ENGINEERING 100: AN INTRODUCTION TO ENGINEERING SYSTEMS AT THE US AIR FORCE ACADEMY

Lynnane E. George and Robert B. Brown
Department of Astronautics
US Air Force Academy

Abstract

Engineering 100 is a required course for all students at the US Air Force Academy (USAFA). It takes an innovative approach to first-year engineering education by introducing engineering in the context of the design process. Students are organized into teams and are given assignments geared towards hands-on exposure to five engineering disciplines: astronautical, aeronautical, mechanical, electrical, and civil. The final project requires them to design, construct, and launch a rocket-powered boost glider. The boost glider is produced in a five-stage process which balances textbook and laboratory work, with each stage focused on one of the engineering disciplines. Faculty from each of the five engineering departments at USAFA teach the course, reinforcing the multidisciplinary nature of engineering projects.

At the beginning of the semester, the students are introduced to the systems engineering design process and computational tools to help them explore design alternatives and communicate their design solutions. They learn practical methods for designing a complicated system and establishing criteria by which they can make good, logical decisions. The students not only learn engineering, they also learn teamwork, peer leadership, and time/resource management.

The format of the course follows five blocks of material, each focused on a particular engineering area. Each block is followed by an exercise that gives the students an opportunity to test their new-found knowledge, such as building and launching a rocket or glider, building a launch platform, and learning about the basics of radio controlled glider operation. For the capstone project, the students must put everything together by building a boost glider which launches vertically like a rocket, transitions into glide phase, and then flies by radio control to a target 100 meters away. The students must combine the knowledge they gained throughout the semester to build the boost glider as well as design and integrate functioning electrical wiring. For the final three days of the course, the classroom experience is moved to an outdoor location where the students actually fly their boost gliders. The factor that makes Engineering 100 unique is its hands-on application of the five engineering disciplines at the freshman level.

This paper will provide an overview of the Engineering 100 curriculum, the systems engineering design process taught, and a description of the capstone boost glider project. Since this is now the seventh year the course has been offered, course development, feedback, and improvements to the course will also be discussed. The detail in this paper is intended to provide enough information for others to use a similar model for course development.

Introduction

The purpose of Engineering 100 is twofold. The primary purpose is to introduce first-year students to the USAFA engineering disciplines in the context of the systems engineering design process. Students integrate these disciplines using a semester-long boost glider design project. They must use aeronautical engineering to design the glider, astronautical engineering to launch it, electrical engineering to power and control it during flight, mechanical engineering to ensure a sturdy design, and civil engineering to build a launch pad.[1]

The secondary purpose is to motivate more students to develop an interest in engineering. In a 2003 interview, then Secretary of the Air Force Dr. James Roche said, "The U.S. Air Force desperately needs airmen and a vibrant civilian workforce with science, technology, and systems-engineering skills[2]." The students learn about the systems engineering design process early in the course and must integrate processes and tools from each engineering discipline to build their final project. There is also a focus on exposing the freshmen to science and technology in the real world. Students are given briefings by personnel serving in engineering jobs. In addition, this year space wing officers from nearby Schriever Air Force Base visited Engineering 100 to observe and provide feedback to the students on their designs. The intent is that this interaction and the motivational aspects of the course will help encourage more students to major in one of USAFA's engineering majors.

The course objectives for Engineering 100 are for students to:

1. … know the steps of the engineering method.
2. … apply the systems engineering approach to meet a given customer need.
3. … use computer software to solve problems, communicate solutions, and optimize designs.
4. … clearly communicate the results of their design experience.
5. … understand the importance of engineering to the Air Force.
6. … have fun!

Student performance is assessed using multiple methods. The total grade consists of on-line quizzes (30%), one individual homework for each block (11%), ten group projects which include hands-on testing, reports, and briefings (49%), and instructor and peer evaluations (10%). An Engineering 100 web site was developed in-house which includes links to all assigned readings, videos, handouts, homeworks and quizzes for each lesson. On-line quizzes are due before class and test knowledge and comprehension of each lesson's material. Immediate feedback is provided to students and instructors so class time can be focused on areas of concern. Given this pre-class preparation, instructors can concentrate on demonstrating concepts and active engagement in class with hands-on demonstrations versus a more standard lecture format.

