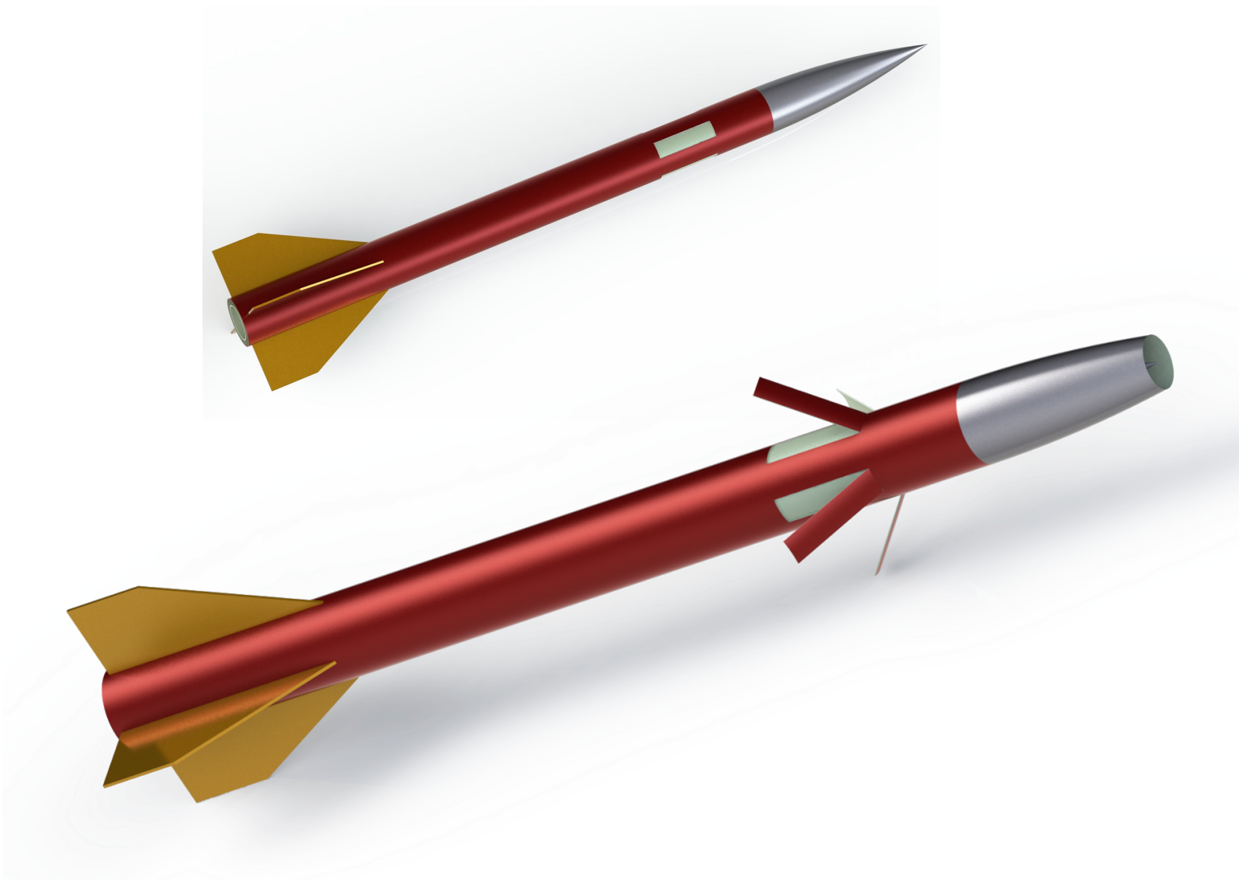

Preliminary Design Report

Freshman Rocket Team
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Executive Summary

