Midwest Collegiate Rocket Competition

2nd Place – Raider Rocketry

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Student teams will be required to design, construct and fly a high-power "true scale model" of a current or retired rocket/missile system used somewhere in history. The rocket is required to use electronic deployment of the recovery parachute and a motor deployment as a backup. The apogee was limited to a range of 2500-3500 feet. The winner of the flight portion of the competition will be the team whose rocket completes a successful flight and whose rocket achieves an apogee closest to their predicted apogee, as recorded by a competition-provided flight recorder. Simulations and flight analysis were done using OpenRocket, a widely used and reliable software package for flight performance prediction. Several different launch conditions were modeled, with varying factors such as wind speed and launch angle. From this, we estimated that out rocket would reach an apogee of about 2600 feet. After launch, the recovered data indicated that the rocket reached an apogee of about 2900 feet.

Problem Statement

Per the competition parameters, our team was to construct and fly a high-power scale model of an existing rocket or missile used at some point in history. A scale model is generally a physical representation of an object, which maintains accurate relationships between all important aspects of the model, so all of the proportions of the model match those of the real-life object being modeled. The rocket had to use electronic deployment of the recovery parachute and also incorporated a motor deployment as a backup. All structural components and materials must be obtained from reputable high powered rocketry vendors or have engineering analysis to demonstrate their suitability must be included with the design. A portion of the overall competition score is awarded for the flight portion, with a given score representing the accuracy of the actual flight against the predicted apogees provided by each team before launch.

Raider Rocketry would like to thank WSGC and Dr. Anand Vyas for their funding and support

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Background Information

The Mercury-Redstone Launch Vehicle was originally based off of the U.S. Army's single-stage Redstone ballistic missile system, which was a nuclear-capable short range ballistic missile system in service from 1958 to 1964. The original Mercury-Redstone Launch Vehicle was 83.38 feet in length and weighed 66,000 lbs. at launch. Several modifications were made to the original Redstone to enable it to carry astronauts to a suborbital spaceflight. The Mercury-Redstone program culminated in the successful launch of the first American astronaut, John Glenn, into orbit. The original ballistic missile system lacked the required thrust to achieve suborbital altitudes. Figure 1 depicts a Mercury-Redstone during launch.

Figure 1: Mercury Redstone system directly after launch

Several changes had to be made in order to achieve higher altitudes, as well as accommodate an astronaut. The original Redstone first stage was replaced with a modified version called the Jupiter-C which had a higher fuel capacity. A small one-man crew capsule was developed and installed, which included an in-flight abort sensing system that would automatically eject the crew in the event of a catastrophic failure by triggering boosters mounted on top of the crew capsule. Fuel pre-valves were eliminated because they could cause an unintentional abort signal. In addition, it had initially been planned to recover the booster section by parachute, though due to a lack of funding and testing for this recovery system, it was never implemented. Instead, a stability ballast was installed in the booster where the parachute would have been housed. The guidance system as also updated, using a design based off of the LEV-3 guidance system from older German V-2 rockets, because of its simplicity and reliability. In total, roughly 800 modifications were made to the Redstone design in adapting it for the mercury project.

Design

Assumptions and limitations. There were several assumptions and limitations taken into consideration in the design of this rocket. These assumptions include that the fins are thin flat plates, and that the rocket is thin compared to its length. Also, the rocket must follow the competition restrictions as previously described in the problem statement. In order to produce a safe and accurate design, several adjustments and modifications were made to the scale model, as well as several details added to closely represent the real Mercury Redstone. These features are outlined in the sections below.

