Space Grant 2014 Design Report

University of Illinois

Student SpaceGrant Systems

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Table of Contents:

Executive Summary

Student SpaceGrant Systems is an Illinois Space Grant team at the University of Illinois. Composed entirely of freshmen, the group has persevered through the difficult task of designing and building a rocket that will accurately fly to an altitude of 3,000 ft.

The group began by holding meetings, where roles were established and the design criteria was laid out. The group decided not to attempt to actively slow down the rocket to achieve the 3,000 ft ceiling, and instead chose to rely on a test flight and simulations. Another goal was to finish the rocket in time for a test launch a week before the competition. Initial concepts for measuring altitude and acceleration ranged from using a camera to pick up ground vision targets, to modifying a laser range finder for extra distance. The team decided to use and Ardunio-connected radio transmitter to relay live-feed from a GPS unit and an altimeter. After two design sessions and a meeting with members of the Central Illinois Aerospace club, the design phase was complete.

On delivery of the kit rocket, it was found that the design provided by the kit was not suitable for the design criteria. The team completed modification of the nose cone and payload design, and proceeded rapidly with the construction of the rocket. Within a single 7-hour build session, construction of the booster section was finished and the payload bay was nearly complete. After modifying the initial simulations with the updated rocket design, the team added weight to the nose cone of the rocket in order to increase stability and to bring the predicted apogee closer to 3,000 ft.

The construction of the payload was hampered by the later delivery of the Ardunio and Xbee radios, and as such was not ready for deployment on the April 19th test launch. However, the team was able to proceed using a StratoLogger altimeter for parachute deployment. At the

launch site, the team was assisted by member of the Central Illinois Aerospace club, and the launch preparations proceeded quickly. Launching on a J357 motor, the rocket reached an altitude of 1022 ft. The predicted altitude for the flight was within the range of 1000-1050 ft, so the test confirmed that the updated simulation was accurate. From there the team continued to work on the radio communication system. While not all design objectives were completed for the communication system due to extreme difficulty in configuring the radios, a breakthrough was made just before the competition, and live transmission of altitude data was achieve. The team looks forward to the Space Grant competition in Minneapolis.

Rocket Design Features

The rocket itself is a modified version of the LOC Precision Big Nuke. It is 76 inches in height and 5.54 inches in diameter. The rocket utilizes 54 millimeter motors. It is a cardboard body rocket, with a three fin set. Originally the rocket did not utilize a payload, and one was ordered. The payload is an EB-5.38, or “Electronics Bay 5.38 inches diameter”. 5.38 inch diameter was too small, so to accommodate the Electronics Bay into the 5.54 inch rocket diameter, we epoxied the bay to a coupler. This allowed us to create a proper electronics bay, with a one inch outer section to hold the bay halfway between both the booster stage, and upper stage, creating a proper dual deploy system. We are using a 2 x 2ft, or 576 sq. inches for the drogue parachute that deploys at apogee. The main parachute, which deploys at 600 ft., is a 72 inch skyangle parachute. The drogue chute is connected to an eyebolt in the motor mount, and an eyebolt to the bottom of the payload bay. The main chute, situated in the top section, is connected to an eyebolt on the top of payload, and the eyebolt in the bulkhead of the modified nose cone. The nose cone was modified to allow the addition of more weight to the rocket. It contained a plastic loop for the main parachute shock cord, but we determined the plastic was not strong enough to support the weight of the rocket. We calculated that we needed to add five pounds to the nose cone section in order to bring the predicted altitude of the rocket down to 3,000 ft. After adding the weight in the form of lead weight and epoxy, we secured a bulkhead right above the weight for added support. We then added the main bulkhead with a half inch eyebolt, connected to the main parachute. With the physical design of the rocket complete, the design of the payload section was next.

