HIGH ALTITUDE STUDENT PLATFORM

(HASP)

MAGNETIC INVESTIGATION OF LUNA (MIL)

PAYLOAD FLIGHT SUMMARY

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Introduction

The Magnetic Investigation of Luna (MIL) flew a proof-of-concept experiment in 2008. The purpose of this experiment was to determine if photogrammetry techniques could be used to develop a topographical map of the Moon's surface. The Virginia Tech team also flew a magnetometer as a follow on to the 2007 Academic Research Team for the Establishment of a Lunar Magnetic Field Investigation System ARTEMIS mission. The primary payload was the camera system consisting of five cameras used for photogrammetry. As a secondary payload the team also flew a data logger and power supply to autonomously collect data from a variety other of sensors including: a magnetometer, a GPS receiver and an Inertial Measurement Unit (IMU). The cameras were located at the end of a fixed mechanical boom. The GPS receiver was used to track the motion of the system and provide ground coordinates for the corresponding magnetometer and photographical data. The IMU was used to measure the gondola's rotation rate during the balloon flight. All data collected is being analyzed post-flight.

Payload Performance

The MIL experiment met most of its success criteria however problems occurred with the photogrammetry payload and the magnetometer. The IMU provided acceleration and temperature data in the expected ranges and GPS data was recorded. The payload experienced three failures during flight. The magnetometer and the data logger failed to record data in the correct format. The photogrammetry payload stopped functioning mid-flight. However, one camera did return to operational status after a period of several hours and resumed taking pictures. The mechanical boom and all structural components survived the flight. The foam insulation did not perform as expected (the foam expanded inside the camera housing) and may have contributed to the failure of the camera system. Overall, the payload performed well since real data was collected from all sensors except the magnetometer at some point during the flight.

Problems Encountered

Several unexpected problems occurred throughout the duration of the MIL project. These included software design, thermal testing, and broken hardware. An environmental testing facility at Wallops Flight Facility was used for thermal testing. The testing procedure called for both pressure and temperature to be varied simultaneously, but because of chamber limitations the procedure had to be altered to vary only one parameter at a time. During environmental testing a voltage regulator malfunction short circuited the camera payload. The cameras were rewired and three of the five cameras returned to operational status, the other two were replaced. During flight the cameras and magnetometer failed to record data over the entire length of the flight. Also, cloud cover severely limited the line of sight to the ground and prevented the use of photogrammetry in the cloudy photos that were collected. Furthermore, the software system was written by primarily by one person who was unavailable during post-processing which made data retrieval difficult.

Lessons Learned

The students involved in the MIL balloon mission picked up a variety of skills related to engineering and the manufacture of scientific experiments. Primarily these skills pertained to electrical wiring, computer coding, sensor communication, testing procedures, and data handling. Working on the project presented various expected and unexpected problems which provided important information on how to proceed with the next balloon project.

Future experiments need to have a greater lead time for parts acquisition, testing, and integration. Greater lead time would facilitate an efficient design process and allow for more time to troubleshoot complications without impacting the project timeline. Other information gleamed from the building of the MIL project is that more time is always valuable, as well as getting as many members as possible on the team. The timeframe for the MIL project was condensed and many stages of the project were shortened to meet deadlines. Additional time would allow for a greater understanding and a smoother assembly of the project. Integrating students with diverse educational backgrounds into the team would have improved all stages of the project. Specifically, students with a greater understanding of electrical theory would have enabled a faster and more efficient design and construction of the electrical systems and pin-outs. More thorough testing of the MIL project would have allowed for a better prediction of the system's capabilities and how the sensors and thermal insulation would perform. In the MIL mission the inertial measurement unit was discovered to have a calibration error and all sensors needed more thorough thermal/environmental testing before flight. More extensive testing would have shown if the sensors could perform outside of operational limits, specifically temperature limitations. For any future balloon missions environmental testing at low pressures is crucial to ensure survival and operation of all the components.

The integration stage of the MIL balloon mission illustrated the need for a cohesive integration plan. A cohesive plan would have prevented the failure of several cameras during integration, the short circuiting of the voltage regulator, and arbitrary assignment of pin-out connections. A thorough plan would have also included better drawings for the cameras and documentation of wiring and harnesses. The computer codes used by the MIL mission were developed and understood by only one team member, which resulted in the reliance of the entire team on one individual. For future projects, the project codes should be written by multiple people. The people who write the code should be available to answer questions from the post-processing team, and should have the post-processing code written in advance to allow for the outputs of the sensors to be checked and calibrated before flight.

