University of Illinois at Urbana-Champaign

NASA's Space Grant Midwest High-Power Rocketry Competition 2016

Illinois Space Society

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Table of Contents

1 Executive Summary

The Space Grant Midwestern High-Powered Rockery Competition is held annually by the Minnesota Space Grant Consortium that challenges teams from educational institutions across the United States to meet some competition-specified function.

This year's challenge is to successfully design, construct, and launch a high-powered rocket containing an active drag system that allows for the manipulation of the vehicle's maximum apogee. In order to actively control the drag, the proposed system will feature a linear actuator that exerts a downward force on a set of 3D printed "wedges", deploying a set of flaps in turn. These flaps, which are the air-brakes, will protrude from the side of the rocket, disrupting the flow of air and greatly increasing the drag on the rocket. A combination of OpenRocket software, finite element analysis, and traditional calculations were utilized to design the rocket and all its components. All systems have been designed to ensure two safe and successful launches that fulfill the competition objective, complete with accurate data collection and recovery of the vehicle.

Traditionally, the Illinois Space Society (ISS) team has been composed of freshmen with a single upperclassman to guide them through the design process. This year, the greater complexity of the desired function demands a team with more experience than the past. This year's team is composed of four freshmen, one sophomore, one junior, and one senior. The older members all have experience in high power rocketry through various other competitions, which maximizes the team's chance of success.

2 Vehicle Design

2.1 Mission Statement

The mission is to design a high power rocket while meeting the criteria set by the Space Grant Midwest High-Power Rocket Competition. The specific challenge set out by the competition is to design and implement a mechanism that will actively control the atmospheric drag during the rocket launch. This will prove to be a challenging and creative experience that will test the abilities of the team in terms of creativity, knowledge, and labor.

2.2 Mission Success Criteria

The flight will be considered a success if these criteria are met:

- The rocket reaches an apogee of at least 3000 ft during its initial launch.
- The rocket is ready to launch a second time within one hour after its first flight.
- The drag system activates after motor burnout and deactivated prior to apogee to reach an altitude of exactly 75% of the initial altitude indicated by the first launch.
- During both launches, the rocket flies with a stability margin of no less than 1 and no more than 5.
- The rocket gathers data to characterize the coefficient of drag during the deployment of the drag system.
- During all flight stages, all rocket components remain attached.
- The landing decent rate is less than or equal to 24 ft/s.
- The rocket remains intact after both launches.

2.3 Dimensional Specifications

The rocket will be 72.5 in long and made up of two major sections: forward and aft. The forward section will contain the payload, which includes the avionics bay and active drag system. The aft section will house the recovery system and the propulsion system. The two sections will be distinctly separate, but will remain tethered together after apogee for the recovery. All body tube sections will be made of Blue Tube 4.014 in in diameter (3.913 in inner diameter), except the ogive nose cone. This will be fiberglass and of the same diameter.

The forward section will be 41.5 in long and will have three subsections: the nose cone, avionics bay, and payload bay, which will be 16.5, 8, and 17 in long, respectively. The avionics bay will contain the radio transmitter and the AltimeterTwo, as mandated by the competition. To provide stability for the payload bay, the avionics bay will be separated by a bulkhead. Within the payload bay will be the active drag system, consisting of a linear actuator attached to three flaps which extrude from the rocket when deployed, thus increasing the drag force on the structure. Also contained in the payload bay and cleverly stored will be the drag system's lithium polymer battery source, accelerometer, and Arduino controller.

The aft section will contain the motor as well as the 30 in recovery system. The motor and recovery system will be separated by the engine block that sits 13 in forward of the tail of the rocket at the top of the motor casing. The remaining length of the rocket will be have a negligible length due to, approximately 1 in, is attributed to overhang of the fins overhanging past the length of the rocket.

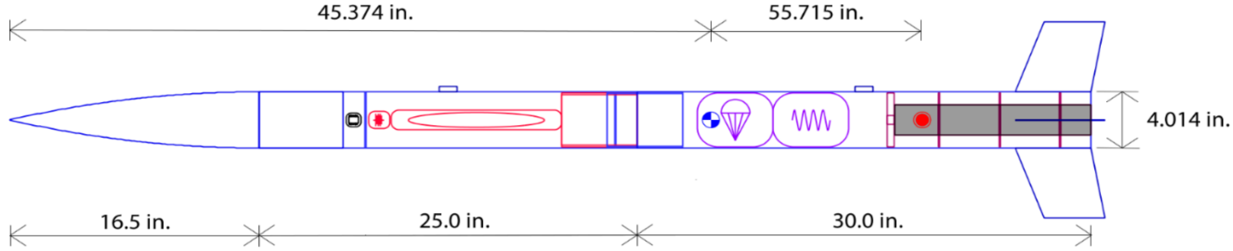

Figure 1. OpenRocket diagram.

2.4 Recovery System

The recovery system will consist of one 52” parachute. The parachute will be tethered to a bulkhead in the aft section of the rocket and will be ejected by the motor ejection charge. This parachute will slow the rocket’s velocity to 18 ft/s, which is within the range of acceptable descent rates. [1]

The parachute will be deployed by black powder charge triggered by a StratoLogger altimeter 16.5 seconds after burnout, or 3 seconds after apogee, at an altitude of 3890 ft. This timing was chosen to ensure that electronic deployment precedes the rocket motor’s built in ejection charge. The motor ejection charge will serve as a failsafe in case of any impedance in the recovery system electronics.

An analysis using a custom MATLAB script that inputs average wind speeds at the competition site (about 15 miles per hour) [2] revealed that deploying the parachute near apogee charge can cause drifts of up to 5300 ft, an unnecessary and unacceptable drift distance. To reduce this distance, a Chute Release device manufactured by Jolly Logic will be used to delay the full deployment of the parachute until 600 ft, significantly reducing the initial drift distance; the updated analysis indicates a drift of around 2200 ft While this still entails a large drift distance, delaying deployment of the parachute any longer risks the chute not deploying fully before landing.

