center of Pressure	169 cm (66.54 in)	169 cm (66.54 in)

Table 3: Center of Gravity and Center of Pressure measured from tip of Nosecone

Environmental Conditions

The launch is in North Branch, MN (45N, -92E) on May 20-21, 2017 with a rain date on May 22, 2017. We anticipate that the launch will not have to deal with rain. The average weather on this day is a high of 21.1 C (70 F) and a low of 7.78 C (46 F). Our rocket can handle flying in these temperatures as the flap system is dynamic. The elevation of the launch site is approximately 274 m (900 ft) above sea-level compared to the elevation of our test launch sites at approximately 233 m (765 ft). The slightly higher launch point means that the air pressure at launch will be lower than what it was during our testing. However, our rocket and our velocity measuring systems will take this into account and should not have an issue. Another major environmental issue during launch would be a significant wind which could cause the rocket to drift. The annual average windspeed in the region is 25.3 km/h (15.7 mi/h). We plan to address this by adjusting the Jolly Logic Chute Release system to deploy at as low of an altitude as possible.

Logistics

Safety

The team used a 1-5 scale to assess safety concerns. A level 1 event is considered highly unlikely, or a minor problem if it occurs. A level 5 event is considered highly likely, or a major problem if it occurs.

Table 4: Failure Modes and Mitigation Strategies

Failure	**Likeliness (1-5 scale)**	**Severity (1-5 scale)**	**Impact**	**Mitigation**
Ejection charge causes failure of components within rocket	2	5	Possible destruction of rocket	Protect all internal components of the rocket from heat and explosions, keep internal components out of the way
Rocket fins detach	1	5	Instability of rocket, inability to recover and fly again	Securely attach fins and test before flight
Parachute does not open	2	5	Destruction of rocket	Fold and roll the parachute neatly and keep internal components of the rocket out of its way
Electrical equipment failure	3	2	Active drag system does not deploy, velocity sensor does not measure	Testing

Rocket drifts	3	1	Velocity sensor may not have an accurate reading	Balance rocket precisely
Active drag system does not deploy	1	1	Higher apogee with K motor	Test electrical equipment before flight
Active drag system does not retract	1	2	Possible damage, possible inability to deploy at next flight	Make sure servos are securely attached, electrical equipment can retract fins when needed
Shock cord failure	2	5	Complete separation of rocket, damage upon landing	Securely attach cord
Breakage of velocity sensor	3	2	No velocity reading, points deducted	Test strength of sensor parts in wind tunnel at actual wind speeds

Table 5: Personnel Hazards and Mitigation Strategies

Hazard	**Likeliness (1-5 scale)**	**Severity (1-5 scale)**	**Impact**	**Mitigation**
Laser cutter	1	3	Skin damage	Use cover for laser cutter
Dremel/Drill	2	2	Bleeding, abrasions to the skin, eye irritation	Wear protective goggles and be careful when using tools
Epoxy	3	2	Skin irritation and possible allergic reaction	Use gloves when handling epoxy
Wind tunnel	2	2	Injuries to fingers and hair	Long hair will tie hair back, and people will be careful when placing objects in.
Electrical equipment (wires, motors, Arduino, etc.)	2	3	Electrocution	Team members will not open wires, and all power sources will be turned off before handling.
Rocket launch and flight hazards	3	5	Components falling on people, rocket crashing into someone or something when landing	Team members will maintain a safe distance from the launch site and will watch where the rocket is at all times.

Timeline

January	February	March	April	May
January 19th: -Computer Aid Design of the Rocket Begins **January 24th:** -Start Developing the Budget **January 27th:** -Formal Budget **January 30th:** -Order parts to Test Different Types of Accelerometers	**February 7th:** -Start work on Mid-Power Rockets **February 10th:** -Competition attendance due **February 14th:** -Work on Mid-Power Rockets, Launching them **February 21st:** -Start Preliminary Design Report **February 28th:** -Work on Report	**March 7th:** -Have the Computer Aided Design done, Working on the Preliminary Design Report **March 9th:** -Internal Deadline for Preliminary Design Report **March 10th:** -Preliminary Design Report Due **March 11-13th:** -Engineering Open House **March 18-27th:** -Spring Break	**April 4th:** -Educational Outreach Due **April 10th:** - Flight Testing Rocket for the Competition **April 25th:** -Modify Build	**May 3rd:** -Instruction Ends **May 5th:** -Final Exams **May 12th:** -Rocket must be completed **May 21-22nd:** -High-Powered Rocketry Competition

