AC 2008-1297: A “BALLOON SATELLITES” PROJECT COURSE

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The WVU “Balloon Satellites” Project Course

Abstract

Over the past six years a “hands-on” aerospace engineering project course has been developed and offered at West Virginia University (WVU), where student teams conceive, propose, design, build, fly, track, and recover small electronic experiment payloads, using helium-filled latex weather balloons to send their payloads well into the stratosphere. Thus, in a single semester, and at relatively low cost, students participate in a space-like mission, complete from mission concept development to data analysis. This course is patterned after similar courses offered at other universities, and has added a much-needed emphasis on “space” in the WVU Aerospace Engineering curriculum. The main course goal is to provide students with a hardware-oriented, hands-on design project experience. This course can fulfill a technical elective requirement in either the WVU Aerospace Engineering or Mechanical Engineering curriculum. The course organization and course procedures are described, along with a summary of the types of student payloads that have been developed and flown by the student teams to date.

Introduction

The WVU Balloon Satellites course instructors are both professors in the combined Mechanical and Aerospace Engineering (MAE) Department at West Virginia University. The WVU MAE Department has a long history of providing high-quality “hands-on” senior design projects as options for the required capstone senior design course in the Mechanical Engineering (ME) curriculum (e.g., formerly, the SAE Formula Race Car and Future Truck projects, and currently the SAE Mini-Baja Car, and Challenge-X, among others). However, there has been much less opportunity at WVU for the Aerospace Engineering (AE) majors to gain experience working on an open-ended design project in a team environment. For approximately the past ten years, AE students have been able to elect to participate in the AIAA “Design, Build, Fly” RC controlled airplane competition and receive credit for one of their three required senior technical electives in the AE curriculum. Additionally, for the past six years, students can also now elect to participate in the WVU “Balloon Satellites” project course, and can chose to count their course credit for this project as a senior technical elective. Neither of these open-ended, hands on design projects can be used to fulfill the capstone design course requirement at WVU; this course continues to be a traditional conceptual airplane design course. This paper will summarize the development of the WVU Balloon Satellites course, as well as describing the recent modifications to the course that have been implemented for the Spring 2008 semester offering of the course.

The WVU Balloon Satellites course has been patterned after similar courses and projects that were first developed as the BallonSats program at the University of Colorado. In the Summer of 2002 the first author attended the Boulder BalloonSats workshop with WV NASA Space Grant Consortium Director, Dr. Majid Jaraiedi, to learn about this program and determine if a similar project could be offered to students at WVU. After returning to WVU, colleague G. Michael Palmer was recruited to co-develop this course, applying his expertise to develop all of the necessary data acquisition and balloon tracking hardware and software.
During Fall 2002 and Spring 2003, this hardware and software was designed, developed, and tested. In the Spring 2003 semester G. M. Palmer and J. Kuhlman offered the first WVU Balloon Satellites course to twelve WVU undergraduates as a special topics course; successful launch, tracking, and recovery of three student payloads was accomplished, measuring temperatures, pressure, and acquiring digital still photographs. In the following Summer G. M. Palmer also participated in the Boulder BalloonSats workshop. Each Spring semester from 2004 to the present the WVU Balloon Satellites course has been offered as a special topics course, with successful launch and recovery of all payloads having been achieved. Details of the WVU Balloon Satellites course are documented on the course web site

Most recently, in 2007 a team of three WVU undergraduates participated in the NASA-sponsored High Altitude Student Platform (HASP) program developed and administered by LSU\(^3\), to propose, design, construct, and fly their successful cosmic ray experiment from the NASA Columbia Scientific Balloon Facility. This initial WVU HASP project has been documented online\(^4\).

**Description of WVU Balloon Satellites Course Procedures**

Student teams respond to a formal Request for Proposals (RFP) from the course instructors, to propose a balloon satellite mission of their choice, developing an experiment instrument package that meets weight, size, and cost constraints specified in the RFP. Teams are provided the necessary data acquisition system, access to a shop area for construction of their payload, and a separate payload that contains the necessary balloon tracking GPS and ham radio hardware. Data acquisition hardware and software and all balloon launch capabilities are also supplied by the course instructors. Course instructors also provide guidance to the teams to ensure that their planned missions are realistic, safe, and within current FAA regulations. All balloon launches are cleared through the FAA.

