THE UNIVERSITY OF HAWAII CUBESAT: A MULTIDISCIPLINARY UNDERGRADUATE ENGINEERING PROJECT

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Abstract - *Undergraduate engineering students at the University of Hawaii are currently working on the most ambitious project ever undertaken by a multidisciplinary group of engineering students in the university's history: designing and constructing a small satellite that will be launched into low-earth orbit. Over 70 undergraduates and nine faculty advisors are participating in the CubeSat Project, which involves the design, manufacture, and operation of a cube-shaped satellite having a mass no greater than 1 kg and a maximum volume of 1000 cm*^{3}*. This paper describes the multidisciplinary nature of the project, its relevance to ABET criteria, the integration of undergraduate research opportunities, and the outreach efforts to high school students.*

Index Terms - Capstone project, Multidisciplinary project, Small satellites, Undergraduate research.

INTRODUCTION

For over 30 years, the engineering curriculum at the University of Hawaii (UH) has followed the same pedagogical paradigm that is in place at most other engineering colleges. Students take calculus, physics, chemistry and introductory engineering courses in the first two years, and discipline-specific engineering courses in the third year. While this bottom-up teaching sequence is intended to provide a solid scientific and mathematical foundation for application-oriented coursework later in the curriculum (typically a capstone design project in the student's senior year), it is not necessarily the best one for providing motivation for students. This is particularly true for today's generation of students that want to see immediate applications of what they are learning. Faced with an alarming 35% retention rate at the UH College of Engineering, the faculty have initiated a project-based education theme throughout the undergraduate curriculum.

This problem is not specific to our university, of course, and is possibly the impetus for successful freshman engineering courses under development recently (*e.g.*, [1]). Providing early and sustaining motivation is just one aspect of a good engineering curriculum, however. The engineering education experience is further enhanced if it allows students to work on open-ended engineering projects that expose them to all of the *realities* of engineering: working to specifications, securing funding and keeping within budget, maintaining documentation, leading and working in multidisciplinary teams, conducting design reviews, and more. A real project, as opposed to just a canned laboratory exercise, also provides the benefit of allowing real-life issues – such as engineering ethics – to be experienced. At universities such as ours, with a faculty that is already overburdened and an engineering curriculum that is already bulging at its seams, real-life engineering issues such as ethics or proposal writing is best *experienced* within the confines of a real project rather than taught as a formal course.

Another motivating factor for students is the opportunity to get involved with undergraduate research, especially at a Carnegie Doctoral/Research-Extensive University such as ours, where research often gets top billing. Integrating research into a project would provide the sense of discovery-based education that steers students toward the pattern of lifelong learning.

All of this has led to a new paradigm: project-based engineering education. While this kind of teaching philosophy is already in place at other universities, it is still in its formative stage at UH. In this paper, we describe one of these projects.

THE CUBESAT PROGRAM

Undergraduate engineering students at UH are currently working on the largest and most ambitious project ever undertaken by a multidisciplinary group of engineering students in the university's history: designing and constructing a small satellite that will be launched into low-earth orbit in 2004. Over 70 undergraduates and nine faculty advisors are participating in the UH CubeSat Program, which involves the design, manufacture, and operation of a cube-shaped satellite having a mass no greater than 1 kg and a maximum volume of 1000 cm^3 (Fig. 1).

The idea of developing a CubeSat as an educational vehicle for engineering students was conceived four years ago by Stanford University Professor Robert Twiggs [2]. Although the original intent of the project was to expose students to the various aspects of small-satellite engineering within a span of approximately one to two years, there has been growing interest within industry and government for expanding this small-satellite program due to its numerous commercial and scientific merits. NASA officials have even discussed future CubeSat missions to the Moon and to Mars.

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FIGURE 1
PART OF THE UH CUBESAT TEAM WITH THE SATELLITE HOUSING. FROM [3].

In just four years, the CubeSat community has already grown to more than 40 universities worldwide [4], with the first CubeSats launched in June 2003. UH's CubeSat Program [5], now in its second year, is unique in that it is one of only two universities that is managed exclusively by undergraduate engineering students.

PROJECT ORGANIZATION

The project is organized as shown in Fig. 2. To maintain leadership continuity over the anticipated two-year span of the project and to limit the turnover associated with graduation, two engineering juniors were selected by popular vote as Project Director and Assistant Project Director. Their responsibilities are to coordinate the overall design effort, secure funds via proposal writing, organize design reviews, and deliver presentations to sponsors.