Payload Design Features

The goals of the rocket payload were to support an Arduino for radio communication with the ground, contain a StratoLogger altimeter for dual-parachute deployment, and to maintain space for the Raven altimeter provided at the launch. Given that the rocket kit selected did not contain a payload bay, one was ordered from LOC Precision. The bay itself at first measured 12 inches long, although this was cut down to 7 inches in order to make extra room for a large parachute.

The payload bay is of standard design, with bulkheads secured at either end of the payload tube using two threaded rods running. These rods support the payload sled. The sled provided by the kit was a thin sheet of balsa wood, and was too small for the electronics. This sled was replaced with two plywood sleds, connected to the centerline threaded rods using epoxy and metal fasteners. Each board provides 7 inches of working space. One board is devoted to the StratoLogger and Raven altimeter, while the other has space for the Arduino and radio transmitter.

The StratoLogger altimeter is mounted on aluminum standoffs, providing clearance over the payload sled for ease of wiring. The altimeter is powered by a 9-volt battery, secured in place with zip ties for quick replacement. Leads extend through both payload bulkheads for the dual ejection system. The StratoLogger handles the ignition of the ejection charges. Several vent holes were drilled in the outer wall of the payload bay so that the pressure within the bay remains in equilibrium with atmospheric pressure.

Student SpaceGrant System's 'homegrown' avionics payload is centered around an Arduino-based radio communication system. The setup includes: an Arduino Uno, 2 Xbee Pro 60mW antennas, a Sparkfun MPL3115A2 Pressure Sensor, and an Adafruit Ultimate GPS

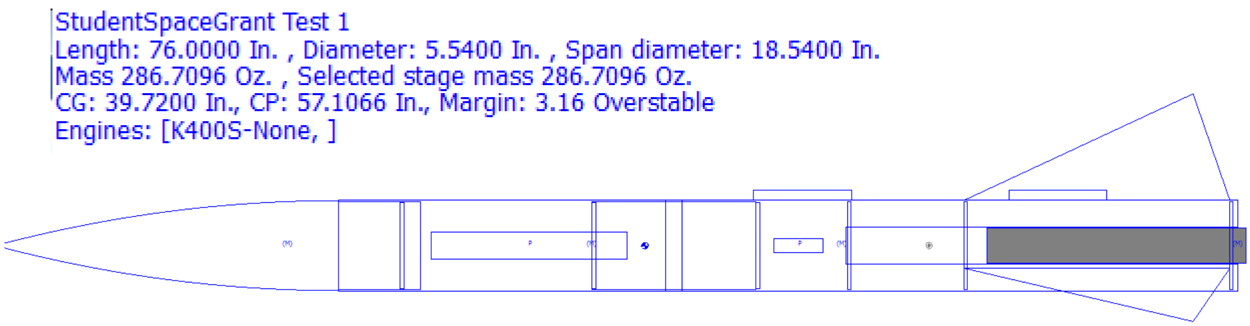
Logger shield. The design calls for one Xbee radio to be connected to a ground station laptop. When activated, the Arduino will transmit both GPS and altitude data to the ground station, where it will be plotted in real time. In the event of a radio failure or loss of communication, the Arduino will store data for recovery.

This system is unique as live-feed rocket communication is rarely attempted in amateur rocketry at this scale. With the total cost of the components coming in at just under $200, this system provides an affordable, customizable communication link. Relaying live altitude is merely the beginning, as the intention of this system from the start was to custom-build a modular rocket avionics kit. Two-way radio communication provides ground operators limited control over basic rocket functions such as parachute deployment.

