Spacemanship at the United States Air Force Academy: Developing a Satellite Ground Station Crew Training Program for Non-Technical Students

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Abstract
To make our educational program realistic and relevant to a cadet's future profession, the United States Air Force Academy (USAFA) has created a center in which we manufacture very modest spacecraft. Each satellite has a real-world mission and is designed, built and operated by our cadets. The program greatly enhances our student engineers' understanding of satellite design and operation—something most small countries are unable to offer their technical personnel. Like our colleagues in civilian universities, we wanted to offer more of our cadets hands-on experience, to broaden the program to expose more cadets to satellite operations. So we now invite non-technical, non-scientifically inclined cadets to participate in satellite operations by maintaining our on-orbit scientific payloads. This paper records how USAFA cadets created a training program to meet that objective and initiated the inaugural running of the program.

I. Introduction

The mission of the Astronautics Department is to produce the world's finest Air Force officers who live our core values of integrity, service, and excellence and understand space. In keeping with this mission, the Department has created the Space Systems Research Center (SSRC) and the *FalconSAT* program[1]. Our philosophy of "Learning Space by Doing Space" is carried out through the SSRC. This center provides a facility in which our astronautics majors can design, assemble, test, and operate small, scientifically relevant satellites. *FalconGold, FalconSAT-1,* and *FalconSAT-2* were the first spacecraft in a series of projects created by cadets. In recent years, the program has expanded to include select management, physics, computer science, and electrical engineering majors—creating a truly interdisciplinary capstone course. The next step is to bridge the gap between education and training in the space arena.

This paper describes how our cadets created a training program that any cadet could enroll in and pass regardless of major. In fact, the objective was to target students whose major was neither technical nor scientific in nature. Because cadets have limited time for extra curricular activities the program was created to be efficient—placing instructor/cadet contact time at a premium and offering opportunities for advancement based on a cadet's schedule. The program must also ensure that each cadet is properly prepared to work autonomously in the ground station. Finally, the program must graduate a high percentage of certified operators by reducing technical data to a bare minimum while condensing operations into a checklist format—an approach that has proven successful for the Air Force in space operations.

We begin by introducing the program's objectives, strategies, and philosophies. From these, we develop course materials and lectures which are tested before we trained the initial team of operators. Questions such as what materials had to be developed, how the cadets were empowered to create a program given their limited experience in this area, and what quality controls were used during the process are answered.

Finally, we address the applicability of our model for training to other, highly technical fields. Although we are interested in *operationalizing* our space program, readers may want to apply this model to programs under their supervision. The last section discusses how that might be accomplished.

II. Developing a Training Program

After six years of satellite design and manufacturing experience and a trend toward more complex and capable spacecraft, the SSRC management decided to extend the program experience to other cadets with an interest in Astronautics but without the usual technical or scientific background. This section describes how a training program was created using the current state of the industry standards and the program's strategy. Much of the paper describes the training products created by our cadets to meet our strategy.

The Training Program Strategy

Our primary goal was to create a training program which supported *FalconSAT-2*. A secondary goal of supporting follow-on satellites such as *FalconSAT-3* was considered. Our initial team was composed of three cadets and two instructor mentors. The strategy was for the team to learn to operate the mission ground station and then create a program to train a larger team in the spring semester--one composed of engineering cadets and Department of Astronautics instructors. A benefit of this approach is to get feedback on the program lesson plans from technically qualified students and instructors. The feedback would be incorporated into the program before the fall semester, 2004. At that point, the training would be validated and ready for a much broader set of trainees with less technical backgrounds.

Program Objectives and Goals

We had two primary objectives for the training program:

1. Train and certify a work force that is capable of operating *FalconSAT-2*.
2. Provide a baseline training program for future *FalconSAT* missions.

Additionally, we needed to support the objectives of our small satellite course that is, to provide an interdisciplinary capstone astronautics-related experience to engineering students. While there are approximately 25 cadets enrolled in the course, their focus was on the design of our next vehicle on the Falcon Satellite series—*FalconSAT-3*. Only three students could be assigned the task of developing our training program. The cadre of cadets and instructors were given a deadline congruent with our training plan—to develop an 18-lesson training program for two positions, Satellite Operations Officer (SOO) and Ground Station Operator (GSO) by the end of the fall semester 2003 (The training for the third position, Crew Commander (CC), would be developed later). This position will initially be filled using a certified instructor. Future CCs will come from cadets who demonstrate proficiency in their initial crew position, either SOO or GSO. They will be required to complete position upgrade training to CC.

