High Altitude Student Ballooning Project: An Intensive Research Experience for Undergraduate Engineering Students

Atin Sinha[1]

Abstract – For over a decade, student ballooning projects have provided a wonderful opportunity of launching small scientific payloads to near space environment in a small budget. Apart from the obvious merits of such projects, one significant outcome is the cross disciplinary training for undergraduate science and engineering students that prepares them for a future career in industry. Students are also exposed to research technique that is a strong motivational factor to work towards a graduate degree. A faculty/student team from Albany State University was one of the two teams that participated in one such NSF sponsored ballooning program in the summer of 2009 conducted by Louisiana State University. The teams were provided training to design, develop and fabricate the payloads that were launched from NASA's Columbia Scientific Balloon Facility at Palestine, Texas followed by data retrieval and science presentations. The summer program is being followed by a yearlong activity of designing and building a payload for a new experiment at the home institution that will be launched in late spring.

Keywords: Undergraduate Student Research, High Altitude Ballooning, Near Space Environment

INTRODUCTION

Research experience for undergraduate students is increasingly considered as an essential part of the undergraduate engineering education. Such training is the first step in motivating students towards a graduate degree. In most universities, students are encouraged to get their first exposure in research in the form of internship during their summer break working in a research laboratory. Traditionally, students work as a member of a large group working in ongoing research activities and often engaged in routine data collection or analysis without a deeper understanding of how the collected data will be used to reach the research goal. The true purpose of undergraduate research experience can be better served if the students can be involved from selecting the research topic, planning the experiment, develop the experimental setup, collect and analyze the data, arrive at a conclusion and make a presentation in support or contrary to the original hypothesis. In a student ballooning project all this steps are carried out by the student researchers thus realizing the true objective of a research project.

HISTORICAL BACKGROUND AND PROGRAM OBJECTIVE

Student balloon project is going on in different parts of USA since the mid 1990. Liefer[1] of U.S. air force academy described the early history of student balloon payload projects in U.S. with particular reference to the first student built "balloon satellite" launch in Spring of 1995. Wick et al. [2] of U.S. Naval Academy reported a junior level project of a balloon-borne environmental sensing mission in a sensor course in systems engineering major. The systems engineering approach was introduced in the classroom at University of North Dakota by Won et al. [3] through the design, document, build and launch of Scorpio Alpha and Scorpio II between 2000 and 2001. Ellison et al. [4] of Louisiana State University described the BalloonSat program for launching multiple student built small payloads carrying different science experiments.

In early 2000, as part of National Space Grant Student Satellite Program, the Aerospace Catalyst Experiences for Students (ACES) was developed in Louisiana State University (LSU) to provide students with cross disciplinary training in science and engineering and practical skills such as teamwork, communications, documentation and project management by means of designing and conducting science experiments in near space environment. With an initial debut in 2002-03 academic year, first launch under the ACES program occurred in May '03. Since then

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student built payload of increasing complexity was launched every year in a high altitude balloon. In 2007, under the sponsorship of National Science Foundation, LSU launched the Physics and Aerospace Catalyst Experiences in Research (PACER) program to attract and retain students in STEM fields in minority institutions, provide them with a research experience that build skills, techniques and methodologies applicable throughout their science career and establish a core of expertise in minority institutions around which a local sustainable student research experience can develop.

PACER program is implemented by training one or two faculty/student teams from minority serving institutions each year during 9 weeks of summer by providing them skills in electronics, real time programming, design and management which they apply to design, fabricate and operate a small science experimental payload (500 gm) carried to the edge of space in a helium filled balloon. During the following academic year, the teams return to their respective campuses, organize new student groups and replicate the activities of the previous summer with a new science experiment thereby establishing a student research culture and infrastructure which is hoped to be self-sustaining. PACER support is provided to the institutions for the first three years in the form of mentoring, site visits, limited financial aids and electronic components to fabricate the payload. In the summer of 2009, two teams, each consisting of three students and a faculty member, from Albany State University (ASU) of Georgia and Central State University (CSU) of Ohio participated in the PACER program that culminated in an eventful launch and recovery of the payload.

