Scarlet Hawk II: Project Completion Report

Armour College of Engineering

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Chicago, IL 60616

Acknowledgements

On behalf of the Scarlet Hawk II team and the Executive Board of the IIT Chapter of the American Institute of Aeronautics and Astronautics, I would like to thank the NASA Balloon Program Office and Columbia Scientific Balloon Facility for such a wonderful opportunity provided to students throughout the country. I would also like to specially thank Dr. Guzik and the entire HASP crew for making the program a unique, invaluable and enriching experience for all the teams. I also want to take this opportunity to express an immense gratitude to IIT's Department of Mechanical, Materials and Aerospace Engineering and his Chairman, Dr. Bowman, IIT Campus Life, IIT Student Government Association and IIT Alumni Hall Machine Shop for all the support provided during this mission.

David Finol

Scarlet Hawk II Project Manager

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Introduction

Scarlet Hawk II has its roots in an initiative started in 2012 by a small of group of students that, with the support that AIAA-IIT provides, started the first ballooning project on campus. Later that year and after its first own flight, the chapter applied for and successfully obtained a seat in the High Altitude Student Platform for its 2013 flight. After a successful flight with more than 80% success rate, team decided to get immersed on the design of a CubeSat mission to fully start by 2015. Having that in mind, the team decided to apply one more year for a HASP mission heavily focusing its design on testing critical parameters for the future CubeSat Mission. The team then came up with the design of Scarlet Hawk II, which mainly involved the development of an independent power system that sets an initial stage for the CubeSat mission.

The design of Scarlet Hawk II started in September of 2013 with a dozen of graduate and undergraduate students. The team mainly had in mind the development of a system that would give the team the ability to power all the internal systems independently from HASP power line during the entire flight. By December of the same year, the team had come up with a final design that mainly consisted of an Independent Solar Power System that would be powering a set of cameras during the flight. Once the final details were completed and the HASP management gave its approval to the design, the team then proceeded to start building the payload by the beginning of 2014. All of the payload's physical components were manufactured on campus from raw materials between January and May. Scarlet Hawk II's systems were independently developed and tested on campus by three of our subgroups (*Independent Power System*, *Structure* and *Electronics and Software*). An initial integration of all the subsystems was made on campus but the final payload integration was made at NASA Columbia Scientific Balloon Facility in Palestine, TX.

Having completed the full integration of Scarlet Hawk II, the payload the payload underwent two Thermal-Vacuum tests and was successfully flight-certified by the end of the summer of 2014 in Palestine. The flight finally took place from Fort

Sumner, New Mexico, on August 9th of this year. After around 5 hours on float altitude (~38Km), HASP landed in Arizona and was recovered by NASA CSBF personnel. Our team then received the payload 2 weeks later and proceeded to corroborate the entire flight data and start the data processing and analysis.

Final Payload Design

After one year of testing and redesigning, the final payload design that was flight-certified consisted of an Independent Solar Power System that was capable of powering a camera system with solar energy harvested during the flight. Its implementation can be divided in three main subgruops:

- A powering circuit, which obtains the energy from the solar cells, and a implementation of a Maximum Power Point Tracker (MPPT), aiming at reach optimal power from the system based environmental conditions

- A battery system. This part had two main functions: to take care of the battery charging system, using the obtained energy from the power circuit, and to power the two cameras on board when the battery has enough power. These two cameras were able to take pictures periodically during the flight.

- A control system, which used an Arduino board to switch ON/OFF components of the independent power system and control the cameras behavior (i.e. change the sampling frequency for the pictures). This Microcontroller is also prepared to receive commands from the Serial Communication link, and send periodically the current and voltage values of every component of the system.