The 2016 Space Grant Midwest High-Power Rocketry Competition's challenge is to build a rocket with an active drag system that will reach an apogee of at least 3000 feet with the system deactivated. A second flight will follow in which the active drag system will be activated and facilitate the rocket's apogee being 75 percent of the original apogee. To design such a rocket, our team utilized several simulation programs, including Solidworks and OpenRocket, along with several hand calculations and a model wind tunnel test. The rocket was chosen to be 75mm diameter in order to fit the requisite electronics. The rocket will be 49 inches long, and will be flying on a 54mm diameter J293BS-13A motor, which will allow for an apogee of 3,600 feet without the drag system deployed. The design is for a single deploy rocket, with an altimeter programmed to fire an ejection charge at apogee. The active drag system is a combination of two mechanisms. The first mechanism is a nose cone that will retract back into the airframe of the rocket, thus increasing the coefficient of drag of the rocket from the nose cone. The second mechanism will be four air brakes 4 inches below the nose cone of the rocket that will deploy in order to increase the coefficient of drag. Both of these mechanisms will be powered and controlled by an avionics bay in the top half of the rocket that will house all electronics and allow for easy access. An on board video camera will be placed in the avionics bay facing upwards to view the nose cone and air brakes deploying during the flight, per competition requirements. The rocket is predicted to weigh 129 oz.

Rocket Mechanical/Electrical Design

Structural Specifications

Dimensional Specifications

The rocket will consist of two main sections, the top nosecone/avionics bay section, and a lower section housing the recovery system and motor. The bottom section will consist of a 16 inch section of 75mm Blue Tube airframe coupled to an additional 10 inch section of the same material. This split is not shown in Figure 1 as it is non-functional. At the bottom of the body tube - within the coupled section - will be located a 9 inch section of 54mm phenolic body tube, secured within the body tube by two ¼ inch thick plywood centering rings. This will act as our motor mount tube. Affixed to the bottom of this tube will be a 54mm HAMR motor retainer. Located ¼ inch from the bottom section of the body tube will be the four fins. The fins will made of ⅛ inch G10 fiberglass. They will have a 9 inch root chord, 3 inch tip chord, and 3 inch semi-span, with a flat tailing edge. A profile of the fins can be seen in Figure 1. The top section of the rocket will be a 10 inch section of 75mm Blue Tube airframe. A Public Missiles 3 inch ogive nose cone will be attached to the top and house the nose cone drag system. An 8 inch section of 75mm Blue Tube coupler will be inserted 4 inch into the other end of the top section body tube. The top section body tube and coupler will be used to house the avionics bay.

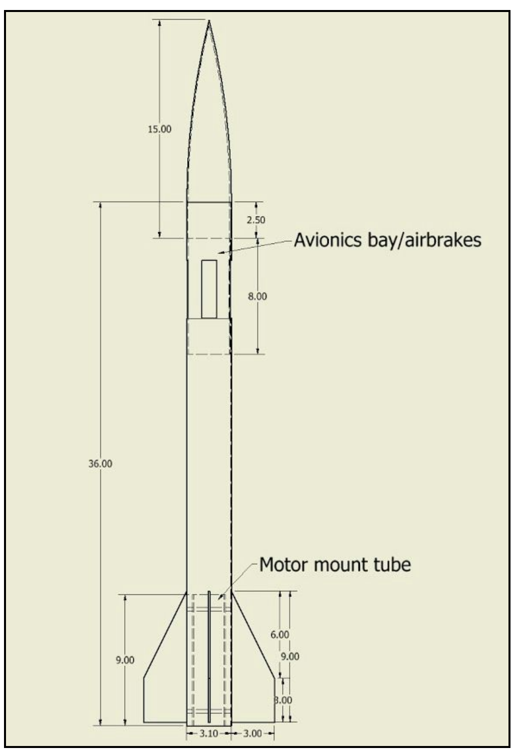

Figure 1: A preliminary diagram of rocket dimensions and part locations

Recovery System Design

The rocket will be a single deploy rocket. It will use our scratch built altimeter to determine our altitude and velocity. At apogee, our primary black powder ejection charge will fire. We will also use a stratologger altimeter to fire the primary charge if the scratch built altimeter fails. In the event that the primary charge fails to fire, we will also have our motor eject charge as a backup. We will use a quarter inch forged steel eye bolt to secure our shock cord to the bottom bulkhead of the avionics bay. The other end of the shock cord will be securely attached to the inside of the body tube with epoxy. For shock cord, we are using 9/16" nylon webbing with a breaking strength of 1500 lbs. We will be using a 58" diameter nylon parachute from a previous project rated for 131 oz. Using this parachute, we predict the rocket will descend at a safe rate of 20.2 ft/s to ensure a safe landing, well under the required 24 ft/s. Prior to the first test flight, the ejection charge will be test fired to ensure the recovery system is operational.

