AC 2009-768: SPACE-SYSTEMS ENGINEEERING: A NASA-SPONSORED APPROACH FOR AEROSPACE UNDERGRADUATES

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Space Systems Engineering
A NASA-Sponsored Approach for Aerospace Undergraduates

Introduction and Motivation:

Since 2004 the National Aeronautics and Space Administration (NASA) has pursued a vision for space exploration. After decades of space shuttle missions close to Earth, NASA was charged to send astronauts back to the moon and eventually to Mars and beyond. NASA's Exploration Systems Mission Directorate (ESMD) maintains the responsibility for building a new generation of crewed spacecraft. The suite of new space vehicles and its launch system, dubbed *Constellation*, are scheduled to carry astronauts back to the moon by 2020. Prior to lunar missions, the vehicles will achieve operational capability via trips to the International Space Station.

In order to fulfill the scope of this exploration vision, NASA will need to design, build and operate numerous systems – from lunar landers to robotic rovers to space suits. So what does this new focus for human spaceflight mean for the future NASA workforce? If you ask this question of the NASA Administrator, or the ESMD Associate Administrator, or the Constellation Program Manager, you will most likely receive the same answer – systems engineers.

Recognizing this future need for systems engineers in the aerospace community, an aerospace engineering department at a major US university, The University of Texas at Austin, partnered with NASA's ESMD to sponsor the development of a systems engineering curriculum. The curriculum includes an undergraduate course focusing on systems engineering for aerospace engineers with an accompanying laboratory course that introduces students to the spacecraft subsystems and methods for assessing their performance. This course and lab combination is intended as a prerequisite to the senior-level capstone spacecraft /mission design course and as a training ground for students involved in UT's student-built nanosatellite program. The systems engineering course was piloted to a select 21 aerospace engineering students in their junior or senior year in spring 2008. The intent from the NASA perspective is to use the host university as a proving ground for the systems engineering course materials. The piloted materials are then distributed to interested universities, particularly those participating in NASA's National Space Grant and Fellowship Program. The initial effort at exporting the pilot to interested academics occurred in fall 2008 at a workshop at the Johnson Space Center. Additional efforts will continue at subsequent venues and through specific website access.

The current paper deals with the scope of the undergraduate systems engineering course and the success of the pilot offering. The paper also addresses the companion subsystem lab. In addition, the formal aerospace engineering curriculum changes at the host university and how the new course set integrates with the current capstone design course are discussed. Special note will be made of curriculum modifications designed to provide self-selected students with hands-on experience in systems engineering.

The Pilot Undergraduate Systems Engineering Course:

At the undergraduate level, the goal is to teach the fundamentals of systems engineering such that future practicing engineers are familiar with the concepts and processes to be exercised further in the work environment. As stated in the first lecture: the course is not trying to make everyone who takes the course a systems engineer, but trying to give aerospace engineering students a systems perspective. The success of that goal is reflected in numerous quotes from the students in the pilot class, such as

- *"It was a 'big picture' view of what we may be involved in as engineers of the future."*
- *"Taking this course makes an engineer realize there is much more to engineering than designing a given component to a set specification. This course really teaches all the factors that go into producing a viable space system, and some tools to achieve that end."*
- *"Everything we've learned will be applied to our jobs, regardless of the engineering position we will have."*

The first offering of the Systems Engineering (SE) Course was in the spring of 2008 in the Aerospace Engineering Department at The University of Texas at Austin. The twenty-one students in their junior or senior year with a grade point average of 3.0 or better were hand-selected to participate in the pilot offering. Some of the pilot students had completed the capstone design class in the previous semester, and often used that experience in class discussions. Many had applicable co-op work experience and even waiting job offers as systems engineers with numerous leading aerospace companies. In addition, one of the students was the lead systems engineer for the in-house satellite build project, called Texas2Step, sponsored by the Air Force Research Laboratory (AFRL). An added bonus to the pilot class was the participation of the capstone design professor, as well as a graduate teaching assistant with a Master's degree in aerospace engineering from Georgia Tech with an emphasis on System Design and Optimization. The participation of all these many perspectives provided continuous improvement on the course content and delivery. {Note that current offerings of the SE Course are available to *all* students in the space track of the aerospace engineering degree program.}

The SE Course content is based on numerous systems engineering handbooks and primers from NASA[1] and the Department of Defense[2] organizations. The content also reflects material from professional training courses offered at NASA and through organizations such as Project Performance International. The lectures also rely on the NASA experience base and documents to provide examples for systems engineering topics. In particular the James Webb Space Telescope (JWST) project and the Constellation program are used as sources for example documentation on topics such as requirements, technology development, and project life cycle. The SE Course does not require a particular systems engineering textbook, although many are available to supplement the course if desired[3, 4].

