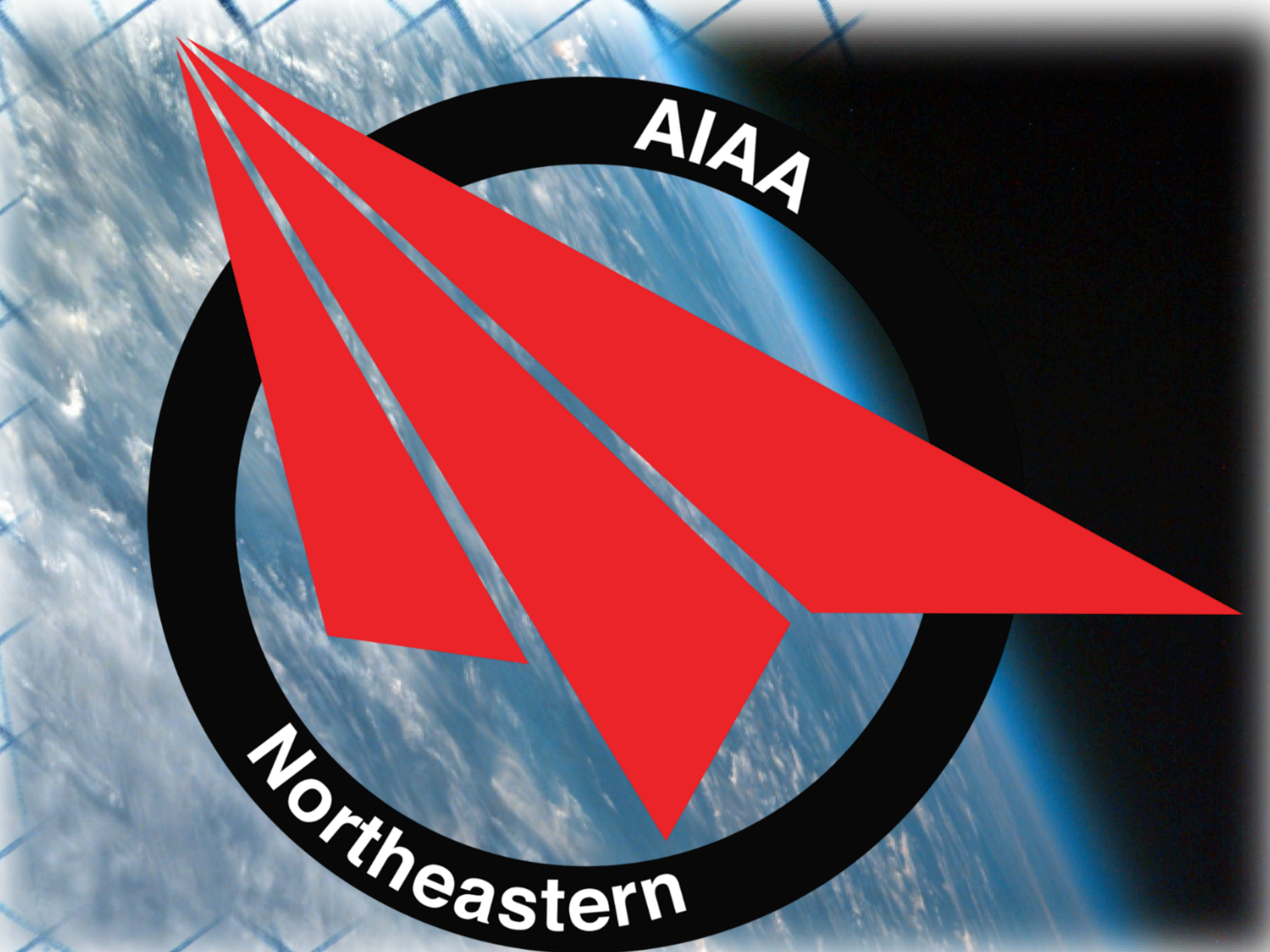
# NUSPACE

## Scientific Payloads: Atmospheric-Measurement and Controlled-Descent Experiment

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2015-2016
NASA Student Launch
Post-Launch Assessment Review

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# 1. LAUNCH VEHICLE

## 1.1 Launch Vehicle Summary

Northeastern University's launch vehicle, named Thrust Capacitor, stood 116 inches tall with a diameter of 7.5 inches. A diagram can be seen below in Figure 1.1.1.