From the beginning, PACER was conceived so that students have to think through each step of their research project, come up with a solution strategy and test it under the guidance of the project advisors. Besides the initial introduction to the electronics and programming, a rigorous training in project management, cost control and documentation as required in any real life science and engineering project is taught in the Student Ballooning Course during the first 3 weeks of the summer training.

STUDENT BALLOONING COURSE

This course is comparable to any normal 3 credit hour course with an additional hour for hands-on laboratory projects. Indeed LSU offers "Student Ballooning Course" (SBC) every fall semester as a graded course and also to participants of the PACER program during the summer to train them in designing and operating the payload. As there is a wide variety of topics covered, team teaching method has been adopted with at least 3 to 4 experts covering materials from their individual specialty. A large multipurpose room with plenty of available table space to complete the hands-on activities as well as develop the flight payload is the right choice to conduct this course.

Figure 1. First lesson on soldering during Student Ballooning Course

The students are first provided an overview of the previous balloon launch and recovery for various science experiments' payload, introduced to electronic components, circuit drawing and prototyping, different sensors for measuring atmospheric parameters, data acquisition and data logging, analog to digital converter, real time clock. Then the students are made familiar with the BASIC Stamp microprocessor that is used to control other components and its peripherals such as EEPROM to store the collected data. A substantial amount of time is spent in teaching real time programming using BASIC Stamp with the help of flowchart developed from the problem statement. Mechanical design, thermal concerns, hardware fabrication and testing, systems integration and testing are covered next. Lectures on project management, cost control, risk tolerance and contingency planning are also included as teams are supposed to meet various deadlines and cost and weight budget. Students are also provided information on balloon tracking software and have to attend weekly classes on ham radio operation to facilitate recovery of the payload. By the end of the summer program it is expected that a majority of the students will obtain at least their technician class ham radio operator's licensing.

Lectures are supplemented by hands-on activities such as soldering the electronics components and real time programming to control LEDs by external input such as light or temperature. Students make Skeetersat prototype and BalloonSat, the electronic platform consisting of BASIC Stamp microprocessor, analog to digital converter, real time clock and EEPROM that will be used later in building the payload with its array of sensors customized for the specific science experiment.

PAYLOAD DESIGN AND FABRICATION

After completion of the course, for the next 5 weeks, the payload design, fabrication and testing took place. Students are required to start their payload design starting from the objectives outlined in the science experiment they want to perform. For the beginners it most likely will be measuring some basic parameters such as temperature and pressure as a function of the altitude though in the past, student teams had developed experiments to measure ozone and ultraviolet radiation as well as cosmic ray intensity. In 2009, both PACER teams decided to measure the temperature and pressure and collect images with digital cameras. ASU team had two temperature sensors, one to measure the surface temperature of the payload and the other to measure true ambient temperature, where as CSU team used only one temperature sensor on the surface. Both teams had pressure sensors to record pressure as a function of altitude while ASU used video camera, CSU had still pictures taken at fixed intervals.