To calibrate the topics to be addressed by the SE Course, various offerings at other universities were surveyed. These systems engineering courses were all at the graduate level at universities such as Georgia Tech, Caltech, University of Colorado, Southern Methodist University, and the Air Force Institute of Technology. The review of other systems engineering offerings showed a variety of approaches from generic to theoretical to aerospace-specific. Given that NASA was sponsoring the development of this course, the resulting SE Course focuses on civilian space approaches and resources. Furthermore, the SE Course is specifically geared to what the undergraduate aerospace engineering student needs to be prepared for the senior capstone design course.

Given the basis of the course and NASA's involvement in its development, the material is presented from an aerospace perspective with an emphasis on what is required to put a space system together. The SE Course approach tends toward the practical rather than the theoretical with an emphasis on concrete examples. The SE Course also exposes students to various practical tools that are helpful in performing real-life systems engineering tasks, such as the analytical hierarchy process, the Taguchi method, failure modes effects analysis, and cost modeling with Monte Carlo simulation. In addition, the SE Course requires students to read associated technical articles and current-event articles related to systems engineering. The lectures include "pause and learn opportunities" which refers to class time for discussion of readings with specific learning points to be made. Example articles include the following,

- Jansma, P. A., Derro, M., "If You Want Good Systems Engineers, Sometimes You Have to Grow Your Own," IEEE Aerospace Conference, March 2007.
- Griffin, M., "System Engineering and the Two Cultures of Engineering," Boeing Lecture, Purdue University, March 2007.
- Taubman, P., "Failure to Launch: In Death of Spy Satellite Program, Lofty Plans and Unrealistic Bids," The New York Times, November 11, 2007.
- Wesson, R., Porter, D., "The Cassini Resource Exchange," NASA ASK Magazine, Fall 2007.

The undergraduate course focuses on a combination of systems engineering topics and design methodology. Many of these topics are to be exercised in the senior capstone design course, such as requirements writing, concept of operations, design margins, and risk analysis. The space systems engineering technical content is divided into 24 different topic areas that are presented during the course lecture periods. The order of these topics follows, to some extent, the system life cycle of development, with system formulation topics at the beginning and system implementation topics later. The 24 topic areas include:

1. What is systems engineering?
2. Teamwork
3. Project life cycle
4. Mission scope and concept of operations
5. System architecture
6. System hierarchy and work breakdown structure
7. Analytical Hierarchy Process
8. Requirements
9. Functional analysis
10. System Synthesis
11. Design fundamentals
12. System interfaces
13. Margins and contingency
14. Technical performance measures
15. Cost analysis
16. Risk analysis
17. Technology readiness levels
18. Trade studies

19. System reliability
20. Validation and verification
21. Technical reviews
22. Schedule development
23. Systems engineering and project management roles and responsibilities
24. Engineering ethics

The course is structured in modules, such that a particular topic module can be pulled for inclusion in another class, thus allowing an easier opportunity for export. Furthermore, the modular structure allows for reordering of the 24 topics per the instructor's preference. Given this approach, modules can also be added or deleted based on topic interest. In fact, there are a number of topics worthy of inclusion in future versions of this course, including software systems engineering, human factors, design for supportability and maintainability, and six-sigma quality methodology. In addition to lecture modules, class time is also devoted to invited guest speakers, watching relevant videos and introducing ethics and professional leadership concepts.

The SE Course uses a variety of student assignments, both group and individual. The group assignments are intended to prepare the students for the teaming aspect of the capstone design course. Example group assignments include assessing the results from a real trade study performed by NASA, and developing the scope and concept of operations for a current aerospace mission in development. Group assignments also offer the students an opportunity to present their work to their peers. The individual assignments address problem solving and programming skills as well as a required writing component. For a semester-long project, students are asked to write about the systems engineering learning concepts based on reading a particular NASA mishap investigation report, i.e. lessons learned through failure. For the pilot offering, students selected an apropos book to discuss its relevancy to systems engineering learning. Sample books from the reading list included:

- Petroski, H., *Success Through Failure: the Paradox of Design*, Princeton University Press, New Jersey, 2006.
- Weinberg, G., *An Introduction to General Systems Thinking*, Dorset House Publishing, New York, 2001.
- Womack, J. P., Jones, D. T., Roos, D., *The Machine that Changed the World: the Story of Lean Production*, Free Press, New York, 1990.
- Columbia Accident Investigation Board, Report Volume 1, Government Printing Office, Washington, DC, 2003.