Propulsion System Design

In this competition, we decided to use a Cesaroni J293BS-13A motor. The J293BS-13A motor provides us 293 Newton of thrust, a total burn time of 2.86 seconds, and a total impulse of 838 Newton-seconds. The motor is fairly affordable so we have more resources for the rest of our rocket. Also, the motor provides us with a thrust-to-weight ratio of 8.045 in a 129 oz rocket and is predicted to take our rocket up to 3,600 feet, well above the required height of the competition.

Electronics/Payload Specifications

Drag System

The drag system consists of two separate actuating components that will create a drag difference between the activated and unactivated states. These components change the drag caused by the nosecone and the body.

Nose Cone

The nosecone drag subsystem is projected to lower our altitude by 25%, given the idealized input parameters. This component produces drastic change in the frontal drag of the rocket by retracting the top 6 inches of our 12 inch ogive nose cone (red area in Figure 2) into the lower 6 inches (green area in Figure 2). The nosecone is supported by a small piston (blue in Figure 2) which is retracted by means of an internal jack, to account for the high pressure on the nose cone. This subsystem will occupy the 12 inches of the nosecone and the 10-12 inches of the body tube below the nose cone.

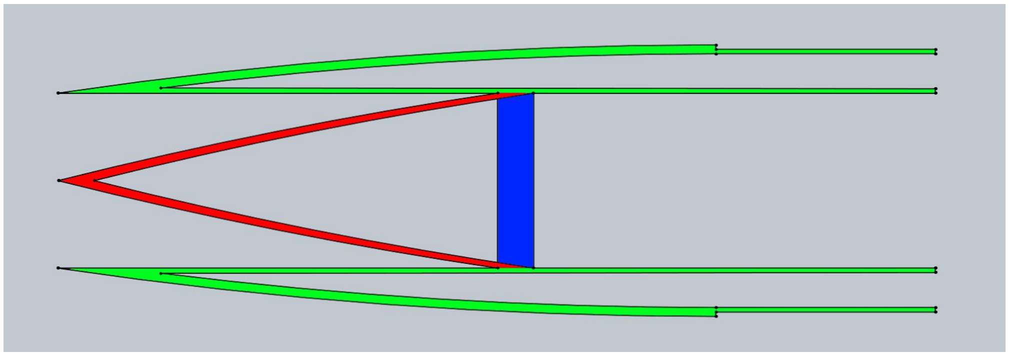

Figure 2: Partial cross section of retracted nose cone. Red is the retracted section of the nose cone; green, the remainder of the nose cone with internal support tube; and blue, the piston supporting the mobile section of the nose cone. Not shown: actuating rod and control electronics below nosecone.

Air Brakes

The air brake drag subsystem is projected to lower our altitude up to 35%, depending on the level of deployment and effectiveness. These air brakes (green area in Figure 3) are located just below the top of the airframe, beneath the nose cone drag subsystem. It consists of 4 reinforced flaps, cut out of the rocket, which will open downwards from 0 to 45 degrees. These are pushed open by means of rods (blue area in Figure 3) attached to a rising platform: as the platform rises (on a fixed jack), the pivoted rods will push out, pushing out the flaps. The motor and control electronics will be stored below this mechanism (red area in Figure 3).