The course is structured in three phases. First, in the first four weeks of the semester the course instructors present content related to FAA regulations, atmospheric properties, sensor selection, data acquisition and data storage, power consumption and power sources, software, and payload tracking. During this time, the teams are formed and they brainstorm to conceive of their mission concept. The RFP is issued to the student teams at about week three or four in the semester, and an initial seven-page response to the RFP is due from each team two weeks later. These initial reports are evaluated by the course instructors, and then they are returned to the teams to be revised and improved and resubmitted. During the second phase, the student teams do the actual design, construction, development and testing of their payloads. Approximately seven to eight weeks are allotted for this process. Finally, the balloon mission is flown, the payloads are tracked and recovered, the teams reduce and analyze their results, and then they submit a technical report that summarizes their results. This final phase occurs during the last three to four weeks of the semester. Actual course schedule is influenced by the timing of the spring semester recess and Easter holiday. The course has not been offered in the Fall semester, in order to avoid a payload recovery during the Winter months.
For the first five years of the course, the student teams were allowed to select their own mission without significant constraints from the course instructors. The only constraints were that the selected mission payload had to satisfy constraints set by the instructors on payload weight (1 kg), size (initially, a 15 cm cube; now a 20 cm cube), and cost ($500). For the present Spring 2008 offering of the course, this process has been changed slightly, so that all first-time participants in the course will be formed into teams that will also be constrained as to the allowed complexity of their payload missions. Also, in the Fall 2007 semester, the WVU Balloon Satellites course was formally approved by WVU Faculty Senate, and established as a two semester sequence of senior technical elective courses, MAE 415 and MAE 417. These new courses will be comprised of, first, construction of a relatively simple initial balloon payload that will consist of temperature and pressure measurements, followed by a more complex second mission where the student payload will be conceived, proposed, and developed by the student teams themselves, with guidance from the course instructors. This two course sequence, along with participation in the HASP program will give interested WVU students the opportunity to experience at least the first three parts of the “Crawl, Walk, Run, Fly” goal of the Colorado Space Grant Consortium BalloonSat program\(^1\) and the National Space Grant Student Satellite Program\(^5\). A week-by-week course schedule in shown below.

Schedule for WVU “Balloon Satellite” Course

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Intro. to course, Standard atmosphere, FAA regulations, Intro. to measurements, Transducers</td>
</tr>
<tr>
<td>02</td>
<td>Introduction to measurements, Units, FAA regulations</td>
</tr>
<tr>
<td>03</td>
<td>Space environment, Potential measurements, Data representation, storage, and transmission</td>
</tr>
<tr>
<td>04</td>
<td>Design issues: size, weight, power consumption, performance, environment, cost</td>
</tr>
<tr>
<td></td>
<td>Mission objectives, Start preliminary design</td>
</tr>
<tr>
<td>05</td>
<td>Hardware selection: sensors, data acquisition/storage, telemetry</td>
</tr>
<tr>
<td></td>
<td>System integration: packaging, powering</td>
</tr>
<tr>
<td></td>
<td><strong>RFP (Request for Proposals) Released</strong></td>
</tr>
<tr>
<td>06</td>
<td>Software, programming, and sensors; Start work on design</td>
</tr>
<tr>
<td>07</td>
<td>Work on design</td>
</tr>
<tr>
<td></td>
<td><strong>1(^{st}) Design Review and Report Due</strong></td>
</tr>
<tr>
<td>08</td>
<td>Work on design: Hardware and software</td>
</tr>
<tr>
<td>09</td>
<td>Work on design: Hardware and software</td>
</tr>
<tr>
<td></td>
<td><strong>2(^{nd}) Design Review and Report Due</strong></td>
</tr>
<tr>
<td>10</td>
<td>Complete design and construction: Hardware and software</td>
</tr>
<tr>
<td>11</td>
<td>No class this week: WVU spring break</td>
</tr>
<tr>
<td>12</td>
<td>Complete hardware and software, Static ground testing</td>
</tr>
<tr>
<td>13</td>
<td>Final ground testing</td>
</tr>
<tr>
<td>14</td>
<td>Balloon flight!</td>
</tr>
<tr>
<td></td>
<td><strong>(Target Date: Sat., April 19; may move to the week prior)</strong></td>
</tr>
<tr>
<td>15</td>
<td>Debriefing, Data analysis</td>
</tr>
<tr>
<td>16</td>
<td>Debriefing, Data analysis</td>
</tr>
<tr>
<td></td>
<td><strong>Final Report Due</strong></td>
</tr>
<tr>
<td>17</td>
<td>Exam Week – no class meetings or deliverables</td>
</tr>
</tbody>
</table>