The SE course format is a biweekly 1-1/2 hour lecture worth 3 semester credit hours. The SE Course contributes to the following ABET EC 2000 Criterion 3 outcomes. These outcomes are validated by mapping specific assignments and exam questions to the specified outcomes. The UT offering of the SE Course has yet to be reviewed during an ABET accreditation. The outcomes addressed by the SE course are noted in Table 1. In particular, outcomes (a) and (e) are achieved by solving reliability problems and failure modes effects analysis, as well as performing Monte Carlo simulations on cost estimations. Outcome (c) is not directly addressed, but the SE course does introduce students to the various tools and techniques of the design process that are applied in the follow-on capstone design course.

Outcome		Outcome	
a. An ability to apply knowledge of mathematics, science, and engineering	√	g. An ability to communicate effectively	√
b. An ability to design and conduct experiments, as well as to analyze and interpret data		h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.	
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.		i. A recognition of the need for and an ability to engage in life-long learning	
d. An ability to function on multi-disciplinary teams	√	j. A knowledge of contemporary issues	√
e. An ability to identify, formulate, and solve engineering problems	√	k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	√
f. An understanding of professional and ethical responsibility	√		

Table 1. ABET Outcomes for Systems Engineering Course

Outcome (d) is achieved by tailoring specific assignments for group participation. Outcome (f) is addressed by a class lecture and accompanying assignment dedicated to ethics, in particular using case studies developed by the Texas Space Grant Consortium. Since this course is designed to meet a university requirement for a writing component, many of the assignments and the final project involve written communication, thus addressing outcome (g).

A case could be made that the course also addresses outcome (h), as the systems approach forces students to think about costs, environmental impacts, etc. However, this outcome would be difficult to defend for all students, so it is not claimed. To achieve outcome (j), the course relies heavily on current NASA missions and associated issues. Most of the systems engineering examples are derived from missions currently in development or recently launched. Finally, outcome (k) is achieved by teaching students various systems engineering tools, such as analytical hierarchy process, Taguchi method, and cost estimation models.

Finally, student feedback was provided regarding the pilot offering through two course evaluations, an official university survey and an unofficial instructor-developed survey. The surveys were completed by twenty-one students. The official survey uses a five-point scale, with five meaning a most favorable response and one meaning a least favorable response. These responses are reflected in Table 2 below in the rows *above* the shaded row. The unofficial survey uses a similar scoring method: (1) strongly disagree, (2) disagree, (3) no opinion/neutral, (4) agree, and (5) strongly agree. These responses are reflected in the table below in the rows *below* the shaded row. It should be noted that the high scores might be attributed to highly motivated students who participated in the pilot course. Future offerings, with a broader spectrum of students, may not demonstrate such positive results.

Official Survey Questions:	
Course well-organized	4.7
Communicated information effectively	4.6
Showed interest in student progress	4.8
Student freedom of expression	4.9
Course of value to date	4.9
Overall course rating	4.7
Unofficial Survey Questions:	
Use of class interaction and Q&A with the professor was at the right level	4.3
Class video and guest lecturer enhanced learning and reinforced topics	3.8
Use of lecture briefing notes and not a textbook was an adequate delivery of the material	4.3
Additional materials (such as JWST examples or outside readings) enhanced lecture notes	4.5
Learned new concepts and methods with assignments	4.6

Table 2. Systems Engineering Course Evaluation Survey Results

The Subsystem Performance Lab:

The subsystem performance lab is offered as a one-hour laboratory course required in the space flight technical area. The goal of this course is to provide students with a basic understanding of the major spacecraft subsystems and how they interact with each other. Particular focus is given to teaching students how to combine and apply the analysis tools they have learned in other classes to estimate the performance of spacecraft subsystems. Throughout the course, careful consideration is given to how subsystems interact and how to approach the design of each subsystem with the objectives of the entire spacecraft in mind.

This course is typically taken concurrently with the newly developed SE course described above. In this laboratory course, students learn the software tools and spacecraft modeling techniques required to implement concepts presented in the SE course. Without the laboratory course, students in the SE course would be unable to exercise the techniques they are learning on a spacecraft concept of their own design. Alternatively, without the SE course, the students in the laboratory course would lack the background and big-picture perspective required to fully appreciate the relationship between the customer's needs, mission constraints, and the different subsystems.