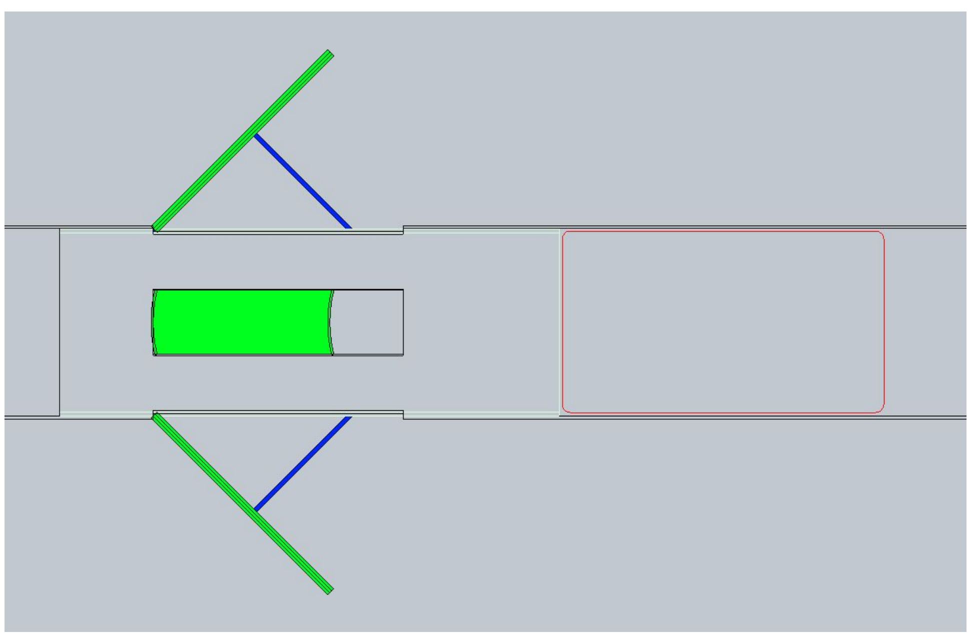

Figure 3: Partial cross section of the air brakes. Green is the airbrake flaps; blue, the supporting rods; and red, the area where the motor and other control mechanism are stored. Not shown: full internals with actuation platform.

Avionics Bay

Scratch Built Altimeter

Since the drag system requires real-time altitude data to control the nosecone and air brakes, a typical rocket altimeter meant to fire ejection charges will not suffice. As such, a scratch-built altimeter will be used to control the drag system. It will consist of multiple intercommunicating Arduino microcontrollers, each reading data from an IMU capable of measuring ten degrees of freedom. Although one Arduino/sensor pair would be enough to achieve this objective, others will be included for redundancy as improper drag system deployment would make accurately reaching the target altitude highly unlikely. Data will be independently collected by each Arduino and fed to a master Arduino to be compared and averaged for use in drag system control.

Other Electronics

The power supply has two parts, a 9V battery for control mechanisms and LiPo batteries for the drag system motors. The motors will consume a high amount of current, projected between 10 and 15 Amps, but will only do so for under 20 seconds, while in ascent. High current mosfets with heat sinks will be used to control these high currents to the motors.

Construction Procedures/Techniques

Nose Cone Drag Subsystem

The nosecone drag subsystem will have two parts, the structural support built into the rocket and a moving component within that structure. The moving part consists of a powerful motor fixed to the end of a threaded rod. Affixed to the other end is the top 6 inches of the nose cone. The threaded rod has 6 inches of distance between the bottom lip of the nosecone and the motor coupling. The structural support extends roughly 7 inches from the top of the body tube and has a translationally and rotationally fixed nut centered on a plate on the top, with two rods extending from that plate to a fixed bottom centering ring. The fixed nut will move the threaded rod vertically as it revolves while the rods allow the motor to move translationally but not rotationally as the threaded rod moves.

Air Brakes Drag Subsystem

The air brake drag subsystem will have two parts, the structural support and jack built into the rocket and a moving component within that structure. The structural part consists of two fixed platforms. Between the platforms is a translationally fixed threaded rod, with a motor attached beneath the bottom plate. Four additional rods extend between the plates. The moving component is a plate with a rotationally and translationally fixed and centered nut. Four equally spaced holes allow this plate to vertically move within the structural component and the rod revolves. On the top of the moving plate are four equally spaced hinged joints between the holes, each connected to a rod. Each rod passes through a guiding slot in the fixed upper plate to a hinged joint on a hinged flap.

Structural Analysis of Scratch Built Parts

Air Brakes

The air brake flaps have hinges connecting to the rocket and hinged rods that connect to the flaps. The flaps are cut out from the rocket airframe and the surrounding airframe is reinforced with another layer of coupler tube. A layer of wood on the inside provides a flat and rigid mounting surface for the hinges. Above the flaps is a thin flat-facing layer of wood to mount the hinges on. The rods should not bend or break because of this shape and these properties, given the support of the hinges. To test this, we will calculate the anticipated forces on the rods and stress test the support system before any launches.

Actuators Moving Cone/Brakes

The jacks utilized to move the drag subsystems are composed of threaded rods and nuts of ½ inch diameter grade 8 steel. These won't bend or have their threads shredded under these conditions. The maximum amount of torque is projected under 10 oz-inch.