Engineering 100 Course Development

The founding committee of Engineering 100 was formed in 2001 and consisted of senior representatives from each of USAFA's five engineering departments. The team wanted to avoid just giving an overview of each engineering discipline, so they decided to develop the course around a single integrating project that provided the motivation for each activity. Another focus was active learning, so many problem-based, group-study, and hands-on activities were developed. In the words of Benjamin Franklin, "Tell me, and I'll listen. Show me and I'll understand. Involve me and I'll learn." It was decided this would not just be a "paper design" course – students would design, build, and test their projects[1].

In addition, there are no subject matter experts who come in to teach individual blocks – a single instructor teaches all topics. This may seem formidable at first, but the material is fairly basic and instructors must be relatively senior, experienced personnel. Instructors have many years of experience working on interdisciplinary engineering projects in their career fields and most hold PhDs. The benefits of this arrangement are tremendous. Teaching tips are shared between departments; for example, in preparation for each block of material, all instructors are "taught" the material by an instructor from that department. This also creates a real-life teamwork learning experience for the students when, for example, they see a civil engineering instructor teaching the basics of electrical engineering.

Capstone Project

Each Engineering 100 section consists of 25 – 30 students who are broken into five teams. The capstone project requires each group to simulate the configuration, launch facilities, and mission profile of a Hypersonic Orbital Global Strike System (HOGSS) weapons system. This fast, long-range strike vehicle will provide the nation with the capability to project military power quickly anywhere in the world. The HOGGS strike aircraft should be able to launch and boost to sub-orbital velocity to arrive over a target anywhere on the earth and is designed to land horizontally on a conventional 10,000 ft runway. This defining concept adds real-world applicability and motivation to the project.

However, building something of this magnitude would be far too difficult and costly. The students' boost glider is a sub-scale model of the HOGGS strike aircraft. It is expected to demonstrate the boost, ballistic, glide, and landing phases of the full-scale vehicle. Boost gliders must be shaped to have a design Mach number of at least 3.0, launch to a minimum altitude of 50 meters and after rocket motor burnout transition into a controlled, sustained glide. Students remotely control their boost gliders to ensure a soft horizontal landing on a target landing area 130 meters from the launch site.[3] An example of a student-designed boost glider modeled in Autodesk Inventor Professional can be seen in Figure 1.

In order to accomplish a task of this magnitude, the course is broken down into smaller projects. Each engineering discipline is introduced in a block of material so the students can understand piece-by-piece what they need to complete the overall project. Typically, there are several lessons taught in the classroom to introduce an engineering topic and an individual homework due about half-way through the block. Each block ends with a hands-on project such as building and launching a rocket (astronautics block) or building and flying a glider (aeronautics block).

A special offering of Engineering 100 was provided in Fall 2003 for 52 sophomores that were not scheduled their freshman year. Although the sections performed adequately, they were difficult to motivate. Most had already declared their major, nullifying one of the course objectives.[4] It has since been decided that all students will take the course their freshman year.

