122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13398

Nano-satellites and HARP for Student Learning and Research

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He enjoys mentoring undergraduate students in aerospace, sensors, and energy-related research projects. Some of the research areas include spacecraft nano-satellite technologies, satellite payload instrumentation, High Altitude research Platform (HARP) experiments, wave particle interactions in space, spaceflight X-ray imagers, construction and renewable energy engineering and architecture, and philosophy of science. Dr. Voss has worked as PI on many NASA, Air Force, Navy, NSF, and DOE research grants and has published over 120 scientific papers.

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Mr. Jeff Dailey, Chief Scientist at NearSpace Launch Inc. (NSL) Mr. Jeff Dailey has launched over 350 balloons with Taylor University and has developed three CubeSats with two of them now successfully launched and missions completed on orbit. Mr. Dailey has worked previously at Taylor University as a Research Engineer. Currently Mr. Dailey is the Chief Engineer at NSL developing High Altitude Research Platform (HARP) balloon sensors and tracking systems and is also developing small satellite subsystems for universities and Government agencies. He has developed a new 24/7 satellite data communication network that is FCC approved and demonstrated in orbit.

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Nanosatellites and HARP for Student Learning and Research

Abstract

University small satellites are now routinely launched into space with the NASA ELaNa program, the AFOSR University Nanosatellite Program (UNP), and the NSF CubeSat program. As part of these programs, undergraduate students have developed several small satellites and many High Altitude Research Platform (HARP) balloon experiments. Student outcomes include augmenting ABET objectives a-k, new ways of enhancing STEM education and undergraduate research, improving publications/resumes, internships and jobs.

In this paper we review over 15 years of undergraduate education developing a number of small satellites. We present case studies on the precursor High Altitude Research Platform (HARP) and two satellites that were deployed in orbit. These two satellites and over 350 HARP student launches to the edge of space (only 2% of earth's atmosphere pressure at 30km altitude) are examples of challenging projects which, when managed properly, can have a magnificent educational, practical, and societal impact. Various teaching pedagogy and assessment data are included so that interested groups can begin their own programs.

1.0 Introduction

Small universities with primary undergraduate programs have historically been teaching-focused with research being a secondary priority or even non-existent. In recent years, there has been a shift toward involving undergraduate students in mentored research activities.[1] The benefits and rewards for the students, faculty mentors, the institution, and the greater scientific and engineering community have been recognized. However, there are many challenges to implementing a successful teaching research program at the undergraduate level. Within the engineering education community, the topic of undergraduate research, and in particular the issues facing primarily undergraduate universities, has been addressed in several papers. [2] [3] [4] [5]

Our 2012-2013 Senior Capstone class helped create the dual-cube nano-satellite, TSAT, with space weather instrumentation. TSAT was launched on a Space-X rocket from the Kennedy Space Flight Center to the International Space Station (ISS) on April 18, 2014 and released as an autonomous satellite at 325 km altitude. The class structure, pedagogy, assessments, and outcomes indicate the effectiveness of advanced student challenges that inspire students but do require significant support from faculty and staff.

The 2014-2015 Capstone class is completing (with Air Force funding) a novel 6-cube satellite to investigate the Extremely-Low-Earth-Orbit (ELEO) region using an aerodynamic nanosatellite design that can probe space weather while demonstrating new technologies. It will provide an observation platform in the relatively unexplored atmosphere and ionosphere in the 120-300 km region. Technology demonstrations include: unfolding aerodynamic solar array structure, a motor retractable carbon fiber boom (3m long) with sensors located on booms, a new real time satellite-to-satellite command/data link using the Globalstar network, and a flight GPS receiver. This aerodynamic ELEO-Sat has a high mass/area ratio to significantly increase lifetime in ELEO. Drag is increased at high altitudes with the quad boom release mechanism. ELEO with the Nanoracks deployer is ideal for ISS missions at 425 km. A Test Particle Monte Carlo (TPMC using individual atoms) software program was developed from first principles to successfully calculate drag forces and torques in the quasi-collisionless ELEO atmosphere. On January 26, 2015 ELEO-Sat was one of the winning proposals to move to a Phase 2 and launch opportunity with new student funding.

To prepare students for advanced satellite projects the HARP balloon launches serve to introduce real end-to-end flight opportunities to study the upper atmosphere (up to 32 km) and test flight sensors, mechanisms, and bus systems. To help other small universities and colleges to implement a nano-satellite or HARP program, three spinoff companies have been started over the past few years for purchasing complete HARP turnkey systems, purchasing express launch service, and providing satellite communication and power system products. The ability for students to meet deadlines, appreciate system integration delays, understand subsystem sensor calibrations, observe software faults, recognize reliability issues, grow from failures, and properly interpret and display real data are some of the benefits of HARP.

2.0 Why Teach a Challenging Project Course: Objectives

Assuming most BS engineering students are motivated by real world proficiencies that are challenging and inspiring and assuming that employers and graduate schools are interested in exceptional experience and ability then advanced projects prepare graduates well. Traditional "small stepping" lab and project classes serve a real purpose but can be limited and geared more for workforce literacy ("Cubicle" engineers). Challenging projects give students freedom and ownership while driving and amplifying their problem solving skills with some failure and creative feedback solutions. Appropriate and inspiring big projects better prepare students for advanced leadership by doing advanced engineering and "swimming with the Big Boys" in national competitions, peer reviewed publications, and selective job interviews.

Advantages

Real world and challenging experiences for students have many advantages:

- improved student resume and career opportunities
- are significant for attracting top students and faculty
- generate publicity and STEM public relations
- enhance publications and academic stature
- help retain department students
- stimulate faculty in cutting edge innovations
- create an entrepreneurial and fun atmosphere
- augment faculty and student income with external funding ($)
- bring in mentors and professional reviewers
- improve society by connecting to real problems of student interest
- overcome fears and failures
- build teamwork and multidisciplinary skills
- show students how to be leaders by teachers and students being leaders in the classroom

Major advances can be made at the undergraduate level by setting the bar high and mentoring students with an environment similar to realistic job or graduate research expectations. The target outcome is for undergraduates to be at a master's thesis level when they graduate with many on-job skill sets. With manifold new teaching tools, equipment advances, software analysis tools, search engines, 3-D printers, and better ways of teaching, our expectation should move far beyond conventional engineering BS, FE and ABET teaching outcomes.

Negatives

Some negative aspects of challenging projects include:

- finding capable faculty who know how to innovate and mentor students
- the extra time and paperwork required to maintain a funded program
- real deadlines and risk of failure
- student lack of responsibility at times
- recovery from problems
- conflict with other student priorities
- schedule conflicts
- requiring good technician and shop support
- maintaining a program with critical mass staff
- travel

Unfortunately there can also be pushback from some traditional "pure academic" faculty who frown on workload expectations and view applied work as a distraction. Some other faculty without industry work experience may have little value for understanding the priority to apply theory to productive and creative work required on the job. Applied, competition projects, business-ready learning, and entrepreneurial playground can be in conflict philosophically with traditional knowledge based labs and teaching, collective group behavior, business as usual, and "don't rock the boat" leadership. Care must also be given to student load hours where some faculty resent the many hours that students spend enthusiastically working on their projects at the perceived expense of their other class areas. Accurate student time tracking is required.

Administration, Admissions, and Advancement departments and most faculty and students are strong supporters of Big and challenging projects while Finance Departments in small schools (Government paperwork, FARS, proposals, indirect cost, reports, and deadlines) and some faculty can understandably look at real world and challenging projects as diversions, too applied, and a waste of resources. A strong department is diverse and usually one that encourages and has a mixture of different teaching styles, scholarship contributions, and faculty gifting so that students receive a better well-rounded education. The negative aspects of entrepreneurship and innovation are real and must be taken seriously, mediated, and addressed in the particular working environment.

Many types of Big Challenge Undergrad Projects in the last 15 years

Major education and discovery advances can be made at the Undergrad level! Challenging Engineering projects were successful in the following fields: Aerospace Engineering, Civil Engineering, Electrical Engineering, Computer Engineering, Automotive Engineering, and

Nuclear Engineering. Specific "Big" projects for students and faculty (one or two faculty per class) that were implemented with undergrads in a small and teaching focused Liberal Arts University with limited resources over the past 15 years are as follows:

1. Solar car vehicle and drivetrain completed and entered into national competition
2. Downhole oil well control and sensor system with 2000 ft fiber optics and wireless link
3. TUSAT 1 DualCube nanosatellites
4. TEST Satellite with Air Force nanosatellite program (several grad school MS projects)
5. BUSAT development with Boston University
6. New Science Building design with new sustainable technologies ($42M project) and Mobile Energy Lab on large trailer to demonstrate new building design features
7. Building Eyelid Design and Heliostat building innovations are now operational
8. Operational Wind Energy Generation and Meteorology Tower
9. High Altitude Research Platform (HARP) Balloon Program (over 350 launches)
10. Hybrid Car with hydrogen engine injection
11. Local city Fire station building student design
12. Engineering Mission projects for tsunami and hurricane relief
13. 25 MeV Accelerator modified (NSF funding) from a donated medical linac
14. NASA instrument developments: Dust and energetic particle spectrometers
15. Astronomy Observatory design and construction
16. Dual helical antenna with satellite tracking
17. Chaos electronic circuit and manufacture to PASCO Scientific
18. Solar Car research lab Building Design
19. VLF radio receiver station and data system with Stanford (NSF)
20. NASA student experiment and flight on microgravity flights ("Vomit" Comet)
21. Many other projects

This paper is focused on the merits, implementation, and evaluation of aerospace satellite and balloon Big Idea projects.

3.0 How a Class is taught: Pedagogy

Big Idea projects are introduced in several classes at different levels. HARP balloon flights are used in the core general education Introduction to Astronomy Lab class (PHY201) for teaching, student participation in the scientific method, and student major growth in STEM education. HARP has also been used effectively for labs in several of the engineering classes (Introduction to Electronics, Fundamentals of Space Flight Systems, Principles of Engineering, Advanced Lab Projects, and in the senior Capstone classes). The balloon experiments are particularly good and fun for preparing students for developing more advanced satellites, testing flight hardware, experiencing teamwork and realistic schedules, performing data analysis and teaching students how to build real designs that work under ruggedized conditions from end to end.