Risk Mitigation

The most unique feature of this rocket is its drag system; as such, the drag system was the focus of most safety concerns during the design process. The nosecone drag system design originated over fears that standard air brakes extending from the sides of the rocket would have to be so large and extend so far as to either render the rocket unstable or suffer so much drag force that they would be torn off. The purpose of the nose cone retraction in the drag system is to reduce the amount of drag the air brakes alone must be responsible for creating, allowing them to be smaller and closer to the body of the rocket, minimizing these issues. In addition, we decided that the air brakes should open from the bottom rather than the top (which likely would have produced the greater drag) so that in the event of a failure in the deployment system, airflow around the rocket would naturally hold them shut rather than force them open, potentially leading to an unstable flight. In the case that only some of the airbrakes deploy, it is not unreasonable that the rocket would become unstable. Further calculations will be done to predict the amount of instability introduced by partial air brake deployment. Despite the potential danger, this scenario is unlikely because each airbrake is actively positioned; the actuation system is the only measure in place to move each airbrake. This means the only way for air brakes to not deploy is an internal structural failure, which would be a larger issue than rocket instability.

In addition to risks posed by the drag systems, there is also the risk of drag separation of the several sections of the rocket. The two sections of the main airframe will be coupled with an extra long coupler and redundant rivets to guarantee these section remain connected throughout the flight. In addition to this, the nose cone will be similarly attached to the upper airframe section to ensure the non-mobile base section remains firmly attached to the rest of the rocket. The upper airframe section will be connected to the main airframe with shear pins to prevent separation until the ejection charges are fired.

Drift is also a significant risk with this rocket. Weight estimations were quite liberal, so the actual apogee may be much higher than currently predicted, and strong winds could cause this rocket to drift a very long ways due to the combination of high altitude and a single deploy recovery system. To combat this risk, we will use at the very least an audible and radio beeper to help locate the rocket after landing. If budget allows and an appropriate module is found, GPS may also be used to track and locate the rocket with better accuracy.

Safety will continue to be a key concern throughout the construction of the rocket. The issue of stability has already been addressed, as current models place the CG well ahead of the CP, even with full drag system deployment. Great care will be taken to ensure that all components will be able to handle the stresses to which they are expected to be subjected (see Structural Analysis) to prevent failures during flight. Few materials used in construction of the rocket are hazardous, with the notable exceptions of epoxy and black powder. Epoxy poses little danger other than being a skin irritant, but care will be taken to ensure that it is only used in well ventilated areas to prevent inhalation of fumes. Black powder, however, can be much more dangerous if handled improperly. It will only ever be stored in a cool, dry container, and ejection charges and motors will never be loaded into the rocket until immediately prior to tests or flights.

Predicted Performance

Simulations of rocket performance were done using OpenRocket, an open-source program equivalent to RockSim. Without the drag system deployed, the rocket obtained a velocity of 623 feet per second after the burn time of 2.9s, and reached a maximum altitude of 3,600 feet after 7 seconds. This is well below the motor delay time of 13 seconds, so the delay grain will have to ground down to an appropriate time for the actual launch. It took 184 seconds after ignition for the rocket to reach the ground under the single parachute, and it touched down with a velocity of 20.2 feet per second. The simulation's relevant results are shown in Figure 4.