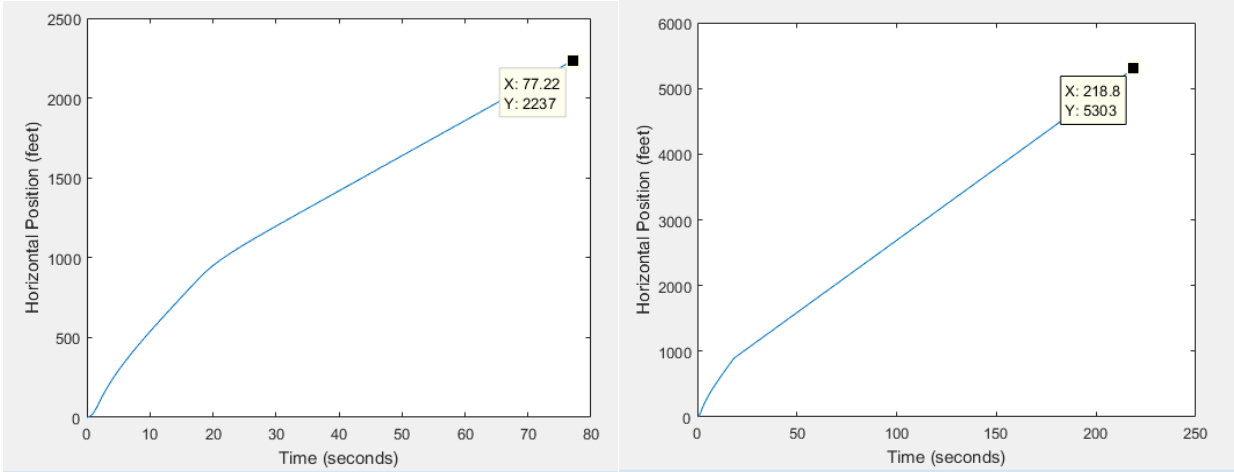

Figure 2. Rocket drift vs time of parachute deployment.

The size of the rocket and significant forward mass necessitates the use of shear pins to prevent drag separation. The calculations for shear pins and ejection charge requirements are calculated in
Table 1 below.

Table 1. Shear Pin and Ejection Charge Calculations

Mass in upper section [lbf]	4.41
Peak Acceleration [G]	4.08
Force Required [lbf]	20
Parachute Tube Length [in]	15
Body Tube Diameter [in]	4
Desired Pressure [psi]	8
Number of 2-56 Nylon Screws	**2**
Black Powder [lbm]	**0.0017**

The recovery system includes a radio transmitter within the systems compartment. This will enable the team to locate the rocket wherever it lands by indicating its direction and distance from the radio receiver possessed by the team after the launch.

2.5 Airframe Manufacturing Plan

The rocket will be composed of four subsections: the nose cone, the payload bay, the recovery system, and the propulsion system. The payload bay will house the avionics and active drag system. To house the various systems, two major sections of Blue Tube will be cut to serve as the body tube. These sections will be held together by a coupler of the same material.

The forward tube will contain two sections, separated by a fiberglass bulkhead, which has been specifically chosen for its structural integrity. The upper section will house the nosecone and AltimeterTwo. The lower section will house the avionics and active drag system. There will be three distinct cutouts in this section of the body tube to allow for the passage of the airbrake flaps (detailed in the following section). This section will also be reinforced with an extra frame of coupler material to enhance strength, as it will have to bear the excess load from the active drag system.

The aft tube will contain the recovery system and the propulsion system. In regards to the former, the parachute will be folded and stored in compliance with the delayed chute release device. For the latter, the motor casing will be stabilized by three plywood centering rings and held in place by a motor block. The aft tube is also the section of the body tube to which the fins will be attached. The three fins will be laser-cut into precise dimensions from ¼ in sheet of plywood, which was determined to be able to withstand the force experienced in-flight while still being relatively lightweight. The fins will be sanded down to rounded edges to decrease the drag they create. Included in the design of each fin will be a fin tab, used as an insert between the centering rings to provide a larger surface area for epoxy and make it less likely for them to shear upon impact. Epoxy filler will additionally be used as a fillet material to create a smooth, round transition between the fins and the body tube.

The nose cone will be friction-fit to the top of the forward body tube. The selected nose cone will be made of heavy and sturdy fiberglass, which provides mass distribution that is conducive to high stability.

When the whole airframe has been assembled, finishing touches will be added to ensure the most accuracy possible in flight. This includes sanding down the whole surface of the rocket to remove any grooves in the material or imperfections generated from the construction process, before painting carefully and polishing the surface for maximum streamlining.

2.6 Mass Statement

Since there is a specific apogee altitude goal, the mass of the rocket is a very important factor considering the initial design of our active drag system and the selection of our propulsion system. As the active drag system itself is a large portion of the mass of the rocket, the mass of the remaining components had to be minimized in order to reach the altitude goal. As the heaviest component, it was especially critical to choose an actuator that was as small as possible while still being able to push with enough force to deploy the airbrakes under the pressure force of the outside air. Compared to the actuator, the electronics and airbrake wedges weigh very little and, as a result, are much easier to manipulate in the overall design of the drag system.

Table 2. Mass Budget

Component	Mass (lbm)
Nose Cone	0.61250
Airframe (Blue Tube)	1.881392
Airframe Coupler	0.271720
Fins	0.507063
Flaps	0.165567
Actuator Head	0.176370
Coupler Bulkhead	0.120152
Kevlar Cord	0.044092
Parachute	0.762359
Linear Actuator	1.300066
Battery	0.324080
Motor	2.373938
Wadding	0.105822
Motor Casing	0.193345
Centering Rings	0.121695
Motor Mount	0.142198
Chute Releases	0.038581
Accelerometer	0.440925
Altimeter	0.028219
Arduino	0.055116
Camera	0.100090
Total	**9.76529**