Rocket Performance Overview

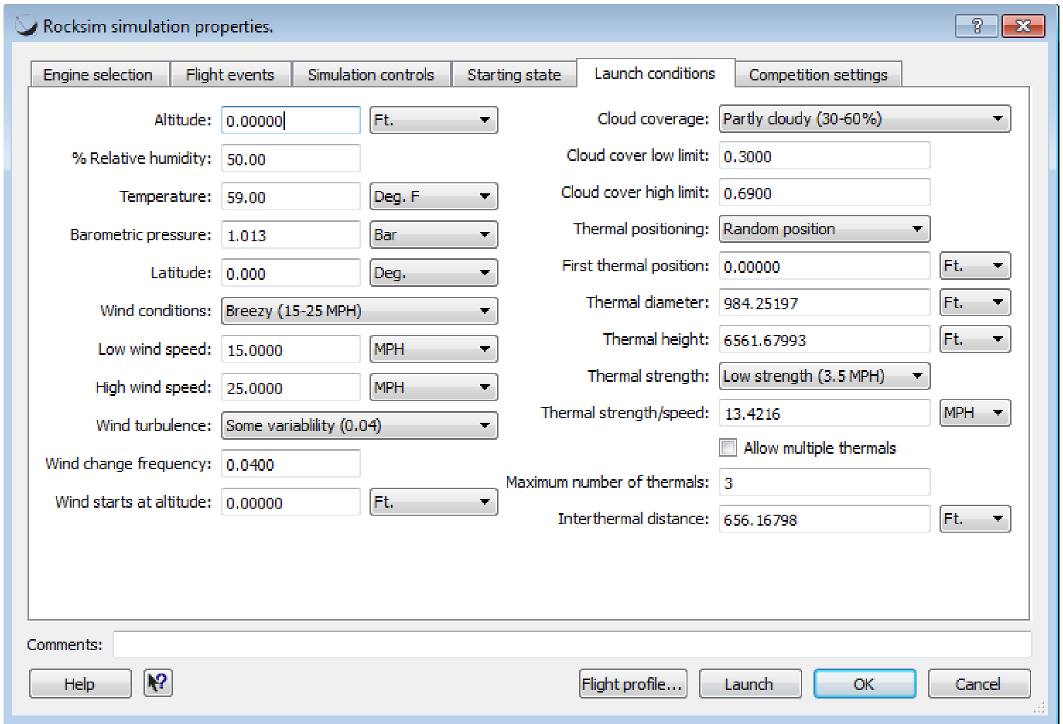
Rocksim software was used in order to gain an understanding of the rocket's flight characteristics. The initial design phase consisted of taking detailed measurements of every rocket component and creating a realistic model in Rocksim. When all of the data was entered and the rocket was reconstructed, a general overview was given, showing the center of gravity, pressure, margin of stability, total mass, length, and diameter. This information is shown with and without the motor attached.

Information with the K-400S Motor attached:



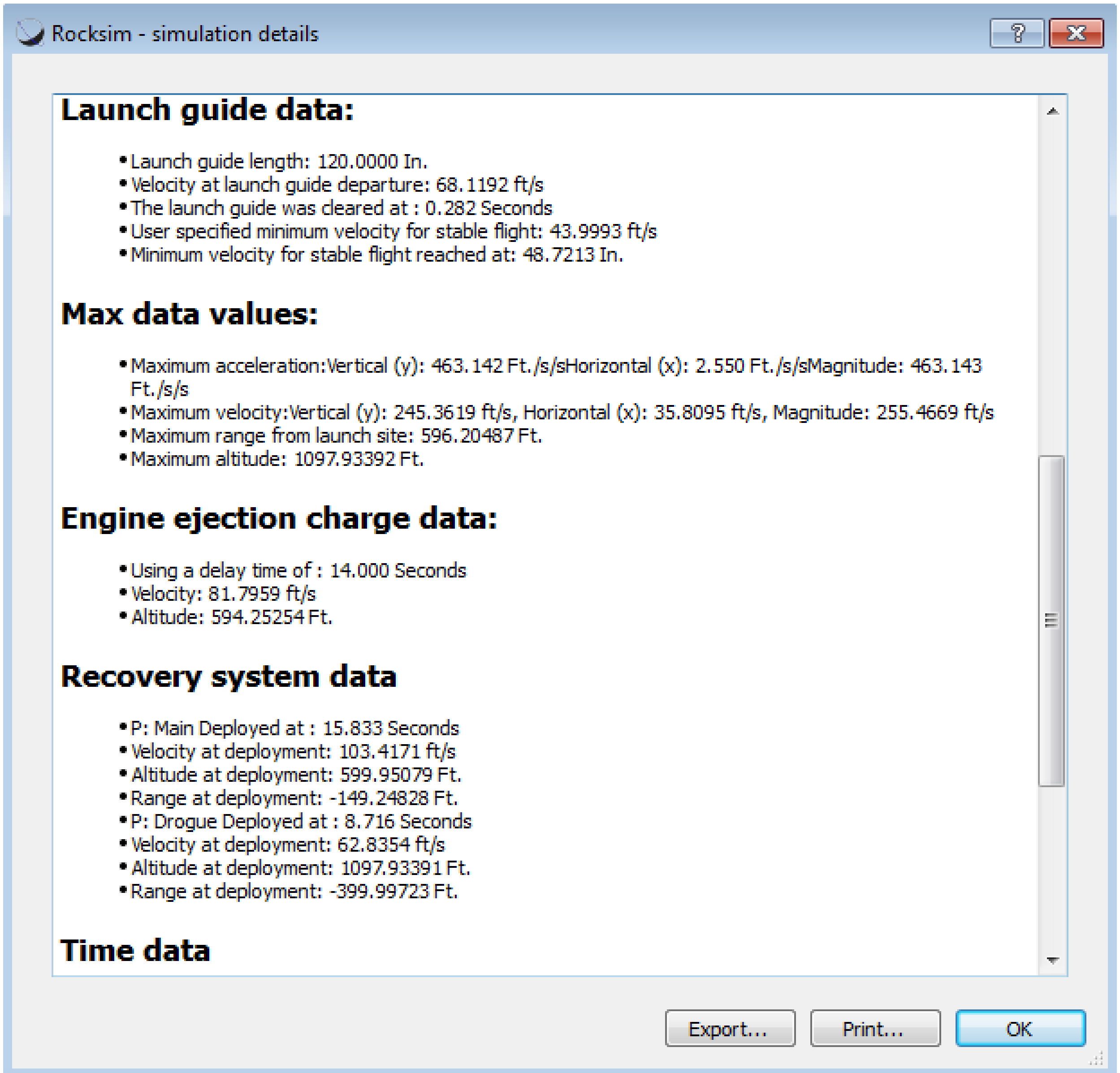
With the added weight in the nose cone, the rocket has a Margin of Stability of 3.16. As a stable rocket should have the stability margin between 1.5 and 2.0, this rocket is over stable, which makes the rocket safer. This margin also increases as the motor burns out, making the rocket even more stable at apogee.

Given this model, a number of simulations were made. These simulations account both for various weather conditions and include several launches on the test motor, a J357.



On the day of the test launch, April 19th, weather forecasts were available online using the TAF data from the Aviation Weather Center. This data is usually relayed to pilots, and provides in-depth reading on wind and weather conditions.

