Illinois Space Society Space Jam

University of Illinois at Urbana-Champaign
NASA Space Grant Midwest High-Power Rocket Competition 2014-2015
Final Design Report
May 4, 2015

Illinois Space Society
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Contents

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1.) Summary of Rocket Design

1.1 Design and Dimensions

The team has built 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. Ultimately, the dimensions of the rocket that was constructed were the same in comparison to those featured in the diagrams and schematics. Great care was taken by members of Space Jam to design and construct the rocket such that it would be flyable by late April. It should be noted that the rocket did not contain either its gyroscope, its aerobrake, or its camera during the test launch.

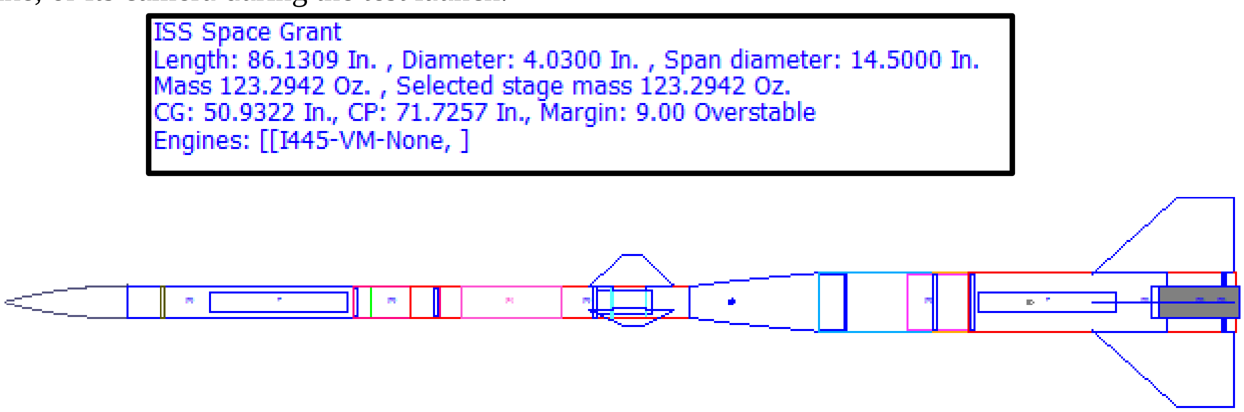

Figure 1. Boosted dart rocket, prior to drag-separation, before motor burnout

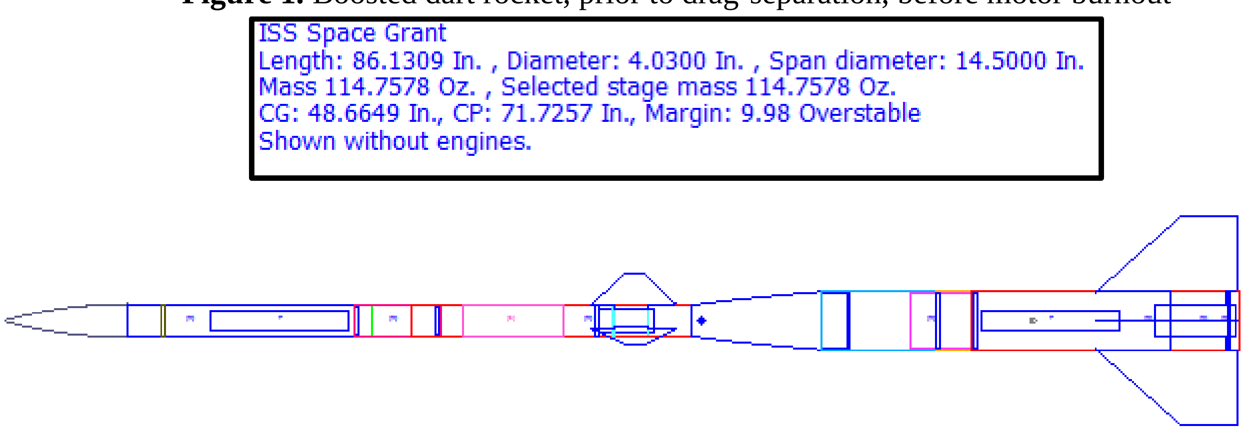

Figure 2. Boosted dart rocket, prior to drag-separation, after motor burnout

The first booster stage mainly includes the motor and 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, engine mount tube, centering rings, motor retainers and rail buttons. There will also be an avionics bay with an altimeter to retrieve data.

In designing the booster stage, the team discussed various different materials for the different parts and ran a trade study comparing the cost and compatibility with the competition goals. The materials that the team discussed using for the booster and dart included cardboard and fiberglass. The team concluded to use LOC airframe tube as the material for the booster.

Seen 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.