The Taylor, Technology, and TEST Satellite (TSAT) was mostly developed by the 2012-2013 Capstone class and became Indiana's first satellite when it was launched and successfully put into orbit on April 18, 2014. The first data communication took place 11 seconds after power was activated. The satellite also implemented for the first time a satellite-to-satellite link to the Globalstar network of phone satellites for the new 24/7 capability global data coverage. Furthermore, no ground station was required since all of the TSAT data from Globalstar was transferred via the internet.[6]

The Capstone class submitted an undergraduate student proposal called Extremely Low Earth Orbit (ELEO) Satellite to the AFOSR University nanosat program in 2013. It was selected as one of the final 10 contestants and funded for Phase 1 at $110K. After a 2 year competition by the 2013-2015 Capstone classes, the ELEO satellite was selected on January 26, 2015 as one of the top 5 satellites for a Phase 2 final development for launch.

The TSAT and ELEO-Sat project provides a unique opportunity for student learning through a real-world design experience. Hands-on satellite development helps students develop important career skills such as teamwork, systems engineering, and integration. Students learn the importance of deadlines and scheduling throughout the design and development process. A high expectation level encourages students to produce quality work and to present it with competency at design reviews with the Air Force and industry professionals. The design process provides insight into the professional world and teaches students to develop individual subsystems within a team.[7]

Team members come from a wide range of disciplines. Students from each of Taylor University's engineering majors, which include Engineering Physics, Computer Engineering, Environmental Engineering, and Systems Engineering, participate in the same senior capstone course. Juniors and underclassman engineering students are also involved in the project, working on smaller subsystems or tasks, in order to mitigate risk presented by student turnover upon graduation. Students in majors including Mathematics, Physics, Business, Accounting, Elementary Education, and Computer Science also participate voluntarily in the senior engineering project under the leadership of the faculty and engineering students. For example, an undergraduate mathematician developed and calibrated Monte Carlo simulations of free-molecular aerodynamics to determine drag effects in ELEO orbits. An example of non-technical involvement is business students who organized events to promote campus awareness of ELEO-Sat. Moreover, the senior capstone course involves local high school students considering STEM careers through outreach programming including participation in high altitude balloon projects. Similarly, the project provides outreach opportunities to local elementary schools using space science curriculums developed by Taylor University elementary education majors. Working on projects like ELEO-Sat equips students from many disciplines with skills they need for the future. Collaboration between non-capstone students, professors, and engineering students benefits student learning as a whole.

Capstone Class Structure and Selections

Near the end of the Junior academic year, students pick their project given a choice from faculty of 4 or 5 areas of interest and potential funding. For the last several years the students picked the TSAT and ELEO-Sat projects because of their interest and faculty expertise.

The Capstone satellite class is structured similar to the industrial environment to help better prepare students after graduation and to win job interviews. A class run like a business is eye opening to the students when they realize that they have team responsibility and commitment to understand, design, and deliver their subsystems on schedule. After initial discussions each student selects their particular subsystem project. The students are required to work in interdisciplinary teams with student each having their own subsystem to design and deliver.

Individual student design responsibility is important for evaluation, problem solving, overcoming fears, and minimizing excuses. When we tried to put students together in teams of two or three the ambitious or sharp student would carry most of the load and the weaker or disengaged student would become passive.

The student team Project Manager (PM) and Project Engineer (PE) are crucial for project success. After we get to know a few of the students at the end of their Junior year it becomes obvious who the best PM and PE candidates are. After talking with all of the students and individually with each student a consensus is made for PM and PE and agreed to at the start of the project. For TSAT we had an exceptional team leader who set the marks for the rest of the team and demonstrated servant leadership to cover many of the gaps in documentation and hardware. For the last two years on the ELEO-Sat project we realized that we would prefer to get a Junior as our Capstone PM so that there would be a better hand off the next year since ELEO-Sat was a two year project. A beginning junior female engineering student was very interested in this role with her organizational and management abilities and served as the PM by taking an Advanced Projects Elective class. Although she was an excellent student she had been thinking of leaving the major since she did not picture herself as an engineer in a box (cubicle). She has run the program superbly for the past two years and has many high level engineering job offers in the Aerospace industry and has given over 10 briefings to top Air Force reviewers, Space Experiments Review Board (SERB), and Competition officials.

Learning is encouraged through participation in conferences and workshops such as the SmallSat Conference in Logan, Utah in August, the Student Hands-On Training (SHOT) Workshop, and the CubeSat Developers' Workshop. The SHOT Workshop and SmallSat Conference were held during the summer of 2013; more than half of the Taylor University team attended one or both events. The focus of the SHOT workshop is to teach small teams from each university the skills necessary to assemble a balloon satellite, which is a low-level satellite prototype for a high altitude balloon launch. The SmallSat conference introduced students to new small satellite technology and developments. Those who attended received an excellent learning experience regardless of their engineering background. [5]

The University Nanosatellite Program (UNP) also provides mentorship for each team. Each UNP team is assigned a point of contact (PoC) at the Air Force Research Labs (AFRL). The point of contact can provide technical guidance for the design process and connect a team with expert contacts for further assistance. Contacts provided by a PoC sometimes become additional mentors on the project.

Design Process

The Syllabus for the Capstone class is given in Appendix 1 and illustrates the structure that is used for the class. The design process in the engineering capstone course facilitates end-to-end design and traces ABET a-k objectives. Figure 1 is a diagram, adapted from Ford-Coulston 2008[8], that illustrates how the engineering capstone course connects the ABET a-k objectives (Figure 1 below) to an intentional, directed, thoughtful, and sustainable design process. The

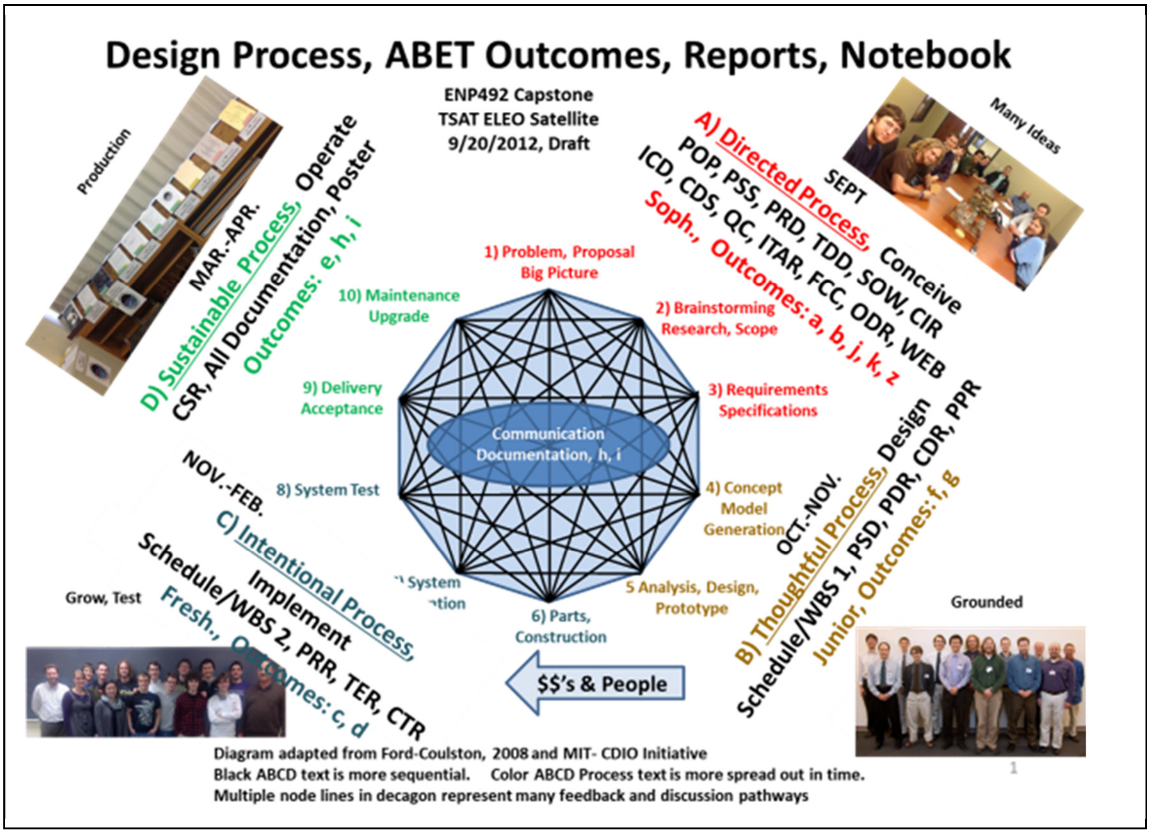

Figure 1: The design Process Organization

curriculum emphasizes each of the four design processes at different points in the course as indicated by the associated dates. The multiple node lines in the decagon represent many feedback and discussion pathways. The black abbreviations underneath the process headings indicate documents required within each phase and the highlighted outcomes indicate ABET a-k objectives linked to each process and stage of the design. Additionally, the design process is guided by UNP standards for design reviews. Review deliverables, e.g. concept, breadboard, brass board, are expected at the reviews indicated, e.g. SRR, PDR, CDR.

The required formal documentation for the ELEO Capstone students is shown in Table 1. All of the documents are on display in the department and in the ABET library. As the documentation was being completed a red card indicated much work was still required, a yellow card that most of the document was completed and a green card when the document was completed. This greatly helped the students to see the scope of the work and our progress.

In addition to the above documentation the students developed three concept review documents and presentations before the PDR document. One of the most difficult assignments for students was the need to keep an updated notebook of all of their work and a detailed logbook that included a spreadsheet of their hours.