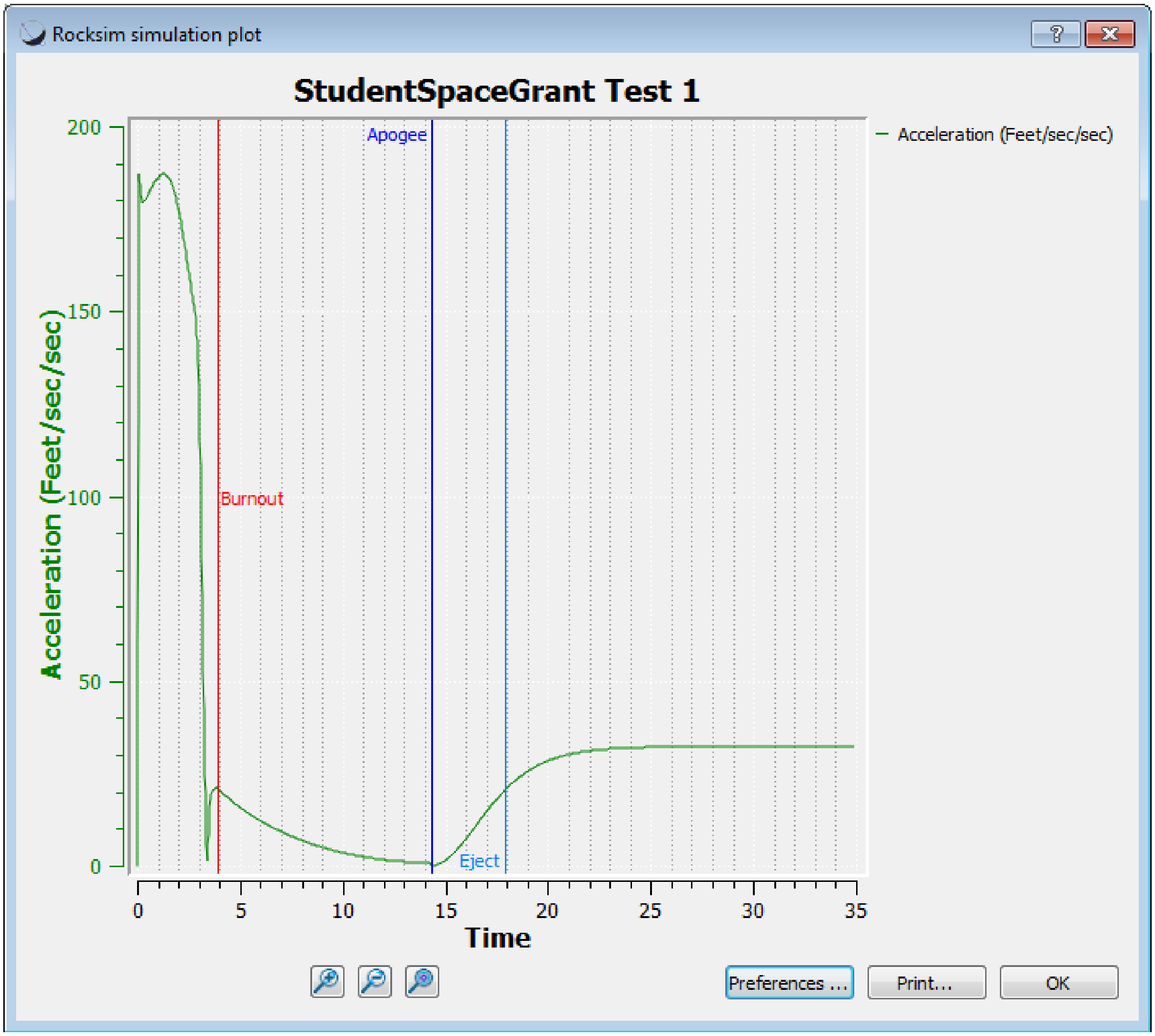
Averaging a number of simulations, the predicted altitude of the test flight was 1,099 ft. This prediction used the same rocket model as the predicted flight on the K400 engine. By comparing the accuracy of this prediction to the actual flight, it became possible to gauge the precision of the K400 simulation.



Following the test launch, the altimeter showed that the rocket reached an altitude of 1,022 feet. This result meant that the 3,000 ft. simulation would most likely be accurate. Following the test launch, several minor weight changes were made to the rocket to account for the minor difference in altitude. Before the actual space grant launch, another series of simulations were run with the weather data for the 26th of April. These results show an altitude of an average height of 2,860 feet.

	Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Feet / Sec	Max. acceleration Feet/sec/sec	Time to apogee	Velocity at deploym Feet / Sec	Altitude at deploym Feet
73	72		[K400S-14]	2861.81	437.26	482.80	14.17	90.80	2861.81
74	73		[K400S-14]	2838.27	437.20	491.90	14.11	95.85	2838.27
75	74		[K400S-14]	2786.00	437.04	484.25	13.99	106.18	2786.00
76	75		[K400S-14]	2803.98	437.09	484.25	14.03	102.75	2803.98
77	76		[K400S-14]	2836.92	437.19	484.25	14.11	96.13	2836.91
78	77		[K400S-14]	2877.99	437.31	484.25	14.21	87.14	2877.99
79	78		[K400S-14]	2773.14	437.00	487.02	13.96	108.56	2773.14
80	79		[K400S-14]	2798.72	437.08	484.25	14.02	103.77	2798.72
81	80		[K400S-14]	2912.32	437.41	484.25	14.29	78.77	2912.32
82	81		[K400S-14]	2846.16	437.21	484.25	14.13	94.19	2846.16
83	82		[K400S-14]	2834.76	437.19	484.25	14.11	96.58	2834.76

The results provided very important data including the peak acceleration, and the acceleration vs. Time graph.



Max data values:

- Maximum acceleration:Vertical (y): 484.248 Ft./s/sHorizontal (x): 5.308 Ft./s/sMagnitude: 484.249 Ft./s/s
- Maximum velocity:Vertical (y): 424.6133 ft/s, Horizontal (x): 25.6307 ft/s, Magnitude: 437.4083 ft/s
- Maximum range from launch site: 1027.71438 Ft.
- Maximum altitude: 2912.31516 Ft.

Recovery system data

- P: Main Deployed at : 38.642 Seconds
- Velocity at deployment: 105.4777 ft/s
- Altitude at deployment: 599.94046 Ft.
- Range at deployment: -534.42961 Ft.
- P: Drogue Deployed at : 14.291 Seconds
- Velocity at deployment: 78.7747 ft/s
- Altitude at deployment: 2912.31511 Ft.
- Range at deployment: -1027.71438 Ft.

The team is confident that, with the extensive simulation, the rocket should perform optimally during the competition launch.

Rocket Construction

The rocket is a modification of the LOC Precision PK-82 Big Nuke kit, which came with the airframe, motor tube, fins, centering rings, couplers, and nosecone. The avionics bay was ordered separately.

To obtain a better fit and adhesion to the epoxy, the motor tube and centering rings were sanded down with gritty sandpaper. The first centering ring was mounted 1/8 of an inch down from the top of the motor mount tube. The middle ring was positioned where the top of the fins would protrude from the fin slots. The bottom centering ring was positioned to align with the bottom of the fin slots, allowing enough room for the Aerotech motor retainer to be put on ½ of an inch from the bottom of the motor tube.

After the epoxy set, an eyebolt was mounted in the 3/8 inch hole in the top centering ring, secured using a washer and nut on each side. The eyebolt was epoxied in once it was set perpendicular to the centering ring. When the epoxy set, the shockcord was securely tied to the eyebolt.

After the epoxy on the centering rings and eyebolt had set, the entire assembly was fit into the booster section tube. It was then epoxied inside the airframe, with the bottom and middle centering rings aligned with the fin slots.

Once the centering ring/motor tube assembly was firmly set in the airframe each fin was carefully sanded down. After making a good fit, a preliminary bond between the fins and the motor tube was made with superglue, and additional epoxy was filleted along the sides of the fins. Later, small holes were drilled in the airframe to apply the epoxy to the motor tube.

The next step was to attach launch lugs to the airframe. Straight lines were measured against the booster section between two of the fins. Once the launch lugs were lined up, they were epoxied down to the frame.

When the launch lugs were firmly attached, work began on the avionics bay. The bay that was ordered was 11 inches in length, and was cut down to 8 inches to make more room for the parachutes. The coupler that came with the kit had to be similarly modified and was epoxied to the exterior of the avionics bay. A 1 inch wide section of airframe was epoxied to the middle of the payload bay in order to hold it between the upper and lower sections of the rocket. The parachutes were then tied to either end of the payload using eyebolts epoxied into the payload bulkheads. The avionics bay is attached to the main airframe by shear pins. The main parachute is tied on one side to the top bulkhead of the avionics bay and on the other side to the bulkhead on the nosecone.