3 Payload Design and Integration

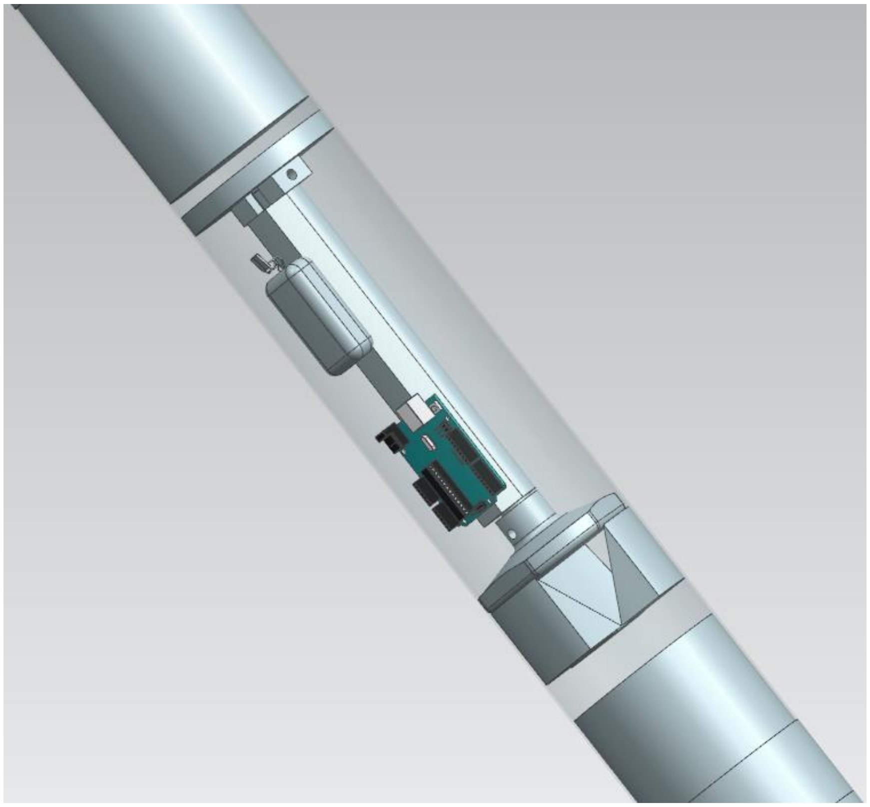

Figure 3. Active drag system integrated into payload section

The Active Drag System consists of a linear actuator, a custom fabricated actuator head, the wedges (which provide drag when deployed), the Arduino and accelerometer assembly (which governs the deployment of the system), and the lithium polymer battery power source.

The linear actuator is affixed to the fiberglass bulkhead that separates it from the avionics bay. At the head of the piston of the linear actuator, a 3-D printed linear actuator head will be fastened by a bolt. The head will have rounded edges that apply force to the wedges, and likewise will be 3-D printed. Both will be sanded, polished, and lubricated to minimize friction on deployment. The wedges will attach the interior of the body tube with hinge tape, epoxied for further stability.

The linear actuator is governed by an Arduino which collects data from an accelerometer and determines what force must be applied to reach the desired apogee. This, along with the LiPo battery that provides power to the linear actuator, will be wired and fastened to the linear actuator itself in an orientation which ensures none of these will be damaged on impact.

The payload will be integrated as its own modular section of the rocket. The flight computer, sensors, and drag system are all considered part of the payload and will be mounted in this section, located midway up the rocket. This design is chosen in order to minimize the volume that the payload occupies while also ensuring its protection from the ejection charge. This will also allow for easy assembly and modification of the payload and electronics during construction and testing.

3.1 Avionics

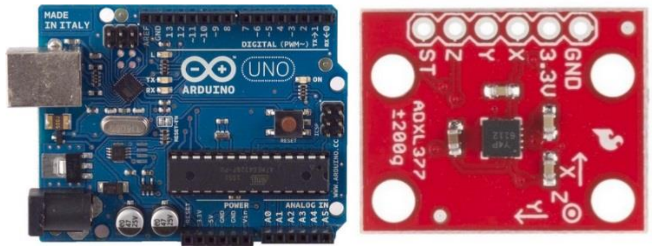

Figure 4. Arduino Uno (left) and accelerometer (right)

One of the key purposes of the avionics bay is to collect data that will "characterize the coefficient of drag over time and use an on-board video camera to document the state of the drag system." To achieve this goal, the electronics section of the rocket will utilize an Arduino Uno, ADXL377 accelerometer, a micro keychain camera, and an AltimeterTwo. The Arduino Uno is designated as the data collection tool for its ease of data retrieval and its diminutive size. The data collected by the UNO can be easily viewed by connecting the UNO to a laptop at hand with a USB cord. The 2.70 in x 2.1 in dimensions of the UNO minimizes the space taken up in the avionics bay. This is practical in regards to space, as the large volume of the linear actuator will occupy most of the capacity of the payload section. Small electronics are key, and the Arduino Uno is perfect for the job. The components of the avionics bay that are connected to the Arduino UNO are an accelerometer, the actuator, a battery, and an electric switch. The ADXL377 accelerometer was chosen for its minimal dimensions; its size is slightly bigger than a quarter. In addition, the ADXL377 does not need a lot of power to operate. It only draws 300 microamperes while in use and the operating voltage is 1.8V-3.6V; perfect for use with the UNO which can output at max 5V. The electronics switch is connected to a LiPo battery that will power the linear actuator. The code in the Arduino will calculate the required airbrake deployment angle to lower the rocket's apogee to exactly 75% that of the first flight, given a burnout altitude and velocity. The Jolly Logic AltimeterTwo will be used as the instant flight analysis tool as specified by the competition guidelines. The AltimeterTwo is autonomous from the Arduino component of the avionics bay and will be mounted separately.

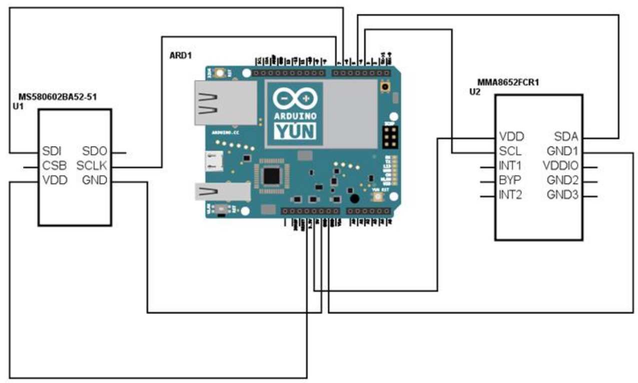

Figure 5. Electrical schematic of avionics.

3.2 Active Drag System

In order to actively control the drag, the proposed system will feature a linear actuator that exerts a downward force on a 3D printed actuator head, deploying a set of flaps in turn. These flaps, the air-brakes, will protrude from the side of the rocket, disrupting the flow of air and greatly increasing the drag on the rocket. The individual components of the drag system were selected and/or designed to function in a harsh environment where they will be subject to extremely high stresses.