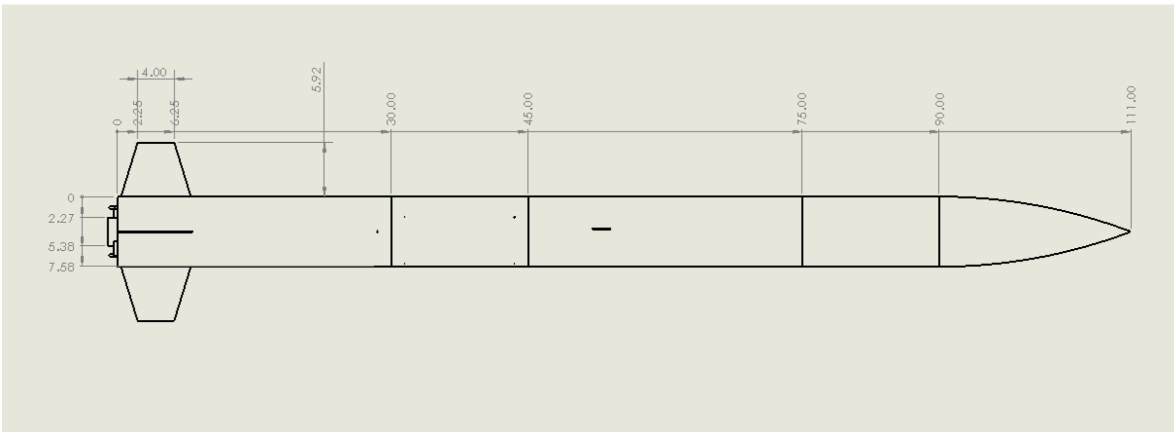


**Figure 1.1.1. Launch Vehicle schematic.**

Northeastern University's launch vehicle was built of a PVC ogive nose cone, Blue Tube airframe and couplers, and garolite fins. Four trapezoidal fins are equally spaced at the base of the launch vehicle. There are two carbon fiber tubes on either side of the motor on the bottom of the launch vehicle; these tubes each housed a drogue parachute. The tubes were sealed at the bottom with a wooden bulkhead shear pinned in place. On the upper end of the tube was a blast cap and terminal block wired to an electronics bay above. These drogue parachutes were intended to deploy at apogee, effectively flipping the launch vehicle upside down to simplify the deployment of the CDLE payload. Above the motor section electronics bay is the main parachute section, secured to the piston section above and the motor section below. The main parachute was to be deployed at 500 feet. A second electronics bay controlled the piston, which was responsible for ejecting the CDLE and ATMOS payload. A black powder charge was to drive this piston, which would then break shear pins holding in the payload. The piston was made up of a coupler tube and wooden bulkheads, with four aluminum rods protruding. These rods reached past the arms of the CDLE to make contact with the surface of the CDLE body. The payload was to be ejected 1 second after apogee, with a backup set to eject it 2 seconds after apogee. The nose cone section was also intended to be ejected at apogee and would have deployed a drogue parachute. The nose cone section had its own independent electronics bay towards the tip of the nose cone, which was set to deploy a main parachute at 500 feet. The nose cone main parachute is contained within a section of 5.5 inch diameter Blue Tube secured beneath the electronics bay.

2-56 nylon shear screws were used to fasten the launch vehicle together at points where it was intended to separate. All sections of the launch vehicle not designed to separate were secured with 8-32 steel set screws. Black powder was used as an energetic for all separations and recovery system deployments. Kevlar shock cord was used to secure all parachutes to their respective sections. The Kevlar shock cord was tied to steel forged eyebolts screwed into wooden bulkheads, secured using epoxy. Nomex thermal wadding was used to protect the parachutes from the black powder charges. The manufacturer of all the parachutes used in our launch vehicle is Fruity Chutes with drag coefficients ranging from 1.6 to 2.2.

The motor used in the launch vehicle was a 75 mm (2.95 in) Cesaroni Technology reloadable motor, the L1115. This motor was 621 mm (24.45 in) in length. Loaded, the motor weighed 4404 g. It had a maximum thrust of 1713.25 N (385.38 lb) off the launch pad. The average thrust rating for the motor was 1119.00 N (251.78 lb). The total burnout time was 4.48 s. The plot below in figure 1.1.2 is the thrust curve for the L1115 motor.

