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The Undergraduate Satellite and Rocket Design, Fabrication, Launch and Operations Program at the United States Air Force Academy

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The Space Systems Research Center at the United States Air Force Academy is building a cadre of space professionals "one cadet at a time". Cadets majoring in astronautical engineering and space operations participate in a two-semester capstone program in the design, fabrication, testing and launching of a sounding rocket (the FalconLAUNCH program), or in the design, fabrication, testing, launching and operation of a satellite in space (the FalconSAT and FalconOPS programs). This paper details the development, challenges, and advantages of conducting an undergraduate space program performing world class research.

I. Introduction

The Astronautical Engineering department at the United States Air Force Academy has always been on the leading edge of space development at the undergraduate level. Recent improvements have resulted in the creation of three capstone projects within the department. The goal of all three projects is to allow cadets to "learn space by doing space". The research contained in this paper details the development, challenges and advantages of maintaining such a program. Two majors offered within the department. The majors offered by the department are the Astronautical Engineering major, which includes the Small Satellite and Rocket programs and the Space Operations major. The three capstone projects are FalconSAT, FalconLAUNCH and FalconOPS, respectively. The goal of all three of these programs is to allow Air Force Cadets to "learn space by doing space". The FalconSAT and FalconLAUNCH programs allow cadets hands-on, real-world experience in design, assembly, integration, testing, and operations within the context of a two-semester engineering course sequence. FalconOPS allows Space Operations majors hands-on experience in all aspects of operations, including commanding FalconSAT.

The secondary goal of FalconSAT and FalconLAUNCH is to support Department of Defense (DoD) and Air Force science experiments. FalconSAT has been leading the way in the nanosat field in terms of payload science.

This paper will outline the development of this capstone program as well as the difficulties and advantages of running such a program in a high-stress, highly-constrained undergraduate program. The history of the capstone

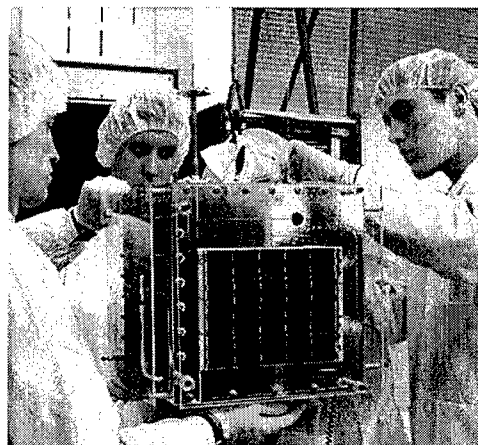


Figure 1. Cadets working on FalconSAT-1

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projects will be given first to set the background of the departments' activities, including successes as well as failures. Discussion will then begin on the development of each of the capstone projects and how recent changes to the department curriculum have allowed each project to give cadets the experience and knowledge they need to take away from the course. This paper concludes with a current update of each capstone project and what projects might be available for future USAFA Classes.

II. FalconSAT

A. FalconGold

The USAFA Astronautics Department "launched" into satellite operations in May 1995 with the launch of several payload packages, using balloons, designed to do everything from laser communications to satellite tests for future projects. These balloon launches were the critical first step in the department's history. They allowed the department the opportunity to develop a curriculum to support more ambitious projects. More importantly, however, these balloon launches gave cadets hands-on experience that they would need when they reached their first Air Force assignment.

Table 1. USAFA Balloon and Space Launches

Date	Event	Satellite	Mission
May 1995	Balloon Launch	USAFASAT-B	Attitude Control Demonstrator
March 1996	Balloon Launch	Glacier	GPS and Magnetometer Experiment
September 1996	Balloon Launch	Phoenix	Laser Communications Demonstration
April 1997	Balloon Launch	FalconGold	GPS Signal Capture
October 1997	Space Launch	FalconGold	GPS Signal Capture
December 1999	Space Launch	FalconSAT-1	CHAWS-LD
Current	Space Launch	FalconSAT-2	Atmospheric Scintillation
Current	Space Launch	FalconSAT-3	FLAPS, PLANE, Micro PPT, Memory Alloy Gravity Boom

The end result of these balloon launches was the launch of the Academy's first satellite, FalconGold. FalconGold was launched in October 1997 aboard an Atlas-Centaur launch vehicle. FalconGold was a barnacle satellite, meaning it was a fixed payload aboard the launch vehicle, but it was still USAFA's first active satellite. The goal of FalconGold was to determine if it was possible to monitor GPS signals above the GPS constellation. FalconGold sent back data for 15 days prior to battery depletion. The mission was a great success. The data FalconGold sent back showed that not only were the signals detectable above the constellation, but they could be used for orbit determination, even beyond the altitude of the constellation.

