Monarch Two

Our mission is to develop a smartphone based control platform and collect invaluable science data on solar activity and flight mechanics.

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1.0 Mission Statement

The mission of Monarch Two is to evaluate and design a smartphone based flight system and transmitter with flight data collection capabilities. Our payload must meet all requirements of the RockSat user’s guide, as well as be capable of data collection through the entire flight.

Our payload is required to collect and store data, and radiate a signal that can be picked up by our ground stations.

The expected results are valuable solar cell data and avionics information collected and stored, as well as radio reception capability at ODU and our portable ground station being verified.

2.0 Mission Requirements and Description

Our mission requirements were centered around our main science and technical goals. We needed to incorporate a smartphone as our processing hub, a radio downlink and the ability to measure current and voltage from the solar cell.

The smartphone was the center of our design. We intended to prove that a smartphone would make an ideal main processor for a sounding rocket mission. This concept was an extension of the missions such as STRaND and PhoneSat, which used android-based smartphones for their CubeSat missions. Smartphones offer a lot of useful features, such as inbuilt sensors, very high processing power for the size needed and a mature development environment allowing for rapid code iteration. For this goal, the objective was to implement the design with a minimum of modification to the smartphone.

With the radio payload, we intended to demonstrate the ODU ground station’s capability to track and receive data from a rapidly moving payload using common AX.25 packets over a UHF link. This design was a follow-up to the radio design flown in 2015, with a significantly improved antenna system and a better method for sending data through the radio. This portion of the payload was required to successfully transmit to ODU through the flight, sending packets created by the code running on the smartphone.

The solar cell is an advanced multi-junction research cell provided by RIT, which we had bonded to a chip carrier and mounted to the special port. A sounding rocket flight allows us to observe above the earth’s atmosphere for a portion of the flight, and analyze the effectiveness of the cell by taking current and voltage measurements. The system needed to collect as many data points as possible through the flight to provide enough information to analyze on return.

Finally, we had a flight telemetry package that was an iteration of the system we successfully flew last year. It needed to provide high resolution accelerometer and
gyroscopes data to support and validate the solar data as well as provide useful information about the flight environment our payload experienced. This board was required to communicate with the smartphone and store a copy of the generated data locally.

For our mission to be a success, we needed to transfer data through the radio, collect solar cell data and validate the design using a smartphone. The radio was linked only to the smartphone, which is a point of failure that can exclude it from potential operation.

3.0 Payload Design

There are two distinct portions of our system. The first is the payload contained within the body of the rocket, which houses our smartphone, radio, flight data and power systems. This is the meat of our design and received the majority of the time spent analyzing and improving. Second is the special port. In a small aluminum cavity, we needed to fit a solar cell, antenna balun and antenna mount points.

To design our payload, we started off by considering the mission critical parts we needed to carry with us. Evaluating the needs of our payload, we decided to use a similar power plate design as the previous year. The battery plate is primarily ballast, with the added value of providing excess power. Using that hardware as an engineering model and preliminary testing gave us a good indication as to our payload space for the scientific hardware. The size of the smartphone and radio were a key factor in our design phases. We initially drafted a layout with the phone and radio placed side-by-side, but quickly realized that this left little room for the flight data board and seriously complicated wiring paths. The next revision placed the radio above the phone, using separate 3D printed brackets. After fabrication and fitting, it became apparent that this design was over-complex and less rigid than we would like, and we made a final revision to using a single bracket that housed both the phone and radio, as shown.

In tandem with the mechanical design, the electrical subsystem was created to fit. The first system designed was the latching power supply, which had two major revisions. We first needed to fix a voltage regulator that was incorrectly wired, and then to completely remove the regulator. As we
wanted to keep the radio as compact as possible, it was decided that we would use an adapter intended to supply the radio from an automotive 12V socket, and modify it to suit. This made the supply regulator unnecessary.