The project has a $120,000 budget as shown in Table I. To date, the students have raised 90% of the funds through grants from the Hawaii Space Grant Consortium, Northrup Grumman Space Technology, One Stop Satellite Solutions, Boeing, the UH College of Engineering, and many UH alumni and friends.

A Project Management team was assembled to manage the financial aspects of the project (fundraising, purchasing, reimbursements), coordinate public relations efforts with the media, conduct educational outreach to high school students, and maintain the project web page and file management system which proved valuable in archiving documentation.

As the largest and most ambitious undergraduate engineering project ever undertaken at our university, the CubeSat project quickly generated widespread interest in the community. Within a few months of our kickoff meeting, CubeSat was featured on the front page of our local newspaper [3] and on the Sunday broadcast of the local TV news. This exposure led to several engineers with prior experience in the satellite business volunteering to serve as technical advisors, forming the Industrial Advisory Board in Fig. 2.

MULTIDISCIPLINARY ENGINEERING

The design, manufacture, and operation of a satellite is by nature a multidisciplinary effort, involving aspects of all types of engineering. The CubeSat Program therefore provided 70 undergraduates with a rare opportunity for students in one engineering discipline to work with those in another.

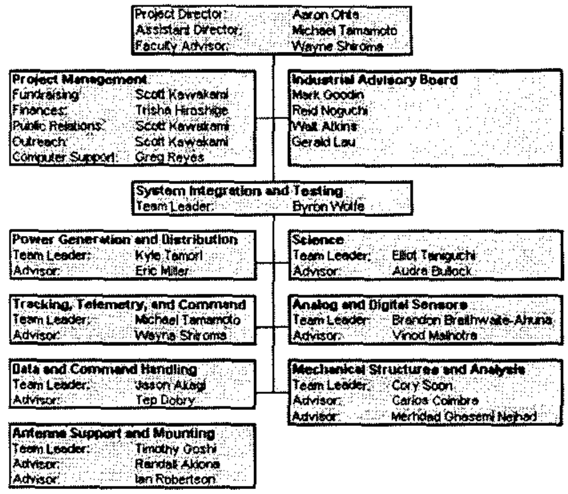

FIGURE 2
ORGANIZATIONAL CHART FOR THE UH CUBESAT PROGRAM.

TABLE I
BUDGET

Launch, integration, and export licensing	$50,000
Parts	$15,000
Equipment	$10,000
Summer stipends for students	$45,000

Fig. 2 shows that each satellite subsystem team, consisting of 5-15 members, was led by an undergraduate student and advised by one or two faculty mentors. Although these teams were divided along the traditional civil, electrical, and mechanical engineering disciplines, they were able to interact with each other through weekly progress meetings and especially through integration sessions where all of the subsystems had to work collectively.

The Power Generation and Distribution team supplies the power for the CubeSat's electronic components. Power is generated with 21%-efficiency gallium arsenide solar cells, providing about 1 W of continuous power. The solar cells charge lithium-ion batteries, which are used during the eclipse periods of the satellite orbit, or when the power demand exceeds the output of the solar cells.

The Tracking, Telemetry, and Command team is responsible for the communication link between the satellite and ground station. Data from the CubeSat's onboard computer is sent to the terminal node controller, which encodes the data using amplitude frequency shift keying and a standard amateur radio protocol. The packets are then broadcast in the 70-cm UHF amateur radio band using a modified, commercial-off-the-shelf handheld transceiver, which in turn is connected to a dual monopole antenna that provides an approximately isotropic radiation pattern.

Although the UH CubeSat communicates in half-duplex mode exclusively at the 70-cm band, the ground station is equipped with both UHF and VHF antennas in anticipation of future satellite missions and collaborations with other universities. The two antennas are placed on a rotator and mounted on a support structure designed and built by the Antenna Support and Mounting team, consisting of UH civil engineering students. The completed ground station will be capable of finding the position of objects in space, and tracking the object in real time.

The Data and Command Handling team is responsible for the microprocessors and other on-board digital support circuitry. Automated tasks are run by a Rabbit Semiconductors microprocessor. A programmable integrated circuit (PIC) chip is also included to aid the Rabbit processor in data routing and handling throughout the satellite. Should the main processor fail, the PIC can function as a back-up processor.

The Mechanical Structures and Analysis team is responsible for the thermal, thermal stress, and dynamic modeling of the CubeSat. In addition, this team is in charge of design and fabrication of all the mechanical support structures needed for the satellite, based upon vibration and thermal stress simulation and testing.