The laboratory course format is a weekly1-1/2 hour lecture and 1-1/2 hour guided computer lab. The lectures focus on providing students with the details of specific subsystems and are presented in a PowerPoint format. From a pedagogical standpoint, the instructor was originally reluctant to present material primarily through PowerPoint lectures. There was a concern of the pace at which material may be presented and if the pre-prepared materials would reduce the students' active engagement in the lecture (i.e. would the students be more likely to "zone-out" if they knew that the complete set of PowerPoint lecture materials was available for download online?). However, given that a large percentage of the lecture material consists of diagrams, historical examples, pictures, and tables, it made more sense to present the materials in PowerPoint than as hand-written notes. When asked if the PowerPoint based lectures were preferable to hand-written notes, 89.6% of the students "agreed" or "strongly agreed."

The guided computer lab period is used to teach students about the various software tools necessary to model the subsystems they learned about in lecture. This portion of the class takes place in a computer lab where each student has a desktop computer with all of the required software installed. It is important for each student to have a computer with the appropriate software during the lab period so that they can follow along with the instructor as software features are demonstrated. In a typical lab, the first 30 minutes is used to learn a new piece of software or a new modeling technique. The remaining time is used for the students to practice using the software tools they just learned to assess the performance of a particular spacecraft subsystem. The course instructor and teaching assistant are available throughout the lab period to give guidance and answer questions as students learn how to use new software.

The technical material for the laboratory course was developed using information from numerous texts in addition to the personal work and research experience of the instructor. Some of the primary texts used include the following:

- Wertz, J.R., and Larson, W.J., *Space Mission Analysis and Design, 3rd Ed*, Kluwer Academic Publishers, Boston, 1999.
- Larson, W.J. and Pranke, L.K., *Human Spaceflight Mission Analysis and Design*, McGraw-Hill, New York, 1999.
- Pisacane, V.L., *Fundamentals of Space Systems, Second Edition*, Oxford University Press, 2005.
- Griffin, M.D., and French, J.R., *Space Vehicle Design, Second Edition*, AIAA Education Series, Reston, VA, 2004.
- Humble, R.W., Henry, G.N., and Larson, W.J., *Space Propulsion Analysis and Design*, McGraw-Hill, New York, 1995.
- Pisacane, V.L., *The Space Environment and its Effects on Space Systems*, AIAA Education Series, Reston, VA, 2008.
- Kanacke, T.W., *Parachute Recovery Systems Design Manual*, NWC TP 6575, Para Publishing, 1992.
- Heineman, W., "Fundamental Techniques of Weight Estimating and Forecasting for Advanced Manned Spacecraft and Space Stations," NASA-TN-D-6349, May 1971.
- Isakowitz, S.J., Hopkins, J.B., and Hopkins, J.P., *International Reference Guide to Space Launch Systems, 4th ed.*, American Institute of Aeronautics and Astronautics, Reston, VA, 2004.

The first text, *Space Mission Analysis and Design* (sometimes called *SMAD*) by Wertz and Larson, is a required text for the laboratory course. Based on an anonymous mid-semester survey, approximately 51.7% of the students found SMAD to be a useful course text and 27.6% of the students were doing the optional readings in SMAD.

The spacecraft subsystem technical content is divided into 12 different topic areas that are presented during the weekly lecture periods. The order of these topics was chosen to allow grouping of similar topics into single lab assignments and to allow the early presentation of material required for the lab final project. The 12 topic areas are:

1. Introduction to Modeling & Simulation: *good modeling techniques, N^2 diagrams (sometimes called Design Structure Matrices), fixed point iteration*
2. Introduction to Spacecraft Subsystems: *overview of subsystems, contingency and margin, ideal rocket equation, mass fractions*
3. Space Environment Modeling: *planetary atmospheres, micrometeoroids and orbital debris, solar radiation pressure, radiation environment, thermal environment*
4. Launch Vehicle Selection: *available launch vehicles, launch sites, launch windows, secondary payloads, payload-orbit plots*
5. Atmospheric Entry and the Thermal Protection System (TPS): *equations of motion for a ballistic entry, Allen-Eggers analytic solution for ballistic entry, heating environment, common TPS materials, TPS sizing*
6. Propulsion Subsystem: *propellant selection, solid and liquid propulsion systems, propellant tank sizing, pressurant system sizing*
7. Attitude Determination and Control Subsystem (ADCS): *review of attitude determination sensors, review of attitude control methods*
8. Communications Subsystem: *antennas, link budget equation, link margin, modulation*
9. Command and Data Handling (C&DH) Subsystem: *C&DH architectures, data buses, types of memory, processors, radiation hardening*
10. Power Subsystem: *power budget, power profile, solar array performance, battery performance, fuel cells, RTGs*
11. Structure and Thermal Control System (TCS): *common spacecraft materials, spacecraft energy balance, passive and active TCS components*
12. Parachutes and Landing Systems: *parts of a parachute, types of parachutes, types of landing systems, calculating landing loads*