Table 1: Documentation

		Major Milestone	
1	POP	Project Big Picture Overview Proposal	Team
2	PSS	Project Scope Statement	Each
3	PRD	Product Requirements Document	Each
4	TDD	Team Definition Document	Team
5	SOW	Statement of Work/Work Breakdown	Each
6	NAS	NASA Cubesat Requirement Documents	Team
7	PSD	Product Specification Document	Each
8	PDR	Preliminary Design Document & Review	Team
9	CDR	Critical Design Document & Review	Team
10	PPD	Pre-Procurement Review, WBS, Schedule	Each
11	ASEE1	Submit ASEE Draft Papers	Team
12	ELEO1	ELEO Kickoff Meeting Travel and Telecom	Team
13	HARP	High Altitude Balloon Research Platform	Team
14	ASEE2	Submit final Papers and Posters	Each
15	SCR	ELEO-SAT System Concept Review	Each
16	SRR	ELEO-SAT Systems Concept Review	Each
17	FINAL	Final Notebook and Documentation	Team
18	POST	ABET and Taylor Poster Session	Each

4.0 HARP Program Case Study

High–altitude balloon launches provide low-cost access to near space and give general education and upper level students the opportunity to experience firsthand the excitement of real science in a relatively unexplored region of the stratosphere. Small balloons achieve heights of 32 km and can carry payloads of up to 4 kgs without needing special FAA waivers. The flight passes through the troposphere, tropopause, most of the ozone layer, and up through 98-99% of the atmosphere (Figure 2).
A balloon travels for about 2-6 hours and covers a horizontal distance of 0 to over 200 km. To date we have launched over 350 balloons and have recovered over 99% due to the reliable and redundant GPS flight computer transceiver system, the ideal launch conditions in Indiana (road access, few trees, flat farm land and good neighbors), and experienced recovery teams (Figure 4).

Figure 2. Video camera frame of student twin balloon ascending while also showing the atmosphere, the curved limb-of- the- earth, and black heavens.

The use of balloons for real projects significantly invigorates and expedites development and teamwork, teaches problem solving and instructor mentoring, drives schedule and creativity, uncovers unexpected problems, permits end-to-end testing, helps students understand failure and workmanship principles, gives a real environmental check (significant thermal vacuum and free-fall vibration tests), and forces completion and validation of the flight and ground station software. Figure 3 illustrates some of the program operational logistics.

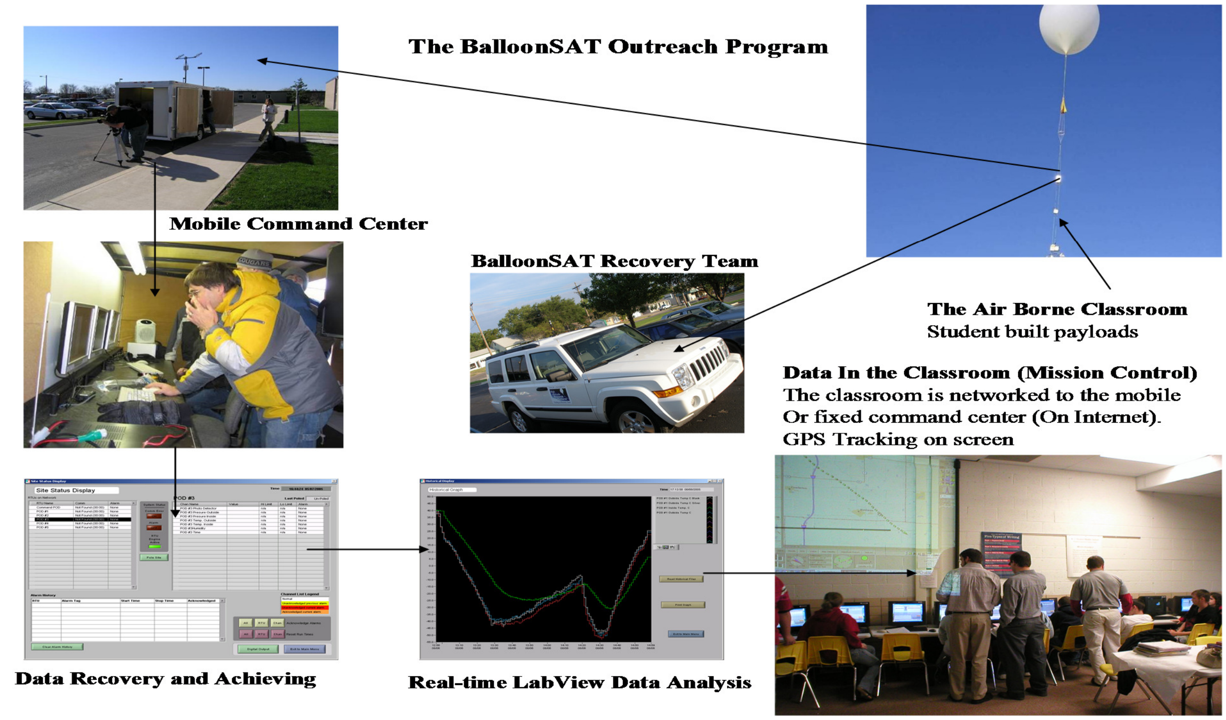

Figure 3. Real experience and real data as student sensors transmit their data in real time while student teams monitor data, track flight path, and chase for the GPS landing.

Specifically, the HARP balloon experiments help students 1) learn the Scientific Method (hypothesis, test, observe, analyze, interpret, predict, repeat, document), 2) learn some hands-on technical skills (design, soldering, fabrication, electronics, assembly, and team work), 3) learn engineering principles (heat transfer, sensors, GPS, communication links, optics, remote imaging, and data processing), 4) learn atmospheric variables (pressure, temperature, wind, troposphere, stratosphere, humidity, dynamics, and others), 5) obtain physics knowledge (fundamental equations, radiation, acceleration, Archimedes principle, etc.), 6) apply data analysis skills (using Excel, handling noisy data, plotting profiles, creating log plots, and applying different plot formats), and 7) documentation (Wiki reports, team report, presentation, and resume). The objective is for students to have fun, efficiently learn, value science, improve in STEM, and advance in critical thinking skills[2].

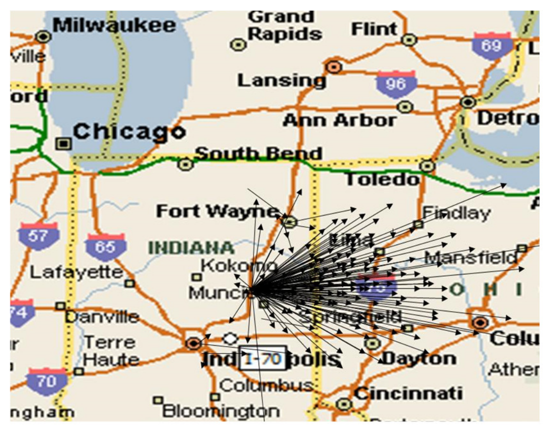

Figure 4. Flight paths for 300 launches in Indiana over the past 10 years. Only half shown.

High-altitude balloon training, hands-on experience, and quick turn-around are foundational to student advancement into more complex experiments such as aerospace and satellite system projects. Without experiencing real flight and some failure feedback it is hard for students to understand the importance of Requirements, sensor noise, workmanship and Quality Assurance, test fixtures, calibration, turn on procedures, clean documentation and configuration control, Concepts-of-Operations (Con-Ops), Program Management and schedule, and ground station software.

5.0 TSAT Example Case Study

Our 2012-2013 Senior Capstone class (Figure 5) helped create the dual-cube nano-satellite, TSAT, with space weather instrumentation into low earth orbit.

Figure 5. Capstone students working on the TSAT and ELEO satellites

A conceptual diagram of TSAT is shown in Figure 6. The 2U spacecraft has dimensions of 10 X 10 X 20 cm and was successfully launched alongside the 1U PhoneSat spacecraft by the Cal Poly P-Pod launcher as part of the ELaNa 5 program (see Figure 7) on the SpaceX CRS-3 ISS resupply mission.

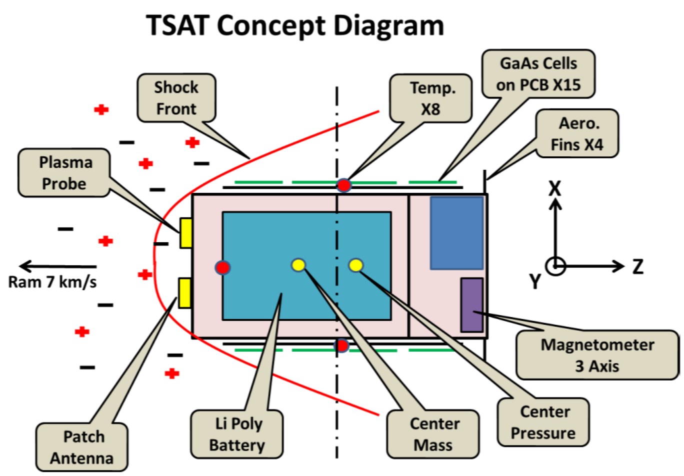

Figure 6. TSAT concept diagram

The satellite was aerodynamically stabilized in the ram direction by designing the Center of Gravity 2 cm forward of the centerline. Small fins on the back (+Z side) created additional drag to move the center-of-pressure behind the centerline and resulted in a restoring torque. Test

Particle Monte Carlo (TPMC) simulations with individual atoms were used to calculate restoring torques, forces, and drag coefficients. Above 160 km, the TSAT was in a free molecular flow region, then entered into a transition region (120-160km), and finally into a hypersonic continuum flow below 120 km. A shock wave (red line, Figure 6) was produced by the 7 km/s orbital velocity. Three orthogonal sheets of mu-metal were used for damping spin in the earth's magnetic field at higher altitudes. The magnetometer, sun, and temperature signals are still being analyzed to better understand TSAT orientation during the different phases of the flight.

Each of the four 10 X 20 cm walls included a PCB board for mounting the GaAs solar arrays (green, Figure 6) and a temperature sensor (red dots, Figure 6). The 3-axis magnetometer was located on the +Z side end cap and within the EMI shield wall. The Plasma probe was biased at 4.1 Volt when not sweeping to collect electron charge (- & + plasma) over 5 orders of magnitude with a log amplifier. The plasma probe and simplex patch antenna were mounted to the –Z endplate and faced the ram flow direction as shown.

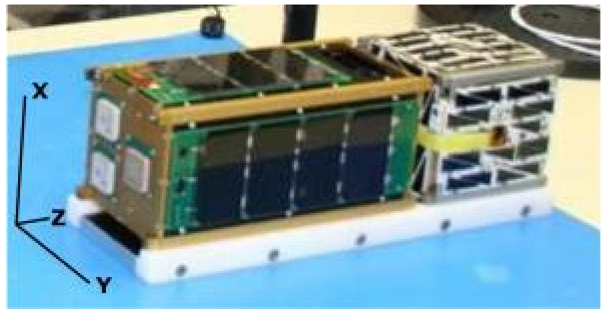

Figure 7. TSAT (2U) and PhoneSAT (1U) in P-Pod launcher during final integration at Cal Poly.

