Rover Delivery

2017-2018 NASA University Student Launch Initiative Post-Launch Assessment Review

Charger Rocket Works

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CONTENTS

1 INTRODUCTION

The Charger Rocket Works (CRW) team flew on 8 April 2018 using an L1520 Aerotech motor. The team flew to an altitude of 5080 ft., but chose not to deploy the rover payload due to safety concerns. These will be discussed later in the report. Overall, the team had a positive experience during launch week and enjoyed networking with the other students. Each member learned a great deal from participating in Student Launch, and the team has compiled a list of lessons learned to share with next year's team.

2 LAUNCH VEHICLE

2.1 Vehicle Summary, Dimensions and Motor Used

The launch vehicle's purpose was to safely and successfully transport and deploy the rover. To transport a 7 lbf. rover to 1 mi., the rocket's total weight at liftoff was 40.1 lbf. The vehicle had a length of 106 in. and two body diameters. The majority of the airframe is 4 in. diameter, while the fairing that contains the rover is 6 in. The rocket flew on an Aerotech L1520 and used a 12 ft. long 1515 rail. The recovery system consisted of an 18 in. drogue parachute deployed at apogee and a 96 in. main parachute deployed at 600 ft. during descent. Both parachutes were deployed using redundant, isolated StratologgerCFs firing black powder charges. The rocket was tracked using an Xbee Pro radio on an in-house GPS system.

2.2 Flight Data Summary and Analysis

Launch conditions on 8 April 2018 were above average. The skies were clear with an approximate wind speed of 4 mph, coming from the southwest. The temperature was approximately 35 degrees. After a successful motor ignition, the vehicle left the rail at an angle of roughly 5 degrees. At apogee an event was detected, which was the drogue parachute deployment. At approximately 550 ft., the man parachute was deployed. The vehicle then slowly descended back to the ground before being recovered when the range was open. There was no damage to the vehicle.

Shadowfax reached an apogee of 5080 ft., just 200 ft. shy of the 5280 ft. goal. The simulations took in account for the weather conditions on the given flight day, as well as the launch angle, coefficient of drag, and any other set variables. Both recovery systems functioned properly, with the main parachute deploying slightly slower than expected. All flight characteristics can be found in Table 1.

Table 1: Flight Results

Flight Results	
Wet Mass (lb.)	40.1
Stability Margin at rail exit (caliber)	2.35
Max Velocity (ft/s)	610
Velocity at rail exit (ft/s)	79.8
Max Acceleration (ft/s^2)	283
Apogee (ft.)	5082

For the flight analysis, a predicted coefficient of drag of 0.33 was used. This value seems to be spot on, as the simulation results align very closely with that of the actual flight data. The figure below shows a comparison of the flight simulations and the flight data. When compared to the OpenRocket simulation, the apogee was 32.9 feet low, which results in an error of 0.65%. When compared to the RASaero simulation, the apogee was approximately 37.35 ft. high, which results in an error percentage of roughly 0.75%. With such low error percentage, it can be said that the simulations are great estimations for the predicted apogee results.

