# Preliminary Design Report

The Ohio State University High Power Rocketry Team

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## Executive Summary

The 2016 Space Gran Midwest High-Power Rocket Competition requires each team to design and build a model rocket which is capable, at minimum, of achieving a maximum altitude of 3,000 feet. The designed rocket must be capable of being safely recovered after multiple flights. The rocket must also incorporate an active drag system which will remain stowed at launch, deploy drag flaps during flight and retract the drag flaps prior to the instant of apogee in order to properly deploy the parachute allowing for safe recovery. The active drag system was designed through collaborative thought amongst the team, and then analyzed using MATLAB, OpenRocket, and hand sketches which can be found in the appendix. The rocket designed will have an overall length of 0.115 meters, a body tube diameter of 0.0762 meters, and an initial mass of 3.512 kg. The installed drag system will consist of three tracks along the two platforms, three drag struts, a threaded rod, and multiple hinges to connect the components. The top platform will be anchored to the inside of the body tube with the threaded rod free to spin inside it at a constant height while the lower platform will be free to slide up and down along the tracks mounted inside the body tube. The bottom platform will be constrained to follow the threading of the rod so that as the rod remains at a stationary height the bottom platform will translate up and down. The translational motion of the bottom platform will cause the drag struts to push the drag flap out of the body tube to some angular displacement based upon the number of rotations of the threaded shaft. The device constructed behaves as described above but is not yet fixed inside the body tube permanently. Before permanently fixing the top platform in the body tube it is required to determine an optimum installation configuration because the range of translation of the bottom platform is dictated by the threading of the rod. Since the bottom platform has a restricted range of movement, in order to obtain a desired angular displacement of the flap, the initial configuration must optimize angular flap displacement for a given upward translation of the bottom platform. The drag system requires further analysis to provide a reliable means of controlling drag during flight.

## Introduction

The Minnesota Space Grant Consortium intends to run a Space Grant Midwest High-Power Rocket Competition during the 2015 – 2016 academic year. The competition objective is to construct and design a high-power rocket with an active drag system that will reach a minimum apogee of 3,000 feet with the drag system stowed, and then upon a second launch reach an apogee of, as near as possible, seventy-five percent of the initial apogee achieved. The rocket must be safely recoverable for future launches, and a non-commercial on-board data collection device for the rocket must be designed by the team which will measure the time variation of drag coefficient. Additionally, the rocket must make use of an on-board video camera to document the time history of the drag system over the flight. To achieve the goal of seventy-five percent apogee a MATLAB simulation was written which, under severe restrictions, determines the drag flap deployment area requisite. Future development in the simulation will strive to account for variable deployment of the drag flaps over time. OpenRocket was utilized to model the rocket motion with the drag system deactivated, and it was found that the max apogee and time at apogee for this case was only larger than that of MATLAB by about 220 meters and 1.4 seconds respectively. The components of the rocket were designed through team brainstorming and prototyping of the active drag system. The preliminary active drag system design and the predicted performance are discussed further and will be improved in the future.

## Rocket Mechanical & Electrical Design

The rocket design consists of a single stage rocket with a built in active drag system. The drag system is comprised of three flaps that can be deployed to a variable angle based on the desired amount of drag needed to achieve seventy-five percent of the initial apogee.

### Dimensional Specifications

The rocket has a length of 115 cm with a body tube diameter of 7.62 cm. Its initial mass on launch is 3.512 kg and final dry mass is 3.102 kg after the fuel has been burnt. The fins are trapezoidal in shape and equally spaced apart in a set of four at the base of the rocket. Each fin has a thickness, root chord, tip chord, sweep length, sweep angle, and planform area of 0.3 cm, 5.52 cm, 2.5 cm, 3 cm, 29 degrees, and 21.69 cm squared respectively. These dimensions were optimized to maintain stability when the drag system is both stowed and fully deployed. The nose cone is 28.6 cm long and ogive in shape. It has been selected for optimal performance based on the operating altitude envelope and predicted maximum speed of Mach 0.6.

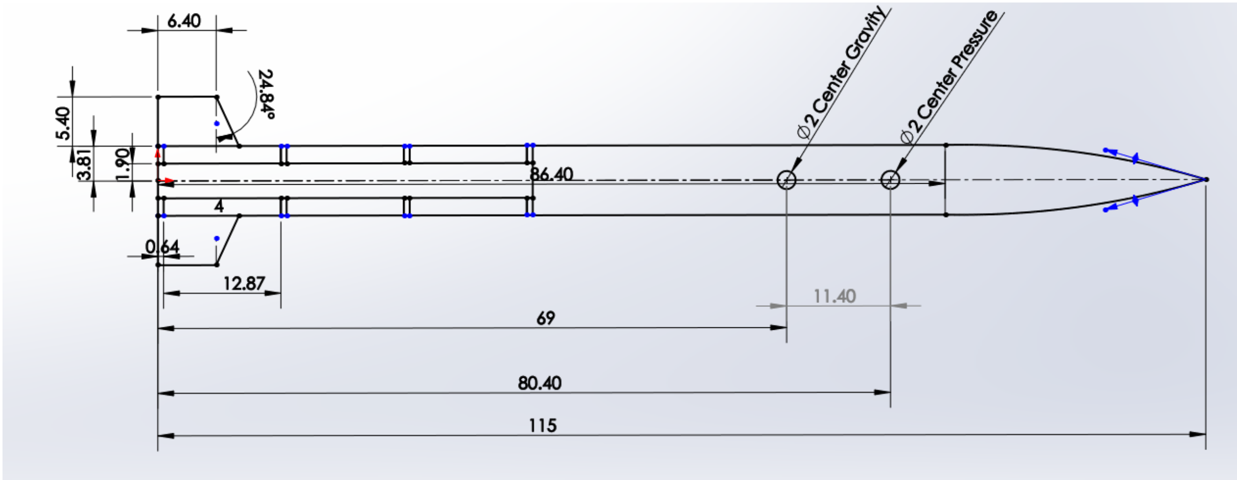
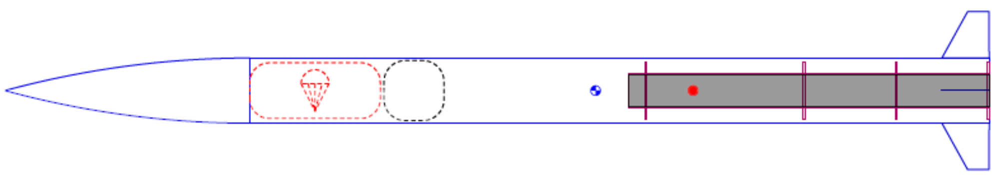



*Figure 1: The above figure shows the positions of the center of gravity and center of pressure for the rocket with the drag system stowed obtained from SolidWorks.*

**Rocket Design**



Rocket
Stages: 1
Mass (with motor): 3506 g
Stability: 1.49 cal
CG: 69 cm
CP: 80.4 cm

