Illinois Space Society Space Jam

University of Illinois at Urbana-Champaign
NASA Space Grant Midwest High-Power Rocket Competition 2014-2015
Preliminary Design Report
March 20, 2015

Illinois Space Society
104 S. Wright Street
Room 321D
Urbana, Illinois 61801

Contents

General Information

Supervisors

Mark Joseph
Email: markjos@illinois.edu

Jonathan Sivier
Email: jsivier@illinois.edu

Team Leader

Austin Scott
Phone: (708) 308-3387
Email: apscott2@illinois.edu

Members

Jacob Drewniak
Yukti Kathuria
Sara Kochanski
Sarath Panicker
Lui Suzuki

1.) Executive Summary

1.1 General

The Space Grant Midwestern High-Powered Rocketry Competition is a challenging project for the members on the Illinois Space Society Space Grant team as it requires a comprehensive knowledge of rocketry to complete the design and construction process. The team members of Space Jam are all members of Illinois Space Society and participate in other technical projects and outreach events hosted by the registered student organization. The team is currently in the process of constructing the boosted dart rocket which will be ready to launch for its test flight planned for April 11, 2015. Mark Joseph and Jonathan Sivier with Central Illinois Aerospace are the two mentors for the team and supervised the design and construction process. The team's subscale and test launches are hosted by Central Illinois Aerospace at their biweekly launches.

The design of the rocket is meant to service a non-commercial data collection package, as required by the competition, and an airbrake system that will maximize the drag-separation distance between the booster and the dart immediately after the propellant in the engine is exhausted. This mechanism will feature a servo motor powered by an Arduino Uno that will exploit the forces of tension and aerodynamics to deploy doors attached to the sides of the booster that will act as an airbrake system or airbrake system.

1.2 Background of the Team

Space Jam, a team composed entirely of freshmen undergraduate students in the aerospace department claim this project to be their first experience with high-powered rocketry. The team endeavored to design, construct and fly a rocket capable of flying at high speeds and to maximize the drag-separation distance, a facet of the grading criteria set by the Space Grant Consortium. Facilitating technical progress made on the rocket's design and capabilities were weekly meetings among the members of the team. The Space Jam members worked to design the rocket and its components based upon fundamental knowledge of concepts related to aerospace engineering such as flight dynamics, basic physics, and creative engineering. The design process began in early September of 2014 and was completed with minimal assistance from the mentors. Construction of the rocket commenced in early March and will continue until the expected test launch date of the rocket.

2.) Mechanical and Electrical Design

2.1 Dimensional Specifications

The team is building a two-staged rocket consisting of a booster stage and a dart stage. The two figures shown below are the models of the various sections created in RockSim 9 with all of the components included in the schematics.

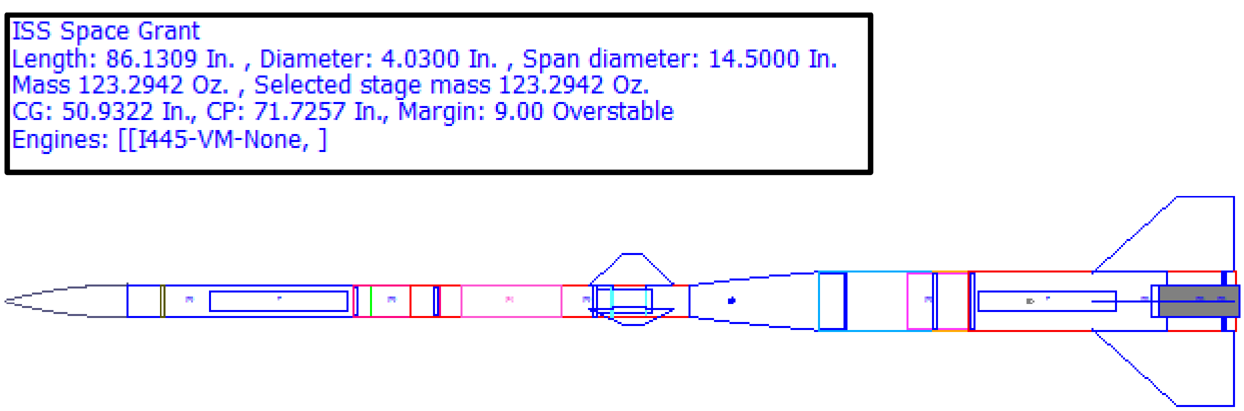

Figure 1. Boosted dart rocket, prior to drag-separation, before motor burnout

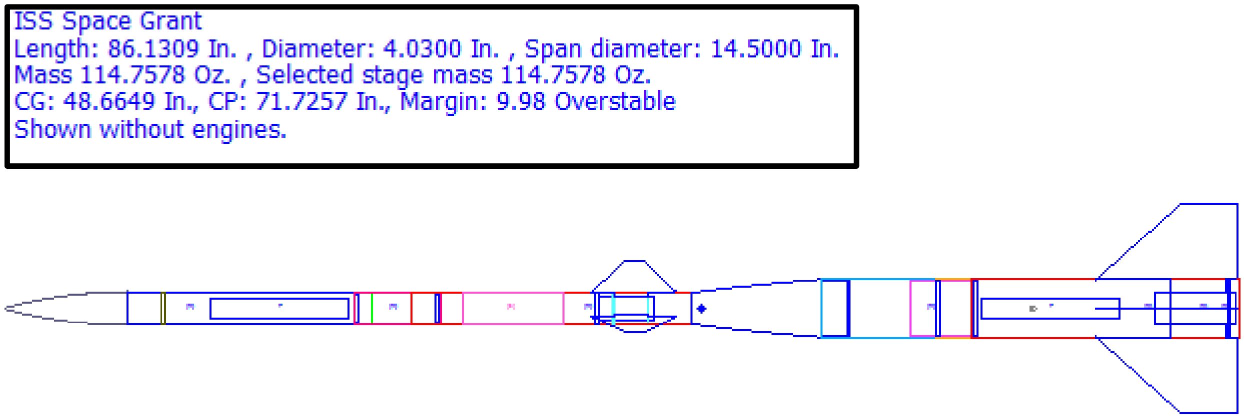

Figure 2. Boosted dart rocket, prior to drag-separation, after motor burnout (this diagram accounts for the empty mass of the motor)

The first booster stage mainly includes the motor and the airbrake system and will separate from the dart segment after motor burnout. This stage also includes the transition piece, body tube, bulkheads, couplers, 3 fins, engine casing and engine mount tube, centering rings, motor retainers and rail buttons.

In designing the booster stage, the team discussed various different materials for the different parts, and ran a trade study that outlined the effects the materials would have on the rocket's performance in terms of altitude and drag-separation distance. The team concluded to use LOC airframe tube as the material for the booster.

