Space Grant 2015
Flight Readiness Report

UNIVERSITY OF ILLINOIS

STUDENT SPACE SYSTEMS

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Summary of Design

The Student Space Systems Boosted Dart rocket was designed to operate at the limits of amateur rocketry in order to meet competition objectives. Our design parameters were: minimize the size of the dart, minimize the weight of the booster, and develop an integrated avionics package that could fit in the dart.

We started our design with the idea that the optimum dart would be a small steel rod, due to low drag and high mass. While this is clearly not workable for the competition parameters, our thought process revolved around designing the thinnest rocket possible. The dart was designed to have the smallest diameter that could fit our avionics package, which we defined as fitting in a cylinder an inch in diameter. The smallest possible size for the dart in which standard components were made was 38mm. We decided to use fiberglass parts due to their high mass compared to cardboard. This added mass gives the dart more momentum at separation.

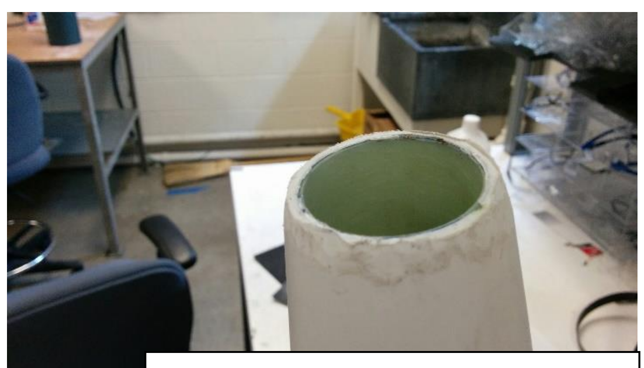
Completed SSS Rocket

The dart starts with a conical nose cone that was chosen due to the high expected velocity for the dart. Below this is a short section of 38mm tubing that holds the drogue chute. Below this is the main avionics bay, a 15 inch section of 38mm body tube, with coupler section coming out of both ends. These two couplers have epoxied bulkheads with eyebolts for the parachutes. The couplers are attached to the main frame using pass-through bolts, which allow for easy disassembly of the dart. Below the avionics bay is a long piece of tubing that makes up the main parachute bay. This section has another coupler attached to the bottom, sticking out several inches to interface with the booster. Also near the bottom are the fins, which were surface mounted using high strength epoxy.

The drogue parachute is an addition that we made for the first test flight to prevent the dart from drifting too far. We had originally planned to launch with a single main chute, although we left open the possibility for a drogue bay in the nose cone of the dart. As the launch date approached, we found that the wind predictions were very high, and we decided to add the drogue bay.

Surface Mounted Dart Fins

The purpose of having the lower bay as the main parachute bay, which is normally the drogue bay in amateur rockets, was to raise the center-of-mass of the dart. The extra length needed for the parachute raises the avionics bay, which raises the CoM and allows us to achieve stability with smaller fins.



Booster-Dart Transition

The booster was designed to be as light as possible, made out of 4 inch phenolic tubing. It has a single main parachute, deployed off motor ejection with an electronic backup. The fins are made of a thin fiberglass material that is lighter that plywood fins. They are epoxied through the booster wall onto the motor tube. The transition piece to the dart was cut from a 4 inch plastic nose cone. A section of dart body tube was epoxied to the opening in the top of the nose cone, and was secured below using a centering ring. Our design has threaded rods coming from the centering ring to the exit of the nose cone, where they hold on a plywood bulkhead. Within the space between the bulkhead and the centering ring are our booster avionics, placed on a fiberglass sled.

When we were conceptualizing the main avionics package for the dart, we knew that we needed to make the package as small as possible, to fit inside a 38mm body tube. We looked at powering our circuit using an Arduino. However, the dimensions of the Arduino are much too large for the dart. The avionics team decided to build their own microcontroller, dubbed the ‘DIY-duino”, as it is based off the main chip of an Arduino Uno. After choosing the components to make the control work, we designed the circuit in a computer program, and had a custom PCB printed out to contain the electronics. This package includes the 3-axis gyroscope, as well as an Xbee radio to communicate the data immediately back down to the ground.