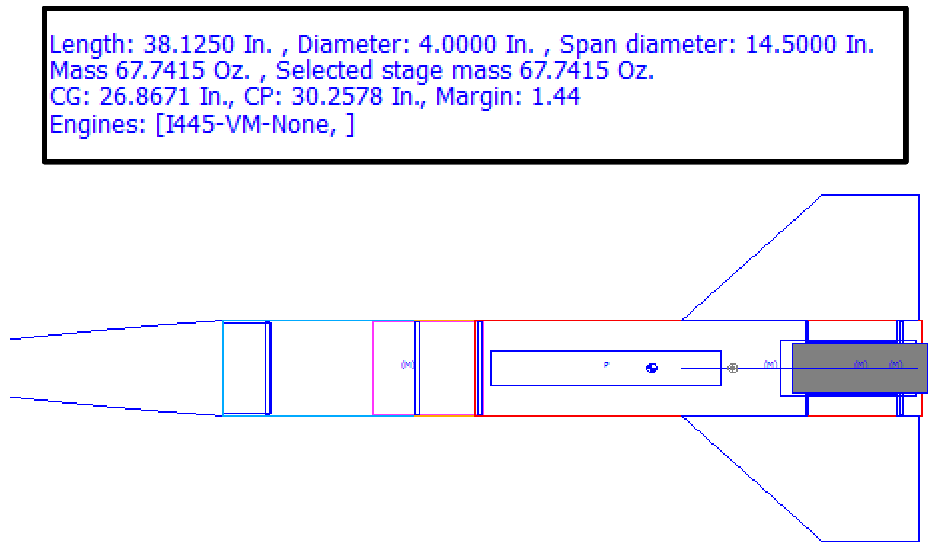

Figure 3. Booster stage with fully loaded rocket motor

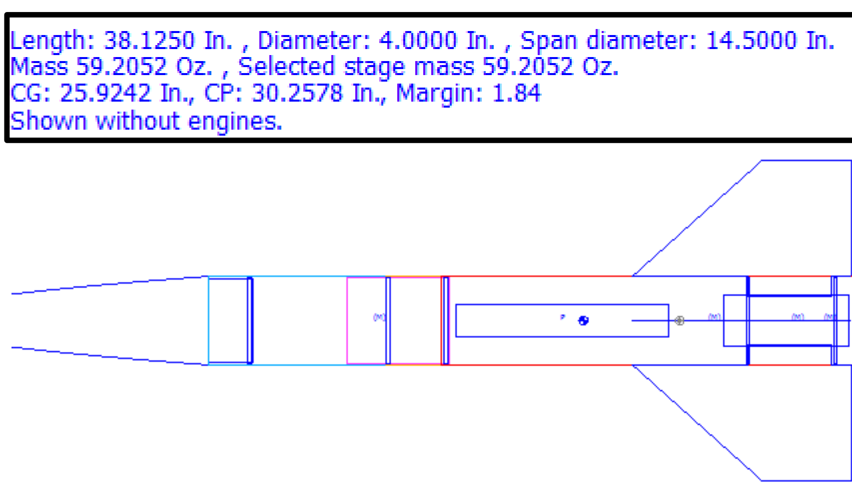

Figure 4. Booster stage after motor burnout

It has been planned that the main payload of the Booster section of the rocket will be the airbrake system. The main components will be located in the top portion of the booster near 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 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 primarily made up of two nose cones, a body tube which consists of an avionics bay, tube coupler, centering rings, recovery system, and 3 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. 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 has been epoxied into the the bottom of the dart so that it can fit snugly into the top opening of the transition piece, prior to engine burnout. It will ensure that the dart 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 sufficiently tight in order 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.With very minor exceptions related to weight, the dimensions of the dart as seen in the diagram are the same as those of the dart that was produced.

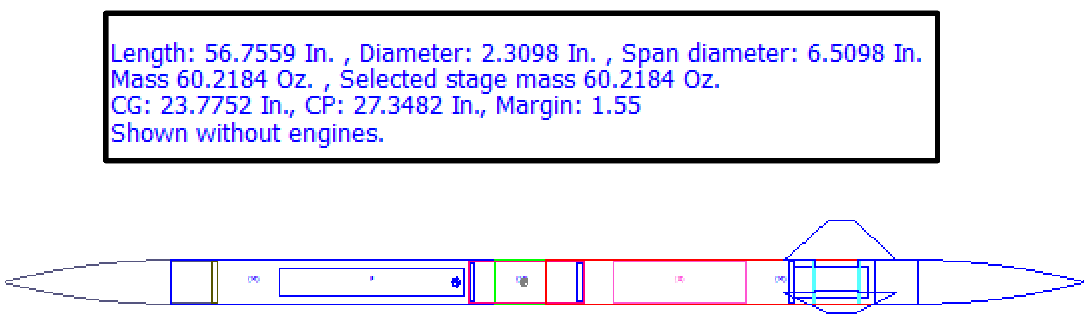

Figure 5. Dart stage

1.2 Construction of the Rocket

Approximately three weeks prior to the launch of the rocket, Space Jam began constructing its rocket, starting with cutting the body tubes and the fins from sheets of aircraft plywood. Initially, it was believed that the best way to construct the plywood fins, which are 1/4 in thick, was by using a laser cutter. After several unsuccessful attempts to cut the fins for the booster and darts at varying degrees of laser power and speeds at which the laser cut the plywood, the members decided that the best way to create the fins with a great degree of accuracy would be to use a scroll-saw. Using the scroll-saw the fins were accurately cut and team could use a sanding wheel to sand down the edges of the fins for both sections. The edges of the dart fins were rounded to make the dart more streamlined, in contrast to the booster fins which were generally left unaltered in terms of aerodynamic profile. The booster was meant to have more drag than the dart to increase separation distance.

The team then proceeded to attach the fin mounting tubes on the insides of the booster and dart tubes. These tubes were attached to the lower ends of the sections, and are situated with centering rings and epoxied in. Eyebolts meant to anchor the shock cords for the parachute in the booster and for the streamer in the dart section were drilled and epoxied into place in the centering rings that hold the fin mounting tubes. Quick links were then used to attach the shock cords to the eye bolts themselves. The shock cords were protected with kevlar sleeves during the test launch.

About two weeks before the test launch, tabs on the fins for both sections were epoxied and attached to the fin mounting tubes inside the sections with through-the-wall fin attachment. Several layers of epoxy and fillets were applied to the edges of the fins where they met the sections of tubing. A mass of about .2 lbs of sand was compartmentalized inside the nose cone to increase the dart’s prospective momentum during flight. The total weight of the nose cone equals 0.5 lbs and once the mass was placed inside the nose cone, a bulkhead was glued inside, already attached to an eyebolt. A quick-link was attached to this eyebolt, which would then anchor the shock cord. Over the course of a few days before the launch of the boosted-dart, the avionics bay was rebuilt so that it could service an altimeter, a 9V batteries, and the other electronic components meant for the gyroscopic data-collection package (this system was not featured in the test flight of the boosted dart).

The holes for shear pins and plastic rivets were drilled in the dart and booster with extreme accuracy. After the primary construction was completed, the black powder charges were tested in the dart section of the rocket. It was determined that, after several unsuccessful attempts to eject the main parachute of the dart that only two, rather than three shear pins and 1.5g of black powder would be enough to eject the parachute. The streamer deployment was successful on the first test with 0.6g

All of the essential components of the rocket have been constructed, such that the boosted dart would be considered fliable for the competition. What remains for the team to do in relation to the structure of the rocket is to continue to sand down excess epoxy on the fins and tubing, and

to attach the mirror shroud (refer to section 1.6) for the camera on the outside of the dart.