Shown below are two figures, outlining the design of the booster stage of the rocket with a fully loaded rocket motor and booster stage after motor burnout.

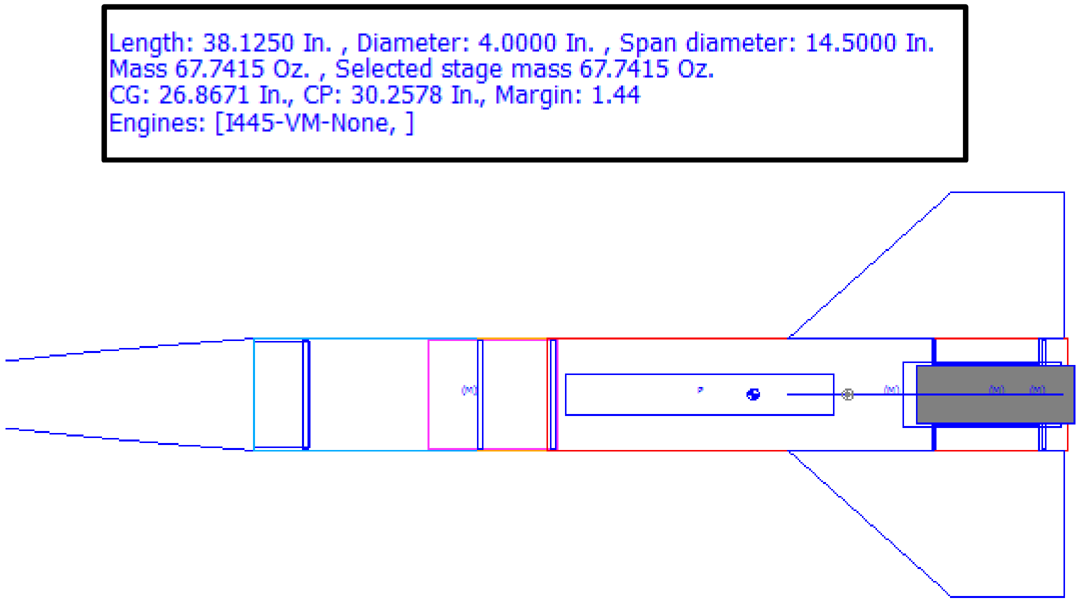

Figure 3. Booster stage with fully loaded rocket motor

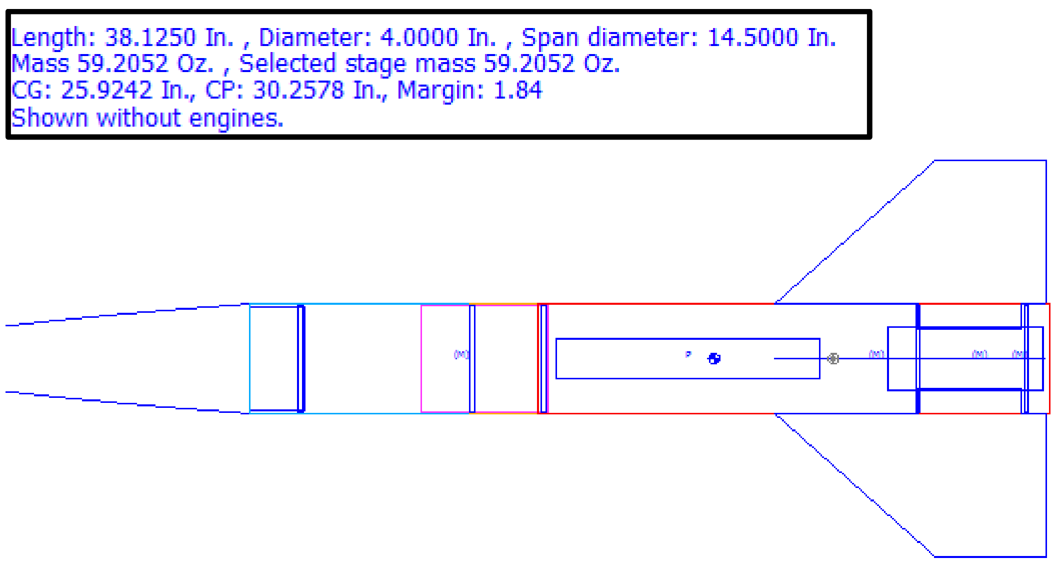

Figure 4. Booster stage after motor burnout

The main payload of the Booster section of the rocket will be the airbrake system. The main components will be located in top portion of the booster near inside the body tube connected to the transition piece. The main electronic components controlling the process will be located inside the coupler to protect them during flight and recovery. These systems have been discussed in detail later in the report.

The dart, the upper stage of the rocket, will separate from the rocket after motor burnout due to the difference in drag compared to the booster. It is made up of two nose cones, a body tube which consists of an avionics bay, tube coupler, centering rings, recovery system, and 4 fins. Through a trade study conducted on the material of the nose cone and body tube of the dart, it was concluded that both would be made of fiberglass. The team considered a variety of materials and different combinations to be able to achieve the greatest dart altitude and dart-booster separation distance. Also, simulations were run on RockSim 9 and OpenRocket to calculate and optimize these values to improve the team's score given the parameters. A tail cone is included at the bottom of the dart so it can fit snugly into the top opening of the transition piece. It will ensure that the dart stays stable and smoothly separates from the booster stage. The team will test the fit between the nose cone and the transition piece and confirm that the fit is tight enough to keep the whole rocket intact during motor burn but loose enough for the dart to separate from the booster after motor burnout. Depending on the fit, some parts will be sanded down or tape will be added on the edges to make the fit tighter.

The following figure represents the design of the dart stage:

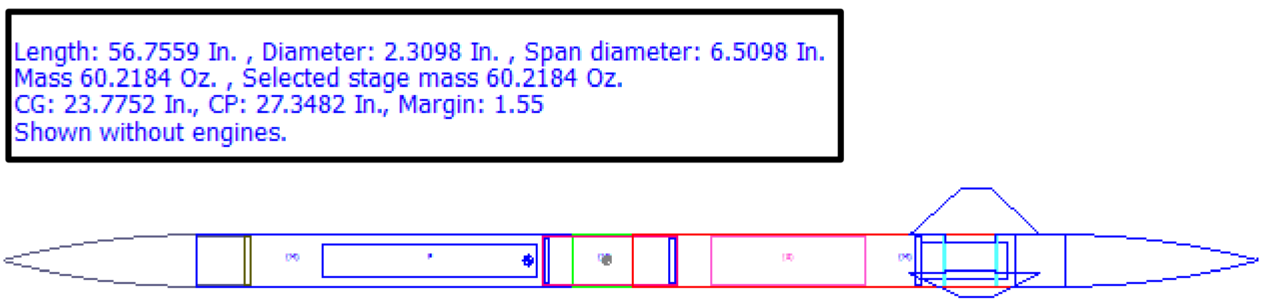

Figure 5. Dart stage

2.2 Recovery System Design Specifications

The booster and dart stage will have two completely independent recovery systems because they will separate mid-flight.