Program Resources and Philosophy

The initial team or "cadre" had access to all the technical and performance documentation developed the prior year for design reviews and testing of the *FalconSAT-2* spacecraft. In addition, they could interview the instructors who guided the previous year's senior engineering students. The cadre could also tap into the expertise of the current senior class of engineers to resolve undocumented issues with the satellite's operations, using the ground station computers and communications gear. The flight qualification model for *FalconSAT-2* was laid out in the clean room and configured for live contact with the ground station. The team thus would be able to test actual contact passes on the qual-model which became known as *FlatSat* or the hardware simulator. Another internal resource was a part time contractor who had been part of the *FalconSAT-2* design team.

Since mastery of the technical aspects of the program was not one of our objectives, the program would not include design-level or highly technical information. It had to distill documents written for design reviews into understandable operational concepts. Information that only added to a better understanding of the spacecraft would not be included. If information could be used during a contact with a satellite and produce tangible effects, then it had to be presented in a way that showed its relevance to the crews' interaction with the space vehicle (Further understanding of the space vehicle would come in time after a cadet was qualified). Anomalies requiring in-depth knowledge of the spacecraft would be handed over to the cadet engineering staff for resolution. In cases where a choice could be made, such as in format, the program would follow the active duty products as closely as possible. This practice has the added benefit of training the way the Air Force operates.

Creating Training Products

The first required product was a breakdown of the individual lesson plans by phase of training. Figure 1 shows the breakdown of Initial Qualification Training (IQT) and Unit Qualification Training (UQT) phases. Within UQT are position specific training followed by crew or Mission Control Team (MCT) training.

Initial Qualification Training (IQT)

1. Mission Familiarization
2. Payload
3. Spacecraft Bus Part 1
4. Spacecraft Bus Part 2
5. Mission Ops Overview
6. Download/Uplink

Unit Qualification Training (UQT)

Position Qualification Training (PQT)

7	GSO: Rack	SOO: Telemetry PC
8	GSO: Rack	SOO: Command PC
9	GSO: Tracking PC/Antenna	SOO: Payload PC/Tracking PC w/SPC
10	GSO: Tlm, Cmd, P/L	SOO: Rack Overview
11	GSO: Cables	SOO: SIM Software Overview

Crew or Mission Control Team Training

12. Detailed Operations Overview
13. "The Pass"
14. Planning for Ops
15. Commissioning Campaign
16. Full Functional Test
17. Emergency Ops
18. Checkride

Figure 1: Lesson Plan Breakdown

The next product was a schedule of lesson plan production for the semester. Field Marshall von Moltke once said, "*No battle plan ever survives contact with the enemy.*" Our experience was no different. The cadets created the first six lesson plans with only minor problems. Lessons 7 through 11, the position-specific plans became more difficult primarily because of the detail required. For each lesson there was a GSO and a SOO version. The cadets quickly identified that the training required hands-on interaction with the ground communications rack located in the mission ground station. Because there was only one rack, this created a problem with larger training classes. Their solution was low tech but effective. We made a digital picture of the rack, and our graphic department produced five full-size color printouts (Figure 2). These were so well done that they made excellent aids for this phase of training.

Figure 2: MSgt Phil Maes standing next to the Communications Rack and holding our rack training aid.

In the last phase of training, the plan was to bring together all three positions and train them together as a mission control team in the control ground station. This is when it all came together for the team, but it is also the slowest part of the program. The answer was to enlist the aid of our part-time contractor, who created three categories of simulations that served as training scenarios. Meanwhile the cadre were producing checklists to be used on console during the satellite pass. Contact Support Plans composed of a Pass Plan, a Pre/Post-Pass checklist and relevant Command Plans followed.

