AC 2007-796: AN INTEGRATED INTERDISCIPLINARY TECHNOLOGY PROJECT IN UNDERGRADUATE ENGINEERING EDUCATION

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Abstract

The ever changing engineering curriculum mandates an emphasis on interdisciplinary projects. Through interdisciplinary projects, students will be exposed to a curriculum that allows them to work in teams of multi-disciplinary members with focus geared towards integrated technologies. This effort requires collaboration of students and faculty from multiple disciplines, and provides students an opportunity to learn from several other engineering systems. In addition, these projects will also help students to learn and deal with the societal aspects of engineering.

The main focus of the paper is the interdisciplinary collaboration of electrical and mechanical engineering students on a senior capstone design of an integrated technology High Altitude Balloon (HAB) system. This project involves the design of a system with a smart high altitude balloon that would reach an altitude of 100,000 feet and return safely to earth. Major challenges in this project were the efficient design of wireless communication modules, and radiation heat transfer analysis on the payload system. The electrical and computer engineering students focused on wireless communication technology, control system design, and data analysis. The mechanical engineering students focused on the design aspects of payload, balloon filling mechanism, flight path prediction based on the study of wind data, and development of a balloon tracking system.

Through this experience, students have learned principles of integrated engineering technology, and nurtured their skills in cooperative learning, team work, and effective planning. This paper presents in detail the modes by which these have been achieved, results obtained and improvements planned for the next senior design team.

Introduction

Weather balloons have been used for many years by meteorologists to study weather patterns in the upper atmosphere. Recently there has been increasing interest in other studies that could be performed using weather balloons in "near space" environment. The exact definition varies, but "near space" is often considered the area of the earth's atmosphere between approximately 100,000 - 200,000 feet. Universities and other scientific institutes, such as University of Montana and NASA Glenn Explorer Post, Cleveland, OH, have been developing programs in this area. The goal of this capstone senior design project was to develop a ballooning program in Wright State University (WSU).

The first step taken in the project was to assemble the team and brainstorm on the approaches and experiments to be performed. The HAB student team comprised of five students (three from mechanical engineering, and two from electrical engineering), and four faculty members (three from mechanical engineering, and one from electrical engineering). The entire HAB team meets once every week to discuss the weekly progress, and sub-teams (electrical and mechanical) meet with their respective advisors more often to make headway on the project. Students undertake this project towards their requirement of a capstone senior design project, and this project is funded through the Ohio Space Grant Consortium.

There are several areas of interest in HAB experiments. These include radiation effects on solar cells, wireless communication, guidance, and detailed maps of atmospheric conditions in relation to altitude. This wide span of information could be used in many areas such as military aircraft and for natural disaster rescue teams. High bandwidth wireless communication between the ground and the balloon, as well as between multiple balloons could be used to design communication methods and systems between high altitude unmanned air vehicles (UAV). There is also hope that balloons could be used in natural disaster situations as temporary communication towers for cellular phones.

HAB Design Description

There were multiple tasks that needed to be completed to make the project a success. The first was designing a command module that would withstand extreme environmental conditions and transmit GPS coordinates to aid the team in recovering the payload once it had been launched. Other tasks included designing a balloon filling mechanism, choosing how to connect the payload components together, choosing balloons, gas, and parachutes to use, constructing a gas tank transport crate, creating pre-launch and launch procedures, and deciding the initial experiments to be performed.

Some of the experiments proposed for the project were solar cell studies of voltage and current at high altitudes, guiding the payload to land in a desired location, achieving high bandwidth communication with the ground, obtaining temperature, pressure, and humidity measurements during flight, and taking pictures from the payload. A timeline was then set for the completion of tasks, and duties were assigned to team members. The breakdown of the timeline and responsibilities are shown in Table 1 and Table 2.

Once the group came to a consensus concerning the desired outcomes of the project, research began to determine the optimal process to follow. Presently, there are many simpler projects being done by an Explorer Post affiliated with NASA Glenn Research Center[1]. Each group designs and performs experiments and learns from other groups' successes and failures. This communication and sharing of information allows future projects to evolve and to be more successful.

For instance, the Wright State University group visit to University of Cincinnati (UC) provided insight into designing and building the payload box, as well as in choosing the core electronics such as the HAM radios. Though many of the parts purchased for the current project were different from the ones used by UC, it was helpful to have an idea of what to look for or avoid. UC was also able to give advice on testing the GPS prior to launch and using a pre-launch checklist.