The camera system, mounted in the bottom coupler of the dart, is a custom designed circuit that uses a small camera similar to those found in current cell phones. This camera is interfaced with a micro Arduino which writes the video data to a microSD card. The camera has a clear view out the bottom of the dart. However, while the dart is connected to the booster, the view of the camera is blocked. We are currently building a periscope that will redirect the view of the camera outside of the booster, which will consist of a series of mirror mounted inside and outside the booster.

In addition to these electronics we are using a Raven 3 Altimeter for parachute deployment in the dart, as well as a Stratologger for electronic backup in the booster.

Actual Budget

Rocket Parts:

Part	Number	Cost
Plastic Ogive Nosecone - Pinnacle - Diagram 4 - 3.90”	1	$21.95
38 mm Fiberglass nose cone	1	$24.49
Fiberglass 38 mm Airframe - 48” long	1	$59.27
Fiberglass 38mm Coupler (6 inches long)	3	$38.70
Fiberglass 38 mm bulkhead disk - Proline	2	$7.30
3.9” Body Tube - 34 inches	1	$11.50
54mm Motor Mount Tube	1	$8.09
98mm to 54mm centering rings	2 2-packs	$16.20
98mm plywood bulkhead	2	$8.10
G-10 Fin material (for both booster and dart) 0.093” - 8”x12”	3	$47.22
Test Motor	1	$53
Motor Casing	1	$43
Extra expenses (Epoxy, bolts, ect.)	-	$50
New Dart Main Parachute	1	$12.99
Total Cost		$401.81

Electronics:

Part	Number	Cost
Altimeter/Barometer	1	$14.95
XBee Pro	2	$37.95
XBee Sockets	2	$1.00
XBee usb connector	1	$24.95

IMU	1	$39.95
PCB Board	1	Free
XBee Sockets	4	$1.00
7670 CMOS Camera	1	$13.46
16GB SDHC Card w/ Adapter	1	$7.95
Arduino Pro Mino 328	1	$9.95
FTDI Cable	1	$20.95
DIY-Duino Parts (ATmega328 chip, LEDs, Resistors, Capacitors, Voltage regulators, wires and solder)		$20
Total Cost	-	$234.03

Travel Expenses:

Expense	Cost
Car/Gas	$525
Hotel Stay	$200
Total Cost	$725

Total Expenses

Expense	Cost
Rocket Parts	$401.81
Electronics	$234.03
Travel Expenses	$725
Total Cost	$1360.84

The Planned Budget summited in the last report came to a total of $1453, so in the end we are $100 under budget. Most of this saving comes from a much cheaper than expected camera. We originally planned on using a FPGA chip to run the camera, which would have been much more expensive. The switch to the Arduino mini saves us a considerable amount.

There are very few extra expenses for the construction of the rocket, the main one being the purchase of a new main parachute for the dart. The old parachute that we were planning on reusing from a previous year was a rather thick parachute that had trouble fitting inside the dart. We ordered a new thin-mill nylon parachute that should be an easier fit.

Please note that the travel costs, while complete, may not represent the total expense incurred to members of the team. Due to the launch occurring after Finals at UIUC, many of our members were not sure if they would be available to attend the competition before we had to arrange for hotels. Therefore, several team members (as well as non-member spectators) will be driving up separately and will pay for their own accommodations, while the majority of the team will travel with the University group.

Construction of the Rocket

Booster and Interstage:

We used a 98mm phenolic tube as the main structural component for the booster stage. Using a 54mm motor tube and centering rings, we secured the motor in the booster stage. Then, we cut slots at 120 degree intervals for the stabilizing fins. Once the fins were cut to the appropriate size, we mounted them on the booster stage. We elected to use translucent fiberglass fins on the booster. Once the motor tube was secured we mounted a bulkhead with a secured eyebolt for the parachute shock cord.

We used a nose cone designed for a 98mm tube as our interstage. The tip of the nose cone was removed to where we could insert a 38mm fiberglass tube to hold the dart. We cut a centering ring to hold the fiberglass tube inside the interstage and drilled two holes for the threaded metal rails. We used a fiberglass disk to cover the exposed tube after dart separation. Then we cut the bulkhead for the bottom of the interstage and secured it with the previously inserted metal guide rails after inserting the booster electronics package. The electronics were secured to a fiberglass sled with holes to guide onto the metal guide rails. The bulkhead also had an eye bolt mount for parachute shock cord. Upon completion of the booster we drilled interface hole so we could interact with the onboard electronics payload.