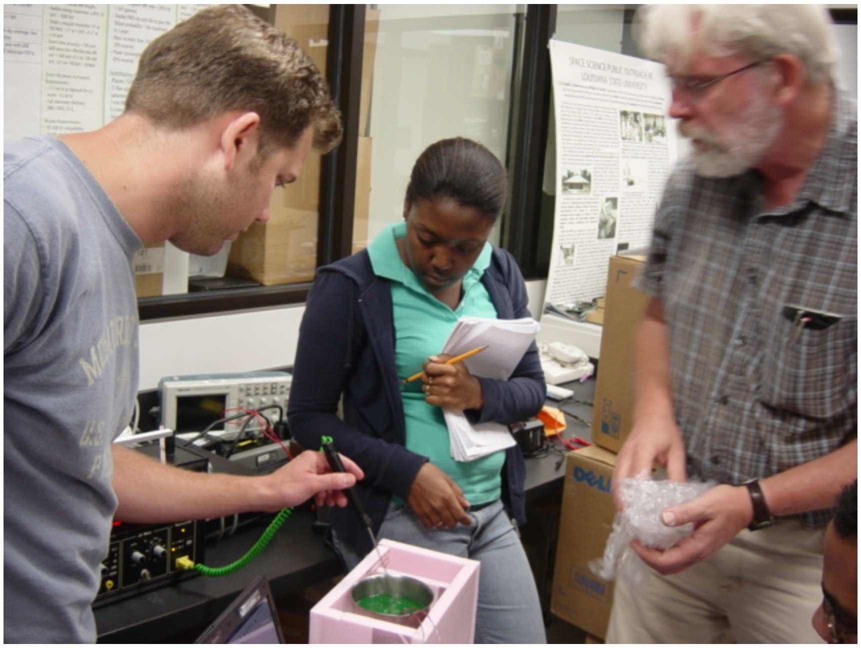

Figure 2. Low temperature testing with dry ice and antifreeze

During the process of payload design and fabrication, numerous decisions have to be made after researching the available data in the manufacturer's website or open literature and applying deductive reasoning to satisfy the science and technical requirements obtained from the mission goal. These include but are not limited to the selection of sensor type, range of operation and sampling rate, calibration, signal conditioning, sensor interfacing and schematic diagram, power requirement, software design for data acquisition and retrieval, mechanical design and fabrication method, integration of all subsystems and testing at various stages.

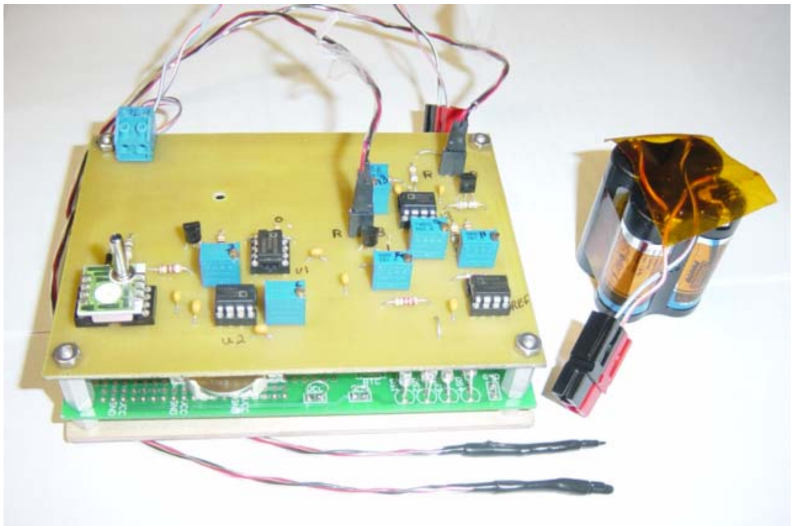

Figure 3. Assembled electronics boards (BalloonSat and sensors) with battery pack

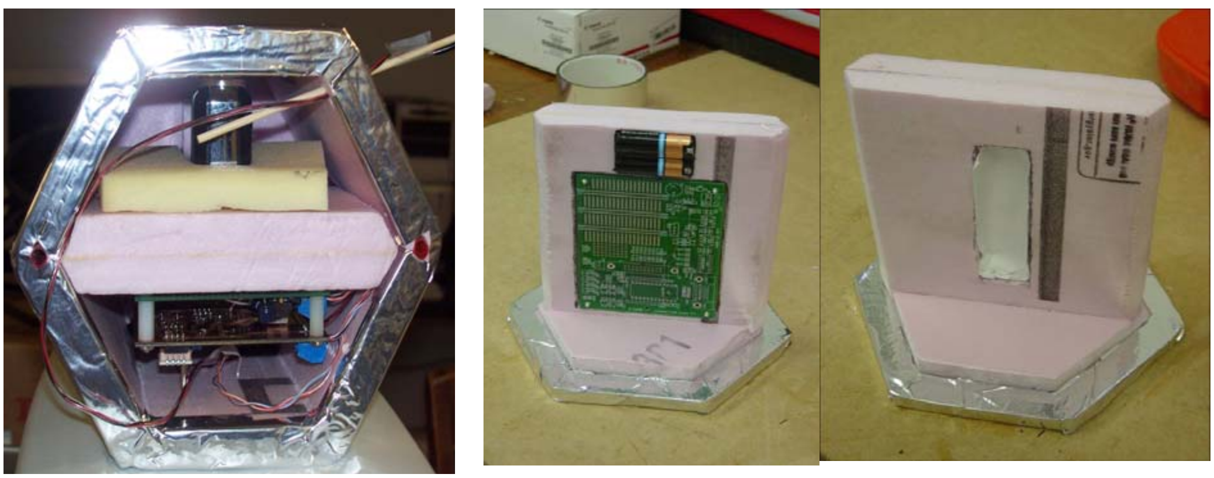

Figure 4. Details of payload interior on left and support for BalloonSat, battery pack and camera on right