Table 1: Timeline for completion of HAB Project

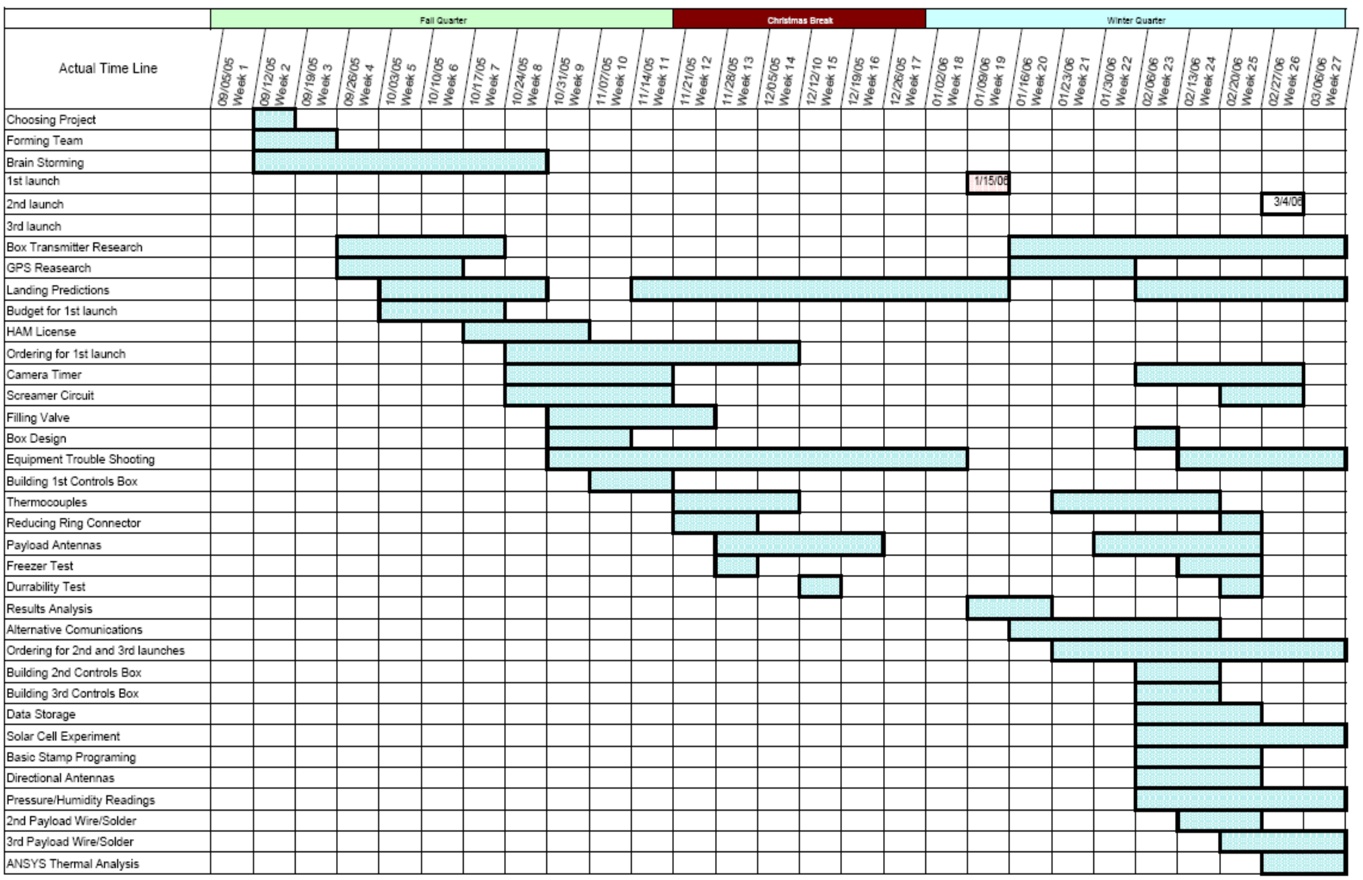

Table 2: Allocation of responsibilities for completion of HAB project

Area	Mike	John	Jessica	Brian	Sean
Camera Timer				x	x
Screamer Circuit				x	x
Data Storage	xx				
Filling Valve			xx		
Thermocouples		xx			
Reducing Ring Connector			xx		
Solar Cell Experiment			x	xx	xx
Alternative Communications	xx	x	x	x	x
Basic Stamp Programming	xx		x		
Predictions	xx		x		
Antenna				x	x
Box Design		xx	xx		
Pressure/Humidity Readings	x		xx		
2nd Payload Wire/Solder	x	xx			
HAM Radio Research	xx	x	x		
GPS Research	x	x	x		
Freezer Test	xx	xx			
Durability Test	x	x	x		
Thermal Analysis		xx			
Data Analysis	x	x	x		
xx - Primary		x - Secondary			