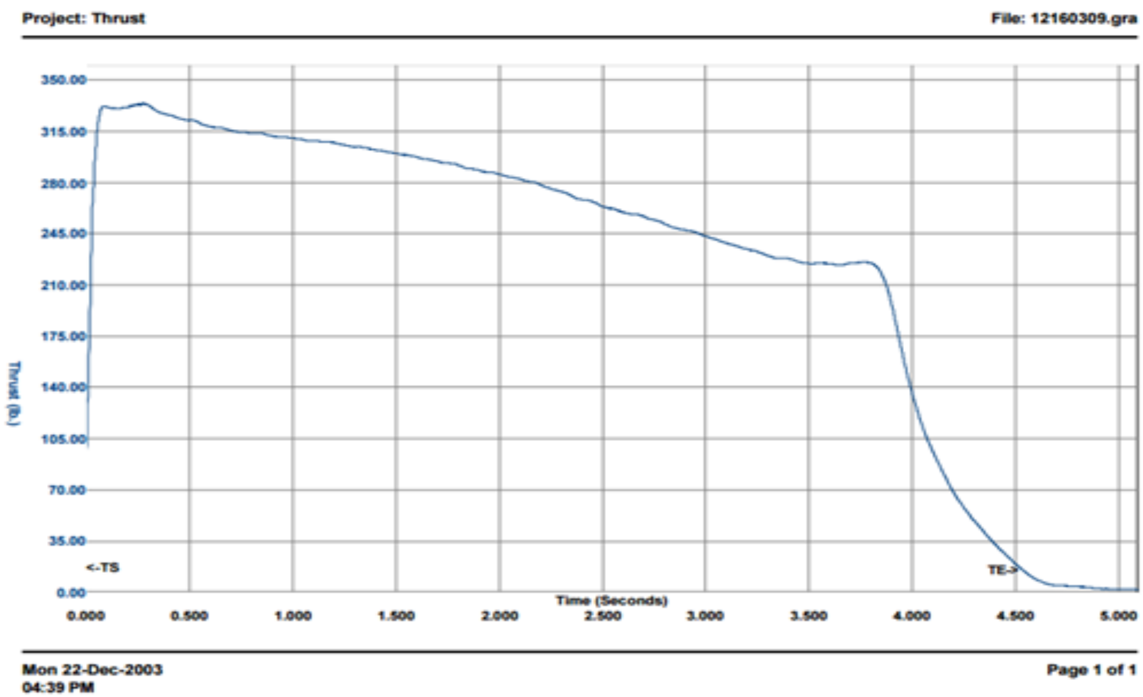


**Figure 1.1.2. Thrust Plot.**

The task set before us was to house two scientific or engineering payloads in the launch vehicle ascending to 5280 feet. One of those two payloads was the Controlled Descent and Landing Experiment, henceforth denoted as the CDLE. This experiment's intent was to explore the possibility of fully controlled descent and landing, an idea that Northeastern's chapter of the AIAA has been intrigued with since our founding three years ago. The CDLE, for the purposes of the Student Launch competition, is a custom collapsible quadcopter capable of being stored within a 7.5 inch diameter launch vehicle and deployed at high altitudes. In full implementation, the CDLE is capable of being programmed to land at a specified GPS location within the boundaries of Bragg Farms in Toney, Alabama. The CDLE would have been particularly useful for this competition, as its goal is to ensure the safe return and stable orientation of our second payload, ATMOS.

The Atmospheric and Topographic Measurement Optics Suite, the aforementioned ATMOS, was the second payload contained within the launch vehicle. ATMOS fulfilled the requirements of the atmospheric measurement payload proposed by NASA, measuring humidity, pressure, temperature, solar irradiance, and ultraviolet radiation. In addition, a near infrared spectrum camera was included to analyze the vegetation present in the field of view and a long-wave infrared spectrum camera was to conduct thermal imaging of the surface. The data obtained would be used to calculate the absorption coefficient of the low atmosphere.

### 1.2 Launch Vehicle Results

The altitude reached by our launch vehicle was especially difficult to achieve due to the destructive nature of our flight. We were able to recover all but one set of data from the six flight computers by downloading the saved data to a computer. The disassembly in flight caused large pressure fluctuations in the interior bays of the launch vehicle; this caused the altimeters to read drastically different results. Based off of the pressure spikes in the altimeter data reports, the launch vehicle broke up four seconds into the flight, at an altitude of 2094 feet. Both of the nosecone altimeters survived the breakup and managed to maintain battery power; they continued to record data as they descended under the drogue chute, which managed to deploy. The plot below is an overlay of the data from the five surviving altimeters.