Launch Procedures

Each launch should go smoothly if a certain set of rules and procedures are laid down that can be general enough to deal with problems with the rocket or team functioning. These should include careful testing of all sub-systems immediately before and after flight, double-checking of anything that needs to be screwed or tightened down in any way, and close scrutiny of the rocket airframe and structure to ensure the rocket is safe to fly once more. Feeding the computer system simulated data should prove to the team that the rocket can successfully take in and analyze flight data dynamically. Ejection charges and other volatile materials will be handled by an experienced member of the Central Illinois Aerospace organization in order to ensure safety for the team.

Before launch, the rocket will be taken apart and inspected inside and out for visible signs of damage. The rocket will be assembled by inserting screws to hold together the nose cone, upper body tube and coupler once the velocity sensor, cameras, and avionics package are ready for flight. The lower body tube will be packed with the parachutes and servo housing. The lower body tube will then be securely fastened to the motor assembly once all ejection charges are in place and servo linkages attached. Once this all happens, the upper and lower sections will be joined at the coupler and the rocket will be ready for flight.

After landing, the rocket will be retrieved using a GPS based tracking system. The rocket will be brought back by two to three members of the team to ensure ease of transport during what could be a long walk. Afterwards, all flight data, including video, will be offloaded from the rocket. The flight data from the flight on the J-motor (altitude and velocity measurements) will be uploaded to the Arduino for comparison and drag flap deployment on the K-motor flight. The pre-launch procedures will be followed from here on out.

Budget

The budget for this project was set at $1000 soft limit. The budget was split between two parts; the full-scale rocket and the mid-power test rockets both used the $1000 budget. One J415W and two K1103X motors will be ordered. The second K1103X will allow testing of all rocket systems in one test flight.

Item	Per unit cost	Quantity	Total Cost	Item	Per unit cost	Quantity	Total Cost
Full Scale Rocket							
Anemometer	To be cut	1	$0.00	Hinges	$5.00	3	$15.00
Anemometer Motor	Owned	1	$0.00	Jolly Logic Chute Release	Owned	2	$0.00
Arduino Altimeter	$9.95	1	$9.95	J Motor (J415W-L)	$79.04	1	$79.04
Arduino Light Sensor	$0.95	2	$1.90	K Motor (K1103X-14)	$96.04	2	$192.08
Arduino Mega	$45.95	1	$45.95	More Tube Couplers	$17.27	2	$34.54
Arduino Servo Shield	$20.00	1	$20.00	Motor Adapter	$59.00	1	$59.00
Battery for Arduino	Owned	1	$0.00	Motor Casing (54-2560)	Owned	1	$0.00
Bigger Servos	$20.45	4	$81.80	Motor Mount Tube (Blue Tube)	$23.95	1	$23.95
Body Tube (Blue Tube)	$38.95	2	$77.90	Motor Retainer	$57.78	1	$57.78
Cameras	Owned	2	$0.00	Nose Cone	$23.05	1	$23.05
Centering Rings	To be cut	3	$0.00	Parachute	Owned	1	$0.00
Chute Swivel	$7.35	2	$14.70	Parachute Protector	Owned	1	$0.00
Connections Hardware	$25.00	1	$25.00	Pushrod (1.2mm)	$6.99	1	$6.99
Control Horns	$1.29	2	$2.58	Quicklinks	$3.94	4	$15.76
Copper Wire	Owned	1	$0.00	Rail Buttons	$10.00	1	$10.00
Coupler (Blue Tube)	$39.95	1	$39.95	Resistors	$0.14	3	$0.42
Drogue Parachute	Owned	1	$0.00	RocketPoxy	$38.25	1	$38.25
Electronics Bay (Plywood)	To be cut	1	$0.00	Rotary Switches	$9.93	2	$19.86
Eyebolts	$5.51	3	$16.53	Servo Extension Wires	$4.95	2	$9.90
Fins and Flaps (Fiberglass)	$15.00	3	$45.00	Shear Pins	$3.10	1	$3.10
Forward Closure (54mm/Open)	$48.15	1	$48.15	Shock Cord	$1.00	24	$24.00
Heat Shrink Tubing	Owned	1	$0.00	Stratologger Altimeters	Owned	1	$0.00
Midpower Test Rockets							
Active Drag Servos	Owned	4	$0.00	USB Adapter for Arduino	$3.95	1	$3.95
Tube Couplers	$15.83	2	$31.66	Voltmeter	Owned	1	$0.00
Total Budget	$1,000.00			Estimated Total Cost			
Total Remaining	$22.00			$2,378			
Team registration	$400.00						
Travel Estimates	$1,000.00						

Educational Outreach

Introduction

The University of Illinois Space Grant Mid-West Rocketry competition team is a technical project under the Illinois Space Society. ISS is a society in which outreach is highly revered and calls for large participation. Due to this all outreach completed by the team was completed under and lead by ISS.