Science and Data Results

The morning of September 15, 2008, a high-altitude balloon carrying the MIL scientific package was prepared for flight and launched from Ft. Sumner, New Mexico. For 25 hours of the 31.8 hour duration of the balloon flight, MIL recorded data from a Systron MotionPak II Inertial Measurement Unit and a Magellan DG14 GPS receiver. The data from a Honeywell HMR2300 Three-Axis Magnetometers was found post-flight to be unusable. The five cameras operated for an average of 7.7 hours before unexpectedly turning off. One camera resumed taking pictures again 8.5 hours later for only 2 hours before turning off again.

The IMU measured three axes accelerations and internal temperature. The accelerations recorded during flight were relatively constant. The y-axis acceleration recorded -1g as expected for Earth's gravity (Figure 1). The internal temperature sensor of the IMU recorded launch temperature of 25° Celsius, and temperature increased over four hours to 36° C (Figure 2). The temperature fluctuated between 32° C and 38° C before decreasing to a minimum temperature of 22° C twenty-two hours into the flight. The general cooling trend and minimum temperature recorded indicates nightfall. After post-flight data analysis and testing, it was determined that the IMU was miscalibrated due to very slight but significant offsets in acceleration readings within the MIL scientific package.

The GPS receiver returned latitude, longitude, altitude, time at this measurement, the true track over ground, speed over ground, vertical speed, the number of satellite vehicles used to the computation of position, and the dilution of precision. There were instances when position could not be measured properly due to a low space vehicle count and this is reflected in a high dilution of precision or lack of recorded data. Overall, there were few cases of unreliable position measurements, and the GPS data was determined to be reliable for most of the flight. Attitude determination is not possible from the acceleration and magnetometer data due to the lack of useable magnetometer data.

All photogrammetry reduction was performed with EOS Systems' Photomodeler 6. A primary objective of this mission was to prove the feasibility of three dimensional photogrammetry, and then to compare the photogrammetry results to a 3D model with known topography data. It was a goal of the project for the accuracy of the photogrammetry results to be within 500 feet of the known data. However, during the flight there was heavy cloud cover, and features such as mountains that could have been used to render a 3D model did not have enough angles or viewpoints imaged for the software to resolve their position and height. In fact, it was very difficult to find a common object in the set of photographs that was consistent and not blocked by clouds. The best candidate was a corn field on the ground that showed up at a variety of different heights. The five different photographs used for analysis can be seen in Figure 4.

There is an arrow drawn to the corn field in each figure for clarity. The x's represent different points common to each set of photographs that the software used to resolve the camera positions and height. A 2D map of the earth's surface, the cornfield studied, was successfully generated in Photomodeler (Figure 5). Defining a reference length by using the position of the lowest camera, and setting the ground equal to zero height, the software was able to solve for the various camera heights for each picture, and composed a 3D model (Figure 6). A comparison of 3 of the camera stations was done with the relevant GPS data for each picture, and accuracies to less than 2% were accomplished (Table 1).

Table 1 Comparison of GPS and photogrammetry altitude data.

Picture	GPS (ft)	Photomodeler (ft)	% Error
Camera 7 389	17794.45	17618.06	0.01
Camera 1 404	25485.14	25076.88	0.02
Camera 1 451	37465.59	37808.11	0.01

An additional attempt to show proof-of-concept of the photogrammetry was to generate a 3D model of the clouds, even though the heights could not be compared to known data. The clouds however did not contain enough height difference and distinguishing characteristics for the software to treat them as anything but flat ground.

Conclusion

The main purpose of MIL was to simulate and test the feasibility of mapping the topography of the Moon by flying five cameras on a high altitude balloon. The aims of further data reduction will be to determine the cause of failure of the magnetometer and the reasons the GPS and cameras stopped functioning during flight. The team will also correlate the IMU and GPS data to actual flight time and establish a timeline of failures. Using Satellite Tool Kit software the team will develop a plot of the flight trajectory and ground track.