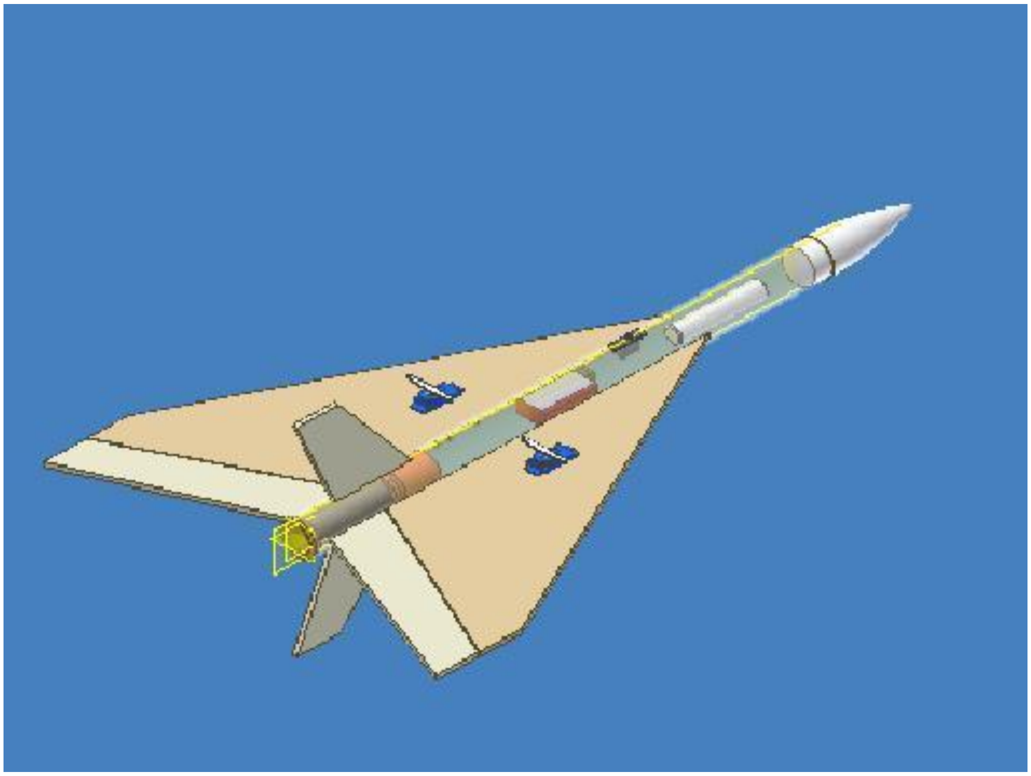

Figure 1
Inventor Drawing of Boost Glider

Curriculum and Systems Engineering Process

The first three lessons consist mostly of introductory material – teamwork development, an introduction to the systems engineering design process, and an introduction to the boost glider project. The design method taught consists of five steps:

1. Define the problem
2. Collect data
3. Create solutions
4. Perform analyses
5. Make decisions

Later in the semester, once the students begin the building and testing phases of their project, an additional three steps are introduced:

6. Construction notes
7. Testing and evaluation
8. Conclusions/Lessons Learned

The students are expected to use this design method for each project completed throughout the semester and to follow this format for written reports.

The first block – astronautics – begins with five lessons in the classroom. These include lessons on Newton's laws, moments and free body diagrams, ballistics, rocket propulsion, and rocket stability. An individual homework is also due where the students complete a basic Inventor tutorial to become familiar with the program they will use later to model their group's boost glider. A rocket design spreadsheet is introduced and an in-class exercise is conducted to give the students practice using it. The spreadsheet predicts rocket stability (static martin), altitude, and range given dimensions for the rocket, an input launch angle, and the properties of the model rocket engines used. This block ends with two lessons in the lab, where each group builds their rocket based on their spreadsheet, and one lesson where they launch their rocket outdoors to test its effectiveness in hitting a target at a specified distance. Each block ends with a formal report due on the result of the group's design and testing.

The next block – aeronautics – begins with three classroom lessons. These include an introduction to aircraft components and nomenclature, stability and control, and hypersonics (although their boost glider is subsonic, they are modeling it after the HOGGS). There is also a spreadsheet provided that predicts aerodynamic forces such as lift and drag and provides stability information such as yaw and static margins given dimensions of their selected glider. This block ends with two lessons in the lab where each group builds their glider, followed by one day for test launches from a balcony to hit a target.

The third block – engineering mechanics – begins with five lessons in the classroom. Basic principles of stress and strength and terms such as factor of safety are introduced. Two lessons are spent learning how to best design their boost glider mechanisms and components, such as the servo rods and control surfaces, to avoid breakage, bending, or buckling. There are several hands-on activities during this block. For example half a lesson is spent in the engineering mechanics lab performing tensile tests to create stress/strain curves and one lesson the students build a balsa wood bridge and test it to failure. This block is also followed by two lessons in the lab to build their launch platform, a bridge-like structure built from balsa wood that will support a 12-pound launch pad and their boost glider on launch day. A spreadsheet is provided that predicts the expected deflection for their platform and the maximum launch wind that it can withstand. The students begin their initial boost glider design during this block, so the spreadsheet also predicts factors of safety for their design.