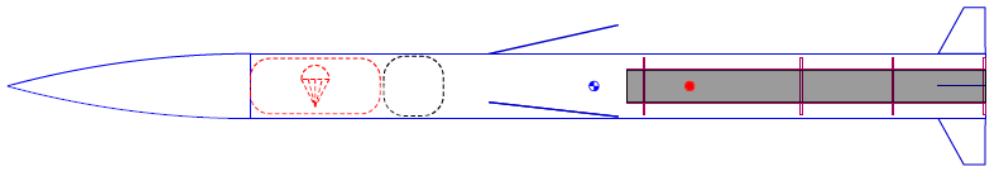
**J410-RL-7**

| | |
|---|---|
| Altitude | 1380 m |
| Flight Time | 310 s |
| Time to Apogee | 16.1 s |
| Optimum Delay | 14.2 s |
| Velocity off Pad | 16.7 m/s |
| Max Velocity | 202 m/s |
| Velocity at Deployment | 2.19 m/s |
| Landing Velocity | 4.36 m/s |

| Motor | Avg Thrust | Burn Time | Max Thrust | Total Impulse | Thrust to Wt | Propellant Wt | Size |
|---|---|---|---|---|---|---|---|
| J410-RL | 417 N | 1.85 s | 508 N | 772 Ns | 12.13:1 | 434 g | 38/421 mm |

*Figure 2: OpenRocket flight summary for stowed drag system*

**Rocket Design**



Rocket
Stages: 1
Mass (with motor): 3512 g
Stability: 1.48 cal
CG: 69 cm
CP: 80.2 cm

**J410-RL-7**

| | |
|---|---|
| Altitude | 1217 m |
| Flight Time | 275 s |
| Time to Apogee | 14.9 s |
| Optimum Delay | 13 s |
| Velocity off Pad | 16.6 m/s |
| Max Velocity | 198 m/s |
| Velocity at Deployment | 2.12 m/s |
| Landing Velocity | 4.37 m/s |

| Motor | Avg Thrust | Burn Time | Max Thrust | Total Impulse | Thrust to Wt | Propellant Wt | Size |
|---|---|---|---|---|---|---|---|
| J410-RL | 417 N | 1.85 s | 508 N | 772 Ns | 12.10:1 | 434 g | 38/421 mm |

*Figure 3: OpenRocket flight summary for engaged drag system.*

## Recovery System Design Specifications

The recovery system parachute is a 60 in. (152.4 cm) rip stop nylon elliptical chute with an estimated coefficient of drag of 1.55. It has 10 shroud lines rated for 330 lb. It was chosen since it was the most effective chute that would fit in the dart. The Kevlar cord used is 3 meters worth of 1500 lb. test strength braided cord (not tubular, but it does have a hollow core) recommended for high-power rockets. It is anchored at one end to the nose cone and to the body via epoxy located above the drag system. The rocket's recovery system will be located below the nose cone, above the drag system and electronics bay.

## Propulsion System Specifications

Propulsion is generated by a 0.735 kg Cesaroni J410 rocket motor. The burn will last approximately 1.9 s with an Isp, average thrust, and maximum thrust of 193 s, 408.9 N and 512.1 N respectively. The motor is mounted in a custom made fiberglass motor tube which is secured within the rocket via four centering rings. This configuration allows for ease of removal and replacement when performing test launches.

## Avionics System Design Specifications

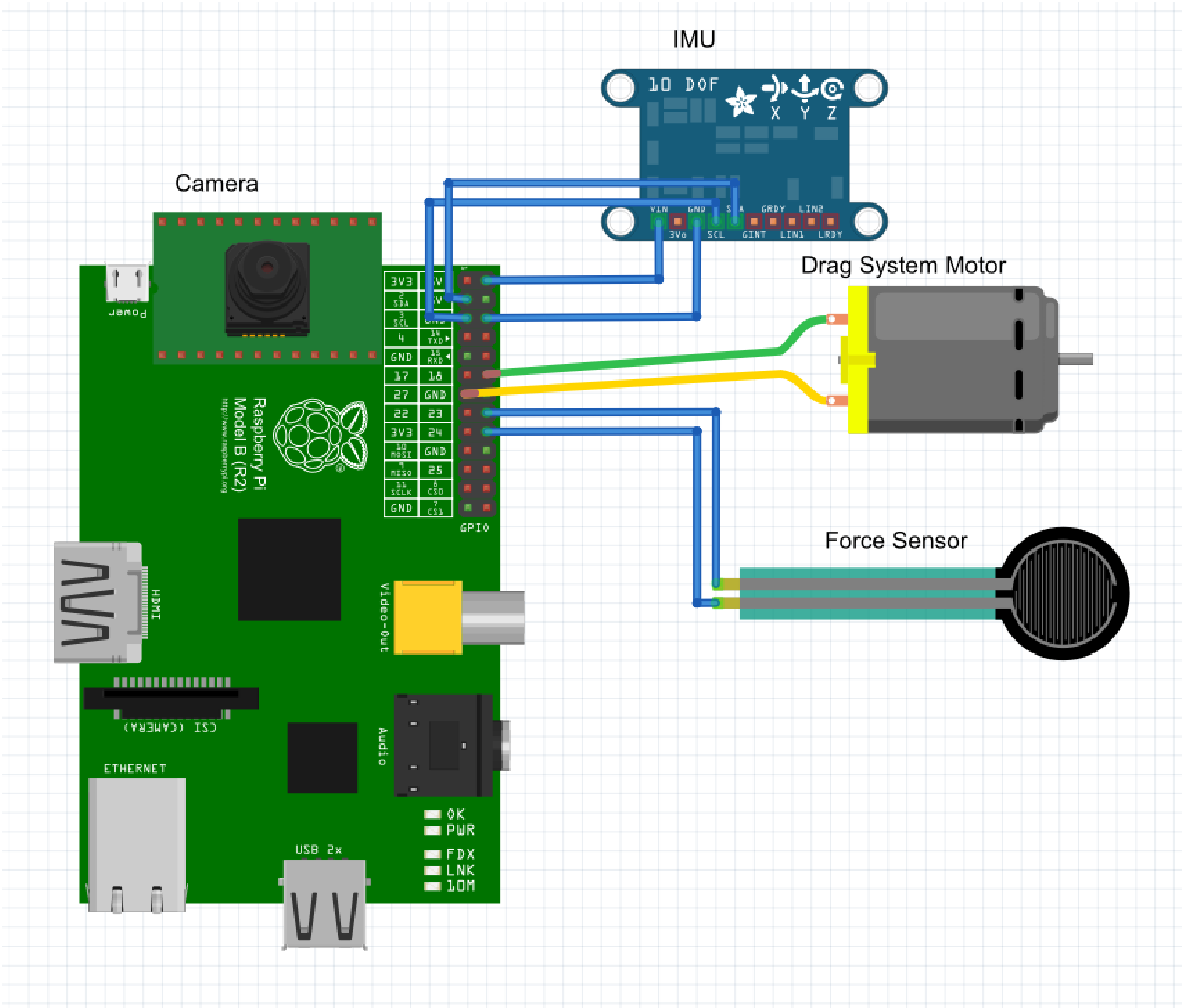



*Figure 4: Avionics design*

*Figure 5: Camera mounts*

*Figure 6: Camera mounts*

The Electronics Package focuses on four main objectives for the flight. The computer will need to record data, record video, activate the drag system & record force, and activate ejection. The package will be operating off of a Raspberry Pi 2 with a LiPo power source.

The Pi will be taking in data from the BerryIMU. The BerryIMU is an all in one flight sensor. The sensors on the chip include a gyroscope, accelerometer, magnetometer, pressure, and temperature. This means the chip can input data to the Pi that can output velocity, orientation, altitude, and gravitational forces. This data will be recorded on the micro SD card on the Pi.

A camera will also be connected to the Pi, and the data will be recorded directly to the micro SD card. The camera will be mounted on a small 3d printed side mount. This will be placed directly about the drag flaps. This will ensure the flaps are deployed after burnout and closed before apogee.