In the first, one-credit, course, MAE 415, students work in small teams to select, construct, and test small experimental packages for missions that are carefully prescribed by the course instructors. In the second, two-credit course, MAE 417, students basically work in the same team environment on the development and flight of a similar experimental payload,
except that for MAE 417 the student teams develop a portion of the mission concept themselves. The concept of two related courses follows the first two steps of the “crawl, walk, run” project course philosophy espoused by the University of Colorado Balloon Satellites course developers that have served as the role model for the WVU course. Students first build, test, and fly a relatively simple balloon payload in MAE 415. This is followed in MAE 417 by a more complex project, where the student teams can conceive of their own mission goals and develop the required measurement methods that are needed to accomplish the mission that they themselves develop. The two courses may be “bundled” together by the student to fulfill one of their required senior technical elective courses.

The individual payloads and the complete payload stack both are designed so as to NOT fall under the FAA Federal Aviation Regulation (FAR) Part 101, governing the operation of moored balloons, kites, unmanned rockets, and unmanned free balloons. That is, our payloads fulfill the requirements of: a.) two or more payloads with a total weight of less than 12 pounds, b.) each payload having a weight/size ratio of less than three ounces per square inch, and c.) payloads suspended by a rope or cord with a breakage strength of no more than 50 pounds; see part 101.1 of the FAR. However, as expected by the FAA Eastern Region in Jamaica, NY or the FAA Southern Region in Atlanta, GA for unmanned balloon flights in the eastern corridor airspace, we request a formal “no objections” memo from the appropriate FAA contact prior to our flight, and follow all procedures outlined in their reply. Currently, these requests are sent to a Mr. Rich Horrocks of the FAA Southern Region at rich.horrocks@faa.gov, 404-305-5619, 404-305-5572 FAX.

Typical missions that have been developed and flown by the student teams over the first five years include: the measurement of vertical profiles of atmospheric temperature and pressure, acquisition of still and/or video pictures, study of high-altitude effects on mosses and fruit flies, attempted measurement of profiles of gamma radiation via a Geiger-Mueller tube and gyroscopic stabilization of a payload, capture of micro-meteorites (“space dust”), balloon thermal wake temperature measurements, three-axis accelerometer data, testing of a cut-down system, radio telemetry of data to the ground, and live TV video transmission via radio. Not all of these missions have been successful on every occasion. Over time there has been a gradual increase in the scope and complexity of the missions that have been proposed and flown by the student teams.

**Description of WVU Balloon Satellites Hardware and Software**

Over the past several years (2003 to 2008) a series of data logger-telemetry boards have been developed by the second author for use in the WVU Balloon Satellites course. The first (Version 1) was used in the 2003 flight, and has been in use since then. The technical details for this board are available from the project web site. An improved board (Version 2) with more on board memory and 8 ADC channels was designed and was flown in 2004 and 2005. A Version 3 board was designed and built in 2005 expressly for high sampling rate acceleration measurements and has not been used since. In 2006 the current and most likely the last in this line of WVU Balloon Boards was designed. This board is designated Version 4A and is the end result of several modifications to the Version 4 board. The 4A board uses a Microchip PIC 18F4620 for its processor and has a radio modem, ADC, timers, relay
output, GPS receiver and much more in a small 3.5 x 3.5 inch board. A comprehensive configuration program allows easy configuration and testing. This board has been fully tested on the bench and in balloon flights. This board will be described in more detail below.