The next block – electrical engineering – begins with three lessons in the classroom. These include an introduction to power systems, the basics of radio control, and a lesson on digital logic. This block is also followed by a group project to design and build a digital logic circuit. The circuit accepts as inputs variables such as wind velocity, gust velocity, and range safety and outputs a go/no-go decision for launch.

The final block – civil engineering and boost glider construction – begins with one lesson in the classroom to introduce siting and noise issues. Half a lesson is spent in the Civil Engineering lab learning to mix and pour concrete supports for their launch platforms (Figure 2). The remainder of this block is conducted in the lab to allow time to finish building and testing of boost gliders. A boost glider design spreadsheet is provided, which is essentially a combination of the rocket and glider spreadsheets used earlier in the semester.

The last three lessons of the semester are boost glider test flight days. Testing days are always a fun and exciting part of the course, but thoroughness and safety are first and foremost. Before launching or testing rockets, gliders, or boost gliders, students must analyze and assess the operational risk, complete an operational risk management worksheet, and brief their classmates on safety procedures to follow in the field. Each student is assigned a launch day responsibility, which consists of recorder, launch control officer (hooks up logic circuit, counts down, pushes launch button), pilot, crew chief, time keeper/observer, and range safety officer. This ensures everyone knows what they are responsible for and no important tasks get overlooked.

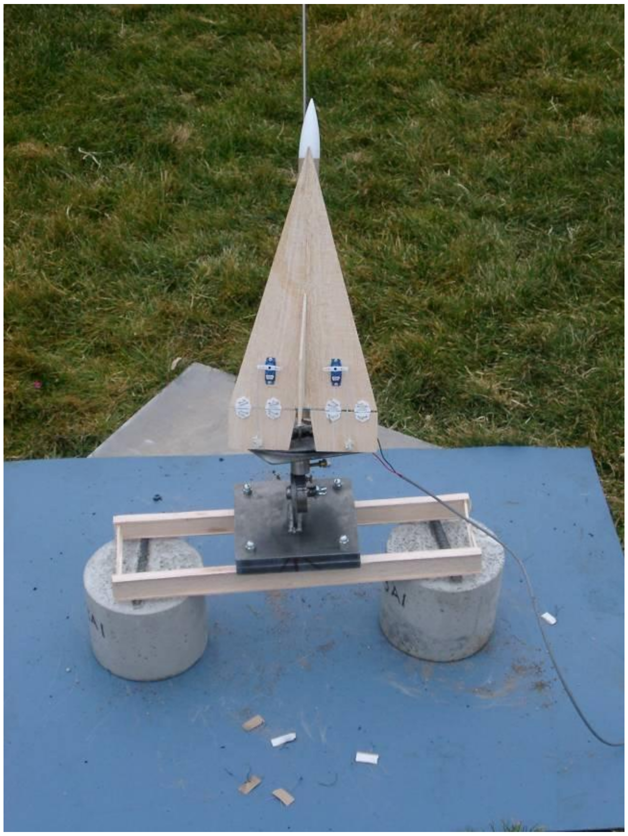

Figure 2
Boost Glider ready for launch on concrete supports and launch platform

Freshman Engineering Design Courses

A survey of freshman engineering courses at some other colleges and universities revealed that many do have an introductory course in engineering at the freshman level. However, most are targeted towards students who have already decided on an engineering major. Many provide a good exposure via seminars, tours, and/or labs, to several different engineering disciplines. Engineering 100 is unique in that every student, regardless of what major they are interested in, is required to take it. This puts the students in groups where they must work with others who have a variety of backgrounds and interests, as they will continue to do during their student years and while serving in the Air Force.

