Multi-Mission Operator Training Practices

Jennifer M. Reiter[1]
University of Colorado – Laboratory for Atmospheric and Space Physics (LASP) Boulder, CO 80303, USA

New operator training is a necessarily high priority for the Mission Operations group at the Laboratory for Atmospheric and Space Physics (LASP). In addition to as-needed professional hires, each spring a group of undergraduate students from the University of Colorado is hired to work as Command Controllers (CCs). The students spend a summer in a three-part classroom training program on their way to a formal certification. Fundamentals are the initial focus, with an intense overview of general spacecraft operations, spacecraft subsystems and real world applications of aerospace engineering. The second phase of training focuses on Mission Operations at LASP and the day to day activities that are required to command four very different spacecraft. Phase three consists of spacecraft specific training, including detailed functionality and subsystem monitoring. Proficiency is gauged throughout the summer by three exams and multiple in-class assignments. At the close of the summer, each CC candidate undergoes a practical exam where they must demonstrate their accumulated knowledge in order to earn their certification. This paper will detail the training and certification process for both professional and student employees, describe training tools used and their effectiveness, and explain how the Mission Operations team continues to stay proficient in an ever-changing operations environment.

I. Introduction

THE Laboratory for Atmospheric and Space Physics (LASP) is a cradle-to-grave space sciences facility with focuses on science, engineering, mission operations, and scientific data analysis. LASP currently conducts operations for four NASA satellites and 14 science instruments from our Mission Operations and Science Operations Centers. LASP is responsible for more than $1.5 billion in NASA assets and processes over 100 gigabytes of data per day to support the ongoing activities of these missions. It is LASP's goal to identify and address key questions in solar influences, atmospheric, planetary and space sciences.

Figure 1 - The Mission Operations Center at LASP is staffed by a mixture of students and professionals

The Mission Operations team at LASP is responsible for command and control of the QuikSCAT (Quick Scatterometer), SORCE (Solar Radiation and Climate Experiment), AIM (Aeronomy of Ice in the Mesosphere), and Kepler missions. These missions are operated and monitored using several customizable software packages developed in-house. The OASIS-CC (Operations and Science Instrument Support – Command Control) software is used as the interface to command LASP's spacecraft and receive realtime telemetry. With OASIS-PS (Planning and Scheduling), standard command products are created daily using templates for science operations and spacecraft activities. All of the spacecraft data is handled by TDP (Telemetry Data Processing), which automatically processes

[1] Student Training Lead/Flight Controller, Mission Operations and Data Systems, LASP, 1234 Innovation Drive, Boulder, CO 80303.

all of the realtime and post-pass data collected during spacecraft supports. These and other tools work together to allow for a streamlined operations center with the ability to easily support a variety of missions.

As an institute of the University of Colorado at Boulder, development of the next generation of space professionals is a prime focus at LASP. To that end, the Mission Operations team is comprised of a mix of professional and student employees, all of whom participate in general operations and mission specific training before undergoing formal operator certifications. Spacecraft operations are constantly evolving and in response, training at LASP continues throughout an operator's tenure. All operators undergo yearly mission reviews and recertifications. Operator training is continuously updated and refined to provide the best resources possible for the entire ops team.

II. Student Operators – Command Controllers

The Mission Operations team employs approximately 20 undergraduate and graduate students from CU. These student Command Controllers (CCs) are involved in every phase of mission development, including prelaunch testing, mission simulations, launch and early orbit operations, and spacecraft decommissioning. As the title implies, CCs are the individuals who issue the actual commands to the spacecraft and are responsible for command verification during realtime uplink contacts. The student operators are also responsible for building the command products loaded to the spacecraft on a daily or weekly basis. In addition, CCs perform short and long term spacecraft telemetry trending, participate in anomaly recovery, generate anomaly reports, and interface regularly with both the missions' scientists and our partners in the aerospace industry.