As a laboratory course, a strong emphasis is placed on teaching software tools as well as modeling and simulation techniques. Current software packages that are taught in the course include MATLAB, Microsoft Excel with VisualBasic, and @Risk. Throughout the course, students will develop a library of functions and files in these software packages that will enable them to quickly perform conceptual spacecraft design tasks.

MATLAB is used for complicated models that require logic, loops, or integration. Students are taught good MATLAB modeling practices and are required to submit their code along with their assignments. During various labs, students will develop portable MATLAB functions to perform various space environment or spacecraft performance computational tasks.

Microsoft Excel is used to develop simple spacecraft subsystem sizing models and dynamically track spacecraft mass and power budgets. Students are introduced to basic Excel functionality, including:

- cell naming, good modeling practices, and creating dynamic Excel models
- using the iterative calculation option to close designs with circular references
- targeting a solution using *Goal Seek* and the *Solver* add-in

Beyond the basic functionality, students also learn to incorporate VisualBasic Macros to automate tedious processes and enable finer detail in trade studies. Finally, the Excel add-in

@Risk, developed by Palisade Corporation, is used to teach students to use Monte Carlo analyses in spacecraft design and performance assessment. Students learn how to perform Monte Carlo analyses and interpret the results through outputs such as probability density functions (PDFs), cumulative distribution functions (CDFs or "s-curves"), and tornado plots.

Grades are determined by frequent lab assignments, quizzes, and a final project. There are five laboratory assignments and quizzes are given weekly at the beginning of each lab period. The quizzes are short closed-book multiple choice assignments intended to encourage students to review lecture material prior to coming to lab. The final project is an in-depth trade study between two subsystems with competing interests. The project is intended to give students the opportunity to exercise their knowledge of subsystem performance modeling and trade studies on a realistic problem. To make sure that each student considers both sides of the trade study, the project is completed on an individual basis. Due to the large scope of the final project, which includes a formal written report, students are typically given about six weeks to complete the assignment. Further, each individual student is allowed to choose the trade study they wish to perform from a set of preselected topics. Each option represents a different trade study that needs to be performed for a common mission. During the Fall 2008 semester, for example, the final project was performing a trade study on an orbiter-lander mission to Mars (similar to the Viking mission). Within the context of this common mission, students were able to select between three possible final project topics:

- Topic 1: Launch vehicle, kick stages, and orbiter propulsion subsystem
- Topic 2: Orbiter propulsion subsystem and lander entry, descent, and landing (EDL) and Thermal Protection Subsystem (TPS)
- Topic 3: Orbiter power subsystem and orbiter communication subsystem

Allowing the students the flexibility to choose from a list of topics lets them to delve deeper into the specific subsystems that interest them most. Further, it helps highlight that there are multiple important trade studies that must be performed for every mission. This connection was made more concrete by having students from each topic group discuss their results with the rest of the class on the last day of the semester.

The Host University's Undergraduate Aerospace Engineering Program:
The undergraduate degree program in aerospace engineering at the University of Texas at Austin was modified extensively for the 2008-2010 catalog. Students in the program choose from one of two technical areas, atmospheric flight and space flight. Prior to the catalog modifications, each technical area contained seven semester hours of coursework. This was increased to thirteen hours in each technical area after the catalog changes. The systems engineering course and the subsystem performance lab are now prerequisites for the capstone design course in the space flight technical area. Students in the atmospheric flight technical area are not currently required to take the SE course.

All aerospace engineering students (students in both technical areas) at UT Austin take a one course introduction to orbital and attitude dynamics. The course is 2/3 orbital mechanics and 1/3 three dimensional rigid body dynamics. The students in the space flight technical area then must take the following 13 semester-hours of courses:

- Applied orbital mechanics (3 semester-hours)
- Attitude dynamics (3 semester-hours)
- Systems Engineering (3 semester-hours, described above)
- Subsystem Performance Lab (1 semester-hour, described above)
- Capstone spacecraft/mission design course (3 semester-hours, discussed below)

Under the revised curriculum, students are exposed to topics in spacecraft design from four different perspectives. The SE Course provides students with a big picture perspective and equips them with the systems engineering tools to intelligently approach complex space systems. The subsystem performance lab gives students the analysis and simulation tools necessary to create an original and technically justifiable spacecraft concept of their own design. The spacecraft/mission design course allows students to apply what they learned in the SE Course and the subsystem performance lab on an end-to-end conceptual design of a spacecraft mission in a team setting. Finally, multiple 1-hour elective courses offer hands-on experience with UT's student-built nanosatellite program to students who want to apply the skills they learned in the classroom to real aerospace hardware. All of these courses together provide the student with a well-rounded educational experience in spacecraft design.