There are some great examples of multidisciplinary freshman-level engineering courses. The University of Florida converted their introduction to engineering course in the 1990s from a lecture-based offering to a laboratory format. It rotates student groups through laboratories in eleven undergraduate engineering disciplines to better inform students about the nature of engineering and its specific disciplines and improve the retention of students in engineering. It also takes a small group, active learning approach. Results have been positive and retention is also reported to have improved since its introduction.[5] North Carolina State University offers a freshman Introduction to Engineering Problem Solving Course for first year engineering students. This course introduces multidisciplinary problem solving, utilizing teams, cooperative learning, and problem solving. Team projects include designing a home insulation system, chemical reactor, cellular telephone support system, catapult and web page; and building a battery operated device and a balsa wood bridge.[6] Virginia Tech offers an Engineering Laboratory for first year engineering students. Their premise is that "first year students today tend to come in with good "virtual" skills, but with limited tinkering and hands-on experiences with devices and consumer products." It focuses on a hands-on approach including experience with assembling and disassembling a camera, bicycle, computer hard disks, and computers.[7] Although students who take these courses are already interested in engineering, they provide excellent examples of the trend towards incorporating more interdisciplinary projects into introductory engineering courses.

Military academies have programs in place to increase interest in engineering, although these programs target potential students before they ever get there. The US Coast Guard Academy offers a Minority Introduction to Engineering, which is a free one-week summer program, designed for minority high school students who are interested in the Coast Guard and Engineering. During this program, students are given team projects to design and build truss bridges, program robots, and design cardboard boats.[8] West Point sponsors a bridge design contest targeted toward students age 16 – 19 to help motivate them towards a career in engineering.[9] USAFA also offers a summer seminar program for high school students to gain exposure to the military environment and the many academic disciplines offered. Although students can select seminars from any of the academic disciplines, each engineering department offers at least one or two seminars each summer, which are always well-attended.

One similar course offered by the University of New Haven is a first-year engineering course taken by both engineering and non-engineering majors. It is a project-based Introduction to Engineering Course and part of their core curriculum. Students work in a multi-disciplinary team-based setting and are given projects that showcase the primary engineering disciplines. Projects require computer simulation, optimization, and construction of physical models. Typical projects include the design, construction and testing of bridges, development of characteristic curves for fuel cell systems, building and programming robots to maneuver through an obstacle course, and solid 3-D modeling of puzzle cubes. This course has been offered since 2002 and has been successful. Although not required for non-engineering majors, enrollment of non-engineers has reportedly increased since the pilot offering in 2002 and has been shown to provide a valuable learning experience for both engineers and non-engineers.[10]

Cost

One question that is often asked is how much it costs to start-up and run a course like Engineering 100. As far as start-up costs, very little special equipment is required. Most equipment needed can be found in most labs – small hand tools such as Exacto knives, rulers, glue guns, and protractors. The two wind tunnels are really the only specialized equipment used. Testing projects (rockets, gliders, and then finally boost gliders) in the wind tunnels verifies stability and controllability before the projects are launched. Although they are not necessary for a successful course, their addition has improved the performance of the projects in the field. One wind tunnel is used to test pitch stability and one tests the ability of the boost glider to perform in roll mode. Each wind tunnel was built in-house, cost about $400 in materials, and took one lab technician about two weeks to build. By far, the most expensive part of the project involves the electronic components – servos, batteries, transmitters, and receivers used to guide the boost gliders (Figure 3). However, even with ~650 students per semester, only ten transmitters are required because there are at most ten groups launching boost gliders at the same time.