The drag system will run from a motor that is operated from the Pi. In the coding, the signal will be delayed by a time function. Once burnout time has passed the motor will turn on and the flaps will be deployed to a set angle. As the rocket nears apogee, the motor will be reversed and the drag flaps will be closed shut. There is also a force sensor that will be connected to the rod holding the flaps open. The drag force produced by the drag flaps. This force will be translated into horizontal and vertical forces on the lifting rod. The Pi will receive the value of the vertical forces produced on the rod. The vertical forces will be input into an algorithm that will calculate total drag force. With the total drag force, velocity, and density at altitude, the Pi will compute and record the coefficient of drag as a function of time.

The final operation of the package will be to send a current to a match. This match will be attached to the ejection charge. The signal will run as a function of altitude. There will also be a redundancy set in place. The package will also have a Perfectflite Altimeter with a commercial ejection function. This will be adjusted to fire an ejection if the Pi fails to ignite the ejection charge.

## Planned Construction Solutions and Techniques

Preliminary construction of the active drag system involved laser cutting of the platform to which the drag struts were anchored by means of a pivot. The pivot was designed by laser-cutting small hinges which were connected by a small nut and bolt which provided rotational freedom of the strut. The preliminary drag system was comprised of two platforms, three wooden guiderails fastened to the inner body tube, and a threaded rod which is designed to be spun by a small motor in order to lift the lower drag platform thereby raising the drag struts which ultimately would lead to an angular deflection of the drag flap. The desired angle of drag flap deployment during flight still must be estimated for the final launch, further the initial installation configuration of the drag system in the body of the rocket tube must be chosen in order to optimize the angular displacement of the drag flap subject to a change in upward displacement of the drag strut pivot anchored to the lower drag platform. This is necessitated in order to reach a desired flap deployment angle as quickly as possible for the minimum number of revolutions per second of the threaded rod. The optimized installation configuration will be determined through analysis of the dynamics of the drag strut. The strut effectively acts as a compound pendulum with one end fixed to the rocket body tube and the other end constrained to move in the vertical direction since it is anchored to the lower platform. Ultimately, experimental estimation will be used in deciding the initial installation configuration.

## PREDICTED ROCKET PERFORMANCE

Predictions of rocket performance were made through utilizing both OpenRocket and MATLAB. Two MATLAB simulations were created to model the motion of the rocket; one for one-dimensional motion and the other for two-dimensional rigid body motion. . MATLAB was used to determine the estimated drag flap deployment angle required in order to reach seventy-five percent of the apogee of the first launch. This was accomplished by running an initial simulation to obtain a benchmark apogee, and then iteratively solving the equation of motion for the rocket while varying the reference area until the simulation reached the seventy-five percent target apogee.

### OpenRocket Simulation Assumptions

- Average windspeed of 2 m/s
- Windspeed standard deviation of 0.2 m/s
- Medium wind turbulence intensity of 10 %
- Wind direction of 90°
- International Standard Atmospheric data during Flight
- Launch rod of 100 cm in length
- Parachute drag coefficient of 1.3
- Parachute Deployment at apogee

### OpenRocket Simulation Limitations

- Improper modeling of drag flaps

**MATLAB Simulation Limitations**

- The required angle of deployment was found by using the one-dimensional simulation
- The required angle of deployment is assumed fixed over the entire duration of the launch
- The reference area needed was taken to be the projected area of the rocket drag flaps
- Average drag coefficient assumed to be 0.7
- Pure one-dimensional motion during Launch and Flight Analysis

**Launch Analysis**

The launch phase was the interval of time over which thrust was nonzero, namely the phase encompassed the time from motor ignition to motor burnout. For the stowed drag system OpenRocket showed an engine ignition at t = 0 seconds, liftoff at t = 0.04 seconds, separation from the launch rod at t = 0.14581 seconds, and motor burnout at t = 1.8985 seconds. At the point of motor burnout the rocket achieved a total velocity of 200.35 meters per second at an altitude of 220.02 meters. In the case of the continuously deployed drag system OpenRocket fails to accurately model the drag flaps since they were treated as extremely thick fins when being created. Despite this inaccuracy, for the deployed drag fins, OpenRocket showed an ignition time at t = 0 seconds, a liftoff time at t = 0.04 seconds, a launch rod separation time of t = 0.14589 seconds, and a motor burnout time at t = 1.9038 seconds. At the point of motor burnout with the flaps continuously deployed OpenRocket falsely predicted a velocity of 193.07 meters per second at an altitude of 228.02 meters.

**Flight Analysis**

The flight phase began immediately after motor burnout and was considered to end at the point of apogee when the parachute was deployed. From OpenRocket for the stowed drag system the rocket achieved an apogee of 1372.4 meters after 16.092 seconds elapsed from launch, and a maximum speed of 202 meters per second. From MATLAB for the stowed drag system the rocket achieved an apogee of 1159.7769 meters after 14.25 seconds elapsed, and a maximum speed of 185.7575 meters per second. The differences between these two results was attributed to different models used to predict the rocket motion. Since OpenRocket incorrectly modeled the drag flaps MATLAB was used for the deployed flap case, despite the severe limitation that the flaps were assumed to be deployed over the entire duration of flight. MATLAB led to a finding of an apogee of 870.2213 meters if the drag flaps are deployed at a constant angle of 12.54°, and a maximum speed of 174.3023 meters per second.

Determination of the drag flap angle required was done by varying the area of the rocket in the MATLAB simulation and iteratively solving the governing equations to obtain the area needed to reach an altitude of seventy-five percent of the initial apogee. The difference between this area and the original rocket reference area was taken and divided by three to obtain a reference area for each flap. Then assuming that the reference area found was the project area of a flap, by using the geometric dimensions of the flap the angle was determined to be:

$$\theta_{required} = \arcsin\left(\frac{S_{flap}}{lw}\right)$$

where $S_{flap}$ was the individual flap area, $l$ was the length of the flap, and $w$ was the width of the flap. MATLAB led to a finding of $0.0013\ m^2$for $S_{flap}$, and the flap geometry was estimated to have $l = 15\ cm$ and $w = 3.99\ cm$.

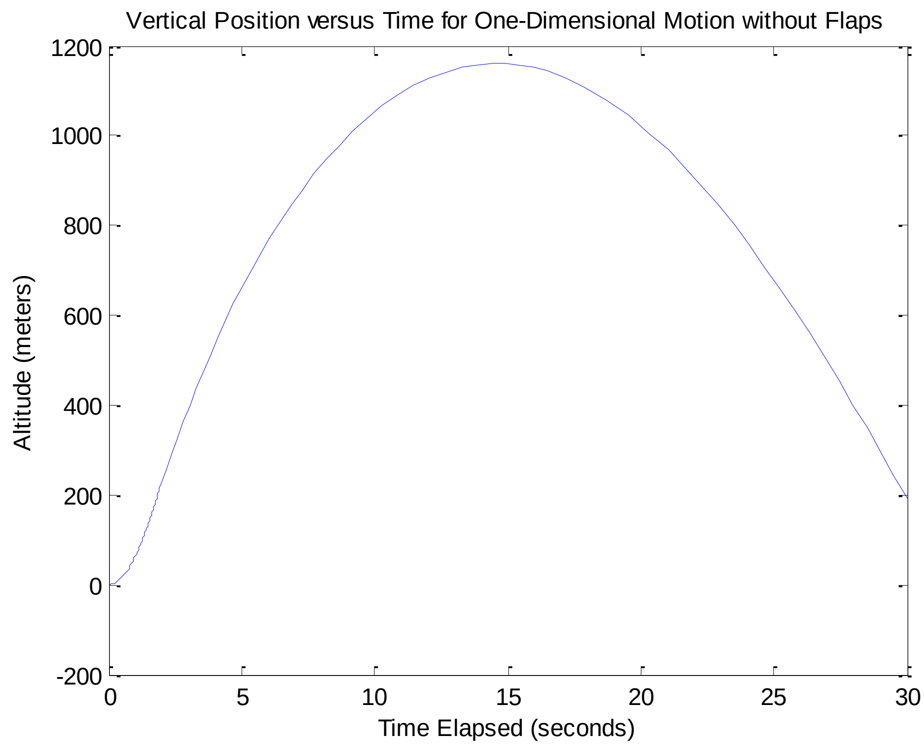



*Figure 7: The simulated MATLAB altitude behavior for comparison to OpenRocket without drag system engaged.*