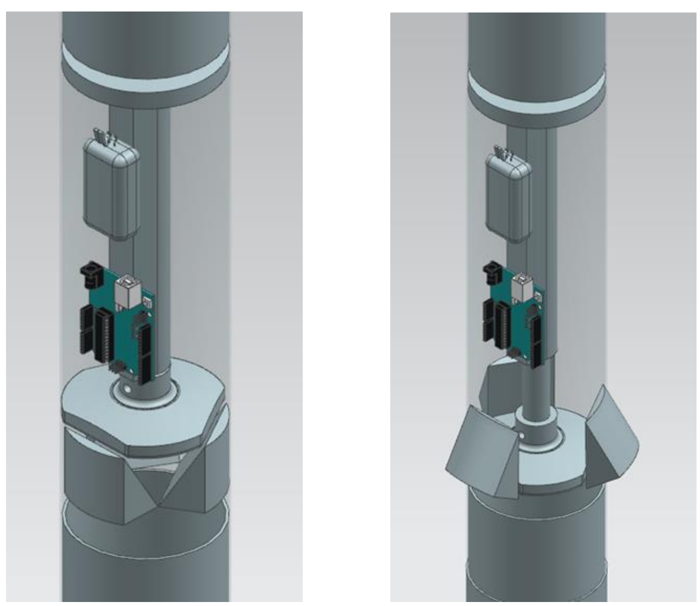

Figure 6. Active drag system un-deployed (left) and deployed (right).

The force required to deploy the air-brakes will be supplied by a linear actuator. Produced by Firgelli Automations, the actuator will feature a 2” stroke capable of providing up to 15 lbs. of force. Since the system is configured to have the actuator push down on a set of wedges, the actuator will experience significant mechanical advantage in the same way a person does pushing a box up a ramp as opposed to lifting it directly. Thus, although the actuator can only supply 15 lbs. of force, its equivalent pushing ability will theoretically be much greater.

Another notable feature of the Firgelli mini linear actuator (Fig. 6) is its tubular design. Unlike most actuators, the motor in the Firgelli will be aligned with the output rod. This will allow the device to be concentrically mounted inside the payload tube without having to incorporate counterweights or offset the drag wedges.

Figure 7. Linear actuators showing motor beside output arm (left) and in-line with output arm (right)

As an isolated component, the actuator's output arm is too narrow to interact with the airbrake wedges. To fix this problem, a custom head was designed and 3D printed to fit onto on the actuator's arm. The head greatly extends the cross-sectional area of the arm, allowing it to push down on the wedges. The head has a flat face every 120 degrees, which acts as the contact surface for the wedges to meet. In between each flat face is a curved edge based upon a circle of diameter 4 in, to fit perfectly within the body tube.

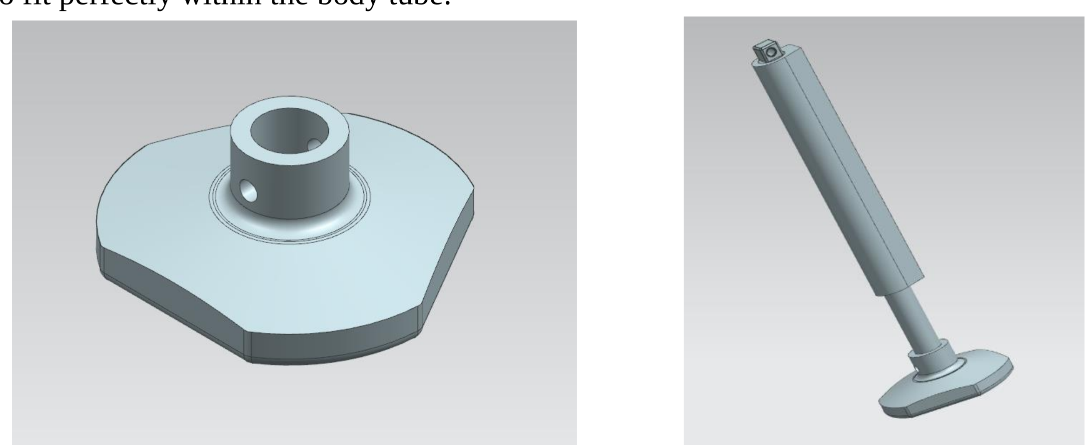

Figure 8. CAD model of the actuator head (left) and how it fits with actuator (right).

The airbrakes are the component of the active drag system that physically slow the rocket down. When a downward force is applied to the innermost face of three wedges, mounted radially to the inside of three cutouts in the body tube, they pivot outwards. These extended cutouts block the flow of air around the rocket body and increase the drag of the vehicle. As a result of this push-and-pivot design, the angle at which the airbrakes deploy can be manipulated as a function of the distance the actuator pushes.

In order to allow the flaps to pivot about the curved edge of the body tube, they are attached to the tube via a hinge made of reinforced tape, similar to the tape used in book bindings. This tape is reinforced with fiberglass, making it strong enough to withstand the downward force of the actuator and airflow, while also being flexible enough to bend around the curvature of the body tube. Weak torsion springs connect the base of the wedges to the body in order to keep the airbrakes in their un-deployed resting position during pre-burnout ascent.

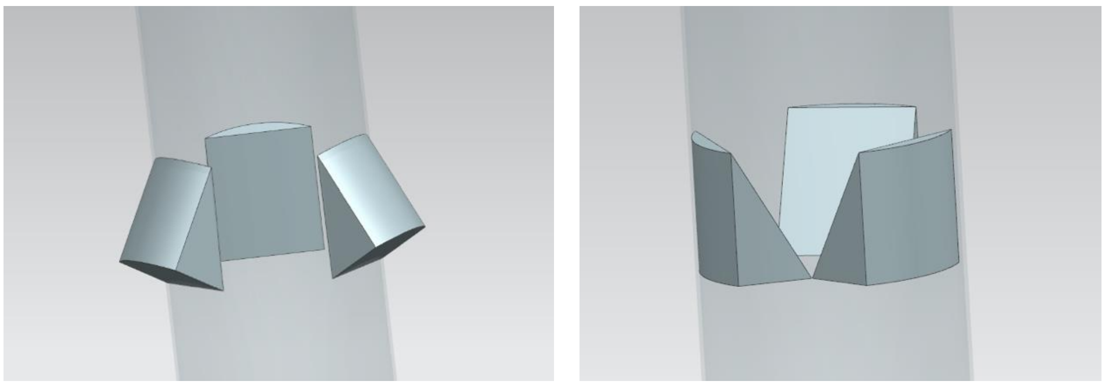

Figure 8. Airbrakes un-deployed (left) and deployed (right)

3.3 Active Drag System Construction Procedures and Technique

As stated above, the airbrakes consist of a linear actuator, a specially fabricated actuator head, three “wedges”, an Arduino controller, and an accelerometer sensor. The linear actuator will be affixed to the forward fiberglass bulkhead separating it from the avionics. To the linear actuator will be attached a 3-D printed actuator head with rounded edges, which will be sanded, polished, and lubricated to minimize friction between it and the wedges as it applies force in flight. The three “wedges” will be crucial components of the active drag system; therefore, each will require precision and specialization in their construction. This cannot be achieved pre-built or personally machined parts, so the team chose to 3-D print each of these parts. The wedges will then be made of the 3-D printed material polylactic acid, which has been chosen for its be smooth, refined surface. Still, the upper surface of 3-D printed material is often rough when it first emerges from fabrication, so this will need to be sanded and ground down extensively to maintain a smooth and aerodynamic surface. Each “wedge” will be carefully attached to the interior of the body tube with fiberglass reinforced hinge tape and epoxy. As mentioned previously in the avionics section, the entire airbrake system will be directed by an Arduino controller taking data from an accelerometer to determine the necessary force the linear actuator must apply to the wedges to create drag on the rocket. For maximum effectiveness in such a minimized space, the Arduino and accelerometer will be fastened to the linear actuator in an orientation that makes both less vulnerable to shock on impact.