There were a number of design constraints in constructing and launching a payload. The first regulations that needed to be considered were outlined by the Federal Aviation Administration (FAA) Title 49 US Code 14 CFR part 101[2]. The operating environment limited the way the payload could be built. The box needed to be lightweight, yet strong enough to take the impact of hitting the ground with the velocity dictated by the parachute. The walls of the payload also needed to be a thermal insulator in order to keep the inside of the box at an acceptable temperature for the electronics. This meant that a process had to be used to make the insulating material stronger and heat transfer involving conduction, convection, and radiation on all sides of the box needed to be considered.

The main economic consideration for this project was to stay within a reasonable budget and not to waste monetary resources. The starting budget was $3000, but additional money became available later into the project. The majority of the parts were one-time purchases. Once a payload command box was assembled, it could be reused for future launches after it was recovered. Each launch required a balloon and sufficient helium to fill the balloon until it provided enough lift.

Calculations and Testing

To try to keep all of the components within their optimal operating conditions, the walls of the payload box were made of materials with high thermal resistivity. Thermal analysis was performed on the walls of the box using ANSYS (finite element analysis package) to determine how cold the inside of the box could get. Once a solution was obtained, temperatures throughout the payload box could be determined. Figure 1 shows the temperature variations inside the box. Once the analysis was complete, the different temperatures inside faces of the box could reach was determined. This analysis helped the team to see how effective the walls of the payload box would be in keeping the electronics from reaching temperatures below their operating ranges.

The inside of payload box was to be maintained at a moderate temperature in order to ensure the functionality of electronic equipment. So, components of the payload were tested in a freezer to ensure that they could withstand the expected temperatures outside of the box at 100,000 feet which could reportedly[3] range from -70^{o}C to +100 ^{o}C. The types of batteries tested were NiMH, Alkaline, and NiCd. For testing, batteries were placed in the freezer for 2.5 hours (expected flight time of the payload during a launch), and voltages were tested every 15 minutes to determine the performance of the battery. At end of the tests, it was determined that NiMH performed the best and would be used to power the electronics of the payload.

When constructing the payload, system level tests were performed using dry ice. Dry ice is able to maintain a temperature of -78.5°C. The air surrounding the dry ice in a cooler was measured to be an average of -45°C. In the tests with the dry ice, in addition to testing the robustness of the payload components, lithium ion 9-V batteries were tested in comparison to alkaline 9-V batteries over the duration of approximately three hours. At the end of the three hours, the voltages of the alkaline and lithium ion batteries exposed directly to the air in the cooler showed that the lithium ion batteries performed significantly better.