Effects of the Systems Engineering Course / Subsystem Performance Lab:

The 2008-2009 catalog became effective at the beginning of the Fall 2008 semester and the transition to the new catalog is expected to take about one academic year to complete. During this time, course accommodations will be made for students possibly taking courses out of sequence or students planning to graduate under the old catalog guidelines (which they are allowed by law to do).

The first offering of the Subsystem Performance Lab was in the Fall 2008 semester. Both the SE Course and the capstone design course were also offered during this semester. As of Fall 2008, most students in the capstone course did not have credit for the Systems Engineering Course and many were taking it simultaneously. Also, many students were concurrently taking the Subsystem Performance Lab course.

There were four students in the Fall 2008 capstone design course who had credit for the pilot SE Course during the previous spring. About half of the 28 students in this design class were concurrently taking the SE Course and the Subsystem Performance Lab. The class was divided into four seven-student design teams, each with one of the students who had credit for the systems engineering course as its systems engineer. Each team organized itself with a project manager, a chief engineer, and a systems engineer, just as discussed in the systems engineering course.

The overall quality of the designs produced during the Fall 2008 was better than that of earlier semesters. They wrote and refined requirements in a much more organized and mature manner. They developed and revised the scopes of their projects and were very aware of the influence of their concepts of operations on their designs. The teams were also much more aware of the importance of costs in their designs. Overall, the exposure of part of the students on each team to systems engineering concepts helped the student to produce better designs. Near the end of the semester, it became apparent that the Subsystem Performance Lab was also having a major impact on the designs produced by the teams. Their subsystems descriptions were much more detailed than in earlier semesters and their mass, power, and volume tables were much more complete.

The Spring 2009 semester has begun, and the SE Course, the Subsystem Performance Lab, and the capstone spacecraft/mission design course are again being taught. There are 28 students in the capstone design course; 18 of them have completed the SE Course and 9 are taking it concurrently. The remaining one student has elected to graduate under the old catalog in which the SE Course is not required. Of the 28 students in the capstone design course, 13 received credit for the Subsystems Performance Lab in Fall 2008 and 11 are currently enrolled in the lab. This leaves 4 students in the capstone design course who will have had no classroom exposure to the topics in the new Subsystems Performance Lab by the end of the semester. We expect the catalog transition to be essentially complete by the start of the Fall 2009 semester.

The addition of the Systems Engineering course and the Subsystems Performance Lab as prerequisites for the spacecraft/mission capstone design course has provided the opportunity to reorganize the topics in the course and to change emphasis. The changes in the course will be described in terms of the course sequence itself.

The course begins with an introduction to the design process and a short teaming exercise. Candidate design topics are presented and students begin the process of forming teams around some of the candidate topics. There are six to eight students per team. After teams have formed, teams are asked to write need statements and then develop a project Scope and Concept of Operations (ConOps). The fact that the SE Course discussed mission scoping and ConOps in detail has resulted in a major improvement in the practicality and detail of the Scope and ConOps presented.

The SE Course stresses the need for a formal three-person team management structure. Consequently, we now require that each team identify a team manager, a chief engineer, and a team systems engineer. Each team is required to write a technical proposal and an accompanying management proposal as the next step in the course. Each person in the three-person team management structure is required to describe how he or she plans to carry out the responsibilities of the position in the management proposal. This forces the team leaders to think about and plan to execute their management functions.

Systems Hierarchy and Work Breakdown Structures are also covered in the SE Course. These items have become a required part of each project proposal. Further, teams in the capstone course are required to begin the process of developing requirements for their project soon after the projects are chosen and are required to modify requirements as necessary throughout the design process. The stress on requirements in the SE course has resulted in the development of much better requirement statements by the student teams. Trade trees are also discussed in the SE Course and students learn to do trade studies in the Subsystem Performance Lab using various tools for comparison of design candidates. During the Fall 2008, students used these tools and were much better at defending their design choices than in earlier semesters.