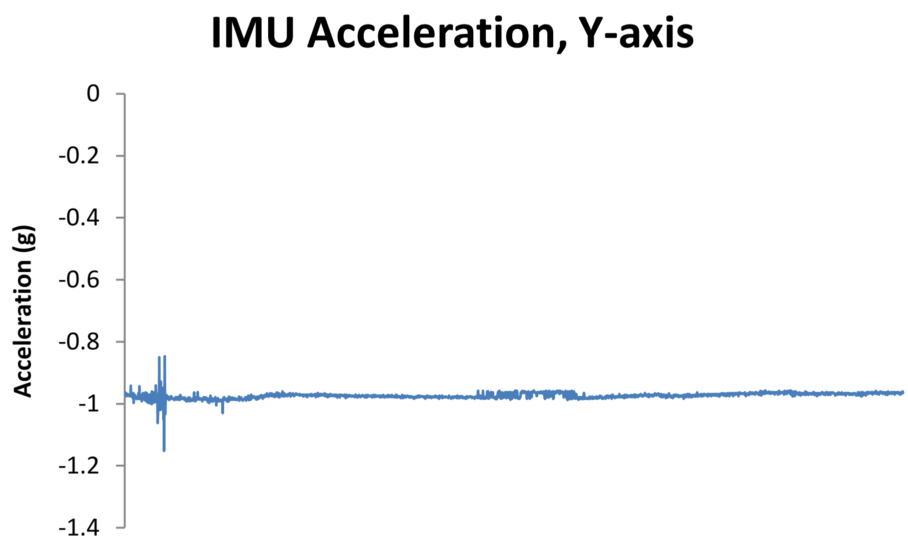

Figure 1 Acceleration measure by IMU along the Y-axis of the body frame during flight.

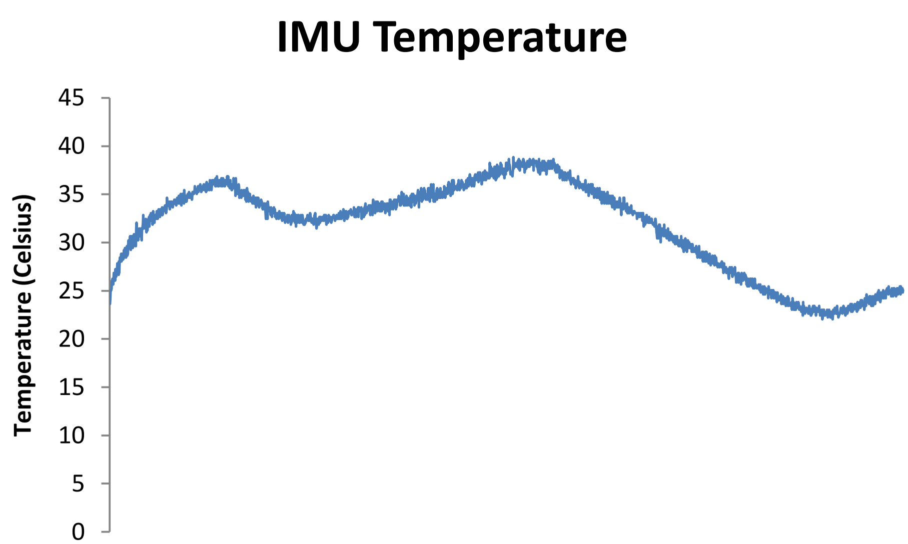

Figure 2 Temperature measured by the IMU during the flight.