With the power board functional, the data board was designed. The board had to provide high quality data at an acceptable rate, so the team examined a number of potential chips and breakout boards that could be used to suit our needs. We settled on using the Invensense ITG-3200 for high-DPS gyroscopic data, with an LSM9DS1 nine degrees of freedom sensor for accelerometer and magnetometer readings. For reading our acceleration under launch conditions, we also used an ADXL193. Data would be written to a standard microSD card, properly secured in a locking bracket. After we had the sensors selected, we used a Teensy 3.2 to provide the control interfacing between the sensors and the smartphone, as well as the microSD card. This portion of the design was relatively straightforward, with only one board revision requiring a remanufacture of the PCB, to correct some improperly laid out traces.

The special port required a lot of careful layout and design. We needed to create a way to pass the antenna lines through the door without breaking the isolation, as well as have a small window for the solar cell to use without being excessively exposed. To accomplish these design goals, we went through an iterative process, creating concepts in inventor and analyzing them for fitness. The final design uses a small ring of aluminum to hold a window made of resilient plastic film in place above the cell, while the antenna lines go through spacers that keep the wires from shorting to the skin of the rocket. Inside the port is a custom four-layer PCB that has mounting pads for the cell on the top layer and a 4:1 balun on the lower three.

Our system is fairly simple on paper, as shown by the functional block diagram. The early activation provided by Wallops will engage the smartphone and begin the boot process, which will have the smartphone active at flight time. The G-switch brings the sensors and radio online, and fully activated the payload. The data is stored on both the phone and the teensy-associated card for redundancy.
Going into the preliminary check in, we were confident that our payload design was solid and would survive testing without mishap, and we were mostly validated in our belief. Once paired with our partners, we chose to add the mass to our payload over theirs to make the canister properly weighted and balanced. This resulted in some quickly implemented additions to our system, such as a small lead plate and a lead strip secured to our battery deck, which were attached to the existing screws and structure as well as taped down to dampen vibration.

4.0 Student Involvement

We had a small but competent team this year, with a talented multidisciplinary team of Connor Huffine, Cian Branco, Jason Harris and Adam Horn.

Connor Huffine (Electrical Engineering) was the team lead and electrical engineering expert. He handled the design and fabrication of the circuits and code used in this mission. Connor also handled the interfacing between the team and ODU, VSGC and RockSat management.

Cian Branco (Mechanical Engineering) was the mechanical engineering expert. Cian handled the design of the 3D printed chassis for the phone and radio, as well as the blueprints for plates and brackets. All parts were manufactured by ODU and evaluated to ensure fit and alignment.

Jason Harris (Electrical Engineering) was the team radio expert. With Jason’s experience we designed a radio payload that was more robust than the previous year’s payload and had a better internal network. Jason was also manning the ODU ground station on the morning of the launch.

Adam Horn (Mechanical Engineering) was the mechanical engineering consultant. He assisted with designs and validated our analysis of the structural design.

5.0 Testing Results

Our payload went through a number of tests we designed to ensure proper flight operation. As the payload was designed and came together, we continually tested subsystems to ensure they communicated as anticipated and functioned with the power systems created to support them.

Once we had the entire system fabricated, we performed a fully integrated systems test. The first test ran for fifteen minutes and provided alarming feedback. After those fifteen minutes, the radio power supply was dangerously hot to the touch, the radio had timed out after ten minutes of activity and the phone application had crashed. While this outcome was humbling, we quickly found solutions; removing the push-to-talk line and engaging the sound-activated transmission feature on the radio ensured that the radio would not time out or overheat, while correcting the function on the phone that checked connections to the data board solved the crashing.
On our second full test, the system ran stably for a full hour and a half, which proved to our satisfaction that the app was functional and the power system was not going to overheat. However, the VOX introduced a delay between the packet start and the actual transmission and the USB connection to the data board was somewhat unreliable, dropping out several times. With the addition of a better attachment of the USB line and a short period of noise sent to the radio immediately preceding a packet, we solved these issues without significant trouble.

The third and final full mission sim went exactly as expected and ran properly for thirty minutes, during which we received and decoded multiple packets from the payload exactly as designed.

During final electronic assembly testing, a slip during continuity testing caused a short between the 12 volt and 3.3 volt rails, burning out the core MCU and several sensors. We had planned ahead for disaster and had a spare set of components on hand and were able to recover with no lasting ill effect from the human error.