The booster stage will contain a parachute which will be deployed by a motor ejection charge with a delay. The exact delay time is yet to be calculated but will be used to optimize the descent velocity and drift distance. The team did discuss the possible addition of an electronic deployment as a backup but concluded that the motor ejection charge is very reliable and a backup is not needed. The booster will separate between the coupler and the bottom section and the parachute will deploy.

The dart stage will have a dual deployment system where streamers and a parachute will be used. Both of these will be deployed electronically with a black powder charge at a certain altitude determined by the altimeters. At apogee, the bottom half of the dart will separate and deploy the streamers. The streamers are used to slow the descent rate but not by too much to minimize the drift distance and descent velocity. When the dart has descended to approximately 200m, the top half of the dart will separate from the coupler and the main parachute will deploy. This parachute will decrease the descent rate of the dart to a safe velocity until touchdown. The amount of black powder needed to electronically deploy the streamers and the parachute will be carefully calculated and tested with the help of the team mentors.

Charge testing will be conducted under the supervision of the team mentors to make sure that the parachutes deploy correctly and a correct amount of black powder charge is being used. Also, sufficient holes will be drilled into the coupler that holds the altimeter so that it can measure the correct barometric pressure to deploy the parachutes.

2.3 Propulsion System Specifications

The competition requires the use of a Cesaroni I445 P-54-1G Vmax motor. This motor serves as the propulsion system for the flight as it powers the boosted dart into the air. The motor will be contained in a 54mm Cesaroni 71030 case and is 142.24 mm long. The motor retainer is the Aeropak 24066 with an inner diameter of 57.5mm, an outer diameter of 66mm and a length of 17.8mm. These components were chosen because of their compatibility with the motor that would be used. Also, both Cesaroni and Aeropak are highly reputable companies, which adds a factor of credibility and safety to the propulsion system.

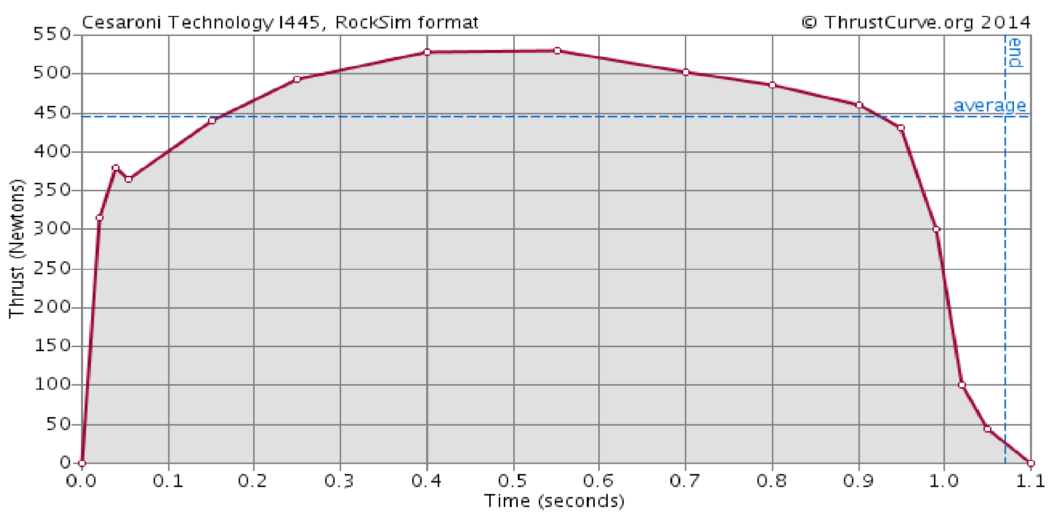

Figure 6. Thrust curve profile for the 475-I445-16A motor

2.4 Avionics System Design Specifications

Since data retrieval forms a major portion of the competition, the avionics portion of the rocket remains extremely vital not only to the performance of the rocket, but also the analysis of the flight. The competition requires an avionics system that collects look-down video from the dart during ascent and an on-board data collection package that measures rotation in all three axes.

The video footage will be taken by a small keychain camera recorder so that it does not take too much space in the rocket and has a small mass. Though in theory a small phone can record the journey of the rocket, the unpredictability of a phone's weight and center of mass has potential to disrupt the overall performance of the rocket. As a result, the use of an 808 Car Keychain Spy Camera Recorder suits the small dimensions necessary so that it's weight and center of mass does not disrupt the performance of the rocket. In terms of positioning, the recorder's lens is slightly protruded out of the rocket such that it still has the ability to record the journey, but also doesn't interfere with the rocket's stability while in the air. It also aligns with the competition objectives.

A portion of the coupler will be cut out and a clear, flexible, plastic shield will cover the portion cut out so that the camera can actually obtain footage. The plastic shielding will also minimize the drag and ensure that the interior electronics in the coupler do not get damaged from outside forces. The team did consider the use of an external mirror but determined it to be not optimal because of the excess drag it will cause on the dart.

The second component of the avionics systems is the data collection package. An altimeter, Arduino Pro-Mini, and a GY-521 3-axis acceleration gyroscope with six degrees of freedom will be the main components of this system to measure the rotation along the three axes. The other components that will be included in the avionics bay are the 9V battery, terminal block, rotary switch, micro SD cards and a pro-mini shield. The rotational data collected from the 3 axis acceleration gyroscope will be transferred to the micro SD card and will be easily read from a computer. The specific electronic layout will be determined in the future and will be thoroughly tested to ensure mission success. As the ordered parts arrive, the team will begin work on the electronics. If there are problems during the construction, the team will attempt to solve them with further research or by consulting with the mentors.

2.5 Planned Construction Techniques

The team has begun construction of the rocket that will fly for the competition. Several of the components of the body tube, fins, centering rings, couplers, and nose cones have arrived, most of the components of the avionics system have not yet arrived. The parts are expected to arrive within about a week and the team will begin work on the electronics as the parts arrive.

The assembly of some of the parts of the rocket, such as the engine motor mount tube, However, before construction began, the team made an outline of things that needed to be designed and things that needed to be assembled.

The two scratch-built parts for this rocket are the fins for both the dart stage and the booster stage and the transition piece which connects the two. The team concluded on building these two components from scratch because the materials with the desired dimensions could not be found for sale.