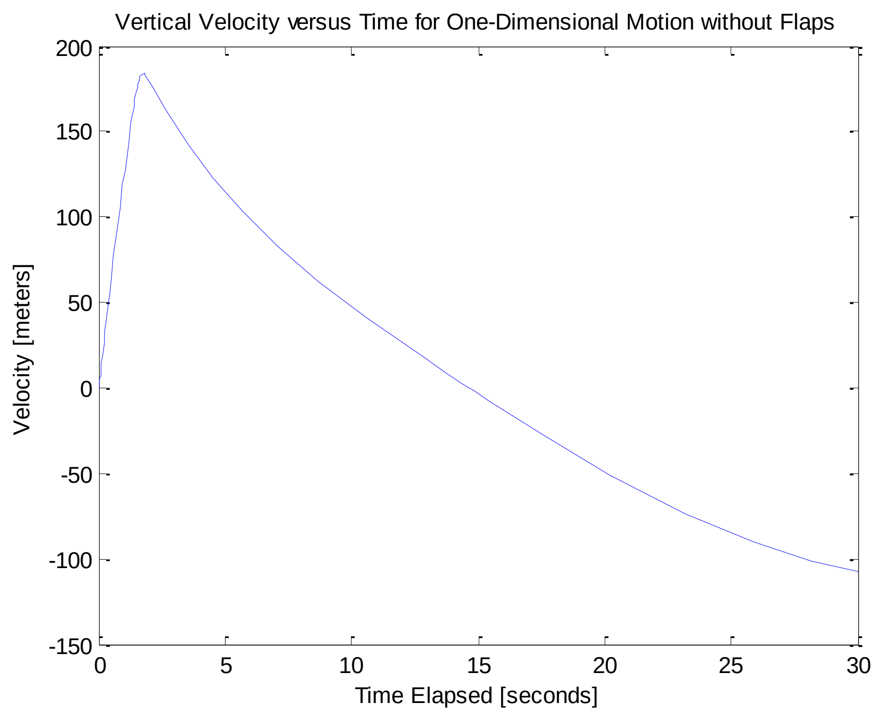



*Figure 8: The simulated MATLAB velocity behavior for comparison to OpenRocekt without drag system engaged.*

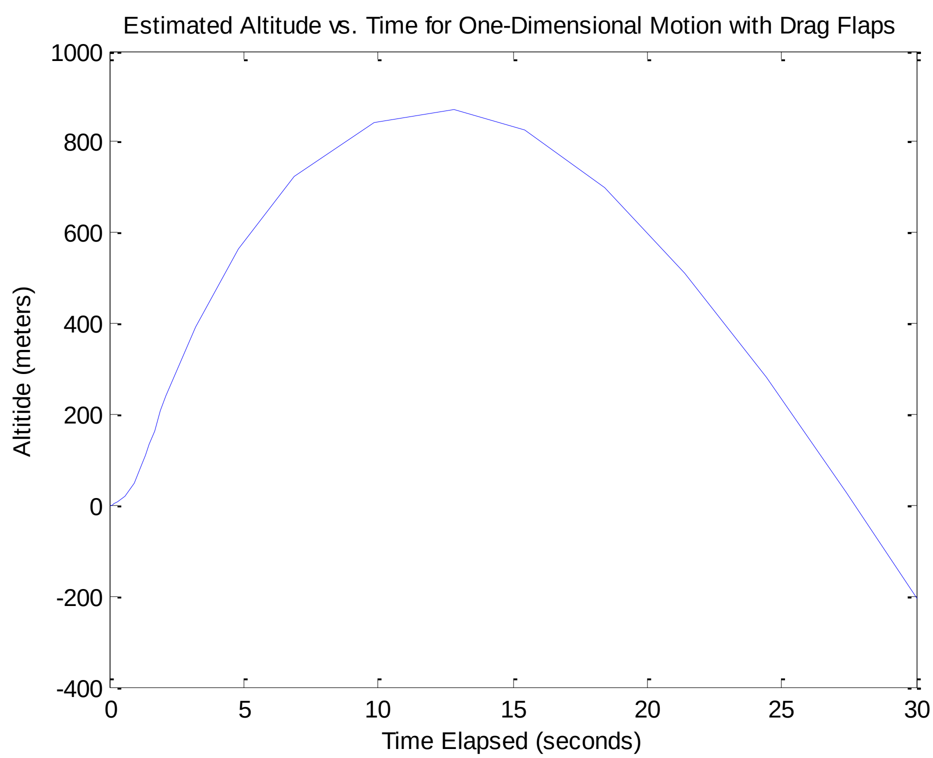



*Figure 9: The simulated MATLAB altitude behavior for comparison to OpenRocket with drag system engaged.*

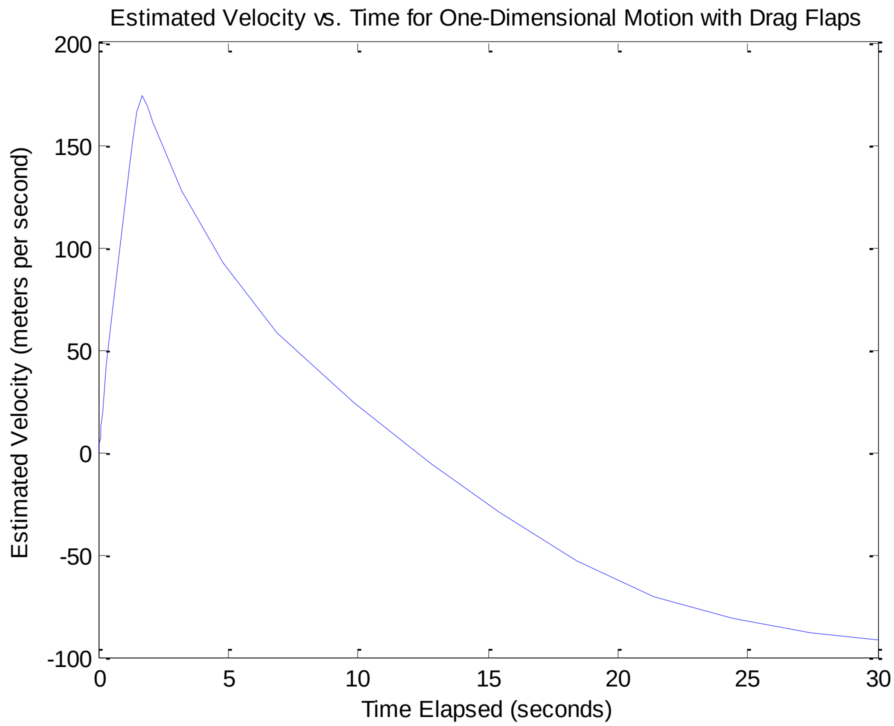



*Figure 10: The simulated MATLAB velocity behavior for comparison to OpenRocket with drag system engaged.*