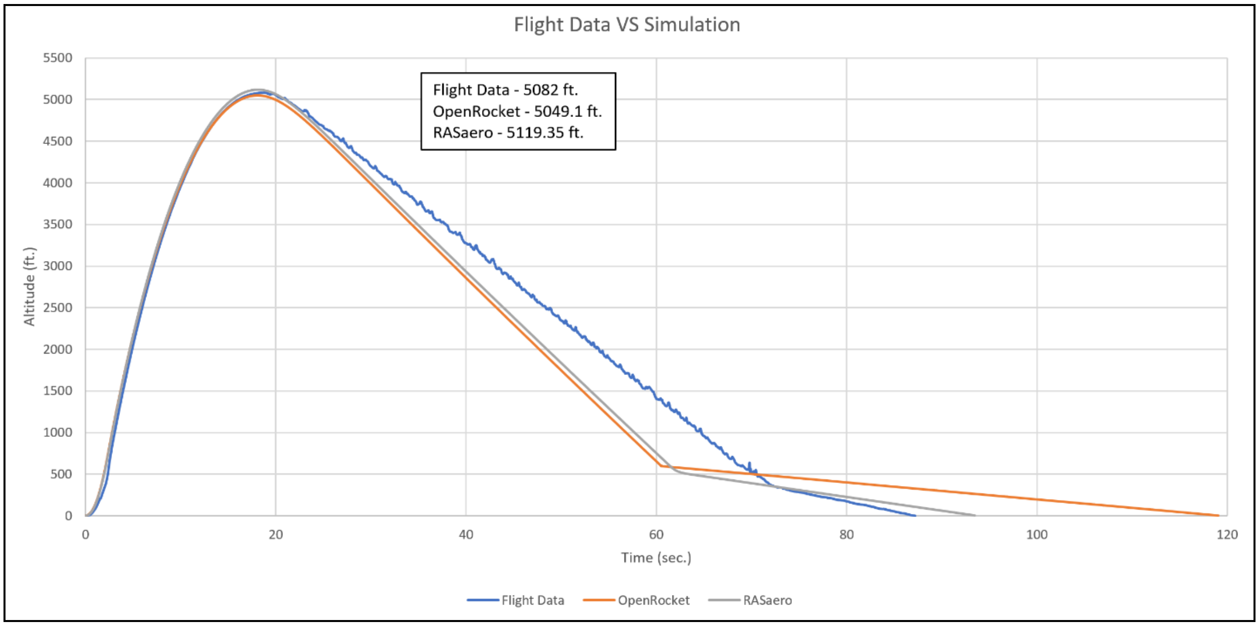

Figure 1: Flight Data Comparison

The flight's apogee can also be compared to the in-house Monte Carlo which was designed to help better predicted an apogee value based on uncertainties. Through flight testing, calculations, and measurements, the uncertainty value input into the Monte Carlo were about to be cut down to very small percentages, with the highly level uncertainty being in the propellant mass section. After running the Monte Carlo simulation for 10000 flights, a mean apogee value was output of 5025.6 ft. This value is slightly lower than what was achieved. This error percentage can be found to be roughly 1.11%. The error can be a result of a high level of uncertainty in the propellant mass weight. The manufacturer claims a rough estimate of ±6% on every motor produced. This is what is believed to be the highest source of error within the Monte Carlo calculation. The results of the Monte Carlo simulations are shown in Figure 2.

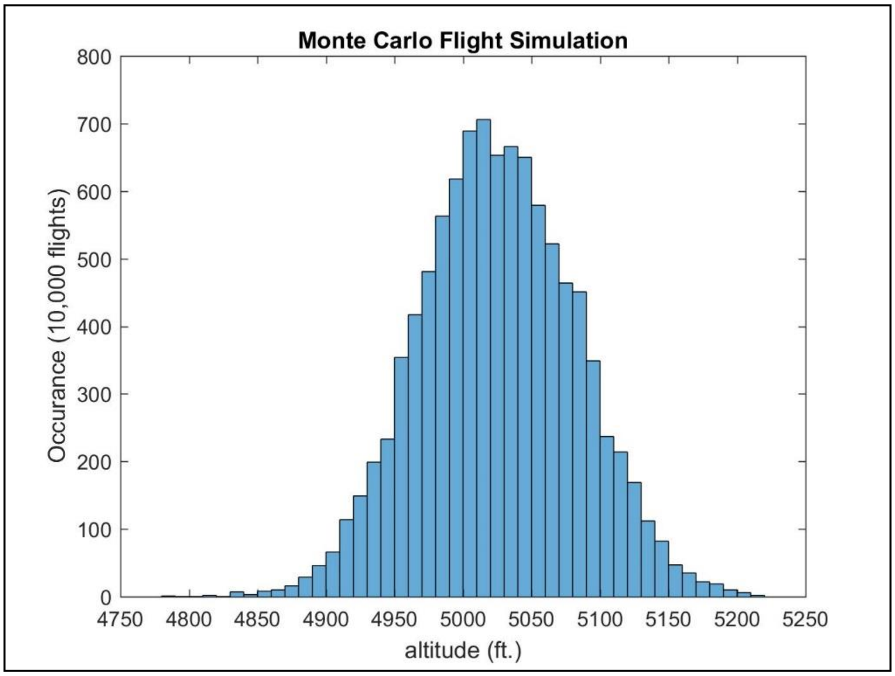

Figure 2: Monte Carlo Simulation Results

Overall, the simulations that were conducted to help better estimate the apogee of the vehicle can be said to be well within the acceptable region for a given flight. This outcome can be accepted due to the low error percentages achieved when running the various simulation method. The low error percentages can be achieved by having a great level of detail which was achieved when putting the various inputs into any given simulation.

The recovery system altimeters (PerfectFlite Stratologger CF's) properly commanded parachute deployment charges at their assigned altitudes. Figure 3 shows the data curve from the primary altimeter (which was the officially scored altimeter). For the primary altimeter, the drogue charge was set at a zero apogee delay and the main was programmed to deploy at 600 ft. AGL. The backup altimeter commanded the secondary drogue charge at a one second delay after apogee, and the second main charge was commanded at 550 ft. AGL. Through pre-launch black powder testing, the team determined the drogue parachute charge should be 2.25g with a backup of 2.75g and the main should be 3g with a backup charge of 3.5g. It appeared that primary charges were successfully ignited and separated the rocket in both cases.