During the course, the teams are asked to make a number of oral presentations. They present their project scope and concept of operations, their requirements, a mid-term presentation of their overall projects, the results of their trade studies, their mass, volume, and power estimates at mid-term and then again as part of the final report, and their final report briefings. They do oral updates of requirements, mass, power, and volume as needed.

The SE Course includes information on cost estimation. The teams are asked to provide two cost estimates. The first is an estimate of the "cost" of their own work during the semester as a design team. The second is an estimate of the cost of implementing their design. The information from the systems course is of most use for the second required cost estimate.

Overall, the placement of the SE Course and the Subsystem Performance Lab as prerequisites for the capstone spacecraft/mission design course is producing students who are much better prepared for work in industry and/or government. Validation of this claim comes from three of the pilot students who interned at NASA's Johnson Space Center in systems engineering assignments. All three of their NASA mentors were impressed with the level of systems knowledge and application on the job. Since this systems curriculum at UT is relatively new, further validation will come with time. The quality of the designs produced is higher and the reports are more complete and more like those produced in industry. The changes made in the space flight technical area of the curriculum are producing a major improvement in the quality of our graduates.

Hands-on Student Experiences:

For at least the past ten years, students in aerospace engineering at UT Austin have voluntarily participated in externally sponsored learning activities for no degree credit. This participation has become more organized in recent years. The increasing number and quality of such activities (AIAA Design-Build-Fly, AIAA Design Competitions, UAV projects, USAF Nanosat Program, etc.) has resulted in a much larger segment of the department's student population becoming involved. During the recent catalog revision, it was recognized that these activities often had substantial educational and motivational benefit and that even more students might become involved if we found a way to grant academic credit for such activities when appropriate. The curriculum revisions for the 2008-2010 catalog include the introduction of six one-hour laboratories that can be taken (one laboratory hour per semester) to provide credit for students who are participating in satellite / UAV / etc., hands-on design and building projects. Students can elect to take zero to six of these credits, and the credits can be added together to count for one or both of their required three semester credit hour technical elective courses. These one hour labs are a modification of a course sequence developed by Dr. Mark Maughmer of The Pennsylvania State University. Dr. Maughmer was a visiting professor at UT Austin in 2005-2006 and was a major participant in our curriculum redesign activities.

The influence of the Systems Engineering course is also being felt at the graduate level and in the student hands-on projects. Two students from the pilot SE course, now both graduate students, have assumed leadership roles in two separate satellite design and build projects. Each has assumed the dual roles of project manager and systems engineer for his respective satellite project. In these roles, they also serve as mentors for the undergraduates who are taking the one-hour hands-on project labs. We are interested in seeing what effect this mentorship and early exposure to systems concepts will have on future student performance in the SE course and the Subsystem Performance Lab.

Sharing of Materials:

Following the pilot offering, a review and enhancement of the materials was performed by a faculty member from the aerospace engineering department of the University of Colorado-Boulder. In addition, changes were made to the materials based on an extensive evaluation by the pilot students. The revised course modules were distributed as part of a NASA outreach plan to institutions in the NASA Space Grant system. The workshop in fall 2008 enabled a discussion on NASA's need for future systems engineers and the many opportunities to introduce the topic to undergraduates — from the pilot course materials to NASA internships to NASA systems engineering paper competitions. The workshop was attended by faculty from over 30 national universities. The workshop focused on discussing the SE course content and delivery as well as the UT Aerospace Engineering Department perspective. In addition, two panels were arranged. One panel discussed the faculty perspective on teaching systems engineering, with participation from University of Colorado-Boulder, Georgia Institute of Technology, Purdue University, and Steven's Institute. The second panel highlighted three of the pilot students who also participated in the summer internships. Their NASA mentors provided endorsement for their ability to apply their SE Course learning to actual systems engineering assignments related to the Orion spacecraft development. The immediate success of the workshop is reflected in the comments below from participating universities.

- Purdue University: "Thanks for your heroic effort and dedication to finally getting this workshop done. I should let you know that there are discussions underway here at Purdue about an SE program, and I've already used presentations from last week in a class and with a colleague involved in the discussion of the SE program. How's that for rapid turnaround?"
- University of Kentucky: "Thank you for all of your good communication and organization of the workshop. I appreciated learning what others were teaching - all of the similarities and also the differences. I'll be sure to give you feedback on my use of any of these materials. I discussed the workshop with my students on Monday, with excerpts from the Thursday morning presentations to spark discussion."
- University of North Carolina-Charlotte: "I taught a class this morning on Systems Engineering and used the materials from the NASA Systems Engineering Workshop. The DVD presentation by Gentry Lee (2005) and the PowerPoint notes, #2 were used and were well received! I even had several people come up to me saying they wanted to be Systems Engineers."
- University of Alabama-Birmingham: "You are realizing our goals…and have done so in an exemplary way. That's what blows me away about how much you have accomplished, and the resources that you have made available to the rest of us. Peers at my workshop table from other institutions remarked at how atypical it is to find this sort of generous collaboration."

