NC STATE UNIVERSITY

Tacho Lycos
2018 NASA Student Launch
Post-Launch Assessment Review

High-Powered Rocketry Club at NC State University

911 Oval Drive

Raleigh, NC 27695

April 29th 2019

Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association

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1. Launch Day Results

Table 1-1 Overview of Launch Vehicle from Launch on 6 April

Detail	Description
Motor Used	Aerotech L1150R
Payload Description	Deployable UAV
Vehicle Length	98 inches
Vehicle Diameter	5.5 inches
Altitude Reached	4102 feet AGL
Target Altitude	4090 feet AGL

2. Vehicle Summary

The launch vehicle was constructed of entirely off-the-shelf fiberglass body tubes and couplers. Fiberglass was chosen due to its superior strength while still being commercially available and affordable by the team. The nose cone was a 4:1 ogive shape and was also constructed of fiberglass. Bulkheads and centering rings were constructed from layers of 1/8 inch aircraft grade birch plywood that were adhered together using West Systems 2-part epoxy. U-bolts of 5/16" diameter were installed in each bulkhead that would be connected to the recovery harness and 5/16" diameter quick links were used to attach the recovery harness to the U-bolts.

The launch vehicle consisted of five total separate sections: the nose cone, the payload bay, the main parachute bay, the AV bay, and the fin can. During flight, the vehicle separated into only three separate sections: the nose cone and payload bay as well as the main parachute bay and the AV bay were attached permanently during flight using stainless steel #6-32 screws. The payload was housed in the payload bay for the duration of flight and was deployed once the vehicle reached the ground.

2.1 Data Analysis

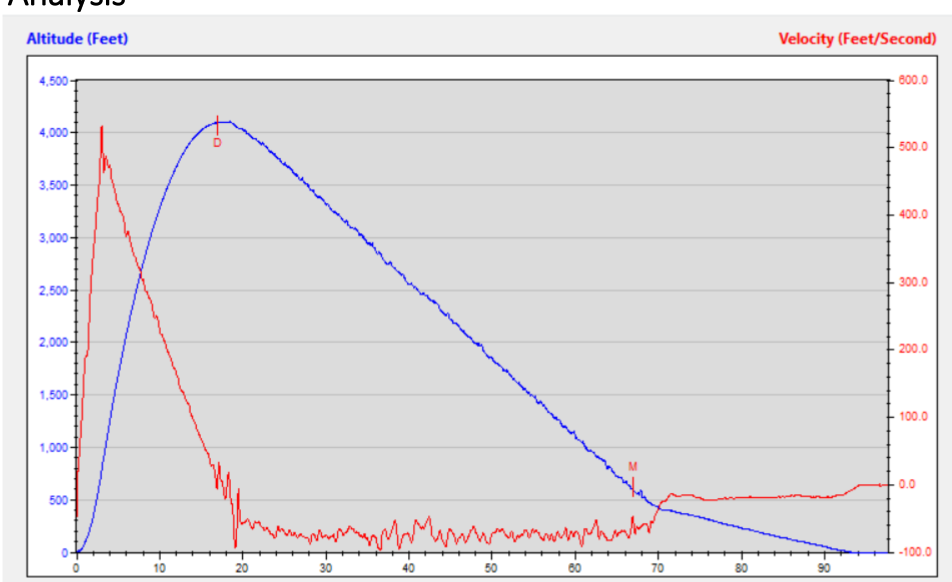

Figure 2-1 Flight Data from Primary Altimeter

Figure 2-1 shows the altitude and velocity data recorded by the vehicle's primary altimeter. Unlike the two previous demonstration flights, the apogee indicated by the retrieved data, matches that of the beeps heard on launch day. Additionally, this data shows no erroneous spikes near apogee like those that were seen on the previous two flights. The team believes that the nominal nature of this flight is the cause of this result. More specifically, the rocket did not weathercock and therefore reached apogee with little to no horizontal or vertical velocity. On the previous two flights, the launch vehicle weathercocked dramatically, which caused it to be travelling with some non-trivial velocity at apogee. Because the altimeters use air pressure to measure apogee, they are only able to detect velocity in the vertical direction. It is likely that this discontinuity caused the anomalies present in previous flight datasets.

2.2 Results of Vehicle Flight

The launch vehicle performed as intended on the day of competition. With minimal weathercocking, the vehicle reached an altitude within 12 feet of the team's target altitude; in addition, recovery systems performed nominally with the drogue deploying at apogee and the main deploying at 600 ft AGL. Because the flight was nominal, the vehicle experienced the loads that were expected and designed for by the team. Upon post-launch inspection, no damage was found on the launch vehicle barring surface scratches due to it being dragged by the parachute after landing. The vehicle has been determined to still be flight worthy with no essential repairs, thus verifying that the vehicle met the reusability design requirements.

