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In This Issue – Technically 2

Articles

- **Flying Free Flight: Pilot Perspective & System Integration Requirement** 3
  F. Maracich
- **Implementation of CAS using TCAS II to UAVs** 8
  H-C. Lee
- **Growth of Cadmium Telluride Crystals for Sensor Use** 14
  B.J. Cantwell, A. Bosu, M. Robinson & A.W. Brinkman
- **Small Aircraft Avionics using Hybrid Data Bus Technology** 17
  C.E. Lin, S.F. Tai, C.C. Li, H.T. Lin & T.P. Chen
- **Low-Cost Dual-Mode Enhanced Vision Sensor Prototype** 22
  T.W. Rand, R.A. Ferrante & J.M. Suiter

Special Report

- **Space Education: A Collection of Seven Papers** . . . . . Centerfold

Columns

- **The ♥ Heart ♥ of Our Society** — *R. Ogan* 27
- ***You, the Reader . . .*** — *Evelyn H. Hirt* 29

News & Information

IEEE AESS Society Organization 28
IEEE's e-books 29
Distinguished Lecturers 30
Student Membership Application 31
Membership Application 32
Directory . . . . . Inside Back Cover
Meetings . . . . . Back Cover

An Overview of Space Science and Engineering Education at Penn State

Sven G. Bilén, C. Russell Philbrick, Timothy F. Wheeler, John D. Mathews, Robert G. Melton & David B. Spencer,
Penn State

ABSTRACT

This provides an overview of space science and space systems engineering education at Penn State University. Students at the graduate and undergraduate levels participate in an educational program consisting of three interdependent components: space systems-related courses, space systems project work, and research. Courses range from Introduction to Space Physics to Spacecraft Design. Student project involvement is realized through a number of student-driven space systems projects completed throughout the past two decades. Students are provided opportunities to do independent study projects, honors theses, M.S. theses, and Ph.D. theses on a number of space science and space systems-related topics. Our educational goal is to prepare students at the undergraduate and graduate levels for productive careers in technical and nontechnical fields relating to space systems. Due to student interest, we are developing a certificate in Space Systems Engineering for undergraduates in the College of Engineering. Strengthening Penn State's position in space engineering are its Center for Space Research Programs, membership in the USAF's Space Education Consortium, and its role in serving as the lead institution within the Commonwealth for the Pennsylvania Space Grant Consortium.

INTRODUCTION

Space science and engineering education and research have a long and storied history at The Pennsylvania State University (Penn State). The Communications and Space Sciences Laboratory (CSSL) [1], which is housed in the Electrical Engineering Department [2] within the College of Engineering (CoE) [3], was established in 1949 as the Ionospheric Research Lab (IRL) with Arthur (Art) H. Waynick as director. CSSL/IRL has long been a leading organization in the space sciences and space-related engineering, especially with regard to radar/lidar remote sensing and sub-orbital rocket exploration of the Mesosphere & Lower Thermosphere (MLT) region. CSSL offers a unique interdisciplinary approach to the space sciences by combining the subjects of aeronomy, astronomy, plasma physics, space physics, ionospheric processes, remote sensing techniques, as well as electromagnetic theory and propagation, together with the topics of instrument design, payload preparation, test plan development, and engineering practices for space applications.

Penn State's Aerospace Engineering Department [4] prepares students for systems engineering careers in the areas related to spacecraft orbit and attitude dynamics and control, rocket and spacecraft propulsion, and spacecraft design. The department is one of the oldest aerospace engineering departments in the United States, with 1 out of 25 aerospace engineers in practice in the US being graduates of the department. Three astronauts and many high-level executives in the aerospace industry are counted among its graduates.

In this overview, we report on space science and engineering education at Penn State. While this overview should not be viewed as comprehensive, it should serve to give the reader a sense of the extent and breadth of the educational and research opportunities available in the CoE at Penn State in "space engineering," and the interested reader should consult the references for more detailed information. Students at the undergraduate and graduate levels participate in an educational program that consists of three interdependent components: space systems-related courses, space systems project work, and research. We discuss each of the components below and finish with a discussion of some ongoing efforts and plans for future enhancements of Penn State's strong standing in space systems engineering.

COURSES IN SPACE SCIENCE AND ENGINEERING

The core of the educational experience for our undergraduate and graduate students is established in the range of courses available to them. We list the courses most closely

Author's Current Address:
S.G. Bilén, C.R. Philbrick, T.F. Wheeler, J.D. Mathews, R.G. Melton & D.B. Spencer, School of Engineering Design, Technology, and Professional Programs, College of Engineering, The Pennsylvania State University, 213 Hammond Building, University Park, PA 16802-1401, USA.