PROJECT MANAGEMENT AND DOCUMENTATION

It is important to mention that the PACER program adopted the systems engineering approach which means that the design and documentation must be completed before any fabrication can be done. Specific emphasis was given on project management such as to meet various deadlines and specifically weight restriction as this turns out to be the most critical operational constraint. Gantt chart was used to keep track of project activities and had to be updated at regular intervals to take care of any delay in completion of tasks due to human failure or non availability of supplies. The teams had to develop and defend a Preliminary Design Review (PDR) of their payload concept, followed several weeks later by a Critical Design Review (CDR) before the PACER program staff members. Both of these reviews required written documents specifying all aspects of payload design as it is progressing and an oral presentation highlighting the important aspects. The input provided by the reviewers had to be addressed before the next go around. Actual fabrication could not start till the CDR was presented and approved. Once the payload design and fabrication was finished, a final document called Flight Readiness Review (FRR) had to be completed to assess whether each payload could be operated safely without any harm to the others.

LAUNCH, RECOVERY AND SCIENCE PRESENTATION

Figure 5. Launch under a cloudy sky

During the last week of the 9 week long summer program, the teams traveled to Palestine, Texas to launch their payloads from NASA's Columbia Scientific Balloon Facility. In all there were 9 payloads, most of them developed by the student teams either from current or previous PACER programs or from LSU students. Each payload was restricted to 500 g though a few did exceed that limit marginally. The day before the launch was spent in the final preparation of getting the equipment and software flight ready. The weather forecast predicted morning shower. But decision was taken to attempt the launch anyhow and as such everyone assembled at the field by 6 in the morning. As predicted heavy shower delayed the launch. After the rain stopped, first attempt to launch had to be aborted because of a leak in the balloon which resulted in significant loss of lift. Around 10 am under a cloudy sky the second balloon was launched with its array of payload boxes hanging down from the strings. Next began the chase in multiple vehicles as the balloon climbed about 85000 ft when the payloads unexpectedly got separated from the balloon and started descending under the parachute and ultimately landed about 60 ft up on top of large group of trees. Repair crew working nearby in a vehicle with high rising cab helped untangle the payload boxes and safely got them to the ground.

Next day the teams went back to the NASA facility to retrieve the scientific data from the payload and worked on the data analysis and preparation of the presentation on the following day. ASU team obtained very exciting result that showed a marked difference in ambient temperature (about 15^0 C cooler) from the temperature measured on the surface of the payload box due to internal heating of the electronics components. Also significant was the unexpectedly higher temperature measured due to stormy condition existing at Palestine than measured by the weather balloon launched from nearby Fort Worth weather station. ASU team's video camera unexpectedly did not record any image possibly due to moisture seeping into the camera compartment though the CSU team's still camera returned stunning images of blue planet against the darkness of space all the way to the point of balloon burst and return to ground. After the science presentation before the NASA personnel and PACER program officials was over, the teams returned to LSU next day. Following day the program ended with everyone leaving for home.

Figure 6. Collecting the payload from treetop. What a relief!