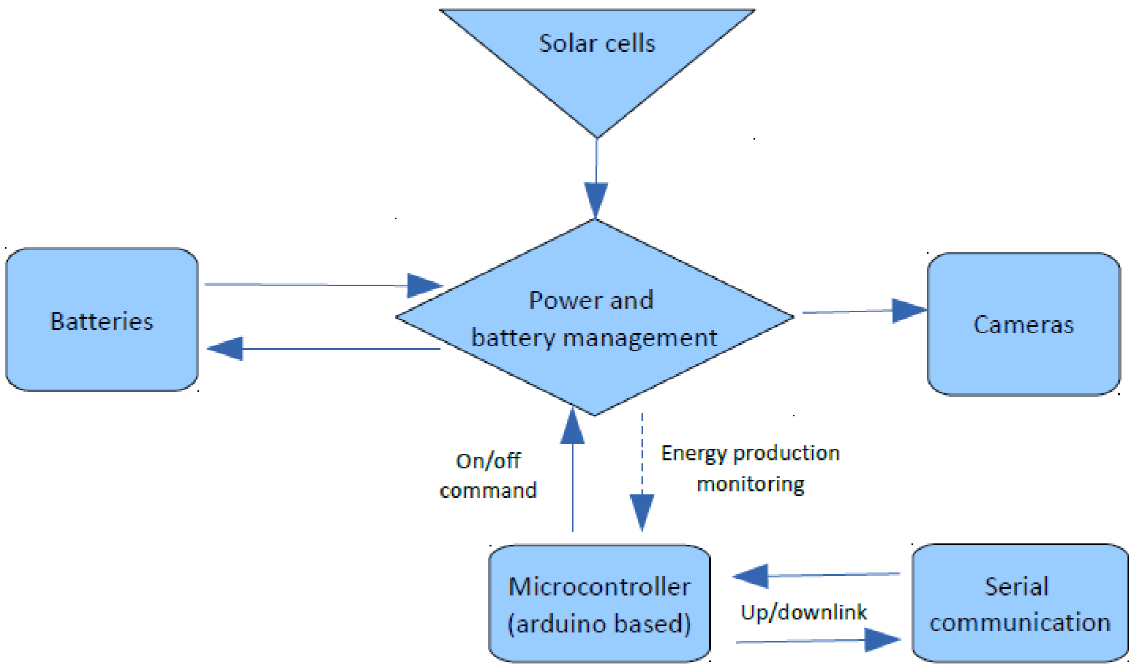


Fig 1. Payload block diagram.

More in detail, the components of the system are:

- 8 solar cells
- 1 MPPT
- 1 Diode protection circuit
- 1 Battery
- 2 GoPro HD Cameras
- 1 Arduino Due
- 2 MOSFET Switches

Final Circuit Diagram:

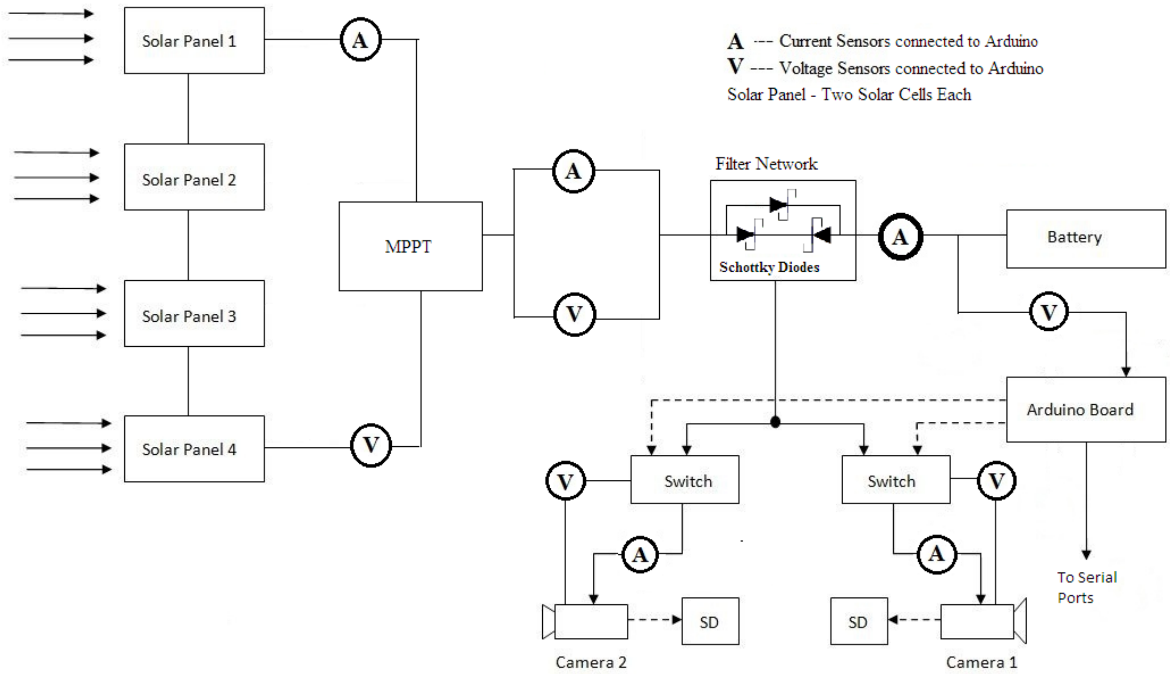


Fig 2: Schematics

The schematic shows how the whole system is assembled together. As we can see, there are 4 solar panels each consisting of 2 solar cells. Current and voltage sensors are then all connected and thereby controlled by the Arduino board. All of the instantaneous data processing and logic response takes place in the microcontroller. A filter network has been set up consisting of 3 Schottky diodes so that the current does not flow in the reverse direction and to avoid that any other electrical component gets damaged in that case. This filter network mainly acts as a protection for the MPPT board. Data communication with the Arduino board has been represented by dotted lines while power connections between components are represented by solid straight lines. It is also imperative to mention that the sensing board, the Arduino board, is connected to the serial ports for data communication and is operationally based on the HASP electrical power supply. The independence of the sensing system from the entire power system was made in order to be able to capture any failures during the flight.

Experimental Flight Data

The sensors placed on the system were design to monitor the power (current and voltage) drawn by any of the electrical components in the payload. As a result, we constantly monitored the behavior of the independent parts of the circuit during the flight as a function of time.