The recovery system functioned as designed. As discussed previously, the drogue parachute deployed at apogee as designed. The drogue deployed and opened fully with no tangled shroud lines. The main parachute deployed after the launch vehicle descended below 600 feet AGL. The main parachute opened fully with no tangled or twisted shroud lines. The deployment bag and all Nomex cloths used to protect the parachutes from thermal conditions during the deployment events were successfully retained by the recovery harness. Neither parachute sustained any damage requiring repair or replacement.

2.3 Results of Payload Flight

After the area around the launch vehicle was deemed safe, the recovery team approached and assessed the landing orientation and state of payload retention systems. As decided at the LRR, the payload bay was sealed with a plywood and epoxy layup plug, which was held on with 4 #6-32 screws to the aft most centering ring. Upon inspection after the launch, the latch and U-bolt would have successfully retained the payload and payload pod even if the plug not been present. Upon confirming the state of the recovered vehicle, the plug was removed, which did require moving the payload bay and nosecone from the exact position they landed in. The payload communications lead was then given the signal to begin the deployment of the payload.

The signal sent by the payload communications lead was successfully received by the Arduino. The latch opened, allowing the payload pod to move axially. The motor began turning, and the pod extended completely from the payload bay. After reaching the end of the motion, the pusher retracted and the pod caught on the final centering ring as designed, allowing the carbon fiber rod to retract. However, the four screws attached to secure the plug for safety interfered with the opening of the flaps, forcing the team to manually move the pod so it could open. It should be noted that the screws were not a designed aspect of the payload deployment system and were added to satisfy LRR safety decisions. The flaps opened under the energy of the opening UAV arms and revealed the UAV for flight. The UAV was in nominal condition, except for the team's simulated navigational beacon which had fallen from the solenoid during flight. In order to attempt the remainder of the mission, the team was required to manually re-attach the beacon to the solenoid. The UAV was the ready for flight.

The payload flight team positioned themselves approximately 200 feet from the recovery site, which is within the required 250 feet designated by the FAA. Once the recovery team gave the all-clear, the UAV was armed and successfully took off from within the pod. With the use of the on-board camera, video transmitter, and video receiver on the ground, the UAV pilot was able to quickly locate and navigate the UAV to the closest FEA, approximately 500 feet from the recovery site. The flight of the UAV lasted between 3-5 minutes, in which the pilot struggled against adverse wind gusts, but was ultimately successful in landing on the FEA.

Figure 2-2 UAV at FEA after Successful Deployment of the SNB

Due to a harsher than expected landing, the video transmission cut out, and the UAV seemed to stop receiving commands. To inspect the successes of the simulated navigational beacon (SNB) deployment, the payload and communications lead approached the FEA. After taking pictures of the payload as it landed, the pilot indicated that video feed had returned. The SNB was successfully deployed, with pictures taken as verification, and then the pilot attempted to leave the FEA with the UAV.

The payload and communications lead retreated to a safe distance for the take-off attempt, and the pilot was given the signal to proceed. The UAV successfully armed and flew to approximately three feet elevation before one propeller suffered catastrophic failure, and the UAV fell to the ground.

After reviewing pictures taken at the FEA, it was observed that the propeller had suffered a cracked propeller upon landing, and this crack propagated through the rest of the chord length upon takeoff. In short, the UAV was able to successfully complete its mission: navigating to the FEA and deploying the SNB. The failure occurred after mission success, and therefore the team is satisfied with the performance of the UAV.

2.4 Scientific Value Achieved

While researching for this challenge, the team was not able to find literature regarding UAV's onboard High-powered Rockets. Consequently, the team has shown, through the results of this competition that with only minor modifications, commercial off the shelf UAV's can be launched, recovered, and deployed safely from sounding rockets.

2.5 Visual Data Observed

Figure 2-3 Launch Vehicle at Rail Exit

The Launch Vehicle exited the rail and experienced minimal weathercocking. Figure 2-3 shows the launch vehicle shortly after rail exit. The recovery systems deployed without causing any damage to the airframe or payload due to collision of body tube sections. Figure 2-4 shows the fin can maintaining a safe distance from the rest of the airframe during the descent under drogue. Figure 2-5 shows the midsection and nosecone sections a safe distance apart during main parachute deployment. Finally, Figure 2-6 shows the nosecone section and midsection descending under main parachute with ample separation between them thanks to proper placement on the recovery harness.