Therefore, the team decide to purchase sheets of ¼ inch plywood and cut the fins with the calculated dimensions. The team decided to use plywood for the fins because they are commonly used within the rocketry community. They are strong, light, and easy to work with which were all important aspects in making the decision. The planned technique for manufacturing the fins involved cutting the wood using a laser cutter owned by the aerospace department. However, after getting several charred pieces using different style options, the team decided to be more creative and developed a plan of utilizing the resources available through the machine shop such as, the scroll saw and the sanding machine.

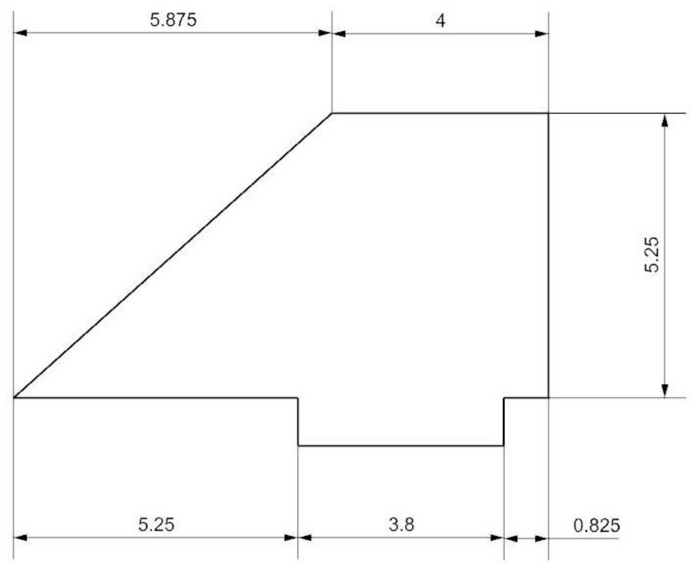

Figure 7. Dimensions of the booster fins (measured in inches)

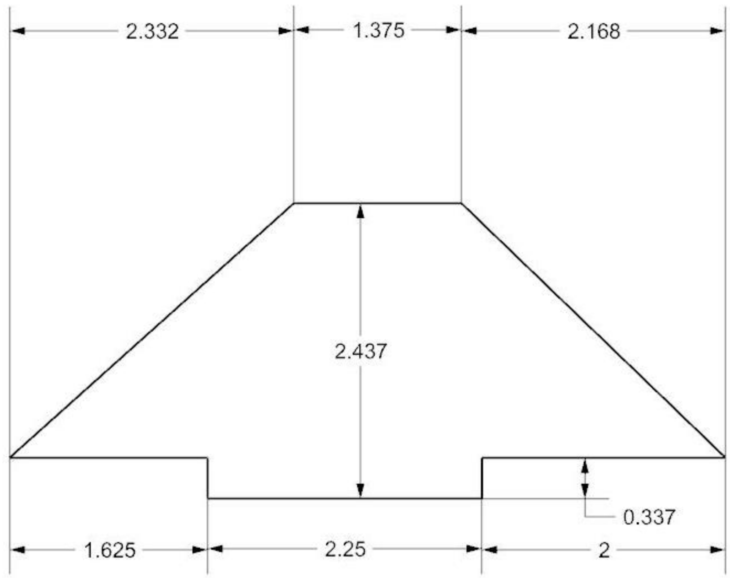

Figure 8. Dimensions of the dart fins (measured in inches)

The second piece that will be built from scratch is the transition piece which connects the 54mm dart body tube to the 98mm booster body tube. The team also determined the dimensions of the transition piece through simulation. A rocket transition piece of the desired size could not be found for sale either so it was decided to manufacture the piece from scratch. A teammate in Illinois Space Society who is not affiliated with this competition had built his own 3D printer and offered to print the transition piece for this rocket. The printer uses a 0.4 mm nozzle which will result in an accurate enough precision for this purpose and uses PLA plastic. Printing the transition piece with a 3D printer was chosen because it is inexpensive and provides a sturdy part that fit the specifications and eases the connection between the two stages.

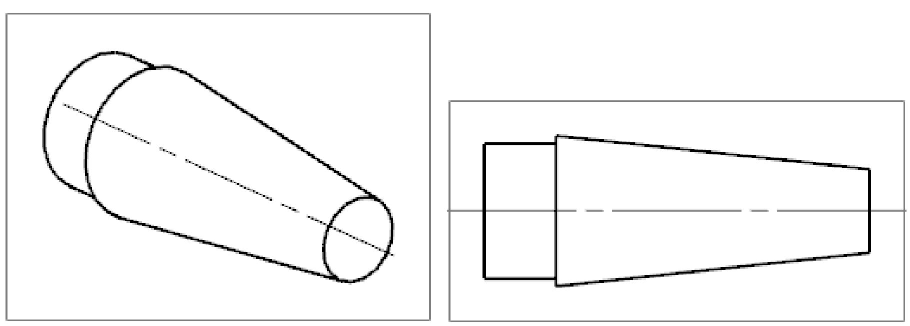

Figure 9. The transition piece of the boosted dart

For assembling the rocket, the team decided to divide into two parts, one of which would work on creating the structures while the other would work on making the electronics functional.

2.6 Risk Mitigation Analysis

Given below is a table indicating the potential risks associated with the rocket's mechanical and electronics systems, the general likelihood of the error occurrence, likelihoods, impacts, and prevention methods of the boosted dart rocket before, during, and after the competition launch.

Risk	**Likelihood**	**Impact**	**Prevention method**
Failure of electrical equipment	Low	Parachutes and airbrake system will not deploy, telemetric data will not be read	Test the components multiple times under stress tests and always use fresh batteries, make sure the electric connections are strong and do not come off.
Size of scratch-build transition piece not accurate	Moderate	Increased drag and possibility of transition piece not fitting and falling out	Make sure to 3D print the transition piece as accurate as possible and sand off any rough parts. Test that the transition piece fits with the body tubes as designed.
Airbrake deploys too early	Moderate	The motor will not be able to burn completely with minimal drag and will lower the maximum altitude lowering the team's score	The airbrake system will deploy at a certain altitude measured by the altimeter. Accurate simulations will be run on RockSim to measure the altitude of the rocket after burnout at which the system should deploy Also, sufficient holes will be drilled into the coupler so the altimeter can correctly read the barometric pressure.
Airbrake deploys too late	Moderate	Will not cause any danger but will lower the teams score because the separation distance will be smaller	The airbrake system will deploy at a certain altitude measured by the altimeter. Accurate simulations will be run on RockSim to measure the altitude of the rocket after burnout at which the system should deploy. Also, sufficient holes will be drilled into the coupler so the altimeter can