The nose cone was the final piece of construction. To add weight to the top of the rocket, the bottom of the hollow nose cone was cut off to allow access to the inside. Lead weights were then epoxied inside the nosecone. The nose cone was sealed with a bulkhead and then bolted to the forward section of the airframe. The forward section is connected to the avionics bay with shear pins, as it is designed to separate to allow the main parachute to deploy.

Rocket Safety

Rocket safety for this project was focused in two specific areas: materials handling and construction safety. Given that the main rocket materials were cardboard, standard precautions were taken, such as use of safety glasses when drilling through materials. The use of epoxy, however, demanded greater awareness and the use of plastic gloves.

During deployment charge testing, ample safety precautions were taken. All members involved wore safety glasses, and stood at least 30 feet back from the charges. Connection of the charges to the ignition box was done with extreme caution.

Rocket Aesthetics

While most of effort was spent on the construction of the rocket, aesthetics were taken into account. The rocket was not painted until after the test launch, and was painted several coats in a black and silver color scheme. Three S's, which stand for Student SpaceGrant Systems, adorn the side of the rocket.

Conclusion

After successfully designing and constructing our rocket, we participated in a test launch on April 19th. For this launch we only wanted to test the rocket’s dual deployment system so the only electronic device that flew was the altimeter responsible for ejecting the two parachutes. We also wanted to check to make sure that the rocket was stable in flight. For the test flight, we did not test the second method of calculating the altitude, the method with the GPS tracker. All of the devices were turned on easily without having to take the rocket itself apart. The rocket flew 1022 ft which was 6 feet off from our predicted value of 1028 ft.

Despite reaching close to our predicted height, after the rocket reached apogee, both parachutes came out at once. The rocket did not have a successful dual deployment because it failed to deploy in stages. When the rocket reached apogee, the first charge was supposed to eject the drogue chute from the booster section and then the second charge was supposed to eject the main parachute from the forward section at 600 ft. However, during the test launch, when the rocket reached apogee both the drogue parachute and the main parachute deployed at the same time. This happened because the higher momentum of the forward section made it separate from the avionics bay deploying the main parachute prematurely. The reason why the momentum of the forward section was so high was because of the added weight to the nose cone.

To modify the rocket we changed the deployment system from a single deployment of a main chute to a dual deployment with the addition of a drogue chute. In order to modify the rocket to have dual deployment, we had to add a avionics bay that separated the forward and aft sections of the rockets. We added 6 shear pins—4 on the top and 2 on the bottom. These shear pins would keep the forward section from prematurely while the booster section deploys.

Completed Rocket

Budget

Big Nuke Rocket Kit http://shop.locprecision.com/product.sc?productId=142	$196.85
Electronics Bay for 5.38'' Rockets http://shop.locprecision.com/product.sc?productId=49&categoryId=8	$42.95
Arduino Uno – R3 https://www.sparkfun.com/products/11021	$29.95
Ultimate GPS Logger Shield http://www.adafruit.com/products/1272?gclid=CPKoufWpi70CFewRMwodlS4AMQ	$49.95
MPL3115A2 Altitude Sensor https://www.sparkfun.com/products/11084	$14.95
XBee Pro 63mW PCB Antenna – Series 2B https://www.sparkfun.com/products/10418	$40.95*2 $81.90
XBee Adapter kit http://www.adafruit.com/products/126	$10.00
USB FTDI cable http://www.adafruit.com/products/70	$20.00
XBee Explorer Regulated https://www.sparkfun.com/products/11373	$9.95
Cesaroni – P38-5G Blue Streak J357 motor http://www.apogeerockets.com/Rocket_Motors/Cesaroni_Propellant_Kits/38mm_Motors/5-Grain_Motors/Cesaroni_P38-5G_Blue_Streak_J357	$57.91

USB Cable A to B https://www.sparkfun.com/products/512	$3.95
Extra Supplies – Epoxy, bolts, plywood, wire etc	$300
Total:	$626.41