The TSAT frame structure was designed and fabricated on a CNC by students. The student sensor suite was also included in the design. Not all of the sensors qualified for the TSAT flight, but are scheduled for the next UNP flight. The design of the student suite is discussed in four student ASEE papers[2,3,4,5].

The Globalstar communication system gave about an 80% throughput of data. The satellite operated in a burst mode to conserve power. TSAT was on for 3 min and then off for 15 min. This operation permitted TSAT to operate effectively for its entire mission until it decayed into the meteor region below 110 km. These new results indicate the promising exploration of the lower ionosphere.

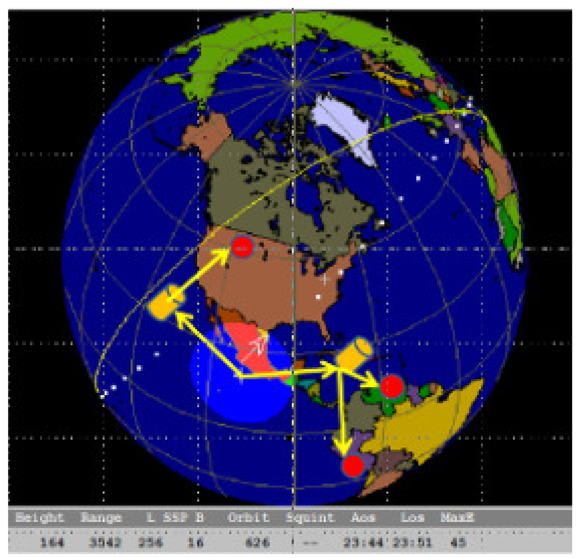
Figure 8. TSAT location of last data packets (~110km) and illustrated bent pipe data paths to the Globalstar satellites to gateways in Peru, Venezuela, and Canada. (Voss et al. 2014)

The orbit geometry for the last packet (highlighted area just west of Mexico on the night side) is shown in Figure 8 using the SatPC32 tracker map. The final reentry location and burn-up was projected by NORAD to be over Italy at 4:01 UT. The last sequence of packets at 3:39 UT is consistent with data being transferred through the Globalstar satellites to ground stations in Venezuela, Peru, and Canada. Predictions from the TLE/SGP4 orbits also placed TSAT over Italy at time of reentry burn-up.

TSAT Reentry heating near 110 km

The new Globalstar satellite to satellite communication link permits new measurements in the ELEO region down to unprecedented low altitudes (<110km). During this time, the PCB board temperature increased to 45 degrees C and was rising at about 20 degrees/minute. On previous packets, the temperature averaged -10 degrees C, so the temperature increase was about 55 degrees from the previous packets, and was increasing rapidly. TSAT was still functioning at this point in its mode of conserving electrical power. These results give a new tool for making measurements with satellites in the lower ionosphere. Students are currently studying the rich database from TSAT for publication.

Plasma Measurements with Langmuir Probe

The Plasma Probe instrument operated at a fixed voltage most of the time, but was also programmed to sweep in voltage from 0 to 5 volts. A preliminary plot of electron density is shown in Figure 9 as a composite for the entire mission (Voss et al. 2014). For each 10 kilometers of altitude, the median plasma density was calculated. Figure 9 is essentially a "quick look" graph representing plasma probe median electron density by altitude for the entire mission. Further analysis and correction for other factors such as temperature variation will be conducted in the coming weeks. The ionospheric E-F boundary is the most prominent feature at 200 to 220 km. The F region median density is about 10^6 electrons/$cm^{3,}$ while the E region is about $2*10^3$electrons/cm^3. The electron density profile may be extended down to lower altitudes, now that the TSAT drag model has provided a clearer picture of the altitude versus time profile. The plasma data was collected in small batches because of the duty cycling of the instrument, in order to conserve power.

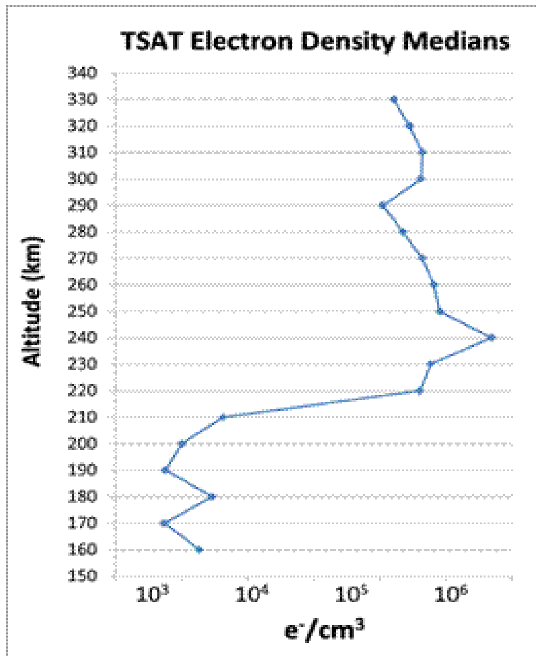

Figure 9: Mission medians of electron density for various orbit altitudes (10km bins). The higher density in the F-region transitions to the lower density in E-region at about 215 km.

6.0 ELEO-Sat Example Case Study

Extremely Low Earth Orbit (ELEO) satellites may open up, "A new space region of exploration for understanding our global sun and earth connection" [6]. At present the near earth space region between 40 and 300 km is vastly underexplored, since only sounding rocket flights (about 20 min) can take measurements in this region at only one location (see Figure 10). LEO satellites, when orbiting below 300 km altitude, spiral into the atmosphere within several days to weeks and simply are not cost efficient to explore this region of space.

The new class of proposed ELEO satellites are aerodynamic, with a high ballistic coefficient, so that they can make measurements down to 120 km, and possibly lower, relaying their data immediately to a satellite network. ELEO-Sats are typically launched at altitudes between 325 to 425 km, and spiral in over several weeks with an earth orbit period of about 90 minutes. By using many low cost and small ELEO CubeSats, this relatively unexplored region will likely reveal interesting atmospheric science. Some of the reasons for opening this new window into the earth's environment are: 1) ELEO orbits rides are very low cost and many are available, 2) to better understand the Sun-Earth climate connections, it is critical to make global measurements in the 100-250km region, 3) being an unexplored space region, many new discoveries are expected, 4) current atmospheric models could be validated or corrected with real data from this region, and 5) the recent availability of a global communication network like Globalstar, with near real time data access from the internet, permits data collection above the "black-out" region anywhere on the earth.

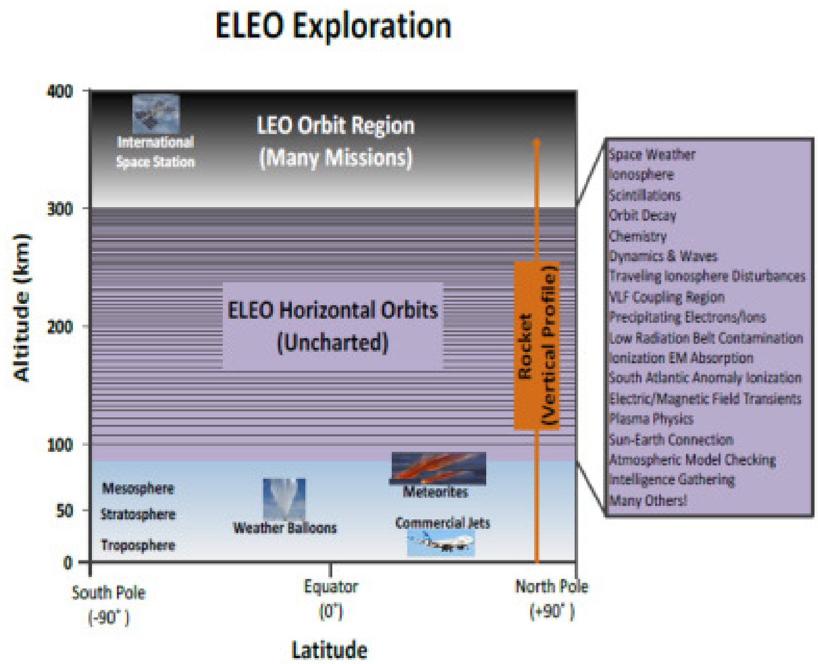

Figure 10. The purpose of the aerodynamic ELEO-SAT is to map and explore the ionosphere and atmosphere in the ELEO region (120 to 325 km). While sounding rockets probe this region (vertical profile at one location) for tens of minutes, the ELEO-SAT will make unique horizontal and global cuts and measurements for over 600 orbits on the order of five weeks.

In the future, ELEO orbits could use high efficiency ion engines to add impulse to compensate for drag. Tether systems could help transform orbital energy into power at high altitudes when drag is low. Furthermore, when an ELEO-Sat enters the reentry region near 80 km, future designs could allow for the heavy exoskeleton and batteries to be jettisoned, while a spring-dampened Kevlar chute could permit instrument reentry and continued measurements as a dropsonde. It is expected that many relatively low-cost rides will become available to ELEO orbits in the future.

UNP-8 ELEO-Sat

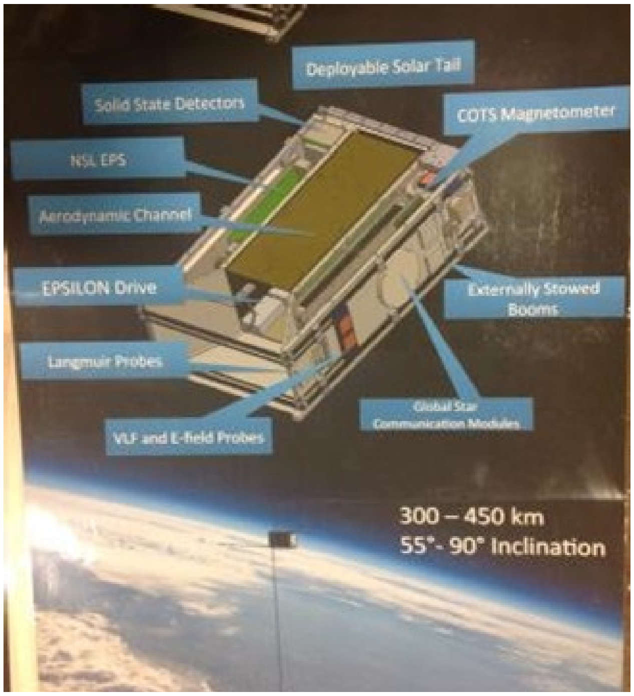

Figure 11. ELEO Sat Concept Design

Taylor University's next student-developed nanosatellite is ELEO-Sat (Figure 11). The primary mission of ELEO-Sat is to explore the 120-350 km region of the ionosphere[7]. The ELEO-Sat mission may be broken down into scientific and technical objectives of 1) developing an open source database of in-situ wave, particle, and plasma ionosphere measurements, and 2) demonstrating new and innovative spacecraft technologies. Key features of the satellite are the science instrument bay, the aerodynamic craft structure, the exterior boom design, the Globalstar communications unit, and a novel in-situ ion engine[7] (Figure 12).