With full mission simulation testing successful, we tested the mechanical integration. The integrated payload was rotated, spun, flipped and tossed to ensure every connection remained solidly connected through integration and testing. Each structural bolt was treated with Loctite and hot melt to secure the joint against backing out under vibration. We also added a small, soft pad between the radio and phone to prevent destructive impacts.

6.0 Mission Results

Our mission had a serious setback to the achievement of the mission success criteria, at launch the smartphone failed to properly initialize. This immediately caused us to fail the mission objective of radio transmission, due to lack of packets to transmit. This was particularly nerve-wracking, as the lack of a signal received at the base station left us knowing only that our payload had suffered a failure but no detail on how severely or why. Once we received the payload back after deintegration, an immediate post-mortem and data backup was performed. Thankfully, we still recorded data on the microSD card that we can analyze to provide partial mission success.

Our payload had a hidden failure mode that we did not see in testing, where the payload will become stuck in a boot-loop and the smartphone will be completely useless. From our evaluation of the failed smartphone, we believe that the failure occurs when the power is cut without removing the internal battery. This leaves the phone in a limbo that it cannot escape. The method of powering the phone on and off is probably the root cause of this issue. To turn on, the phone has a script that activates when power is applied to the USB line, and has a similar script for when power is removed. In this manner we could control phone operation with a simple power switch, and it functioned excellently in testing during the full mission simulations. However, during the integration and launch, something
caused the smartphone to be powered with a lower voltage than intended. This left the phone attempting to power up, bringing the voltage below threshold due to the increased draw, and then powering down. To remedy this problem, we designed a shim that would be inserted between the battery terminal and the battery within the smartphone. This would provide the capability for external switching of the power that does not rely on the potentially unreliable smartphone code.

However, the smartphone was the only actual failure in our payload. This automatically fails the radio objective, but provides a counter-point to our objective of proving the smartphone by explicitly demonstrating the shortcomings of the smartphone based system. We came to the conclusion that the smartphone does not provide enough of an advantage over the common uses of simpler MCUs like the Arduino Mega and single board computers such as the Raspberry Pi to create a viable use case.

Our final mission objective of collecting viable flight data is successful. We recorded an amount of very useful data on the solar cell through the atmosphere. Shown below is a graph of current and voltage versus time.

There are significant noise spikes during the launch and re-entry time periods, which could be due to a number of reasons, but most likely vibration causing intermittent connectivity. During the period of parabolic flight, there is a clear trend in current, which is expected due to the atmospheric variation. This provides enough information to analyze the solar cell’s effectiveness at altitude, and will be examined in greater detail over the semester. As the mission goal with the largest
direct science impact, we were pleased to be able to recover quality data we can use to draw conclusions on the solar cell’s performance.

Our flight computer also generated interesting information, especially comparing our different gyroscope hardware.

The green line in the graph is the LSM9DS1 9DOF gyroscope, which has a useful range up to 5.55hz, at which point it cannot report values that are useable for data analysis beyond the fact that the gyro is at its maximum capability.

In contrast, the purple line is the ITG-3200, which has an operation range up to 11.1hz, and is not saturated by the high rotation rate of the rocket at burnout. The data is overall more insightful; for example, you can clearly see the spin-up from the first stage, the drag slowing the spin rate during the coast, and then second stage spin-up to a maximum of 6.12hz. The low range gyro becomes saturated almost immediately, and interestingly remains saturated for some time after the higher range gyro reports that the rotation should be within the capability for it to resume reporting valid data. This raises some questions about the behavior of the gyroscope outside of the defined operation region and the lasting effect of being overspun on avionics hardware.

Our sensor package was the most mature part of our payload, and produced correspondingly useful information. A significant advantage of the sensor packages we use are the relatively low cost, size and power consumption of the components. This allows us to fit more on a board than we would otherwise be able to fly.
Another interesting use of the data we have is the potential to create a crude inertial guidance system; we have all of the requisite information to generate a heading and velocity at a low accuracy.

