The Undergraduate Satellite and Rocket Design, Fabrication and Launch Program at the US Air Force Academy

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***Abstract* - The Space Systems Research Center at the United States Air Force Academy is building a cadre of space professionals "one cadet at a time." Its motto and aim is for cadets to "Learn Space by Doing Space." Cadets majoring in astronautical engineering and space operations study either the design, fabrication, testing and launching of a sounding rocket (the FalconLAUNCH program), or the design, fabrication, testing, launching and operation of a satellite in space (the FalconSAT program). This year's FalconLAUNCH is scheduled to go to 20,000 meters. The goal of next year's launch, from San Nicolas Island, California, is to carry a 5-kg payload to 100,000 meters. The FalconSAT program has already built a 19.5-kg satellite, FalconSAT-2, ready for launch on the next Space Shuttle. The cadets are currently working on FalconSAT-3, a 50-kg satellite due for launch in 2006 on an Atlas V. Both missions have payloads approved by the Department of Defense Space Experiments Review Board to conduct space-weather experiments and Air Force Research Laboratory avionics and propulsion experiments. The programs work just like any Air Force program, with the cadets being the contractor, and the faculty and Air Force funding agencies being the Air Force Manager. Each program has approximately 25 students, with six to eight faculty mentors. The programs are multidisciplinary, including cadets majoring in, physics, electrical engineering, computer science, and management. All of the normal milestones, reviews, presentations, and reports required in an Air Force Program are required of the cadets in this program. The current goal is to have one rocket launch per year and a new satellite launch every two to three years. This paper details the development, challenges, and advantages of conducting an undergraduate space program performing world class research.**

Keywords-undergraduate engineering education; systems engineering; sounding rockets; small satellites

1. INTRODUCTION

The Space Systems Research Center (SSRC) program at the United States Air Force Academy (USAFA) is building a cadre of space professionals "one cadet at a time." The program gives cadets the opportunity to "Learn Space by Doing Space" through a capstone course in the Department of Astronautics. This program allows cadets to gain real-world experience with rocket and satellite system design, assembly,

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14. ABSTRACT
The Space Systems Research Center at the United States Air Force Academy is building a cadre of space professionals "one cadet at a time." Its motto and aim is for cadets to "Learn Space by Doing Space." Cadets majoring in astronautical engineering and space operations study either the design, fabrication, testing and launching of a sounding rocket (the FalconLAUNCH program), or the design, fabrication, testing, launching and operation of a satellite in space (the FalconSAT program). This year's FalconLAUNCH is scheduled to go to 20,000 meters. The goal of next year's launch, from San Nicolas Island, California, is to carry a 5-kg payload to 100,000 meters. The FalconSAT program has already built a 19.5-kg satellite, FalconSAT-2, ready for launch on the next Space Shuttle. The cadets are currently working on FalconSAT-3, a 50-kg satellite due for launch in 2006 on an Atlas V. Both missions have payloads approved by the Department of Defense Space Experiments Review Board to conduct space-weather experiments and Air Force Research Laboratory avionics and propulsion experiments. The programs work just like any Air Force program, with the cadets being the contractor, and the faculty and Air Force funding agencies being the Air Force Manager. Each program has approximately 25 students, with six to eight faculty mentors. The programs are multidisciplinary, including cadets majoring in, physics, electrical engineering, computer science, and management. All of the normal milestones, reviews, presentations, and reports required in an Air Force Program are required of the cadets in this program. The current goal is to have one rocket launch per year and a new satellite launch every two to three years. This paper details the development, challenges, and advantages of conducting an undergraduate space program performing world class research.

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integration, testing, and operations within the context of a two-semester engineering course. It provides a practical platform for Air Force and Department of Defense (DoD) space experiments. Since the Department of Astronautics was established in 1965, cadets have been making and launching rockets. It started with small rockets, but the program became more serious with the launching of the cryogenic hybrid rocket, CHIRON in 1994 that went to 7,000 meters. Other hybrid systems were tested, before the present program of using solid rocket fuels was initiated. Through FalconLAUNCH and FalconSAT participation, cadets are given a hands-on opportunity to apply the tools developed in the classroom to a real program, ideally preparing them for the situations they may encounter as officers and engineers after graduation. The end scientific goal of the FalconLAUNCH program is to launch small scientific payloads to study upper levels of the atmosphere at 100,000 meters plus. Just as any space mission is multidisciplinary, select students from the Departments of Management, Mechanical Engineering, Electrical Engineering, Computer Science, and Physics participate with Astronautical Engineering and Space Operations majors in the program. This program uses an evolutionary design approach in which cadets employ or refine cutting-edge technologies and procedures developed by their predecessors. Because there is almost a 100% cadet turnover every year, documentation is crucial to the success of the program. This program must be reproducible such that undergraduate students can launch a new rocket every year [1]. Fig. 1 shows the launching of FalconLAUNCH-2 and cadets fabricating FalconSAT-2. The recent and future milestones of the rocket program are summarized in Table 1. The USAF Academy started experimenting a decade ago with small satellites via cadet-built prototypes "launched" on high altitude balloons to 30,000 meters. These projects gave the students immediate, hands-on experience and inspired the Department of Astronautics to evolve the curriculum to accommodate increasingly more ambitious space projects. A major milestone was the launching of FalconGold, a 15 Kg fixed, secondary payload on an Atlas-Centaur launch vehicle in 1997. FalconSAT-1 was a 52 Kg satellite launched on a Minotaur. The learning experience of the cadets designing, fabricating, testing, launching and operating these satellites, guided the Department of Astronautics in developing a reproducible program for cadets to launch a new satellite every two to three years. The recent and future milestones of the satellite program are summarized in Table 2.