Specific Activities

ISS participates in numerous educational outreach events each semester. However, due to dates and the scope of the project, the team chose to volunteer at The University of Illinois' Engineering Open House (EOH). EOH is a weekend long event hosted for the community and focused at educating and encouraging younger students to enter the field of engineering through fun demonstrations and hands on activities, including liquid nitrogen, space shuttle tiles, orbital simulator, egg drop lander construction, rocket races, and model rockets. This is an annual event that draws almost 20,000 people to learn about the College of Engineering.

Liquid nitrogen and space shuttle tiles are normally demonstrated together as one exhibit to teach kids about the extremes of outer space, thermal control, and cryogenic fuel management as applied in space. Various objects are submerged into the liquid nitrogen to show how material properties change under extreme cold. These include pennies, flowers, balloons, and even marshmallows. The space shuttle tile is used in the opposite format to show the extremes of heat. Using a blowtorch and a heat sensor the kids can see how the material can be held even at high temperatures and how it insulates and ship upon reentry into the earth's atmosphere.

The orbital simulator and egg drop lander construction allow kids to experience hands on scientific experiments at EOH. Marbles are thrown onto a circular sheer with a lowered center to simulate basic orbital mechanics. They can both physically see the result along with learn how to manipulate orbits. Egg drop landers allow kids to build their own protective casing for a raw egg to protect it from breaking after being thrown off a third floor balcony. This allows them to learn about the necessity of protecting a payload and the use of parachutes.

Finally, rocket races and model rockets allow our teams to get hands on experience along with the kids in working on smaller rockets. Rocket races at EOH are comprised of different registered student organizations (RSOs) building model rockets at a length of approximately two feet and launched while strung on a wire horizontally at the same time another rocket is launched. The rocket which makes it to the finish first, wins. This is repeated until all have competed and one RSO has won. The hope is that ISS will win along with the help of our team. Secondly, basic model rockets are built with the students. These allow them to learn about body tubes, nose cones, fins, motors, and motor mounts in the simplest of methods.

Every demonstration and event included in EOH is a vital learning opportunity for the students and families alike. Each piece focuses on a different aspect of rocketry allowing a holistic approach to the concept in a simple format to make understanding easy. Our team will use the knowledge gained through this project to spread important information to the community along with presenting aspects of our own rocket.

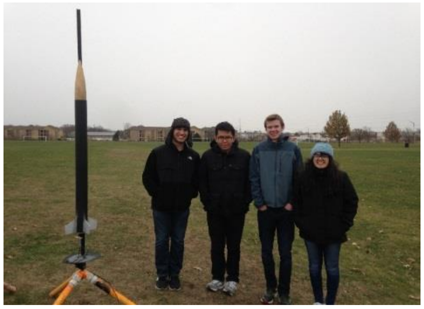
Mid-power Rocket Demonstration Launches

Prototyping

During prototyping, the team went through a tutorial provided by the local rocketry association and senior members of the Illinois Space Society. This mid-power rocketry tutorial introduced the team to OpenRocket and the design of a rocket. Out of the 14 active members of the team, four teams were created that designed their own rockets using OpenRocket. These four teams were tasked with making their rocket go to 304.8 m (1000 ft).

Launching

The launch day was a cold one. Only 11 of the 14 were able to make it to launch, but all members were involved in construction and design of their respective rockets. All teams were able to make the rockets achieve an apogee within 15 m (50 feet) of the original goal.



Post-Flight

After the rockets were launched, each was assessed for damage. All of them were deemed safe to fly again. Since it seemed wasteful to get rid of the rockets, it was decided that the rockets could be repurposed to fly the prototype sub-systems like the velocity sensor and active drag system and achieve a new goal related to the successful functioning of the sub-system.