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related to space science and engineering within the CoE at Penn State. Of course, a larger selection of courses exists to supplement these and provide the necessary background material.

Courses at the undergraduate level in Electrical Engineering include: EE (METEO) 433 - Fundamentals of Remote Sensing Systems; EE 439 - Radiowave Propagation in Communications; EE (AERSP; NUC E) 490 - Introduction to Plasmas; EE (AERSP) 492 - Space Astronomy and Introduction to Space Science (3); EE 497F - Satellite Communications; and STS 497I - SPIRIT Companion Course. Those at the graduate level include: EE 534 - Laser Remote Sensing; EE 536 - Inversion Techniques in Remote Sensing; EE 539 - Microwave Radar Remote Sensing; EE (NUC E; AERSP) 540 - Theory of Plasma Waves; EE (NUC E) 541 - Plasma Theory; EE 580 - Radio Waves and the Ionosphere; and EE 581 - Constitution of the Ionosphere.

Courses at the undergraduate level in Aerospace Engineering include: AERSP (GN) (STS) 055 - Space Science and Technology; AERSP 309 - Astronautics; AERSP 401A - Spacecraft Design - Preliminary; AERSP 401B - Spacecraft Design - Detailed; AERSP 430 - Space Propulsion and Power Systems; AERSP 450 - Orbit and Attitude Control of Spacecraft; and AERSP 497/597I - Spacecraft/Environment Interactions. Those at the graduate level include: AERSP 550 - Astrodynamics; and AERSP 597B - Statistical Orbit Analysis.

Due to space limitations, we are unable to describe each course individually; however, we mention herein a few particulars. Space Science and Technology (AERSP/STS 055) is taught to students in non-technical majors who have an interest in the applications of space science and technology. Its ultimate goal is to help prepare those students whose careers may eventually impact the direction of space policy, funding of NASA, and other aspects of public support for space research and exploitation. Space Astronomy and Introduction to Space Science (EE/AERSP 492) provides sufficient introductory background that an individual is ready to function in the workplace environment upon entering a scientific or engineering career in the modern aerospace industry [5]. In Spacecraft Design (AERSP 401 A/B), the students learn the design process, complete a conceptual and a preliminary design, and begin a detailed design of a spacecraft, while learning to work in teams [6, 7].

SPACE SYSTEMS PROJECT WORK

Space systems projects prepare students with many of the abilities that industry desires in the engineering graduate, such as the ability to address a customer's needs, practice effective time management, understand integrated product development/concurrent engineering, use effective communication skills, understand current design tools, and develop a sense of the total business equation. These projects also provide the student with "hands-on" experience in "real-world" engineering problems that are not possible through courses alone and which map well to ABET's Engineering Criteria 2000 [8]. Instruments and sub-systems must be developed to meet the scientific objectives in a technically feasible way that, given the constraints of economics, time, and other factors, provides challenges to the students. To address the project requirements, students form into teams comprised of a mix of academic backgrounds to work on the wide variety of problems presented by the design and construction of an instrumented rocket payload, satellite, or other space system. Additional benefits are derived from the experiences of integration, testing, sensor calibration, and participation in the flight operations associated with these projects.

Different instructional models are used to involve students in the projects, based on educational objectives and the students' interests. A particular strength of these projects is the opportunity for students to grow academically as the project matures, and to develop skills not available in the classroom, such as team building, group learning, and mentoring. These aspects have been successfully introduced by engineering faculty at Penn State into a "vertically integrated laboratory experience" [9 - 11]. Assessment of our educational programs has been quite positive, and we find benefits from the engineering experience through the collaboration of the engineering students in these projects.

For most of the projects, we generally employ a vertical laboratory model, i.e., one in which the student cohort is mixed in academic maturity. An excellent example is our NASA-sponsored Student Launch Program called "SPIRIT" (Student Projects Involving Rocket Investigation Techniques), which has proven quite successful in utilizing teams for educational mentoring and vertical design [12]. In these projects, some students come from the lower-division (first year/sophomore) level so that they have the opportunity to grow academically with the project. Since projects of this type usually span several years, the upper-division (junior/senior) and graduate students provide the academic maturity and leadership to the group during the initial planning and design phase, and the lower division students advance to complete the project. An important consideration in working with such groups is fitting the students' interests and abilities to the tasks, while presenting the challenges to motivate and not overwhelm them educationally.