Body tube. When determining the overall scale of the rocket, the main constraint was the body tube. The body tubes that were considered from ApogeeRockets.com came in specific diameters, which drove the determination of scale. In the early planning stages, it was decided that the rocket should be around 4 feet tall. This led to using a body tube diameter of 4 inches and a scale of 17.5:1. The choice of material for the body tube was another important consideration. In the end, the material of "Blue Tube" was chosen due to its relative high strength compared to other paper tube types and its low cost compared to fiberglass and carbon fiber tubes. This material was also chosen because of the accessory parts also available from ApogeeRocket.com such as the electronics bay and centering rings. A potential risk that is observed when using blue tube however is the danger of moisture absorption and swelling in humid environments. This can cause a serious deterioration in mechanical properties of the body tube, as well as structural stability of the rocket as a whole, increasing the likelihood of failure upon launch or parachute deployment. To address this problem, the body tube was coated in a protective lacquer to repel moisture.

Fins. The primary influence on center of pressure (CP) for the rocket are the fins. After several flight analyses were performed in OpenRocket, it was determined that the true scale fin size was too small to produce a stable and safe design. On the real Mercury Redstone, as shown in Figure 2, the fins provided sufficient stability because the square protrusion at the bottom of the fin is a control surface. Because model fins are rigid and fixed, the solution was to scale up the fin size to 150% of the scale model, while keeping the same fin profile, resulting in an unchanged model scale of 17.5:1 and a fin scale of roughly 11.5:1. This adjustment, increasing the fin surface area lowering the CP, produced successful results in OpenRocket. The fins of a Mercury Redstone have a unique and characteristic profile, so it was important to keep the model fin profile as close to the real shape as possible. Polycarbonate (Lexan) was used as the material for the fins because it is easy to cut/machine and therefore easy make freeform profiles.

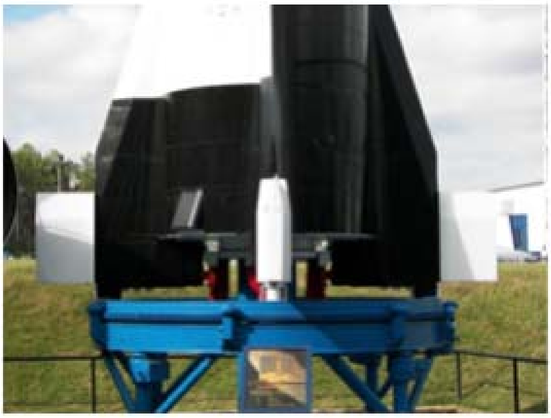


Figure2: Fin shape of the Mercury Redstone, including paint scheme

Electronics bay. The electronics bay of the rocket includes a hand-machined sled that can be easily accessed for maintenance. Two 9V batteries are mounted on the sled, with pre-drilled holes for installing the competition altimeters. These are wired to a key switch mounted on the side of the electronics bay, which allows the entire assembly to be activated on the launch pad, with no need for disassembly.

Nosecone. One of the most complex and detailed features of the Mercury Redstone is the capsule/nose cone. In order to create a realistic replica, it was decided that the nosecone for the build should be 3D printed. Working with MSOE's Rapid Prototyping Center, the nosecone was printed using a technique known as selective laser sintering (SLS), using a glass-filled Nylon 12 material. Design considerations had to be made in order to assure structural integrity of the 3D printed capsule during flight and landing, as well as to accommodate limitations of the 3D printing process.

The center of pressure for the model was estimated using OpenRocket. Several changes were required to model the nosecone accurately. One such change was the removal of detail from the surface of the capsule. Originally, the capsule surface featured a corrugated surface made out of nickel. It also featured a single window for the astronaut to see out of. For the printed design, these features were omitted due to limits with the printing process, as well as to simplify the aerodynamic model for more accurate predictions.