CCs are the eyes and ears of the Mission Ops team, with a refined and specific knowledge base that allows them to see trends in data that might go unnoticed by the untrained eye. They are considered our first line of defense against behaviors that could indicate a near-term or future failure and their reporting often helps to guide operations concepts in different directions. This attention to detail extends to their on-console responsibilities, where careful accounting of commands issued to the spacecraft can prevent a command error and the long recovery following it. CCs are encouraged to question even the most senior of the professional staff (Flight Controllers) if the safety of the spacecraft is at stake. It is only through a sound understanding of a spacecraft's systems that undergraduate CCs become comfortable speaking up, and the knowledge they gain through LASP's Command Controller training program gives them the awareness and confidence to do just that.

Each spring the Mission Operations team selects approximately 10 undergraduate students from CU to train and work as CCs. Candidates must have a minimum cumulative Grade Point Average of 3.0 and at least 2 years left in their undergraduate work to be eligible for the position. CCs are selected based on an in-person interview and the recommendation of 1-3 professional references. While the majority of students who apply are Engineering majors, all backgrounds are welcome as long as they meet the stated criteria. The Mission Ops team selects only those candidates who are responsible and mature enough to handle the job of supporting our on orbit assets, and those who successfully complete the program are eager to meet and exceed the expectations placed upon them.

III. Command Controller Training

Command Controller training takes place over 10 weeks from late May to mid-August. Students spend 8 hours a day, 5 days a week in training both in and out of the classroom. Due to the limited nature of their time at LASP, CCs are trained on all 4 of our spacecraft to allow for easier backfill when staffing gaps arise. It is a vast amount of knowledge to transfer in a very limited amount of time so training is a very structured affair.

Training consists of classroom instruction, hands on application, and small projects and assignments. The material is broken into three phases and projects are assigned throughout to support the lecture material. CCs attend lectures on basic aerospace concepts, LASP specific operations methods, and in-depth, mission-specific training. The in-class instruction is complimented by out-of-the-classroom projects that apply the lectures to actual spacecraft behavior. CCs also learn several programming languages that make the analysis side of their jobs much easier. The hands-on component of the training allows CCs to work on actual NASA missions with close oversight by senior CCs and professionals. This aspect is heavily emphasized as it is vital to understanding how the classroom material applies to the job the CCs are hired to do.

A. Phase I – The Basics

The first phase of training introduces students to LASP and the QuickSCAT, SORCE, AIM, and Kepler missions, with high-level overviews by the missions' Flight Directors (FDs). CCs also learn how to navigate the networks of LASP and how the MOC fits into the NASA network as a whole. Students are immediately introduced to UNIX, the operating system used to support planning and scheduling as well as realtime operations. The majority of the students are completely unfamiliar with UNIX and its command-line interface takes some getting used to. Their first week primer gives the CCs the basic training they need to log in and run the software necessary to do their jobs every day.

Because LASP hires students from all majors it is important to equip them with a context for the job they will be doing. To that end, phase one also provides students with a basic aerospace primer. Lecturers from around the lab come into the classroom and teach topics like Command and Data Handling, Propulsion Systems, and Remote Sensing Techniques. Through these sessions students learn the foundations of spacecraft design and how subsystems work together. The proposal process is also explained along with a mission's life cycle from development to test to launch and commissioning. Attention is placed on subsystem interactions and robust design processes to emphasize considerations necessary when designing and operating a space mission. These lectures are complimented by examples from LASP's missions to highlight how changes in one subsystem can be seen in trending by another (e.g. how routinely power-cycling instruments affects spacecraft heater cycling).

B. Phase II – Operations Overview

With a firm background in basic spacecraft design training moves on to the specifics of spacecraft operations at LASP. This is the point at which CCs learn how commands are routed from the MOC to the spacecraft. Network protocols are revisited with an emphasis on how the MOC interacts with the various antennas of the Ground Network, Space Network, and Deep Space Network. Detailed training in spacecraft data flows compliments this overview and the CCs begin to understand how data is routed to our end users.

During the operations overview students become familiar with the features of OASIS-CC, the interface used to command our spacecraft and receive realtime telemetry, and CSTOL (Colorado System Test and Operations Language), OASIS-CC's control language. To do this, CCs write basic CSTOL scripts to check telemetry points, send commands based on spacecraft conditions, and respond to user inputs. CSTOL scripts are used to execute all command activities during uplink contacts so a firm grasp of the language is essential. Eventually, CCs are expected to be able to read a CSTOL script and understand everything that will or could possibly happen during a contact based on the script's structure and the response seen at the spacecraft. The students' understanding of the CSTOL language is combined with training on OASIS-PS, the software tool used for nominal daily command planning. It is only through an understanding of these two tools that CCs become proficient command planners.