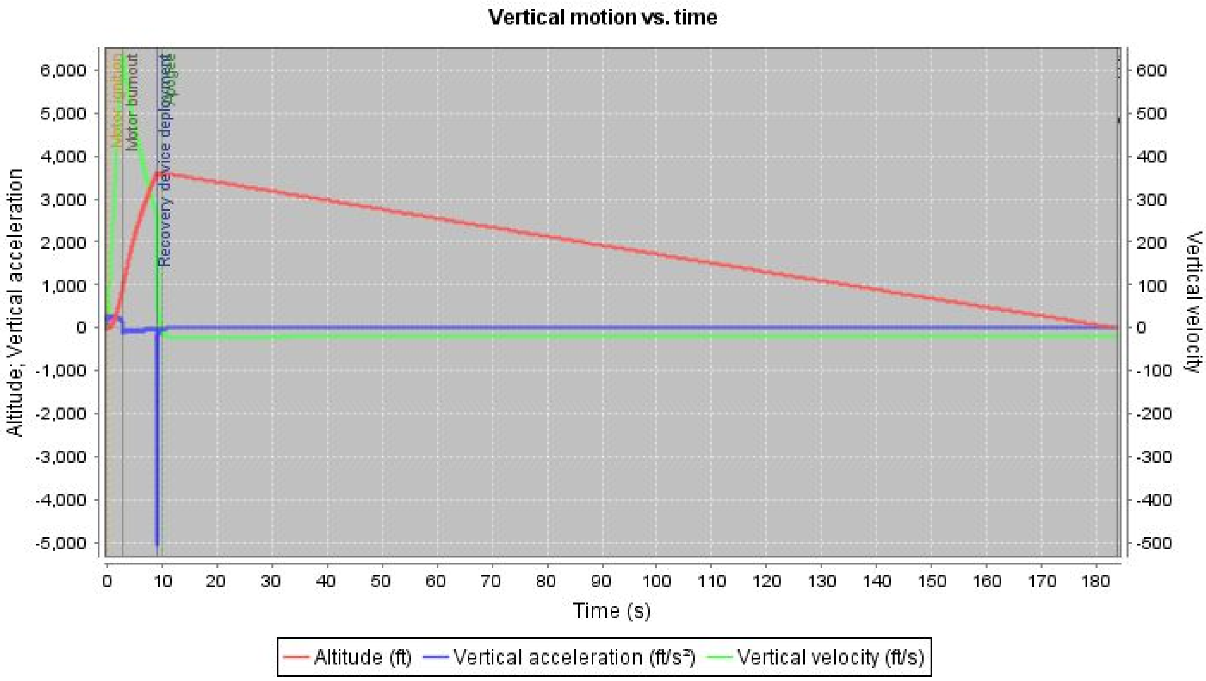

Figure 4: Simulated altitude and velocity versus flight time

To predict the effects of the drag system on the flight, preliminary calculations were done using Solidworks to find the maximum coefficient of drag for the rocket at a combined maximum velocity and full drag system deployment. This coefficient of drag used was assumed to be constant throughout the flight for estimating rocket performance.

Without Drag System Activated

Launch Analysis

Burn time for the selected J293BS motor is 2.86 seconds. The maximum acceleration experienced by the rocket during this time was calculated to be 9 G, and the maximum velocity at burnout was calculated to be 623 ft/s.

Flight Analysis

Under the assumption of a drag coefficient of approximately 0.55, the projected apogee is approximately 3,600 feet. This is reached 9.9 seconds after motor ignition.

Recovery Analysis

Under a 58 inch parachute, the predicted decent time is approximately 175 seconds after apogee. With an average wind speed of 4.47 miles per hour, the projected total drift of the rocket is approximately 950 feet. At an average wind speed of 20.5 miles per hour, approximate worst-case launch conditions, the drift was simulated to be approximately 5,000 feet. Descent speed is predicted to be 20.2 ft/s in both cases.

Stability Analysis

Using approximate weights and mass distributions for the rocket model, the fully loaded rocket has a stability margin of 2.07 caliber. After, burnout, simulations indicated this increases to approximately 2.64 caliber.

With Drag System Activated

Launch Analysis

Using the same motor specifications as the base simulation and assuming the rocket experiences maximum drag during the entire flight, the simulated maximum velocity is decreased to 440 feet per second with full drag system deployment for the duration of the boost phase. Maximum acceleration also decreased to 7.6 G. We acknowledge that drag system deployment is not allowed until after the boost phase by competition rules, so actual launch results for the active drag configuration will closely match the base rocket. The analysis reported in this section reflects the assumption made for the sake of simplifying simulations. As the project progresses, we will attempt to develop better simulations that account for different coefficients of drag and drag system deployment.

Flight Analysis

Assuming full drag system deployment and effect during the coast phase, the reduced apogee was simulated to be 2,490 feet - a decrease of 31%. The time to apogee is 8.7 seconds after burnout, so motor eject will not be an issue in this case either.

Recovery Analysis

Landing is projected to take 101 seconds after the reduced apogee. Simulations for the rocket with active drag systems were not capable of predicting rocket drift, but it is safe to surmise the rocket's drift will decrease by approximately 31% as well.