Booster Nose Cone – Threaded Rods

Dart:

The dart was constructed out of 38mm fiberglass tubes cut into three sections for a dual deploy parachute system. We cut and epoxied three fiberglass disks with mounted eye bolts and holes to run ejection charge wires to fiberglass couplers to act as bulkheads. We constructed a fiberglass sled for the dart electronics payload and inserted it into the middle section of the dart. Once everything was lined up, we drilled holes for screws to secure the bulkheads in place as well as keep the electronics payload properly aligned inside of the middle section of the dart. We drilled a small hole to interface with the dart switch. The nose cone was secured to the top section of the dart. Once everything was secured in place we drilled holes for the shear pins on the middle couplers. Finally we added the ejection charges and secured the main parachute in the lower section and the drogue in the upper section of the tied the shock cords to the eye bolts attached to the bulkheads.

Dart Body Tube – Avionics Bay

Safety:

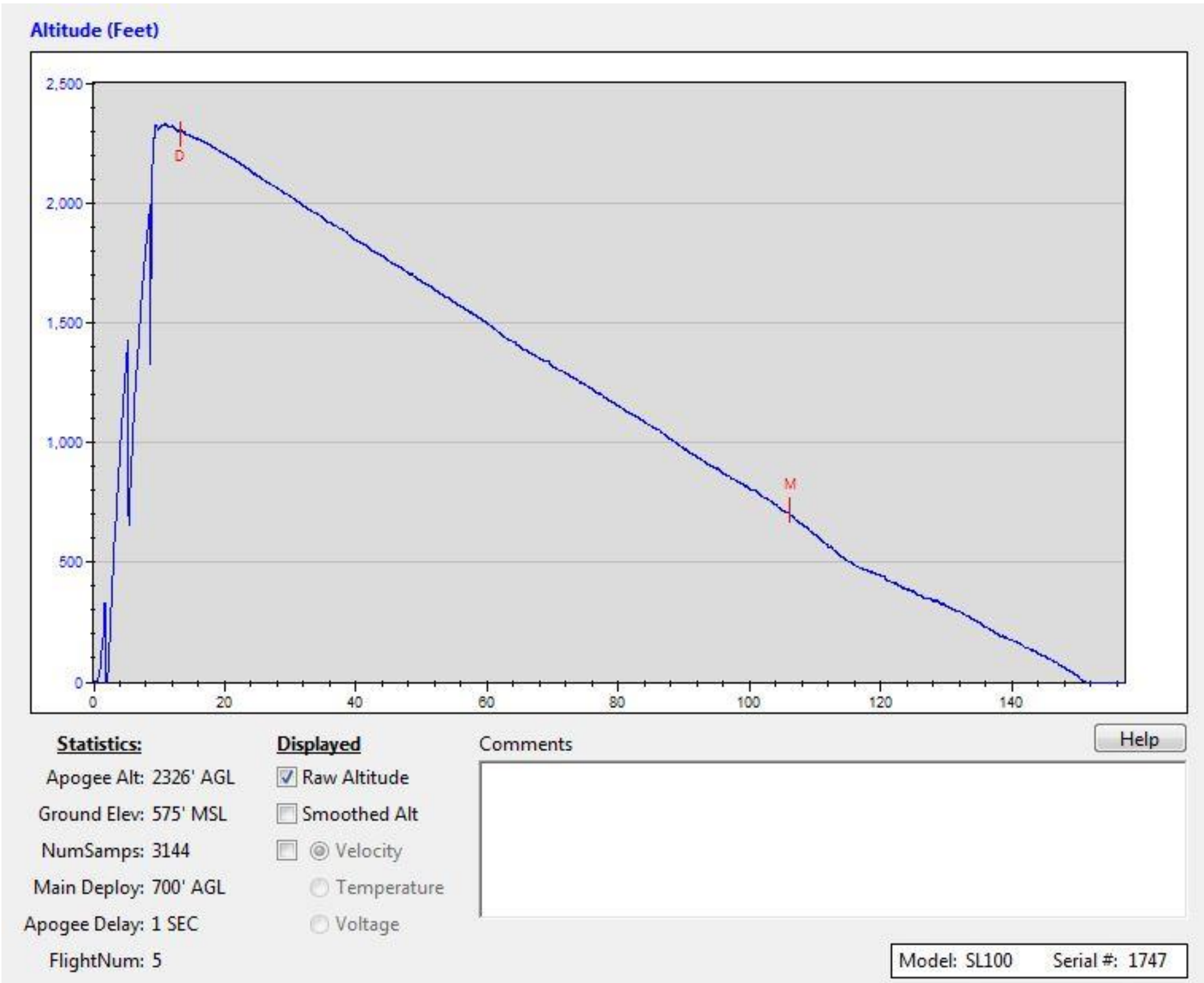
Whenever we were cutting or sanding any component on the rocket, we took care to use dust masks and safety glasses, as well as gloves when required. Each member on the team had to go through training on the tools we used, such as dremels and epoxy.