Figure 6. Team members working on the construction of the rocket

1.3 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 would exist between approximately 1.00 and 2.00.

The fins on the dart stage of the rocket were designed to provide the most stability for the rocket while, 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 a sweep angle of 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 important that the accuracy of the dimensions, which were created in a RockSim file, be replicated during the construction of the dart.

One of the major drawbacks to the design of the rockets remains the very large static margin of the boosted-dart combination, which exists before the separation of the dart from the booster. The static margin of the booster-dart combination is 9.00 and the rocket's susceptibility to turning in the wind was made evident during the test launch of the rocket on April 26th, 2015. The results of this launch and the characteristics of the flight path of the rocket, the dart, and the booster are discussed below in section 2.

1.4 Safety of Flight and Recovery

According to the value of the descent velocities of the parachute by RockSim, the booster would have had a descent velocity of 13.5 ft per second, the dart will have a descent velocity of 46 meters per second during the streamer deployment, and a descent velocity of 15.2 feet per second during the parachute deployment. Assuming that the the booster, parachute and dart streamers deploy exactly at their respective apogees, the graph of the predicted descent phase of the flight for both stages is represented below.

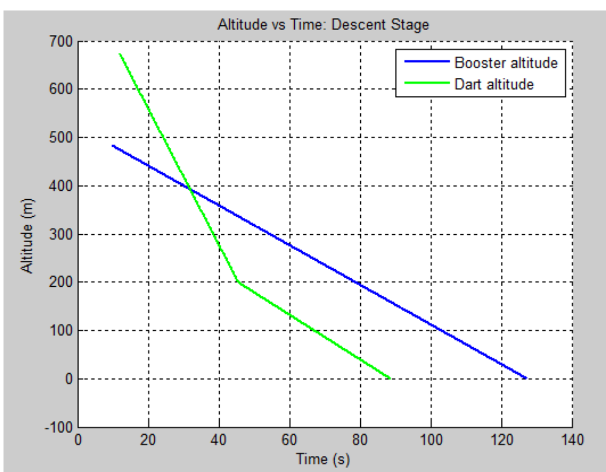

Figure 7. The altitude vs. time graph of the flight profile of the booster and dart sections following the deployment of the recovery systems

In the simulation of the rocket's flight, a height of 656 feet was chosen arbitrarily as the deployment height for the dart main parachute so as to give it plenty of time to fully expand and minimize drift distance. This would lead to a total flight time 89 seconds for the dart and 127 seconds for the booster.

1.5 Changes Made to the Rocket Since PDR

One change that is being made regards the method of retrieving downward facing video coverage. The team came to a conclusion that the best way of getting great footage was to attach a mirror shroud on the outside of the body tube. Essentially, the mirror shroud will work like a periscope. The camera will look straight out of the body tube horizontally at a mirror and the image will redirect downwards. The mirror will be attached to a block of balsa wood that has been sanded down to be as aerodynamic as possible to minimize drag. Unfortunately, this shroud was not placed on the rocket by the time the practice launch arrived, though the shroud had been constructed. One challenge that will face team before the competition is successfully situating the camera itself inside the rocket. The massive forces of the motor thrust, as well as the shock caused by the sudden ejection of the streamer and parachutes in the dart section would be substantial enough to dislodge the camera from the its mount inside the tube. Thus, the team has considered using zip ties, tape, and/or epoxy to secure the camera horizontally pointing towards the mirror.

Figure 8. Mirror shroud (periscope) for the camera to take downward footage

2.) Rocket Operation Assessment

2.1 Launch and Boost Analysis

The assembly and disassembly procedure were rehearsed the days prior to the launch when the supervisors discussed preparation for the launch. Following the testing for the black powder charges, it was determined that 0.6 grams of black powder were are required for streamer ejection and 1.5 g were required for main chute ejection in the dart. The recovery system in the booster relies upon motor ejection, and thus, black powder was not tested in that section of the boosted-dart.

After the rocket was assembled at the launch site, it was put onto the launch pad. High winds of about 10-15 mph were making the boosted dart sway on the pad and those winds indubitably hampered the flight of the rocket. The team lowered the rail, carefully passed the rail buttons through the rail, lifted the rocket to the upright position, inserted the igniter into the motor, and connected the lead clips. On the launch pad, the booster sat nicely on the launch pad but the dart seemed a little tilted on top of the transition piece. This could have been because the ground was unlevel. For the competition launch, the team will make sure to secure the dart as vertical as possible by adding a centering ring inside the transition piece and wrapping the tailcone with a thin layer of masking tape to make the fit tighter. Even though the dart was a little tilted towards one way on the launch pad, it was vertical and stable enough to be safe and it was cleared for launch. Altering with the stability margin of the rocket will be a topic of discussion by the team in the near future.

The team members stood about 200 feet away from the pad where the launch could be seen with a clear view and at a safe distance. As expected, when the rocket left the launch rail, it swayed towards the side a little bit. It did go vertical but headed sideways at the beginning of the ascent. This could have been because of the original orientation on the launch pad but also could have been because the whole rocket was a little too overstable and the winds were quite strong that day. Even though this error probably decreased the altitude of both the booster and dart, the launch was successful.

According to the raw altimeter data, both the dart and the booster had a normal boost phase. The altitude vs time graphs shows a smooth parabolic curve and the velocity vs time graphs show a sharp increase in velocity the during the boost phase. These graphs were as expected. The Cessaroni I-445 engine with a short but strong force would cause the rocket to accelerate causing the altitude and velocity to rapidly increase during the boost phase.

In the different altitude vs. time graphs for both sections of the rocket, one can observe large spikes in the data. This is an indication that there spaces in the avionics bay and or coupler stage, itself, that were exposed to the air that should not have been. Several holes were drilled in the side of the coupler to account for accurate measurements of the altitude by the altimeter in the booster and dart sections. In addition, several globs of putty were meticulously placed over the holes through which the wires ran to attach to the terminal block on either end of the avionics bay in the dart. This putty blocked holes and spaces that might have greatly skewed the results of the data gained from the altimeters. The team plans to further investigate the dramatic spikes in the data as they probably resulted from human error in the construction of the avionics bay.