The following figures show the overall behavior of these values, for the Solar Panel and the MPPT output (meaning battery input) during the flight.

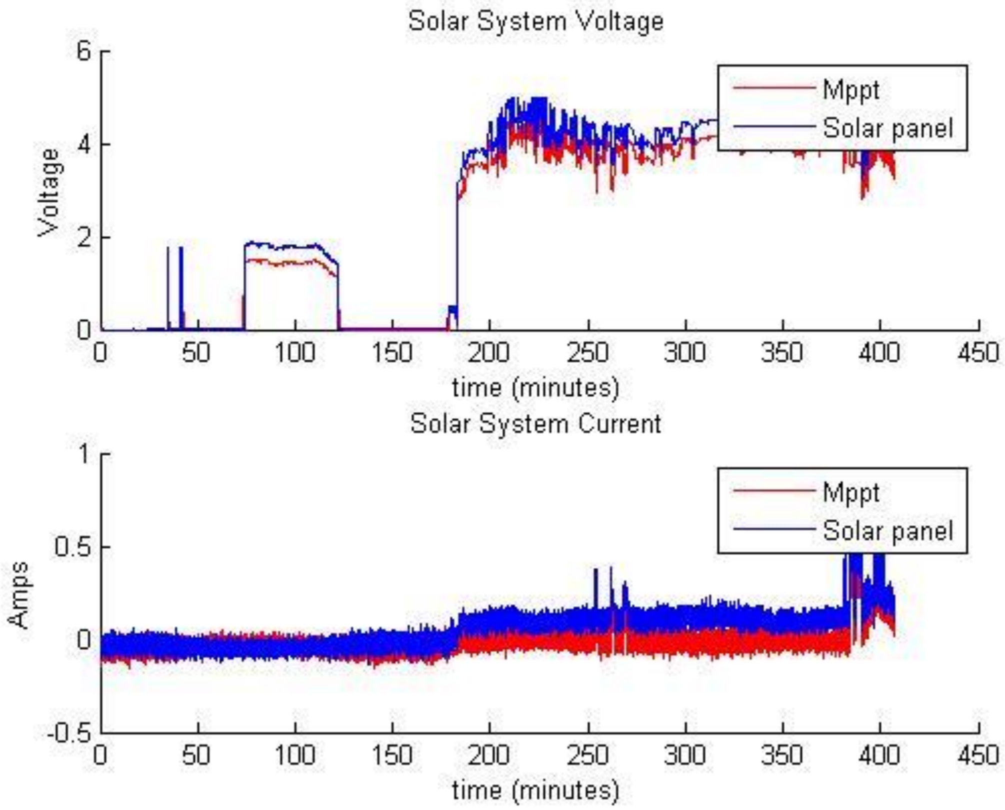


Fig 3. Solar Cells and MPPT.

From the data, we can conclude that the solar panels started receiving light after 180 minutes since the flight operations for the day started. There is an increase in both the voltage and the current values at that point. From the graphs, we can see that the voltage is very stable around a value of 4.2V, with a maximum of 4.5V and a minimum of .3.8V. In the same manner, the current stays around the 0.25A, with a maximum peak of 0.6A during the cameras operation.

The peaks at the minute 350 are due to the switching ON of the cameras (please see following figures, where camera current and voltage are displayed). The MPPT works by adapting the impedance value of the system in order to drain the maximum power from the solar cells: when the cameras are included, the MPPT requires more power from the source.