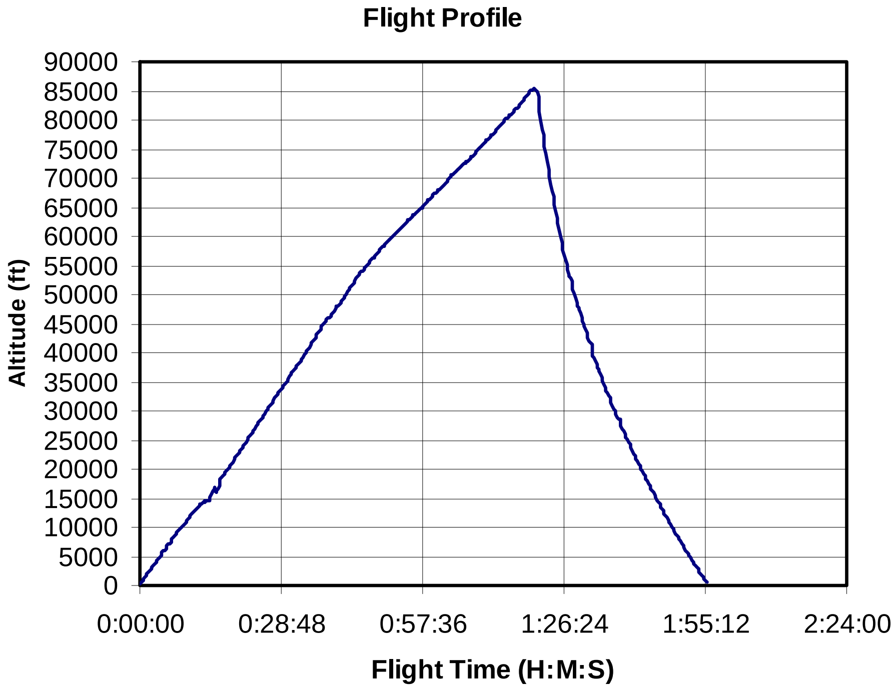

Figure 7. Balloon Flight Profile

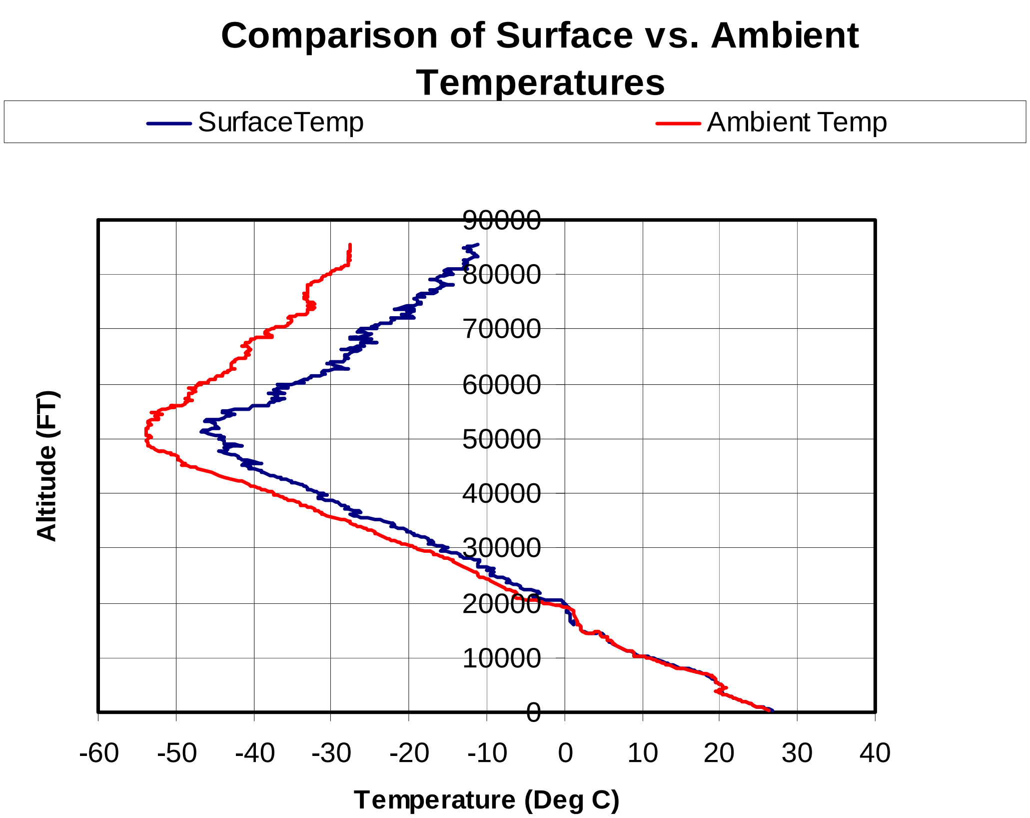

Figure 8. Comparison of ambient vs. outside surface temperature of the payload

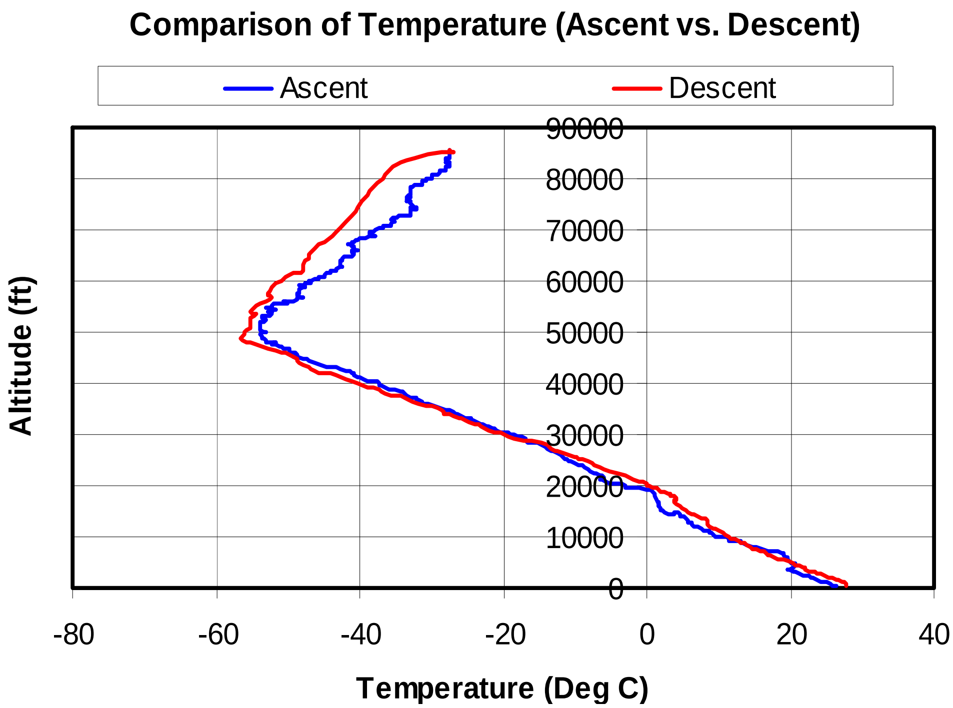