Figure 1. FalconLAUNCH-2 launch and Cadets fabricating FalconSAT-2.

Table 1. Summary of FalconLAUNCH Program Milestones.

DATE	ROCKET	TYPE	PEAK THRUST / ALTITUDE
1965-1994	Numerous Small Rockets		
Apr 1994	CHIRON	Hybrid	4,000 N / 7,000 m
Apr 1998	DOMINATOR	Hybrid	1,800 N / Launch Problems
Apr 2003	FalconLAUNCH-1	Solid	3,500 N / 10,000 m
Apr 2004	FalconLAUNCH-2	Solid	5,000 N / 5,000 m Premature Deployed Parachute
Proj Apr 05	FalconLAUNCH-3	Solid	Projected 6,500 N / 20,000 m
Proj Apr 06	FalconLAUNCH-4	Solid	Projected 13,000 N / 100,000 m

Table 2. Summary of FalconSAT Program Milestones [2].

DATE	LAUNCH VEHICLE	SATELLITE/ SIZE	MISSION
May 1995	Balloon Flight	USAFASAT-B	Attitude Control Demonstrator
Mar 1996	Balloon Flight	Glacier	GPS & Magnetometer Experiment
Sep 1996	Balloon Flight	PHOENIX	Laser Communication Demo
Apr 1997	Balloon Flight	FalconGold / 15Kg	GPS Signal Capture
Oct 1997	Atlas - Centaur	FalconGold / 15Kg	GPS Signal Research
Jan 2000	Minotaur	FalconSAT-1 / 52 Kg	Spacecraft Charging Hazards Research
Ready for Launch	Space Shuttle	FalconSAT-2 19.5 Kg	Ionosphere Plasma Bubble Research
Projected 2006	Atlas V	FalconSAT-3 50 Kg	1. Ionosphere Plasma Research 2. Attitude Control Propulsion Research

2. THE IMPORTANCE OF A STANDARDIZED PROGRAM

With almost 100% cadet turnover every year, a standardized program is essential for both FalconLAUNCH and FalconSAT. Involving cadets from a variety of departments expands the knowledge base of the participants and gives every cadet, regardless of major a priceless opportunity. This approach better reflects how technical programs in the Air Force are conducted, involving engineers, scientists, managers, technical writers and other experts from a variety of fields. For example, the experiment flown on FalconSAT-1 was conceived and built by faculty and students from the USAF Academy's Physics Department. Since then, select computer science, electrical engineering, mechanical engineering, and management majors have joined the program. This partnership has not only given an interesting scientific focus to the missions, but has brought them real-world credibility. The experiments on all FalconSAT missions compete for recognition across the Department of Defense (DoD) for approval by the DoD Space Experiments Review Board (SERB). The FalconLAUNCH missions are coordinated with the needs of active Air Force units. Such credibility gives the added bonus of critical additional