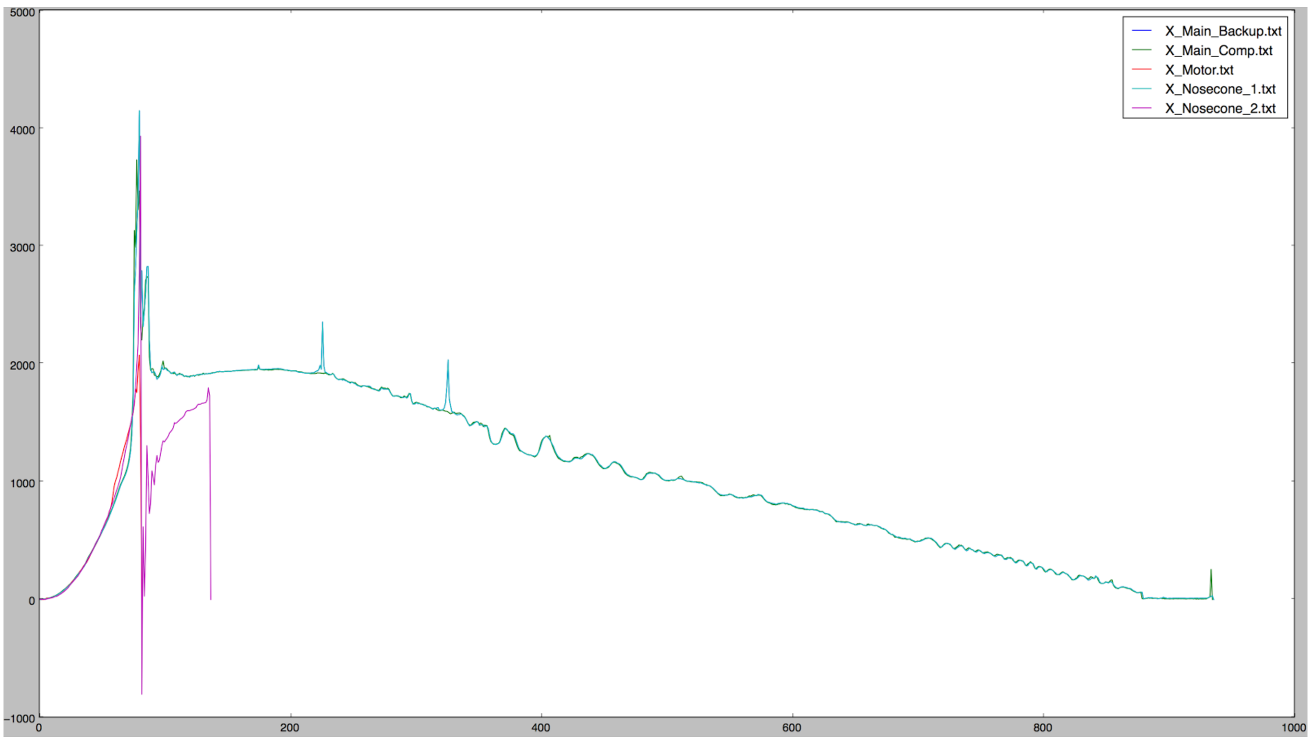


**Figure 1.2.1. Overlay of altitude data of the five surviving altimeters.**

The altitude data shows the pressure fluctuations of the disassembly, where both the positive and negative pressure spikes are visible. The nosecone altimeters (green and blue curves in figure 1.2.1) provide fairly smooth data for the remainder of the flight, while the altimeters in the other avionics bays stop working due to power failure. The nosecone altimeters stopped reporting several seconds after landing as a result of their programming, not because of the high-speed impact with the ground. The faraday cage protected the electronics from the rough ground impact.

The launch vehicle disassembly caused large positive and negative pressure fluctuations throughout the airframe, as measured by the six altimeters. Some altimeters were tricked into firing their charges at a false measurement of apogee and main deployment altitude. These false measurements resulted in the piston charges detonating, one motor section drogue deployment, and the nose cone drogue deployment. Some charges had to be manually detonated on the ground post flight because they did not fire during flight.

At ignition, the motor appeared to stutter, and then take off with very low thrust; causing the vehicle to leave the launch pad at a less than ideal velocity.


**Figure 1.2.2. Launch Vehicle taking off.**

The low thrust coupled with the shallow coupler interface caused the launch vehicle to spin and flex. Figure 1.2.3 shows the moment when the upper portion of the vehicle broke off and experienced a 90º angle of attack, ripping it apart at Mach .5 speeds.

**Figure 1.2.3. The Launch Vehicle at the moment of break up.**

**Figure 1.2.4. The launch vehicle moments after break up.**

As evidenced by the above figures, the launch vehicle experienced a catastrophic failure around 2000' above the ground. Upon observing the various pieces of wreckage, it was possible to determine that the failure most likely started at the joint between our nose cone section and our payload sheath; both sections were attached to the CDLE payload coupler with 1.5 inches of airframe interface and shear pins. When the motor ignited, we suspect that this joint failed and the shear pins broke due to the shear forces. The CDLE was now free to slide around inside the launch vehicle, no longer tethered to body tube it slid down into the airframe, further reducing the coupler to body tube interface and accentuating the oscillations which led to deconstruction.

