Near-Space and the BAMASAT Program

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Abstract – This paper examines the challenges associated with designing, fabricating, and flying near-space platforms as undergraduate design projects. Details of The University of Alabama’s near-space platform, known as the BAMASAT, are presented and the process by which it was developed is outlined. The goal of the paper is to provide an engineering faculty member, interested in starting a student near-space program, a starting point from which to develop his or her first near-space platform. The paper will discuss both the technical challenges associated with near-space platform design as well as lessons learned from managing a student near-space program. In addition, information on Internet-based informational sites that are valuable for developing near-space platforms will be provided.

Keywords: Balloonsat, Near-Space, BAMASAT, Space Systems.

INTRODUCTION

Near-space may be defined as an altitude of 20 km (approximately 65,000 ft) to an altitude of 100 km (approximately 328,000 ft) above the surface of the Earth. The 20 km mark is slightly above the current maximum controlled airspace limit of 18.3 km set by the International Civil Aviation Organization (ICAO), the ICAO being the United Nations agency that sets standards for international civil aviation. While there is obviously no explicit upper boundary to the Earth’s atmosphere, the 100 km mark is the Kármán line which is the internationally recognized boundary of space. Figure 1 provides a schematic diagram of the Earth’s atmosphere showing the various layers of the atmosphere and the region called near-space. Most student-built, near-space platforms operate at altitudes on the order of 30 km or less. To put this into perspective, the space shuttle has a typical orbital altitude of approximately 400 km and satellites in geosynchronous orbit have orbital altitudes of around 35,786 km.

While the 30 km altitudes for student-built, near-space platforms are no where near the above-mentioned altitudes for the space shuttle and satellites, the 30 km altitudes pose design challenges that are not without merit. It is important to note that at 30 km, a near-space platform is well above most of the Earth’s weather and is above almost all of the mass of the atmosphere. To reach this altitude, a near-space platform must pass through the troposphere, which extends from 6 to 20 km in height. Most of the Earth’s weather occurs in the troposphere and as a near-space platform passes through this region of the atmosphere it can experience temperatures ranging from 20 °C on the ground to -60 °C as it passes through the tropopause, the boundary between the troposphere and the stratosphere. Above the tropopause, the temperature of the atmosphere begins to increase due to the absorption of ultraviolet radiation by the atmosphere. Even at a 30 km altitude, however, the temperature can still be below -40 °C and so

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thermal management of the near-space platform is a major design consideration. This is especially important when one considers that most student-built, near-space platforms are powered by commercially available batteries. Another consideration is the pressure experienced by the near-space platform. The pressure changes from approximately 101 kPa on the ground to about 1 kPa at an altitude of 30 km, i.e. the near-space platform is essentially exposed to the vacuum of space at altitude. While this typically does not pose a problem for most student-built, near-space platforms, the change in pressure must be considered when designing a thermal management system or when designing any sort of experimental package to be carried to altitude by the near-space platform.

Figure 2 provides information on yet another challenge faced by students when designing near-space platforms - the wind. It is critically important that a student-built, near-space platform can maintain structural integrity as it passes...
through the jet stream. The location of the jet stream will also have a strong influence on where the near-space platform eventually lands. Since the jet stream is a somewhat localized phenomenon, care should be taken to have accurate weather data for any launch. The jet stream’s location can change considerably over the course of a few days and this change can dramatically affect the distance between where the near-space platform was launched and where it landed. Recall that the temperature of the air begins to increase in the stratosphere and this increase in air temperature produces a region of relative calm. The effect of this change is that most of the horizontal motion of a near-space platform occurs when the near-space platform is ascending and descending with a relatively stable period near apogee.

THE BAMASAT PROGRAM

The University of Alabama’s student-built near-space platform is the BAMASAT. The BAMASAT is a free-floating BalloonSat. BalloonSats use lighter than air balloons to transport payloads to near-space. Figure 3 provides a typical image taken at altitude by the first launch of the BAMASAT platform. Students participating in the BAMASAT program typically receive credit for the design/build/fly exercise via the capstone design course in the mechanical engineering program. The University of Alabama’s BalloonSat program was started after Dr. Baker attended the “Starting Student Space Hardware Programs” workshop sponsored by the Colorado and the Montana Space Grant Consortia [3]. This workshop is an outstanding introduction to BalloonSats. Another good source for information on BalloonSats is a series of articles by L. Paul Verhage appearing in *Nuts & Volts* magazine. A collection of these articles can be found on the Parallax, Inc. website [4].