We describe below several of the space science projects on which Penn State undergraduate students have had the opportunity to participate during the last several years. Graduate students often work on space-related topics for their MS and PhD degree requirements and mentor undergraduates in these projects.

- **SPIRIT Rocket Payloads:**
  The SPIRIT program [13, 14] is a project-based curriculum that uses scientific research in service of undergraduate educational objectives. Each payload takes approximately three years to build and strictly follows the NASA design and testing sequence. Students gradually assume higher levels of responsibility for the fabrication of the sub-systems. At any given time, 35 - 40 students

Fig. 1A.(l) Students begin assembling the LionSat nanosatellite in CSSL's cleanroom facility; Fig. 1B. (r) ESPRIT students gather at Wallops Flight Facility during the payload Design Review, February 2005

participate in SPIRIT, with about 100 students claiming involvement in a typical 3-year project. The excitement of building a rocket payload and working with NASA engineers is highly motivational. The rigors of the sounding rocket design environment, the open-ended nature and the complexity of the task make it ideal for the development of professional skills in undergraduate students. The current SPIRIT payload, called ESPRIT, features an international collaboration with students and faculty advisors from three Norwegian universities. The payload will be launched from Andøya Rocket Range (ARR) in Andenes, Norway. The instruments measure selected parameters that further our understanding of Noctilucent Clouds (NLC) and Polar Mesospheric Summer Echoes (PMSE). Some parameters to be measured include: collision frequency, plasma density, X-ray bremsstrahlung, and aerosol particle characteristics.

- **LionSat – Small Satellite Program:**
  The Local Ionospheric Measurements Satellite (LionSat) mission [15] provides a breadth of learning experiences for students involved in designing, building, and flying Penn State's first student-built satellite [16]. The LionSat mission was selected as a participant in the Nanosat-3 (NS-3) program, which is a joint program between AIAA, NASA GSFC, AFOSR, and AFRL/VS. The objectives of the NS-3 program are to educate and train the future workforce through a national student satellite design and fabrication competition. The program enables small satellite R&D, payload development, integration, and flight testing, as well as the opportunity to fly new technologies to prove them in space. LionSat is a "sciencecraft" with science experiments and bus fully integrated. It will explore the ram/wake structure of a small spacecraft via plasma probes [17] placed on booms that will move in and out of the wake as the nanosatellite "rolls" along its orbit [18]. The primary engineering goal of LionSat is to flight test a miniature RF ion thruster (MRIT) by increasing the spin-rate of the spacecraft using a pair of MRITs [19]. LionSat will also employ and test Internet Protocol (IP) communications for uplink and downlink [20].

Space limitations do not allow us to present all past and ongoing space projects, so we mention some of the others only briefly. During an extended period of time from the mid-1980s until the *Columbia* disaster in 2003, a series of projects were carried out at Penn State to design and fly three Get-Away-Special (GAS) payloads. These payloads were designed and built by Penn State students and were launched into space on the Space Shuttle. The *Flyin' Lions* design, build, and fly microgravity experiments as part of NASA's Reduced Gravity Student Flight Opportunities Program (RGSFOP) [21]. On 18 June 2005, NASA launched a high-altitude balloon from Fort Sumner, New Mexico, carrying an experiment called *Characterization of Aerosols in the Troposphere and Lower Stratosphere (CATS)*, designed and built by Penn State undergrads.

There is also considerable student interest in more narrowly focused studies appropriate for theses and scholarly papers. Several senior Honors Theses have been completed on topics from the GAS, SPIRIT, and LionSat projects. While the educational objectives of the space projects are focused on collaborative learning experiences, activities for independent research projects are also supported, and these students are encouraged to also become involved in group collaborations. Several Masters Degree theses have been completed based upon work performed as part of these projects.

The project faculty advisors mentor a large number of students, and they are willing and interested in sharing their expertise with students as voluntary advisors, providing a very meaningful forum for learning [22]. The excitement from these interactions is impressionable and contagious. Facilities include project laboratory space located adjacent to both a dedicated Class 10,000 clean room for student space research projects and the offices of several of the faculty, so that informal faculty - student mentoring can also easily occur.

SPACE SYSTEMS RESEARCH

In addition to the faculty and facilities of the Electrical Engineering and Aerospace Engineering Departments, research activities benefit from the presence of several other enterprises at Penn State as described below.