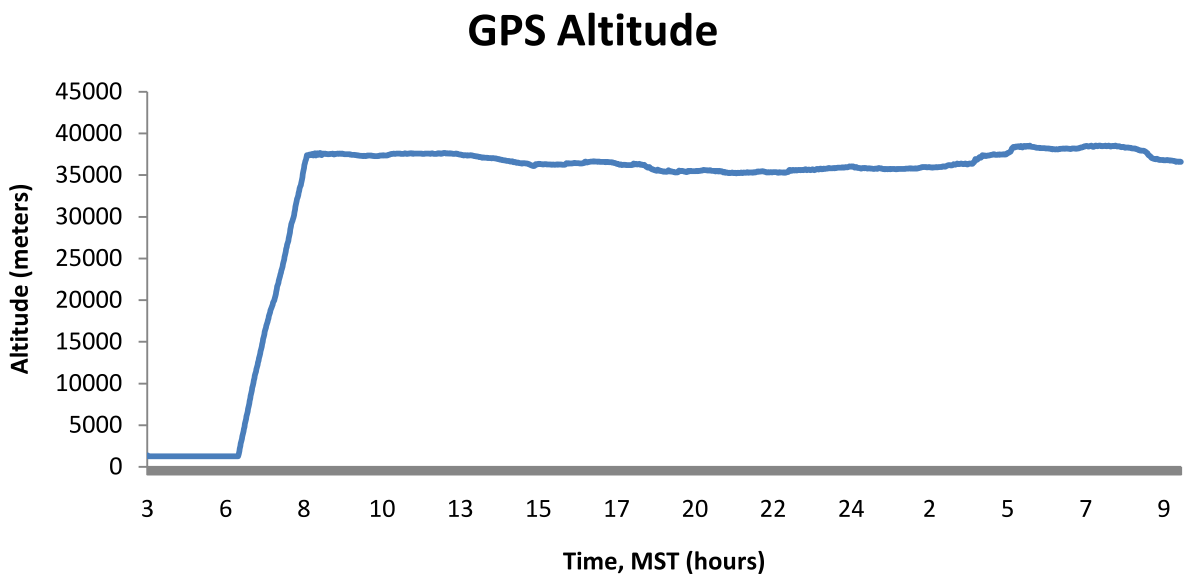

Figure 3. Altitude data from GPS over the duration of the flight.

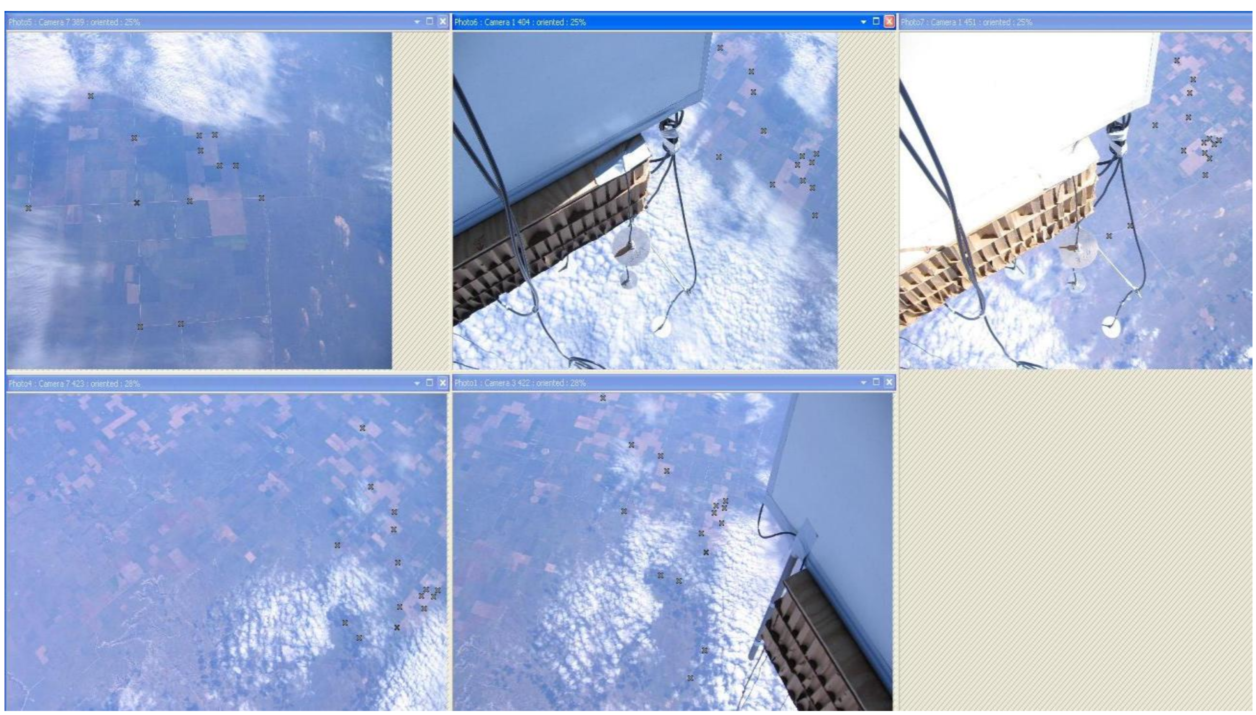

Figure 4 Pictures used for the photogrammetry reduction, with arrows to the reference objects.