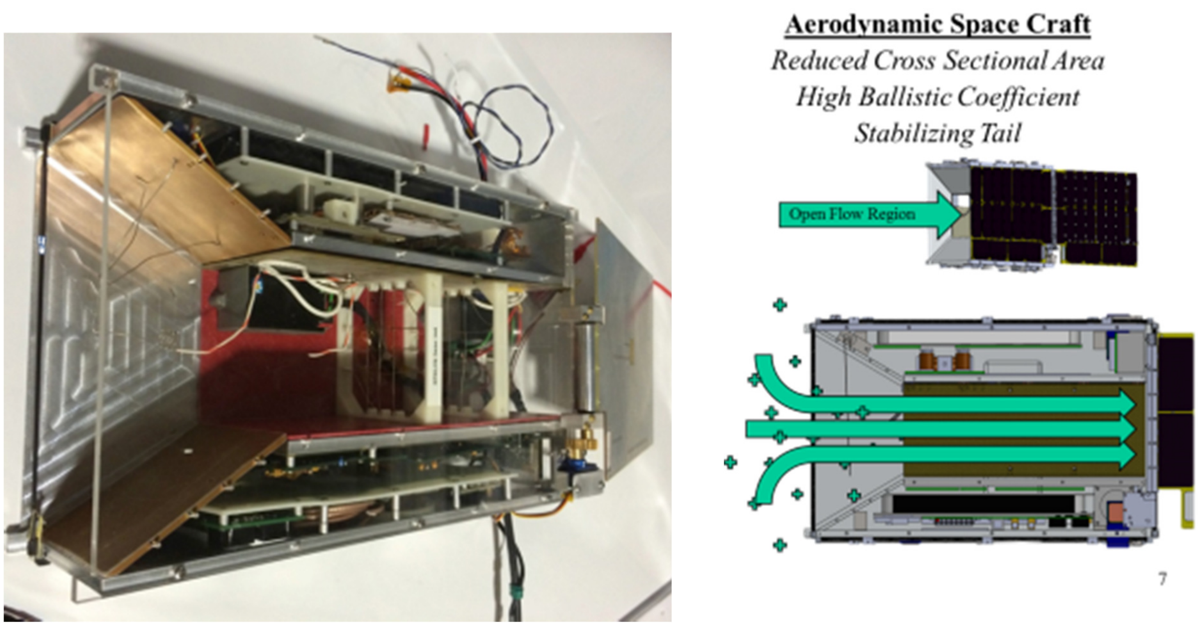

Figure 12. Epsilon Ion Engine Drive and Mechanical Engineering unit.

Monte Carlo Drag Simulation

In order to extend spacecraft lifetime in ELEO orbits, the drag coefficient needs to be understood and reduced. For aerodynamic stabilization, the forces and torques also need to be computed in the different flow regimes, from free molecular flow to hypersonic continuum flow below 120 km. Using millions of Test Particle atoms the complex fluid behavior was investigated to obtain torques and forces on the spacecraft (Figure 13). From these the drag coefficient could be obtained and the stability of aerodynamic pointing quantified (Table 2).

The ELEO-Sat simulation results show that as the cross section is decreased and the ram structure becomes more pointed (streamlined), the drag drops significantly. TSAT, with its flat ram direction shape and full surface area of 100 cm^2, was not very aerodynamic, but still had one of the longest lifetimes of the ELaNa-5 CubeSats.

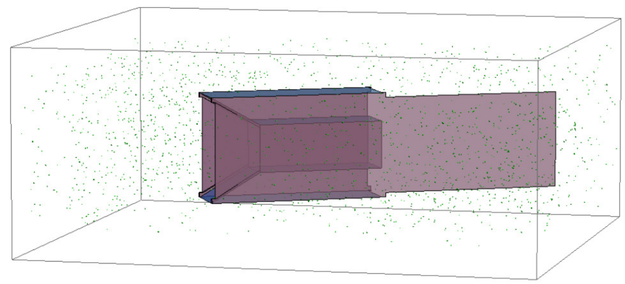

Figure 13. ELEO-Sat TPMC Monte Carlo simulation to compute and compare drag, force, and torques.

Table 2: TPMC of ELEO drag and torques

Yaw Angle (deg)	F_x (N)	F_y (N)	F_z (N)	T_x (m-N)	T_y (m-N)	T_z (m-N)
0	-6.37E-19	-3.12E-18	6.00E-06	6.11E-08	-9.55E-09	2.27E-21
15	9.11E-07	-5.50E-16	1.35E-05	1.24E-07	-1.03E-07	1.09E-08
30	-2.83E-06	-2.67E-14	1.38E-05	1.75E-07	-1.84E-07	5.76E-08
45	-7.66E-06	-6.72E-14	1.76E-05	3.02E-07	-3.85E-07	1.14E-07
60	-1.00E-05	-1.63E-13	2.43E-05	4.52E-07	-5.02E-07	1.27E-07

CONOPS

Concept of Operations (CONOPS, see Figure 14) and Risk Management in UNP are an important part for student planning, understanding the finished product and completing Test Procedures. The AF gave the students a series of eight Expert Area Teleconference (EAT) interactive sessions that were very helpful to the students and faculty.

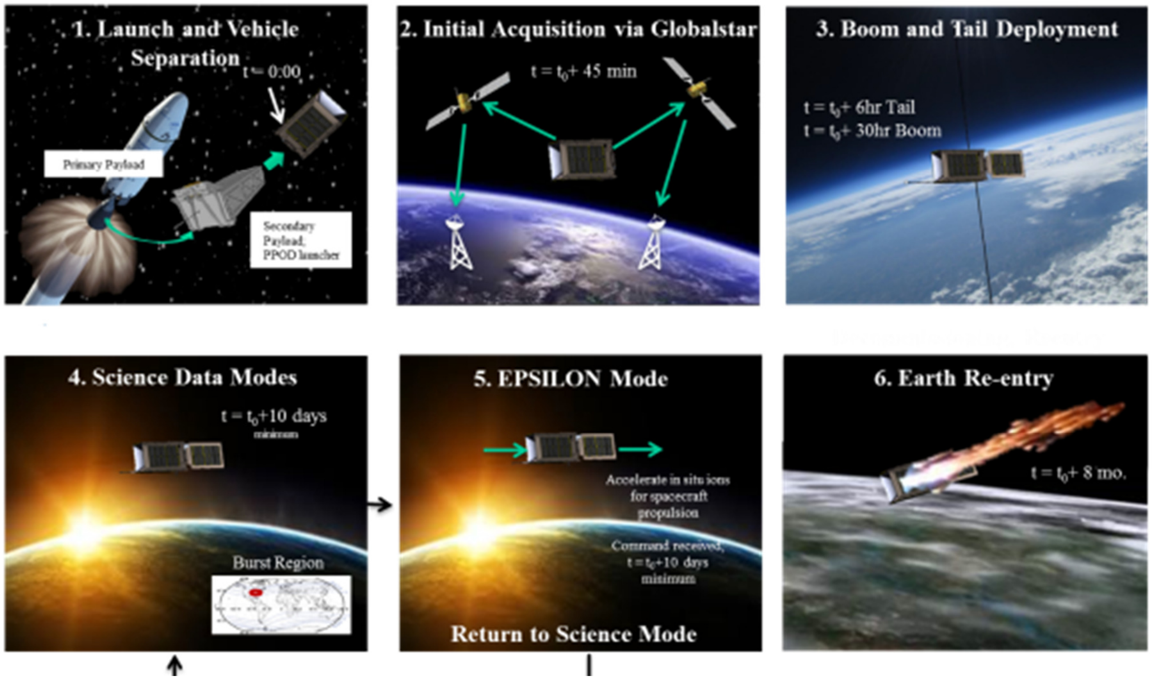

Figure 14. Concept of Operations for ELEO Sat

7.0 Assessments

Assessment data were collected on the Balloon HARP launches from over 1,470 students from a number of universities that were part of our NSF funded CCLI grant. The ElaNa launch student proposal was approved by NASA for the TSAT launch. The students' creativity and craftsmanship were evident from the mission success for a very difficult challenge. The Student ELEO Proposal was in competition with over 25 research universities and was selected as one of the top ten universities. The final competition review placed ELEO-Sat in the top five for a Phase 2 funding including launch costs. The six year ABET review placed the satellite program and its summer internships as one of the key strengths of the department. Students published eight papers in the regional ASEE meeting over the past two years and have received a first place student paper award and a second and third place presentation award. In addition, alumni were interviewed and all of them that responded gave very high marks to the satellite and Big Program approach that they experienced.

HARP Assessment of College Students

A study assessing the impact of high altitude ballooning on 1,470 students from 16 different universities and 51 classes was completed through Taylor University's two NSF grants. The study included students answering a series of self-assessment questions before and after ballooning projects in the classroom. Table 3 below discusses the areas where statistically significant increases in student learning occurred as a result of using ballooning in undergraduate classes.

Table 3: Areas where statistically significant increases occurred in undergraduate courses

Area	Description
Intrinsic Motivation	Motivation in curiosity, challenge, contextualization, challenge, control, and cooperation
Valuing Science	Valuing problem solving, calibration, the scientific method, reproducibility, data analysis, metacognitive planning, monitoring and assessing, teamwork, and meeting deadlines
Application Knowledge	How to use problem solving, prototyping, evaluating, calibrating, and documenting
Metacognitive Processes	Planning, monitoring, and assessing ones thought processes
Cognitive Skills	Application of the following to a complex problem at the appropriate time: problem solving, prototyping, evaluation & calibration, the scientific method, reproducibility, and data analysis
Content Knowledge	Knowledge of the scientific method and high altitude ballooning

Assessment of College Professors/Instructors

Thirty-two professors/instructors at universities using high altitude ballooning responded to a survey assessing how high altitude ballooning has impacted their ability to teach STEM courses. In general, the respondents felt that implementing high altitude ballooning into their courses had a significant impact on their ability to teach. A summary of the results is shown in Table 4.