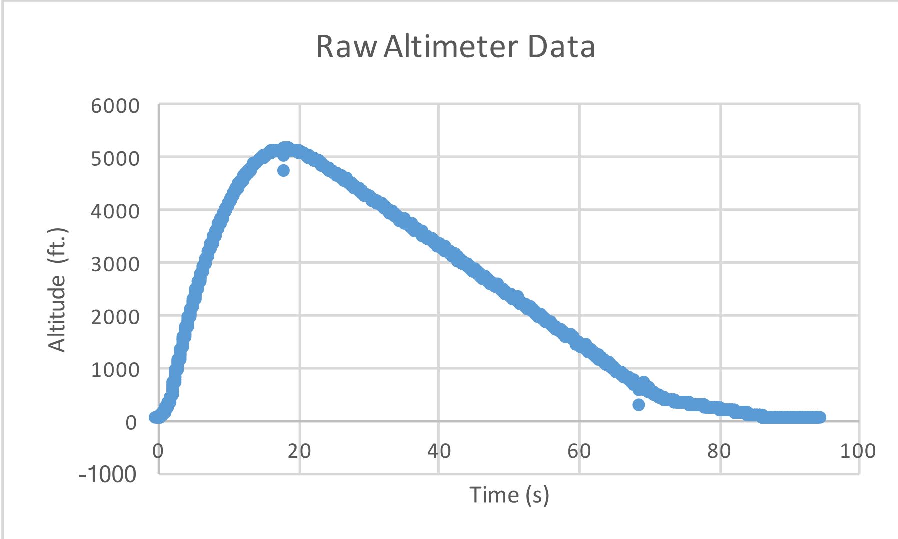

Figure 3: Stratologger CF Flight Data

The recovery system that was used on competition day incorporated a Fruity Chute CFC-18 drogue parachute and a Fruity Chute 96" Iris Ultra main parachute. Both these parachutes were connected with ½" Kevlar recovery harness and quick links at the connection points.

The drogue parachute successfully deployed after the first charge event, completely unfurled, and controlled the rocket descent in a linear fashion. The velocity under the drogue parachute was about 89.16 ft./s which is very similar to previous full scale flights. Similarly, the main parachute deployed after its first charge event and slowed the rocket to a descent velocity of 23.45 ft./s which is slightly higher than predicted, resulting in a landing kinetic energy of 154.21 ft-lbf (for the heaviest section). It is unclear exactly what caused this higher descent speed, though it is theorized that the main parachute did not completely unfurl during its descent. Figure 4 shows the rocket during its descent under main.

Figure 4: Descent Under Main

A comparison was done for all three full-scale flights including the competition flight to show the time it typically takes the main parachute to fully deploy and to also show the difference in descent velocities experienced. The results are summarized in Figure 5. It can be seen that the main parachute took just a fraction of time longer to inflate but the descent speed is drastically different.

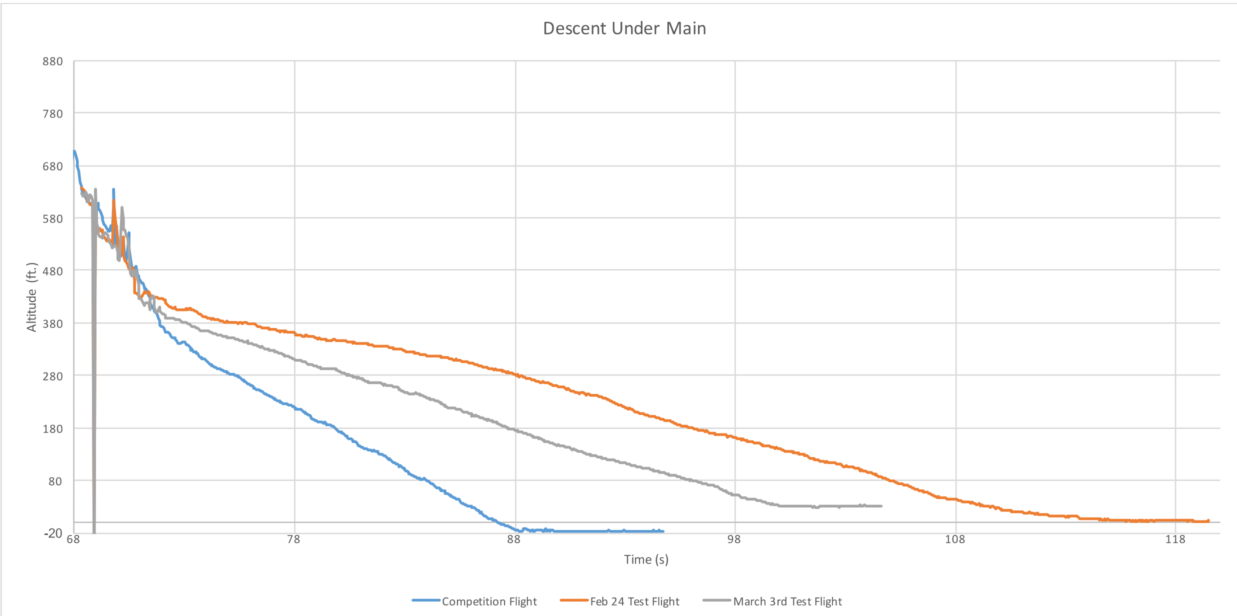

Figure 5: Comparison of Descent Under Main Parachute

When the rocket was recovered, there was no damage or dislodged batteries or broken internal components. All four black powder charges were discharged during the flight. A summary of the kinetic energies of each section upon landing can be seen below in Table 2.