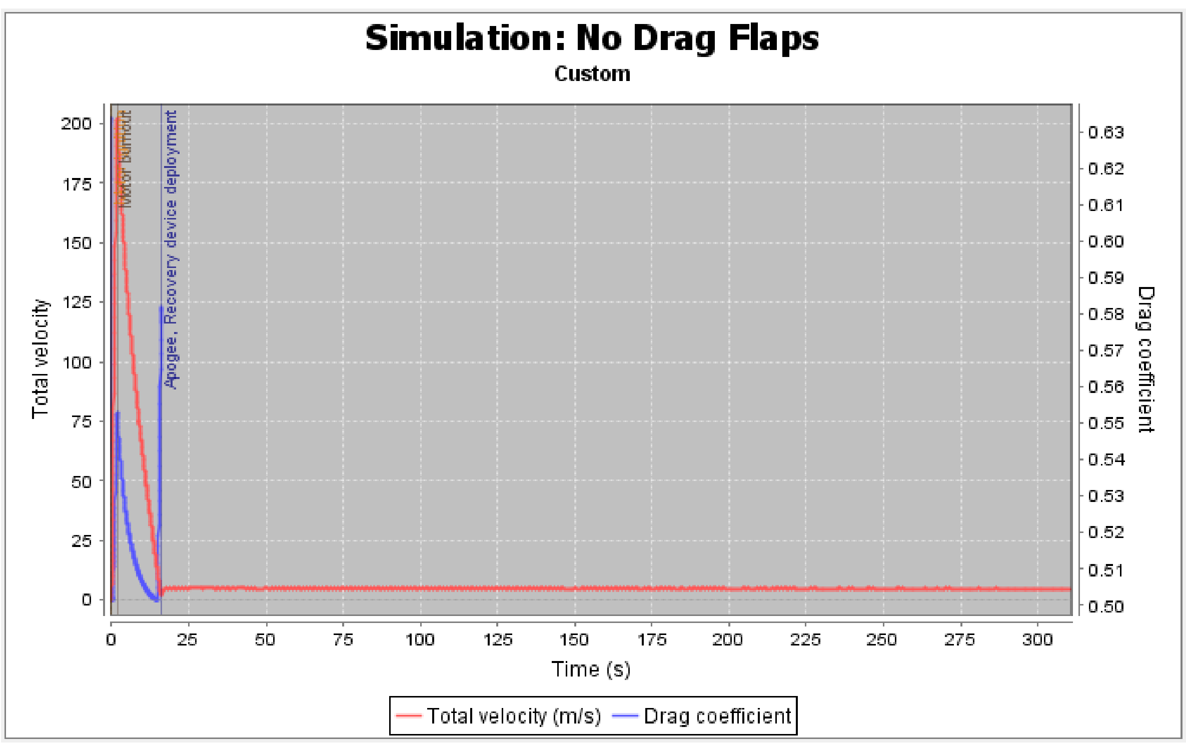



*Figure 11: Above is depicted the OpenRocket results for variation of total velocity and drag coefficient with time with no flap deployment.*

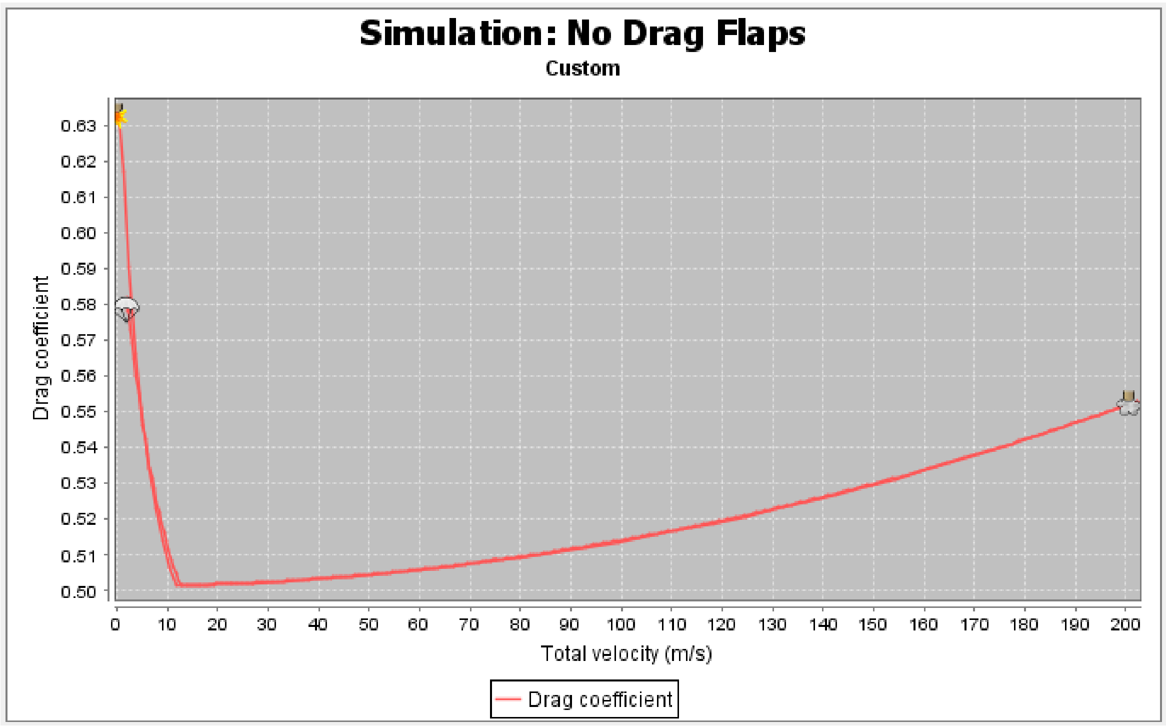



*Figure 12: Above is depicted the OpenRocket results for variation in drag coefficient with total velocity with no flaps deployed.*