			correctly read the barometric pressure.
Airbrake does not deploy at all	Low	Will not cause any danger but will lower the teams score because the separation distance will be smaller	Test the airbrake system multiple times and make sure that all electrical wirings are firmly connected.
Fins on either the dart or the booster stage come loose during flight	Low	Destabilization of the rocket	Through-the-wall fin attachment, in which tabs of the fins will be epoxied to centering rings tubes inside the two sections of the rocket.
Airbrake components come loose during flight	Moderate	Loose pieces falling from above could cause danger to bystanders	Each component will be tested and made sure that they are secured tightly to the booster main stage.
Streamers in the dart do not deploy	Low	Descent rate will be very fast and may rip the parachute when it deploys	Test the black powder charge to make sure that the parachute can properly deploy.
Parachute in the dart or booster do not deploy	Low	The descent velocity of the dart will be too high and could cause danger to bystanders	Test the black powder charge to make sure that the parachute can properly deploy.
Altimeters do not read the altitude correctly	Low	The parachutes or streamers do not deploy at the correct altitude, the rocket may drift too far descend too fast	Make sure to drill adequate number and sizes of holes in the side of the rocket to allow the altimeters to measure barometric pressures
Motor does not ignite	Low	The rocket will not launch	Ensure that the igniter is pushed up to the top of the motor

3.) Predicted Performance

3.1 Structural Analysis

The predicted performance of the rocket during its flight will be based upon the structural integrity of the rocket, its aerodynamic profile, and the efficiency of the recovery system for both the booster and the dart stages of the rocket, the effectiveness of the airbrake system, and the accuracy of the dimensions of the scratch built components. The team used the rocket design and simulation computer program RockSim 9 to formulate the design for both the booster and dart sections as well as to progressively optimize the value of the static margin and altitudes for both sections of the rocket. Based upon the projected mass of the rocket, the thrust of the engine and the aerodynamic profiles of both the booster and the dart sections, the team was able to restrict the static margins to values that would allow for stable ascents and descents.

3.2 Launch Analysis

All of the launch characteristics of the rocket are based off of the thrust and mass profile data for the competition motor, the Cesaroni 475-I445-16A. Based on the data imported from thrustcurve.org into a MATLAB script, the altitude vs time graph during the rocket's burn, which lasts 1.1 seconds, looks as follows:

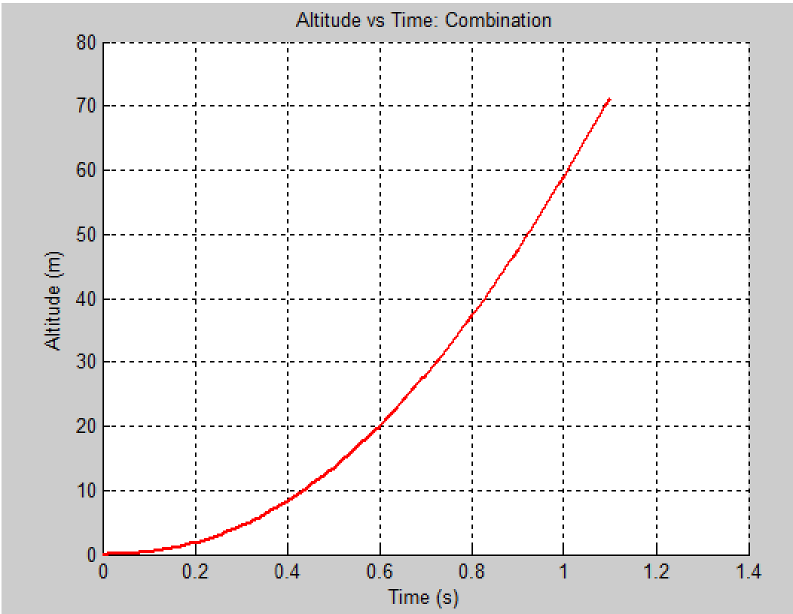

Figure 10. The altitude vs. time graph of the boosted dart prior to drag-separation

The maximum velocity reached by the booster-dart combination is approximately 120 meters per second while the maximum acceleration reaches approximately 136 meters per second squared. The altitude at which separation occurs is approximately 71 meters. To calculate these numbers, both the varying thrust, varying mass, and rocket drag were taken into account. The coefficient of drag for the whole rocket profile was estimated at 0.2, but no actual wind tunnel testing occurred. Subsequently, this value may not be entirely accurate.

3.3 Flight Analysis

Graphs of the booster and dart sections from separation to their respective apogee points are as follows:

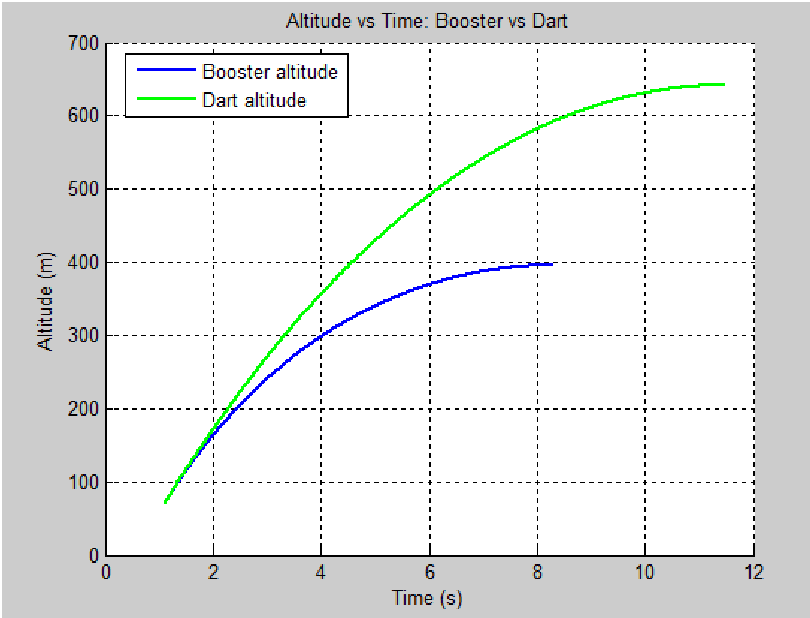

Figure 11. The predicted flight profile of the dart and booster sections after drag-separation but prior

The apogee for the dart section is approximately 642 meters if drag-separation occurs successfully, whereas apogee for the booster section is approximately 396 meters. The total separation is approximated at 246 meters. The estimated coefficient of drag for the dart section was lowered to 0.15 due to the smoother body due to lack of a transition in diameter. The coefficient of drag for the booster section was estimated at 0.8 for the graphs and code because of the anticipated use of a drag separation mechanism and the hole in the top of the transition piece due to separation. In reality, the drag coefficient for the booster section could range from as low as 0.5 all the way up to around 1.3 depending on the exact aerodynamic nature of deployment and separation. This could cause the separation between the apogees of the two sections to range from as little as 150 meters up to 500 meters.