The board is made on one-ounce, double-sided, FR-4, 62.5 mil thick, fiberglass circuit board. The early boards were hand etched by the second author. This is a tedious process and would not accommodate plated-through holes. The latest circuit boards have been made commercially. Figure 1 shows a photograph of this most recent board.

![Figure 1. Top View of WVU Balloon Board Version 4A with Trimble GPS receiver.](image)

Each student team is provided with a Version 4A board, a battery holder for three AA cells, LEDs, and wiring. A copy of the manual for the board is provided on CD along with other programs to help with data reduction. Instruction is provided for the use of the board. The course instructors also provide guidance to each team in the selection and purchase of their own transducers and will aid with any problems of interfacing.

Features of the Version 4A Balloon Board include:

- Board SPI buss for a number of devices (transducers, ADC, digital temperature and pressure sensors, etc.),
- Eight single ended 12 bit or 4 differential unipolar 13 bit analog (ADC) inputs on a SPI buss,
- Precision 2.048 to 5.000 V voltage reference for ADC,
- Two isolated relay outputs with settable pulse period and duration (for camera trip, cut-down device, etc.),
- Three bits of TTL I/O with multifunction use (counter input, period measurement, Geiger tube input, etc.),
- Two LED outputs for signaling and diagnostic use,
• Two timer inputs for resistive transducers (for thermistor input),
• Four SPI ports for user-supplied SPI devices and inputs,
• Serial port for configuration of the board, this port communicates with host
computer to set configuration,
• Onboard GPS receiver or serial port for external GPS receiver to record position
and altitude during flight,
• Second serial port for GPS receiver (4800 baud serial port for on board GPS or
external GPS receiver),
• EEPROM to store configuration information for board operation,
• Dallas Real Time Clock (RTC) with battery backup on the SPI buss to record the
time and date,
• Two 13-bit digital temperature sensor on the SPI buss (board temperature and
outside or other temperature),
• Data Flash Card storage for up to 32K data scans on the SPI buss (each scan
includes all input and GPS data),
• Bell 202 packet MODEM for APRS and data transmission (this interfaces
connects with a radio),
• Bell 202 packet MODEM for command reception (this allows the reception of
commands),
• Operation from 1.5 to 4.5 Volts or one Li-ion cell with low battery drain,
• Data logger start input (to insure positive start of data logging and visual
confirmation with LED),
• Diode protected power input (reverse polarity and over voltage),
• High efficiency (85-95%) 5V switching power supply provides 5V power from 1.5
to 4.5 V battery,
• Linear 3.3 Volt regulator for memory card and GPS receiver and other 3.3V
devices,
• Small size board (~3.5 x 3.5 in.),
• Light weight; about 85g for board, GPS receiver, and battery (3 1.5 V Lithium
cells), and
• User configurable using a simple PC based program.

Detailed circuit diagrams for the Version 4A Balloon Board are shown in Figure 2 below.
Figure 2a: Balloon Board CPU, MODEM, and I/O connections.

Figure 2b: Balloon Board I/O.

Figure 2c: Balloon Board power supplies.
The resistor combination of R1, R2, and R2A are sized to set the “5V” supply voltage to about 5.2V. This is done to insure the supply is above the 5.000 V reference when used.

The WVU Balloon Board is configured using the PC-based configuration program named BALL_V4.EXE. This is a DOS based program that will run fine using DOS under all versions of WINDOWS through XP. The program line in the MS-DOS shortcut icon may have the communications port name of COM1 or COM2. If it is not included on the program line the program will prompt the user to input the port number. BALL_V4 has the main screen given in Figure 3. Most items and commands on the main screen have help screens behind them. To see the help screen for an item use the command “ITEM?”. For example; for help on item 17 use “17?”. All data files will be placed in the folder that contains BALL_V4.EXE.

![Configuration program main screen](image)

Figure 3. Configuration program main screen.

The individual items on the screen have the functions given below. Note that not all items are shown on the main screen.