When we were testing ejection charges, we were careful to stand at least 20 feet away from the rocket.

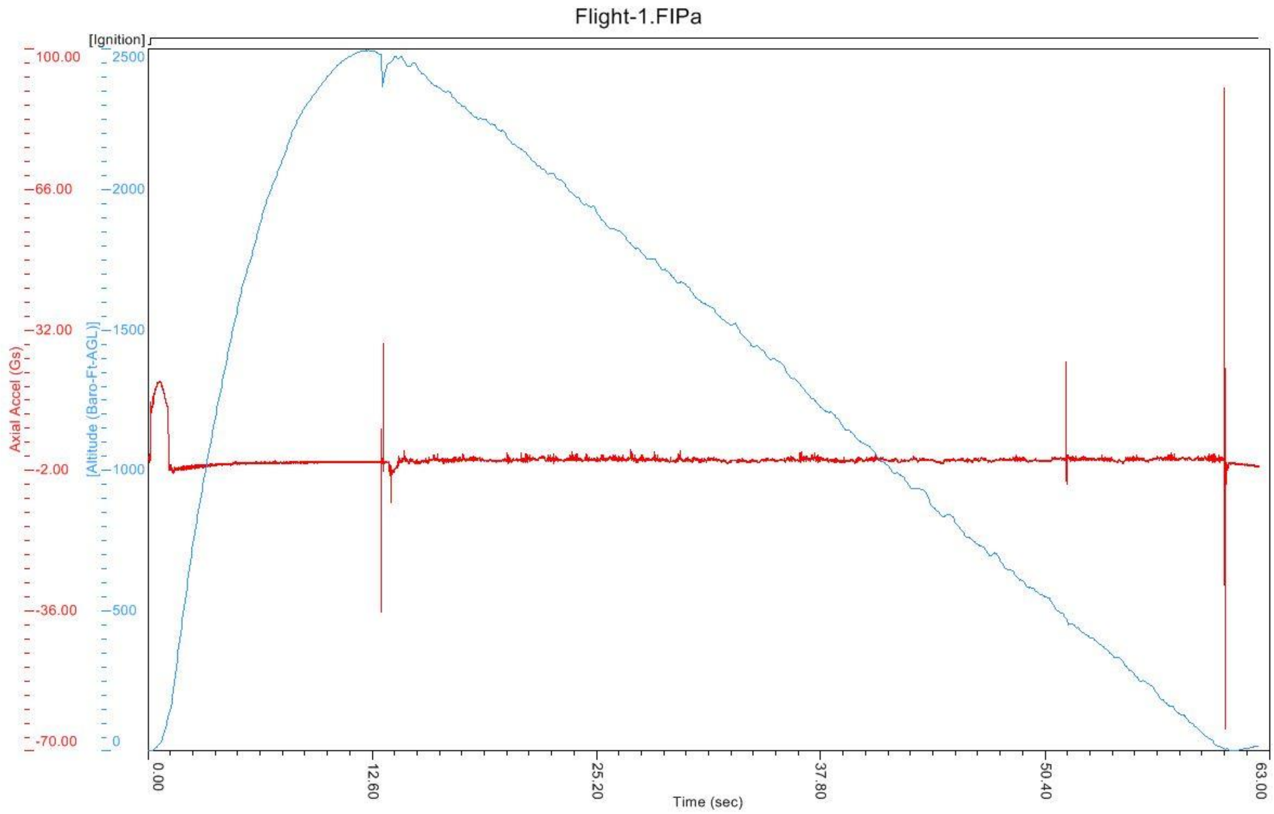
During the launch, we followed the standard Tripoli safety guidelines under the supervision of the Central Illinois Aerospace rocketry club.