3.4 Recovery Analysis

According to the value of the descent velocities of the parachute by RockSim, the booster will have a descent velocity of 4.114 meters per second, the dart will have a descent velocity of 14.01 meters per second during the streamer deployment, and a descent velocity of 4.634 meters per second during the parachute deployment. Assuming that the parachutes for the booster and the dart, and the streamer for the dart deploy exactly at their respective apogees, the graph of the descent phase of the flight for both stages is represented below:

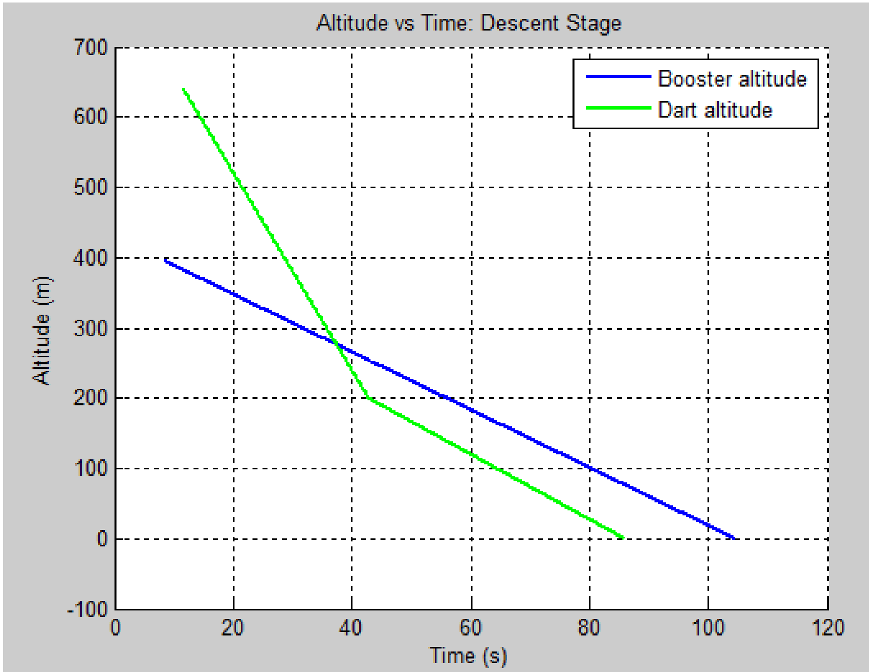

Figure 12. The altitude vs. time graph of the flight profile of the booster and dart sections following the deployment of the recovery systems

A height of 200 meters was chosen arbitrarily as the deployment height for the dart main parachute to give it plenty of time to fully expand and minimize drift distance. This would lead to a total flight time 86 seconds for the dart and 105 seconds for the booster.

3.5 Stability Analysis

The principal factors that influenced the stability of the rocket stages were the location of the center of gravity, the center of pressure, and the dimensions of the fins. It was recommended by the team mentors and discovered through research on fin design and rocket aerodynamics that the static margin for a ballistic object that would permit the greatest stability during the ascent phase of the flight of both the dart and booster sections would exist between approximately 1.00 and 2.00. Because the flights of the sections before and after drag-separation would be susceptible to loss of dynamic control by the fins in moderate and/or high winds if the static margin exceeds 2.00 to 3.00, and under normal environmental circumstances if the margin is less than 1.00, manipulation of the dimensions of the fins became a priority for the team members.

The fins on the dart stage of the rocket were designed to provide the most stability for the rocket while, simultaneously, maintaining a reduced drag profile for the dart's individual phase of ascent after motor burnout. Adjustments made to the dart fin dimensions such as sweep angle

(48 degrees), root and tip chord length, and location of the fins relative to the aft of the dart section itself all impacted the static margin of the dart. It is imperative that the accuracy of the dimensions, which were created in a RockSim file, be replicated during the construction of the dart.

3.6 Environmental Conditions Analysis

The static margin of the full rocket is relatively high and depending on wind speed, could cause the rocket to overcorrect and fly too much into the wind. Because the time between launch and separation is so small, this will ultimately be a non-issue. The static margins of the individual stages are nearly ideal, leading to optimum performance post-separation, regardless of environmental conditions.

The estimated descent velocity of the booster section after parachute deployment, based on the RockSim model, is quite small and could possibly lead to large drift distances in high winds. Because a radio tracking system will not be installed, this could be problematic for recovery. Because the team is using a dual-deployment recovery system in the dart, its descent velocity is quite high until fairly close to the ground, leading to relatively simple recovery except under extremely high wind conditions.

Any other hazardous weather conditions would lead to a delay of the launch date and therefore would not affect flight performance.