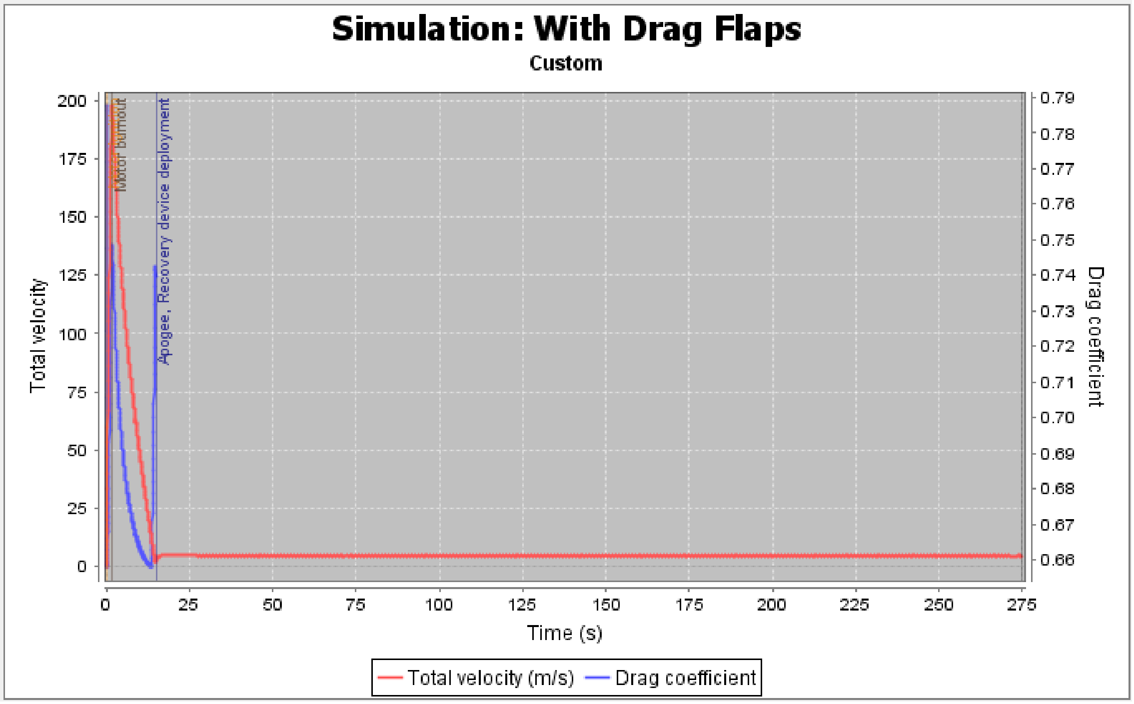



*Figure 13: The above figure shows the variation in total velocity and drag coefficient as a function of time for the case of continuously deployed drag flaps obtained from OpenRocket.*

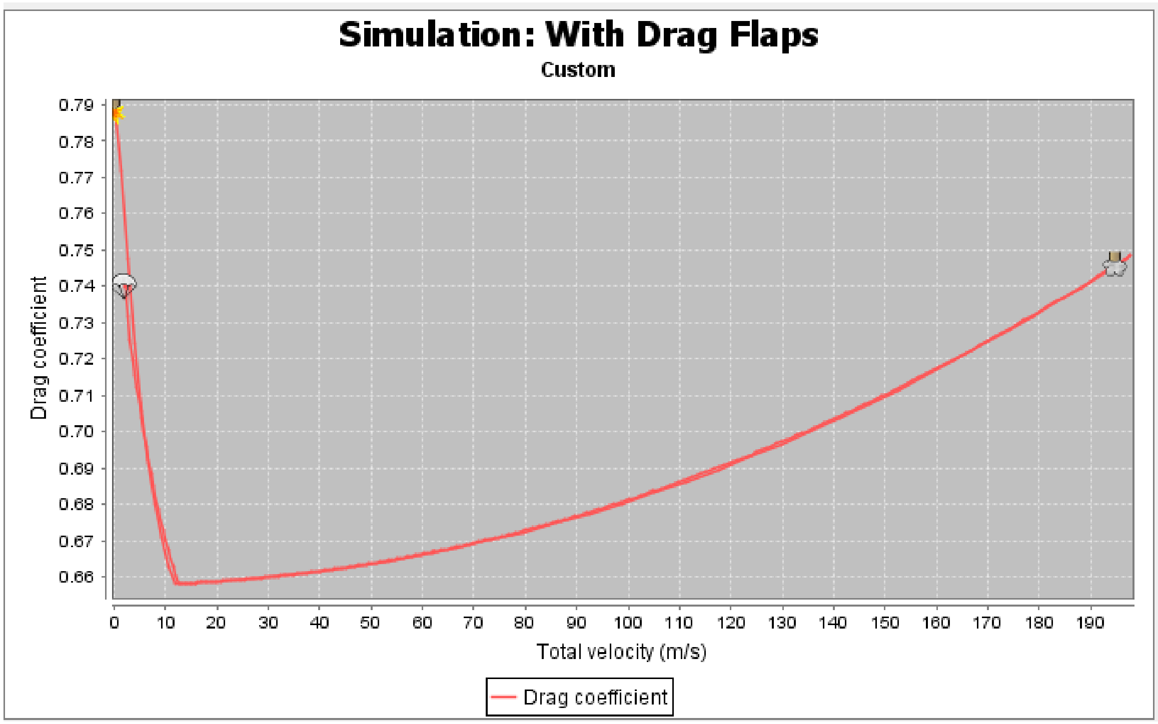



*Figure 14: The above figure depicts the variation in drag coefficient with respect to total velocity for the case of continuous drag flap deployment obtained using OpenRocket*

## Stability Analysis

Stability of the preliminary rocket design was tested both through OpenRocket and MATLAB. OpenRocket showed a stowed flap static margin of: 1.496 and a max deployed flap static margin of: 1.47. Further analysis in a two-dimensional MATLAB simulation showed that for a variety of flight conditions the sideslip angle suggests phugoid stability. Below is depicted the variation in sideslip angle as a function of time for prescribed values of moment slope with respect to sideslip angle, polar moment of inertia, initial sideslip angle, and specific impulse of the rocket.