Figure 9. Surface temperature recorded during balloon's ascent and descent

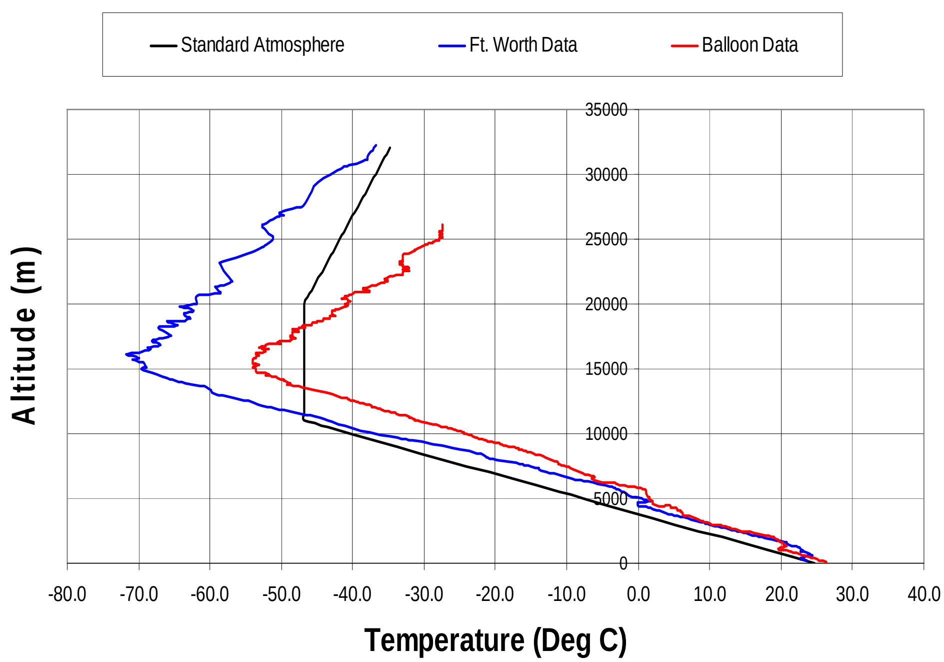

Figure 10. Temperature data collected from balloon and nearby Ft. Worth. The marked difference is believed to be the result of inclement weather at the launch site.