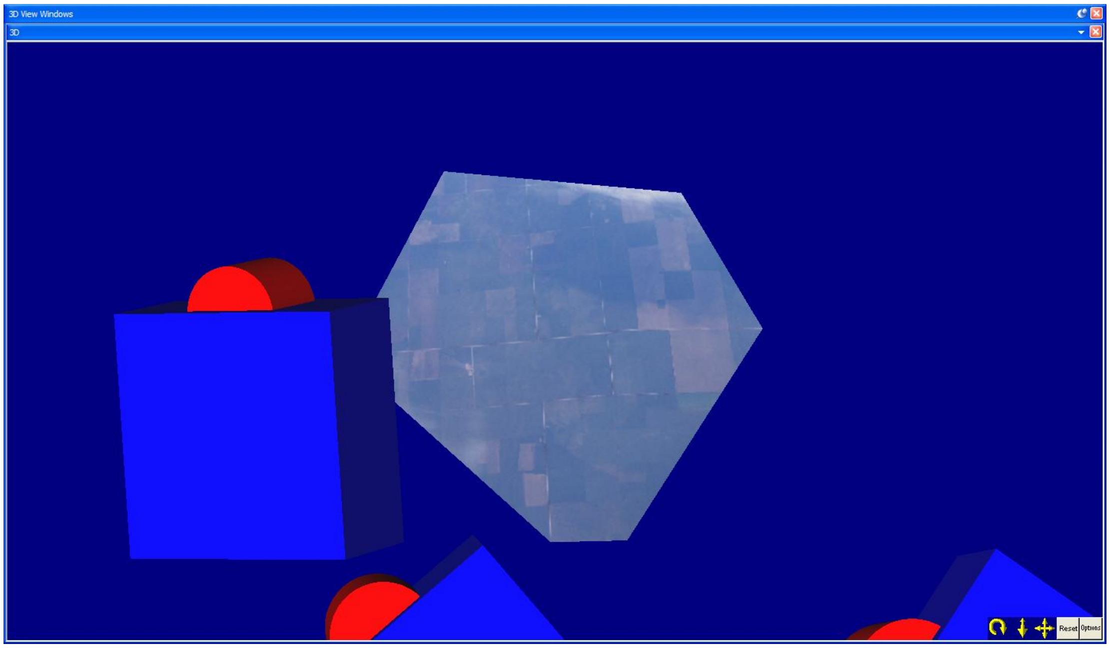

Figure 5 2D map of the area studied, rendered by the photogrammetry software.

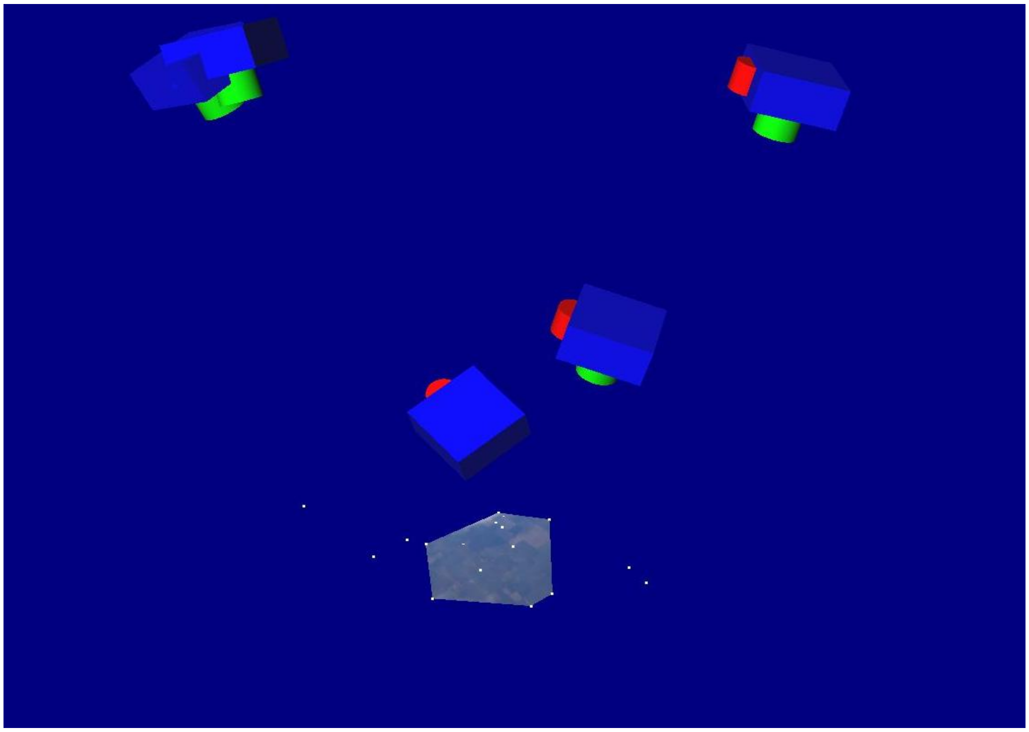

Figure 6 3D model depicting the camera heights for each picture.