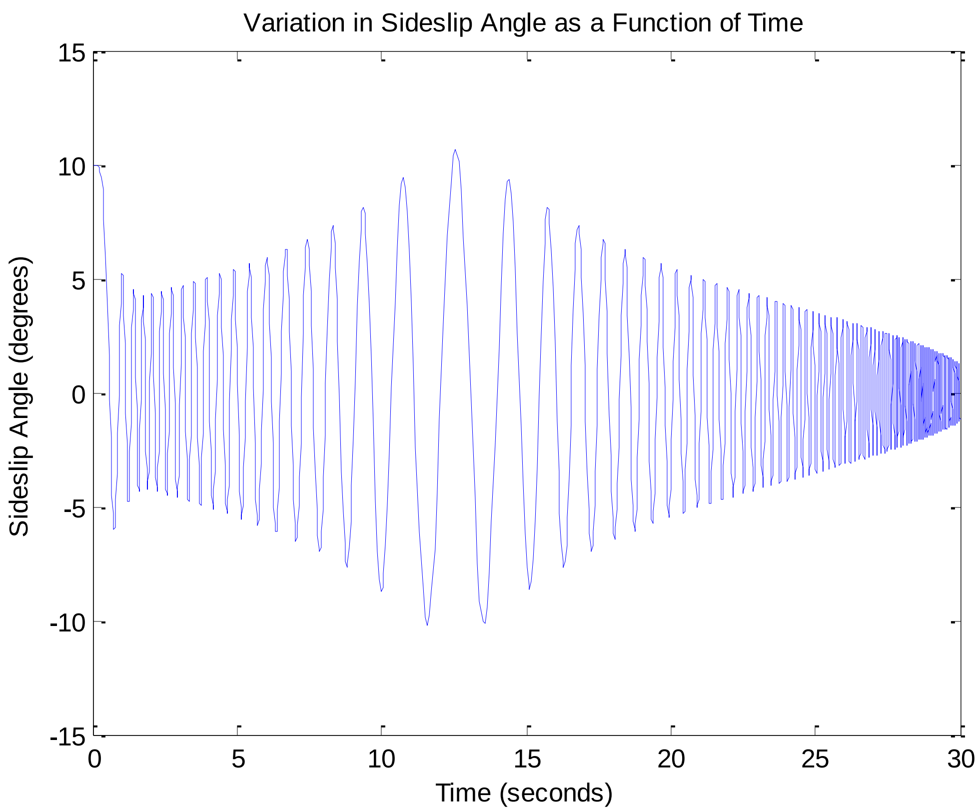


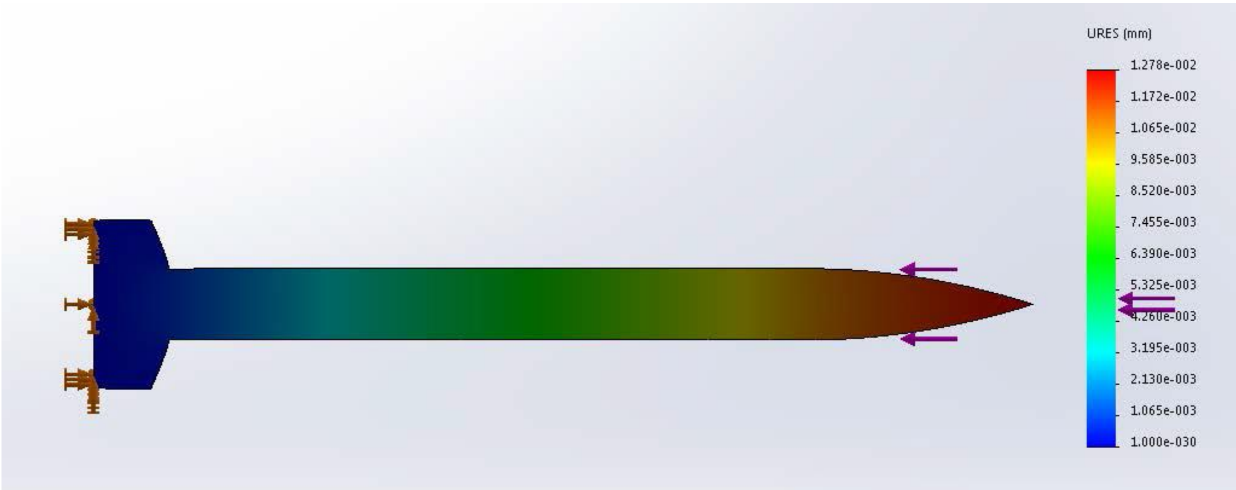

*Figure 15: Variation in sideslip angle over time for:* $\frac{dC_m}{d\beta} = -0.08$, $J = 9.69 * 10^{-4}\ m^2$, $\beta_0 = 10^{\circ}$, *and* $I_{sp} = 193\ s$

The rocket parameters were chosen to observe the tendency of sideslip angle for a typical physical case for two-dimensional motion; actual physical values for the rocket being designed will be included in future simulations.

## Recovery Analysis

The parachute will be deployed at apogee by a black powder ejection charge that will be fired by a commercially available altimeter as well as a motor ejection charge as a back-up. The chute is protected by wadding against the ejection. This recovery system was designed to provide a dart landing velocity of 4.5 m/sec.

**Structural Analysis**




SolidWorks was used to computationally show the load distribution due to an applied distributed loading over the nose cone. This is a conservative measure of the forces which the rocket are subjected to over its flight. This suggests that most of the force will be distributed over the leading edge of the nose cone which stresses the necessity of a material chosen that is capable of withstanding these loadings.

**Environmental Conditions Analysis**

OpenRocket allowed for simulation of variable wind speed, direction, and turbulence. The launch environment will always be subject to unpredictable and variable weather conditions so in order to protect the rocket from the environment the components were designed to improve the chances of safe recovery.

## Budget

| | | |
|---|---|---|
| Midwest Budget | | 1300 |
| Travel/hotel Budget | | 2200 |

| | Quantitiy | Cost Ea. ($) |
|---|---|---|
| **Registration** | 1 | 400 |
| **Rocket Body** | | |
| 74 mm Body Tube (4 pack) | 1 | 20.57 |
| 38 mm Casing | 1 | 59.15 |
| 38 mm Retainer | 1 | 43.87 |
| 74 mm Coupler | 1 | 4.13 |
| Flight Tags (5 pack) | 1 | 10.95 |
| J410 motor | 2 | 12.95 |
| 34 mm long Nosecone | 1 | 17.95 |
| In house materials | 1 | 0 |
| **Electronics** | | |
| Raspberry Pi Kit | 1 | 69.99 |
| Perfectflite Alt. | 1 | 54.95 |
| BerryIMU | 1 | 34.00 |
| Camera | 1 | 39.95 |
| Force Sensor | 1 | 30.76 |
| Protoboard (3 pack) | 1 | 8.50 |
| LiPo Battery | 1 | 89.23 |
| | | |
| Remaining Budget | | 2590.1 |

Funding was secured from private donations, Ohio Space Grant Consortium, and TREP Funding.

## Safety

Only members of the build team with proper certification will store, handle, and install the J410 solid rocket motors. They are kept in storage until used for tests or competition and only ignited by certified operators as well. Application of fiberglass epoxy and hardener is performed with gloves on and only done after training by experienced senior members of the team. Furthermore, the cutting and sanding of custom fiberglass components is always performed with eye protection and facemasks in a ventilated workshop. All assembly procedures are done in the team workshop except for the application of paint which is performed in an outside space.

The demanding stresses that the rocket design will be subject to during flight require strong structural materials to prevent deformations and fractures. Fiberglass composites will be used to reinforce the exterior of the body tube and can be dangerous to work with. Before being coated in the hardening epoxy solutions, glass fibers are strong skin and eye irritants; safety gloves and glasses must be worn during the coating processes and respirators must be used post-hardening sanding to prevent inhaling the airborne glass fiber particles. The J-410 Rocket Motor is a highly flammable solid rocket fuel that can be ignited with high temperature sparks. The motor must be stored in fire-safe cabinets when not in use and must be handled with care during transportation to the field and during launch procedures.

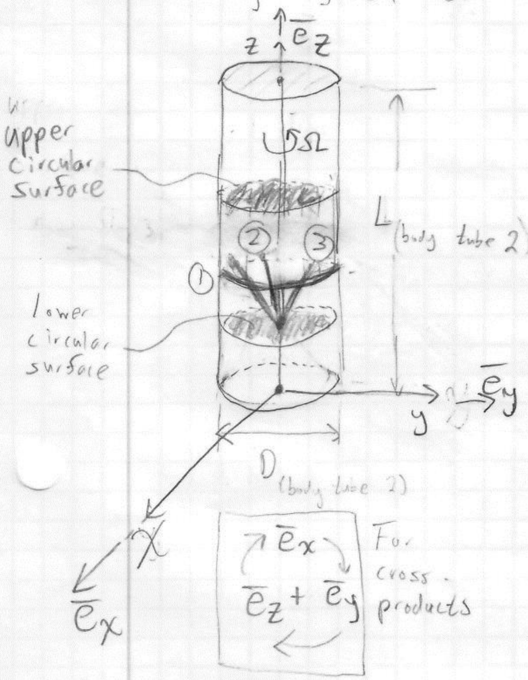
Preparing the rocket for launch will include the packing of the parachutes into the body tube sections with protective wadding. Once assembled, the rocket motor will be slid into the aluminum motor housing and secured into the motor tube. After the rocket is secured to the launch rails, the electronics devices will be armed to prepare for data collecting. Only after the rocket has been secured to the launch rails will the rocket ignitor be placed inside the motor and discharge leads connected to the launch station. The commercial recorder will be set to record data following the thrust of the motor start up and will record until they have sensed that the rocket has returned to the ground. Upon completion of the launch, the rocket will be recovered and the saved data log file will be recorded to a computer for analysis and comparison to estimated results. The motor tube will be extracted from the booster upon cooling down and will be cleaned with rubbing alcohol in preparation of the next anticipated launch as the electronics batteries are recharged and memory reset.