The nose cone section was no longer connected to the rest of the launch vehicle after losing its coupler interface, and was pushed aside by aerodynamic forces. The moment of the shear is captured in Figure 1.2.3. Aside from the main parachute bay, all sections of the launch vehicle were recovered with minimal structural damage as their respective parachutes were pulled from their bays and deployed due to air currents.

# 2. PAYLOADS

## 2.1 Controlled Descent and Landing Experiment

The controlled descent and landing experiment (the CDLE) was designed as a folded quadcopter to be deployed from our rocket at apogee. We designed and built an ejection charge driven piston to deploy the CDLE and a spring mechanism to unfold the arms. The CDLE was designed to carry the ATMOS as it autonomously flew to a predetermined landing location. The mobility and stability of the CDLE platform would have allowed ATMOS to achieve better data than if it descended under parachute.

The CDLE was not loaded in a mission ready state on launch day. The cataclysmic failure in flight would have made it impossible for the CDLE to complete its mission. Even so, the CDLE was not prepared to descend to a predetermined location as a quadrotor helicopter and instead was configured to descend under parachutes. The parachutes allowed the CDLE to survive the vehicle breakup without damage and prompted the master of ceremonies to declare in surprise that "the pieces are coming down on little parachutes?!" At the time of launch many functions, including integral safety measures, of the CDLE were either untested or incomplete and as such the experiment could not be flown.

The flight software was not ready for the full CDLE mission before the launch. Although the flight software was in a state where a quadrotor could be successfully flown, it was not ready to activate the quadcopter at deployment and autonomously guide it to the landing site. Our guidance software was based on the PX4 flight stack that runs natively on the Pixhawk flight controller. We used the Pixhawk for tests and intended to use it during the launch. The software development team did not gain enough understanding of the pre-existing PX4 infrastructure to be able to modify it in order to complete our mission goals. This was a result both of a lack of team members with experience developing in large software libraries and a lack of man-hours devoted to the flight guidance aspect of the project.

The systems to control the emergency parachute deployment were also incomplete at the time of launch. A circuit board was designed with the task of deploying the CDLE parachute in emergency scenarios and making sure that the motors did not receive power while the parachute is deployed. The board was designed, laid out, and assembled. Due to the inexperience of the design team as well as insufficient man-hours dedicated to the project, the design process of the emergency systems took longer than planned. Not enough time was left for assembly. The initial assembly process was sloppy and not enough time remained to make a second attempt or to fix the problems with the first board. As of the launch date, the microcontroller controlling the system was not in a programmable state.

Several mechanical systems were also not tested at the time of launch. Test flights of the CDLE as a quadcopter did not occur before launch due to an extended design process delaying the final assembly. At the time of launch the CDLE was considered ready for testing in quadcopter flight. The arm deployment system was also flight untested, so the CDLE payload was flown without the arms. We believe that the piston was responsible for successfully deploying the CDLE during the launch vehicle breakup. In the future we hope to ensure the safety of the CDLE through software improvements and further testing. Proving the dependability of the deployment and stabilizing mechanisms is essential in order to guarantee a safe controlled descent for the quadcopter.

### 2.2 Atmospheric and Topographic Optics and Measurement Suite

The (ATMOS) was an collection of atmospheric instruments programmed to start taking data at an altitude of 400 meters above ground level (about 1,300 feet). Because launch vehicle breakup occurred below that altitude no data was measured or logged. Had our system run perfectly, it would have taken atmospheric measurements every second, horizontal images every ten seconds, and 100 ground images in-flight. While the ATMOS didn't acquire any data, we did learn that there were malfunctions between the Arduino and Raspberry Pi subsystems. These malfunctions corrupted communication, and would have led to the Raspberry Pi powered subsystem taking ground images at incorrect times. We hope to address these issues in future iterations of the ATMOS.

### 2.3 Scientific Value of Payloads

There are numerous applications of a self-contained and autonomous sensory drone. Some potential uses include surveillance in the fields of agriculture, meteorology, military/defense, aerospace, and research. The CDLE payload allows for a controlled landing, which controls the time of the descent as well as the location of the measurements. This allows ATMOS to get cleaner, properly oriented images. The ATMOS payload gains its versatility from its suite of sensors. The sensory system is capable of measuring air temperature, humidity, pressure, solar irradiance, UV radiation, surface IR radiation, and atmospheric transmittance. This variety of measurements is useful in many fields. The ATMOS can assess crop health for agricultural applications, examine weather patterns to help predict storms, and determine incident irradiance for the solar energy industry. The objective of the ATMOS payload is to verify that small, inexpensive drones can be used to consistently and accurately take measurements for these applications. Therefore, the ATMOS is intended to be a robust atmospheric measurement sensing system that is able to take measurements and photograph its surroundings in the visible spectrum and photograph the surface in the infrared spectrum.