Figure 2-4 Launch Vehicle Descending under Drogue

Figure 2-5 Main Parachute Deployment

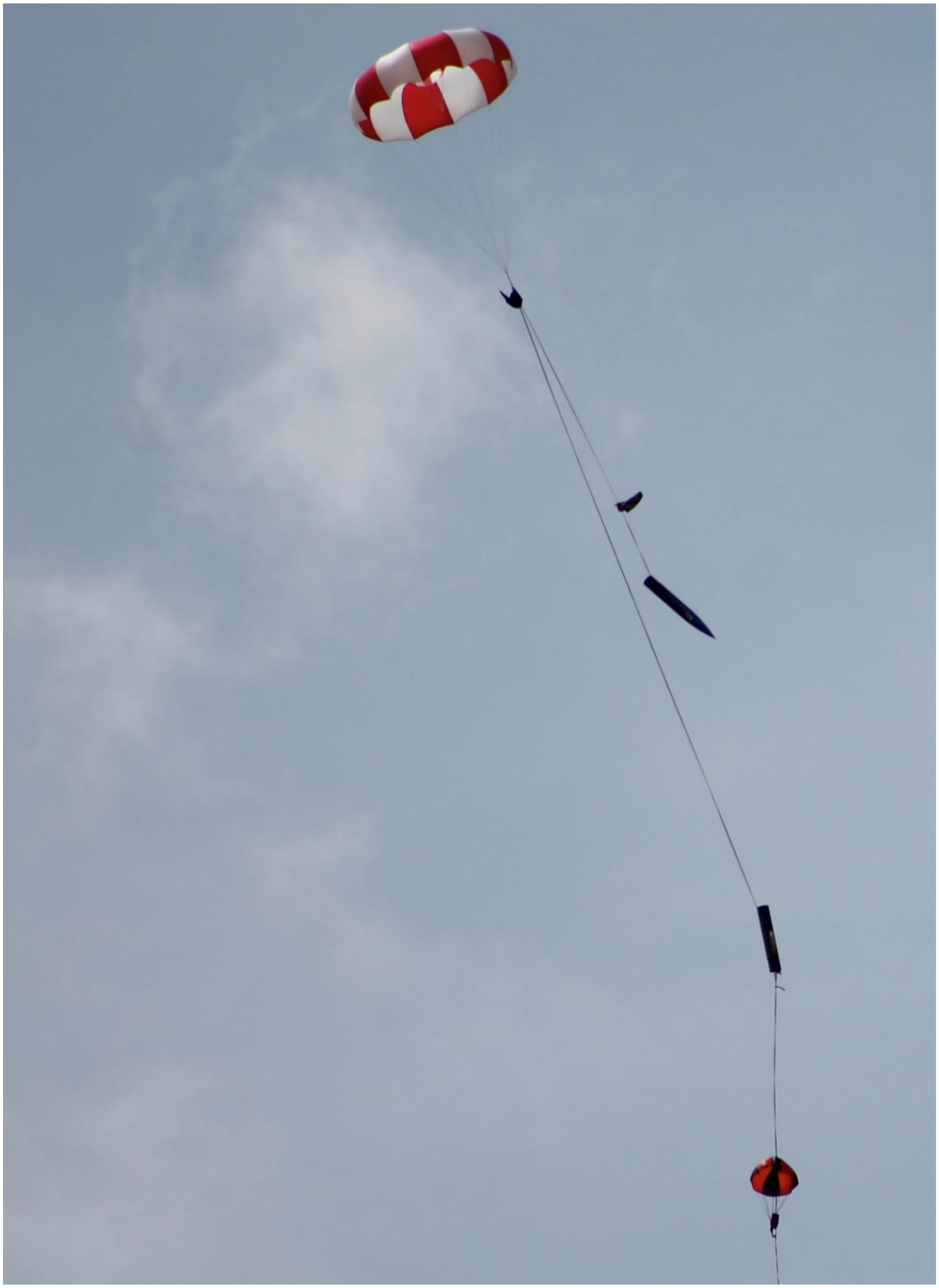

Figure 2-6 Launch Vehicle Descending under Main

3. Lessons Learned

Table 3-1 Lessons Learned Throughout the Competition

Lesson Learned	Reason
Tests need to be reperformed upon changes to the tested systems.	A change in the infill percentage of the 3-D Printed payload pod may have caused a failure in a part that had been tested for flight loading along with a factor of safety.
When prototyping or computer modeling, ensure every aspect that can be modeled is represented.	Often issues with the payload could have been discovered sooner in the design process had more details been modeled.
Build extra time into build schedules to allow for mistakes.	A few mistakes were made during the build requiring replacement bulkheads be made, etc. with insufficient time to reinstall each separately to ensure accuracy so other methods became necessary in the rush.
Research Capabilities of simulation software to ensure models are accurate.	The true consequences of the relatively small fin sizes were not portrayed in initial RockSim models. As a result, the team proceeded to manufacture a launch vehicle that was very susceptible to weathercocking.
Security of all electrical connections should be tested during assembly.	The secondary altimeter experienced a continuity failure on the launch pad as a result of a faulty Molex connector.

3.1 Summary of Overall Experience

For most of the senior design team, this was their second year participating in the competition. Following our teams less than successful 2017-2018 season, the team is very pleased with the outcomes of this year. While the team had intended to have a working payload by December, that was not the case. Furthermore, while not a focus of documentation requirements, the payload deployment system proved to be the most challenging facet of the competition and the team feels that more focus should be put on this subsystem in the future. With regards to documentation as a whole, the team feels that the requirement-focused nature of the documents very closely reflected the realities of the professional world. Because of this the team found the creation and development of the documentation throughout the competition cycle to be a rewarding and worthwhile endeavor. In the end, the team was able to launch a fully functioning payload with a semi functional deployment system. This result is the closest the team has come to fully executing the mission objectives of a USLI challenge since our victory in 2015. This is a result that we are very happy with and we hope to take the lessons we've learned and produce a fully working payload in the next competition year.

4. STEM Engagement Summary