One major realization came from the operation of FalconGold. The satellite could not be heard from USAFA, so ground operations were transferred to Boulder, Colorado. However, the site at Boulder was not practical for cadet use. USAFA needed its own ground station if the FalconSAT program was going to be of full use to the cadets and to the department.

By the time FalconSAT-1 was readied for launch, the Astro Department had put together its own ground station so operations could be done directly from USAFA. The ground station, depicted below in its original configuration, allows for both cadets and faculty to receive telemetry and send commands to any operational USAFA satellites.

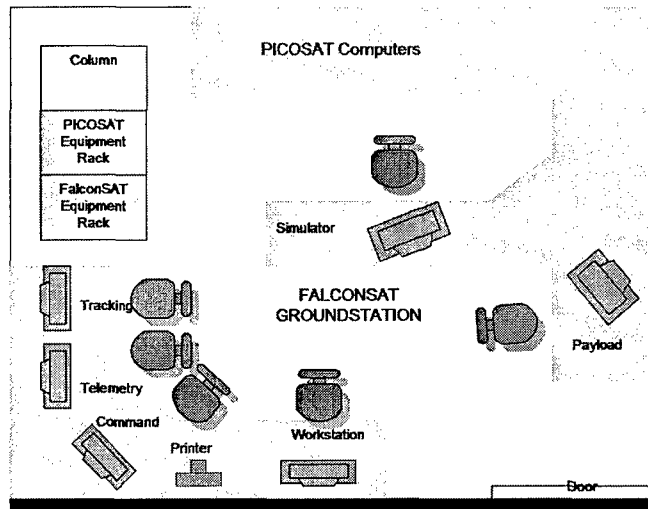


Figure 2. FalconSAT Ground Station

The Astronautics Department now had the infrastructure to run their own operations, making it more practical for both faculty and cadets. This also opened the door for Space Operations majors who were interested more in the daily operations of a satellite instead of the design, construction and launch. In December of 1999, the Astronautics Department along with the DoD SERB and Air Force Research Laboratory (AFRL), launched FalconSAT-1. The purpose of FalconSAT-1 was to measure the electric potential created by a spacecraft wake, examine how charging of a spacecraft varies throughout its orbit and to assess the hazards for spacecraft operations in the wake of larger bodies. Secondary goals included a test of the ground station hardware and operations as well as flight qualification of new hardware.

B. FalconSAT-1

The department made a large jump from FalconGold to FalconSAT-1. FalconGold was made primarily from contracted or pre-constructed, flight qualified parts. FalconSAT-1, however, was the department's first attempt at making almost the entire satellite at USAFA. Construction, assembly, integration and even some of the testing was done in the USAFA Astro Lab. The result was less than encouraging. FalconSAT-1's USAFA-built solar panels did not charge the battery properly and the satellite did not survive for long. Eventually, the batteries drained totally and the department lost contact after about 15 days in orbit.

Despite the loss of the satellite, the department viewed FalconSAT-1 as a success. The main mission of allowing cadets hands-on experience with a real-world mission was achieved. Cadets did everything from designing and building the payload to creating the operations plans for each pass.

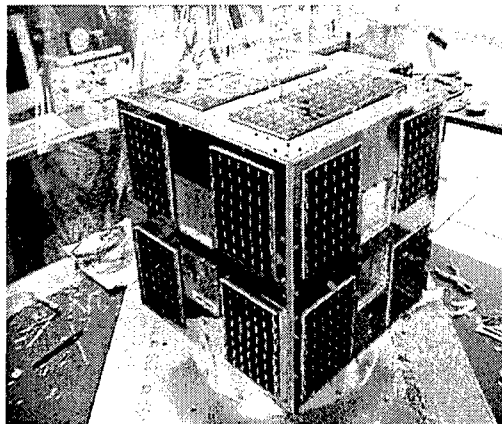


Figure 3. FalconSAT-1 in the USAFA Clean Room

C. FalconSAT-2

The department took time to reorganize and understand the technical problems that FalconSAT-1 encountered in order to avoid re-creating the same mistakes later. In the fall of 2000, the department was ready to create the first free-flying satellite, FalconSAT-2. This project is different from FalconSAT-1. The Astro Department decided that, instead of doing all the major manufacturing at USAFA, it was more efficient to buy commercial off-the-shelf (COTS), flight-certified hardware and assemble it at USAFA. There would be very few parts manufactured in the USAFA lab, but the combination of USAFA parts and COTS parts would allow the cadets to focus on the assembly,