# 3. PROJECT SUMMARY

## 3.1 Lessons Learned

The unplanned disassembly of the launch vehicle during competition highlighted a couple of design practices our club should pay attention to when designing future vehicles. Both issues identified below resulted from overzealous weight cutting measures between FRR and competition.

One aspect of design we will pay closer attention to is coupler interface length. We discovered that using insufficiently long couplers between launch vehicle body sections could cause structural flexing that may result in shear pins breaking. The short coupler interface in the competition launch vehicle allowed for small aerodynamic fluctuations to compound into large oscillations in the rocket body, culminating in the upper half of the body aligning itself perpendicular to the thrust.

The set screws holding the nose cone to the nose cone e-bay ripped through the shoulder as a result of the short coupler interface and high aerodynamic forces, allowing the nose cone itself to free-fall. In the future, more shoulder will be left on the nose cone to prevent the set screws from shearing through the body. The nose cone section with e-bay and the motor section descended under parachute. Some parachute charges failed to fire due to stratologger power failure; however, as a result of the extreme aerodynamic forces on the rocket, some parachutes were pulled from the airframe and deployed.

## 3.2 Educational Engagement

Over the past two semesters, our team has conducted and assisted with several educational outreach programs for middle schools and high schools in our community. Our goal for these programs was to convey the sense of excitement and wonder that we all felt when introduced to rocketry and space exploration for the first time. To complete our outreach goals, we partnered with Northeastern University's Center for STEM Education. We fully intend to maintain this partnership in the coming semesters. Below is a summary of the programs we conducted and assisted with during the past two semesters.

**Table 3.3.1: STEM Outreach events.**

| **Event** | **Date** | **Number of Students** |
|---|---|---|
| STEM Field Trip | September 9 | 22 |
| NEPTUN | November 7, 14 | 20 |
| STEM Field Trip | November 6 | 50 |
| Summer STEM Callback | February 19 | 20 |
| STEM Field Trip | February 26 | 64 |
| Tiger Woods Foundation | March 12 | 26 |
| Total Number of Students | | 202 |

The number of students we reached during the last two semesters was just over 200, which is much lower than our anticipated total. As stated in other documents, we had several weather related cancellations. As a best practice we should have had enough events scheduled that weather cancellations did not affect our numbers so dramatically. Our club recently elected a new Outreach Coordinator whose primary responsibilities include scheduling STEM events and maintaining the club's public presence. Our new Outreach Coordinator, Sam, already devotes much of her personal time to STEM events and has volunteered at the Museum of Science in Boston since she was in high school. She is unbelievably passionate about STEM education and we anticipate an increase in STEM activities hosted by Northeastern AIAA under her leadership. Unfortunately, we have been unable to engage in any additional STEM events between the FRR and PLAR.

### 3.3 Budget Summary

**Table 3.3.1: Total breakdown of costs of complete project.**

| NASA Student Launch Budget | | | | |
|---|---|---|---|---|
| **Item** | **Quantity** | **Primary Vendor** | **V1 Price** | **V1 Total** |
| | | | | |
| ***Launch Vehicle*** | | | | |
| 7.5" Blue Tube | 1 | Always Ready Rocketry | $139.95 | $139.95 |
| 7.5" Full Length Coupler | 1 | Always Ready Rocketry | $91.95 | $91.95 |
| 7.5" Nose Cone - 21 in. | 1 | Always Ready Rocketry | $124.95 | $65.95 |
| Rail Buttons | 2 | Always Ready Rocketry | $1.25 | $2.50 |
| 48" Fruity Chutes Parachute | 2 | Apogee Components | $126.85 | $253.70 |
| Motor Mount Kit | 1 | Apogee Components | $14.95 | $14.95 |
| Motor Retainer | 1 | Apogee Components | $47.08 | $47.08 |
| 1/8" Quick Link | 10 | Apogee Components | $3.25 | $32.50 |
| Shear Pins | 4 | Apogee Components | $2.95 | $11.80 |
| Shock Cord | 150 | Apogee Components | $0.92 | $138.00 |
| 9in Reusable wadding | 12 | Apogee Components | $7.44 | $89.28 |
| StratoLogger | 10 | Apogee Components | $58.80 | $588.00 |
| Eye Bolts | 10 | Apogee Components | $4.50 | $45.00 |
| G10 Fiberglass | 5 | ePlastics | $40.91 | $204.55 |
| 18" Parachute | 4 | Apogee Components | $56.90 | $227.60 |
| Rotary Switch | 6 | Apogee Components | $9.46 | $56.76 |
| Carbon Fiber Tubing | 1 | Rock West Composites | $207.99 | $207.99 |
| | | | | |
| Launch Vehicle Budgeted Total | | | $2,217.56 | |
| **Launch Vehicle Spending** | | | | |
| Apogee Rockets Spending Total | | | 474.22 | |
| Always Ready Rocketry Spending Total | | | 867.56 | |
| Fruity Chutes Spending Total | | | 697.88 | |
| Mcmaster Spending Total | | | 586.47 | |
| Animal Motor Works Spending Total | | | 437 | |
| ***Launch Vehicle Spending Total*** | | | 3063.13 | |