Another design consideration involved the escape tower trusses, which is colored red in Figure 3. A scaled version of the truss structure would not be structurally sound using this 3D printing method, so the entire inner section of the truss was filled. Care was taken to make sure the original structure of the truss would be raised on this filled in portion to add to the realism of the model. The final change was the removal of the shock cone spike at the very top of the escape tower. Originally in place to deal with the aerodynamics of breaking the sound barrier, a scaled version of the spike would be entirely too thin to survive the landing. In addition, this flight will be subsonic, meaning the spike will serve no functional purpose. Therefore, a removable display spike will be used, and removed before the flight. As aforementioned, the process used for printing the nosecone was selective laser sintering, or SLS. SLS is a method of 3D printing in which powdered plastic is melted and deposited layer by layer to form a 3D shape. This method was selected mainly for the properties of the material used, which is a glass-filled Nylon 12. Nylon 12 is a high-strength polymer used by the Rapid Prototyping Center for functional prototype testing. The material strength is further improved with the addition of glass beads to the powder mix. This added strength comes at a cost, however. In this case, the addition of glass beads to the mix can have an undesirable effect on the roughness of the surface. This roughness makes small details on the capsule surface impossible to print, and degrades the aerodynamic characteristics of the capsule. To deal with this, the model will be sanded after printing, and then painted over for a smooth surface.


Figure 3: 3D model of the nosecone used for printing

Deployment and recovery. As one of the objectives of this project is recovering the rocket in an undamaged and ready-to-fly state (minus fresh motors), much consideration went into making sure the rocket had a safe return and was able to be located easily. The GPS system is designed to be able to be used even in areas with unreliable cell phone/internet connection. The deployment mechanism used to release the parachute incorporates a black powder charge intended to separate the fuselage, a shock cord to tether the separated rocket, and an emergency powder charge, should the electronic deployment of the main charge fail. The emergency charge will be included when the motor is installed prior to launch. In order to simplify the construction and deployment mechanism, the electronics bay was to be permanently attached to the upper body tube and nose cone section. Because of this, the parachute and deployment charge are packed under the electronics bay resting on the top of the upper motor centering ring. Upon deployment, the rocket will separate into two halves with the parachute and shock cord attached at the bottom of the electronics bay. The alternative was to pack the parachute and deployment charge above the electronics bay while the emergency charge would be at the top of the motor. This would have resulted in two shock cords and separation into three sections upon deployment (nose cone, electronics bay and motor section), which was deemed overly complicated and unnecessary for the objectives of the flight.

Besides simplification of construction and deployment, another advantage to this design is that the main deployment charge is located in the same position as the emergency charge. Therefore, the design will behave the same way upon deployment weather triggered by the main charge or the emergency charge, making for a more reliable deployment mechanism. The parachute to be used is a skirted circular 52” silicon coated rip-stop nylon parachute manufactured by LOC Precision Rocketry. The parachute has a cross section of 29.5ft^2 with a carrying capacity of this parachute is 6-12 lbs., which will be sufficient for the 7.1lb rocket. When modeled in OpenRocket, this parachute resulted in a descent speed of 16.4ft/sec, which should be slow enough for the rocket to sustain no damage on impact.

Open rocket model. Figure 4 is an image of the developed OpenRocket model that was used in out flight simulations. The rocket would be 54 inches in length, had a maximum body diameter of four inches, and had a launch weight of about 7.1 lbs.