Table 2: Kinetic Energy Under Main

Vehicle Section	Mass (lb)	KE (ft-lbf)
Fairing	18.06	154.21
Coupler and Forward Body	6.79	57.98
Aft	8.93	84.45

To determine the total drift distance from the launch pad, the tracker coordinates for the launch and landing were input into a mapping software to measure the distance. Figure 6 below shows the rocket drifted a total of 2127.84 ft. from the launch rail, which is within the 2500 ft. requirement. This landing zone was determined by the team however, based on where they found the rocket. It appears from the altimeter data that the rocket landed and then was dragged several feet by the main parachute before the team reached it. The last packet from the GPS tracker indicates that it was only 434 ft. from the launch rail, but it is suspected that there was an issue with the tracker that caused it to lose its GPS lock.

Figure 6: Drift Diagram

2.3 Visual Data

The flight started off mostly vertical. There was a noticeable amount of weather cocking shown pictures and videos taken. This was expected due to the heavy mass in the front. The rocket had also exhibited the same behavior in previous flights. However, the issue corrected itself and the vehicle continued to rise in altitude. The rocket reached an apogee of 5080 ft. (according to the official scoring altimeter). The vehicle then deployed the drogue and continue to descend downwards. At the altitude of 600 ft., the main parachute deployed. The vehicle and payload touched down approximately 0.4 mi. away from the launch pad. When the team arrived at the landing site, it was found that the parachute has dragged the rocket roughly 50 feet from its original landing spot. The content of the rockets was covered in wet mud but was intact.

Figure 7. Rocket after Landing

The rocket landing spot was within the predicted radius 2153.61 feet under 10 mph winds. Analysis of altimeter data showed that the descend rate under the main parachute was abnormally high compared to the two test flights. Upon inspection of photographs and videos of the flight, it was discovered the main parachute did not open to its full diameter (only 80% or 90% of its full size) and continued to do so till touchdown. The cause of problem is yet to be determined since the procedure for recovery preparation was followed properly at every launch attempts.

3 PAYLOAD

3.1 Design Summary

At FRR, the rover was not fully completed due to manufacturing delays caused by machinist and equipment availability. The rover parts were all manufactured, and the rover was assembled 28 March 2018. Electronics were soldered and assembled to the electronics tray on 31 March 2018. The rover was finished and operational before LRR, but the deployment system tests were unsuccessful. The safety officer made the decision that deployment would not occur at launch day and to be safe, the nosecone would be fully bolted to the fairing instead of held by the solenoids. Therefore, the rover was not deployed at launch day.

The rover chassis was completed after the FRR. The chassis housed all the electronics which were contained in an electronics tray. It was made of five assembled plates of aluminum to avoid any damage to electronics during flight and deployment.

The pieces were ordered from McMaster-Carr and were cut to length using a vertical bandsaw and a manual mill to finish the surface. Holes were added to the front plate for the camera and power switch for the rover using a CNC. The other plates only had holes to assemble the plates together using 4-40 screws, so they did not require as much precision.

The wheels were designed as three pieces as initially planned in the FRR. The spokes and hinges were already made at FRR, but the wheel hub was not made yet. The spokes and hinges were cut to length on a manual mill. The hole originally designed for the spring on the spoke was drilled using a regular drill press in the PRC, but the hole designed to assemble to the wheel hub needed to be more precise, so it was drilled using the manual mill. The holes on the wheel hinges were also made using the manual mill.

The wheel hub was made using the CNC. After it was made, there were some complications with assembling the springs as initially planned using fishing line. It was decided that the springs would be attached in the following configuration: one end would be attached to a key ring in the center of the wheel hub, while the other end was attached to a 4-40 bolt which protruded from the base of the spoke. It was also discovered that the springs deformed a lot more than expected so if given more time, a redesign would have occurred to cause less strain on the springs.

The stabilizing arm and arm hinge were 3D printed using a Fortus in the UAH machine shop. There were some issues with the design. The torsion spring used to fold the arm out during deployment did not line up with the holding piece on the arm, so an additional screw was put in the arm to hold the spring in place. Unfortunately, the arm was broken during integration in the rocket. This was due to the location of the torsion spring inside the arm hinge causing too much binding with the arm if not folded properly. A newer print of the arm was made on the 3D printer in the PRC along with a new arm hinge piece that would have a stopper to keep the arm from binding. The stopper piece also solved another issue, that the arm would sometimes interfere with the wheels causing improper movement during rover movement tests.