Stability Analysis

Computational fluid dynamics (CFD) simulations were conducted using SolidWorks to predict both the characteristics of the drag systems as well as their effects on the rocket's center of pressure. CFD simulations indicated a negligible change in the center of pressure between the no deployment and full deployment of the drag systems. Wind tunnel tests conducted using a rough model of the rocket also indicated this was the case. The rough model consisted of a semi-retractable nose cone and a collar to simulate the air brakes and nose cone drag system. We were primarily interested in the effect of these items on the coefficient of drag and the stability of the rocket. By testing the rocket with airbrakes retracted and deployed at different wind speeds at angles, we could compare the moments of the rocket to find the change in forces. We found the coefficient of drag to be sufficiently changed by the airbrakes and nose cone, and the change in the stability of the rocket, measured by its ability to recover from an angle in wind, was found to be nearly identical in all situations. As such, the stability characteristics of the rocket with drag systems deployed are predicted to closely mirror those of the base rocket.

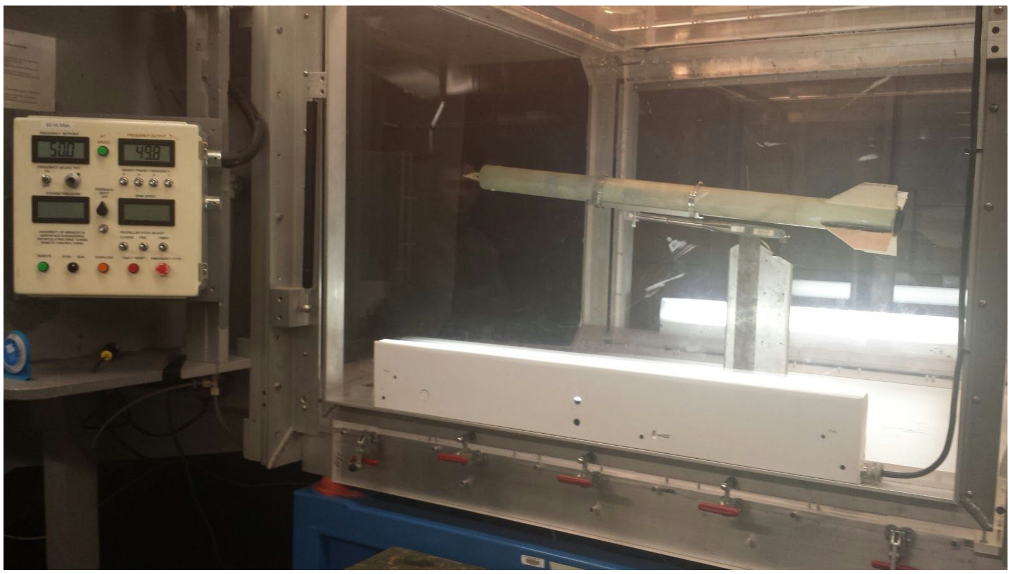

Figure 5: An image of wind tunnel testing for the rough model

Innovation

One unique component of the rocket is the drag system. Instead of just using the traditional airbrakes. our team elected to also use a nose cone that retracts back into the airframe of the rocket to produce drag. This system uses multiple motors to achieve quick movement in and out of the rocket. In addition to this, our avionics bay and drag system will be combined into one large, removable electronics system inside of a custom cut coupler. Everything within, excluding electronics at the bottom that are in a traditional avionics bay, will be hard mounted into this coupler. There will access points cut into the coupler to allow for easy access to these systems before the flight. This unique design will allow for a secure electronics system that is also completely removable and accessible.

Safety

Material Handling Procedures

There are materials we are using that may be harmful to our health and safety, and they must be handled with care while constructing our rocket. These materials include epoxy, paint, black powder, and various electronics. While constructing the rocket at any time using materials that have potentially dangerous fumes we will move to a well ventilated area. This will dissipate any of the fumes that may lead to health issues. While handling the black powder we are using for the ejection charges we will not be near any open flame or area of intense heat. While using any of the electronics we will be sure to not handle any wires that are connected to a live source of energy, especially while loading the ejection charges. We will be extremely cautious around the black powder and the electronics to make sure that there are no unexpected firings of the black powder charges. Eye protection will be used in any construction technique that may be harmful to the eyes including, but not limited to, working on loading ejection charges and test-firing them. The rocket motor will be stored in a cool and dry place until launch, to prevent any motor malfunction come launch day.