The predictions made prior to the launch of the boosted-dart were inaccurate. In several of the graphs visible below, the members anticipated that the mass of the boosted-dart would be much less than what is actually was on the launch pad. It is possible, that the RockSim program did not account for certain masses that were added on to the rocket during construction. For example tape, extra epoxy, the self-created transition piece, construction imperfections of the boosted-dart's completion account for the variation in mass between what was indicated on the RockSim file, what was implemented as the mass in the predicted values, and the final rocket, and that which flew during the test flight. In addition, it was difficult to estimate the drag coefficient of the dart and the booster especially with the margin for construction error.

Figure 9. The boosted dart rocket on the launch pad prior to launch

2.2 Coast Phase Assessment

From the ground, the coasting of the booster and the dart sections occurred very smoothly. Both sections continued on a curved trajectory as a result of the wind that initially shifted the flight of the boosted-dart prior to separation- this was a result of a large static margin in the boosted-dart combination. As it can be seen from the altitude graphs extracted from the altimeters, the coast phase of both the dart and booster also seems relatively smooth and follows the trend from the boost phase. Both the dart and booster reach apogee as expected.

For both the dart and the booster, in the altitude vs time graphs, there are unexpected negative spikes. These spikes are probably from the charges that deployed the parachutes and streamer. This means that the avionic bays were not as airtight from the black powder charges as wanted. The charge caused an increase in pressure and caused the barometric altimeters to read a lower altitude than which it was at. Even though it did not cause any problems, the team will make sure that the avionic bays are airtight except for the vent holes on the sides.

2.3 Separation Assessment

From the data retrieved by the Stratologger barometric altimeters in the booster and the dart, the apogee altitudes were 1065 ft. and 1608 ft. respectively. This puts the separation distance between the apogees of the booster and dart at 543 feet.

For the preliminary design report, it was estimated from the simulation that the separation distance would be roughly 800 feet. Even though the prediction was off by approximately 264 feet, this prediction was based on assumption that the drag-inducing device would be implemented. For the test launch, the team decided not to incorporate the aerobrake system because there were other parts of the rocket that needed more attention with a higher priority. Also, the team wanted to observe how the separation would be without the drag device to reconsider whether adding the deployable flaps would be beneficial or not. After the launch, the team was surprised at how good the separation distance was even without the drag inducing equipment. Because of how successful the rocket was at separating, the team will discuss the use of a drag device in the near future (refer to section 5.1).

Figure 10. The rocket in flight prior to separation

Figure 11. Seconds after the dart had separated from the booster

(Photo Credits: Christopher Deem, Central Illinois Aerospace, 4/26/15)

2.4 Recovery Assessment

At the test launch, the recovery systems worked as intended and both the dart and the booster were retrieved in a flyable condition. All the recovery components consisting of the booster parachute, dart streamer, and the dart parachute all deployed successfully and brought the pieces down at a safe descent rate. Also, even though the wind was a little strong on the launch day, the rocket did not drift too far.

The parachute for the booster was deployed by a motor ejection charge with a with a delay. Through simulations, it was determined that if the booster and dart stayed intact during the whole flight, the apogee would be about 11.5 seconds after ignition. This time was also used to be the apogee of the booster section itself. Since the motor burn time is 1.1 seconds according to the retailer, it was decided that the motor delay would be ten seconds. It is better that the delay is an underestimate because it is better to have the parachute a little after apogee than during ascent. Also, the motor delay is a physical burn delay and cannot be made that precise anyway so the exact time was not a concern. The motor and the motor delay was handled by the teams' supervisors because the process requires precision and extra caution relating to alteration of the fuel grains. The descent speed of the booster was approximately 23 feet per second.

As for the dart, the streamer was deployed at apogee by an electronic charge triggered by the Stratologger altimeter. The streamer was designed slow the descent rate of the rocket down by not by too much that it drifts a long distance. At an altitude of 500 feet, the main parachute of the dart section was deployed in the same way as the streamer, with an electronic charge from the Stratologger. An altitude of 500 feet was arbitrarily chosen as a plausible altitude for deployment of the parachute as it allowed enough time for the parachute to open and inflate, and also made sure that the dart did not drift too far. The descent rate of the dart with the streamer was approximately 90 feet per second and with the main parachute deployed was approximately 18 feet per second.

The recovery system was safe and successful but there was one trivial point of error. At apogee when the streamer was deployed, the parachute protector that wrapped the streamer up to guard it from the black powder charge separated from the shock cord. The detached parachute protector came down on its own and landed near the dart and was easy to follow in the air and find because it was a bright red color. Because the parachute protector is just a small nylon blanket, it came down slow and was not a safety threat. After recovering the parachute protector, it was observed that it did not get undone from the knot but actually tore at the point of attachment. A decisive reason why it became detached was not determined but some conjectures were made. The parachute protector may have been worn down for previous use and was weak at the area it was knotted to the shock cord. To prevent this from happening again, a brand new parachute protector will be used at the competition launch. Another possibility was that the black powder charge was too strong and damaged the protector. To deal with this possibility, the team will be conducting black powder charge testings again to determine an ideal amount of black powder that is enough to deploy the streamer but not too much such that it damages the rocket and its components.

Figure 12. Recovering the dart portion after the test launch

2.5 Pre- and Post- Launch Procedure Assessment

Prior to the day of the launch, the team compiled a checklist of parts and tools to take, steps to assemble the rocket, and things to review before launch. Before the launch, the team followed the checklist and made sure that the rocket would safely prepared. The team made sure that two members were on each task to confirm that correct procedures were taken. Safety was the number one priority and each team member took their time on each task to make sure that it was done properly. Once all the necessary steps for assembly had been taken, the rocket was taken to the launch pad and put on the launch rail. Then, a team member used a screwdriver to turn on the altimeters and a final confirmation of the deployment altitudes were made.