**Item 1**: Amateur Call Sign and SSID for APRS transmissions. SSID should be set to –11 for a balloon.
**Item 2**: APRS “TO” Call Sign. This call sign will set the screen icon seen by receiving stations.
**Item 3**: Digipeater 1 Call Sign and SSID. If blank no digipeater will be used.
**Item 4**: Digipeater 1 Call Sign and SSID. If blank no digipeater will be used.
**Item 5**: Number of base periods (Fast = 10ms and Slow = 10s) between data scans.
Item 6: Number of scan periods between APRS transmissions.
Item 7: Number of APRS transmissions between GPS transmissions.
Item 8: Base data logging period Fast = 10ms and Slow = 10s.
Item 9 through Item 22, Item 25, and Item 26:
   These items are 8-byte text fields describing the measured quantity in the field.
Item 23, Item 24, Item 27, and Item 28:
   These items give mode numbers for SPI-A through SPI-D devices.
Item 33 and Item 35:
   These are LED 1 and LED 2 ON/OFF fields. If the LED is set to OFF it will not flash.
Item 34 and Item 36:
   This field sets the LED 1 and LED 2 modes.
Item 37, Item 40, and Item 43:
   These items set the data direction of the I/O bits.
Item 38, Item 41, and Item 44:
   These items set the period between pulses when the bit is used as an output.
Item 39, Item 42, and Item 45:
   These items set the pulse width when the bit is used as an output.
Item 46: This field is a 32-byte text field that will be sent every APRS transmission.
Item GPSM: This field sets the GPS Mode to either Polled (P) or Continuous (C).
Item CMD: This field sets the packet command mode to either ON or OFF.
Item H: This command establishes communications between the Balloon Board and the PC.
Item R: This command item reads the configuration data from the Board EEPROM.
Item W: This command item writes configuration data from the PC to the Board EEPROM.
Item C: This command item displays a screen with data from the Board I/O devices.
Item D: This command item downloads data from the Data Flash card to files on the PC.
Item S: This command puts the board into data logging mode.
Item ?: This command will display several screens of help topics on the items on the main screen.
Item E: The “E” command allows a clean exit of the configuration program.
Item DM: This item is used to set the active I/O devices. The default setting is ALL devices are active.
Item SC: This command will save the currently stored configuration to a disk file.
Item RC: This command will read a configuration disk file and restore the setting to the configuration program.
Item RTC: The Dallas RTC may be read or set to the current PC clock time using this command.
Item G: A current frame of GPS data may be obtained with this command. This is used to check GPS operation.
Item RS: This command is used to reset the configuration to the initial state.
Item SDP: This will allow the inserting of a new number for the number of data points.
Item RL1 and RL2:
   These commands send one short pulse (1 sec.) to either Relay 1 or Relay 2 for testing.
Item LED1 and LED2:
   These commands send one short pulse (1 sec.) to either LED 1 or LED 2 for testing.
Item IO1, IO2, and IO3:
   These commands send one short pulse (1 sec.) to IO1, IO2, or IO3 for testing.
Overview of WVU Balloon Satellites Missions, 2003-2007

The initial WVU Balloon Satellites flight occurred on April 27, 2003; see Figure 4 for an image of the launch and views at the landing site. The payloads were launched from the WVU Jackson’s Mill 4-H Facility, after an unsuccessful attempt on the previous day. For this initial mission, three payloads that were developed by the teams formed by the twelve WVU Aerospace Engineering (AE), Mechanical Engineering (ME), and Industrial Engineering (IE) majors in this initial offering of our course were flown, along with the tracking payload developed during the fall 2002 semester by course instructor G. Michael Palmer. The balloon and payloads were successfully tracked and recovered. The landing site was southeast of Elkins, WV, in the tops of trees, approximately 70 ft in the air. Since we had not brought any climbing gear with us on the chase, it was necessary to return the following weekend with a professional tree climber to complete the actual recovery of the payloads. Maximum altitude attained was approximately 74,000 ft. For these initial payloads, students were directed to measure inside and outside air temperature, as well as one additional type of data. Two teams chose to use digital cameras to take still images from the air. Both of these teams were successful in obtaining records of indicated outside air temperature, as well as air pressure versus altitude; see Figure 5 for an example, from Group 2. It was noted that the measured outside air temperatures were all consistently much warmer than would be expected based on the US standard atmosphere (black line in Figure 5A.). The cause of this error was unknown at the time. The third team designed a wind anemometer to measure air velocity relative to their payload; however, their anemometer was broken during the launch process and they did not obtain data.