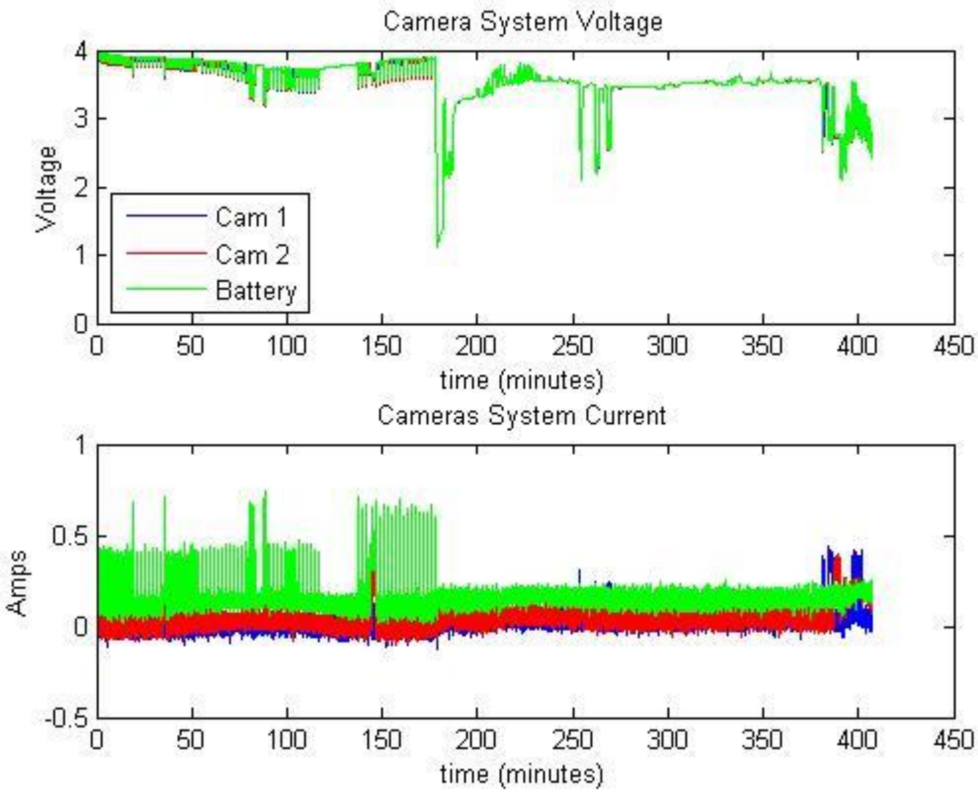


Figure 4. Battery and Cameras.

During integration, it was detected that one of the cameras may malfunction when it was off and this could then drain the battery. This problem was mitigated by setting a mechanical switch that would cut any communication between the camera and the battery whenever it were set to off. Throughout all the data, we could see that somehow the switch was activated during transportation and the battery was at its minimum level just before flight operations. Once the flight operations began and the solar panels started receiving sunlight, the battery begins to recharge again. This corresponds to mean values of 0.2A and voltages over 3.6V.

Due to the fact that the flight started with the lowest battery level possible, the cameras could only be activated in the last 30 minutes of the flight during float altitude. We can then see that the cameras are turned on during this period on the data: at the 2.3x10^4 minute (when their current goes up to 0.4 A).

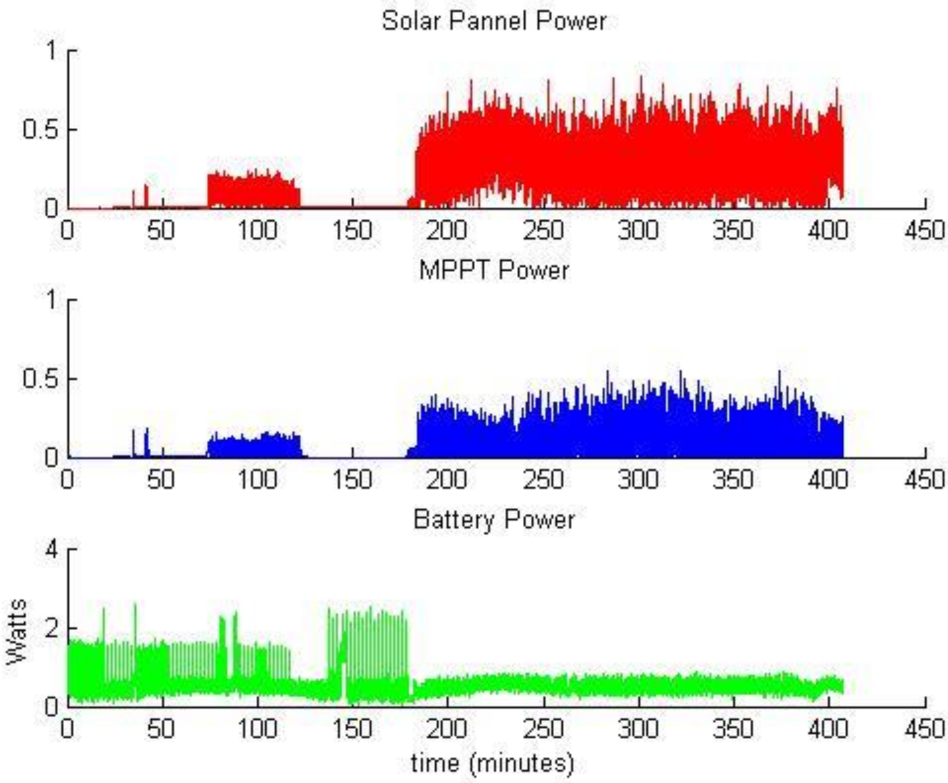


Fig 5. Power values.

Looking at the previous graph, we can see the power values for the Solar panel, the MPPT and the battery. We achieved 0.5W for the solar panels and a smaller number for the MPPT (0.4W).

Additionally, the micro-controller will also send the state of the cameras (either ON or OFF). This state only reflects when the micro-controller sends the ON command to the cameras (which means that some of the ON of this graph may not correspond with real ON states of the camera).