3.7 MATLAB Code used for Analysis

The following code was used in the various analyses conducted regarding the launch, flight, and recovery analyses for the rocket, prior to drag-separation and following drag-separation:

```
time_increment = input('Enter time increment: ');
velocity1(1) = 0;
altitude1(1) = 0;
acceleration1(1) = 0;
Datafile= 'Data.txt';
data=importdata(Datafile);
thrust=data(:,2);
time1 = data(:,1);
mass_propellant=data(:,4);
Drag_coefficient = .2;
Drag_novelocity = 0.5*(0.049)^2*pi*1.225*Drag_coefficient;
L=length(data);
burntime= 1.1;
time(1) = 0;
mass_rocket = 3.49533;
i = 1;
while time(i) <= burntime
i = i + 1;
time(i) = time(i-1)+time_increment;
CurrentTime=time(i);
```

```
[Thrust]=ComputeThrust(CurrentTime,burntime,thrust,time1);
[Mass]=ComputeMass(CurrentTime,burntime,mass_rocket,mass_propellant,time1);
acceleration1(i) = (Thrust/(Mass) - 9.81-(Drag_novelocity*(velocity1(i-
1))^2)/(Mass));
velocity1(i) = velocity1(i-1) + time_increment*acceleration1(i);
altitude1(i) = altitude1(i-1) + velocity1(i) * time_increment;
end

figure (1)
hold on
plot(time, altitude1, 'r-', 'linewidth', 2)
xlabel 'Time (s)'
ylabel 'Altitude (m)'
title('Altitude vs Time: Combination')
grid on

mass_booster = 1.6800;
mass_dart = 1.70716;
j = 1;
k = 1;
altitude2(1) = altitude1(i);
altitude3(1) = altitude1(i);
velocity2(1) = velocity1(i);
velocity3(1) = velocity1(i);
acceleration2(1) = acceleration1(i);
acceleration3(1) = acceleration1(i);
time2(1) = CurrentTime;
time3(1) = CurrentTime;

Drag_coefficient2 = 0.8;
Drag_novelocity2 = 0.5*(0.049)^2*pi*1.225*Drag_coefficient2;
Drag_coefficient3 = 0.15;
Drag_novelocity3 = 0.5*(0.049)^2*pi*1.225*Drag_coefficient3;

while velocity2(j) >= 0
j = j + 1;
time2(j) = time2(j-1)+time_increment;
CurrentTime1=time2(j);
acceleration2(j) = (Thrust/(mass_booster) - 9.81-
(Drag_novelocity2*(velocity2(j-1))^2)/(mass_booster));
velocity2(j) = velocity2(j-1) + time_increment*acceleration2(j);
altitude2(j) = altitude2(j-1) + velocity2(j) * time_increment;
end

while velocity3(k) >= 0
k = k + 1;
time3(k) = time3(k-1)+time_increment;
CurrentTime2=time3(k);
acceleration3(k) = (Thrust/(mass_dart) - 9.81-(Drag_novelocity3*(velocity3(k-
1))^2)/(mass_dart));
velocity3(k) = velocity3(k-1) + time_increment*acceleration3(k);
altitude3(k) = altitude3(k-1) + velocity3(k) * time_increment;
end
```

```
figure (2)
hold on
plot(time2, altitude2, 'b-', 'linewidth', 2)
plot(time3, altitude3, 'g-', 'linewidth', 2)
legend('Booster altitude','Dart altitude')
xlabel 'Time (s)'
ylabel 'Altitude (m)'
title('Altitude vs Time: Booster vs Dart')
grid on

max_acceleration = max(acceleration1)
max_velocity = max(velocity1)
max_altitude_booster = max(altitude2)
max_altitude_dart = max(altitude3)
max_altitude_combo = max(altitude1)

x = 1;
m = 1;

altitude4(1) = altitude2(j);
altitude5(1) = altitude3(k);
velocity4(1) = velocity2(j);
velocity5(1) = velocity3(k);
time4(1) = CurrentTime1;
time5(1) = CurrentTime2;

while altitude4 >= 0
    x = x + 1;
    time4(x) = time4(x-1)+time_increment;
    CurrentTime3=time4(x);
    velocity4(x) = -4.1138;
    altitude4(x) = altitude4(x-1) + velocity4(x)*time_increment;
end

while altitude5 >= 0
    m = m + 1;
    time5(m) = time5(m-1)+time_increment;
    CurrentTime4=time5(m);
    if altitude5 >= 200
    velocity5(m) = -14.098;
    altitude5(m) = altitude5(m-1) + velocity5(m)*time_increment;
    else
    velocity5(m) = -4.6339;
    altitude5(m) = altitude5(m-1) + velocity5(m)*time_increment;
    end
end

figure(3)
hold on
plot(time4, altitude4, 'b-', 'linewidth', 2)
plot(time5, altitude5, 'g-', 'linewidth', 2)
legend('Booster altitude','Dart altitude')
xlabel 'Time (s)'
ylabel 'Altitude (m)'
```

```
title('Altitude vs Time: Descent Stage')
grid on

CurrentTime3
CurrentTime4

function
[Mass]=ComputeMass(CurrentTime,burntime,mass_rocket,mass_propellant,time1)
if CurrentTime <= burntime
Mass = mass_rocket + interp1(time1,mass_propellant,CurrentTime);
else
Mass = mass_rocket;
end

function [Thrust]=ComputeThrust(CurrentTime,burntime,thrust,time1)
if CurrentTime<=burntime
Thrust=interp1(time1,thrust,CurrentTime);
else
Thrust=0;
end
```

4.) Model Rocket Demonstration Flight

4.1 Specifications Regarding the Model Rocket

The model rocket test flight occurred on December 13th, 2014 at Dodds Park in Champaign, Illinois and the model rocket that the team chose to launch was a Dyna-Star Rising Star rocket. The rocket airframe, including the motor mount tube, was purchased as a kit from Apogee Components, a notable rocket vendor. A D-12-5 Estes motor was used to power the rocket.

4.2 Construction of the Model Rocket

Because the model rocket was purchased in a kit from Apogee Components, the team did not modify the design of the rocket and followed the instruction manual provided by the seller. The goal was to launch a rocket that was relatively simple to construct, to decrease the chance of error during and after the rocket launch, and gain experience with the construction process. Space Jam used one of the department's student work laboratories to construct the rocket, which took approximately four hours over the course of two days to complete.

4.3 Flight Performance of the Model Rocket

The rocket's flight performance was subject to various factors including the weather and the potential imperfections in the accuracy of the rocket's construction with regards to the build instructions. These factors were taken into account prior to the rocket launch, when the team mentors, Mark Joseph and Jonathan Sivier, recommended that the team run simulations of the rocket's flight based upon its specifications. At Dodds Park, when the mentors examined the rocket, it was noted that aspects of the construction were flawed. For instance, the epoxy that the team used to reinforce the strength of the connection between the shock cord and the top stage of the rocket had hardened the shock cord causing it to become brittle. During the first launch of the model rocket, the shock cord connection point broke as a result of the tension force in the cord. The mentors helped the team members to diagnose the problem, as well as other potential causes for a failure in the next flight of the rocket.

After adding more recovery wadding, and re-attaching a stronger, nylon shock cord to the top stage of the rocket, the second flight proved to be successful, The rocket, itself, flew to approximately 150 meters and was recovered successfully.

4.4 Experience

The construction of the model rocket proved for the team members to be a very enlightening and important experience. It was realized that a myriad of problems should always be anticipated regarding the predicted operation of a machine, especially one that is as complex as a rocket. In the near future, the team hopes to test the airbrake system before implementing the device into the rocket design for the competition. This will allow the team, as indicated during the launch date of the model rocket, to progressively analyze the various flaws of the airbrake system that is constructed prior to its operation. The test results will permit refinements to be made to the airbrake system that will induce a greater drag-separation distance.

Reliability in technology, the team learned, is not omnipotent. Rather, the reliability of machines and mechanical processes is indicated through testing and thorough, methodical examinations of what errors may occur.

Figure 13. Team picture prior to the model rocket flight

5.) Innovation

5.1 Uniqueness of Components/Systems and Functional Relevance of Components

Given the nature of the competition, creating a two stage rocket ("boosted dart") can be a an especially complicated task.
Some of the components where the team decided to use their creativity were the recovery system and the airbrake system.