Exercises in uplink pass protocol teach the CCs how to communicate with the Flight Controller (FC) during realtime contacts. Clear communication between CC & FC is vital to the prevention of command errors during both routine and non-nominal spacecraft supports. CCs learn the importance of command verification and the basics of our spacecrafts' command and telemetry systems. At this point, CCs are introduced to the many information resources available to provide more insight on current spacecraft health and safety. The operations overview flows into the next phase of training, where the basics are brought together with the specifics of the spacecraft LASP controls.

C. Phase III – Mission Specific Training

In the third phase of training, CCs learn how each of our spacecraft are designed and operated. One mission is covered per week through lectures and out-of-the-classroom exercises. The Flight Directors give in-depth lectures covering each mission's evolution from launch to present day highlighting the changes in operations over the life of the mission. The student subsystem leads teach the new CCs how their subsystem operates and any special operational considerations to be aware of. Practical exercises teach CCs how to spot the effects of seasonal variations on our spacecraft and how they differ from anomalous behavior. CCs begin to work on projects that demonstrate basic troubleshooting of potential spacecraft anomalies and are given the tools necessary to determine the root cause of any abnormalities in telemetry trending.

D. Training Tools

Each new topic that is introduced is often a very foreign concept for undergraduate college students lacking real-world engineering experience. While lectures are the standard format for much of the training, they really only allow students an introduction to concepts and do not provide a sufficient understanding of how these concepts exhibit themselves on-orbit. In an effort to make the connection between lecture topics and the realities of daily spacecraft operations, the Mission Operations instructors make use of several training methods that greatly enhance the CCs' comprehension of what is usually very advanced material.

One of the main ways trainers gauge the CCs' understanding of new concepts is through the use of a classroom response system. This is an interactive way to engage the students and judge their understanding of new material. At the start of each lecture day students answer 5-15 multiple choice questions with time for discussion and explanation following each. The entire class sees the distribution of answers selected after all responses have been registered so the instructors can discuss with the class the why one answer might be better than another. The interactive discussion highlights the intricacies of the question and gives students a better background for understanding the answer. It also exposes deficiencies in the training and provides opportunities for re-training where necessary. The classroom response system has been a popular and highly effective tool in revisiting and reinforcing new topics from day to day.

Early in the summer the students begin shadowing the senior CCs to gain hands-on experience and familiarize themselves with the day to day responsibilities of their job. At the start of the third week of training, one or two students per day will follow the CC on shift and do everything he or she does. The new students build daily command products under close supervision so they can become comfortable with the process and potential problems. Trainees observe realtime contacts alongside their CC and mimic the CC's activities whenever possible. The shadowing roles are soon reversed and trainees begin running passes themselves with careful supervision from the CC and FC throughout the contact.

Figure 2 – New CCs prepare for certification by shadowing certified CCs

Additional hands-on training comes as the students complete their practical checklists. At the beginning of the summer CC trainees are issued a checklist of approximately 100 practical tasks that they must be able to perform on their own by the end of training. Each task must be explained to and watched by the trainee, and then performed independently before it can be considered mastered. These tasks include things like creating and verifying daily command products, extracting data from an engineering file, and implementation of mission rules. It takes a great deal of time to become proficient at all of the checklist items so students must be motivated to be successful. Checklist completion also encourages interaction with the rest of the Mission Operations team because an FC has to sign each step on the checklist once it has been mastered.

Translating in-class lectures into real-world knowledge application is a critical part of CC training. Without this step CCs will never understand the underlying causes of trends they see in their analyses. To encourage this transition in thinking the training staff regularly introduces small investigative projects that can only be completed by applying the lecture material to unfamiliar spacecraft behavior. These projects are as open-ended as possible, challenging the CCs to use the resources available to them and to think outside the box for their answer. The student trainers initiate these investigations with questions like, "Why has this temperature profile changed?" or, "Explain why this data is discontinuous." These projects are usually completed in teams to mimic the way a subsystem team should work. Ultimately these projects help trainees develop into self-sufficient workers who can attack open-ended problems in the same way as professional engineers.