Test Flight Report

Booster Performance:



Dart Performance:



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Average PreLaunch Altitude (ft)          = Val: 548.00
Average PreLaunch Axial (Gs)             = Val: 1.06
Average PreLaunch Axial Offset           = Val: 1.06
Axial Accel (Gs)                         = Min: -2.73      Max: 19.58
Baro (Atm)                               = Min: 0.8948     Max: 0.9803
Current Draw (A)                         = Min: 0.25       Max: 0.31
Flight Count                             = Val: 6.00
Lateral Accel (Gs)                       = Min: -1.96      Max: 1.38
Motor Ignition Time (sec)                = Val: 0.153
Temperature (F)                          = Min: 75.74      Max: 76.54
Time (sec)                               = Min: 0.000      Max: 12.730
Velocity (Accel-Ft/Sec)                  = Min: 1          Max: 499
Volts Battery (V)                        = Min: 8.32       Max: 8.40
Volts Pyro 3rd (V)                       = Min: 0.02       Max: 0.04
Volts Pyro 4th (V)                       = Min: 0.02       Max: 0.04
Volts Pyro Apogee (V)                    = Min: 8.34       Max: 8.40
Volts Pyro Main (V)                      = Min: 8.36       Max: 8.40
[Altitude (Accel-Ft)]                    = Min: 0          Max: 2380
[Altitude (Baro-Ft-AGL)]                 = Min: 1          Max: 2497
[Altitude (Baro-Ft-ASL)]                 = Min: 549        Max: 3045
[Velocity (Accel-Ft/Sec)]                = Min: -46        Max: 496
[Velocity (Accel-MPH)]                   = Min: -32        Max: 338
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Dart Apogee	2497 ft
Booster Apogee	2326 ft
Burn Time	1.2 s
Time to apogee (dart)	12 s
Time to apogee (booster)	10 s
Maximum Velocity(combined)	499 ft/s

Separation Performance:

The dart and the booster did separate, as evidenced by the fact that the dart had an apogee of 2497ft while the booster had an apogee of 2326 ft. However, the separation occurred only a few hundred feet below the booster's apogee, leading to a difference in apogees of only 171ft. Ideally, separation would occur shortly after motor burnout.

Recovery System Performance:

The booster's recovery system performed adequately. The single parachute was deployed by motor charge ejection shortly after apogee. It successfully slowed the descent of the booster to about 16ft/s (estimated from graph of booster's altitude), allowing the booster to land safely.

The dart's recovery system did not perform as expected. The drogue chute was deployed electronically shortly after apogee. However, the main parachute failed to deploy. A post-flight inspection revealed that a shear pin had not been broken and the main parachute's charge may have leaked. With only the drogue chute deployed, the dart hit the ground at about 45ft/s (estimated from graph of booster's altitude), experiencing an acceleration of roughly 90 Gs on impact. However, the dart was not damaged despite the speed at which it landed.

Pre- & Post-Launch Procedure Assessment:

Our preflight procedure consisted of checking electronics for damage or broken connections, folding and packing the parachutes, hooking up the ejection charge, and sealing the rocket. After this, a single member would take the rocket out into the field and activate the electronic ejection packages to confirm settings and continuity. We would then place the rocket on the launch pad and follow the standard procedure for launch.

Postflight procedure called for several members to stay in one place after the rockets landed in order to guide the recovery team. The recovery team would make their way to the rocket sections, check the rocket for damage, gather up the parachutes and return to the launch site. After returning, altitudes would be obtained from the altimeters.