The tray was originally printed using a Fortus in the UAH machine shop, but it was reprinted on the 3D printer in the PRC after discovering the electronics did not align with the standoffs. This printer was smaller, so the tray was redesigned to be a bit smaller so that the printer could make it. It was also decided that the tray should also have UAH and labels for the electronics added to it in the actual print. Despite leaving plenty of room for the electronics, wiring made everything fit very tight and given more time, more wire management would have been planned in the design.

Figure 8. Rover Assembly

Figure 9. Wheel Assembly

3.2 Payload Data Analysis

The rover is complete with a 9-axis IMU, an altimeter, and a GPS to capture data throughout the mission. The data is recorded locally onto a micro SD card as well as streamed to the ground station using an XBee Radio. The onboard camera records video facing forward and saves to its own micro SD card. Using an analog pin on the rover's Arduino, the solar panel's voltage can be determined. However, due to the safety decision not to deploy the rover at the competition, no data was able to be recorded for the rover. If data was recorded, the altimeter would have been used to plot the rover's altitude vs time. This altitude would have been compared to data collected on the rocket to confirm the performance of the vehicle and detect launch and landing. The 9-axis IMU and GPS data would have been used to determine the vehicle flight and descent pattern. Once the rover was deployed from the rocket, the IMU and GPS would be used to track the rover's movement and confirm a distance greater than 5 ft. traveled. The onboard camera footage would then be used to confirm the analysis of the IMU and GPS. Throughout the mission, the rover would also record the voltage of the solar panel. Once the rover deploys the solar panel, it would detect a voltage between 6-9 V to confirm deployment.

3.3 SCIENTIFIC VALUE

A deployable autonomous rover offers significant scientific value. With autonomous operations, the rover can be utilized in very remote locations such as other planets without requiring human presence to control the rover. Once it is deployed on land, it can function and perform maneuvers on its own without any additional controls. With the onboard deployable solar panels, it can also recharge its own battery. This would be beneficial on planets that are somewhat close to the sun so the solar panels can open and use the sun to charge the battery powering the rover. Another benefit to deployable solar panels is that they can retract or close back up. This would be helpful to keep from damaging the solar panels during flight and while the rover is traveling the planet. Once the battery is low, the rover can stop and deploy the solar panels and let the sun recharge the battery. Once the battery is charged, the solar panels can close back up for protection against debris. The rover that the team built was developed in a manner that allowed it to operate autonomously with deployable solar panels.

4 PROJECT MANAGEMENT

4.1 OUTREACH SUMMARY

Over the course of the project, the CRW team reached 225 students through 5 direct interactions and additional 20 students and parents through indirect actions. These activities included building and launch rockets at the Girl's Science and Engineering Day hosted by UAH; building LEGO cars, making paper airplanes, watching bubbles be made with dry ice and soap, and tracing electrical circuits with Holy Family School hosted by UAH AIAA; building and launch rockets with the Cub Scouts at their STEAM Camp; working with sensors, radios, and their codes; working with students as they competed with their battery operated vehicles and mousetrap powered vehicles. As the CRW's last outreach, the team talked to students at the Rocket City Robotics Regional for the FIRST robotics competition about preparing for college, what it is like to be an aspiring engineer, and what the team has learned so far while building their rocket.

4.2 BUDGET SUMMARY

The preliminary budget was discussed in the CDR document. As the CRW team is local to Huntsville, AL there is no travel budget for the launch week. The ASGC has provided part of the project budget. The UAH PRC has matched what the ASGC provided. The total amount that is allotted for spending is $5000; this is due to some matching being used for Dr. Lineberry's salary and for facilities and administration. The projected total cost at CDR to field two full scale rockets and two payload rovers was $5708.36. The on-the-pad cost of one rocket, one rover, and one motor was projected at CDR to be $2046.34.

4.3 EXPERIENCE SUMMARY

The CRW team planned to use a CO_2 activated piston for rover deployment. This system, however, was not tested to completion in time for the competition flight. The testing campaign for the system ended after an unsuccessful deployment test in which the puncturing device was broken during the test. This was a result of several major modifications to the system to ensure a successful puncture of the cartridge and to enhance the safety of the system.

The first major change to the piston occurred after the first round of testing, where the small 8 lbf. springs were unable to produce enough force to puncture a cartridge. This resulted in needing a stronger spring which was in turn larger. The chamber housing for the cartridge was therefore modified to accept the larger spring. Due to a backlog of parts needing printing on the 3-D printer, a new chamber was not printed but instead the previous chamber modified. For the same reason, a new holding device for the puncturing screw also could not be printed. The puncturing screw and the old holding device were therefore epoxied to a washer, which was then epoxied to the top of the stronger spring. The failure mode of the system which ended the testing campaign came from a weak epoxy connection between the puncturing screw and the washer. When the screw made contact with the cartridge the bond was broken, preventing a successful test.