IV. Command Controller Certification

At the end of the summer CCs are formally certified on all four LASP missions. (Prior to certification, CCs are not permitted to create command products or send commands to our spacecraft without a certified CC to monitor their actions and verify correctness.) Certification requires students to pass three exams over the course of their training summer and successfully complete an oral exam. Failure to accomplish either of these items will result in cancellation of a student's appointment at the end of the summer.

Certification exams each consist of 50 questions which are a mix of short-answer and calculations. The exams test a CC's ability to understand the basics of the classroom lectures and apply that information to their job in operations. They are administered at three week intervals over the summer and are graded on a pass-fail basis. Exams are written from scratch each year and focus on the current state of operations as well as basic knowledge of how the spacecraft work.

If a student passes his or her written exams the oral certification is conducted at the end of the summer. The questions draw directly from the certification checklist items so the tasks should be well practiced by the end of training. Students explain every item on their checklist and the potential risks involved with each. The FC administering the certification introduces twists in nominal scenarios to ensure the CC has a basic understanding of how to react when activities become anomalous. The trainer must be comfortable that the student can competently complete each task on their own before he or she will sign off on a CC's certification.

V. Advanced Student Training

CC training does not end with their first summer at LASP. Because a CC's career lasts for 2-4 years the operations training team has implemented advanced instruction in engineering practices and applications that takes place during a CC's second summer as an operator. The training familiarizes students with DOORS, Earned Value, ITAR practices, and space policy. They are taught advanced technical topics like CCSDS standards and space weather as it relates to spacecraft operations. This is also an opportunity for advanced training on LASP's spacecraft and a chance to delve into the more complex aspects of operations that are sometimes missed by first-year students.

During this summer CCs also prepare failure analysis reports for past NASA missions. The CCs are divided into small groups and assigned a specific project to research and present to the entire operations team. The groups describe the mission failure and explain the root cause and how it could have been avoided. The CCs extract lessons learned from these failures and apply them to how LASP does business in order to identify areas for improvement in our operations.

VI. Flight Controller Training

While Command Controllers are hired in a batch once per year Flight Controllers are hired on an as-needed basis throughout the year. FCs are only assigned to one or two missions so their training is much more individualized than that of the CCs. New FCs work closely with their mission's Flight Director during their training to develop a detailed understanding of the mission to which they are assigned. Despite this more fine-tuned approach, FC training leverages heavily off the CC curriculum. Whenever possible, new Flight Controllers participate in the operations overview week, as this introduces them to MOC-specific software packages and LASP's unique way of doing Mission Operations. New FCs also participate in subsystem specific CC training for the mission(s) to which they are assigned. If timing does not allow this, they are provided with the slide packages to study on their own time.

FC training also uses shadowing techniques to teach realtime activities. FC trainees start by shadowing the CCs during contacts to get a firm grasp of the mechanics of a realtime support. Like CCs, they progress to commanding the spacecraft themselves under the watchful eye of both certified controllers. Trainees then move on to shadowing the FCs during supports and finally into the driver's seat. This shadowing progression ensures that new FCs understand the full flow of realtime supports and are comfortable with all aspects.

Flight Controller trainees have a practical checklist similar to the CCs' with a detailed list of topics a new FC needs to understand in order to do his or her job. The operator is expected to research these topics in depth and consult with their Flight Director to clarify complex material. Through this regular interaction, the FD easily gauges when a new FC is ready to be certified (usually after 2-3 months).

The Flight Controller certification process involves both a written exam of short answer questions and an oral practical exam. The practical covers activities that a certified FC must be able to complete quickly should the need arise. As with the CC certification, practical tasks are taken directly from the FC checklist. Possible duties include scheduling a TDRSS support, starting an automated connection procedure, or navigating between the planning and operational networks to retrieve command products. When the certification process is complete, the results are reviewed with the FC to clarify any areas of confusion.