Planned Assembly Procedures

We will begin the building of the rocket with the bottom section. The motor tube area of the rocket will be separable from the rest of the body in order to allow us to begin work on it early. In addition to this, the separation will reduce the impact of a catastrophic motor failure on the rocket since it is removable and hence modular, making it easier to repair or replace. This separation will allow us to work on the installation of the motor tube and fiberglass fins at the same time as the avionics bay and electronics/drag system on the top half of the rocket. After both of these systems are completed, the recovery system will be added to the rocket to finish it.

Planned Test Flights

Test flights are planned to be conducted on April 23rd, 2016. Two flights are planned for that day in a manner similar to the actual competition flights. The first will be conducted without drag system deployment to gain a baseline performance for the rocket and test initial flight data collection and retention. The second flight will use this data to test the flight computer’s ability to pilot the rocket to the target altitude calculated from the first flight as well as test the efficacy of the combined drag systems. These two flights will serve to indicate the degree of completion achieved in the active components of the rocket. Results will be used to modify the rocket and optimize the control program as necessary. Any further tests may be conducted using the wind tunnel mentioned in a prior section of the report. However, further tests using the wind tunnel to simulate flights may not be useful due to the limited wind speeds available.

Pre/Postflight Procedures

Pre-flight Procedure

- Inspect the shock cords.
- Inspect the wiring connection in the avionics bay.
- Inspect on the battery voltages ready for flight.
- Inspect all mechanism function properly.
- Install avionics bay.
- Install the camera.
- First flight: Check drag system is not armed
- Second flight: Check drag system is armed
- Install motor.
- Check and record center gravity and center pressure .
- Place rocket on launch rail.
- Arm the avionic equipment.
- Turn on the camera.
- Last visual inspection.
- Photograph(s) of the rocket before, during, and after launch.

Post flight Procedure

- Locate landing area.
- Inspect for any damage.
- Take pictures of the rocket.
- Record any data such as damage, and flight data.
- Disarm avionics equipment.
- Turn off camera.
- Remove SD cards.
- Disconnect and recheck for battery level from avionics bay.
- Remove spent motor from mount.
- Retrieve footage from camera SD card and flight data from logger SD card.

Budget

Item	Number Needed	Raw Weight	Total Cost
Arduino Pro Micro/Mini	3	.1	24.00
10DOF Motion	2	.2	13.18

Sensor Module			
9V Batteries	1	1.6	4.00
MOSFET	1	.1	3.00
485 RPM Gearmotor-106.3 oz. inch	2	3.05	29.98
Copper launch lugs	2	.8	1.18
¼” wing nuts	1	.8	1.18
6-wire terminal blocks	2	.6	1.00
½” pvc cap	2	.5	1.00
9V Battery Holder	1	.4	2.80
Altimeter Two Snap Mount	1	.14	9.95
Miniature TTL Camera	1	.1	35.95
Micro SD Card module	2	.12	15.00
4GB Micro SD Card	2	.2	8.60
54mm motor 2 grain casing	1	4.25	55.27
Stratologger Altimeter	1	.5	79.86
Window/door alarm	1	1.3	6.97
Screw Switch	1	.1	5.85
½” 13tpin rod	1	.5	2.00

½” 13tpin nut	2	.2	0.30
75mm Blue Tube Airframe	1	19.95	29.95
75mm Blue Tube Coupler	1	18.52	31.95
Plastic Nose Cone	2	5.6	39.95
54mm Phenolic Body Tube	1	6.72	8.09
G10 Fiberglass Sheet-⅛”	2	21.74	51.42
¼” Plywood	1	4	9.95
Cessaroni J293BS Motor	2	29.6	145.90
54mm HAMR retainer	1	.8	34.95
¼” forged eye bolt	2	.8	3.00
Epoxy	1	2	19.99
Flame Protector	1	1	22.99
Shock Cord(9/16”)	1	3.5	6.00
Main Parachute(58”)	1	4.86	33.90
E-matches for ejection tests	4	.2	8.00
Registration Fee	1	N/A	400.00
Extra Motor Fee	2		90.00
	TOTAL:	133.55 oz.	$1,160.17