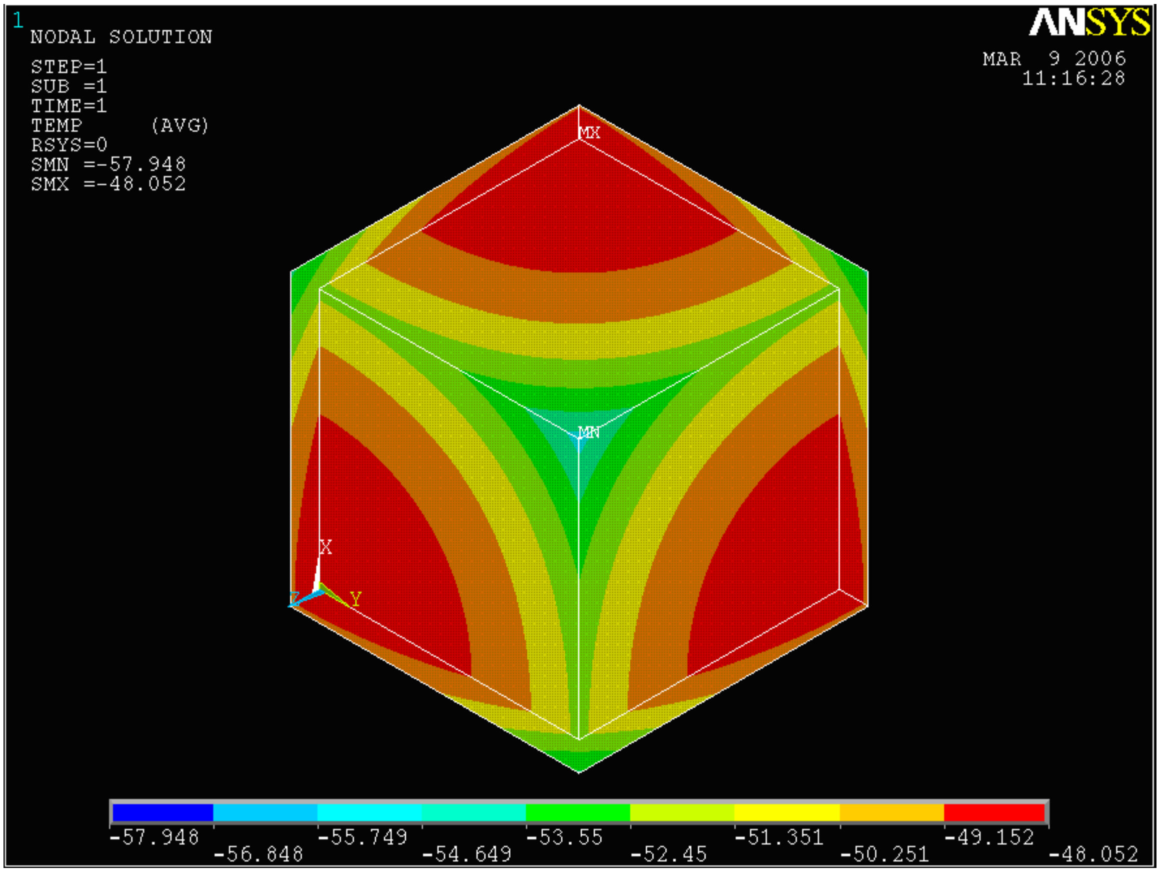

Figure 1: Variation of temperature inside the Payload box

The payload box was to include a GPS receiver, a transmitter, a temperature measuring device, a camera, and a screamer circuit. A Garmin 15L was chosen for the GPS as it operates at low voltages of 3.5 - 5.5 volts. A Kenwood TH-D7A was chosen to be used as the transmitter. This particular HAM radio was picked because it contained a built in Terminal Node Controller (TNC), and can also be used for custom packet operation on any allowed frequency in the 2m band. To take pictures, a timer circuit was connected to the camera so a picture would be taken once every minute. An Onset HOBO Temperature Logger[4] was selected to measure the temperature both inside and outside the box. The screamer circuit was made from a dissected smoke detector and was to be used to help locate the payload once it had landed. Figure 2 shows the entire balloon assembly.

Calculations were also performed to determine the size of the parachute that was needed to carry a payload of 12 pounds to the ground with a maximum landing speed of 15 feet per second. The results showed that a parachute with a 6.35 ft diameter was needed.

Implementation

For the initial launch, some of the tasks that needed to be completed included choosing equipment, designing and constructing the fill valve and the payload box, disassembling a camera and attaching it to a timer circuit, integrating a GPS system with a HAM radio, getting a HAM radio license, running pre-launch predictions, and choosing a launch site. The timer circuit was required so pictures could be taken at set intervals over a designated time period. The GPS tracking system includes the GPS chip, an antenna to receive information from satellites so that its location could be determined, and a HAM radio to communicate with the ground. A Technician Class (or higher) licensed radio amateur must be present to oversee the use of the HAM radio to transmit GPS data. A fill valve and nozzle was designed and built to be able to get the helium from 244 cubic foot tanks into the weather balloon. Predictions were also made based on wind patterns to determine where the payload would land if it was launched.

In order to pick a launch site, wind data from the past ten years was analyzed and fed through a path prediction program called Balloon Track[5] to make predictions of where the balloon would land. Depending on the strength of the winds at higher altitudes, the balloon could travel 300 or more miles during its short (approximately 2.5-3 hour) flight. The prediction data was used to create a scatter plot of potential landing locations. A single prediction run could be plotted using Google Maps, Yahoo Maps, or a similar Internet based mapping software from within Balloon Track. For multiple points, Xastir[6] was used. After reviewing a large range of predictions, it was decided that a balloon launch would be canceled if the most recent upper air wind forecast contained any five data points with winds above 100 knots, or any one data point with winds above 120 knots.