Figure 4. First WVU Balloon Satellites mission, Spring 2003.

Figure 5. Sample data from first WVU Balloon Satellites mission, Spring 2003.
The second year flight of the WVU Balloon Satellite project occurred on April 17, 2004; we again launched from the Jackson’s Mill facility, and successfully tracked and recovered all payloads. For this second mission, we again landed southeast of Elkins, WV in the tops of trees; however, this time we had a tree climber with us who was able to recover the parachute and all payloads on the same day. Two images of the launch are shown in Figure 6, along with an image from the ground of the chute and payloads. For this second offering of the course, we had sixteen students enrolled (all ME or AE majors, except for one Computer Science (CS) major), who were formed into four teams. The RFP specified the same mission requirements as for the previous year, so all teams measured inside and outside air temperatures. Two teams chose to also use inexpensive CMOS video cameras to record in-air video from their payloads. A third team chose to interface an on-board GPS to their data acquisition board, to measure and record altitude, while the fourth team chose to measure pressure versus altitude, along with temperature, and also tested (unsuccessfully) a cut-down system. Maximum altitude for this second mission was approximately 77,000 ft. Sample atmospheric data are shown from this mission in Figure 7. For this year, the students chose to use a commercial HOBO pressure recorder that was calibrated; thus, their data were much more accurate than the previous year (Figure 5B.). Temperature data again was much warmer than expected (almost 30°C off at maximum altitude; see Figure 7A.). Again, the reason for this data inaccuracy was not known.

A.) Launch, 4/17/04  B.) In the air  C.) In a tree, again

Figure 6. Second WVU Balloon Satellites mission, Spring 2004.

A.) Air temperature vs. altitude  B.) Air pressure vs. altitude

Figure 7. Sample data from second WVU Balloon Satellites mission, Spring 2004.
The third mission was successfully launched and recovered on April 16, 2005 from the Jackson’s Mill facility; see Figure 8. This year, we were lucky; the entire payload stack landed only about 20 to 30 miles due south of the launch site, in a field immediately adjacent to a large stand of tall trees. Also, for this mission the chase team was able to observe the actual descent of the payloads from our chase vehicles; further, one of the in-air video cameras captured images of the chase team vehicles during its descent! For this year there were only nine students (8 MEs or AEs, and one Physics major) enrolled; they were formed into three teams. All teams measured inside/outside air temperature. One team used a Geiger-Muller tube and GPS to attempt to measure cosmic ray intensity versus altitude. One team added a GPS and a 3-axis accelerometer and tilt sensor, to record payload accelerations. The third team developed a deployable sticky surface, in an attempt to capture micrometeorites (“space dust”) at altitude. All three of these ambitious projects met with some degree of both success and failure. The Geiger-Muller tube failed at altitude, and no cosmic ray data were obtained for the flight, although test data at ground level were obtained and analyzed. The micrometeorite experiment deployed, but did not capture any particles. Three-axis accelerometer, tilt, and GPS data were obtained, but it was too noisy to be completely analyzed. Sample temperature and altitude data for this year are shown in Figure 9. Maximum altitude was approximately 87,000 ft. During this year, the course instructors attended the HASBE Workshop held at NASA Goddard on May 13, 2005. Also during this year the instructors became aware of work by Tiefenau and Gebbeken\textsuperscript{6}, explaining the source of inaccuracy in our temperature data.

Figure 8. Third WVU Balloon Satellites mission, Spring 2005.