4 Predicted Performance

In order to ensure a well-functioning system, a drag system that is simple to manufacture and easy to deploy was designed.

Size is the primary constraint impacting the design of the rocket and its drag system. In this scenario every component involved in the process must fit into a 4 in tube. To work with the size constraint, space must be treated as a resource and used sparingly.

Given the extreme length of the linear actuator compared to other components in the rocket, minimizing the size of the actuator was essential. By calculating the flap size required to achieve the desired drag force, a linear actuator with the minimum stroke length required for deployment was selected in order to shorten the payload bay as much as possible. Furthermore, since the diameter of the linear actuator is sizably smaller than the diameter of the body tube, a significant portion of space within the payload bay is left open. As such, all electronic components could be fitted alongside the actuator inside the payload bay, eliminating the need for a separate electronics bay.

Many forces act upon the rocket and its drag system during flight and, as a result, it is critical to ensure each part is strong enough to withstand such strains. The part in particular that must endure extreme stress is the hinge tape connecting the airbrake flaps to the rest of the body tube. The tape must withstand a downward force from the linear actuator, as well as that of the air pressure. In addition to this tension, the tape must be able to bend over the curved surface of the body tube. Given these factors, a reinforced material capable of withstanding a stress of 150 psi before tearing was selected. Other component materials were also carefully selected for their structural integrity. For example, Blue Tube was chosen over standard LOC tubing for the rocket body for its superior stiffness. The fins were cut from rigid plywood in order to avoid the risk of snapping midflight.

A structural Finite Element Analysis (FEA) was performed on the active drag system, simulating the forces this system is likely to experience during flight. This simulation showed that under the specified loading conditions, the maximum stress experienced by the system was 130.60 psi, which is below the failure point of the material used in the hinges.

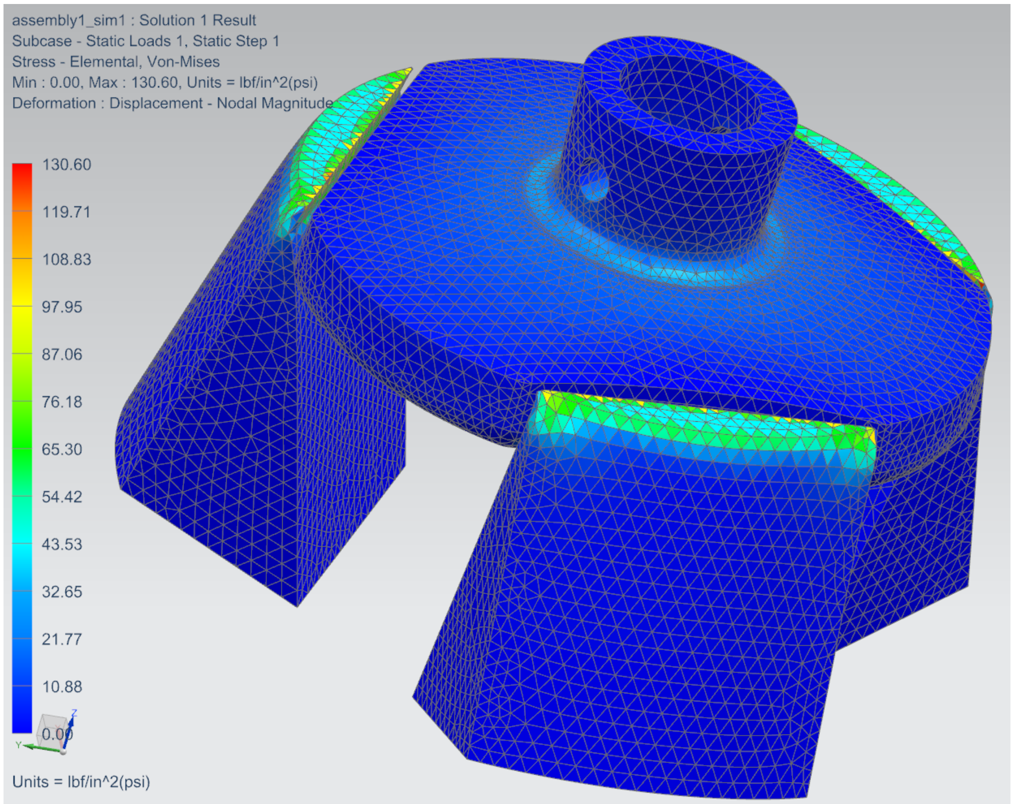

Figure 9. Results of structural FEA

4.1 Flight Prediction Methods

Two distinct simulator programs were used to model the rocket's overall flight profile. The first simulation was done using the software OpenRocket, only requiring team members to model the rocket in the program before running the its ready-made simulator. Modeling primarily involved the input of key characteristics such as component weights, data on vehicle design, parachute dimensions, and the thrust curve of the engine. OpenRocket is commonly used and well-respected for its flight modeling capabilities, and the team has had success using it in the past.

The second simulation was more involved and utilized a custom MATLAB program written by team members. Like OpenRocket, this custom simulator factors in data on vehicle and parachute design, thrust curve, and individual component weights. The program uses this inputted data to model forces acting on the vehicle like thrust, drag, and gravity. Then, by numerically integrating the vehicle's equations of motion and working in two dimensions, the simulation is able to solve for horizontal and vertical position and velocity at each time step. These calculations allow the simulator to predict multiple flight aspects including apogee, maximum velocity, vehicle drift, descent rate, and exit velocity off the launch rail. Accuracy was emphasized when designing the program, and team members implemented a modified version of the Runge-Kutta fourth order scheme in order to achieve highly accurate predictions. Finally, an added benefit of the custom simulator is its ability to independently model the flight profile while the active drag system is active.