The sharing mechanism continues through a systems engineering website hosted by the National Space Grant Foundation (http://www.spacegrant.org/). The website will provide access to curriculum material updates as well as new resources in the NASA community, including space-related case studies. The website will also host the presentations from the 2008 workshop as well as a video of the event. The plan is for the systems engineering website to be available by the summer of 2009.

Value to NASA:

The long-range plans associated with human space exploration will require a pipeline of systems engineers for NASA and its contractors. The introduction of systems engineering concepts and practice in an undergraduate aerospace curriculum enables the fresh-out engineer to be more effective in the workforce. The benefits of this program extend beyond just graduates from the institution where the materials were first introduced, but help numerous graduates from other institutions that adopt the systems engineering curriculum. Although it takes years of experience and exposure to space missions and the relevant disciplines to truly be a competent systems engineer, being aware of the discipline at the start in one's career can only benefit the aerospace workforce in general. As the most recent NASA Administrator, Michael Griffin, stated in a speech to engineering educators:

"System engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, and many, many more disciplines are weighted and considered and balanced, one against another, to produce a coherent whole that is not dominated by the view from the perspective of a single discipline. System engineering is about tradeoffs and compromises, about generalists rather than specialists.

…

Educators are far less certain how to teach "generalship" than we are of how to teach the laws of thermodynamics. And yet it is clear that an understanding of the broad issues, the big picture, is so much more influential in determining the ultimate success or failure of an enterprise than is the mastery of any given technical detail. The understanding of the organizational and technical interactions in our systems, emphatically including the human beings who are a part of them, is the present-day frontier of both engineering education and practice."[5]

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3. Blanchard, B.S., and Fabrycky, W.J., *Systems Engineering and Analysis, Fourth Edition*, Prentice Hall, 2006.

4. Kossiakoff, A., and Sweet, W.N., *Systems Engineering Principles and Practice*, John Wiley & Sons, 2003.

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NASA Systems Engineering Handbook. NASA STI Program â€¦ in Profile. Since its founding, the National Aeronautics and Space Administration (NASA) has been dedicated to the ad-vancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this impor-tant role. The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, orga-nizes, provides for archiving, and disseminates NASAâ€™s STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its publ Aerospace Engineering Commonsâ„¢. Open Access. Powered by Scholars. Published by Universities.Â®. Search Aerospace Engineering.Â Aerospace Engineering. An Electromagnetic Railgun (EMRG) was designed, built, and tested, capable of firing a projectile a 1 gram projectile at 650 m/s muzzle velocity. The EMRG utilizes an injector, a high voltage power supply, a capacitor bank, inductors and rails.Â Mechanical Engineering Undergraduate Honors Theses. ARKSAT-1 is a nanosatellite developed at the University of Arkansas as part of NASAâ€™s CubeSat Launch Initiative (CSLI). The goal of ARKSAT-1 is to utilize an LED emitter paired with a ground-based tracking system to perform measurements of the composition of the atmosphere using spectroscopy. Space Transport and Engineering Methods - Wikibooks , 2017 Space systems engineering is a worthy field of study within the larger context of all sciences and engineering. This book is an introduction to both the historical design challenges of transport and space hardware design, and new engineering methods. (4539 views). Fundamentals of Aerospace Engineering by Manuel Soler - Create Space , 2014 This book covers an undergraduate, introductory course to aeronautical engineering and aims at combining theory and practice to provide a comprehensive, thorough introduction to the fascinating, yet c The National Aeronautics and Space Administration was founded in 1958 as a response to the Cold War. In 1969, Apollo 11, the first manned space mission to the moon took place. It saw three astronauts enter orbit around the Moon, with two, Neil Armstrong and Buzz Aldrin, visiting the lunar surface.Â A Ball Aerospace engineer performs final checks before the spacecraft is shipped to NASA's Kennedy Space Center in Florida for launch processing. An important innovation came on January 30, 1970, when the Boeing 747 made its first commercial flight from New York to London. This aircraft made history and became known as the "Jumbo Jet" or "Whale"[12] due to its ability to hold up to 480 passengers.[13].

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