Prior to the failure of the puncturing screw, two unsuccessful tests were conducted with the modified cartridge. The first test concluded in a successful penetration of the cartridge; however, the deployment was unsuccessful. The point of failure for that test was due to holes in the forward section being left unplugged. This included two large holes in the piston and several holes in the transition piece. The ultimate reason for the holes being left unplugged was due to the team rushing to get a successful test before the deadline. The second unsuccessful test did not have a successful puncture of the cartridge. This was due to FOD being in the chamber, causing the spring to cock sideways before the screw could make contact with the cartridge. It is believed the FOD came from a hole being drilled in the chamber to allow for a safety pin. The safety pin would prevent the screw from puncturing the cartridge while the final bracket was being placed over the chamber. Once again, the time crunch to get a successful test off before the deadline led to the oversight of not inspecting the chamber after the hole was drilled.

While the system was not working by competition week, it is still believed the system could have worked if given more time. After the first unsuccessful test all of the holes were plugged with hot glue to prevent leaks. With the backlog for the 3-D printer fulfilled a new chamber that accepts the larger diameter spring could also be printed and include all the necessary safety features. Lastly, a new holding device could be printed for the puncturing screw. The new holder would be able to prevent the screw from separating and therefore guarantee it punctures the cartridge on a direct hit. With this the deployment test could be completed to see if a single cartridge could provide the necessary pressure. If not, a second system could be added inside the transition to double the amount of CO_2. If the system met its requirements the next step would be drop testing to expose the system to the max possible forces. The drop tests performed previously were deemed to exceed expected loading conditions and therefore would prove the system could survive the flight profile. Only after completing successful drop tests would the system be deemed ready for flight.

The flight avionics proved to be very reliable and not only ignited the ejection charges at the pre-programmed phases but also collected accurate altitude data on all test flights. The avionics system used redundant Stratologger CF altimeters which proved to agree with one another on each subscale and full scale flight within 5 feet of each other. Through deployment testing which was performed before the first full scale flight, the ejection charges which were needed were determined, however, it took several tests before finding the correct amount of black powder. It is believed that the pressure caused by the charge could have been dissipated through the piston so the ejection needed a larger charge than what was initially calculated. The recovery system itself had several advantages and disadvantages. It was theorized that the drogue parachute did not cause more drag than the separated vehicle which was why the descent speed during drogue descent was about 89 ft./s when it was intended to be 117 ft./s. Because the vehicle did not fall as fast as intended for most of its descent, this meant that the drift of the vehicle was difficult to control and predict and seemed to vary greatly with the winds.

The fin can functioned as designed, however, there were a few minor setbacks. One major setback was due to the fin can breaking during travel back from the first full scale launch location in Childersburg, Alabama. The fin can was packed, fins inserted, into a travel case and carried to the location. After the launch was cancelled, the fin can was removed and repacked for the trip back to Huntsville. Somewhere along the way, one of the supports holding the fin in broke, causing the fin to become essentially free. The probable cause was that things were loaded on top of the fin can, causing it to yield. This was fixed by carrying the fin can separately from other components to ensure it experienced minimal stress during travel. The only other major setback with the fin can was due to tolerance issues. The fin slots, as well as the centering ring, had to sanded to accommodate for the tolerance issues. The fin can's functionally worked perfectly as design. The fin slots allowed for different sets of fins to be interchangeable. This ensure that if a fin was broken, it can be easily replaced/change if need be. It also ensures that the center of pressure for the vehicle can be shifted, depending on the payload weight. The centering ring function of the fin can also worked perfectly as designed. It securely held the motor case in flight and allowed for easy removability after flight. Also, the slot that were removed from the fin can to save ABS plastic allowed for perfect placement for ballast at the aft of the vehicle. Overall, the fin can design and functionally worked perfectly as design.

The simulation results were fairly accurate. The only problem came when transitioning from the sub-scale to the full-scale vehicle. The method of predicting the coefficient of drag was via flight data and OpenRocket. With both data and simulations, the coefficient of drag was determined to be roughly 0.56 for the sub-scale rocket. When transitioning to the full scale, the first flight test reached an apogee of roughly 6900 ft., which was 1800 ft. higher than predicted. This is due to the coefficient of drag not translating from the subscale. This is believed to be due to the flow over the transition not having time to develop for the subscale, which produced more drag. The first full scale flight resulted in a coefficient of drag of approximately 0.33. However, with the given Cd for either flight, the simulations produced accurate results. Once the drag coefficient was changed to accurately represent the flight test data, the simulation results matched the flight data. With this error in drag coefficient, another simulation software, RASaero, was used following the first full scale flight. In order to confirm the result, a total of three simulations were conducted. These three simulations were OpenRocket, RASaero, and an in-house Monte Carlo simulation.