VII. Continued Training, ORBs, and Recertification

The MOC's operations concepts are adjusted routinely in response to the degradation of an ageing spacecraft or when developing a new, better way to perform an old task. Because of this, continuous retraining is essential to keep the FCs and CCs up to date on the current method of operations. This is primarily accomplished though instruction during the weekly All-Hands meetings where the state of each mission is reviewed in detail. All members of the operations team attend this meeting each week and notes are issued as a record. The All-Hands meeting is the easiest place to explain changes in operations as it reaches the entire ops team and provides time to answer questions operators may have regarding these changes.

When significant modifications are made to an ops concept they are also reviewed in detail at the weekly Flight Controllers' meeting. These types of changes are typically accompanied by an Activity Change Request (ACR), a standard form that explains and authorizes deviations from routine operations. When ACRs cover a long-term change or direct a new routine activity they become Standing Activity Change Requests. Flight Controllers are required to initial each of these Standing ACRs to indicate they have been trained on them and understand when and how to execute them.

A. ORBs

Mishap review and prevention often drives retraining not related to spacecraft degradation. When an operator-controlled incident occurs that puts our spacecraft at risk (e.g. an error in commanding, a change in a telemetry trend that went unnoticed) an Operational Review Board is held to assess the cause and determine if corrective action is needed to prevent a similar situation from occurring in the future. The ORB team is comprised of the QuikSCAT, SORCE, AIM, and Kepler Flight Directors, the Mission Operations Lead, the Director of the Mission Operations and Data Systems division, and the Training Lead. Whenever possible, the FC and CC on duty at the time of the incident also participate in the ORB. The individual at the center of the incident documents what happened and how the event could have been prevented. The board provides input on the situation and attempts to identify any other areas for potential mishap relating to the event. When the board has compiled their findings an overview of what happened and any lessons learned are presented to the team at the weekly All-Hands meeting. The entire ops team reviews all ORBs occurring in the past year annually to keep these incidents fresh in everyone's minds with an aim to preventing their recurrence.

B. Recertification

FCs and CCs are required to recertify on a yearly basis. CCs recertify during the summer by taking either the second or third exam given to CC trainees. FCs are recertified each January by completing an abbreviated version of the written FC exam for their mission(s) and performing the practical portion of the original FC certification. Questions on the exam and practical are revised annually and special focus is placed on major changes to operations over the past year. FCs and CCs unable to successfully complete the recertification process are subject to retraining and possible termination.

VIII. Conclusion

In an ever changing operations environment with a high turnover rate operator training is never finished. The LASP Mission Operations team has implemented several techniques to train new operators and keep veteran operators current. The training and development students receive during their time with LASP's Mission Operations group allows them to transition into the professional world leaps and bounds ahead of other new graduates. Students are expected to operate as junior professionals by the end of their tenure at LASP and their continued on the job training ensures their success. LASP's Flight Controllers posses a detailed knowledge of how our spacecraft function, and this expertise allows for quick and effective response when presented with anomalous situations.

The continual retraining required in this dynamic environment cannot be effective without motivated team members who take pride in the work they do. The Flight Controllers' and Command Controllers' job descriptions are constantly changing and their willingness to adapt to these changes is vital to the success of the team as a whole and the missions LASP supports. An educated and willing workforce is the true key to the success of a Mission Operations Center. By frequently revisiting subjects and striving to make our processes as well-understood as possible LASP provides the comprehensive training that is vital to both maintaining a skilled team of operators and producing the talented spacecraft engineers of the future.

Appendix A
Acronym List

ACR	Activity Change Request
CC	Command Controller
CSTOL	Colorado System Test and Operations Language
CU	University of Colorado
FC	Flight Controller
FD	Flight Director
LASP	Laboratory for Atmospheric and Space Physics
MOC	Mission Operations Center
OASIS-CC	Operations and Science Instrument Support Command Control
OASIS-PS	Operations and Science Instrument Support Planning and Scheduling
ORB	Operational Review Board
TDP	Telemetry Data Processing
TDRSS	Tracking and Data Relay Satellite System

Acknowledgments

I would like to thank Katelynn McCalmont and Danielle Richey for their tireless efforts and invaluable contributions to the summer training program. To Jack Faber, thank you for your guidance and ongoing participation in CC training. Thank you to Sean Ryan, who continues to push to make each year of training better than the last. And finally to LASP's Command Controllers, past and present, thank you for providing me with the opportunity to be a part of your education. As always, I succeed when you succeed.