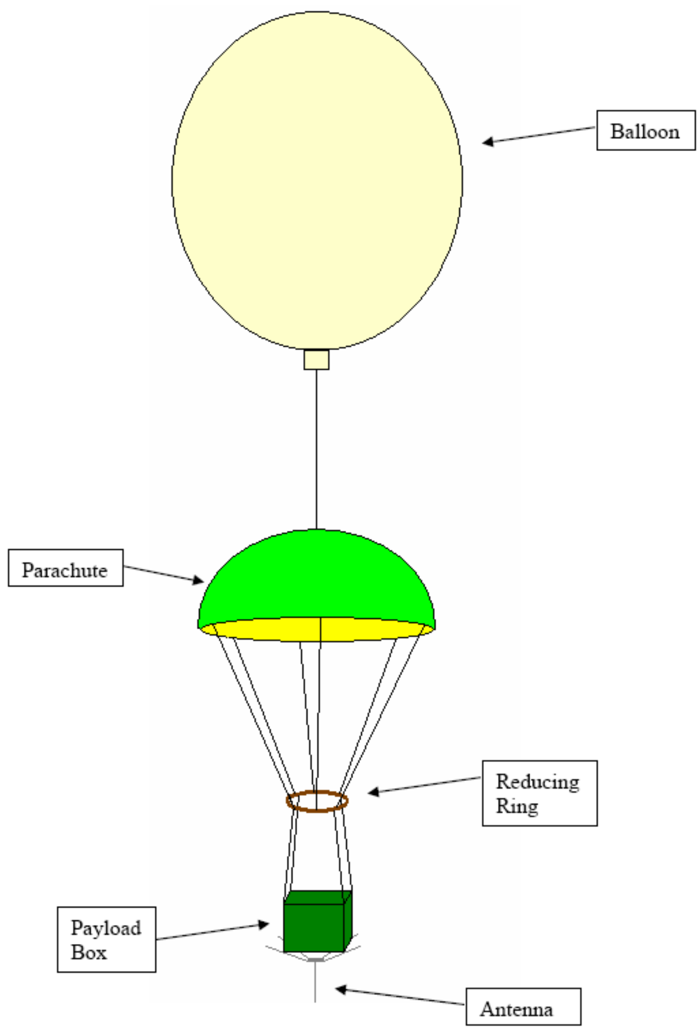

Figure 2: HAB Module

First Launch

The first launch took place on January 15, 2006. The balloon was launched from the municipal airport in Portland, IN. There was less than 5% cloud cover and the surface winds were less than one mile per hour. The temperature outside was -6°C (22°F). The balloon took approximately 45 minutes to fill and used slightly more than one tank of helium (one tank contains 244 cubic feet helium) to achieve the desired lift.

The release of the balloon occurred around 9:10 am. The release went smoothly and the balloon went almost straight up. Once the payload was in the air, it had a pendulum motion as it ascended. The first fifteen minutes of the flight went according to plan. The ground unit was able to successfully track the movements of the payload. Once the balloon reached approximately 11,000 feet, no data was received from the HAB system. Repeater stations throughout Ohio and Indiana were able to receive the packets transmitted by the onboard radio and record them on the Internet. An analysis of these packets showed that for approximately four hours the payload transmitted the same coordinates, altitude, and velocity. By using knowledge of which repeaters logged packets and the wind prediction data, the location of the payload was estimated approximately, but the design team did not have success locating the HAB system.

The packets that were received from the GPS before it locked-up were analyzed and compared to the wind data collected from the weather station at Wilmington, OH[7]. The general trend was that the payload moved slightly slower than the wind speed due to drag. The direction of the flight was not completely with the wind. Both the flight path and the wind direction were toward the southeast, but the correlation was less than expected. This might be due to two factors:

1. The GPS data were not updated frequently enough to be very accurate.
2. The payload was swinging below the balloon in a pendulum type motion as the entire system moved in a southeast direction. This would add some error to the direction that the GPS indicated the system was moving.

Second Launch

After the first launch, results were gathered and hypotheses were made regarding the failure of the command box. Some of these ideas included failure of the GPS chip, failure of the HAM radio, broken wire connections, or low voltages and currents supplied by the batteries. Any one or a combination might be the reasons behind the failure. More research was done concerning failures related to GPS systems and it was concluded that the GPS probably locked up.