Contact Support Plans

When a ground station communicates with a satellite, it is called a satellite contact or a satellite pass (derived from spacecraft in low Earth orbit having a relative motion over the ground station). The satellite contact consists of three parts: pass planning, pre- and post-pass activities, and command activities. The Contact Support Plan or CSP is the result of pass planning. It has three sections. The first is the cover sheet or Pass Plan, a one-page overview of the satellite contact that provides information such as satellite acquisition and fade times, required commanding, and which crew is responsible for the contact. The second part of the CSP is the pre-pass and post-pass checklist, a standard set of steps the mission control team has to accomplish to setup the ground station and prepare for the pass or to turn off the communications equipment and record critical mission data after the pass. It is a form of checklist. The last part of the CSP is the command plan, a pre-coordinated set of steps the mission control team can take during the satellite contact. In most cases it involves sending commands and helps the team accomplish the contact requirements in a timely fashion. Not all contacts require a command plan. Some contacts will require only a basic state-of-health review of the satellite's telemetry. In this case, no commanding is required. Figure 3 illustrates the parts of the CSP. Each part has a different look to help the crew identify which phase of the pass they are in at any given time.

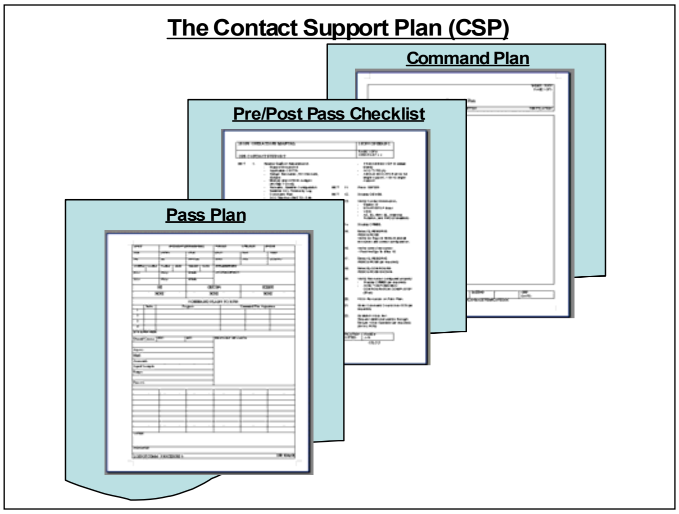

Figure 3: The Contact Support Plan

The Pass Plan

The pass plan is a form filled out prior to the satellite pass and used by the crew to take notes during the contact. They enter information pertinent to the satellite contact, which guides the MCT during the contact.

The Pre/Post-Pass Checklist

This checklist is a double-column list of steps that each position must accomplish before beginning a pass and after the pass is complete. The MCT moves through the plan sequentially, completing a step before moving on. Not all steps are accomplished by every crew member. The team uses a copy of the approved checklist which has the signatures of the Mission Director (MD), the Director of Operations (DO), and the Chief Engineer (CE). Because the steps seldom change, once the pre- and post-pass checklist is approved it is used over and over again.

The Command Plan

The Command Plan is a single-column document that provides the procedure for accomplishing a specific mission requirement. The plan, like the pre/post-pass checklist, has to be approved by the MD, DO, and CE. Some tailoring is allowed and is built into the checklist. Therefore, in the pass planning the checklist must be modified to meet the mission requirement. Once that is done, the Crew Commander reviews any changes and initials that version of the Command Plan.

Training Scenarios

Training scenarios have three levels of complexity. The easiest are the normal operations simulations. Using these, a trainer can give the MCT an understanding of the basic rhythm of a satellite contact. The team can go through the steps of creating Contact Plans then exercise their checklists. In the end, the crew should become proficient at operating the ground equipment and also have a basic degree of checklist discipline.

The next level of simulations is the early orbit checkout or commissioning phase of operations, which occurs when the satellite is released from the launch vehicle and must be turned on and operate in space. The many steps in the commissioning campaign all can not be accomplished in a single ten-minute pass. Therefore, the steps are broken into shorter pieces that can be executed during a satellite contact.

The most severe level of complexity is the anomaly-resolution simulations. Using this training aid, the trainer presents to the MCT a series of problematic situations that the team must analyze and determine the proper course of action to restore the satellite's functionality. There are numerous situations in which the health of the spacecraft can be endangered, so the MCT must know how to respond to each.

As the cadre neared completion of the training program and the team required the use of the mission ground station, it occurred to them that other activities may be scheduled in the ground station. Examples of these activities are periodic maintenance (PM), corrective maintenance (CM), training, tours, classes, etc. Deconfliction of these activities with satellite operations had to be accomplished, but how?

Pass Planning

To solve the problem of prioritizing the various activities in the ground station, our cadets developed a three tiered planning process. The highest level of operations planning is the long-range schedule followed by the 48-hour schedule and ends with contact support plan generation.