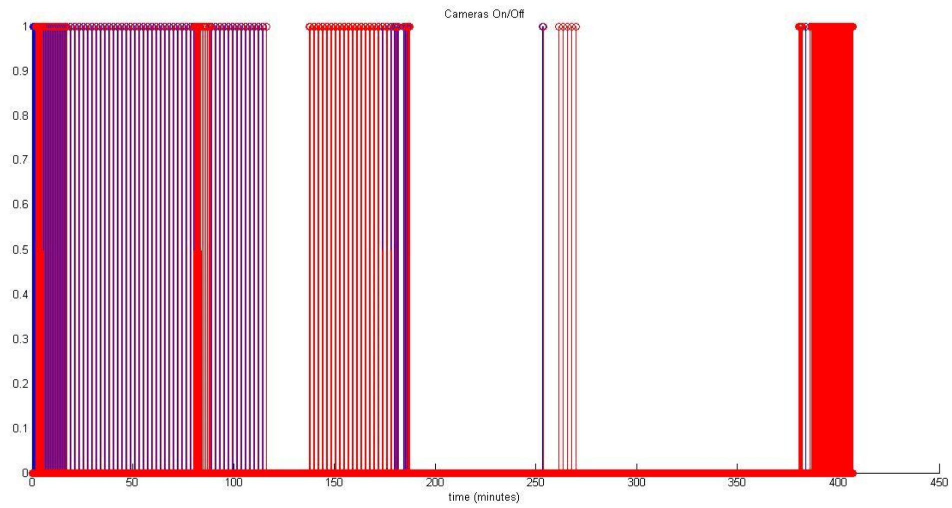


Fig 6. Cameras ON/OFF

Comparing Fig 4 and Fig 6, we can confirm that a camera is ON when there is an increase of the current level of that camera. It is when the camera is drawing power from the battery.

Objectives and Results

The objectives set at the beginning of the project, regarding the independent power system were:

- Test an independent source of energy in space-like conditions to be used in a future CubeSat mission.
- Autonomously monitor the performance of the power production in order to make accurate predictions of power output and battery behavior in space-conditions.
- Asses the power efficiency for the Independent Power System for flight conditions.
- Be able to use the obtained energy to power the two cameras on-board to take pictures throughout flight

After one year of work, we were able to implement this independent power system in space-like conditions to be used in a future CubeSat mission. This system is fully able to:

- Charge the 3.3V battery with the solar system, while maintaining it at a steady level for a low power system.
- Power and control the 2 cameras onboard.
- Control and manage an entire sensing system
- Control and manage internal communication and logic states

Even though that at the beginning of the flight the cameras were not able to take any pictures due to the low levels of the battery, by the end of the flight the battery had enough energy for the cameras to take several pictures.

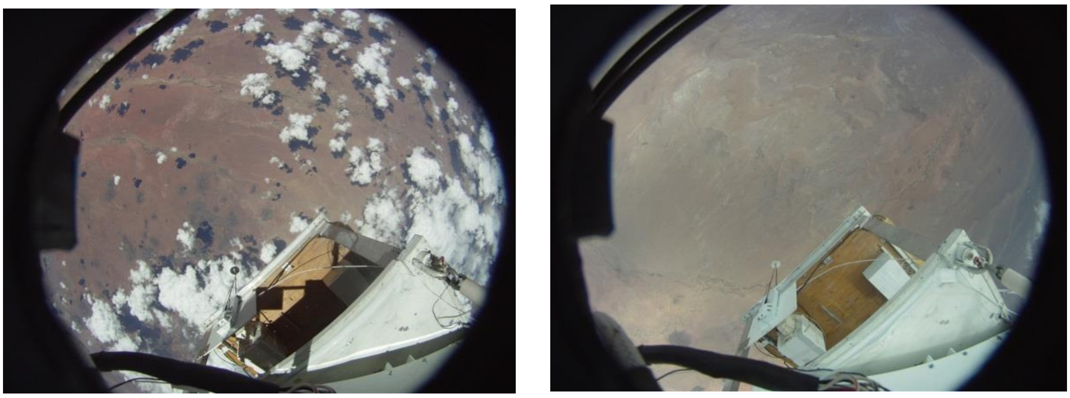


Fig 7. Pictures recovered from the Camera pointing down to the ground.

Recommendations and Improvements for the Independent Power System

Since the starting of the battery at the lowest level during the flight was the only unexpected event during this mission, the battery issue was the biggest problem encountered during the mission for this system. If there is any likelihood any electrical component may malfunction and the team still decides to put it on board, an at least 2-level mitigation plan should be implemented. That way the probability of failure is minimized. For the initial discharge of the battery, the solution could be a starting command along with an extra safety switch. It is a good idea to think of the location of any mechanical switch and try to minimize the possibility of its unaware activation.

Structure Design and Completion

Beginnings: Initial payload design and constraints

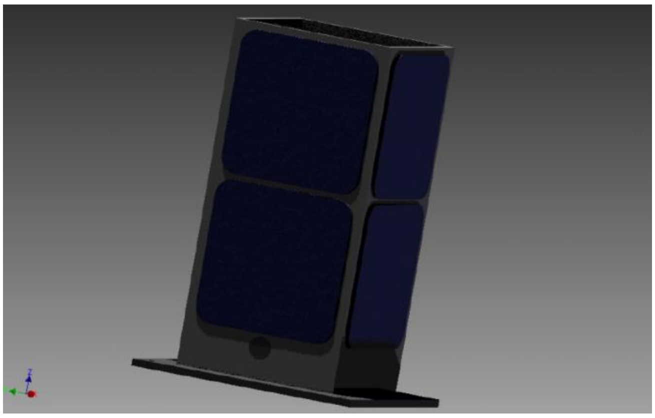
Our payload was approved for flight as a "small payload" with outer dimensions of 15cm x 15cm x 30cm. The initial proposal included the implementation of two different experiments: the first one would consist of a box carrying samples in test tubes for a biology experiment, and the second one would involve implementing a system that would collect energy through the use of solar panels, and then store and deliver that energy in a controlled manner to a camera array that would perform high-altitude imaging.

