RoverSat

RoverSat’s mission was to take altitude and temperature readings during flight and through these readings autonomously deploy a rover that would photograph the landing site.

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1.0 Mission Statement
During flight, RoverSat will take solar radiation measurements, as well as altitude and temperature readings throughout ascent and descent. This data will indicate how temperature and solar radiation fluctuate in different layers of the atmosphere. Upon landing, a rover will be deployed which will function autonomously for at least five minutes. Throughout its maneuvering, the Rover will photograph the landing site and surrounding area. The Rover will take at least two pictures.

2.0 Mission Requirements and Description
RoverSat will weigh at most 1.5 kg and contain an autonomous rover that is designed to photograph the landing site. During flight, solar radiation measurements will be taken using a Li-COR 200SZ Pyranometer and compared to altitude and temperature data, measured using an ASDX015A24R altimeter and two LM34CH Precision Fahrenheit Temperature Sensors. Upon landing, a rover will be deployed using a mechanism controlled by the altimeter and temperature sensors. The Rover will maneuver around the landing site for at least five minutes and take at least two pictures of the landing site.

Figure 1: Rover design

Figure 2: Structure Design
3.0 Payload Design

The Structure is built out of 0.2 inch thick, black foam core. The octagonal structure is 10.5 inches tall, and has a diameter of 6.9 inches. Each panel is 2.82 inches wide and the caps are 6.5 inches in diameter. The panels are folded at an interior angle of 135 degrees. A 0.35 inch diameter, 12 inch long rod runs along the side panel by the micro servo, located 0.9 inches in from the edge of the structure. The rod is secured using two metal washers and nuts and is stabilized by circles cut from a thin, flexible, plastic cutting board. The caps are secured by 16 brackets, with nine located on the top and seven on the bottom. Two of the brackets on each end are directly attached to one panel of the lid. A nut for each of these brackets was embedded into the caps with five-minute epoxy so that the lids would be easily removable. Twelve of the brackets are only attached to the body of the structure, allowing for the body to open freely so that the Rover can deploy. The brackets prevent the caps from sliding out of the structure during flight.

Figure 3: Bracket

The mechanism consists of two sets of aluminum interlocking teeth, held together by stainless steel pins, which are attached to the arms of the servo with 40 lb. fishing line. The mechanisms are each located 2.5 inches, lengthwise, away from the edge of the structure, and are 3.433 inches apart. The micro servo is centered between the two sets of interlocking teeth, and has 16oz/in. of torque which provides a sufficient amount of force to pull the two pins free of the interlocking teeth. Each interlocking pair weighs 8g and the micro servo weighs 32g. In order to ensure the opening of the structure, regardless of the orientation in which it lands, a metal tape measure was fixed to the center of the outside of the structure using nuts and bolts. (See figure 2)
The Rover weighs 0.601 kg, including the weight of other subsystems’ components housed inside the body. The body was made out of Carbon Fiber donated by Composite Technologies Development in Lafayette, Colorado. It is approximately 4 inches long and 4.5 inches in diameter. The components were positioned so most of the weight fell below the axle, providing a bottom-heavy cylinder. Thus, when the wheels, turned the body did not. The battery is epoxied to the bottom of the Rover because it has the most weight. There are ceramic heaters placed on and around the battery in order to maintain a stable temperature. The camera and the electronics board are places on either side of the battery to allow heat from the battery to transfer to the components. Two motors are mounted to the sides of the structure in opposite directions so that the combined torque of the two motors is applied in the downward direction, and the torque of a moving motor would cancel the torque of a stalled motor. On the end of each motor is a miter gear which is in perpendicular contact with another miter gear. This gear has an axel that runs through the support nut and out to the wheel. The structure’s support system was constructed using a custom drilled nut with 1/8 inch aluminum rods to hold it in the center of the structure. The hemispherical wheels were fabricated using the CNC Milling Machine out of aluminum 6061 and have a radius of 2.5 inches. They also have interior supports for more strength and stability. The wheels were coated in clear and yellow Plasti-Dip rubber coating for grip. Vellum, secured with 2-Ton Epoxy, was used to cover the ends of the wheels and the ends of the body, so that if the Rover were to land in grass, the grass would not get tangled in the spokes. A hole was cut into the lower part of the carbon fiber for the placement of the camera. Another hole was cut in the top of the body for easier access to the interior electronics.
The flight board consists of an AVR microcontroller (ATmega32L) connected to a small sensor package, made up of the altimeter, temperature sensors, and pyranometer. This set-up was designed to detect atmospheric changes during different phases of the flight. This board also contains a relay controlled heater system, programmed to maintain the internal temperature within +/- 10 degrees of room temperature. The flight board’s purpose is to log data during ascent and descent and to signal the Rover board and initiate the micro servo after landing. The micro servo then actuates and allows the box to open. In order for the Rover to deploy, all of the temperature readings must be above freezing and the altimeter readings must stay within a certain percentage, indicating that the satellite has landed. The Rover board consists of an AVR microcontroller (ATMega32L) that is connected to the flight board utilizing a disconnecting communication device. The Rover board, once separated from the flight board, has the capability to control both of the Rover’s motors, separately or together, using a preprogrammed path. After a series of moves, the microcontroller activates the camera which then takes a picture. This sequence of events is then repeated until the end of the battery life.
4.0 Student Involvement

Leah Crumbaker: Aerospace Engineering- Project Manager. Organized RoverSat, monitored budget, oversaw testing and completion, Rover components modeled using Solid Works, and completed documentation and presentations.