| | | | | |
|---|---|---|---|---|
| | | | | |
| ***Software*** | | | | |
| RFD900 Radio Set | 1 | Event34 | $179.99 | $179.99 |
| Spektrum AR8000 | 1 | Amazon | $175.99 | $175.99 |
| 3DR Pixhawk GPS | 1 | 3DRobotics | $89.99 | $89.99 |
| APM Power Module | 3 | 3DRobotics | $24.99 | $74.97 |
| ATMEGA328P-AUR | 10 | Digikey | $3.70 | $37.00 |
| (10) 10x10cm 2 layer PCBs | 1 | Seeed Fusion | $26.90 | $26.90 |
| TSR 1-2450 | 10 | Mouser | $7.36 | $73.60 |
| IRLB8721PBF | 26 | Mouser | $0.97 | $25.22 |
| 2.54mm Spring Terminal Bloc | 10 | Digikey | $1.95 | $19.50 |
| | | | | |
| | | | | |
| Software Total Budget | | | | $703.16 |
| Digikey Spending Total | | | | 385.52 |
| Amazon Spending Total | | | | 226.06 |
| 3D Robotics Spending Total | | | | 164.95 |
| Software Spending Total | | | | 776.53 |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Nylon 1/4 OD Spacer 3/8 | 1 | Mcmaster | 9.14 | 9.14 |
| Linear Slides | 8 | Mcmaster | 19.66 | 157.28 |
| Linear slide Rails | 4 | Mcmaster | 118.45 | 473.8 |
| Quadcopter Motors KDE 380 | 6 | KDE | 118.95 | 713.7 |
| Quadcopter Propellers (15.5 i | 4 | KDE | 77.95 | 311.8 |
| Quadcopter Battery Turingy 6 | 4 | Hobbyking | 50.26 | 201.04 |
| Carbon Fiber Arms (1x1.5x36 | 2 | RockWestComposites | 117.59 | 235.18 |
| Delrin Block | 2 | Professional Plastics | 79.99 | 159.98 |
| | | | | |
| ***CDLE Prototype*** | | | | |
| 1/8" X 12" X 12" Plywood 45 | 1 | Amazon | 49.99 | 49.99 |
| 1/8" X 12" X 24" Plywood 6 p | 1 | Amazon | 29.99 | 29.99 |
| .118" Acrylite Sheet | 3 | Evonik | 3.64 | 10.92 |
| 1/8X12X24 Aluminum Sheet | 2 | OnlineMetals | 30.35 | 60.7 |
| .5x1/8x 3ft 6061 Al Bar | 6 | Mcmaster | 2.55 | 15.3 |
| 3/32x1/8x6in 6061 Al bar | 10 | Mcmaster | 1.51 | 15.1 |
| Nylon #10 Spacer 1 inch thic | 2 | Mcmaster | 10.21 | 20.42 |
| Nylon #10 Spacer 1/8 inch thi | 2 | Mcmaster | 7.25 | 14.5 |
| Nylon # 10 Spacer 1.5 inch th | 2 | Mcmaster | 10.25 | 20.5 |
| 3/8-18 lead screw | 2 | Mcmaster | 13.16 | 26.32 |
| 3/8 Bearings (3/8ID) | 4 | Mcmaster | 5.59 | 22.36 |
| Quadcopter Propellers (15.5 i | 4 | KDE | 77.95 | 311.8 |
| | | | | |
| **CDLE Budgeted Total** | | | | **3645.79** |
| **CDLE SPENDING** | | | | |
| Mcmaster Total | | | | 827.71 |
| Rockwest Composites Total | | | | 137.18 |
| Hextronic Total | | | | 133.21 |
| KDE Direct Total | | | | 1113 |
| ***CDLE TOTAL SPENT*** | | | | 2211.1 |