When comparing the effectiveness of the two simulations, each has its own benefits. OpenRocket is a tested and proven piece of software that countless people use, and its development team has no doubt spent a great deal of time over the years perfecting the mathematics behind it. Still, while OpenRocket's simulation is likely more robust, it does not offer access to any of the assumptions or decisions it makes when creating a flight profile. Team members do not know the exact process that the program uses to make its predictions. The custom simulation, in contrast, is decidedly more open and allows the team to know exactly how it creates predictions and what assumptions it makes. As mentioned before, it also permits modeling active drag system and its effect on the rocket's performance. While the custom program is certainly not as time-tested as other simulators, it offers access to its decision-making process that OpenRocket simply cannot match.

ISS members have used the custom MATLAB code to simulate past rockets, and found that it undershoots apogee predictions where the OpenRocket Simulation overshoots them. The average of both simulations tends to be the best prediction for the early stages of flight.

4.2 Launch Analysis

The initial launch analysis will include the analysis of both the velocity off pad as well as the velocity at deployment. Analyzing these two characteristics will yield in accurate descriptions of the vehicle as it exits the launch pad and off the launch rail. Taking these characteristics into account, a predictable assumption can be made for the flight analysis later on. Performance predictions were taken from OpenRocket, which was used to model the vehicle, piece by piece, and then simulate its flight.

Using OpenRocket's simulations, the calculated velocity off the pad is 62.99 ft/s, which is fairly above the average off-pad velocity for a vehicle of this size and weight. The initial velocity shows that the vehicle will be fairly stable as it leaves the guide rail, which is a good sign that the vehicle will be stable throughout its flight.

Additionally, for any flight to be successful, the vehicle's maximum velocity also factors into the performance of the vehicle. OpenRocket predicts the vehicle to have a deployment velocity of 61.8 ft/s. The recommended deployment velocity is around 131.23 ft/s so the vehicle deploying at the predicted velocity will have no trouble with stability as it leaves the launch rail.

4.3 Flight Analysis

The key flight characteristics made for the vehicle include the apogee, maximum velocity, and the total duration of flight. Using OpenRocket's simulation software and custom MATLAB code, the team has available a range of predictions for the flight parameters of the rocket.

A comparison the simulated apogees while not using the active drag system is shown below in **Error! Reference source not found.**. The early stages of flight are nearly identical between the simulations and scales with respect to the apogee. The OpenRocket simulation predicts the vehicle will be reaching an apogee of 4900 ft while the custom code predicts apogee at 4000 ft. This is the absolute maximum apogee this vehicle will achieve since, as stated previously, this simulation assumes that the flaps will not be deployed during launch. This decision to acquire the absolute maximum apogee is intentional as the target altitude for the competition is 3000 ft and with the addition of the drag, the approximation will be less than the predicted apogee as given by OpenRocket. Additionally, overshooting the intended the altitude allows for small changes to made to the design of the vehicle without having to alter portions of the overall design.

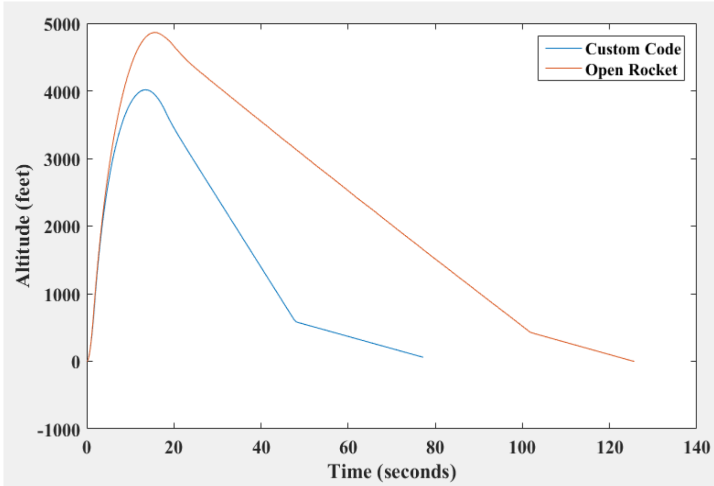

Figure 11. Predicted altitude without drag system as a function of time from both simulations.

The MATLAB code is also used to estimate the effects of the active drag system. With the system engaged, the rocket reaches an apogee of 3250 ft. This is 18.75% less than without the drag system. The code used to predict the coefficient of drag for a given velocity. This is calculated through the manipulation of the drag equation as well as the equation used to calculate the Reynold's number. By solving for the density, thereby minimizing the effects of altitude change, the team was able to equate the two otherwise dissimilar equations with one another. The resultant of this manipulation yields an equation which relates the coefficient of drag to the velocity. Figure 14 shows the results of this calculations during the simulation.

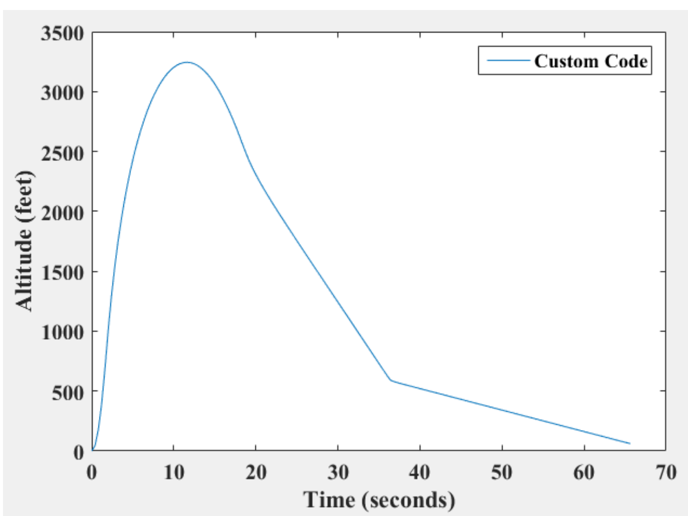

Figure 10. Altitude as a function of time with the drag system engaged.

In addition to the predicted apogee, the vehicle's maximum velocity is simulated at 850 ft/s by OpenRocket, approximately Mach 0.76, and at 800 ft/s by the MATLAB code. The velocity curves, shown in Figure 11, match up nicely in both simulations, suggesting a high degree of accuracy in this estimate. A Mach number of 0.76 will not be close to transonic speeds, so structural integrity will not be compromised and there will be evaluation of the effects of supersonic or transonic airflow on the vehicle required. Knowing that this maximum velocity is well below the transonic range, the team is confident that performance will not be impeded.