Loren Schuessler: Aerospace Engineering- Project Manager. Organized RoverSat, assisted the Rover team in construction and assembly, and did presentations.

Patricia Femmer: Aerospace Engineering- Science Team Lead. Developed the science experiments, prepared data analysis and expected results, and assisted software.

Michelle Tamayo: Aerospace Engineering- Structure Team Lead. Developed the cap ideas, the mechanism for RoverSat, and made Solid Work pieces for structures and mechanisms, machined the interlocking teeth, and tested the structure and mechanism.

Steve Wilson: Aerospace Engineering- Mechanisms Team Lead. Machined the interlocking teeth and pins, tested the structure with the mechanisms, and made a few structures.

Bill Bixler: Aerospace Engineering- Software, Power, and Thermal Team Lead. Wrote the flight and rover software, made both electronics boards, designed the thermal and power systems, and completed the cold test.

S Lawrence-Simon: Aerospace Engineer and Electrical and Computing- Rover Team Lead. Designed, built and tested the Rover.

5.0 Testing Results

For structure testing, six similar octagonal structures were created. Each had approximately 1 kg of weight either loose or secured within it. These structures were tossed off a second-story balcony onto either cement or grass. The structures with the weight secured by tape survived the first few Drop Tests. Those that had the loose weights were damaged from the weights moving rather from the impact. Each structure was tossed off of the balcony at least four times. After the Drop Tests, each structure was subjected to the Stairs Test. The structure and mechanisms were tossed down a flight of stairs to see what damage would occur and to see whether or not the pins would remain in the interlocking teeth until the servo was activated. The structure and mechanisms survived these tests.
The first tests of the mechanism involved the pin and interlocking teeth being attached to the structure with 1kg attached to the inside. This testing revealed the need to add a metal tape measure to the outside of the structure so that the structure would “spring open” no matter what landing orientation was encountered. Later testing included the micro servo. The micro servo was activated during these tests by wires protruding from the seam of the structure, added to the design only for testing. Failed tests revealed the need to adjust the length of the fishing line was adjusted until the line was taut. After this adjustment, it would consistently pull the pins from of the interlocking teeth. Hot glue was affixed to the fishing line to prevent it from loosening. As a precaution in case the mechanism failed upon landing, a manual deployment switch was added to the outside of the structure so that the structure could be opened manually.
All electronic components were tested individually using the AT5TK500 Programming Board before being placed on the appropriate electronics board. Everything was then tested together. The first camera (Radio Shack FlatFoto 3MP Camera) encountered problems on the Rover board, and those problems were never identified, so it was replaced twice with a Che-ez! Snap Mini Digital Camera before it functioned properly. The first altimeter did not work properly, so it was also replaced. The second altimeter functioned properly. The microcontrollers were tested through a variety of simulations regarding the flight and Rover operation. A Cold Test of the flight electronics inside a mini-fridge revealed that the heaters functioned properly and kept the batteries at an adequate temperature. This test also revealed that the pyranometer data became unreliable at colder temperatures. The pyranometer’s performance also skewed the altimeter readings, so the pyranometer was scrapped due to lack of time to fix the problem. After the pyranometer was removed, all the data returned to expected values and everything functioned properly.

The Rover motors were tested separate from the Rover itself, and when those functioned satisfactorily, the wheels were attached for further testing. The Rover became fully functional immediately after the University of Colorado’s Launch Readiness Review presentation. However, when the Rover was tested on grass, it was revealed that there was not enough ground clearance for it to drive. Due to the lateness of this discovery, there was not enough time to correct this problem. However, the Rover worked well on concrete and other flat surfaces. The landing site would determine the Rover’s success.

After the individual systems’ tests, a Cold and Full Systems Test was performed. The structure and flight electronics were placed in a large cooler with 25.6 pounds of dry ice. After three hours, all of the components were still functioning well, and the mechanism was still able to open. Everything was then tested again, including the Rover this time, and everything functioned properly.

### 6.0 Mission Results

RoverSat completed one out of its original four objectives. The first objective was not met due to the pyranometer not being able to function properly at cold temperatures and affecting the rest of the data. The pyranometer was removed in order to allow the rest of the RoverSat missions to have a possibility in succeeding.