In terms of safety, the team have overall executed the project and launches well. Some things that could have been done better is the communication of the details of the launch procedure with the rest of the team. In particular, communication about the preparation of the recovery system could have been improved. The safety officer prefers that all black powder charges loaded at the end right before the motor installation. However, many of team members prefer to work the rocket aft to forward. The differences in the order does not affect safety in any form, however, this created some confusion and conflict between the person executing the procedure and the safety monitor. The confusion mainly slowed the team down at early launches when the team overall did not have much experience with rocketry. The team did not have issue with systems outside of recovery.

The rover team built an autonomous rover to travel at least 5 ft. before stopping and deploying solar panels. With this challenge came several concepts that worked out as planned and several that had to be adjusted or just were not operational. The rover was not deployable at the competition flight mainly due to the fact that the deployment system did not function properly, but there were also a few minor issues with the rover by competition day.

To reflect back on the process, there was a completely operational rover before the competition. The rover had plenty of clearance between the spokes and the chassis such that it could operate on rough terrain. The rover was tested in the grass with dirt and rocks, and it was seen that the spokes and wheel assembly were well designed in a manner that allowed it to gain traction in order to hold up the 7 lb. rover, and it also moved successfully on rough terrain. Another positive with the wheel and spoke design was its ability to properly expand when the rover was pushed out of the fairing of the rocket. The springs that are used to keep the spokes expanded were initially going to be tied to the opposite spring with fishing line. When the team was assembling the wheels, the team had an idea that would be easier which was to use a keychain ring at the center of all the spokes. This put just the right amount of tension on the springs in order for the spokes to collapse and expand. The downside of this process was that the springs became permanently deformed with prolonged use. This was countered by having plenty of spares to switch out before important testing.

As the assembly of the rover continued there were other positives that were experienced with the design and assembly. One of those was the lid and gear assembly that was used to reveal the solar panels. The lid had two tracks on it that fit down inside of the tray that was holding the solar panels. A motor and gear was on just one side of the lid, and for it to work, the track on one side of the lid had to be cut off. Once that was complete, there was a problem with the gear rubbing up against the inside of the chassis which would cause the gear to stop turning. This required a little bit of sanding on the teeth of the gear, but once that was finished the lid was fully operational as intended and our solar panels could be revealed. One more adjustment to the mechanical aspect of the rover was reprinting the stabilizing arm.

The initial stabilizing arm design extended too far and caused an interference with the spokes which would also cause the rover to drift to one side as it was moving. This problem was fixed by redesigning the stabilizing arm assembly. This included adding a stopper on the hinge so that the stabilizing arm could not extend past 90 degrees. Once this was redesigned and 3D printed, the stabilizing arm worked properly as intended.

The rover was completely assembled mechanically so the only thing left was the electronics. All of the sensors, code, and electronics were working properly before the competition as well, however they did not consistently work. There were a few different sensors aboard the rover which included an IMU, GPS, altimeter, and a camera. The sensors were writing to a micro SD card with accurate data and the camera saved all data to its own micro SD card. The code worked properly as the rover moved the required distance and then stopped and opened the lid to reveal the solar panels. The initial plan was to program the rover to detect obstacles so once that detection was made, the rover could make a slight turn to avoid the obstacle and keep moving. Due to the time crunch that the rover team was under, this was just not possible to implement. The rover was initially working and was functioning properly throughout several tests. After running several successful tests, there seemed to be an electronic problem. After a series of continuity checks, the team came to the conclusion that there was likely a problem with the motor shield. There was an initial motor shield as well as a backup motor shield and both shields were non-operational after several tests. Since there were not any people on the payload team that have a lot of experience with electrical components, there's a possibility that there may have been an issue with the soldering and wiring that could have caused the motor shields to burn out. In addition to this, it is also possible that there was a open connection that touched against the aluminum chassis, shorting the shield. If more time was available to the team, a more thorough investigation of the electronics would take place.

4.4 Lessons Learned

The competition was very challenging, but also incredibly rewarding. The UAH USLI team is new to the competition every year, but the lessons learned while working on this project will be taken with the students throughout their careers. One of the biggest issues that the team agreed on was the lack of proper scheduling. Most of the team was focused on finishing their individual tasks and then waiting for more items to be assigned to them. Compounding the issue, most of the team only thought about the internal deadlines for the PDR, CDR, and FRR work. If more internal deadlines for individual systems were made and enforced, and there was a better distribution of work between all the students, there could have been a much steadier amount of work instead of a lot of work at the last minute. Many members should have kept the big picture in mind when working on their tasks. This would have additionally helped give the team extra time in the case of inclement weather or delays due to equipment failure; both of which happened through the duration of the competition.