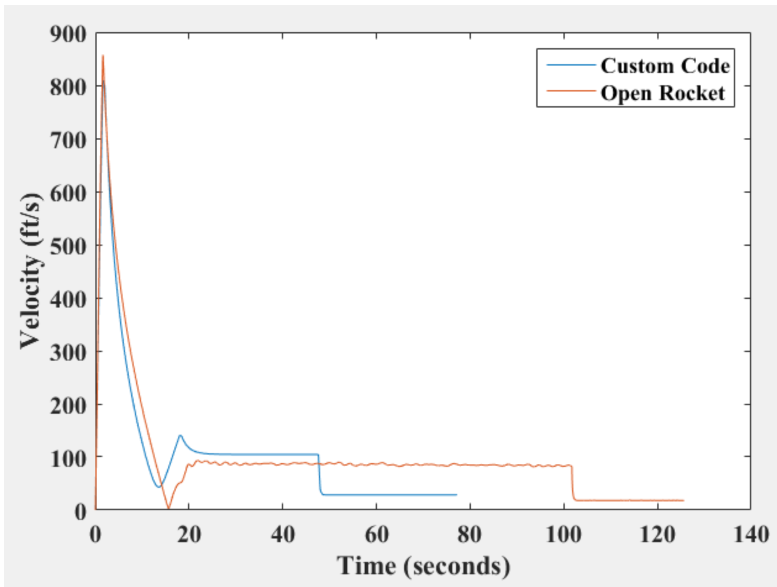

Figure 11. Predicted total velocity without drag system from both simulations.

Finally, the duration of the flight is also taken into account when analyzing the characteristics of the simulated flight. The reason in doing so is so that the team is able to have an estimation for the total launch time, accounting later on for recovery and set up as well. The duration of the flight as simulated by OpenRocket is 244 s which is a fairly average length in time for a flight of this size of vehicles. With the flight of the duration taken into account, the team is confident in making sure that the time spent during the competition is dedicated to the launch characteristics of the vehicle.

Over the time of flight, the coefficient of drag changes. Figure 12 and Figure compare the coefficient of drag to both the time, and velocity of flight. It is clear from Figure 12 that coefficient of drift is reliant on velocity of the rocket. These values were generated by the OpenRocket software.

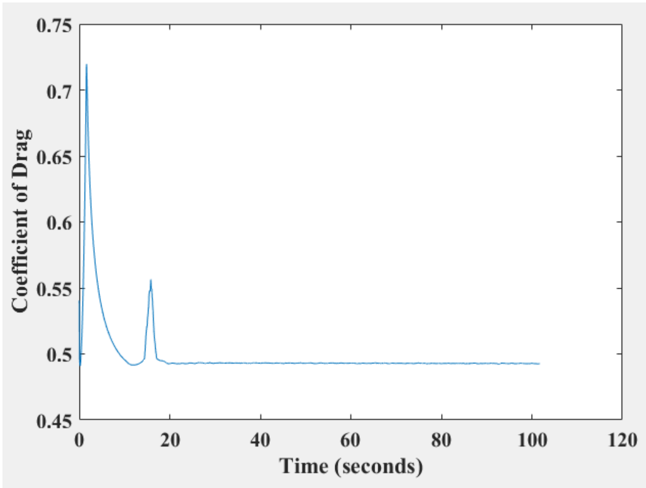

Figure 14. Coefficient of drag without drag system as a function of time predicted by OpenRocket.

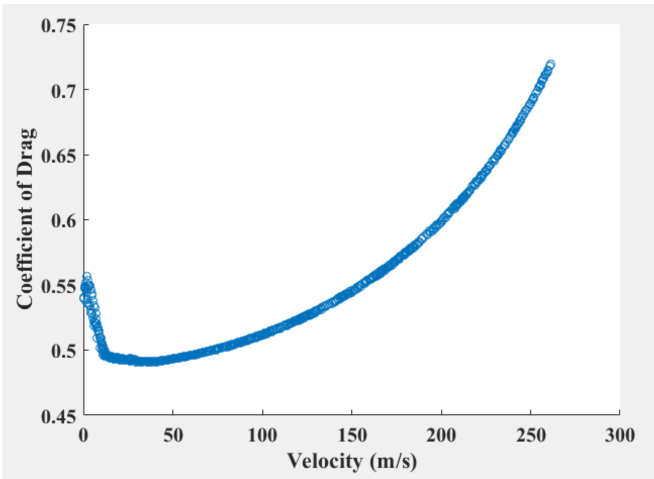

Figure 12. Coefficient of drag without drag system as a function of velocity predicted by OpenRocket

5 Logistics

5.1 Risk and Mitigation

Table 3 indicates the potential risks associated with the structural, electrical, and payload systems, likelihoods of occurrence, consequences, and prevention methods of the rocket before, during, and after the competition launch.

Table 3. Risk Mitigation Analysis

No.	Risk	Likelihood	Severity	Impact	Mitigation
R1	Airbrake deployment causes failure of the body tube	2	5	Destruction of the rocket.	The body tube around the drag system will be reinforced and FEA will be performed to predict the stresses on the rocket.
R2	Drag System destabilizes rocket	2	4	Possible loss of rocket.	Extra margin of stability has been carried through the design.
R3	Airbrake components come lose during flight	2	3	Possible instability of rocket. Inability to fly again.	Quality materials will be used to construct the drag system.
R4	Airbrake system does not deploy	2	3	Failure to meet competition requirements.	Extensive testing of the system will be performed.
R5	Rocket is not ready for flight within one hour	2	3	Failure to meet competition requirements. Point deduction.	The team will practice the procedure to reset the rocket before the competition to ensure meeting time requirement.
R6	Failure of electrical equipment	1	4	Drag system does not deploy, drag characteristic not measured.	Extensive testing of the system will be performed before flight.
R7	Structural failure of fins	1	4	Possible instability of rocket. Inability to fly again.	Quality materials will be used to construct the rocket.
R8	Parachute does not deploy	1	5	Loss of rocket.	Redundant ejection system is in place.
R9	Airbrake System deploys too early	2	1	Apogee will be lower than predicted. Loss of points.	Both predictions and sensor data will be used to trigger the drag system.

R10	Airbrake deploys too late	2	1	Apogee will be higher than expected. Loss of points.	Both predictions and sensor data will be used to trigger the drag system. The system is capable of creating more drag than necessary.
R11	Drag system does not retract	2	1	Possible, but unlikely, damage on landing.	A set of torsion springs will hold the system closed when actuator is not engaged. Beyond this, extensive testing of the drag system will be performed.