The dart stage requires a dual deployment recovery system in which streamers and a parachute are ejected after apogee. The drag separation that increases the separation distance is coupled by the material and shape of the drag fins in addition to the dimensions and material of the body tube. For example, in the case of the dart stage of the rocket, the material of the tubing would be less dense than the booster stage of the rocket. This is due to the inclusion of the airbrake system that increases the drag on the "booster" stage of the rocket and helps promote the separation of the two components. As a result of simulating different densities, the altitude the "dart" stage of the rocket reaches would be maximized due to the increased separation between it and the "booster" stage of the rocket. Moreover, promoting drag on the "booster" stage while minimizing drag on the "dart" stage builds more and more separation between the two stages which would help satisfy a main objective of the competition.

Applying an effective form of drag on the "booster" stage of the rocket would help promote its separation from the "dart" stage. As a result, the drag separation mechanism remains the most vital portion of the rocket. The drag separation mechanism is primarily fixed in the "booster" stage of the rocket. Based on the concept of a wheel and pulley type of mechanism, the drag separation mechanism portion of the rocket consist the major components of two Arduino Servo Motors, an Arduino Uno and some string/rope. The two servo motors would be rotational portion of the drag separation that essentially controls the opening of two opposite flaps on the outside of the rocket. Programmed into the Arduino, the two servo motors, which are connected to their respective opposite doors with string, would rotate and open the respective flaps creating a substantial amount of drag on the outside of the rocket. As a result of this mechanism, the induced drag would be maximized and therefore, the "booster" stage of the rocket would be more prone to separation from the "dart" portion of the rocket. Coupled with the different densities of the tubing as well as the fin shape and material, the drag would be enough to separate the two stages of the rocket and help maximize the distance between the "booster" stage's deployment and the "dart" stage's deployment. Using this mechanism, not only is the overall weight of the rocket minimized, but the team would also be able to control the exact separation time of the rocket, giving us more maneuverability and flexibility when it comes to how much the performance of the rocket can be controlled.

This mechanism is unique in the sense that the concept behind its operation, as the team discovered, is relatively unexplored. Therefore, multiple tests will be needed to confirm that the airbrake will actually deploy at the desired altitude, remain intact, and effectively create drag. Further improvements and problems to the design will probably come up during the construction process and the team will consider other methods to make the airbrake mechanism work promptly and efficiently.

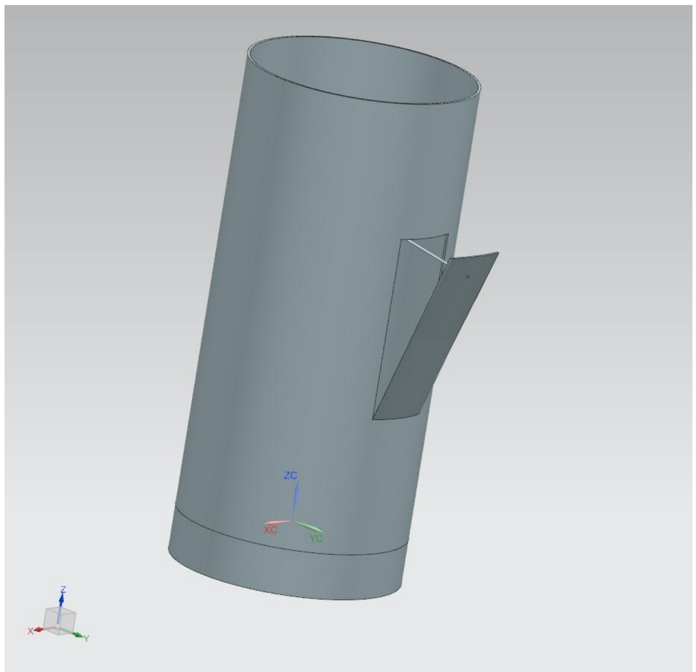

Figure 14. Display of the Airbrake Door Opening

5.2 Relevance to Competition Objectives

The main competition parameter that the team focused on was getting the maximum dart altitude and separation distance between the dart and the booster. This was because optimizing these values would be the most difficult and most important in the performance in the competition. All the design specifications of the rocket was based on these parameters. The airbrake system the team designed was purely meant to increase the drag on the booster at burnout, increasing the separation distance between the booster and dart apogee.

Another competition objective was the collecting look-down footage and rotational data of the rocket. The avionics system in the dart is designed to serve both of these functions.

Lastly, the rocket must be recovered in flyable condition and to do that, the team made sure that the descent velocity of the booster and dart were not too fast or too slow.

6.) Safety

The components of the rocket were purchased from renowned rocketry websites which ensures good quality and safe parts. The whole rocket, booster stage, and dart stage all have reasonable static margins and have the center of gravity above the center of pressure. Both the booster and dart stage will have a safe descent velocity at it falls to the ground with the recovery systems.

During the construction process, the team will use all safety precautions that are necessary such as goggles, gloves, face masks, ear plugs, and ventilation depending on the process. To use the department's laser cutter, a few team members underwent safety training for the machine and learned how to use it safely. Most of the materials used for this project are non-hazardous, but with materials of concern, such as the fiberglass, a team member with previous experience will handle the process.

As for the planned pre-launch procedures, the team will make sure all components of the rocket are fully functional and secured. As the construction process proceeds, many tests will be conducted to ensure the safety and strength of the rocket. Assuming that the weather is clear and safe for launch, the rocket will be carefully slid onto the launch rails. The igniters will be inserted into the throat of the motor until it reaches the top and the ends of the igniter will be connected to the clips leading to the launch pad. After the launch area has been cleared and all persons have relocated to a safe distance away from the launch pad, the operator will countdown and press the ignition button. After the rocket has safely left the launch rail, the team members will make sure to keep the rocket in sight. Because this boosted dart rocket will separate into two components, half of the team will follow the booster and the other half will follow the dart stage. After the launch pad operator has announced that the pads are clear, the team members will proceed to recover the stage of the rocket they were following. If the rocket lands in an unexpected area such as up in a tree, on top of a roof, or on private property, all legal ordinances will be followed and the rocket will be recovered in a safe and proper manner.

Under the supervision of the two mentors, the team will make sure to follow all the safety codes during construction and at the launch site. Throughout the construction process multiple tests will be conducted and will be approved by the team's mentors.

7.) Budget

A parts list was compiled by the team and sent to the mentors for confirmation. After they looked over the parts list, it was sent to the Illinois space grant coordinator for the components to be ordered. The Illinois space grant department owned rocketry parts from previous years and the team was able to use some parts owned by the department. The team was granted a rough budget of about $1000 from Illinois Space Grant and the estimated budget only including the components needed for construction was approximately $743.69. The registration fee was paid by the university and it is not included in the budget with which the parts for the rocket were purchased.