Carrying the whole setup consisting of cameras, solar panels, batteries, biology experiment container and other miscellanea would require maximizing the available amount of space available, as well as reducing the structural weight of the payload by as much as possible.

However, as IIT's proposal was more carefully evaluated, it was determined that the biology experiment would not fly during this mission. Nevertheless, the progress achieved in the structure design up to this point had been considerable, and the choice was made to retain it for further development even without the biology experiment. The decision was made due to the fact that the structural configuration would provide ample space and low weight that make installation of the camera array more flexible. Only small changes were made to this design over the course of the project.

Final Design of the Structure

The final design of the payload structure is a two-piece design, as originally intended. The idea behind this is to have an inner, fixed structure that acts as the main structural support, and an outer removable structure that can be easily removed for access to components located inside.



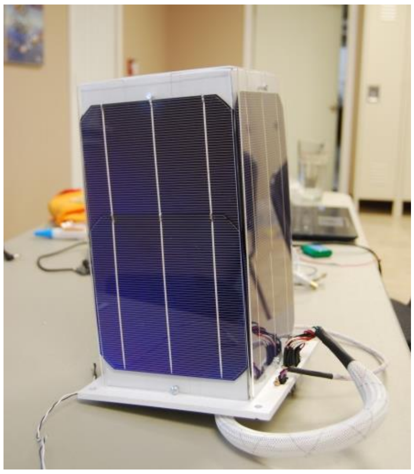


Fig 8. Original Payload Design and Final Payload Design

The inner structure consists of an aluminum frame with a geometry that allows easy access to electronic components located inside. Aluminum was chosen as the main structural material due to its low density and the ability to withstand the predicted 5g and 10g shocks with the chosen payload geometry (outer dimensions within 15cm x 15cm x 30cm, parallelepiped shape, and empty inner space). Four bolts permanently connect the aluminum structure to the baseplate. The inner structure also acts as an attachment point for the outer structure.

The outer structure of the payload consists of a parallelepiped-shaped box that completely encloses the inner structure, protecting inner electrical components from direct solar radiation. The outer structure also provides a mounting surface for the solar panels. The main material used for the outer part of the structure is FRP (Fiberglass Reinforced Plastic). The low thermal conductivity and high strength of this composite make it a good match for this application. Attachment to the inner structure is attained with use of two screws near the top.

Fig 9. Aluminum Main Frame and FRP Shield

Building Process

The inner aluminum structure was designed using the CAD software Autodesk Inventor. The physical design consists of four 2-D truss structures machined from a single aluminum plate with the use of a CNC mill, and then welded together. After key specifications about the structure design had been established (general configuration, inner dimensions required for components, materials to be used, and CAD model) the manufacturing process for the inner structure basically followed the following sequence:

- Purchasing required materials (1/16 in aluminum plate)
- Conversion of CAD drawings into compatible formats for CNC mill
- Cutting aluminum plate into a manageable size using a band saw
- Cutting out general outline of aluminum panels using a table saw
- Cutting out truss layout on aluminum panels using CNC mill
- Eliminating excess materials and other defect from the resulting aluminum structures
- Welding all major aluminum parts into one part
- Cutting and welding smaller components to bottom of aluminum structure (attachment point for bolts that connect to baseplate)

Challenges encountered:

- Aluminum plate as thin as 1/16 in is extremely hard to weld. The low thickness of the material hampers its ability to transfer heat during the welding process, and excessively high localized temperatures occur as a result, easily melting the material or warping it. Finding adequate supports to weld the aluminum parts together in a precise orientation is also difficult.
- The CNC milling process with older machines is long and tedious, requiring about one hour per side of the aluminum structure.