Figure 9. Sample data from third WVU Balloon Satellites mission, Spring 2005.
Our fourth year flight occurred on April 6, 2006; launch was again from the WVU 4-H Camp facility. Launch (Figure 10A.) and tracking were quite successful, and eventually we did recover all of the mission payloads. However, this year we learned that we could actually be much less lucky than to land in the tops of seventy foot tall trees: this year our payload stack landed tangled in telephone wires (Figure 10B.) that just happened to be crossing an active CSX railroad spur line just east of I-81 in Virginia (Figure 10C.). During the time between touchdown of our payloads and the time that the chase team arrived on-site, a train hit our payload stack, scattering the payloads over a six-mile distance along the railroad right of way. The components of the primary tracking payload developed by course instructor G. M. Palmer were recovered, but had been destroyed. One student payload (the one caught in the telephone wires; see Figure 10B.) was recovered intact. The other two student payloads were also recovered, but suffered some damage. For this fourth year, three teams were formed from the nine students (8 AE/ME majors and one dual ME/biology major). All teams again measured air temperature and GPS data; one team also measured air pressure. Additionally, one team chose to use a pair of photomultiplier tubes to measure cosmic radiation level versus altitude. This payload was discovered by CSX employees alongside the railroad tracks about six miles beyond the impact, and returned to WVU over a month after the flight; the PMTs were destroyed by impact with the train. The second team developed a controlled environment to keep fruit fly and moss specimens alive during the mission, and also studied the effects of exposure to the environment of the upper atmosphere on other uncontrolled moss and fruit fly specimens. All of the fruit flies were destroyed by the impact of the train, but the mosses yielded useful results (Figure 11) that were analyzed and presented by one of the students at a technical meeting. The third team attempted (unsuccessfully) to deploy and track their payload (fitted with a video camera and a second small parachute) using a cut-down system that had worked in lab tests. It was very fortunate that this payload was not deployed, because the primary tracking payload failed to broadcast GPS coordinates partway through the mission. (On the other hand, students pointed out that had this last payload deployed as planned, we would have never been hit by a train!) Video from this payload was recovered intact. Maximum altitude for this fourth mission was approximately 80,000 ft. During this year, a second launch was also conducted on April 24, 2006 during Aviation Day held at the Morgantown Municipal Airport. No student payloads were flown, and a larger 3000g balloon was used. Maximum altitude for this flight was reported as 118,186 ft.

A.) Launch, 4/6/06  B.) On the ground, in phone wires, but also:  C.) Over train tracks!

Figure 10. Fourth WVU Balloon Satellites mission, Spring 2006.
Our most recent, fifth WVU Balloon Satellites mission was launched on April 14, 2007 from Jackson’s Mill, and was again successfully tracked and recovered; see Figure 12. Ten students (9 AE/ME majors and one EE major) formed three teams. Team one measured the temperature distribution of the “thermal wake” of the balloon. This is caused by solar heating of the balloon during daylight hours, so that as the balloon rises a heated wake is left behind, so that the measured air temperature is hotter than the undisturbed air temperature. This team obtained high-quality data. They developed a horizontal temperature rake; see Figure 13A.). Their temperature data during ascent is shown in Figure 13B.). The second team attempted to gyroscopically stabilize their payload, and also tested a cut down system and an internal heating system. Their payload suffered failures of the gyroscopic and cut down systems due to overheating. The third team attempted to broadcast live video feed to a ground station, and recorded solar cell signals to determine payload spin rate. Successful solar data was obtained, and spin rates were determined to be approximately once every 2 to 4 seconds. Some limited video was received just after launch, but the transmitter used was not strong enough to for the team to receive significant video from the air. Maximum altitude recorded for this mission was over 88,000 ft.
A.) Mission underway         B.) Ascent temperature data from rake

Figure 13. Sample data from fifth WVU Balloon Satellites mission, Spring 2007.

Also during the Spring 2007 flight, we partnered with faculty at nearby Fairmont State University (FSU), and one payload developed by a student team there was flown as a part of our mission. The authors presented an overview of our existing Balloon Satellites course at FSU to both the faculty and students who were participating in an initial offering of a similar project course given at Fairmont State during the Spring 2007 term. We are continuing this collaboration for the upcoming Spring 2008 flight. During the Fall 2007 semester, G. M. Palmer was an invited speaker at the Idaho Balloon Workshop held at Idaho State University in Pocatello, ID on October 12-13, 2007.