integration and testing rather than individual part engineering. This curriculum change allows cadets to understand the bigger picture of satellite production rather than getting bogged down in the low-level engineering.

FalconSAT-2 is carrying a USAFA Department of Physics payload that analyzes scintillation in the upper atmosphere. Scintillation causes plasma bubbles to form which disrupts communications. The goal of FalconSAT-2 is to collect data to see if there is any way to predict the formation of these plasma bubbles. If there is a way to predict these bubbles, the satellite operators can plan on having communication outages or find a way to get around them.

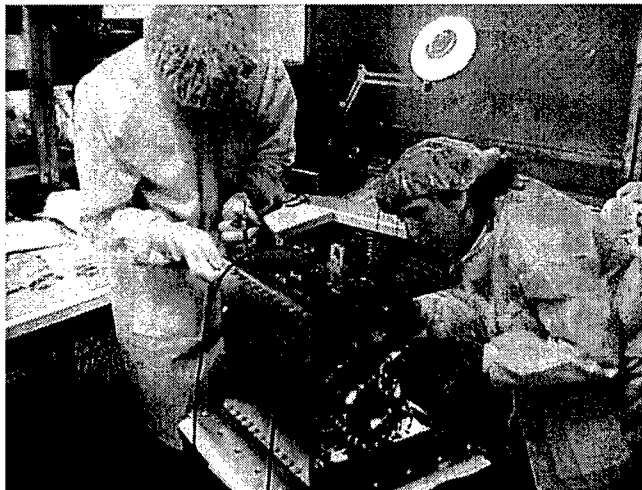


Figure 4. Cadets and faculty working on FalconSAT-2 in the clean room.

FalconSAT-2 was originally scheduled for launch in late 2002 aboard the Space Shuttle in the hitchhiker program. Delays caused that launch date to be pushed back. That delay has placed created additional problems for the project. With the loss of the shuttle Columbia and the restructuring of NASA, all Space Shuttle flights have been temporarily put on hold in the interest of safety. The hitchhiker program has been sacrificed in order to gain money for other NASA projects. When the Space Shuttle does fly again, the remaining missions will be solely dedicated to finishing the International Space Station. The chance to launch FalconSAT-2 will be more remote the longer the Space Shuttle remains grounded.

The USAFA Class of 2005 has taken on an interesting challenge for the academic year 2004-2005. Not only will this class build and test the qualification and flight models of the new FalconSAT-3, but this class has taken on the project of finding a new launch vehicle to launch FalconSAT-2. A new launch vehicle may also require structural modifications to the satellite and its interface, creating engineering challenges. This is the first time in department history that two major satellite engineering projects are going on simultaneously. The goal of the Class of 2005 is to produce two satellites for the Classes of 2006 and 2007 to launch and operate. [1]

D. FalconSAT-3

FalconSAT-3 is the newest USAFA satellite. The department worked with the DoD and obtained Air Force Research Laboratory and DoD science and mechanical demonstrator payloads. These payloads are described in Table 2, shown below.

Table 2. FalconSAT-3 Payloads

Payload	Sponsor
Micro Propulsion Attitude Control System (MPACS)	AFRL/VS
Flat Plasma Spectrometer (FLAPS)	AFRL/VS
Plasma Local Anomalous Noise Environment (PLANE)	USAFA/DFP
Shape-memory composite Gravity Gradient Boom	AFRL/VS
Shock ring vibration suppression	AFRL/VS

FalconSAT-3 is the biggest of the FalconSAT family. Plans for the future have suggested a return to the original designs of FalconSAT-1 and -2; a simple cube design with fewer parts and experiments. The FalconSAT-3 team is currently dealing with a problem in the gravity boom. There are engineering issues with the boom and

redesign may create problems. Therefore, the department has ordered a back-up boom in case AFRL cannot get their experimental one to work. This is just an example of the problems that the cadets encounter and have to study and work through in order to produce the satellite on time.