Table 4 Results from Assessment of College Professors/Instructors

(6-Strongly Agree, 5-Moderately Agree, 4-Mildly Agree, 3-Mildly Disagree, 2-Moderately Disagree, 1- Strongly Disagree)

Statement	**Avg. Rating**
I see the educational potential of high altitude ballooning	**5.8**
High altitude ballooning enhanced my ability to have students apply the concepts that they learned from my classes	**5.1**
High altitude ballooning enhanced my ability to inspire students to be creative with science and technology	**5.2**
High altitude ballooning enhanced my ability to stimulate an interest in students for science using a hands-on project	**5.4**
High altitude ballooning enhanced my ability to engage students in problem solving activities that are challenging	**5.5**
High altitude ballooning enhanced my ability to help students excel beyond what has been done before	**5.1**
High altitude ballooning enhanced my ability to enable students to have ownership in the learning process	**5.3**
High altitude ballooning enhanced my ability to have students learn how to work as a team	**5.5**
High altitude ballooning enhanced my ability to have students see that cooperation is needed in order to be successful	**5.4**
I see the value of ballooning in creating a learning environment where students monitor their thinking in order to accomplish the task	**5.3**

I see the value of ballooning in giving students freedom and control to take ownership of a research project	**5.6**
High altitude ballooning has enhanced my ability to have students select a strategy to accomplish the mission objective	**5.0**
High altitude ballooning has enhanced my ability to have students predict their results	**5.1**
High altitude ballooning has enhanced my ability to have students handle obstacles that are encountered	**5.4**
High altitude ballooning has enhanced my ability to teach students how to complete a specific task within a project timeline	**5.4**
High altitude ballooning has enhanced my ability to have students keep in mind possible obstacles and errors	**5.2**

TSAT and ELEO Satellite Documentation and ASEE Publications

Another assessment marker was the evaluation of all of the documentation (Figure 15) by Engineers at the AF. In addition, the students gave their Critical Design Review (CDR) for TSAT to an engineering review panel at the ITT Aerospace (Exelis) company and were questioned and approved for their work. For ELEO-Sat the AF flew four engineer reviewers to our university for a 12 hr. student design review. In competition the students were commended for their thoughtful work.

Figure 15. Documentation.

The students also worked in four small groups to write four professional engineering papers for the ASEE regional conference. Each student group was assigned a faculty member to help them edit their work. All four ASEE student papers on TSAT were peer reviewed by an ASEE committee and were all accepted for publication and presentation. In addition, each student presented a Poster Document at the regional ASEE meeting in competition with other engineering capstone projects from other schools. Our students received a second and third place award out of the 30 student posters which included many Capstone projects.

In addition, the next year Capstone class wrote four peer reviewed papers on ELEO-Sat for presentation at the Regional ASEE conference at Rose-Hulman Institute of Technology, IN. In this conference our students received first place for their satellite work.

Also included in assessment is individual progress on the hardware subsystems, software architectures, CAD mechanical drawings, thermal and testing methodologies, and overall design process. Project management, Work Breakdown Structure, Bill of Materials, schedules, and overall status were also assessed by faculty members in individual meetings throughout each semester.

The Capstone class faculty assessment was consistent with the student assessment questionnaire. The student assessments to the question "Did the Capstone experience open your eyes and abilities to better implement the full design process and accomplish many of the ABET objectives A through K?", resulted in 86% students with the highest mark ("Strongly Agree") and 14% with a reply "Agree" giving a score of 3.9 out of a 4.0 scale. A student (S1) comment associated with this question is, "I learned tons about timing, prototyping, testing, failure analysis, project management, and much more".

Assessment of the quality of a national level project with documentation and lab work was excellent. This is also similar to what the students reported in the questionnaire assignment. A second question received a 3.7 score, from 71% "Strongly Agree" response and 29% "Agree" response. The question was, "Do you value that TSAT and ELEO-Sat are national level projects with interaction with other universities (ASEE, UNP), students, industry (ITT Aerospace), NASA and the Air Force and undertake important research?" Student comments (S4, S6, and S7) stated the following: "This project, and its level of recognition, means a lot to me. I would not feel I was getting my money's worth in the engineering curriculum if we did not have this sort of project, and I may have considered transferring schools", "This experience has been priceless to put on a resume and learn what industry is like. I hope more students have this opportunity.", and "everyone seemed shocked".

Grading for the capstone course is based on each student's weekly status and spreadsheet reports, the formal design reviews, all formal documentation, the hands-on design and prototyping and testing of their systems, the team effort to integrate their PC boards, SolidWorks mechanical drawings, each student's completion and acceptance of their ASEE papers and Posters, the oral, individual finals taken each semester, each student's detailed Design Notebooks, and a final analysis of each student's weaknesses and strengths. A spreadsheet was made of all their points. Also shown in the table below is the grading rubric, Table 5, for last semester's 3 hour Capstone class.

Table 5: Senior engineering capstone grading rubric

1	Design Notebook and Logbook (Depth and Breadth of project)	**15%**
2	Engineering Analysis, simulations, and ABET i-k proficiency	**15%**
3	ASEE Paper and/or Small Sat Paper/AHAC paper	**10%**
4	Your system maturity, Proto-flight fully working, Flight system	**15%**
5	Understanding, Calibration, test data, and Thermal/Vacuum testing	**10%**
6	Sustainability, ICDs, EDR Material for Summer Handoff	**10%**
7	Overall team work, class participation, field trip, and work ethic	**15%**
8	Your Creativity, Research, Problem Solving, Completeness, Details	**10%**

ABET Six Year Evaluation of Program

During our six year ABET engineering program evaluation in 2013 the evaluation committee identified three Department strengths. The TSAT and ELEO-Sat projects were one of the strengths. The summer practicums for most of our students was another based in part on the AF internship ELEO funding. Summer work for Freshmen and Sophomores advances their overall engineering proficiency and ensures better success in the classroom.

Typical Example Quotes from Alumni Surveys

Graduate A: "*For the past 15 years, the Physics and Engineering department has integrated a rare blend of theoretical rigor and practical application. At Taylor University, I learned 'where there's a will, there's a way.' I have found that this basic outlook on life is a prerequisite to becoming a successful entrepreneur, who must challenge the status quo and beat incumbents on a shoestring budget. In my days at Taylor University (1997 - 2001), we were pushing the limits of undergraduate education in a variety of categories. From space probes under contract to NASA, to building a solar racing car on 5% of the budget of our competitors, to the nanosatellite program, where our design was built around non-radiation hard componentry, my time at Taylor University was saturated with creative, entrepreneurial problem solving opportunity. Directly following graduation from LACU, I teamed up with Dr. Voss (Chair at the time) and student graduate (fellow 2001 Physics graduate) to create a new startup called NanoStar. Our collective goal was to commercialize the nanosatellite technology we built in the lab and deliver a store-and-forward communications system to the World. We pitched this concept to venture capitalists in six cities across the country and learned a great deal about how to design a robust startup in the process. These lessons undergird my current venture, MyFarms, which is going head-to-head with agricultural giant, Monsanto, to apply big data concepts to day-to-day* *farming practices and dramatically increase food production worldwide. My experience at LACU was truly transformational. I learned the core principles of managing science, technology and entrepreneurship; lessons that continue to serve me well each day."*

Graduate B, *"TSAT has played a tremendous role in my career decision and has been a major stepping stone in adjusting to my current job. I am currently doing ECU development in the automotive industry, and working on TSAT gave me the flexibility of learning more about the academic side and the practical side of embedded systems"*

Graduate C: "*My senior project was good preparation for the 'real-world.' The experience of going through the entire design process of developing a scope, working hard to make sure the project is successful, and presenting the final product is similar to what I do now. I think that having the freedom to develop an idea and also to fail is important. I have some specific tasks that I must complete, but a lot of my job requires taking the goals of my department and developing 'projects' to fulfill those high level goals. I do not have a 'professor' or boss telling me everything I need to do. Allowing students to develop their own 'project' as long as it meets the high level requirements of the engineering curriculum is a good way to grow and develop engineers. The science building project that I worked on was not my original project. We had started a different one, and realized it really was not a feasible project midway into fall semester. This was good experience, because sometimes you need to be able to swallow your pride and admit that your original idea was not as good as it initially appeared."* Quotes from alumni reference materials (see References).

8.0 How to implement your own Program

Starting a Balloon program can be a difficult process since there are so many system choices, a myriad of parts (Figure 16), and risks associated with developing a sustainable program. The good news is that there has been much progress in the past few years in miniaturized electronics, communication technology, and groups that can now collaborate and help. For example, many universities are now trained in balloon flight through workshops, a number of new companies have started to help make launching a balloon much easier, more excellent publications are available, and there are good professional and amateur organizations that also help[9]. The Academic High Altitude Balloon

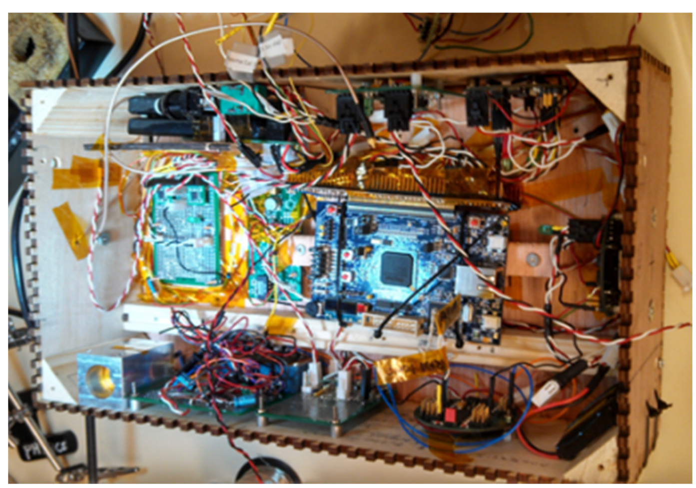

Figure 16. This is a picture of a Flat Sat that was tested in a HARP balloon flight. The launch opportunity allowed students to understand the importance of integration, calibration, cabling and workmanship for a satellite system. Typically it takes three launches with failures for students to learn the design process and have success.