The image above provides an example of the information we have recorded that provides a potential use. The purple line is the high-range gyroscope along the z axis, and the brown line is the magnetometer reading for the x axis. The point at which the sample rate of the magnetometer becomes useful is quite clear, and linked to the spin rate of the rocket. Once the rocket begins to re-enter and tumble, the heading goes wild, but after chute deployment a clear heading and slow rotation becomes apparent.

7.0 Conclusions

While we had a hard failure for one of our mission objectives, the remaining objectives provide enough information for this to be called at least a partial success. The failure of the radio was the least damaging of the objectives, as the radio was a small amount of information and validation of the ODU ground station.

The issues and non-functionality of the smartphone are still useful information, if not information we wanted to see. The complexity of the system and support structure for the smartphone eliminates a large amount of the utility that the phone brings to the table. While we still believe the system has valid applications, the involved nature of development makes it quite a challenge.
Our recovered data for the solar cell and avionics package are the core of our science payload that makes our mission worthwhile. Even if our mission had been a complete success, this is the data we would be analyzing most closely. The other mission objectives are more of a simple pass/fail, while the avionics and solar data are nuanced and complex.

We declare this mission a partial success, with a disappointing failure of our implementation of the smartphone concept.

8.0 Potential Follow-on Work

We are still confident there is potential in the design using a smartphone, but it requires a larger team than we had. A dedicated team for software design would also make the process more viable. The development of a framework to use on a smartphone to create a flight ready platform ready for integration into multiple projects is a project of value but very effortful. If a team were to approach the challenge in the future, it would behoove them to recruit for the task and begin as soon as feasible.

Transmission to the ODU ground station is an ongoing task, and would benefit from additional testing. While we can receive from many amateur and radio satellites, we have not communicated with ODU space hardware in the air. We also continue to improve and upgrade our ground station, adding new hardware and rebuilding older equipment to make our system better.

Additional analysis of the sensors we used and others in comparison, especially near saturation would most likely yield valuable information to the community. Better understanding of the way these sensors behave could yield more improved ways to filter the sensors and create more accurate sensor fusions.

9.0 Benefits to the Scientific Community

The data we recovered from the solar cell measurements could be of use to the analysis of multiple junction cells in space, as well as the consideration of this cell design by altitude. It can be difficult to simulate the behavior of cells exactly in a laboratory setting, and flying them aboard sounding rockets is a good way to determine characteristics with real environmental information.

Consideration of the sensors used in these applications can be considered more effectively using the data gathered by our payload, which will provide useful reference for future research, especially research dependent on the use of precise and accurate gyroscopic sensors.

Our experience with the smartphone provides a useful data point for any future endeavors looking to attempt a similar system. The information we gathered from our failure will be of use to others, and will hopefully assist them in avoiding the pitfalls we encountered.
10.0 Lessons Learned

The failures we encountered throughout the manufacture and flight of our payload taught us a number of important lessons.

Our biggest lesson to take away from the project was that the smartphone requires a huge amount of code development and work to create a stable program that will work as expected, and also needs additional work to create a more reliable method to control the boot process of the phone in a way that can be switched directly. If we had allocated more time, earlier, to the smartphone we may have discovered the fatal issues sooner and been able to mitigate them prior to the flight.

Our challenges with the time management also extended to the other portions of the project. We had a small but dedicated team, but it would have been beneficial to have more members to spread the work over and put the system in front of more eyes. While having one person in charge of large portions of the system makes the design phase simpler, it makes verification of the system by outside members arduous.

Caution with test equipment was taught with the destruction of the sensors when the previously mentioned probe mistake occurred, and there was a tense few minutes while we tested all the components singly to determine if anything else sustained damage. If the smartphone had been fried, we would have been seriously in trouble. It was only a week from launch, and the smartphone is the single most expensive component of our system.

Every member of our team gained valuable experience from the project in the areas of PCB design, CAD modeling and fabrication as well as practice presenting information to a managing group.

We also developed forensic failure analysis experience evaluating our payload post-flight and developing potential mitigation measures for any future payloads utilizing similar concepts.