This issue with scheduling affected both subteams. The launch vehicle team was responsible for a lot more system designs, had there been a stricter schedule, there would have been more time for subscale testing and individual system tests before the full scale flight. The payload team made the mistake to put their system at a much lower priority than launch vehicle, which made the last few weeks before the competition very stressful for its members. This is a big reason why the rover was not deployed on launch day. Both teams had access to the machine shop, but because of improper planning, there were many times when nothing was being machined. This lead to a huge demand for machined parts in a short amount of time. Quality of the parts suffered as a result, and many pieces did not fit as intended. Most of the rover was not machined until after the FRR because of this failure in scheduling. The deployment system parts were also not printed until after FRR, which is partially why the deployment did not work. The late time crunch did not give enough time to redesign the system. Luckily, the rover still worked as planned.

The other big lesson learned was to improve communication between members and teams. It can be difficult to keep everyone on the same page and make final decisions when there are so many people on the team. The diversity of each of the team members is a great benefit as it leads to a lot of new ideas. However, the various viewpoints can also lead to arguments and ultimately complicated and delayed the bigger decisions. The team members in charge of making decisions did a great job, but it was a difficult task nonetheless. Additionally, despite the division of work between launch vehicle and payload, everyone on the team should have a decent understanding of the entire rocket design, to the point where anybody could present any part of the rocket. Not understanding this early on the year led to many single points of failure in the subscale build and with other subsystems later in the year. If a certain student was unavailable to answer questions, mistakes or delays would occur in other subsystems dependent on that part. Better communication between subsystem teams could have prevented several of the redesigns that took place.

There were big communication failures between the launch vehicle and payload teams throughout the entire year. The night before the CDR was due, it was discovered that the rover did not properly fit inside the fairing and piston assembly. A simple misunderstanding with the length constraint caused a new simulation and slight change to several parts in the main launch vehicle. It was extremely stressful to find this out so close to a big deadline. There was also a problem when it came to ordering LiPo batteries and solar panels. This was because there was not enough communication between students to confirm that the orders were actually placed. Several issues like this could have been avoided with better documentation and communication. Revision numbers were attempted for new designs and google drive was used to keep files between students, but this was another issue with single points of failure. Sometimes, the newest files were not uploaded, so only a few students on both payload and launch vehicle had access to the correct files in CAD.

It takes some time to keep up with meeting notes and putting information in excel spreadsheets, but it is worth it to avoid wasting time fixing mistakes due to miscommunications. Therefore, this documentation is extremely important in professional environments to keep moving forward with projects. This was done well the first semester, but the second semester was more reliant on the meetings in person, without the documentation. If the team were attempting the competition again next year, there would be more time dedicated to documenting CAD revisions, manufacturing plans for individual parts, test procedures for the subsystems, and managing file locations for CAD and other software used. This would help keep everyone on the same page, while also making the documentation for NASA much easier to compile.

When it comes to designing, simple designs are almost always better than complicated ones. The rover and launch vehicle were unique and stood out from the other rockets and rovers, but they could have been designed in a much simpler way. The complexity in designs caused many issues for the team throughout the year. With more time, these issues might not have been a problem. The team is limited to a year to design, order, and build all the components of the rocket, and so a slightly simpler design should have been better considered. In addition to time constraints, there are also constraints in work and equipment availability. At any given time, some of the equipment was unavailable to the team, either because it was broken or being used by others at the school. On top of all this, students also had other projects and classes to focus on.

As mentioned before, manufacturing caused a lot of issues for the team. Parts should have been designed with manufacturing in mind. The rover team struggled with a lot of this; they had several parts that were impossible to machine. Originally, the rover chassis was designed to be machined out of a single block of aluminum. This was discovered much later to not be possible given the machine shop capabilities. A lot of money was wasted buying blocks that could not be used, and then 5 smaller plates had to be ordered later. Launch vehicle did not account for proper fit between parts and more printed test pieces would have avoided spending extra money and parts printing slight variations of parts. Also, there should have been more research on electronics and materials that were ordered. For example, there was a wasted McMaster-Carr order because it was not discovered until after delivery that the pieces had a ± 1-in. tolerance. This lead to the ordered pieces were too short. Some of the electronics on the initial rover design could not even be bought anymore because the supplier no longer made them. These issues were discovered way too late, and a little more time dedicated to research could have avoided some redesigning.

There may have been many lessons learned this year because of negative reasons, but there are many positive reasons as well. As said before, many lessons learned will be taken with the students throughout the career. Some of the students had little experience with the PDR/CDR format before this class, and now they are very familiar with it. Many of the students learned new software, like open rocket, that they never needed before and they became more skilled with the software, like CAD, they have used in other classes. It was also rewarding to use many of the theory and calculations, used heavily in a classroom setting, applied to an actual design class that results in a physical product. The students learned how to build a rocket, how to easily integrate it, and learn how to design and build with a focus in safety. It also makes for an impressive project to talk about in interviews and mention in resumes. With enough determination and work, success can be earned.