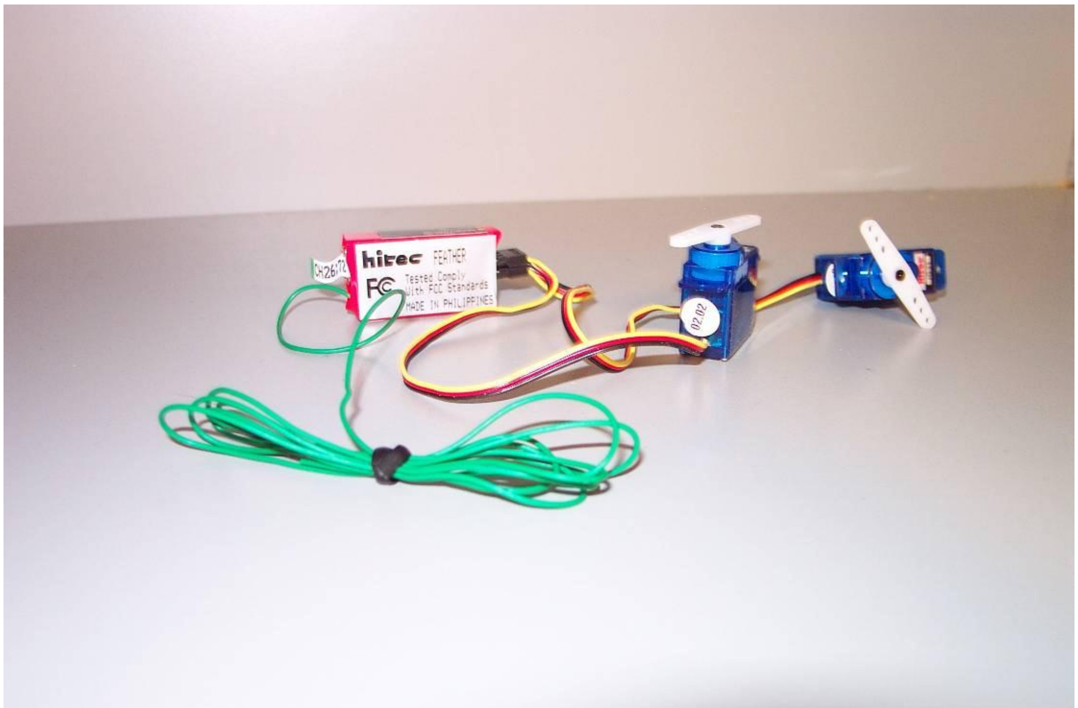

Figure 3
Boost Glider Electronics

Initial reusable item costs were approximately $40,000, while replacement/new parts cost about $25,000 per year for an annual enrollment of approximately 1300 students.[1] Each boost glider costs $90.25 in material (balsa wood, body tube, electronic components, etc); if all electronic parts survive, $73 can be recovered and reused for a total cost of $17.25 per boost glider. A small fee of $20 for per student could be charged to cover the recurring costs. One additional way to reduce costs, which USAFA will be implementing in AY 2008-2009, is a no-electronics boost glider – i.e. with only the rocket and glider phases. Estimated costs are approximately $5,000 per year, or approximately $3.85 per student

Feedback

As part of course assessment and curriculum development, USAFA conducts end-of-course surveys to gather feedback on all courses and instructors. Overall, feedback from the students on Engineering 100 is positive, with 70% of student responses in Spring 2006 rating the course as good or better than other USAFA courses and 76% ranking the relevance and usefulness of the course as good or better. In comparison with other engineering courses, the course-related questions were all ranked higher, which included questions on course organization, degree to which the course met stated objectives, and intellectual challenge. In Fall 2005, the course was ranked higher in comparison with other courses in nearly every area, including course organization, clarity of course objectives and requirements, the degree to which the course met it stated objectives, quality and usefulness of course text (material), and the course as a whole[11].

Another useful tool is the use of on-line course surveys, which the students take three times throughout each semester. The purpose is to assess the amount of effort undertaken by each student, pre- and post-knowledge of each topic area, and to gain feedback on specific blocks. For example, in Spring 2006 students ranked the rocket and glider exercises and the beam construction/testing high. Ranked lower was the inventor homework, materials testing lab, electrical engineering, and civil engineering exercises. The launch logic circuit exercise was overall ranked the most challenging and difficult for the students. In addition, it is interesting to note that before taking the rockets block, 63% of the students reported that they either had a “fair” or “non-existent” understanding of the topic, while after completing the block 81% reported a “good” or “very-good” understanding of the topic[12]. Feedback from both methods is used to make overall improvements to the course, as discussed later.

Optional written comments are also overall very positive. Some notable comments from Fall 2007 include “This is a great course where you can incorporate what is learned in class to real life exercises,” “I like this class because of the hands-on work and interaction, and I can actually see the usefulness,” “A good course because it opened my eyes to the world of engineering as a major and in the Air Force.” The biggest complaint from the students is the group work and grading methodologies, such as “when your group members don’t put in as much effort to succeed as you do it becomes quite disillusional.”