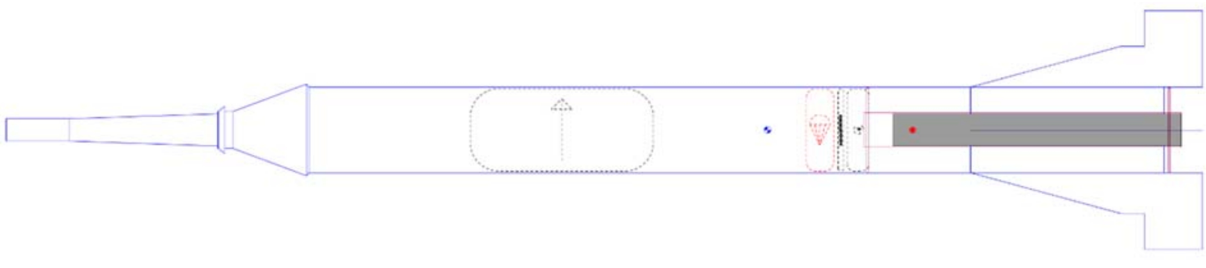
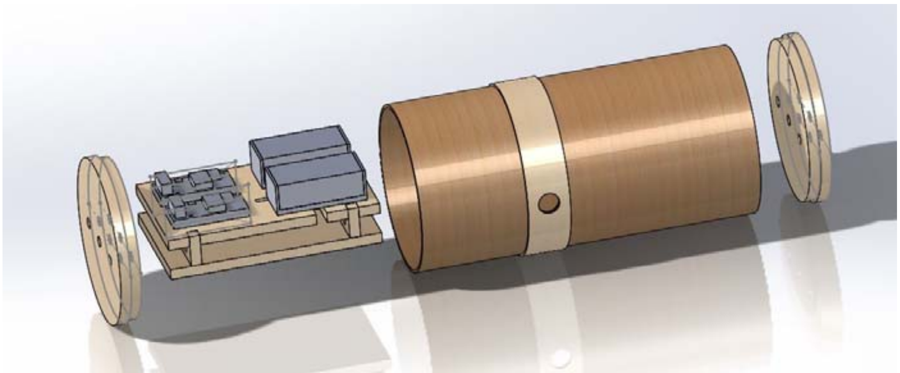


Figure 4: OpenRocket model of the Mercury Redstone. Parachute location, center of gravity, and center of pressure are shown

Construction

Electronics bay. The upper half of the electronics bay (Ebay) was epoxied to the upper body tube/nose cone section, so that the payload can only be accessed through the lower Ebay cap. In addition, the Ebay was modified by adding a rear mounting plate, so components could be mounted on both sides of the sled. This was done in order to accommodate the GPS system. The Ebay was modeled in SolidWorks to ensure that there was room for mounting all of the components. The altimeters and GPS components will be attached through mounting holes and fasteners, and 9 volt batteries will be attached in battery holders fastened to the mounting sled. Figures 4 and 5 are models of the planned Ebay assembly:



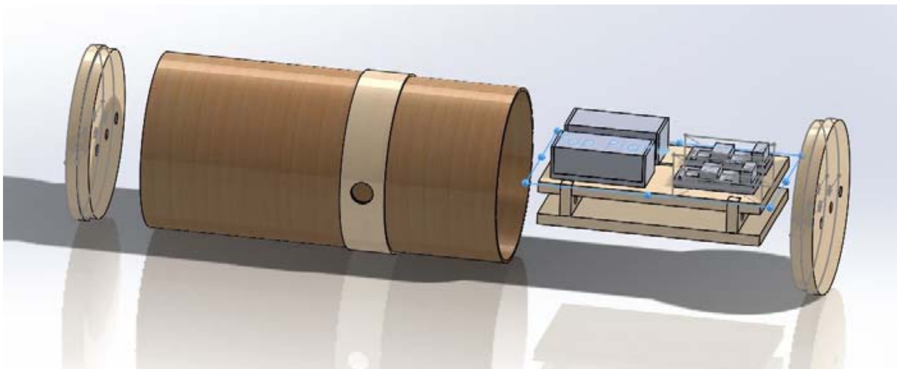


Figure 5 (top) and Figure 6 (bottom): 3-D Model of the layout of the Electronics Bay

Fin construction. For the fins, a stencil was created from the design stated above. The fin material was Lexan sheets which was low weight and durable in regards to strength. The design was drawn onto the sheets and then cut out using a band saw. In order to detail the Lexan sheets, a Dremel was used with two ends-sander and rotating blade. After the fins were finished and detailed, the body tube was cut using the rotating blade Dremel bit. By placing two 2x4 blocks on each side and having two extra people holding the tube, it was securely cut as fin placement and accuracy was of utmost importance. Similar to cutting, the fins were glued by incorporating the blocks on each side. Wood was placed on each side of a pair of fins in order to obtain the same height and accuracy as desired from the design. Figure 6 shows the fins under construction, layered in fiberglass as a form of reinforcement.