Penn State's Center for Space Research Programs (CSRP) [23] is a Penn State mission-oriented science and technology center catalyzing the conceptualization, formulation, and implementation of advanced space missions. The Center facilitates development, growth, and sustainability of the unique human and physical resources required for space research at Penn State. The Center enables and coordinates the collaborative use of Penn State space research resources, without regard to artificial college boundaries, in support of missions and their enabling technologies.

The Pennsylvania Space Grant Consortium (PSGC) is a highly visible state-wide educational program in the Space Sciences involving eleven affiliate and member institutions and industries across the Commonwealth with Penn State as the lead. PSGC activities range from K-12 and education and public outreach (EPO) activities through graduate student research support. PSGC [24] seeks to improve the quality of science and engineering education and to open up the science and engineering pipeline to women, minorities, rural populations, and those with disabilities. Current NASA education planning emphasizes Space Grant efforts.

A continuing research involvement with the Sounding Rockets Program Office at Wallops Flight Facility of NASA Goddard Space Flight Center has led to a very good working relationship with those scientists and engineers. In 1997, a formal Memorandum of Understanding was implemented between GSFC and Penn State to facilitate collaboration between the two groups on a no cost basis. As previously described, the student SPIRIT launches have involved several hundred undergraduates who directly interacted with NASA engineers to design, construct, perform payload integration tests, and support the launch of the payloads. A number of these students have either held summer internships or chosen permanent employment careers at NASA; while some have returned to Penn State to provide guest lectures in our senior capstone design course.

THE FUTURE

Building on our strong tradition of space science and engineering education and research activities, new initiatives are underway to continue strengthening this area at Penn State in response to recommendations in the National Research Council decadal report *"The Sun to the Earth - and Beyond"* [25]. Penn State was recently awarded an NSF proposal that will help assure a "critical mass" of faculty in the space sciences, so that we can successfully offer a wide range of well-populated courses and individual/team research in the space sciences as described herein. These new positions will help counter the erosion of the space science faculty noted in the NRC report, enhance our ability to attract top students at all levels in the space sciences and engineering, and strengthen bridges to other on/off-campus educational, research, and industrial activities that require expertise in the space sciences.

In the spring of 2005, CSSL faculty held a focus group with students involved in a number of the space system engineering projects. The purpose of the focus group was to discuss the needs of the students, as they saw them, for the facility that they design, build, and test their space systems. A lot of good information was gathered, and some changes are currently underway to meet the needs to students identified. Perhaps one of the most important things uncovered in talking with the students is their desire to receive "official" recognition for their hard work, especially helpful when searching for jobs in the space industry. Their desire is guiding our development of a Space Systems Engineering Certificate, which could be awarded to students who have been involved in any one of these projects and taken a core group of space systems courses. We anticipate having this available to students within a year.

Penn State also recently gained membership in the US Air Force's Space Education Consortium (SEC) [26], which is a network of teaching and research institutions focused on promoting education, research, and cooperation related to and supporting the development of a professional space cadre concerned with the advancement of space systems design, development, operation, and application. The consortium is focused on complementing and supporting related efforts of participating military or civilian organizations. The SEC focuses on education and research as opposed to training and certification. The consortium's interests include: space operations in all environments (land, sea, air, space, cyber); development and integration of space systems; interaction of DoD, national, civil and commercial systems; and interdependency of technology, operations, business and policy/doctrine.

The part of human nature that thrives on scientific discovery and creates the long range vision that motivates humankind is easily drawn toward the expanse of space and a curiosity about our universe. The primary driving force for new engineering developments and technology advances of the last five decades has been born out of national and international activities to explore and develop useful systems in the space of our solar system.

It is little wonder that space science/engineering programs, which we offer for student involvement in the university, draw many of the best and brightest students. The projects described herein have provided an important experience for many working in industry and government laboratories today and

these programs continue to provide a valuable part of the educational process for Penn State students.

REFERENCES

[1] Communications and Space Sciences Lab, http://www.ee.psu.edu/cssl/.

[2] Electrical Engineering Department, http://www.ee.psu.edu/.

[3] Penn State College of Engineering, http://www.engr.psu.edu/.

[4] Aerospace Engineering Department, http://www.aero.psu.edu/.

[5] Philbrick, C. Russell, Education in Space Science, Proc. 17th ESA Symposium on European Rocket and Balloon Programs and Related Research, ESA SP-590, pp 25-32, 2005.