Long Range Planning

At the highest level of the planning process, we developed a long range schedule (LRS). This is a plan that captures all activities intended to be performed in the ground station for a two week period starting on Monday and continuing through the following Sunday. An example of an LRS is in figure 4.

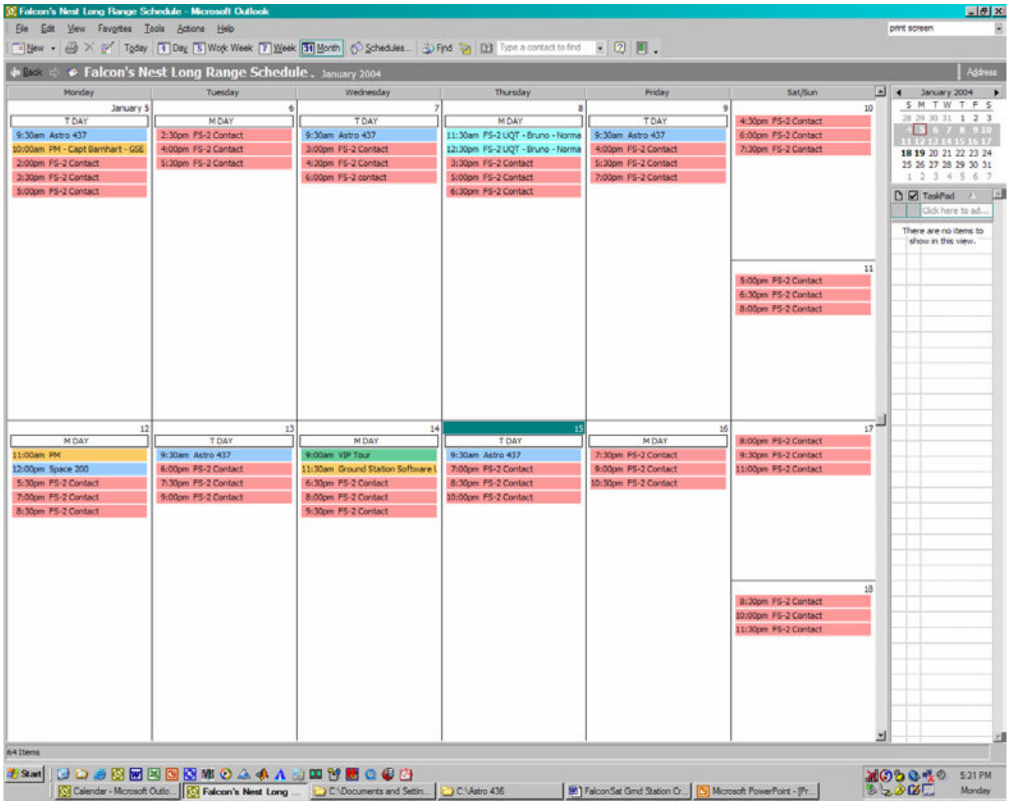

Figure 4: The Long Range Schedule

The LRS is used to roughly schedule activities in the ground station and associated facilities. It is a two-week schedule. Events occurring in the first or current week have greater detail than those of activities in the second or future week. The LRS is used to schedule resources required to meet mission needs and is produced during the day. Planners use the information on the LRS to deconflict and prioritize activities within the ground station. The LRS is the primary source of information for generating a 48-hour schedule (discussed in the next section). Each new LRS overlaps the current schedule's second week. In this way, a draft schedule is being developed while the current schedule is in use. The LRS must be finalized by 0000z on the Thursday before it is executed. This allows for coordination and approval before execution of the schedule.

48-Hour Schedule

The 48-hour schedule (figure 5) is more detailed than the LRS. The 48-hour schedule is created from the LRS by adding more specific information to each scheduled event. For instance, it would include acquisition of signal and fade times for each satellite contact. It would also include the names of the maintenance crews and how to contact the crews in the event of a late hour change. Tours appear on the LRS. The 48-hour version would include points of contact for the tour, the number expected to attend and a note about high ranking officials. Training events are also part of the LRS. The 48-hour schedule would have the trainers/trainees names, the objective of the training and equipment required. This schedule maintains a list of personnel who are "on-call" for the shift. The 48-hour schedule is created daily by 0000z with a 96-hour version created to cover the weekend.