Recommendations and Lessons Learned

The course instructors are convinced that West Virginia University Balloon Satellites project course has been a very valuable experience for the participating student team members, and it also has been an enjoyable experience for the course instructors. We have some observations and recommendations for those who might be considering creating a similar project course at their university.

It is a significant undertaking to develop all of the necessary hardware and software for the data acquisition and balloon tracking. We recommend that either off-the-shelf hardware and software be used, if possible, or else develop these items prior to offering an actual Balloon Satellites course. The initial offering of our course was a somewhat stressful experience, at least partly because some of the necessary hardware and software for the initial mission was developed while the course was being taught!

While we have not conducted any quantitative assessment of student outcomes for the course sequence to date, we are quite convinced that the students benefit significantly from their exposure to a “hands-on” open-ended design project. The experience serves both as a motivator for many of the students, as well as an opportunity for them to learn to apply their classroom knowledge to the solution of a “real” problem. It appears to us that the result tends
to be an increase in their overall engagement in the educational process, and in their self-confidence and maturity. The three written reports and class homework that also emphasizes writing contribute to improved technical writing skills. The collaborative team environment for the project is good preparation for their careers, and we believe that it also helps in their verbal communication skills.

Also, those who have provided financial resources for the Balloon Satellites course sequence (see Acknowledgement) have benefited significantly both in terms of publicity about the Department, the College, and the University, and as an aid in student recruitment.

We believe that the Balloon Satellites project experience would achieve the greatest benefit if it were either a required course in the Aerospace Engineering Curriculum (e.g., a class section for the Senior Flight Vehicles Design course, MAE 475 at WVU), or a part of an existing required course (e.g., a required project for the sophomore level Introduction to Aerospace Engineering course, MAE 215 at WVU). However, in order for this to happen, one would need both commitment of the necessary financial resources, and the consent of the Aerospace Engineering curriculum committee. Lacking either of these necessities would leave only the option of offering the project as an approved technical elective course, open to those who were interested. Also, if the Balloon Satellites course sequence became a required course in the curriculum, it would be beneficial to the course instructors, in that they would then receive full course teaching load credit.

The Balloon Satellites project course sequence has added another dimension to the (relatively small) amount of “space” emphasis available to the students in our Aerospace Engineering undergraduate program. However, since they are not required courses, this limits the curricular benefit of the course in the eyes of ABET, since only a fraction of the program graduates are exposed to the course.

Participation in these two Balloon Satellites projects is good preparation for our more motivated students to develop proposals for an experimental mission aboard the NASA-sponsored High Altitude Student Platform (HASP) program administered by Louisiana State University. However, at present, funding for the HASP program is only in place for the current calendar year; it is hoped that HASP will be funded on a continuing basis.

We recommend that participants plan ahead and take climbing gear and an experienced tree climber along on chase and recovery missions. It is likely that the payloads and parachute will end up “down”, but not actually on terra firma! Also, program participants, both faculty and students, must be prepared for the possibility that the payloads may be lost; this could happen for example, due to separation of the balloon from the payload stack, or due to failure of the GPS tracking system or loss of signal from same. Or as for us in 2006, the payload stack could end up caught in telephone wires directly above an active railroad line, and the payloads could be hit by a train (Figure 10)! A related recommendation is the development of a cut-down system to enable termination of the mission when necessary. This could possibly save the payloads if they were in danger of being caught in the jet stream and being swept out to sea, or could also help to avoid the danger of a mission
with a slow or intermittent balloon leak that ends up at an unsafe cruise altitude (say between 5,000 to 35,000 ft).

**Conclusions**

The development of a Balloon Satellites project course at West Virginia University has been described. This course gives WVU students the opportunity to conceive of a mission, and then to design, build, launch, track, and recover small experimental electronics payloads that are launched using small latex weather balloons and are tracked and recovered via GPS. Course procedures and the required hardware and software that was developed to enable the missions to be flown have been summarized, as has the history of the student missions that have been flown to date.

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