Tacho Lycos had an extremely successful year in outreach, reaching 3850 K-12 participants and additionally participants ranging from school teachers to museum guests in 7 events over the course of the year. The team's goal this year was to continue with relationships built in previous years and expand the outreach program to new events and places. The goal of the outreach program is focused creating hands on events and activities for students from K-12 and inspiring them to pursue a career in STEM fields.

During these events, team members assisted members in events such as building and launching water bottle rockets while teaching about Newton's Laws of Motion. Additionally, the club helped the Tripoli Rocketry Association's booth at Astronomy Days, a major event at the North Carolina Museum of Natural Sciences to help repay them providing fantastic mentors. Event organizers were extremely pleased with the professionalism shown by the team and the enthusiasm the team members brought to the events.

Table 4-1 Table of Outreach Events for 2018-2019

Date	Event	Location	Number of Participants (K-12)	Interaction
10/25/18	STEM Night	Cleveland Elementary School	100	Direct
10/30/18	FLL Team	Laurel Park Elementary School	30	Indirect
11/09/18	Science Go Round	Joyner Elementary School	100	Direct
01/24/19	STEAM Night	Laurel Park Elementary School	100	Direct
01/26/19	Astronomy Days	NC Museum of Natural Science	3000	Indirect
02/09/19	STEM Expo	Weatherstone Elementary School	400	Direct
02/22/19	Outreach Event	Apex Friendship Middle School	120	Direct
		Total K-12 Interactions	3850	

With this year's focus to expand our network in order to reach more students, next year the club hopes to continue to build our relationships and to bring more diverse activities to the community. Throughout the NASA Student Launch competition, the club witnessed how several other teams handled their outreach program. Some programs planned unique hands-on activities for their events. In some cases, a team was able to reach multiple students through the development of design activities which span multiple weeks. This year's outreach event with the Durham Museum of Life and Science allowed the club to experience a similar series of activities but on a smaller scale. In the coming year, the club aims to integrate more activities, beyond bottle rockets, and to possibly even create a design project for interested K-12 students.

5. Final Budget Summary

Table 5-1 Project Budget 2018-2019

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	$340.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$12.68	$76.08
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			$988.46
Full-Scale Structure	Aerotech L1150R-PS	3	$200.00	$600.00
	5.5" G12 Airframe, Half Length (30"), 3 Slots	1	$130.00	$130.00
	5.5" G12 Airframe, Full Length (60")	1	$188.00	$188.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$100.00	$100.00
	5.5" G12 Coupler 12" Length	3	$55.00	$165.00
	5.5" Fiberglass 4:1 Ogive Nosecone	1	$84.95	$84.95
	Domestic Birch Plywood 1/8"x2x2	8	$12.68	$101.44
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	Motor Retainer	1	$44.00	$44.00
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00