[6] Spencer, D.B., R.G. Melton and S.G. Chianese,** Selecting Projects for a Capstone Spacecraft Design Course from Real World Solicitations, accepted for publication, Journal of Aviation/Aerospace Education and Research, 2006.

[7] Mathew, A.,** Incorporating Cooperative Learning Activities Into Traditional Aerospace Engineering Curricula, M.S. Thesis, Department of Aerospace Engineering, The Pennsylvania State University, August 2005.

[8] ABET Engineering Criteria 2000, http://www.abet.org/criteria.html.

[9] Maughmer, M.D. and D.W. Jensen, Enhancing the aerospace educational experience with a multi-year sailplane design project, Proc. of the 1992 ASEE Annual Conference, Toledo, OH, June 21-25, 1992.

[10] Bieniawski, S., D.W. Jensen, E.C. Smith and M.D. Maughmer, Evolution of a vertically integrated aerospace vehicle design and fabrication course, Proc. of the 1994 ASEE Annual Conference, Edmonton, Alberta, Canada, June 26-29, 1994.

[11] Kunz, P.J. and M.D. Maughmer, The PSU sailplane project, 1996 World Aviation Congress, Los Angeles, CA, October 21-24, 1996.

[12] Mitchell, J.D., T.F. Wheeler, C.L. Croskey and D.M. Meisel, SPIRIT: Student Projects Involving Rocket Investigation Techniques, ESA SP-437, September 1999.

[13] Wheeler, T.F., The sounding rocket as pedagogical tool: A report from ten years of experience with the SPIRIT Undergraduate Sounding Rocket Program, 17th ESA Symposium on Rocket and Balloon Programmes, 30 May-2 June, 2005.

[14] Wheeler, T.F., C.L. Croskey, J.D. Mitchell and R. Marra, SPIRIT Student Rocket Payload: Characteristics of a long-duration undergraduate research project, Proc. of the 2001 ASEE Annual Conference, Albuquerque, NM, 24-27 June, 2001.

[15] Mistoco, V.F., R.D. Siegel,** B.S. Surrusco,* E. Medoza* and S.G. Bilén, Design of the Local Ionospheric Measurements Satellite, 17th Annual, AIAA/Utah State University Conference on Small Satellites, 11-14 August 2003.

[16] Bilén, Sven G., Charles L. Croskey, Robert Melton, David Spencer, Deborah Levin and Michael M. Micci, Students designing and building satellites: Penn State's LionSat and the University Nanosat Program, 2005 ASEE Annual Conference, Portland, Oregon, 13-15 June 2005.

[17] Siegel, R.D., IV,** Design of a Hybrid Plasma Probe System, M.S. Thesis, Electrical Engineering Dept., Penn State University, University Park, PA, May 2004.

[18] Surrusco, B.,* R.D. Siegel,** P.M. Sorber,* D.V. Morr,* N.F. O'Connor,* C.L. Croskey, S.G. Bilén and J.A. Soloff, Mission planning for employing internet protocol (IP) communications on the Local Ionospheric Measurements Satellite (LionSat), NASA Third Space Internet Workshop, Cleveland, OH, 4-6 June 2003.

[19] Mistoco, V.F.M.,** S.G. Bilén and M.M. Micci, Development and chamber testing of a miniature radio-frequency ion thruster for microspacecraft, 40th AIAA/ASME/ASEE Joint Propulsion Conference, Ft. Lauderdale, FL, 11-14 July 2004.

[20] O'Connor, N.F.,* B.S. Surrusco,** S.G. Bilén and C.L. Croskey, Software-Defined Radio Ground Station for Internet-Protocol Communications to a Low Earth Orbit Nanosatellite, NASA Fourth Space Internet Workshop, Hanover, MD, 7-9 June 2004.

[21] Reduced Gravity Student Flight Opportunities Program, http://microgravityuniversity.jsc.nasa.gov/.

[22] Bilén, S.G., Enhancing engineering education by harnessing the student-initiated design project, ICEE 2001, Oslo, Norway, 6-10 August 2001.

[23] Center for Space Research Programs, http://csrp.psu.edu.

[24] Pennsylvania Space Grant Consortium, http://www.psu.edu/spacegrant/.

[25] NRC, *The Sun to the Earth — and Beyond: A Decadal Research Strategy in Solar and Space Physics,* p. 177, The National Academies Press, Washington DC, 2003.

[26] Space Education Consortium, https://www.nissc.org/spaceeducationconsortium.aspx.

** Graduate Student, * Undergraduate Student