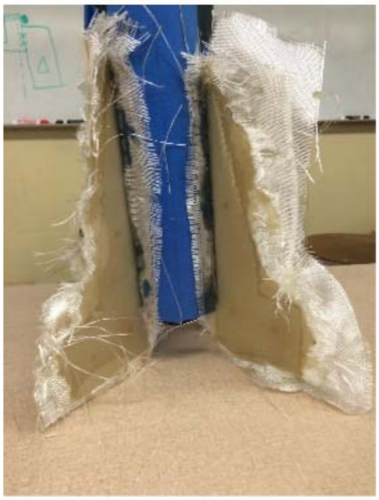


Figure 7: Fins during construction. Layers of fiberglass added to increase rigidity

Flight Performance

Apogee predictions. With the OpenRocket model completed and changes made during construction accounted for, we could accurately model several different flights. Each modeled flight is modeled with specific atmospheric characteristics. The calculated apogee predictions for the OpenRocket model are shown in Figure 7, with the wind speed and barometric pressure varying between predictions.

12mph	2,823	2,770	2,729	2,688	2,653
9mph	2,829	2,782	2,740	2,699	2,655
6mph	2,837	2,792	2,748	2,706	2,664
3mph	2,843	2,798	2,754	2,711	2,671
0mph	2,846	2,800	2,756	2,714	2,673
Wind speed (y), Pressure (x)	25inHg	26inHg	27inHg	28inHg	29inHg

Figure 8: Predicted apogees based on wind speed and barometric pressure

Predicted flight profile. Figure 8 is a graph of our predicted flight profile.

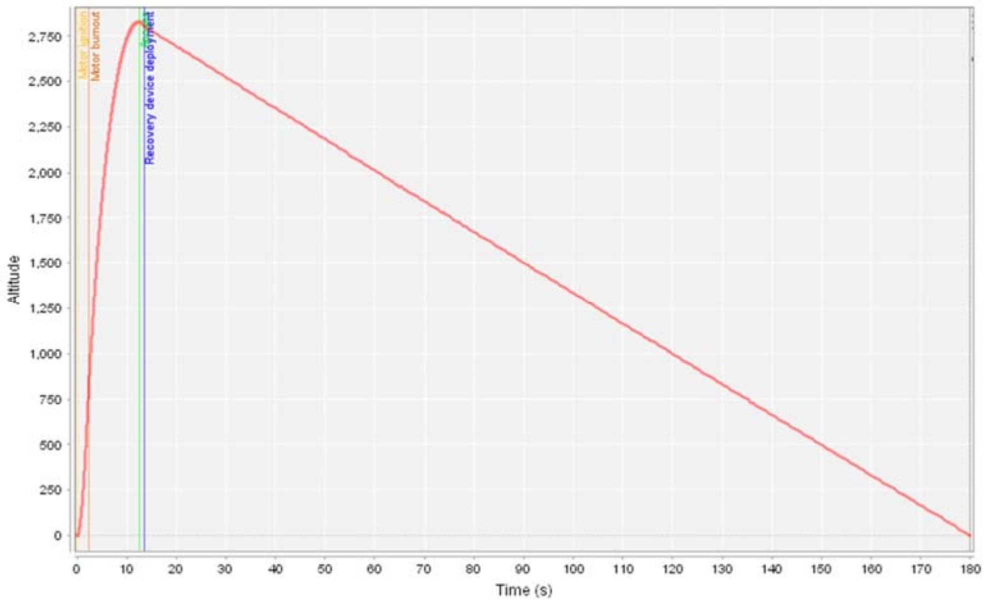


Figure 9: Plot of predicted flight altitude over time based on modeling in OpenRocket

Actual flight. According to the models we had previously run, we predicted that our launch apogee would be around 2600 feet. After launch, the provided Raven 3 altimeter reported that, in fact, our rocket had reached around 2900 feet. The flight profile for our rocket can be seen in Figure 10.