Figure 2: An illustrative example of wind speed as a function of altitude.
Until now, two BAMASATs have been successfully launched and recovered with a third launch planned for late February 2006. The complete BAMASAT system has basically six components. Figure 4 is a schematic diagram of the BAMASAT system with the location of each of the component identified. The specifications below represent the BAMASAT-III system which will be flown in late February 2006.

**Balloon**

BAMASAT-III uses the Kaymont KCI TX 3000 balloon. The KCI TX 3000 is a 3000 gram cold weather balloon. It was selected because the TX 3000 is made of a special latex compound which permits the balloon operate at temperature less than -75°C. The KCI TX 3000 has a bursting altitude of approximately 38 km (125,000 feet). When fully inflated, the balloon rises at a rate of approximately 5.3 m/s (1050 ft/min).

**Parachute**

The parachute that is used for BAMASAT-III is a type R-9C parachute from the-rocketman.com. It is rated for a 6-12 lb weight. The overall length of the parachute is 14 ft and its calculated descent rate is 17.8 ft/s with 12 lbs of weight.

**Avionics Module**

The purpose of the avionics module is to enable tracking and recording digital still images of the flight. Inside the avionics module is a GPS track engine, a transceiver, a digital camera and its timing circuit, and a wire cut-off circuit. A Garmin GPS-25 HVS track engine is used to locate BAMASAT-III during its flight. The track engine uses a GPS 35 receiver and embedded antenna to determine its location from global positioning satellites. The track engine forms data packets of information that contain its longitude, latitude, and altitude. These data packets are then sent to a transceiver to be broadcast to the ground using a ham radio frequency. A Kenwood, TH-D7AG Dual Bander is used as the transceiver for BAMASAT-III. This transceiver operates in the VHF Band from 144 to 148 MHz and uses a PB-39 nickel-cadmium battery. The PB-39 battery supplies the TH-D7AG Dual Bander with 9.6 V

![Figure 3: A picture of the Earth (Eastern Alabama) taken by BAMASAT-1 in December 2004.](image-url)
volts of direct current at 600 milliamp hours. The Sony Cyber Shot DSC-W1 digital camera records still images to a 512 MB memory stick. A picture can be taken every minute for 3 hours with the 512 MB memory stick, which is more than sufficient for the duration of the flight. The interval timing was provided by a timing circuit that was hard wired to the digital camera. A detachable wide angle lens is needed to allow for panoramic pictures to be taken.

**Antenna**

A quarter-wave, grounding plane antenna is used to transmit data to the ground tracking system. The antenna consists of a small aluminum disk that has an SO-239 connector placed through a hole that is drilled in the center of the disk. A ½ wavelength dipole vertical radiator is attached to a BNC connector which in turn connects directly to the SO-239 connector. Copper welding rods, 20.5 inches long with a 3/32 inch diameter are used as the ground radials. The small aluminum disk has 3/32 inch holes drilled in the sides that allow the ground radials to slide into the aluminum disk. The radials are held to the aluminum disk with set screws. The antenna is attached to the Kenwood TH-D7 AG transceiver through a coaxial cable connection.

**Instrumentation Module**

The purpose of the instrumentation module is to record video of the entire flight and allow space for future data acquisition systems. Currently, the instrumentation module contains only a hard disk camcorder. The JVC Everio 40GB Hard Disk Camcorder is used because of its capability to record directly to a hard disk drive non-stop for 4 hours and 50 minutes on the highest available quality setting. This particular camcorder comes with a JVC Data Battery which allows for up to 2 hours of power. An additional JVC Data Battery (model BN-VF733US) was purchased to increase the recording time to the full 4 hours and 50 minutes.
**Ground Tracking**

The BAMASAT is tracked from the ground during its flight using a mobile ground tracking system. The data packets broadcast by the Kenwood TH-D7 AG transceiver during the flight are received on the ground by a Kenwood TM-D700A transceiver on a ham radio frequency. The Kenwood TM-D700A transceiver uses a MFJ-1729 vertical half-wave antenna to receive the signal. The Kenwood TM-D700A transceiver connects to a notebook computer via a 9-pin RS-232 serial cable. The data packets are sent through this cable to the laptop where APRS software uses the packets to determine the longitude, latitude and altitude of the balloon satellite. A DeLorme Earthmate GPS module connects to a USB port on the notebook computer and sends data packets containing the location of the ground tracking system to the laptop. The APRS software takes the two sets of data packets and shows the position of the BAMASAT relative to the ground tracking system.