In order to avoid this problem on a future launch, it was decided to include redundant GPS systems in one payload, as well as a constant tone beacon to be utilized in foxhunting as a backup tracking system. A Parallax BASIC Stamp[8] was set up to manage sensor data (temperature, pressure, and humidity), and acquire coordinates from three different GPS chips. This information was transmitted directly to a computer on the ground via HAM radios and was also stored on the BASIC Stamp for analysis when the payload was recovered or in case there would be a problem transmitting it to the ground in real time. The code pertaining to the GPS information and sensor input was written entirely by the design team.

A fourth GPS chip was used to transmit to the Automatic Position Reporting System (APRS) digipeater network. The APRS packet eventually reaches an IGate (Internet Gateway), which uploads the information on the Internet, cataloged by both the call sign of the HAM operator and by the time and date. If the team's receiving antenna became unable to pick up the transmissions because the payload was out of range, the information could be accessed later to track the flight path.

Foxhunting was implemented as a backup system in case all the GPS chips failed. The system was set up so a beacon would transmit a pattern of tones in Morse code (.-- ... ..- / -... .- .-.. .-.. --- --- -. which translates to "WSU Balloon") that could be picked up by the use of directional antennas. With several directional antennas, the group would be able to figure out where the transmitter was located.

Using all of these methods, it was the hope of the group that the payload would be found once it was launched. On March 4, 2006, the group headed to Huntington, IN with hopes to have a successful launch and recovery. The balloon was inflated while the rest of the group worked on testing the GPS system with the BASIC Stamp. The previous night the entire system had been tested and worked perfectly, but at the launch site the GPS chips did not function correctly. After three and a half hours it was discovered that two of the GPS antennas were too close to each other. This close proximity caused them to jam all the GPS receivers in a 200 foot radius. The problem was fixed, but by that time, the batteries in the HAM radios had been used for too long and were judged not to be dependable for an entire flight. This HAB system with slight modifications was later tested by the 2006 team, and had a successful flight.

Future Goals

Though the group has accomplished much in the process of establishing the Wright State University High Altitude Balloon program, many ideas for experiments were not implemented due to time constraints. Starting a High Altitude Ballooning program at Wright State University was a challenging task. Advice was taken from other groups, but there was much the Wright State University group had to learn on their own. Now that the Wright State University group has started the program, they have been able to share the information gathered through research and system checks to help other groups to start their own programs. Five students and an advisor from a neighboring university came to Wright State University to get ideas of what a balloon project might entail.

Other universities and federal programs have shown interest in the Wright State program. With a working payload, specific launching procedures and guidelines in place, future groups are able to start designing more advanced and detailed experiments.

Observations and Conclusions

As a part of senior design class, all students are required to participate in background research, design, integration, testing, and documenting the progress of the project. These requirements have been stated clearly early during the project, and all students were required to share equal responsibilities during the project. During the course of the project, it was observed that students with more enthusiasm take on the task of the others. To aid in this process, a team leader was chosen, with one of his/her primary responsibilities being ascertaining equal responsibilities of work within his/her team members Also, this allows students to learn to work successfully on inter-disciplinary projects.

This project not only allowed for the collaboration of different departments, but also of different universities. Before embarking on the project, students traveled to neighbor universities to learn from their experience, and later presented their work at different technical meetings. This provided students insights on pitfalls to avoid, and get a jump-start on the project. Through working on this real-time project, students not only enhanced their technical skills, but also their interpersonal skills to work as a team, and were able to improve their intellectual self-confidence.

The Wright State University Balloon project began with the expectation that it would be a straightforward process to create a program for launching payloads, and within two quarters, complex tests could be integrated into the system to be performed during a flight. It became clear as the first box was being designed and built that the project entailed more development and design aspects than the group had anticipated. After the unfortunate loss of the first payload, it was determined that the complex tests planned for would most likely not make it into one of the current group's launches. Instead, the current group decided to focus on establishing the program and a detailed system in which launches could take place with a significantly greater chance of recovering the payload.

The failed recovery was analyzed and different modes of failure were suggested. The weak areas in the original design were investigated and improvements were made to the system to create a more robust communications box. Studies were performed on GPS chips and their high failure rate. It was soon realized that a single GPS chip was not reliable enough to depend on it as the only means of locating a payload. The decision was made to implement multiple GPS chips from different manufacturers in the same payload. This way, a failure of any single component would not cause the payload box to be unrecoverable, and future groups would have a better idea of which GPS chips performed the best in high altitude applications.

Most of the components in the new payload were integrated with a BASIC Stamp. The BASIC Stamp would be able to store information from the flight, and be used for future groups to perform basic algorithms to control their experiments

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