The second objective was not met due to the safety of the balloon and other payloads. The components were activated continuously on the way to the launch site due to a short underneath the flight board that was later discovered (See section 7.0). In order to prevent the structure from opening and the Rover from deploying during flight, all of the batteries were disconnected and the activation pins on the Rover were removed. With these changes, no power was supplied to the flight board and thus temperature and altitude readings were not taken during
flight. Without these measurements, no data was collected, preventing data analysis from being completed.

The third objective that RoverSat failed to meet was to deploy a rover that would move autonomously for five minutes. The mechanism on the structure had to be manually opened due to the fact that all power had been cut right before flight. The structure was opened by a member of RoverSat and the Rover was also activated by a team member. Despite the Rover being manually activated, the deployment of the Rover still failed because the gears on one side became misaligned due to the impact of the landing, therefore causing that wheel to fail to turn. This meant that if the Rover had successfully been able to crawl out of the box, it still would have failed to move.

The fourth objective was met by RoverSat. The Rover’s pre-set path that was programmed into the Rover board allowed it to try and spin its wheels, stop and take a picture. Two pictures of the landing site were taken by the Rover fulfilling the last objective.

7.0 Conclusions

The only data collected from the RoverSat mission were two photos taken of the landing site by the Rover. They were showed what was expected from the Rover due to the placement of the camera.

Figure 10: Photographs taken by the Rover after landing and manual deployment
The reason for RoverSat missions’ failures, after testing, was found to be due to a short beneath the flight board. A nut and bolt located directly beneath the flight board was covered with a thin piece of foam insulation and duct tape. The nut and bolt stuck through the foam insulation and shorted out the flight board. This short caused both the mechanism and the Rover activated early. When tested after launch, and after the nut and bolt beneath the flight board was properly covered with electrical tape, the satellite worked properly, with the exception of the Rover movement which was due to its gear problem.

8.0 Potential Follow-on Work

The Rover is worth continuing, however, major changes need to be made to the design of the Rover. The framework of the Rover and how the motors will operate will be redesigned. In order to allow easier access to interior components, a removable frame will be created. A gear system and track for the inside of the wheels would be created to replace the single gears that were used. Smart motors that measure the amount of torque and then adjust accordingly might be included in the future design. Components will be secured by means other than epoxy. Using epoxy makes it too difficult to change parts already secured. Along with this, all parts will be designed to be removable. The design of the Rover will affect changes made to the structure; however there are no current plans to alter the design of the structure or the mechanism.

9.0 Benefits to NASA and Scientific Community

RoverSat is providing NASA with an experienced undergraduate workforce. With a group of all freshmen, everyone learned to work in a team environment and succeed under pressure as well as design, build and troubleshoot a balloon satellite meant to deploy a rover. All of the parts and ideas for the Rover came directly from members of team RoverSat. The gear system and wheels were made by the Rover team, the mechanisms were designed and machined by the mechanisms/structures team, and the flight and Rover boards were designed and populated by the software team. RoverSat is also providing NASA and the scientific community with an innovative rover design and a fresh outlook on how
to design and build a rover. Instead the standard four-wheel system, RoverSat designed a two-wheel rover with a low center of mass construction that will allow it to work in any orientation. The hemispherical wheel design, also designed by the Rover team, allows for the Rover to return to a horizontal position if it had landed vertically.

10.0 Lessons Learned (0.5 to 1 page)

Many valuable lessons were learned throughout the RoverSat project. Not only did the team learn how to come together and design a new structure, mechanism and rover, but the members also learned what not to do for future projects. If given another chance for another DemoSat project, or another engineering project, team members would know to plan for every possibility. Fine details were caused most of the problems, and thus the delays, of this project. One example of these details is not insulating a nut with electrical tape before flight, causing it to short out the flight board. Another design flaw was mixing metals such as the aluminum flight rod and the steel bolt. It would have been better to have been consistent in the materials used. Also, most of the components in the satellite should be designed to be removable instead of being permanently affixed with epoxy so that changes to the design can be made with fewer resultant problems. Also, extra parts should be ordered initially just in case any parts needed to be replaced. This eliminates the time that was wasted waiting for these replacement parts.

Paying attention to specific deadlines would also contribute to a more successful mission, but unfortunately this is a hard lesson to learn. If the team had stuck to prescheduled deadlines, such as the design freeze, construction, integration and testing dates, there would have been enough time to solve problems, such as the pyranometer malfunctioning. The importance of planning more time for conducting testing to create a successful project was also a critical lesson learned. More full systems tests would have revealed that there were several problems with the size of the Rover compared to the structure, that something was causing a short in the flight board, and that the Rover had some major design flaws. In order to compensate for this needed testing time, critical subsystems (ones that other subsystems depend on for their part of the project) would be given earlier deadlines or preset design requirements for their subsystem. This would prevent the entire project from being put on hold due to their delays.