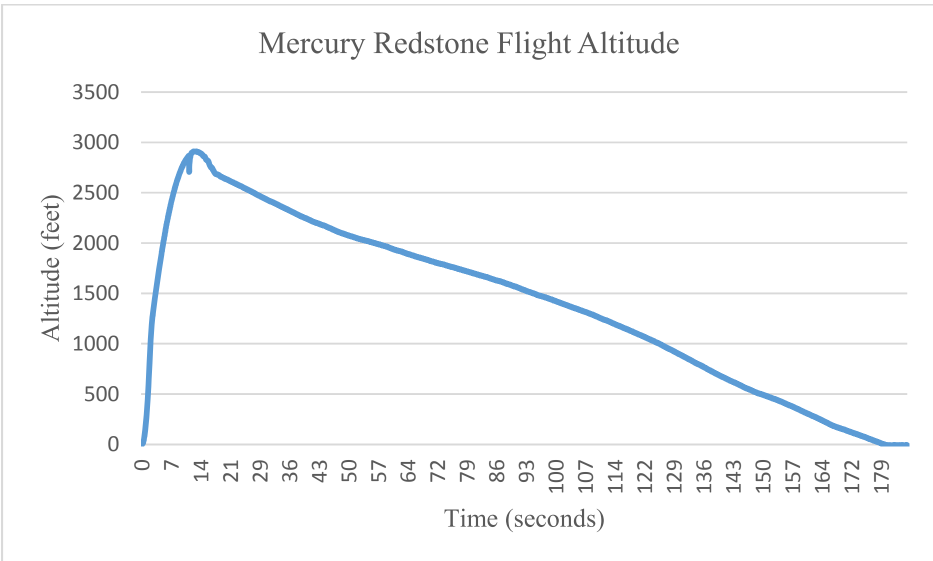


Figure 10: Rocket altitude over the flight time. Entire flight time around 180 seconds

Analysis. Overall, our rocket altitude reached about 300 feet higher than we had previously predicted. Several factors may have contributed to this discrepancy. We believe that the issue was the nosecone, which was, by far, the most complicated part of the rocket. In the OpenRocket model, the nosecone is modeled as several, solid pieces. This is not entirely true, though, as there are multiple surface details that could not be modeled into the OpenRocket simulation. These include truss detail and fake boosters on the nosecone. We modeled the rocket as close as we could, but there were limitations with the software. Due to this, we believed that the OpenRocket model encountered more air resistance than the actual rocket experienced, resulting in our rocket over shooting its predicted apogee.

Conclusion

This objective of this build was to model a real rocket/missile with the highest possible accuracy, in Raider Rocketry's case, the Mercury-Redstone. Although several design challenges had to be overcome in scaling the model, the appearance and detail closely resemble the Mercury Redstone when compared with other Mercury Redstone models. Many other design decisions, such as electronics bay positioning, parachute choice and rescaling of the fin size were made by flight modeling and trial-and-error in OpenRocket.

While we were not as close to our predicted altitude as we had hoped, the challenge of replicating an iconic rocket system was an extremely rewarding experience for the team. The design problems with the nosecone and fins allowed the team to learn new skills in construction materials and problem-solving techniques.

As a whole this project has posed a unique set of challenges to be overcome, as well as an abundance of opportunities for gaining experience and skill development. As most of the team members first custom high powered rocket build, each team member has certainly gained valuable experience in model rocket design, developed technical and hands on building skills, and ultimately gained a better understanding of rocketry. These new skills and experiences will no doubt serve the Raider Rocketry team well in the future. Raider Rocketry expresses its highest gratitude to WSGC for providing resources and making this valuable opportunity available to students and model rocketeers, and wishes the best for all teams and individuals involved in the Collegiate Rocket Launch event.