Conference (AHAC) encourages participation in Open Source information to contribute to growth.

Balloon Flight Options and Technology

For those starting high altitude ballooning or wanting to upgrade their portfolio there are a number of technology options. The most complex and demanding part of a balloon system is coming up with a reliable flight processor and communication system that has high performance. These are summarized in the following Table 6. Communication units include 1) using APRS ham radio tracking on the 2m band (whip antenna), 2) using spread spectrum on the commercial International (ISM) band at 900+MHz, 3) using a ground based Globalstar (Figure 17) tracker device called SPOT (slow rates) which can be purchased at many sport and electronics stores (also requires a data plan), and 4) using a high altitude and high data rate Globalstar modem operating near 1.6 GHz and using a 1 inch square patch antenna purchased from NearSpace Launch with HARP Value Added Reseller (VAR) License and FCC license included.

From Table 6 it can also be seen that there are eight basic approaches to design and operation of your system depending on your objectives: 1) Build your own system, 2) buy a full working system, 3) buy a high-data-rate All-in-one flight data and communication system, 4) buy a medium-data-rate All-in-one system, 5) build only your payloads and let a Launch-for-Hire group launch your experiments while you watch live (in person) or watch live on the internet, 6) buy or build a simple tether balloon system for testing experiments and teaching, 7) buy a low cost disposable data and tracking system that you attach your experiments to and watch your launch live while your data streams live on the internet without the need to recover payloads because of difficult terrain, and finally 8) just fly a simple data logger to a SD card with a simple tracking device for chase and recovery.

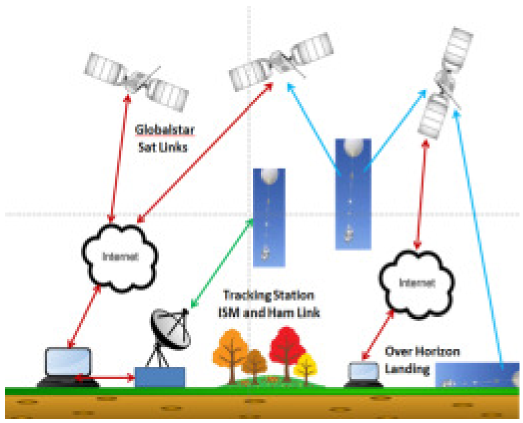

Figure 17. High Altitude balloons are ideal for teaching and testing experiments. With the Globalstar network of satellites many balloons and satellites can be in flight simultaneously so that new constellation measurements can be made and data is stored in a time ordered database.[9]

Table 6 Technology Options for starting a Balloon Program[9]

Approach and Radio	Purchase	Performance	Initial Cost	Risk	Data Rate	Ground Station	Need for Training
1) Build from **Scratch** Ham Radio, ISM, SPOT Tracker	Study, design, develop, build	Team up with experienced group, Workshops, May need Ham License, Custom features	Very High	High	Variable	Yes	High
2) **Full Flight** Turnkey 1W ISM, Zigbee	StratoStar LLC	Real time data, GPS, sensors, Constellations, Service	High	Low	High	Yes	Medium
3) **All-in-one System** Globalstar VAR, ISM, and Zigbee	NearSpace Launch Inc. **Full EyePod**	Real-time data & SD Card, GPS, sensors, tree cut-down, options Constellations, Research Grade	Medium	Low	High <1 s sampling	No	Medium
4) **All-in-one System** SPOT Tracker	High Alt. Res. **Eagle Sky-Probe**	GPS, SD Card, sensors	Low	Low	Medium 10s sampling	No	Medium
5) **Launch for Hire**, Full flight system, sensors, Data Base	NSL & others **Full EyePod**	Globalstar and ISM, Real-time data, common data base, SD card Research Class	Very Low	Very Low	High <1 s sampling	No	Very Low
6) **Tether system** Low power ISM	NSL & others **EyePod-Lite**	Realtime data, SD Card, GPS, <1000ft height, no Chase	Very Low	Very Low	High <1 s sampling	Yes	Low
7) **One-use** (dispose) Globalstar VAR	NearSpace Launch Inc. **EyePod Lite**	No chase cost, GPS, fly over poor recovery terrain (water, trees, etc.) Common data base	Very Low	Very Low	Medium 1- 100s sampling	No	Low
8) **Data Loggers**	**HOBO EyePod-Lite**	Earth and flight support systems, Must add GPS and Radio	Very low	low	High	No	Very Low

9.0 How to implement your own program

The HARP Balloons and Satellite Design projects by the AF University Nanosatellite Program and NASA ELaNa Program allow students the opportunity to develop a project with real-world scientific relevance. Student involvement in satellite design promotes creativity, ingenuity, and the development of vital engineering skills that are applicable to a wide range of engineering disciplines. Student response is very positive: "*The educational value of satellite design in a capstone course cannot be overemphasized*"[7]. The target outcome for investment in challenging educational projects is for undergraduates to be at a master's thesis level when they graduate with many on-job skill sets. With manifold new teaching tools, equipment advances, software analysis tools, search engines, 3-D printers, and better ways of teaching, our expectation should move far beyond conventional engineering BS, FE and ABET teaching outcomes[10].

Acknowledgements:
Many thanks are extended to all of the many students and volunteers who made these advanced projects possible over the years. Special thanks are also given to the Air Force Office of Sponsored Research (AFOSR) through the University Nanosatellite Programs through national competitions and project funding. Thanks are also extended to NASA through the Educational Nanosatellite (ELaNa-5) Program for the launch cost associated with TSAT and also to the Indiana Space Grant Consortium (INSGC) for student scholarships and project support. The National Science Foundation (NSF) also supported through the CCLI program much research and workshops for enhancing High-Altitude Research Platform (HARP) balloon work. Taylor University also contributed space, facilities, and assistance for completing the STEM projects.

10.0 Abbreviation and Acronym List

Table 7: Abbreviation and Acronym List

ADCS	Attitude Determination and Control System
AFRL	Air Force Research Labs
AFOSR	Air Force Office of Scientific Research
Cal Poly	California Polytechnic State University
CDR	Critical Design Review
CDH	Command and Data Handling
DSX	Demonstrations and Science Experiment
EAT	Expert Area Teleconference
EDR	Engineering Design Review
ELEO	Extremely Low Earth Orbit
EMI	Electromagnetic Interference
EPS	Electrical Power System
FAR	Federal Administrative Regulations
FCR	Flight Competition Review
GEARR-Sat	Globalstar Experiment and Risk Reduction Satellite
HARP	High Altitude Research Program
ICD	Interface Control Document
L-C	Likelihood-Consequence
LEO	Low Earth Orbit
LEP	Lightning-induced Electron Precipitation
PDR	Preliminary Design Review
PE	Project Engineer
PM	Project Manager
PoC	Point of Contact
RVM	Requirements Verification Matrix
SHOT	Student Hands On Training (workshop)
SCR	System Concept Review
SRR	System Requirements Review
SSD	Solid State Detector
STEM	Science Technology Engineering and Math
TEST	Thunderstorm Effects in Space and Technology
ThEEF	The Earths Electric Field
TRL	Technical Readiness Level
TSAT	Taylor, Technology, & TEST Satellite
UNP	University Nanosatellite Program
VLF	Very Low Frequency (Radio waves)

References

[1] Friend, R. D. and J. N. Beneat, Development of Aerospace Engineering-Focused Undergraduate Research at a Small University: Accomplishments and Lessons Learned, 120th ASEE Annual Conference & Exposition, Atlanta, GA., Paper ID #6986,, June 23-26, 2013.

[2] Robert D. Eagelken, "Participation of Undergraduates in Engineering Research: Evolving Paradigm over Three Decades of Change," 210 ASEE Annual Conference and Exhibition.

[3] Eric Larson and Agnieszka Miguel, "Performing Engineering Research at Non-PhD Granting Institutions," 2007 ASEE Annual Conference and Exhibition.

[4] Peter Schuster and Charles Birdsong," Research in the Undergraduate Environment," 2006 ASEE Annual Conference and Exhibition.

[5] Robert D. Engelken, "Engineering Research at Predominately Undergraduate Institutions: Strategies and Pitfalls for the New engineering Educator," 1999 ASEE Annual Conference and Exhibition.

[6] Hank Voss and Jeff Dailey, "TSAT Globalstar ELaNa-5 Extremely Low-Earth Orbit (ELEO) Satellite" Small Satellite Conference, Utah, August, 2014, paper SSC14-WK-6.

[7] Joseph Emison, "Satellite Design for Undergraduate Senior Capstone," 2014ASEE Annual Conference and Exposition, Indianapolis June 2014.

[8] Ford-Coulston, Design for Electrical and Computer Engineers: Theory, Concepts, and Practice, McGraw-Hill, 2008.

[9] Hank Voss and Don Takehara, Strengthening Balloon Programs: University and Business Collaborations , Research, Outreach, and Internal Support, 5th Annual Academic High Altitude Balloon Conference (AHAC), South Dakota, 2014.

[10] Hank Voss Bill Chapman, and Scott Moats, Engineering Program Growth with Mesh Network Collaboration , ASEE Annual Conference, Seattle, WA, this proceeding.