| | | | | |
|---|---|---|---|---|
| Data Logger Shield | 1 | Adafruit | $19.95 | $19.95 |
| Solder | 3 | Adafruit | 14.95 | $44.85 |
| Flux | 1 | Adafruit | 15.95 | $15.95 |
| Solder wick | 1 | Adafruit | $3.00 | $3.00 |
| Jumper Wires | 2 | Adafruit | 3.95 | $7.90 |
| Wire set | 1 | Adafruit | $15.95 | $15.95 |
| Resistors | 1 | Amazon | $4.95 | $4.95 |
| Protoboard | 3 | Adafruit | $5.00 | $15.00 |
| Male headers | 2 | Adafruit | $0.95 | $1.90 |
| Female headers | 5 | Adafruit | $1.95 | $9.75 |
| Push buttons | 1 | Adafruit | $2.50 | $2.50 |
| Switch | 5 | Adafruit | $0.95 | $4.75 |
| LEDs | 1 | Amazon | $3.20 | $3.20 |
| Raspberry Pi Display | 1 | Adafruit | $79.95 | $79.95 |
| Keyboard | 1 | Adafruit | $14.95 | $14.95 |
| Mouse | 1 | Adafruit | $7.50 | $7.50 |
| ATMOS BUDGETED TOTAL | | | | $742.78 |
| **ATMOS SPENDING** | | | | |
| Adafruit Spending Total | | | | 445.32 |
| Optical Filter Shop Spending Total | | | | 109.74 |
| Digikety Spending Total | | | | 29.94 |
| ATMOS Spending Total | | | | 585 |
| | | | | |
| | | | | |
| | | | | |
| | | Total Budgeted | | $7,309.29 |
| | | Total Spent on Launch Operations | | 6635.76 |

### 3.4 Summary of Experience

The NUSPACE USLI design began as a highly ambitious project to expand the horizons of what kind of payloads a rocket could deploy. Choosing to eject a quadcopter at apogee as one of the team's two scientific payloads was one of the most aggressive design challenges the team had ever faced, but it was met with great determination to succeed by each member on the team. The industriousness that existed at the conception of the project persisted through the entire eight months, leading the team to the completion of the project and the final launch in April 2016.
The envisioned project caused the team to separate into smaller subgroups with a focus on individual aspects of the project. A group was formed to design and construct the quadcopter payload, another to design and program the electronics that would govern the quadcopter's downward flight, a third to design the other scientific payload of atmospheric sensors, and finally the group that would design and construct the launch vehicle itself. Having these separate teams all working toward the same end goal created an interesting dynamic within the group. Team leads had to learn to communicate and plan for integration of parts more. Each section became

more specialized in their particular field, bringing more knowledge to Northeastern's AIAA club in general.

As the year continued, designs were frequently discussed and improved, causing many new ideas to be expressed to the team, and many others that would not move into the next phase of the design process. Subscale models of the launch vehicle were tested, proving that the rear drogue parachutes on the motor section and the piston ejection system not only put the launch vehicle in the right flight profile after apogee but also could properly eject the quadcopter from the vehicle. The software group had to test code on a manufactured model, and the atmospheric sensor payload group had to determine how to integrate with the quadcopter itself. Essentially, each proof of concept, static test, and subscale flight showed the team where the strengths and weaknesses of the design existed.

As the final launch date came closer, it became clear that the quadcopter should probably not fly during the competition flight because of safety concerns, which was definitely disheartening to many on the team. From the beginning, the team hoped for success, but this decision did not put a damper on the determination of the team to see the quadcopter fly. Focus moved to proving that the CDLE ejection system was a viable design for launch day, and that the atmospheric sensor payload would be ready to take scientific data as it descended with a parachute in a similarly massed model.

The final launch did not occur as planned. Some flaws in the vehicle design prevented the launch vehicle from having a proper flight, resulting in sections separating prematurely, improper parachute ejection, and the vehicle itself missing the goal altitude. Although these results were disappointing, the team had many successful subscale launches prior to the competition launch, and the desire to accomplish what the team originally set out to do is still very prominent. Members of the team plan on continuing to improve upon the design of both the launch vehicle and the quadcopter so that soon both will be able to fly together. This will begin to occur once a full assessment of the launch is made, as well as improvements to the entire project design are incorporated.

The Northeastern AIAA team participated in the Student Launch last year with the MAV challenge, but this year sparked just as much team growth and learning as last year. Not only did the team expand with many new members that had never participated in the Student Launch, but also with a new project for the returning members that brought new challenges and accomplishments. Overall, the group learned to properly document and defend an aggressive design, professionally report progress, work as a group to meet deadlines, and end up with a final launch vehicle that each member was extremely proud of.