**A BAMASAT Campaign**

As previously mentioned, students involved in the BAMASAT program typically use the experience as part of their capstone senior design project. This model of operation has many advantages and a few very serious disadvantages. Since students in the capstone senior design course have already had multiple design experiences, they tend to not be overwhelmed by the scope of the project and these students have also had the courses necessary to competently analyze system performance. The capstone senior design course also provides a formal structure for the design effort which usually promotes the meeting of deadlines. Unlike projects that rely primarily on a club type model, the capstone senior design course does not allow the students to neglect the project when their schedules become busy, as they usually do during the end of the term. Perhaps the most serious drawback to using the capstone senior design project for the BAMASAT program is the fact that the students typically graduate immediately after completion of the BAMASAT flight. This produces two problems. The first is that the BAMASAT program has, until recently, not had the sort of corporate memory that would allow for the smooth operation of the program. The second is that there is rarely an extensive analysis of the results from the flight. The students are usually too busy to pay serious attention to the results of the flight as they are completing the final design report for their capstone senior design course and are getting ready for graduation. The University of Alabama now has graduate students leading the BAMASAT effort and are trying to encourage the participation of sophomore and junior level undergraduate students. The hope is that the graduate students will provide leadership and continuity to the program. The undergraduate students who are not in the capstone senior design course will provide assistant where possible and should be better prepared for the design experience when they ultimately take the capstone senior design course.

A typical BAMASAT campaign can be divided into five phases: design/fabrication of the BAMASAT hardware, hardware testing, pre-launch analysis and predictions, launch, and recovery/analysis. The difficulty of the design/fabrication phase was significantly decreased after the completion of the first BAMASAT campaign. There continues to be significant engineering challenges associated with the BAMASAT design and fabrication however. Every BAMASAT flight provides ideas for improvement and, at times, these improvements are more challenging than the original design effort. For example, the use of a cut-off system to release the balloon prior to its rupture has proven exceptionally difficult. The students involved in the program have all, to date, been mechanical engineering students and have not had the expertise needed to develop anything other than a very basic cut-off system. Efforts to recruit students in electrical engineering and other majors have not been successful. This problem is likely to be due to the fact that the program is strongly centered around the mechanical engineering capstone senior design project. Regardless of the cause, increasing the interdisciplinary character of the student teams is a long-term goal of the program.

Once the BAMASAT system has been developed for a given flight, the students are required to demonstrate the functionality of the system. This is typically accomplished through the use of tethered flights. While these tethered flights never achieve any significant altitude (typically less than 150 feet above the ground), they do serve an important function. For both the BAMASAT-I and the BAMASAT-II, problems with the avionics systems and with the launch procedures were identified prior to the actual launches. The tethered launches also provide outreach opportunities at local schools and even generate excitement among people on campus when BAMASATs are tethered-launched on the UA Quad.
With regard to pre-launch analysis, the bulk of the design effort is focused on the heat transfer from the modules. The reason for this is the effect that the sub-freezing temperatures have on battery performance. In BAMASAT-I and BAMASAT-II, the heat from the digital camcorder provided a convenient heat source that was sufficient to remove the need for active heating of the payload module. In addition, the structure of the payload module for BAMASATs I and II consisted of 2 inch thick insulation of the same type used on the Space Shuttle External Tank. One of the design goals for BAMASAT-III was to reduce the weight of the payload module structure and thus an analysis was required to determine the impact this would have on the heat transfer from the module. BAMASAT-III also has two modules, the avionics and instrumentation modules. Since the digital camcorder is now located in the instrumentation module, it is likely both modules will need active heating to maintain the strength of the batteries. One very important point to make is that to be exempt from FAA requirements for balloon launched payloads, the BAMASAT-III payloads (including the parachute and rigging) can not exceed 12 lbs. For more information on FAA requirements, the reader is referred to the EOSS (Edge of Space Sciences) website that provides the appropriate FAA regulations [5]. In addition to the analysis of the payload modules, students use the Balloon Track for Windows program to predict where the BalloonSat will land. For more information about Balloon Track for Windows, the reader is referred to an EOSS website providing documentation and links for downloading the software [6].