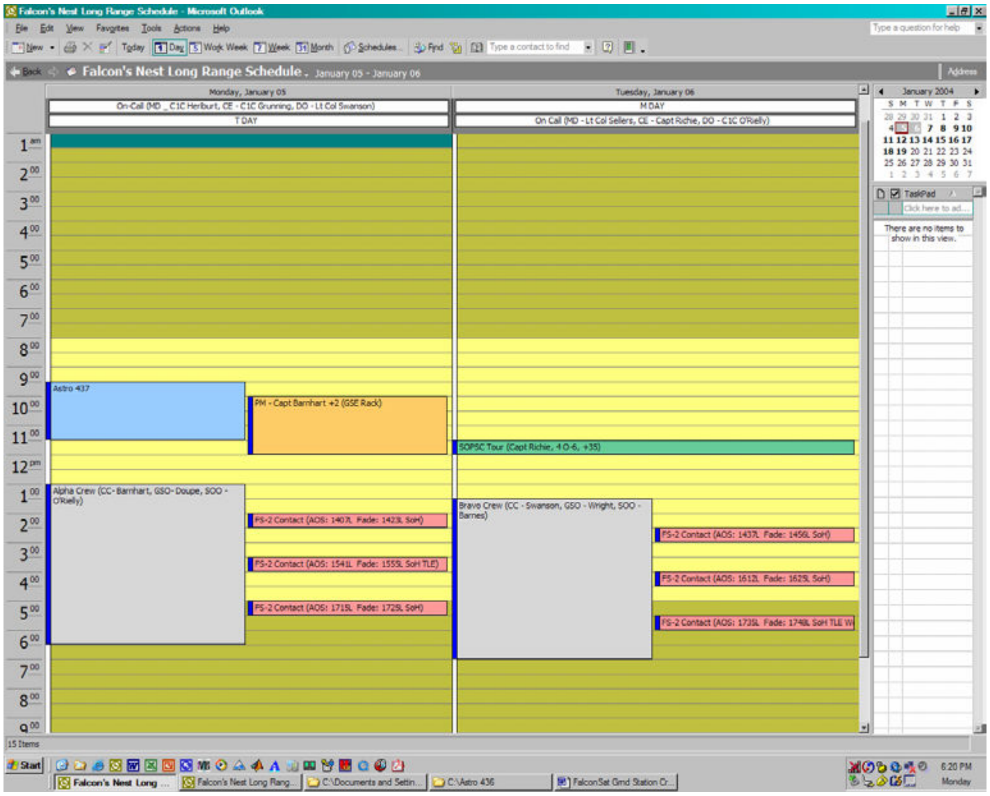

Figure 5: The 48-Hour Schedule

Contact Support Plan Generation

CSPs are the responsibility of our operations crews. They are generated using data contained in the 48-hour schedule. The SOO of the crew generating the CSP would fill out a Pass Plan form and add the approved pre/post pass checklist. If the support requirements called for commanding of the satellite, the crew would reproduce an approved command plan and include it in the CSP. The on-duty CC is then responsible for reviewing and approving the CSP as generated for a specific support. We limit the chance of CSP mistakes by mandating that all CSPs be completed and approved before the crew shift begins. Therefore, each crew is responsible for generating all the CSPs for the subsequent crew's shift. In this way, all operations products are ready before the crew reports for duty—and the cycle repeats.

The First Course

After a long semester of writing and quality checking lesson plans, our cadets were ready to present the material to the first class of trainees. In keeping with our strategy, the next step was to "blue-team" the material. Our Blue Team was composed of four instructors from the Astronautics Department and seven underclass-cadets. While the blue team was not representative of our target demographic, they had the requisite understanding of our small

Figure 6: FalconSAT Ground Station during MCT training. Left to Right: C1C Doupe, Maj Baker, C1C O'reilly, C1C Diaz, C1C Wright, and Ms. Bruno

satellite programs to offer informed comments on our training materials. Follow-on teams would be less technically oriented.

Since the operation of the ground station was an extra curricular activity, our instructors and cadets had very limited free time to devote to a long, drawn out training program. The program had to be engineered to give a jolt of information to each trainee and then to fit additional skill development into our trainee's complex semester schedule.