The Small Satellite program is the best in the nation for undergraduate space studies. The hands-on work that cadets receive in the lab is invaluable upon graduation. The experience of working in leadership positions, dealing with contractors and working with operational deadlines does not come from any other school in the nation, at least not in the realm of satellite design and construction.

III. FalconLAUNCH

The Space Systems Research Center, a part of the Astronautics Department, is not only interested in the development of small satellites. In the spring of 2001, the department started a new capstone project – FalconLAUNCH. The department had long had a rocket track within the major, but no designed capstone class like the FalconSAT program. FalconLAUNCH gave the department the program they were looking for. The goal was a big one – develop a sounding rocket that could take a 5kg payload to 100km and return under a recovery system. The program would be a full-year course and it would produce a new rocket every year. Originally, the program goal was to produce two rockets – one with a liquid propellant and one with a solid propellant. The liquid propellant developed problems with the tanks. Eventually, the department went to producing only a single, solid-propellant rocket each year.

While the department keeps all the records of past classes' documentation of problems and solutions, each year a brand-new rocket is produced. The Class of 2003 is credited with the first actual FalconLAUNCH rocket, although the program had been in existence since 2001. The rocket was dubbed the "Humble Rumble" and made it to 30,000 ft MSL. The recovery system worked as advertised, the rocket was recovered and now rests in the department museum. The FalconLAUNCH-2 team, made up of the Class of 2004, built upon the lessons learned from the Class of 2003 and FalconLAUNCH-1. They set the goal for themselves that they would design, test and launch a sounding rocket to 100 kilometers. The team worked for two semesters to solve problems encountered by the FalconLAUNCH-1 team and to solve issues that came about due to a design change in the rocket itself.

The result was a launch on 24 April 2004 at the Pinon Range Maneuver Area of Fort Carson, CO. The rocket launched successfully but encountered an anomaly at 16,300 ft and Mach 1.5. Despite the anomaly, this rocket was the first USAFA-built rocket to break Mach 1. Currently, the reason for this anomaly is not known. A "tiger team" has been established to investigate all information and provide improvements for the current design work.

The FalconLAUNCH program, regardless of the actual results of the rocket, still fulfills the goal of the Space Systems Research Center – to allow cadets to "learn space by doing space". Whether the rocket meets the original goal or not is trivial when compared to the operational experience cadets' gain by going through the FalconLAUNCH program.

IV. FalconOPS

The newest program in the Astronautics Department was started in the fall of 2004. It is the capstone project for the Space Operations majors. The FalconOPS program takes advantage of the ground station and the FalconSAT program to give cadets an idea of what operating a satellite is like. Being responsible for proper operations of a \$2.5 mil satellite is a big job for a college senior. Yet, when that cadet graduates, he or she may be in charge of the operation of satellites worth hundreds of millions. The establishment of a Space Operations capstone project was the next logical step for the department.

With the help of the 2nd Space Operations Squadron (SOPS) from Schriever AFB, CO, the Class of 2004 established a basic training program as well as rough operations checklists for FalconSAT-2. The Class of 2005, with three times as many people in the program as the Class of 2004, has taken on the task of developing the training program as well as the operations checklists with



Figure 5. Cadets going through a checkride in the FalconSAT Ground Station.

the idea that FalconSAT-2 will launch after graduation. That means that the Class of 2005 will be responsible for training the operators of FalconSAT-2, which is no small task. The class is broken down into a Space Operations Squadron organization, shown in Fig. 2 below.

The FalconOPS program, while started as support to the FalconSAT-2 program, has developed into an overarching program designed to support all USAFA space missions. The Space Operations majors involved in FalconOPS work with the designers in the FalconSAT-2 and -3 programs. Without that interface, the engineers cannot possibly understand the requirements that a Space Operator has. The communication between engineer and operator is critical because the operator needs to be able to talk to the satellite. If the engineer does not take into account the operations aspect while designing the satellite, it could, once launched, become just another piece of space junk. To prevent such an occurrence, the operators use the ground station to communicate with the satellites while they are still in the clean room, located next to the ground station. This allows the operators to get real operational experience and test all the systems before the spacecraft is launched. [2]