CURRENT ACTIVITIES

At the start of the 2009-10 academic year, a concerted effort was undertaken to recruit students for the ASU ballooning project. Past summer's exciting activity at LSU and Palestine was reported to the faculty and student bodies by small group discussion and departmental seminar attended by over 70 people. However at the end only 3 freshmen students actually signed up for the project in spite of offering stipends available from various sources. The student ballooning course started in early September and met twice a week for 5 to 6 hours each week. As was done in LSU, we followed the same curriculum with the supporting hands-on activities. After the initial practice in soldering electronic components, the students developed SkeeterSat and program it to operate the LEDs with temperature and light sensor input. They also completed the BalloonSat prototype board with all its peripherals. The last task in last semester completed by the group was to submit the pre-PDR report for review by the faculty advisors.

In the current spring semester the project lost a student as he left the university. This loss was more than made up as a junior level non-traditional student joined the group. Two different payloads are being developed this time. One of the payloads will carry the BalloonSat with its array of temperature and pressure sensors and a digital camera as done previously. But we will have an extra temperature sensor this time to measure the inside temperature of the payload box which will help determine the temperature gradient from inside to outside. This will also allow us to have a specific value of low temperature limit to decide on the operating range of the electronic components for future missions. As a new experiment in the second payload box students will use as a microcontroller an Arduino, an open source electronics prototyping platform that can receive input from a variety of sensors and can affect its surroundings by controlling lights, motors and actuators. A GPS module with data logging capability will be attached to the Arduino microcontroller and GPS data logged to a SD flash memory card can be retrieved and displayed on a Google map showing balloon's actual flight path. Also, an array of solar cells will be attached to the outside surfaces of this second payload box to measure the amount and change in energy collected as the balloon ascends through the atmosphere to determine if it can be used as a primary power source in future balloon missions.

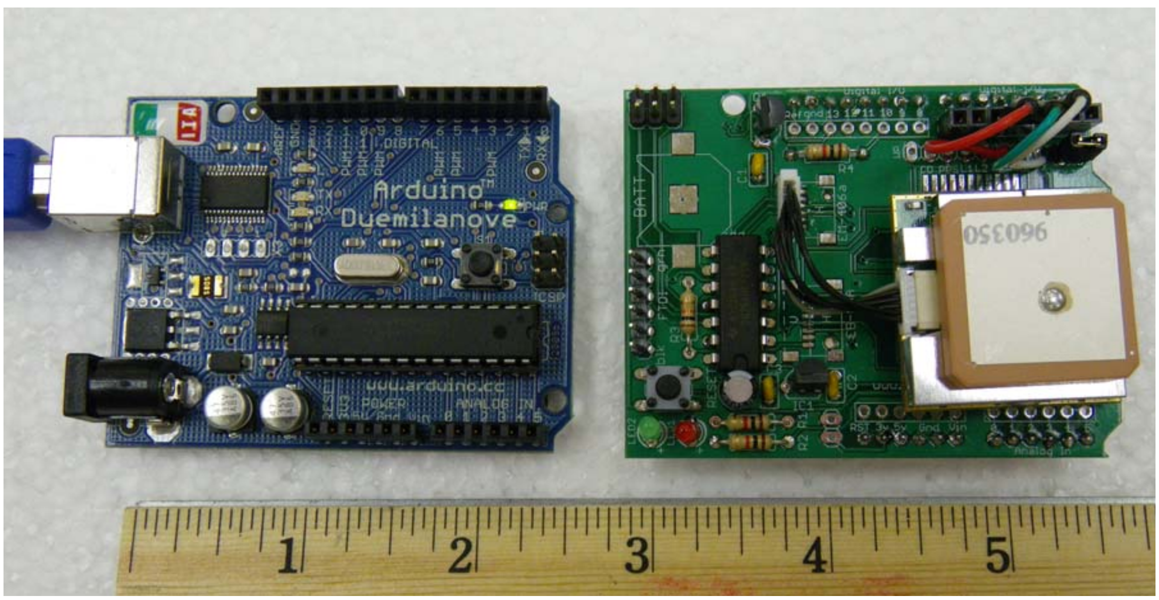

Figure 11. Arduino electronics prototyping platform on the left and GPS shield with GPS module on the right