The Science team is designing the CubeSat's passive stabilization system. One part of this system consists of nickel-iron alloy hysteresis rods to reduce the satellite's spin, resulting in improved power generation since solar cells work more efficiently if the spin is reduced. Another part of the stabilization system consists of neodymium-iron-boron magnets that align the CubeSat with the Earth's magnetic field; this is important for aiming the active antenna, to be discussed in the next section, towards Earth.

The role of the Systems Integration ant Testing team is to coordinate the weight management, module layout, assembly procedure, subsystem interfaces, and launch sequence. This team is also responsible for ensuring that the satellite meets all qualifications for environmental test.

UNDERGRADUATE RESEARCH

While the CubeSat project is an excellent engineering project for pure education, it has also allowed real research to be conducted at the undergraduate level.

One of the payloads aboard UH's CubeSat is a 5.8-GHz active antenna that facilitates faster data transmission rates for future data-intensive missions. This type of active antenna, known as a grid oscillator, uses an efficient power-combining scheme packaged in a compact, low-profile structure that can be mounted on the side of a cube. Compared to conventional CubeSat antennas, grid oscillators do not require deployment, are tolerant to single-point failures, and facilitate long-link communications at microwave frequencies – important advantages in satellite design, and necessary design features for future CubeSat missions. Although grid oscillators have been in development for several years [6], this UH CubeSat grid oscillator will be the first one in space [7], [8].

Another research aspect of the UH CubeSat is the thermal modeling. To the best of the authors' knowledge, there has been very little detailed thermal analyses of picosatellite-class satellites. The thermal conditions of the CubeSat will be simulated using a hybrid resistance-capacitance model. A student poster on the thermal modeling of the UH CubeSat took first place at an American Society of Mechanical Engineers conference last year, and a research paper is currently being prepared.

To verify the thermal simulations, the Analog/Digital Sensors team is designing and fabricating a thermal sensor system. Thermal sensors are attached to each side of the interior of the CubeSat. A microcontroller handles the analog-digital conversion of the sensor data, and sends it to the main CPU for transmission to the ground station.

ABET 2000 CRITERIA

Although the UH CubeSat Program was not specifically initiated as a means of satisfying our upcoming accreditation visit in Fall 2003, it is fortuitous that the project does address so many aspects of ABET's evaluation criteria:

- *Manufacturability*: Since the satellite is constrained to a relatively small 1-kg, 10 cm x 10 cm x 10 cm form factor (as prescribed by the CubeSat standard [4]), both the electrical and mechanical designs had to incorporate manufacturability from the very start. Our Industrial Advisory Board was assembled so that satellite engineers could mentor our students on real-world manufacturing issues.
- *Sustainability*: In addition, since the satellite must survive the harsh thermal and radiation environment of an 800-km sun-synchronous orbit over the satellite's two-year lifetime, the design had to include considerations for surviving this environment.
- *Economic constraints:* The students themselves organized an aggressive campaign to secure $120,000 from industry, academic, and government sources to fund expenses for materials and supplies, launch costs, and student summer stipends. Decisions had to be made between a more expensive domestic launch vs. a less expensive Russian launch.
- *Political constraints:* As a result of deciding with the Russian launch, the students have had to deal with the ramifications of export licensing under the International Trafficking and Arms Regulations (ITAR), as satellites are classified by the United States as sensitive technology. Some of the problems with ITAR resulted

in launch delays, so the students became acutely aware of how the political environment affected their project.