On the day of the launch, the students file a Notice to Airmen (NOTAM) to ensure that any aircraft operating in the area are aware of the fact that the BAMASAT is being launched and will be flying. Flight procedures should be checked and double checked to make sure everything is working properly. New and fully charged batteries should be used for all flight hardware. It is critically important to use new batteries. A typical launch for the BAMASAT occurs just after daybreak and lasts about 3 hours. The reason for the early launch is to take advantage of the fact that there is less atmospheric turbulence during the early morning hours. Once launched, the BalloonSat is tracked using the mobile ground tracking system that is located in the chase van. This is perhaps the most exciting part of the experience as the students (and the faculty advisor) anxiously watch as the balloon speeds through the jet stream, hovers for a while in the stratosphere, and then descend after the balloon ruptures. Note that the balloon increases in size as the BalloonSat ascends due to the decreasing atmospheric pressure. There is anecdotal evidence to suggest that one can actually see, with the naked eye, the BalloonSat at altitude on a clear day. The balloon continues to expand as it ascends to the point it ruptures. After this occurs, the payloads fall back to Earth, their descent sufficiently slowed by a parachute.

If everything works as planned, the team in the chase van will arrive shortly after the BalloonSat has landed to recover the payload. Since the payload will likely land on private property, it is important to get permission from the owner before attempting to recover the payload. After the payload has been recovered and with a little planning, the images from the flight can immediately be viewed on the notebook computer in the chase van. For BAMASAT-II, a data logger was used to collect temperature data (both inside and outside of the payload module) during the flight and this data provide experimental evidence of the temperature profile shown in Figure 1. While not of any great scientific interest, this temperature data also provides information that can be used to improve future BAMASAT designs.

**BAMASAT FLIGHTS**

Figure 5 provides a schematic view of the flight of BAMASAT-I and BAMASAT-II. BAMASAT-I was launched from a farm in Vance, AL on 4 December 2004. The excitement of the launch was dampened by the fact that the ground tracking system drained the battery of the chase van prior to launch. While this proves to be only a minor inconvenience, it became the standard practice to power the ground tracking system using an external 12-volt battery from that point onward. The peak altitude achieved by BAMASAT-I was approximately 85,000 ft. The term “approximately” is used because the team periodically lost the signal from BAMASAT-I during its flight. Fortunately for the BAMASAT team, local ham radio operators help track the BAMASAT and it was not difficult to locate once it had landed. The problem was that the payload and the parachute were caught about 100 ft up a tree. After spending the day trying to devise ways to get the payload down, the team returned to Tuscaloosa. The following Monday, a local tree service was hired to climb the tree and retrieve the payload and parachute.
BAMASAT-II was launched from the Quad at The University of Alabama on 24 March 2005 and achieved a peak altitude of just slightly less than 100,000 ft. It again landed in a tree located in Jonesboro, GA (a suburb of Atlanta, GA). Fortunately for the team, the owner of the property climbed the tree and retrieved the payload/parachute. This flight shows the limitations of the Balloon Track software as it had predicted a landing some 10 to 15 miles west of the landing site. Obviously, the prediction of the Balloon Track software is only as good as the input data so care should be taken to provide the software with the most accurate estimates of climb rate, burst altitude, etc. as possible. The flight also provided some very interesting pictures of vapor trails from airplanes since it landed just south of the Atlanta airport. The population density is another potential hazard associated with launching in the southeastern United States. As was pointed out by the gentleman who retrieved the BAMASAT-II, if the payload had landed a mile or so away, the equipment would have most likely ended up in a pawn shop.

CONCLUSIONS

Elements of The University of Alabama’s near-space program, the BAMASAT program, have been presented. The BAMASAT platform is a free-floating BalloonSat. BalloonSats offer a relatively inexpensive way for students to design, build, and fly actual space hardware. The challenges associated with designing and building near-space platforms are quite similar, if not the same, as those of spacecraft. There is a large body of information about BalloonSats on the Internet offering a would-be BalloonSat faculty advisor a wealth of information on developing and managing a BalloonSat program. The BAMASAT program has now had two successful launches and recoveries and the response from the students has been extremely positive. Use of these hands-on space-related projects is an ideal way to stimulate interest in space among undergraduate engineering students.
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REFERENCES


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