The pre-flight routine went very smoothly and efficiently with no errors thanks to the checklist and careful attention of the team members. The checklist will be reviewed again and possibly modified before the competition launch. It will be brought to the competition and will be used extensively so that the team can recreate the successful pre-launch procedure.

After the rocket was launched and had descended to the ground, a couple of team members went to recover both the dart and booster section. As recommended from the experienced rocketry members, the team divided tasks to successfully and easily recover the components. Half of the team would follow the dart and the other half would follow the booster. This was important because both parts needed to be recovered and it is common for someone to lose sight of the rocket due to the distance or the sun. After both parts had landed, two people stayed at the initial position looking towards it. The remaining members then headed towards the landed parts with guidance from the members that stayed at the initial spot. It was important that some members stayed at the initial position because after moving and walking around, it is common to lose the direction of the part. Because the dart and booster did not drift too far at the test launch, it was fairly easy to successfully recover both parts. These procedures will also be used at the competition launch to ensure an easy and successful recovery of the components.

After the team members picked up the parts and returned to the working area, the team confirmed that all the component of the rocket were collected and that all of the parts were unharmed. The team listened to the beeps of the altimeters to obtain the information and then turned the altimeters off. After returning to campus, the altimeters were connected to a computer to retrieve more specific data and the graphs. The e-matches were appropriately removed from the rocket and the machine itself was secured for storage and further examination. This process will also be followed after the competition launch to retrieve the data.

Figure 13. Team members activating the altimeters prior to launch

3.) Discussion of Results

The predictions in this report are slightly different than those presented in the Preliminary Design Report. The flight values in the PDR were based on predicted dart and booster masses as well the anticipation of including an aerobrake mechanism.The predictions that were made for the PDR did not correspond with the rocket that was tested and therefore are not an accurate prediction of performance. If the actual values presented in this report are compared to the predicted values of the PDR, all of the predictions would be grossly overestimated. Once the actual section masses and the lack of an aerobrake were incorporated into the launch analysis MATLAB code that was written for PDR, the theoretical values that were outputted were much closer to the values measured during the test launch. The following comparisons will all be made with the altered code that accounts for the lack of aerobrake and increased mass of the rocket during the test launch. Unfortunately, there is not enough room in this report to include the code, but no alterations were made to it other than changing the masses for both sections and the drag coefficient of the booster.

Additionally, the data pulled from the altimeters may not be completely accurate because the data collected from the booster states that the velocity was actually decreasing during some of the motor burn which not only disagrees with the data provided by the dart's altimeter and the engines thrust profile, but also denies the laws of physics. The most likely cause for this is improper sizing of the pressure holes in the booster, causing improper exposure of the altimeter to the outside atmosphere.

3.1 Peak Altitude Comparison

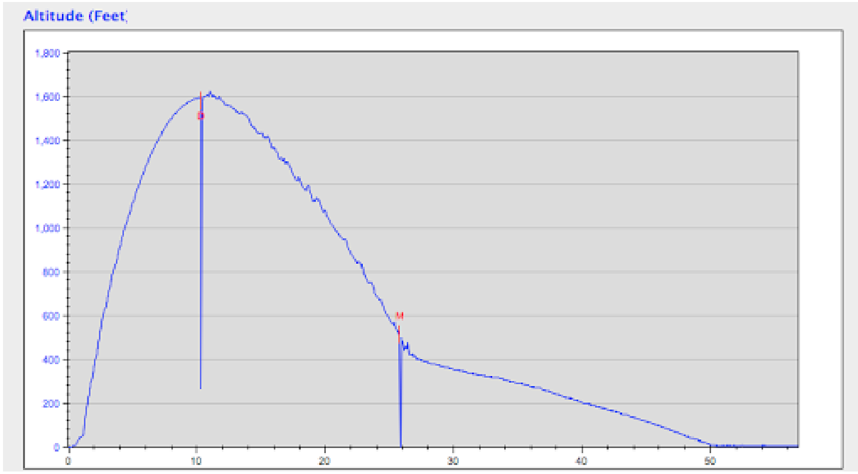

Figure 14. Actual altitude vs time graph of the dart section

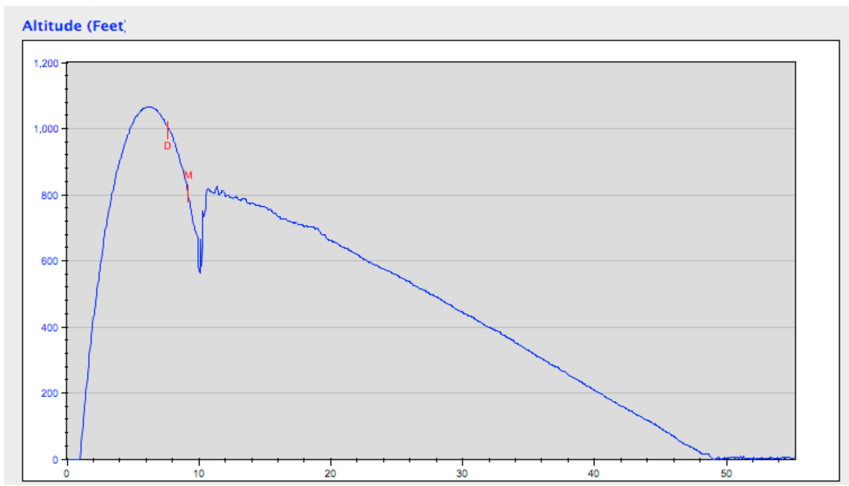

Figure 15. Actual altitude vs time graph of the booster section

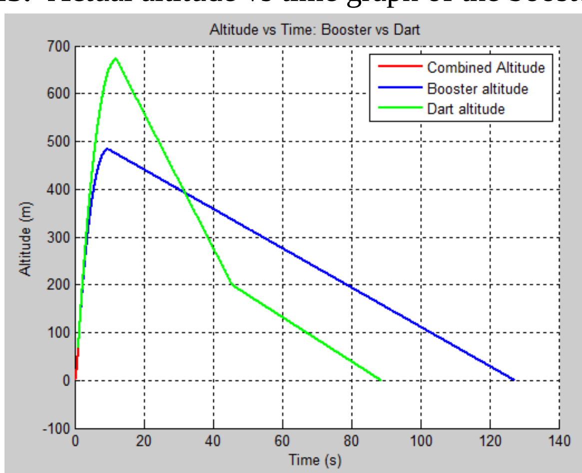

Figure 16. Predicted altitude vs. graph for both the booster and dart

The actual altitude data collected by the Stratologger CF altimeter states that the peak altitude of the dart section of the rocket was 1608 ft and the peak altitude of the booster section was 1065 ft. This corresponds to a separation of 543 feet. The massive spikes that are shown in the graphs are due to the parachute ejection charges and are not true representations of the rocket's performance.