- *Ethical:* As in any large organization, ethical issues occasionally came up. As an example, the Hawaii Space Grant Consortium offered to provide summer stipends to some of our students as long as they submitted an individual research proposal. When it was found that one student tried to write a proposal on behalf of his friend, a faculty advisor intervened to explain the unethical nature of this situation. In another case, a local TV reporter attempted to scoop the CubeSat story from a TV reporter on a different station based on inside information, and the students had to learn how to deal with such unethical practices not under their control.
- *Health and Safety:* In Phase I of our CubeSat project, students had to learn and implement the Federal Communications Commission safety regulations regarding radio-frequency emissions prior to conducting their antenna tests. In Phase II of our CubeSat project, the intended launch vehicle is the Space Shuttle. NASA has required all of our students to study and pass an extensive and exhaustive set of NASA safety exams and safety reviews to ensure that our satellite and its deployables pose no hazard to the Shuttle crew.
- *Social:* As one of over 40 institutions worldwide that are working on CubeSat projects, UH has had numerous meetings with other CubeSat teams, including those from Japan, Europe, and the mainland US. [9], [10]. Such technical interactions also aid in helping our students understand a different culture. Two trips to Japan and three trips to the mainland US have already taken place for the specific purpose of having students exchange technical and cultural information.
- *Environmental*: Although the impact of CubeSat on Earth's environment is minimal, the issue of space junk is of growing concern among the international space community. Students have had to consider lower orbits so that the decay rate could be faster and so that the satellite could burn up on its own after two years.
- *Communications:* Throughout the project, students held weekly subsystems team meetings. Leaders of each subsystem team met with each other weekly as well. Documentation was archived in the form of written reports and web pages. A preliminary design review and critical design review involving all of the students and the Industrial Advisory Board also took place. All of these activities reinforced the fact that communication was essential to project success.
- *Interdisciplinary engineering:* Students from all of the UH electrical engineering tracks found that they needed to work together, as the satellite combined subsystems in command software, programmable controllers, solar cells, power distribution, thermal sensors, antennas, and radio-frequency transceivers. Students from the different mechanical engineering tracks (mechanics, materials, and heat transfer) had similar experiences.
- *Multidisciplinary engineering*: Electrical engineering students are exposed to other typically non-EE manufacturability constraints such as vibration, thermal dissipation, outgassing, and deployable structures. In a like manner, civil engineering students are learning how to tailor their antenna ground station structure to optimize signal reception and mechanical engineering students are learning how the choice of epoxy affects dielectric properties of the on-board active antenna.
- *Mentoring:* Seniors using CubeSat as their capstone design project serve as team leaders for the various subsystems. Younger students taking CubeSat for their freshman, sophomore, and junior projects are mentored by the seniors and serve as apprentices. Last summer, two high school students served as summer interns on the project, working on the on-board gas gauge and dipole antennas [11].

CONCLUSIONS

The University of Hawaii CubeSat is a prime example of an all-undergraduate engineering project that involves all of the engineering disciplines at UH. It incorporates real-life engineering experience and undergraduate research into a fun and exciting package; all while satisfying numerous ABET criteria.

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REFERENCES

[1] Piket-May, M. J. and Avery, J., "Service Learning First Year Design Retention Results," *31st ASEE/IEEE Frontiers in Education Conference*, Reno, NV, paper F3G-19, Oct. 2001.

[2] Heidt, H., Puig-Suari, J., Moore, A. S., Nakasuka, S., Twiggs, R. J., "CubeSat: A New Generation of Picosatellite," in *Proceedings of the 15th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, August 2001.

[3] Creamer, B., "UH to launch little do-it-yourself sputnik," *Honolulu Advertiser*, p. A-1, Feb. 15, 2002. Photo by Ambo, R. http://the.honoluluadvertiser.com/article/2002/Feb/15/ln/ln02a.html

[4] http://CubeSat.CalPoly.edu/

[5] http://www-ee.eng.hawaii.edu/~cubesat

[6] Popovic, Z. B., Shiroma, W. A., and Weikle II, R. M., "Grid Oscillators," Chapter 8 in *Active and Quasi-Optical Arrays for Solid-State Power Combining*, R. A. York and Z. B. Popovic, editors, New York: John Wiley & Sons, 1997.

[7] Fujishige, T. S., Ohta, A. T., Tamamoto, M. A., Goshi, D. S., Murakami, B. T., Akagi, J. M., and Shiroma, W. A., "Active Antennas for CubeSat Applications," in *Proceedings of the 16th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, paper SSC02-V-2, Aug. 2002.

[8] Ohta, A. T., Tamamoto, M. A., Fujishige, T. S., Akagi, J. T., and Shiroma, W. A., "The University of Hawaii CubeSat: Grid-Oscillator Technology in Space," in *Proceedings of the Korea-Japan Microwave Workshop*, Yokosuka, Kanagawa, Japan, Oct. 2002.

[9] Ohta, A. T., Tamamoto, M. A., Wolfe, B. L., Soon, C. M., Sakagawa, R. K. H. , and Higuchi, N. K., "The University of Hawaii CubeSat: An Undergraduate Student Satellite Project," presented at the *University Space Systems Symposium*, Honolulu, HI, Nov. 2002.

[10] Wolfe, B. L., Ohta, A. T., Tamamoto, M. A., Murakami, B. T., and Shiroma, W. A., "Mea Huaka'i: The University of Hawaii CubeSat," presented at the *First International CubeSat Symposium*, Tokyo, Japan, Mar. 2003.

[11] http://www.xtreme.hawaii.edu/wazzup/intern02/