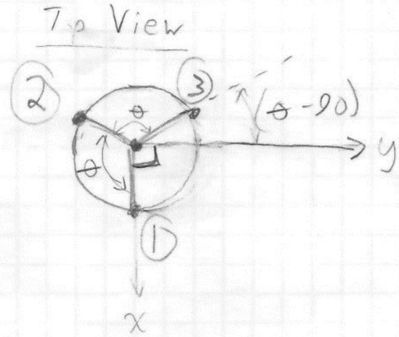
Rocket Team simulation

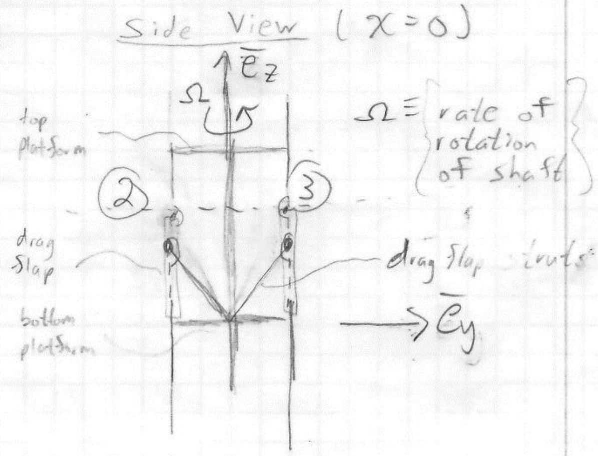
Engine Type: J410

Midwest Rocket Prototype:

For drag system need stability analysis. (In $\mathbb{R}^3$)

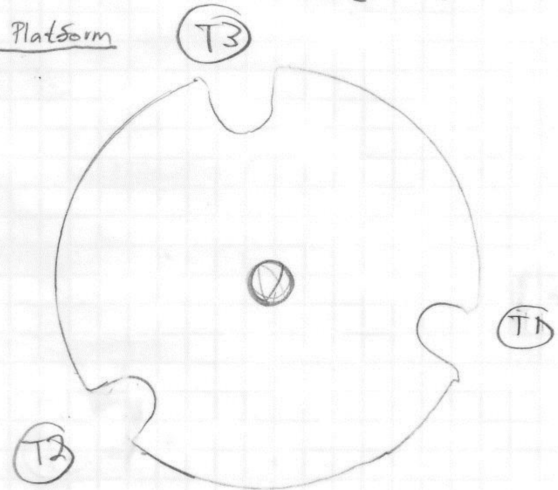


Rocket Team | Drag Sytem | By: Clinton Rosa

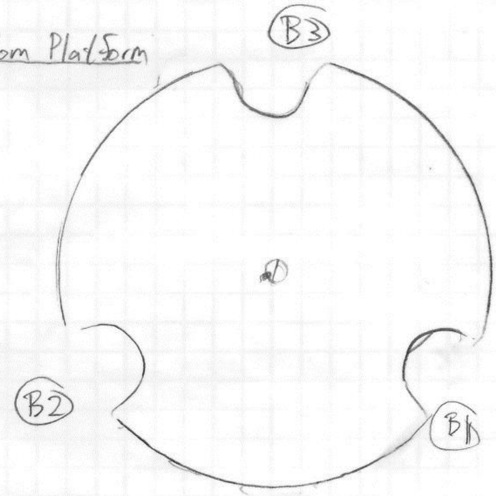
Top Platform




Body Tube
1' 4" $\frac{14}{16}$

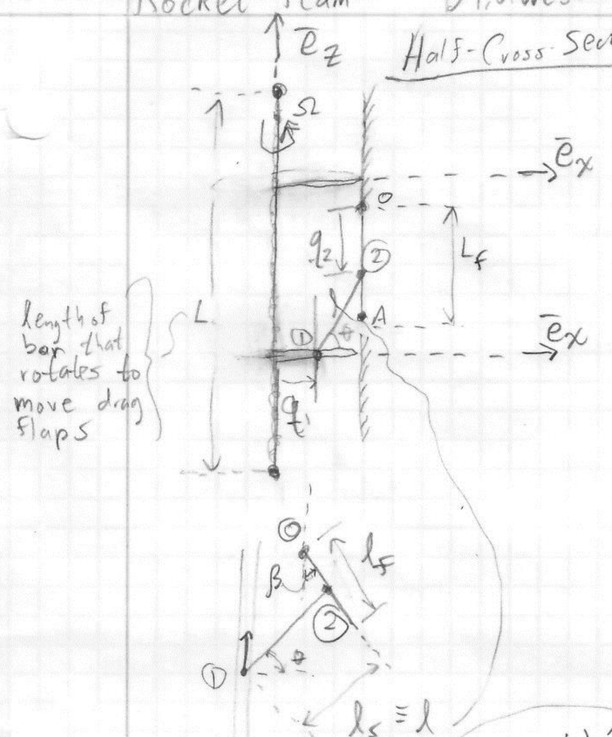
Inner Diameter
3"

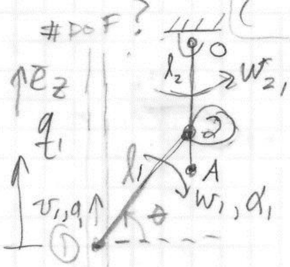
Bottom Platform

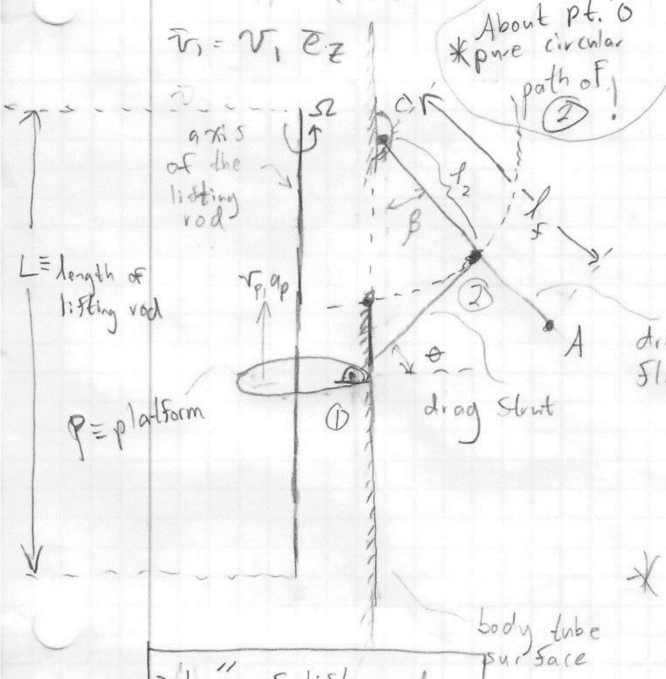


Half-Cross Sectional View

{*Member $l_2$ is the drag flap}




Configuration coordinates: $q_1, q_2$

$q_1$ denotes upwards translation of the platform to which the struts are attached

$q_2$ denotes the angular displacement of the drag flap since $l_1$ is const!

O $\equiv$ stationary pt. on body tube of rocket

2 $\equiv$ pivot between rocket drag flap & strut

1 $\equiv$ A point on the platform to which all struts are connected by pivots... constrained to move in only the vertical direction

$\Omega \equiv$ rate of rotation of lifting rod

* Need to analyze constraint relation between the threading on the lifting rod to the upward translational motion of the platform P.

$3\left(\frac{1}{2}\right)$" of lifting rod motion allowed