In the meantime, we have been able to make contact with a similar ballooning group operating from Columbus High School at Columbus, GA. Their team leader, Mr. Richardson, was one of the original participants in the NASA Space Grant conference in 2002 and used to lead the ballooning project at Auburn University before shifting base to Columbus. As a result there exists remarkable similarity of design and operation with LSU group, though they follow somewhat different mechanical construction procedure, electronic packaging and software for programming. For convenience, it was decided that we will join hands with the Columbus group to launch our first payloads. As of now in the last week of February, ASU students are going through finalizing the selection of sensors, calculating the power budget, software development and fabricating the payload box. It is expected that the payload integration and final series of testing will start in a couple of weeks. We are committed to launch our payloads along with next balloon launch by the Columbus group which has been tentatively fixed at the first or second weekend of April 2010. Since the launch will take place within an hour's drive from ASU, it will allow us to involve a much larger group of students in the launch and recovery process, undoubtedly the most exciting part of the entire project.

SUSTAINABILITY AND INSTITUTIONAL COMMITTMENT

The original intent of the PACER program is to create a sustainable student led research environment in a group of minority institutions which will act as a catalyst for extending the research activity in future. As expected in the beginning of any project one has to overcome many hurdles probably the most challenging one is buying in by a substantial number of students which will act as critical mass to carry the student ballooning project forward. Undoubtedly, ASU ballooning project has not reached that stage in the first year of operation though it is probably in the best shape among all the participating institutions in the PACER project in this year as is evident from the bi-weekly teleconference conducted by PACER program staff at LSU. But with the next successful launch and recovery, it is hoped that we will be able to change many minds from mere curiosity to active participation.

One positive aspect of our ballooning project as of now is that we are relatively well off in terms of funding primarily because ASU is an affiliate member of Georgia Space Grant Consortium. A portion of the annual funds allocated may be tapped into when support from NSF runs out at the end of three years. Also, the university has supported to the extent of $4000 made available from the indirect fund account from various federal grants awarded which is being used to pay stipends to the students. University also has approved one course release time in Fall 2009 semester for the principal investigator which demonstrates their commitment to support student research in science and engineering.

LESSONS LEARNED AND FUTURE PLANS

One of the major problems encountered so far in ensuring successful conduct of this project was not having sufficient number of students enrolled. A non credit Student Ballooning Course may appear to be a non starter even with sufficient financial incentive. It may also pose continuous challenge to have the students attend the class or hands-on activities after hours because of conflicts with other extra-curricular activities scheduled at the same time. It is specifically true before a long weekend or prior to any upcoming test. Though awarding stipends does provide some incentive, it by no means ensures complete student engagement. As a solution a proposal is being evaluated to teach a 3 credit course in "Real Time Programming in Application Oriented Digital Electronics" as an elective under the Computer Science degree program starting in the upcoming fall semester. Students who successfully complete this course will be invited to develop their own payload in the next spring semester when they will also be awarded a stipend. It appears to be a better alternative of recruiting students for the ballooning project.

In the end after experiencing first hand the excitement and sheer joy of participating in a balloon launch it can safely be said that the best way of ensuring the project's success is to get maximum number of students participate in the launch day activities. We may indeed be able to do so as our next launch site will be no more than an hour's drive from the home institution. Students who have seen a balloon launch will have a dramatically change attitude towards ballooning as a research tool and will be our best recruiting agent for the project in future.

REFERENCES

[1] Liefer, R.K., *Into Space Without a Rocket (and Not Much Money, Either)*, 1996 Proceedings of ASEE Annual Conference and Exposition.

[2] Wick, C., et al, *Sensors for a Weather Balloon – a Classroom Design Experience*, 1996 Proceedings of ASEE Annual Conference and Exposition.

[3] Won, C., et al, *Spacecraft Systems Engineering – The Initiation of a Multidisciplinary Design Project at the University of North Dakota*, 2001 Proceedings of ASEE Annual Conference and Exposition.

[4] Ellison, B., et al, *The Louisiana ACES student-built BalloonSat program,* ScienceDirect, Advances in Space Research, Elsevier, 2006.

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