The predicted altitudes for the dart and booster section were 2205 ft. and 1588 ft. This corresponds to a separation of 617 ft.

The most likely cause for the discrepancy between the predicted performance and the actual data is the arbitrary choice of drag coefficients for the rocket sections. Without wind tunnel testing, it is impossible to know exactly what the drag coefficient for the rocket and individual sections would be. The chosen values were merely based off of the shape of the rocket and the drag coefficient of general shapes found online. The windy conditions on the launch date may have also hindered the rocket's performance.

3.2 Peak Velocity Comparison

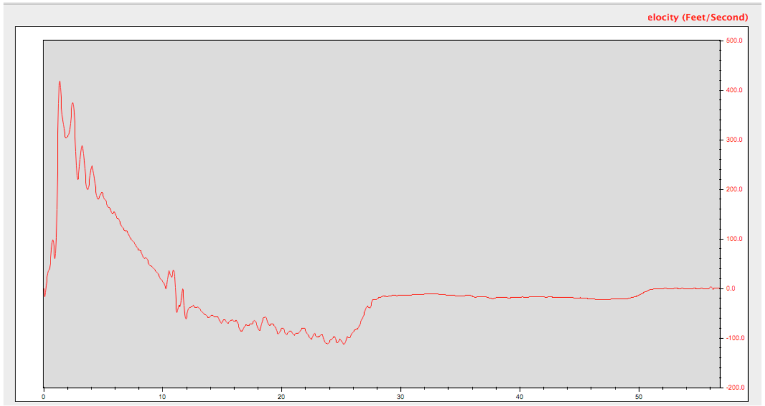

Figure 17. Measured velocity vs time graph of the dart section

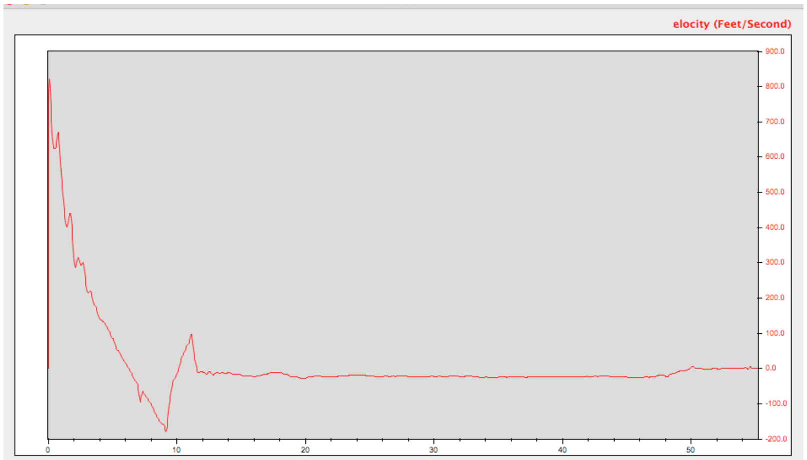

Figure 18. Measured velocity vs time graph of the booster section

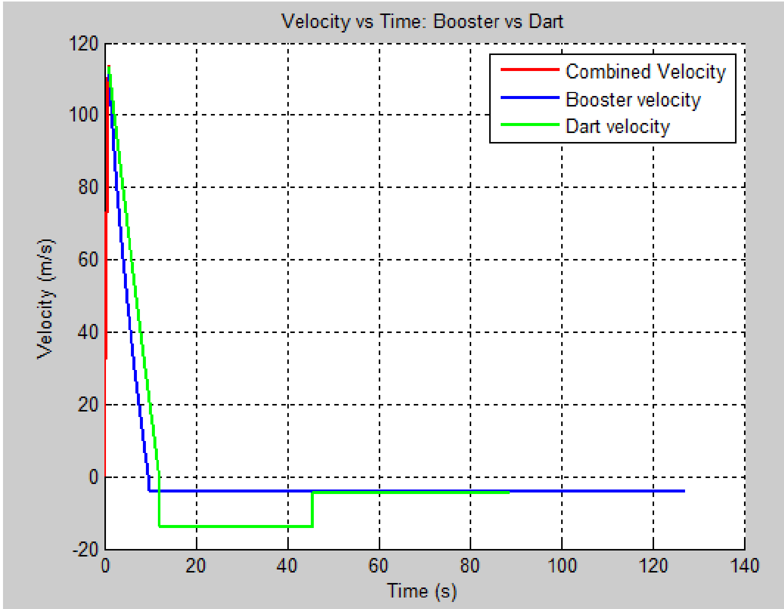

Figure 19. Predicted velocity vs. graph for both the booster and dart

The measured peak velocity for the dart section was 418 ft/s, and the maximum peak velocity for the booster section was 796 ft/s. The predicted peak velocity for both sections was 373 ft/s.

Another reason behind the belief that the booster's altimeter may have been incorrect is that, theoretically, the maximum velocities of both sections should be the same. In addition, the measured velocities conflicted while the sections were still connected which is impossible. The velocity should be the same until after separation.

Assuming that the data collected from the dart was correct, the 45 ft/s difference between the measured value and the predicted value is relatively small and likely a correct measurement. The discrepancy measured and predicted value is likely caused by the same reasons stated above in the altitude section.

The descent velocity of all the phases of the actual test launch were much higher than the predicted descent rates, and the dart's main parachute was deployed lower than predicted due to the high winds. This caused a much shorter flight time (49 seconds for the booster and 50 seconds for the dart) than the anticipated flight time stated earlier in the report.