To meet these requirements, we presented the IQT on a Saturday early in the semester. Recall from figure 1 that IQT covered the first six lessons. The objective was to give our blue team an intensive day of foundational education in a large group setting. An added benefit was that our senior cadets were required to lead an eight hour class, giving them experience standing in front of an audience to present technical information. Each trainee took an IQT test and upon completion, was allowed to move on to the next phase of training—UQT.

The blue team was separated into a group of GSOs and a group of SOOs. Over the next three months, each group paced itself through PQT. They completed approximately two lessons a week. During this phase, the trainees required more hands-on interaction with the limited ground station hardware. Trainers maintained an Initial Plan of Instruction (IPOI) for each trainee to track the trainee's progress. The trainer verified that the trainee could demonstrate each skill required and subsequently annotated the trainee's IPOI. Upon completion of all the tasks in the IPOI, the trainee advanced to the next phase—MCT training.

MCT training is the most difficult phase to manage. Like the previous phase, this is focused on operating the ground station equipment. New is the need to perform as a team. In this phase the trainee put all the education and skills developed in earlier phases to use and develop their teamwork skills. Communication, checklist discipline, and satellite operation are the emphasis here. The objective is to pass an evaluation and become certified to perform crew activities.

Overall, the first showing of the training program was a resounding success. Most importantly, all eleven trainees completed the program and were certified to operate the *FalconSAT-2* space vehicle. Additionally, the program highlighted both errors in our training materials and produced our initial team of satellite operators. As the semester closed, our senior cadets—the corporate knowledge of the program—graduated. Because of the training program, we now had a new cadre of cadet operators ready to offer the program to an increased number of non-technically oriented cadets in the Fall. The next step would be to create a cadet space operations squadron—but that is another paper yet to be written.

III. Application to Other Technical Programs

The model described in this paper was beneficial for our Space Systems Research program in that it expanded the pool of eligible participants required to meet our scientific objectives. It freed our student scientists and engineers to focus on designing our satellite, *FalconSAT-3,* while ensuring that the mission objectives of *FalconSAT-2* would be met. Conversely, for the cadet with an interest in space but not a technical foundation, *operationalizing* the program opened an opportunity not available one year earlier. Our focus has been on a space-related program.

However the reader may have a similar program for which broader participation would be desirable.

Programs that our model could be applied to might include a particle accelerator, a large laser research program, or an astronomical telescope. Generically, any complex program that involves the repeated use of highly technical, low density systems requiring consistent, on-going management would be a candidate for *operationalization*. Programs that represent large investments and that demand reliable and repeatable operations are prime candidates for *operationalization*. Because of the overhead involved with our model, smaller, lower cost programs may not warrant this level of formal training simply for reasons of cost versus benefits derived.

IV. Conclusion

During the 2003-2004 school year, our cadets created a training program that now offers hands-on space operations experience to the entire cadet wing—4,000 in all. In so doing, they have created a firm foundation on which the Academy will build its *spacemenship* program. The program also ensures continued competency over the gaps of summer break when we continually lose corporate knowledge. The process described herein can be extended to a wide variety of operational programs.

V. Acknowledgements

The authors would like to acknowledge the contributions of our cadre of cadets. Cadets First Class Kevin O'Reilly, Cole Doupe, and Jordan Wright were the engine behind the development of our training program. Without their dedication to the SSRC and the *FalconSAT* program, these operational products would not exist. We would also like to mention the critical support provided by Mr. Jim White and Mr. John Clark. Their technical knowledge and hands-on approach to satellite operations were instrumental in the creation of our ground station. Thanks also go to Master Sergeant Phil Maes, and Technical Sergeants Chad Bruce and Benjamin Hazen for their non-stop involvement in and maintenance of the ground station hardware. If you enjoyed reading this article, credit our editors Dr. Fred Kiley, Mr. Donald Swanson, Major Tammy Baker (USAFR).

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Biography

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Glossary of Acronyms

CC - Crew Commander
CE - Chief Engineer
CM - Corrective Maintenance
DO - Director of Operations
GCO - Ground Station Operator
IPOI - Initial Plan of Instruction
IQT - Initial Qualification Training
LRS - Long Range Schedule
MCT - Mission Control Team
MD - Mission Director
PM - Periodic Maintenance
SOO - Satellite Operations Officer
SSRC - Space Systems Research Center
UQT - Unit Qualification Training
USAFA - United States Air Force Academy