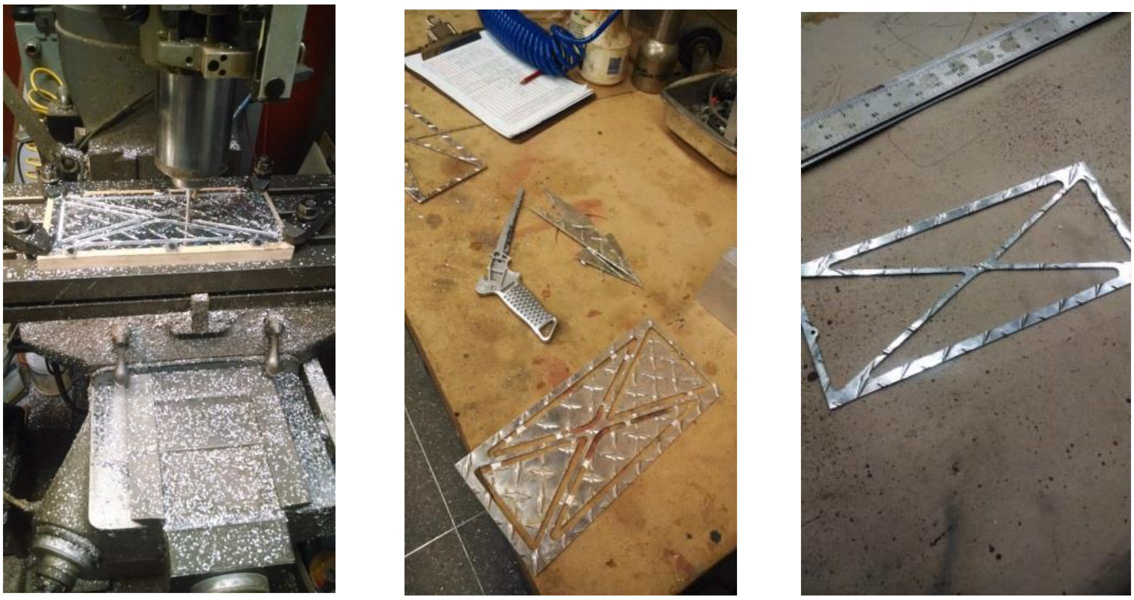


Fig 10. Main Frame Building Process

The outer structure was also designed using Autodesk Inventor. The design consists of five FRP panels that are glued together to form a parallelepiped-shaped structure. Other details include an opening for the sideways-pointing camera and two holes on the sides and close to the top to allow the two attachment screws to go through. After the CAD design had been completed, the manufacturing process followed the following sequence:

- Purchasing of required materials (FRP plate, high-strength epoxy adhesive)
- Drawing outlines of panels on FRP plate
- Cutting out the panels from the FRP plate using band saw at the machine shop
- Removing imperfections and making small adjustments to the resulting panels

- Drilling holes for the camera and attachment screws
- Gluing panels together using epoxy adhesive

Fig 11. Welding of the Aluminum Frame

Challenges encountered:

- FRP panels contain fiberglass and potentially hazardous substances that can cause respiratory problems. During the manufacturing process, respirators had to be used together with good ventilation to ensure that no health hazards were present at any time.
- The FRP panels contained high amounts of glass fibers that can severely wear down machine shop equipment (more specifically, band saws). Additional time had to be invested in finding an appropriate blade that could be used for the task. Also, the FRP type used could only be cut using a band saw or some sort of abrasion cutting device.

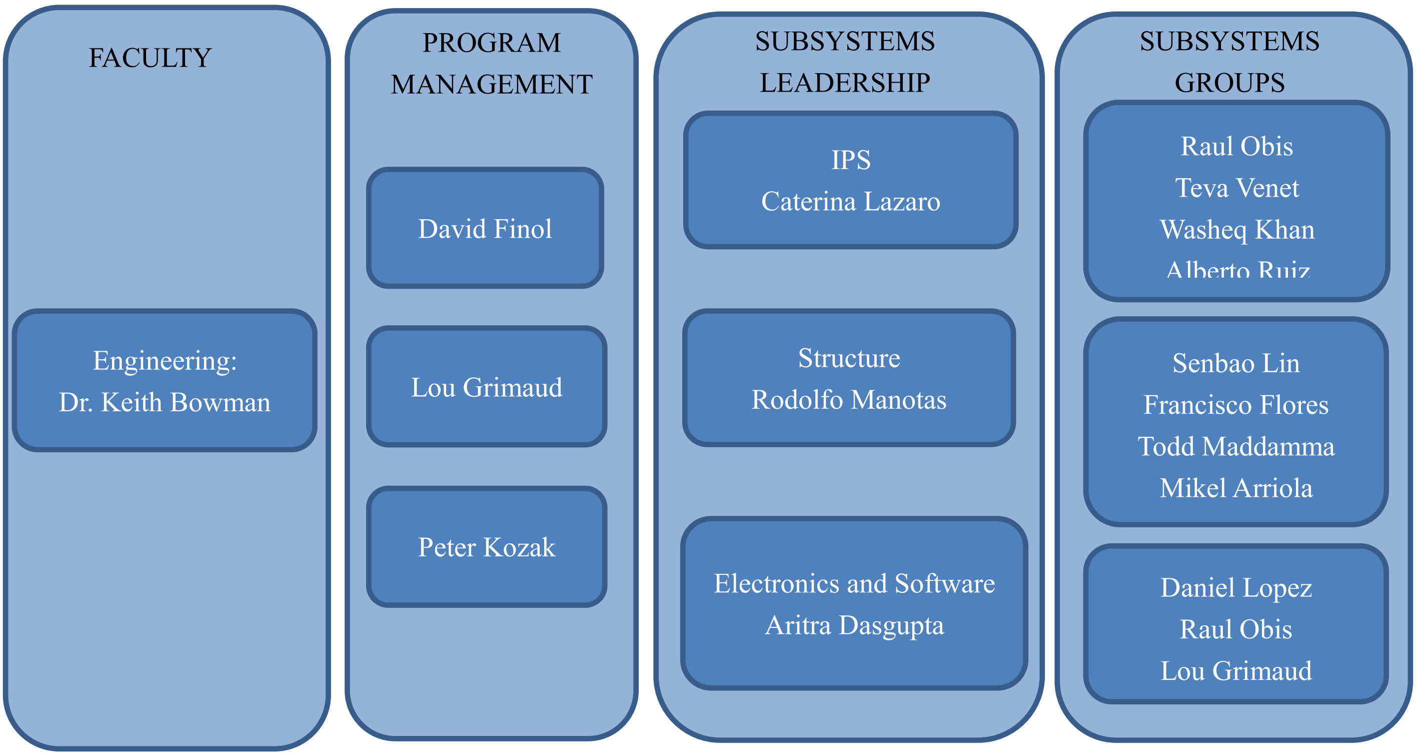
Recommendations and Improvements for the Structure