	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Poster Printing (feet)	4	$10.00	$40.00
	Subtotal:			**$2,077.77**
Payload	Crazepony EMAX Brushless Motor	1	$56.99	$56.99
	OmniNXT F7 Flight Controller	1	$59.99	$59.99
	Electronic Speed Controller	1	$59.99	$59.99
	11.1V Lipo Battery	1	$21.99	$21.99
	FPV Camera	1	$19.99	$19.99
	Circular Antenna	1	$6.69	$6.69
	Lumenier 5x3.5 2 Blade Propeller	2	$1.79	$3.58
	Readytosky FPV Racing Drone Frame	2	$22.99	$45.98
	Lumenier circular polarized antenna	2	$10.19	$20.38
	AKK K31 Transmitter with Race Band	1	$11.99	$11.99
	FrSky XM+ SBUS Mini Receiver FPC Drone	1	$17.49	$17.49
	Lumenier DX800 DVR w/ 5.8GHz 32CH Receiver	1	$149.99	$149.99
	FRrSky X-Lite Radio Controller	1	$139.99	$139.99
	Arduino Uno	1	$24.95	$24.95
	Arduino USB Cable	1	$6.99	$6.99
	Arduino Servo Shield	1	$19.95	$19.95
	2KM Long Range RF Link Kit	1	$18.00	$18.00
	Breadboard	2	$9.95	$19.90
	LEDs	1	$6.99	$6.99
	Button	1	$5.85	$5.85
	Batteries	1	$15.20	$15.20
	Battery Clips	1	$5.66	$5.66
	Southco R4-EM Latch	1	$68.36	$68.36
	1.1”x1.1” stepper motor	1	$17.90	$17.90
	Hinges	4	$1.97	$7.88
	Aluminum rod	2	$2.21	$4.42
	Carbon Fiber Rod	2	$9.25	$18.50
	Surgical Tubing	2	$2.82	$5.64
	Nema 8 Bipolar Smallest Stepper Motor	1	$24.95	$24.95
	Subtotal:			**$886.18**
	Iris Ultra 84" Compact Parachute	1	$504.00	$504.00

Recovery and Avionics	24" Compact Elliptical Parachute	1	$53.00	$53.00
	Quick Links	8	$1.25	$10.00
	Kevlar Shock Cord (yard)	20	$4.34	$86.80
	Black Powder	1	$30.00	$30.00
	E-Matches	2	$29.00	$58.00
	Shear Pins	3	$3.00	$9.00
	StratoLogger CF Altimeter	4	$60.00	$240.00
	6" Deployment Bag	1	$43.00	$43.00
	18" Nomex Cloth	1	$24.00	$24.00
	BRB 900 Transmitter	1	$200.00	$200.00
	4" Deployment Bag	1	$39.00	$39.00
	13" Nomex Cloth	1	$13.00	$13.00
	Iris Ultra 60" Compact Parachute	1	$225.00	$225.00
	18" Compact Elliptical Parachute	1	$60.00	$60.00
	Kevlar Shock Cord (yard)	13.33	$2.55	$33.99
	Subtotal:			**$1,628.79**
Miscellaneous	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	4	$5.50	$22.00
	Screws (box)	4	$5.00	$20.00
	Washers	4	$5.00	$20.00
	Wire	3	$13.00	$39.00
	Zip Ties	2	$11.00	$22.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	2	$25.00	$50.00
	Battery Connectors	3	$5.00	$15.00
	3-D Printer Filament	1	$19.99	$19.99
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,200.00
	Subtotal:			**$2,944.23**
Travel	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (# rooms)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00

	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Outreach	Bottle Rocket Launcher	1	$30.00	$30.00
	Paper	4	$10.00	$40.00
	Printing	500	$0.10	$50.00
	Subtotal:			**$120.00**
Promotional	T-Shirts	40	$14.00	$560.00
	Polos	30	$20.00	$600.00
	Stickers	1000	$0.30	$300.00
	Banner	1	$200.00	$200.00
	Subtotal:			**$1,660.00**
Total Expenses:				**$18,088.93**

Table 5-2 Costs for 2018-2019 Competition Year

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
SGA Appropriations	$640.00	$1,520.00	$2,160.00
Engineering Technology Fee	-	-	$1,500.00
NC Space Grant	-	-	$5,000.00
Rockwell Collins	-	-	$5,000.00
College of Engineering	-	-	$5,500.00
Total Funding:			**$19,160.00**
Total Expenses:			**$18,088.93**
Difference:			**$1,071.07**