Although the number of engineering majors has increased since the inception of Engineering 100, it is next to impossible to pinpoint the root cause. There are many factors such as increased recruiting by the engineering departments and an increased percentage of students coming in already interested in engineering. However, some of the written comments provide some positive indicators that Engineering 100 is making a difference. These include “Thanks to E100, I will most likely pursue a Civil Engineering major,” “Decided to change from fuzzy to tech major after this course,” and “Engr 100 showed me that engineering isn’t this big mighty giant to be afraid of…”

Course Improvements

Throughout the course development, changes/assessments have been made at the end of each academic year based on feedback from student evaluations and instructors. For example, in AY 2003 projectile demonstrators were added to the astronautics block to better demonstrate ballistic motion. These devices launch plastic balls at three force levels and at varying angles. They are used to demonstrate several of the principles in the readings and the rocket spreadsheet can be used in class to have the students estimate launch velocities needed to reach an assigned range. In 2005, a noise exercise was added to the civil engineering block. This exercise requires the students to build a noise suppression device and use a noise source and decibel meter to determine which group's design block the noise best.[4] In addition, a boost glider launch competition was added to the final day of launches to stimulate motivation near the end of the course. It also provides an incentive for the students to rebuild their boost gliders.

One recent addition to the course is more of an effort on the part of the instructors to discuss group work aspects with the students. The group aspect is often cited by the students as a challenging part of the course; instructors are now including discussion of group work as a leadership challenge and how it fits into USAFA's Officer Development System. If a group is having trouble getting along, instructors may intervene; however by and large the students must learn how to motive their groups toward success – a very important leadership exercise (Figure 4). There has also been more interaction with professionals serving in engineering fields in the local area who can provide insight into the importance of leadership and teamwork in the field.

Figure 4
Fall 2006 group with their Boost Glider

Conclusions

This paper has presented the basic course organization and development of USAFA's freshman-level engineering course, Engineering 100. The course is organized around a final boost glider project and focuses on a hands-on interdisciplinary approach to introducing students to the various fields of engineering. In order to minimize cost, a sub-scale project was developed so that students could actually build and fly their final projects (Figure 5). The course has continued to be well-received by students and provides excellent learning and leadership experiences for freshmen. Hopefully this paper has provided enough information for other universities interested in developing a similar course to model after Engineering 100.

Figure 5
Engineering 100 Boost Glider Launch Fall 2006

Bibliography

1 Brandt, S.A., C.A. Fischer, D.S. Hansen, S.T. Kuennen, and P.J. Neal, "Get 'Em While They're Young! Integrated Engineering for Freshmen," Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition, 2004.

2 J. E. Bartolomei, S. L. Turner, and C. A. Fischer, "Using the Systems Engineering Method to Design a System Engineering Major at the United States Air Force Academy." Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition.

3 Engineering 100 Course Material, HOGSS Statement of Work

4 End of course reports for Engr 100, AY 2003 – 2004 and AY 2004 - 2005

5 Hoit, Marc and Matthew Ohland, "The Impact of a Discipline-Based Introduction to Engineering Course on Improving Retention," University of Florida

6 Porter, Richard L., Laura J. Bottomley, Mary Clare Robbins, Sarah A. Rajala, Hugh Fuller, and Walthea V. Yarbrough "Introduction to Engineering Problem Solving – A New Course for 1100 First Year Engineering Students," College of Engineering Academic Affairs, North Carolina State University

7 Crumbley, Liz. "For Sea, Land, and Air: Hands-on Experience Produces Some of the Nation's Hottest Projects," Virginia Tech News.

8 "Minority Introduction to Engineering – US Coast Guard Academy," MAES Hispanic Network

9 West Point Bridge Design Contest, bridgecontest.usma.edu

10 Nociti-Gobel Jean, Samuel Daniels, Michael Collura, Bouzid Aliane "Project Based Introduction to Engineering – University Core Course" School of Engineering and Applied Sciences, University of New Haven, Proceedings of the 2004 Society for Engineering Education Annual Conference and Exposition

11 Engr 100 End of semester course critiques

12 Engr 100 On-line course survey data