These procedures worked according on the launch day, however, our booster section drifted very far, and we had to break up into search teams in order to find it.

We may attempt to have more of the rocket assembled and the parachutes packed before showing up at the launch, or at the very least run practice rounds the night before the launch to ensure quick and easy setup at the launch. We managed to launch after three hours of setup, most of which was spent repairing the shock cords after ejection charge tests, as well as setting up the altimeters. We believe we will be ready to launch at competition within one hour of arriving at the launch site.

Discussion of Results

Value	Predicted	Actual
Apogee (Dart)	3,900 ft	2,497 ft
Apogee (Booster)	1,250 ft	2,326 ft
Max Velocity	475 ft/s	499 ft/s
Average Acceleration	23 ft/s^2	20 ft/s^2

Our predicted values for the dart and booster were 3900ft and 1500ft, respectively. It is obvious that we did not achieve either of these for the test flight, mainly due to their failure to separate immediately. However, the rough height of 2400ft for the combined rocket gives us a very good picture of how the rocket will fly given that it separates during the competition flight. If we look from the perspective of the dart, having a large, extra drag component like the booster attached would lead to a significant reduction in altitude, most likely somewhere right between the two predicted altitudes, due to the two sections having similar weights. This reduced altitude would be in the area of 2000-3000ft, which is where the combined rocket ended up. We view this test flight as a rough confirmation of our simulations.

This view is supported by the similarities in maximum velocity and accelerations to their predicted counterparts. The predicted average acceleration during launch was roughly 23 Gs, and the actual value was 20 Gs. This discrepancy may be accounted for through extra mass in the dart, which required lengthened body tubes to accommodate the parachute. In addition, the maximum velocity of the combined rocket at 499ft/s actually exceeded the predicted maximum velocity of 475ft/s. This result is surprising, given the actual acceleration was lower than predicted. This discrepancy can be attributed to inconsistencies in OpenRocket simulations of the drag coefficient at velocities where compressible effects start to occur.

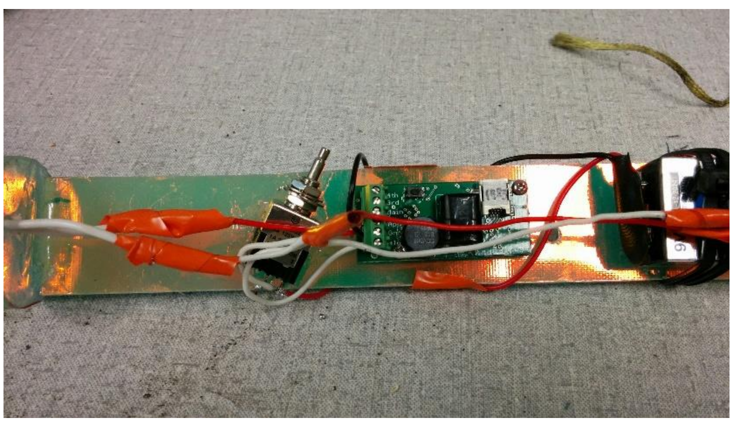
For the test flight, we did not have the 3-axis rotation logging avionics, nor the camera, so we are unable to discuss those results at this time.

Planned Changes and Improvements

While the test flight was largely successful, several issues arose that need to be addressed. The main issues involve the separation of the dart and the booster and the deployment of the darts main chute. Several design modifications need to be made in order to resolve these issues and achieve the desired performance. In addition to these changes, the rocket's avionics need to be updated in order to meet their designed capabilities.

The first of the design modifications involves the staging mechanism of the booster and dart. Currently, the design consists of an outer tube in the booster nose cone that fits over a slightly smaller coupler that extends from the back of the dart. The problem with this design is that in order for it to minimize friction, there must be a gap between the inner and outer tubes. However, it is possible because of this gap for the dart to be shifted at an angle during flight, which causes the tubes to become jammed together. When this occurs, the sections do not separate properly. Our design modification in order to correct this involves replacing the tube design with conical staging. We are currently considering methods to give this section a conical profile, which will prevent the dart from jamming in the booster section. We believe this modification may work with the addition of acrylic strips mounted to the dart coupler which tapper down towards the bottom.