Based on the experiences and lessons learned from the manufacturing processes for the entire structure, the following recommendations can be made for future payload designs:

- Avoid using welding in any part of the structure. Even though welding allows manufacturing strong metal structures with high integrity, it is also a very inaccurate process at the scale of the payload. Errors in the welding process can easily render a part useless (by melting or warping it) and the whole process needs considerable planification and individuals who are able to carry out the highly specialized process of welding itself.
- Use automated production processes when possible; avoid using CNC machines that require constant supervision and adjustments. Using automated CNC mills and laser cutters can produce parts with considerable structural strength without the need to spend the time to supervise the machine. For components with low structural demands, 3-D printing can produce very accurate parts with complex geometries otherwise impossible with the use of CNC mills and laser cutters.
- Carefully choose materials, taking a close look at the resources needed to machine them and any hazards associated with them. Use more familiar metals, plastics and composites whenever possible (the more specifications and data available the better).

Team Organization and Demographics

Adding up all the people involved in the project, Scarlet Hawk II consisted of 15 undergraduate and graduate students plus our faculty advisor. The team organization was as follows:



Participants' Demographics:

Last Name	First Name	Gender	Ethnicity	Race	Status	Disability
Ruiz	Alberto	M	Hispanic	Caucasian	Grad	NO
Dasgupta	Aritra	M	Non-Hispanic	Indian	Grad	NO
Lazaro	Caterina	F	Hispanic	Caucasian	Grad	NO
Lopez	Daniel	M	Hispanic	Latino	Undergraduate	NO
Finol	David	M	Hispanic	Latino	Undergraduate	NO
Flores	Francisco	M	Hispanic	Latino	Undergraduate	NO
Arriola	Mikel	M	Hispanic	Caucasian	Grad	NO
Obis	Raul	M	Hispanic	Caucasian	Grad	NO
Manotas	Rodolfo	M	Hispanic	Latino	Undergraduate	NO
Grimaud	Lou	M	Non-Hispanic	Caucasian	Grad	NO
Lin	Sembao	M	Non-Hispanic	Asian	Grad	NO
Kozak	Peter	M	Non-Hispanic	Caucasian	Grad	NO
Teva	Venet	M	Non-Hispanic	Caucasian	Undergraduate	NO
Maddamma	Todd	M	Non-Hispanic	Caucasian	Undergraduate	NO
Washeq	Khan	M	Non-Hispanic	Indian	Undergraduate	NO

Conclusion

Having gone through the design, building, testing and integration process of Scarlet Hawk II, we can definitely say it has been a very unique an enriching experience for all of us. As it was noted through this report, the initial design of the payload positively evolved throughout the year and it suffered some important adaptations. The initial idea of an independent solar power system was successfully put in practice and tested in this mission. The solar panels along with the MPPT system demonstrated the ability to charge the battery system, sufficiently enough to be able to constantly run two 1.5W cameras during the last minutes of the flight and at a steady state. Even though low-quality electrical components were used for the payload, the efficiency of the system stayed within the desired levels. This can and will certainly be further optimized for the CubeSat application.

The most important failure during this mission was in a pre-flight procedure. The mixture between a vulnerable point of our design and an unconscious activation of a mechanical switch led to the unexpected discharge of the battery before the flight. This certainly represented a good challenge for our mission as we were planning on having backup battery for the flight. Despite this failure and the short flight, we were able to get to regular voltage battery levels during the float altitude and recover again our image capturing capabilities.

Finally, for future payload designs, it is important to keep tight mitigation plans to minimize the possibility of failure during the flight. The fact that we had a comprehensive sensing system allowed to successfully monitor the exact state of all of our electrical components. One of the main lessons learned during this mission was that the more data the engineer can get about the system and the more comprehensive the mitigation plans are, the higher the likelihood of success for current and future missions.