Appendix: ENP 492 Capstone I Fall Syllabus

Professors: Dr. Hank Voss[1] and Others
Office: EU-236 /EU212/EU-238/NS208
Office Hours: HV, JD, JG, DT by appointment or regular office hrs posted
E-mail:
Phone:
Cell Phones:
Class Meeting Times: M W F (option) 1:00 p.m. - 1:50 p.m. in NS210; we will also meet, as required, on additional days throughout the week (Lab times TBD on Tuesday and Thursday)
Course Information and Updates: Shared CSE Disk Space or via Email

Textbooks:
1) FE Review Manual, 2nd Ed., Michael Lindeburg, Professional Publications, Belmont, CA, 2006 (You should have this book already….for review of principles we plan to use)
2) Need a 3 ring binder notebook and the sprial bound brown logbook from the bookstore.
3) Free, FE Supplied – Reference Handbook published by the National Council of Examines for Engineering and Surveying (http://www.ncees.org/exams/study_materials/fe_handbook/)
4) Free, Matlab, Solid-Works, OrCAD, Cadence, Eagle, STK, and other Software access
5) Free, Copied Educational Materials from Ford/Coulstgon and Dieter on Design Process (copy approval update with McGraw-Hill PRIMIS)
6) Free, Proposals, design methods, and satellite requirement handouts (For your notebook)
Optional Textbook (Available in Capstone Library for reference)
7) Engineer-In-Training Reference Manual and Solution Manual (SI units), 8th edition, by M.R. Lindeburg, Professional Publications, Inc., Belmont, CA 94002, 1992.
8) Ford-Coulston, Design for Electrical and Computer Engineers: Theory, Concepts, and Practice, McGraw-Hill, 2008.
9) Dieter: Engineering Design: A Materials Processing Approach, 3rd edition, McGraw-Hill, 2005

Professional Organization Memberships: Because we have reduced our textbook requirements we expect students to join 2-3 professional societies in their field of interest. For a modest student membership fee (~$20) you receive many full membership benefits: Journal, conferences, Web Site, downloads, collaboration,… Membership is also good for your resume, job interviews, lifelong learning, and how to interact with professional groups. Some professional groups that you might want to look at that I have memberships in include:
IEEE, AIAA, ASEE, ASCE, AEI, AGU, ASA, ASP, AAAS, AAPT, USGBC, and others

Course Description:
For the 2013-2014 academic year we will be working on the ELEO Multi Cube SAT that was approved by AF for a 2-3yr competition for Spaceflight. Our interdisciplinary team consists of three Engineering Physics (ENP) seniors, three Computer Engineering (CSE) seniors and one Environmental Engineer (ENE) senior.

Based on the student Capstone survey last May you selected the ELEO project as your first choice. The Design Process and engineering tools that we use in ELEO are general and are the same ones that we used developing the Solar Car, the new science building, well logging tools, and many other student projects in the past. The NASA TSAT ride and integration is valued at about $1M so we want to make this opportunity successful. This Capstone project should add much to your professional qualifications and resume.
Professor Dailey and I with five students just returned from the Small Sat conference in Utah and have the latest "Know-How". UNP AF Office and Professor Dailey will be the main spacecraft customers for our UNP Capstone project.

Course Goals:
The overall goal of Capstone 2013 includes: 1) to provide a challenging new project to "put it all together" at a system level, 2) be inspired, creative and independent while successfully working in teams, 3) Understand the advanced Design Process and fulfill the ABET Capstone requirements, 4) learn and build on skills related to hardware, machine shop, electronics lab work, software and computer modeling, management/team work, proposal writing, requirement creation, design reviews, documentation, communication, manufacture, testing, calibration, system integration, and many more real world experiences, 5) Visit ITT aerospace and work with other professionals, 6) understand multidisciplinary project requirements, 7)connect science and engineering with implementation, 8) better understand how to be Christ Centered and a servant to bring light into darkness, and 9) other achievable goals. We can only accomplish our goals within the time, dollar, schedule, and ability constraints that we have. However, if we work as a team we can greatly improve our learning efficiency while having fun and meeting the Capstone requirements.

Faculty/Staff Teaching Plan:
Dr. Voss is the class lead professor and is responsible for the many aspects of the class: Lectures, documentation, UNP Principal Investigator, design mentoring, course planning with student team, NASA two proposals (POP1 and 2), ASEE papers and Small Sat papers.
Dr. Chapman is the CSE faculty point person and is responsible for some lecture materials, the ABET pre/posttest and assessments, documentation and CSE/ENP poster materials, and mentoring focus on the CSE students and their documentation, proposals, and ASEE and papers and posters.
Prof. Dailey is the Capstone customer along with the UNP program office. He will mentor student s in the design efforts, help secure parts and equipment, and review all documentation.

Definition of Design:
1) ABET Definition for Engineering Design: *Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.*
2) Dym, Agogino, Eris, and Leifier Definition : *Design is a systemic, Intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.*

Other Peer Reviewed Design Process Groupings: Note that definitions of Engineering Design Groupings abound and you should be aware of some of these…

1. Dieter/others 2005-Four C's: **Creativity, Complexity, Choice/Compromise, Communication**
2. Dieter 2005- The Design Process is like the Scientific Method: **State of Art** (Existing Knowledge), **Identification of Need** (Scientific Curiosity), **Conceptualization** (Hypothesis), **Feasibility Analysis** (Logical Analysis), **Production (**Proof)
3. MIT 2004- **Conceive, Design, Implement, Operate** (CDIO Initiative)
4. Dym et al. 2005**,- Scope, Generate, Evaluate, and Realize** Ideas
5. Eide et al. 2012,- **Define** the problem, **Acquire** and assemble the pertinent data, **Identify** solutions and constraints, **Develop** alternative solutions, **Select** a solution based on analysis of alternatives, and **communicate** the results.

Furthermore, In the Design Process there are many feedback loops between the steps to modify the problem, requirements, scope, models and designs based on analysis and evaluation.

ABET Class Outcomes: ENP492 Senior Capstone I –….Later we will help you connect these in a weighted matrix to the unique Design Process. We plan to touch on all these outcomes at some level (see typical contact hour breakdown in spreadsheet) so you need to be competent in all of them.

a. Be able to design a system, component, or process to meet desired needs within realistic constraints such as functionality, performance, economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

b. Be able to develop realistic design criteria from an open – ended problem statement.

c. Be able to plan, implement and follow a formal design process to completion including building and testing.

d. Be able to make informed decisions through – out the design process.

e. Be able to document the entire design process in written documentation in such a way that the thought process, design options, analysis, decisions, final detailed design, implementation and testing are easily understood by superiors and engineers only vaguely familiar with the project.

f. Be able to use their science, mathematics, and engineering knowledge and skills to solve problems and make informed decisions.

g. Be able to develop a mathematical model, use that model to make predictions and verify those predictions with known experimental results or simplified theoretical models.

h. Be able to work on a team to complete a problem.

i. Be able to communicate effectively with team members and superiors in formal and informal situations.

j. Be able to consider the positive and negative impacts of their engineering decisions on society.

Content

The major learning objective in this course is real world engineering design. The ability to design is both an art (like sculpture) and a science. Previously you have had a chance to learn about different elements of the design process in courses like Principles of Engineering (high-altitude balloon payload HARP projects); you have had a chance to work on many other different projects and labs. This class is designed to demonstrate to you and future employers that you're ready to develop and implement substantial engineering solutions.

Schedule

The Senior Capstone design project is a *significant year-long* project that necessitates careful planning and execution. Failure to do so will result in failure to meet the project objectives. In order to increase the likelihood of success, a number of milestones have been listed which your team will need to meet. Each milestone includes one or more deliverables, as noted in the following table:

	Major Milestones			**Due**
1	POP1	Project Big Picture Overview Pre/Proposal	Team	Sept. 21 (POP1 Pre), Sept. 25 (Final)
2	POP 2	NASA Microgravity and ELaNa ComSat	Team	Oct. 21
3	PSS	Project Scope Statement	Each	Sept. 23 Good Draft
4	PRD	Product Requirements Document	Each	Sept. 23 Good Draft
5	TDD	Team Definition Document	Team	Sept. 23 Good Draft
6	SOW	Statement of Work/Work Breakdown	Each	Sept. 23 Good Draft
7	CR1-3	Two-three Concept Reviews	Each	
8	NAS	NASA Cubesat Requirement Documents	Team	October
9	PSD	Product Specification Document	Each	October
10	IDR	Intermediate Design Document & Review	Team	Mid October, 2013
11	FINAL	Final BOM, Schedule, PCB review	Each	December, Final
12	CDR	Critical Design Document & Review	Team	J-term/Spring Semester
13	PPD	Pre-Procurement Review	Each	J-term/Spring Semester
14	PRR	Proto-Qualification Review	Each	J-term/Spring Semester
15	ETV	Testing Environmental Review	Each	J-term/Spring Semester
16	CTR	Calibration and Test Review	Each	J-term/Spring Semester
17	CSR	Completion and Sustainability Review	Team	J-term/Spring Semester

Proposed Team Organization: Based on the discussions and presentations last May we have tentatively placed each of you in the area that you selected or expressed most interest in. Changes can still be made and everyone will need to interact because of the very integrated satellite instrument suite that you will be developing. Although you have individual responsibility you still are required to understand and assist each other on the overall ELEO-Sat design. This organizational format is very similar to how industry or professional work is conducted (except you will be getting paid much better).

Student 1 : Project Engineer
Student 2: Project Manager, Education and Public Outreach, Langmuir probe
Student 3: Spacecraft Lead Mechanical Engineer
Student 4: Payload mechanical systems and boom design
Student 5: Payload processor, Actel Fusion FPGA, GSE interface
Student 6: Solid State Spectrometer and Power system
Student 7: Thermal Design and sensors, Solar Array power system

Student 8: Bus 8620 processor system, Com unit command and TM interface, Attitude sensors
Student 9: Spacecraft Power Board, Battery, switching, power processor, safety, GSE power
Student 10: RPA and Epsilon Drive
Student 11: Computer and math model of spacecraft drag forces, Attitude and epsilon propulsion
Student 12: GSE portion or Web site
Student 13: E-Field and VLF receiver
Student 14: Ground Support software and display software

Work Expectations: Although the Fall Capstone class is a 2hr class we expect that you will need to put five additional hours a week working on your ELEO related responsibilities and about 3 additional hours per week working on your review of the Design Process materials and building up your expertise in hardware and software skills. In addition, as a general requirement for our Capstone class you will need to keep a spreadsheet of all of your time spent on the project

Planned Outside Activities: (Interdisciplinary)
Financial, Legal, Government, Grant procedures (Ms. Sue Gavin, Sponsored Research Office)
IDR Intermediate Design Review at ITT Aerospace in For Wayne
Facilities visit field trip to ITT Aerospace
Papers and presentations at ASEE, Small Sat, AHAC, and others

Shared File Space Documentation:
Location: engineering_capstone

Facilities Plan: We plan to meet in NS 210 General Lab room, NS303 New Sensor Lab, NS214 Conference room, the EU000 Machine Shop in lower level, NS014 Clean rooms near the loading dock area, and the 3-D Printing Project Room.

Notebook, Logbook, and Documentation: For your professional growth it is very important you keep a well-organized and neat notebook of all your Capstone activities. This is also very important for ABET and for our self-study to see the depth and breadth of your understanding wrt to the design process, your overall capacities, and other creative abilities you are gifted with. We may include some of these for the ABET review team to review as well. Book library will be located in the Sensor Lab.