The next modification resolves the parachute issue. In order to properly slow the dart to a speed that would minimize the risk of damage, we calculated that we would need a 30 inch diameter parachute. The problem is parachute needs to be stored in a small enough bundle so that it can fit into a 38 mm tube. The issue was compounded by the need to wrap the bundled parachute with a protective heat shroud in order to prevent any damage from the ejection charges. This proved to be such a challenge that if it were not for one our member's considerable experience rolling up sleeping bags, we would not have been able to properly pack and prep the parachute for launch at all. Unsurprisingly, the parachute was unable to deploy, although previous ejection charge tests had been successful. While the culprit behind the failed deployment was an intact shear pin, we hypothesize that shear pin's failure to break is largely due to the amount of friction in the design, This results in a large amount of the ejection charge's energy being wasted trying to move the chute, weakening its effect enough that it was unable to break the shear pin. In order to resolve this issue, we are implementing two changes. First, the current parachute is being replaced by one of a microfilm design. This drastically reduces the thickness of the chute without reducing performance. Therefore, the parachute will have a reduced footprint and should more easily fit in the rocket. In addition, we will be replacing the parachute protector with heat wadding. This will also further reduce the footprint of the system and, combined with the previous modification, will minimize the impact of friction during the ejection of the parachute, helping to ensure a successful deployment.



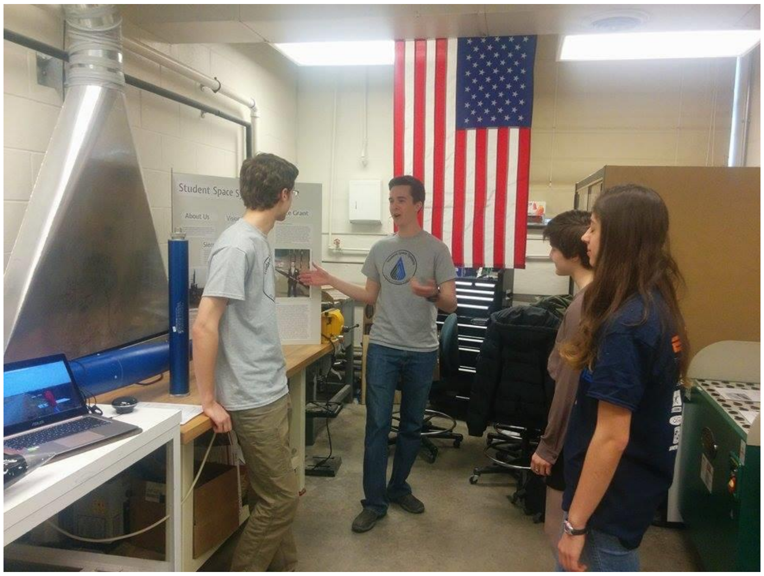
Temporary Electronics Bay - Dart

The final modification is an update of the avionics package. In order to prioritize the construction of the rocket's structure as well as to give time to further develop the complete avionics package, the test flight only contained basic electronics that were deemed essential for a successful flight (such as the altimeters that controlled the deployment of the parachutes and recorded altitude for comparison to predicted models). This change is neither labor intensive or invasive, as the overall structure of the rocket will be unaffected. The avionics sleds will be updated to include the full avionics package with all of the components for tracking the rocket's three dimensional orientation as well as providing real time telemetry and properly record video footage of the flight. The sleds will then be installed into the same avionics bays as their predecessors for future flights, completing the modification process of the rocket.

Education Outreach

Student Space Systems conducted its education outreach through UIUC's EOH, or Engineering Open House. This event draws hundreds of school children and spectators from the local community, as well as prospective students. Student Space Systems had an exhibit where members of the Space Grant team discussed this year's competition challenge with many members of the community over the course of the event, which lasted two days. Our goal was to make the community aware of the NASA Space Grant Consortium and bring attention the skills we learn while participating in the competition.

EOH took place March 13th and 14th of 2015. We were sponsored by the University of Illinois to exhibit our projects to the community in order to create an atmosphere of innovation and creativity.



Launch Photos