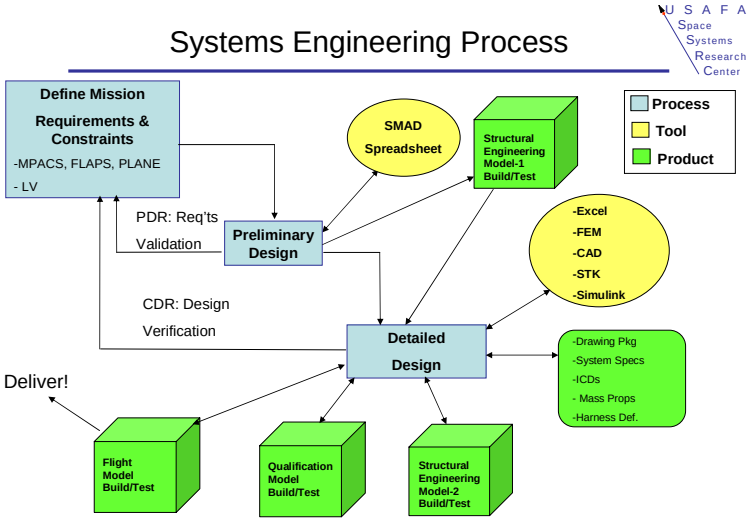

Figure 2. Systems Engineering Process

funding, and all-important space launch opportunities [2]. With this real-world focus, real-world funding and real-world visibility, it has become ever more important to run the program using real-world tools. Chief among these are rigorous systems engineering processes including technical reviews. The DoD mandates a tailored acquisition sequence for all its programs that closely follows the IEEE *Standard for Application and Management of the Systems Engineering Process* [2]. This process begins with requirements analysis and culminates in system deployment. This systems engineering process in combination with a Gantt chart with milestones, is essential to the success of the program. Along the way, major milestones in the form of formal technical reviews are conducted. As seen in Fig. 2 in addition to multiple status reviews, these milestones include: Preliminary Design Review (PDR), Critical Design Review (CDR), and Flight Readiness Review (FRR). It should be emphasized that the cadets do *all* the briefing, including the many informal and semi-formal status reviews conducted throughout the program. The Preliminary Design Review (PDR) is a formal briefing with the objective of gaining permission to proceed with the fabrication and test of subsystems. The cadets are not allowed to acquire materials or begin construction until all action items are closed from the PDR. This review forces the cadets to have a detailed and well thought out design before committing funds and effort to fabrication and testing of subsystems. They thus come to understand the problem of how to produce a successful program on time and under budget. The Critical Design Review (CDR) is a formal, multi-day briefing to reviewing experts from outside of the Air Force Academy. The objective of the CDR is to gain permission to proceed with the integration of all subsystems and the performance of operational/field testing of the total system. As usual the cadets are the briefers—which amounts to an oral examination of their project. Just as teachers really learn a subject when required to teach it, being subjected to questions throughout the student's briefing by outside experts, stimulates increased understanding of the subject – hopefully before the

briefing, but always afterwards. The Flight Readiness Review (FRR) is the equivalent of the Prototype Acceptance Demonstration (PAD) in the DoD procurement program. The FRR is a formal review ensuring that all the requirements of the program have been fulfilled. It includes the thermal bake-out testing, the shake test, etc. Satisfactory completion of this review means the satellite is ready to be launched [2]. In order to launch a rocket every year, the FalconLAUNCH program proceeds by designing, building and testing the subsystems. After the subsystems satisfactorily pass all tests, a Flight Model (FM) is constructed and tested for launch in April of each Spring Semester. The FalconSAT program requires the cadets to build three models of the satellite during the satellite development for a single mission. First, an Engineering Model (EM) is built to make sure all of the components fit and are compatible for the mission. Next, a Qualification Model (QM) is constructed, which has all of the characteristics of the Flight Model and is tested to above the limits for all aspects required of the Flight Model. Finally, a Flight Model (FM) is fabricated, which is the satellite that will be flown in space. To assure their reliability in space, each model of the satellite must complete the entire review process through FRR before starting the fabrication and testing of the next model of the satellite [2].

3. COURSE GRADING AND CADET REACTION TO THE PROGRAM

Assigning individual grades to a multidisciplinary group project of this size is a challenge. The grading system developed includes peer evaluations by members of each subdivision team and evaluations by the faculty mentors of these teams. The final grades are assigned by the senior faculty members in charge of the course. The overall reaction of the cadets to the program has been very positive even though everyone, including the faculty, is a volunteer. Many cadets come into their own in this type of course. Typical comments:

- "Most amazing opportunity at the Academy."
- "I learned more about engineering in this course than any other. It's frustrating at times because of so many constraints, but that is usually what makes the final outcome so rewarding."
- "Definitely the best class I've taken at the Academy."

are examples of optional written comments on the student critiques. The student response was high in all 21 categories of questions on the critiques. In regards to the answers to the questions [3]:

- "Intellectual challenge and encouragement of independent thought were?" scored in the top 2 % of all the courses taught at the Air Force Academy
- "Relevance and usefulness of course content" – scored in the top 2% of all courses in the Engineering Division.
- " Encouragement given students to express themselves and participate." - scored in the top 2% of all courses in the Engineering Division.

4. CUSTOMER REACTION TO THE PROGRAM

One of the satisfying aspects of this program is the fact that the mission is a real space mission and not just a textbook exercise. The program is continually reviewed

by outside experts and evaluated against the work of the real space community, not just academia. Confidence in this program is verified by several outside agencies committing to as long as five years of funding. The comments by outside space experts and some of the customers of the program who were the reviewing officials at a recent Critical Design Review (CDR) were very positive:

- "Very comprehensive in terms of the spacecraft subsystem/elements covered."
- "Team was well prepared, organized, and used the right level of complexity to address technical issues."
- "Cadets were very professional."
- "The cadets did 95% of the briefing."

In response to the question, "On a scale of 1 to 10, 1 being the worst design review you've ever seen and 10 being the best, how would you rate this CDR?" there were responses of 7, 8 and 9 and one comment of "10 if based on university satellite programs and an 8.5 compared to all satellite programs".

5. CONCLUSIONS

Of course, all programs are judged on their results. The physical results of the FalconLAUNCH and FalconSAT programs has been world-class quality research. Professional Air Force officers who have had the "Learning Space by Doing Space" experience while at the Air Force Academy are the real product of the FalconLAUNCH and FalconSAT programs. The exposure to solving ill-defined problems in these programs, prepares cadets for the challenges of a professional military career. The space aspect of the programs, prepares them to join the cadre of space professionals.

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