The oscillations apparent in measured velocity graphs likely occurred because of fluctuations in the airflow through the pressure holes during the flight. These fluctuations were likely a result of the high winds during launch. An unfortunate consequence of these oscillations is that any analysis of the acceleration data is most likely inaccurate.

3.3 Peak Acceleration Comparison

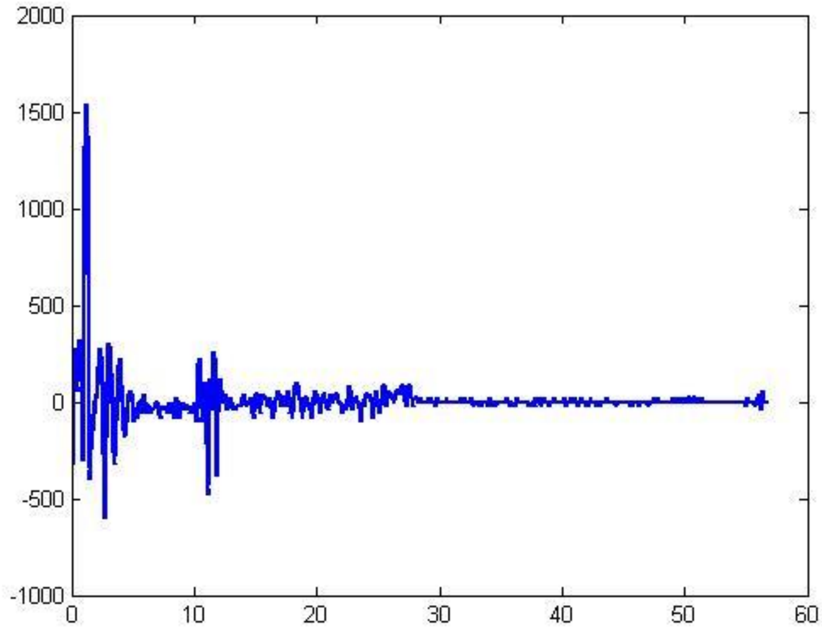

Figure 20. Acceleration vs time graph of the dart section

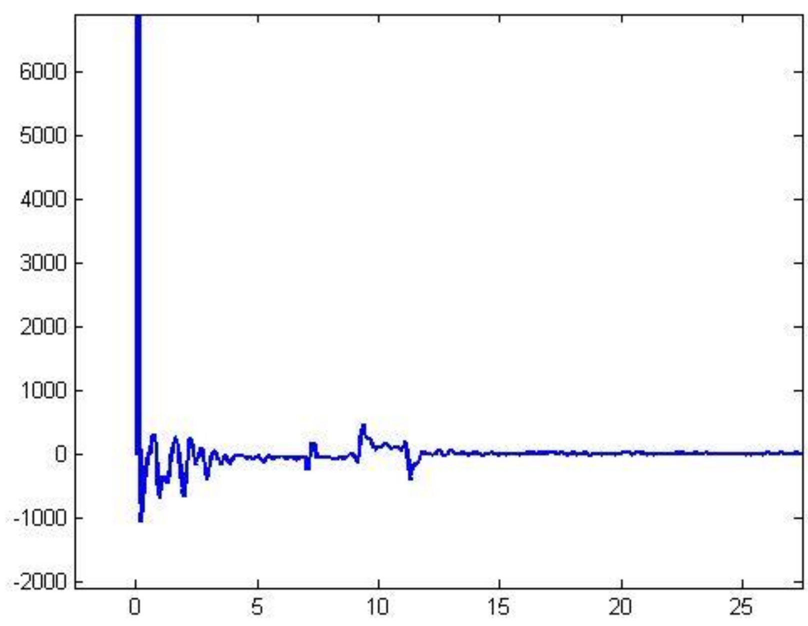

Figure 21. Acceleration vs time graph of the booster section

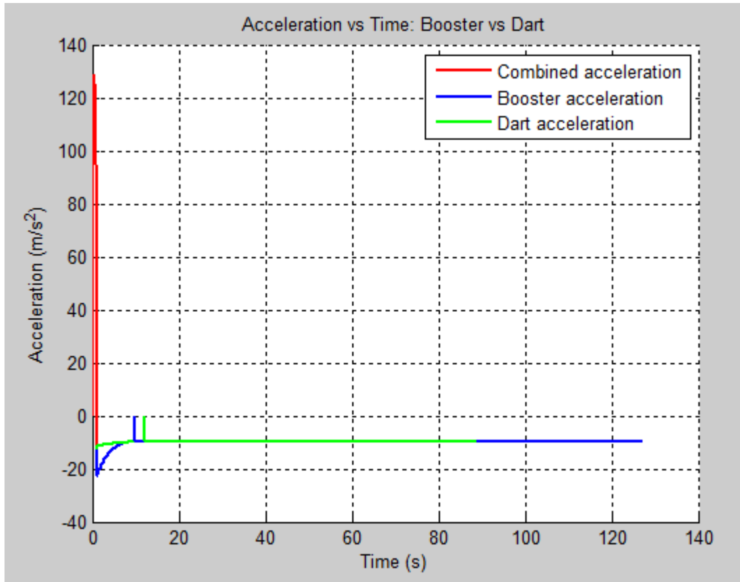

Figure 22. Predicted acceleration vs. graph for both the booster and dart

The Stratologgers that were placed in the both the booster and dart section did not produce acceleration data, so the acceleration graphs and data for the launch were created by running a MATLAB code that differentiated the collected velocity data.

As with the velocity data, there is a large disparity in the data collected by the two altimeters. The peak acceleration measured in the dart was 1540 ft/s^2 and the peak acceleration for the booster was a ridiculous 15740 ft/s^2.

Both of the graphs of measured acceleration showed the proper acceleration trends for a rocket launch, but the magnitudes departed quite heavily from the predicted value of 423 ft/s for both sections.

As with velocity, the maximum acceleration values for both the dart and booster should theoretically be the same, as there is no further acceleration after separation other than gravity. The disagreement between the two altimeters can probably be attributed to a faulty booster altimeter.