5.2 Safety

The main source of materials hazard is the rocket motor. However, since the team will be using quality products from a trusted rocketry vendor, the motor is relatively safe. The propellant being used is mostly ammonium perchlorate. It is not likely to cause irritation to the eyes or skin. The motor is stable under normal temperatures and pressures with the only conditions that need to be avoided are heat, static electricity, friction, and impact. During the construction process of the rocket and all its components, the team will use all necessary safety precautions such as goggles, gloves, face masks, ear plugs, and proper ventilation of the lab area. The majority of materials are nonhazardous, however, any materials of concern will be handled by the senior mentor with experience. The following launch procedures have been created to make sure all components of the rocket are fully functional and secured before and after each launch.

Pre-Launch Procedures (first and second launch):

- Inspect avionics bay wiring
- Confirm that Arduino and all its connected components are turned on
- Turn on the AltimeterTwo that is mounted separately
- Turn camera on and check if it is properly secured
- Make sure the active drag system is hooked up to the LiPo battery (ignore on first launch)
- Inspect parachute section of the rocket for damage
- Inspect that rail guides are properly aligned
- Make sure no parts of the rocket are protruding out of the body
- Leave the immediate launch area before the launch
- Stand a safe distance away from the rocket during launch
- Maintain visual of the rocket during its flight.

Post-Launch Procedure:

- Locate rocket
- Wait until the rocket has completely landed before approaching
- Inspect rocket for damage
- Remove altimeter and retrieve flight data

5.3 Budget

Factors of the budget include estimated construction cost of the rocket airframe and active drag system, miscellaneous items, and competition and travel fees. There is a cap limit on the teams' spending, limiting the total amount of money that can be spent to $1000. The Illinois Space Grant Consortium has covered most costs.

Table 4 catalogs the total spending by the ISS Space Grant team, demonstrating that the expenditure is inside the cap.

Table 4. Cost Analysis

	Part	**Price($)**	**Qty.**	**Total Price**
Structure	Nose Cone	37.95	1	37.95
	Body Tube Coupler	10.95	1	10.95
	Body Tube	38.95	2	77.90
	Bulkhead	6.15	1	6.15
	Shock Cord	0.92	10	9.20
	Parachute	84.00	1	84.00
	Engine Hook	ISS Inventory	-	0
	Motor	92.95	2	185.90
	Wadding	ISS Inventory	-	0
	Motor Casing	69.39	1	69.39
	Centering Rings	8.10	2	16.20
	Rail Buttons	ISS Inventory	-	0
	Chute Release	129.00	1	129
	Motor Mount	40.66	1	40.66
Avionics	Accelerometer	24.95	1	24.95
	Altimeter	ISS Inventory	-	0
	Arduino	ISS Inventory	-	0
	Radio Transmitter	Illinois Space Grant	-	0
	Camera	ISS Inventory	-	0
Active Drag	Linear Actuator	119.99	1	119.99
	LiPo Battery	37.80	1	37.80
	Wedge Material	ISS Inventory	-	0
	Filament Tape	21.46	1	21.46

Total Expenditure: $971.45

5.4 Timeline

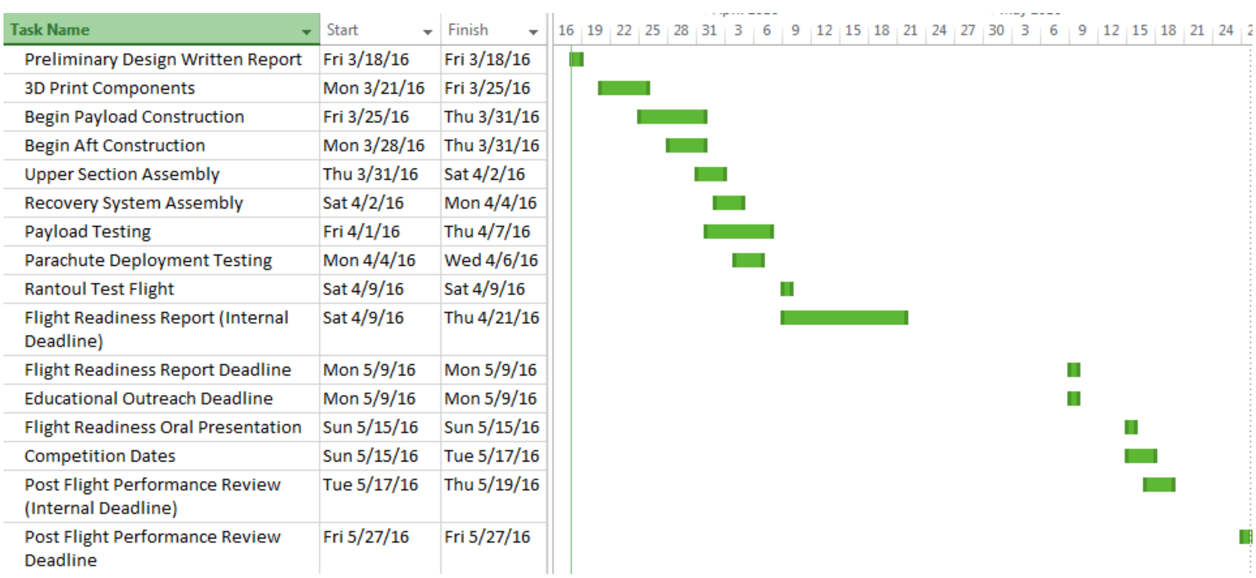

Figure 13. Timeline

5.5 Educational Outreach

Illinois Space Society took part in a University of Illinois sponsored event called Engineering Open House, which is a College of Engineering event where student groups demonstrate their various tech projects. The ISS space grant team presented on the goal of competition and on the concept of the active drag system being used.

The team was also part of a hybrid rocket engine hot fire test demonstration. This served to educate attendees on the various types of propulsion systems used in rockets. Additionally, last year's finished Boosted Dart and a variety of ISS's veteran rockets from past years were set up for display.

To appeal to a younger audience, an interactive orbital simulator was set up. The simulator was made by attaching the ends of the sheet onto chairs in a circular shape with a weight in the center. Participants were given marbles to throw onto the sheet and it simulated how mass affects the fabric of space. The simulator also demonstrated gravitational maneuvers. This demonstration served to explain the trajectory of the New Horizons mission which allowed it to perform a flyby of Pluto and capture never before seen pictures of the far away dwarf planet.

5.6 Model Rocket Flight Demonstration

The team constructed and launched a subscale rocket on November 7, 2015, in Monticello, Illinois, thus fulfilling the requirement.