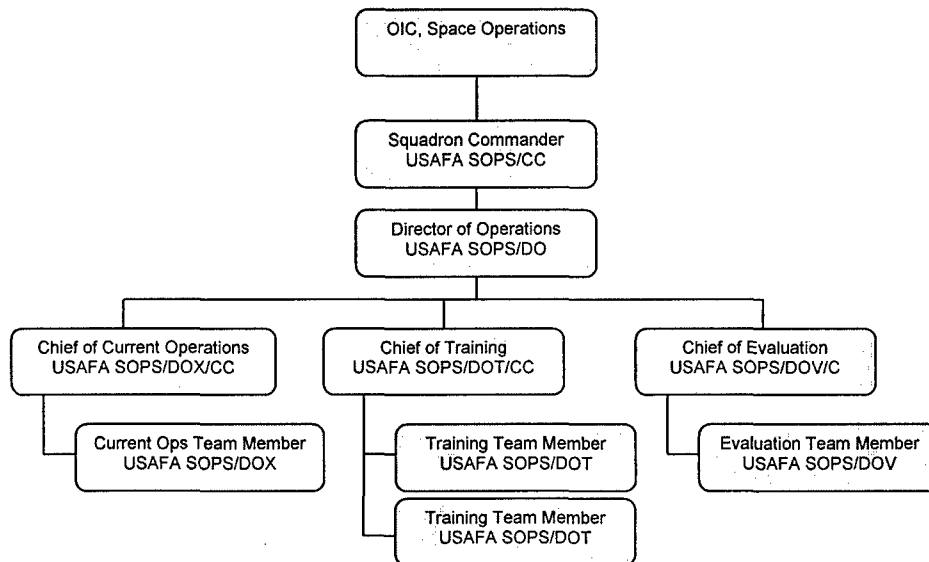


Figure 6. USAFA SOPS Organization

The FalconOPS program, however, is not just about sitting behind a desk and pushing buttons on a keyboard. The FalconOPS team is also responsible for the maintenance of the ground station and the supporting equipment, including the tracking antennas. The fall of 2004 is a time for training for FalconOPS. Only one of the nine members is trained in ground station operations. Once all nine are qualified, however, the program will branch out. The goal is to expose the entire Cadet Wing at the United States Air Force Academy to space. When a satellite is launched, the theory is that the FalconOPS team can draw upon members of the Cadet Wing to help in the ground station operating that satellite instead of relying solely on the Space Operations majors. The goal of this is to have a cadre of 40 cadets available to conduct operations in the ground station at any time.

The FalconOPS program was a logical extension of the FalconSAT and FalconLAUNCH programs and provides Space Operations majors with experience in an operational capacity rather than an engineering one. With the goal of educating the entire Cadet Wing about space, the FalconOPS program is going to have a large impact on the education of the Air Force's future leaders.

V. Conclusion

The capstone projects at the United States Air Force Academy, while extremely time-consuming and expensive, are worth the extra effort when it comes to educating undergraduate cadets. Allowing cadets to "learn space by doing space" was a lofty goal in 1995, when the department started putting experiments in balloons. Now, with the support of the Air Force and the Department of Defense, the Falcon programs have become the model for undergraduate space programs all over the world. Taking the time to develop such a capstone program is a critical step in the education of Astronautical Engineers and Space Operators. Allowing students to gain operational experience before entering the space community increases their production and lessens the likelihood of a catastrophic problem.

The capstone projects at USAFA would be somewhat difficult to recreate at another university due to the fact that the Astro Department does not fund the projects. All projects are funded by the Air Force Research Laboratory or the Department of Defense. Universities would have to put forward quite a bit of their own money not only for the satellite or rocket itself, but also for the infrastructure to assemble, integrate and test. However, the gains made by spending that money are invaluable to both the university as well as the entire space community. All Astronautical Engineering programs should have a similar capstone program in order to introduce their students to the operational world of space. The hands-on technical experience as well as the operational experience (AIT) is absolutely invaluable to any space contractor, including the Air Force. There is no reason to avoid these types of capstone programs. Although the program will run into problems, that is the operational risk that any project runs. Exposing students to that early gives them a start on understanding ways to mitigate those risks and work around them. The capstone project is a valuable tool that ties the theoretical with the operational, and it should be embraced by everyone in the space community in order to provide a strong foundation for the future of space.

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