Again making the assumption that the dart altimeter was functioning properly, the large output of 1540 ft/s^2 was most probably caused by the fluctuations in measured velocity because it differed from the predicted acceleration far more than the measured velocity and altitude differed from their respective predicted values.

3.4 Video and Rotation Data

The video and rotation data loggers were not ready to be implemented in the rocket at the time of the test launch. They are not yet constructed at this point in time but will be completed in the near future.

The video and rotation data will be thoroughly ground tested and confirmed that they work correctly. After the camera has been mounted in the avionics bay and the mirror shroud has been attached on the dart externally, the camera will be turned on and sample footage will be taken. A team member will vigorously shake and move around the dart in all directions as a stress test to make sure that the camera doesn't move around during flight and continues to take downward facing footage. The SD card from the camera will be removed and the footage taken will be viewed to confirm that the camera continuously takes a clear video.

Also, when the electronic rotation data logging system is completed, it will go through a similar process. A team member will shake the dart vigorously to make sure that all the components are secured safely on the avionics bay. In addition, the dart will be tilted and rotated along each axis. Then, the data will be read off of the components and the team will determine whether the data was consistent with the movements or not.

3.5 Table of Flight Characteristics

Parameter	**Predicted**	**Actual**
Dart apogee altitude	2205 ft	1608 ft
Dart streamer descent rate	48 ft/sec	90 ft/sec
Dart parachute descent rate	15.2 ft/sec	18 ft/sec
Booster apogee altitude	1588 ft	1065 ft
Booster parachute descent rate	13.5 ft/sec	23 ft/sec
Dart maximum velocity	373 ft/sec	418 ft/sec
Booster maximum velocity	373 ft/sec	796 ft/sec
Dart maximum acceleration	423 ft/sec	1540 ft/sec^2
Booster maximum acceleration	423 ft/sec	15740 ft/sec^2
Dart flight time	127 sec	50 sec
Booster flight time	89 sec	49 sec

4.) Findings and Future Work

4.1 Key Findings

One main area of concern of the team was whether the dart and booster would separate a substantial distance on its own without the need of a drag-inducing device. Moreover, the inclusion of a drag-inducing device would add additional weight to the rocket which may be detrimental to the rocket's performance. Upon looking at the data from the altimeters, it was noticed that the dart and booster did separate a substantial distance. In addition, both parachutes deployed in a timely manner such that both the booster and the dart descended safely.

After the rocket was built, the team noticed that the rocket was slightly unbalanced along the central axis. Though given the overall weight of the rocket compared to the overall weight of the electronics, the team hypothesized that the slight imbalance shouldn't have a substantial effect on the overall performance of the rocket. It was also noticed that given the imbalance, the rocket rested on a small tilt which may have slightly affected the angle of ascent.

4.2 Planned Changes and Improvements

Over the course of the weeks leading up to the competition, Space Jam plans to improve the boosted-dart in terms of aerodynamics and in terms of the competition parameters. Namely, the gyroscopic data-collection package will be tested and installed in the avionics bay of the dart in addition to the camera. The camera will be positioned in such a way to allow vision out of the side of the dart and towards the mirror shroud.

In addition, discussion is underway as to the best way to construct and integrate the aerobrake mechanism. The team is considering whether or not adding extra weight that the mechanism would constitute if integrated is worth sacrificing extra drag-separation distance. During the test flight of boosted-dart, the separation occurred very smoothly and the drag-separation distance as the rocket stands without the mechanism is considerable. The question remains, is it worth it to risk making such dramatic structural changes to either stage of the rocket to increase drag-separation distance? This matter will be further discussed by the team members and a decision regarding the inclusion of the mechanism will be made before the competition commences. Also, the team plans to have another test launch in Minnesota prior to the actual competition date with the aerobrake system. The data retrieved at that test launch will determine whether the team will incorporate the drag separation mechanism or not.

5.) Budget

The list below indicates the parts that were purchased for the rocket, but some of these parts were purchased from local hardware stores.

Product	Quantity	Total Price ($)	Comments
Dart nosecone	2	73.46	
Dart body tube	1	64.65	
Dart parachute	1	55.95	

Dart shock cord	2	23.00	
Bulkhead dart coupler	2	5.30	
Bulkhead dart body	2	5.30	
Dart coupler tube	1	8.95	
Dart centering rings	2	9.50	
Streamer	2	20.00	
Aircraft plywood	2	112.76	
Transition piece	1	0	3D printed
Booster body tube	2	23.00	
Bulkhead booster	3	22.30	
Booster coupler tube	1	4.95	
Booster centering rings	2	17.82	
Motor mount tube	1	8.09	
Engine case	1	42.75	
Rail buttons	1	7.00	
Motor retainer	1	31.03	
Booster parachute	1	0	Previously owned by the organization
Terminal block	2	6.50	
Rotary switch	2	16.44	
Arduino Uno	1	27.95	
Keychain camera	2	33.7	
Epoxy	4	17.00 (approx.)	Purchased at hardware store because we ran out
Eye bolts (packages)	4	15.00 (approx.)	Purchased the wrong size so purchased new ones
All Thread	1	1.04	Purchased at hardware store
Zipties	5	0	Previously owned by the organization
9V battery connector	4	5.00	
PerfectFlite USB Data Transfer Kit	1	34.61	
Standard Capacity Ejection Canister	1	10.00	
Quest Q2G2 Motor Starter	1	8.55	
Stratologger CF Altimeter	2	98.92	
GY-521 breakout board	1	3.7	
Pro-Mini Shield	1	2.95	
Arduino Pro-Mini	1	9.95	
Micro SD Card	1	6.00	
Micro SD Card Adapter	1	12.95	
Shield Pins	1	3.00	
9V Battery	4	~10.00	Purchase more later on
Hitec HS-311	2	19.56	
Jumper Wires	2	7.90	
Altimeter Mounting Hardware	3	5.07	
Coupling nuts	2	5.00	Coupling nuts will help attach the eye bolts to the avionics bay
Quick links	4	10.12	Purchased at hardware store

Nuts	1 box	6.20	Needed for the eye bolts with the coupling nuts
Engine (475-I445-16A)	1	53.00	Purchased for test launch on April 26th, 2015
Total		**935.86**	