A Mission Operations Staffing And Training Plan For Small Satellites In A University Environment

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Abstract:

As with any spacecraft, competent and efficient mission operation is a necessity for small satellites. The need for efficient use of staff resources is even more important in a university setting than in industry, due to the time limitations inherent in students' academic schedules and the monetary limitations of academic organizations. Additionally, efficient staffing structure, coupled with proper training and mission simulation, increases the probability of mission success by reducing reaction times to system failures, ensuring correct responses, and providing for thorough and timely analysis of engineering and science data. Finally, if training, simulation, and operations are conducted properly, these can be an excellent educational experience for any student involved. This plan incorporates lessons learned in American manned and unmanned spacecraft operations over more than four decades, adapted for application in an academic environment, including methods for evolving small satellite mission operations from launch to an extended mission of several months.

Introduction

The Unites States space program is now in its sixth decade of existence in what is and continues to be a long and distinguished history. In that time, significant experience has been gained in the field of spacecraft operations, both manned and robotic. As with anything else never before attempted, the first efforts at this were not always perfectly successful, but this was only a natural part of the learning process.

Spacecraft mission operations changed drastically from 1961 through 1967, as NASA strove to land the first man on the moon with the Apollo program. A new philosophy emerged, due to the immense importance of accomplishing the goals of each mission in reaching the moon before President Kennedy's deadline of December 31, 1969. This philosophy can be summed up in the words of the long-time NASA flight director Gene Kranz: "Failure is not an option." Over the decades, mistakes have been made, and they will continue to be made, but it is the design of the mission operations system and the training, determination, and skill of the people in the program that ensure overall mission success.

While operations of a small satellite are not nearly of the same importance or magnitude of that of manned space flight, many of the same lessons learned there can be directly applied and can serve as the foundation of a robust mission operations plan for implementation in an educational environment. The staffing and training plan detailed herein incorporates elements of both manned and robotic space flight mission operations since the flight of Alan B. Shepard in *Freedom* 7 in 1961, adapting the lessons of past programs to produce a system that addresses the specific needs of a university environment, as well as issues unique to small spacecraft operations.

Motivation

Since Citizen Explorer 1 (CX-1) will be the first satellite operated by the Colorado Space Grant Consortium, success of that mission will be crucial to future reputation of that organization. However, being first also means that the organization has little experience with mission operations, and, therefore, much has needed to be designed from the ground up. There are many challenges new to the Colorado Space Grant Consortium (CSGC) in the Citizen Explorer program, including extended operations and limited communications[1]. Dealing with these factors in an environment so dependent on student time constraints and a small budget requires new and creative solutions to these challenges.

Objectives

Design of the mission operations staffing and training plan for a university satellite program must be driven by the following goals.

- Provide for successful mission operations, ensuring that all goals of the Mission Operations team[2] are met.
- Enhance the educational experience of students participating in the program.
- Reduce cost of operations to maintain budget flexibility.
- Reduce required daily time commitments of student personnel in order to accommodate class schedules.
- Quickly solve any problems that may arise with the spacecraft or the operations system.
- Achieve efficient and thorough planning prior to real-time operations.
- Evolve autonomous operations, facilitating transfer of operations workforce to future projects.
- Represent the best traditions of space mission flight control.

Each of these goals has been addressed in the design of the Mission Operations staffing and training plans for CX-1.[3,4]

Mission Operations Staffing[3]

CX-1 Mission Operations will consist of nine subdivisions of personnel, including planning, real-time operations, communication operations, science operations and analysis, systems analysis, data processing, systems maintenance, operations supervisor, and early orbit support. Students working in each of these subdivisions will be required at various times prior to and during the CX-1 mission. The following sections will summarize the roles of each subdivision, as well as the time commitments involved with each.

Mission Operations Manager

The Mission Operations Manager (MOM) will be the final authority on all operations activities, including team management, real-time operations, and activities of members of other subsystem teams participating in spacecraft operations. The MOM will determine the goals to be achieved during operations, overseeing team member training, reviewing mission operator performance, and certifying mission operations personnel for various positions within the Mission Operations team. There will be only one MOM at any one time, and preferably only one for the duration of the mission. The MOM will also be qualified to serve under any position in the Operations team. This person will be required to work daily to oversee operations, training, and, prior to launch, mission simulation. NASA experience with space operations has shown that a single person overseeing all operations, slightly removed from low-level activities, can provide a stabilizing force for the Operations team, as well as providing unified leadership and a single final authority for operations. In the Apollo program, Christopher Kraft served in an analogous role as the head of the NASA Mission Operations Directorate.[5]

Planning

One person, the Mission Operations Planner, will be responsible for determining the sequence of events for each day, week, and month of operations. In coordination with management and Mission Operations and Systems

Engineering leadership, the planner will document the desired high-level goals for month and week timescales, and lower level sequences of events in each day of operations. The CX-1 staffing plan calls for daily meetings involving all members of the Mission Operations team, led by the planner, in which attendees will discuss the high-level goals for that day of operations, any problems in previous shifts that need to be addressed, and specific schedules of activities to be performed during real-time communications with the spacecraft that day. Final decisions will be made through consensus of the planner and Mission Operations Manager.

Real-Time Operations

Real-time operations will consist of all activities during, in preparation for, and following communications passes and simulations with the spacecraft that specifically involve sending commands, receiving telemetry, and real-time engineering data analysis. These personnel will send commands to the spacecraft, receive engineering telemetry data, and perform real-time assessments of the spacecraft status. This may include making modifications to the predetermined sequence of events as the situation dictates, solving problems with the spacecraft, and consulting other team members as necessary to facilitate these tasks. This group will operate in two shifts of four hours each per day. This schedule is designed to allow the majority of students to serve in these roles, as four to five hours (including the planning meeting and pre-communications briefings) every few days do not constitute an extraordinary time commitment. Real-time operators for each shift will include a shift supervisor (Flight Director) and a Command Controller. The Flight Director will make all final decisions regarding commands to be sent to the spacecraft, as well as software to be uploaded and problem troubleshooting. Because no single person can know everything about a spacecraft, especially in an operation so heavily involving full-time students, the Flight Director will rely in large part on input from every other team member as well as project documentation from each subsystem team. The Command Controller will focus entirely on actual interaction with the spacecraft graphical user interface[2] and other methods of communicating with the spacecraft (i.e. telnet, ftp, and SCL windows[2]). This person will operate all software necessary for real-time operations and send spacecraft commands. All real-time operations personnel will interact as necessary with Communication Operations personnel (described below) to maintain contact with the spacecraft during communications passes. The importance of a Flight Director has been shown time and time again during the manned space flight program in situations that demand quick and crisp decision-making. This will be applied in the CX-1 program, although the number of other real-time personnel is far smaller than in other spacecraft operations situations, due mainly to the availability of time for the student participants and the small scale of the operations involved.

Communication Operations

At least one person from the communications team will be responsible for operating the ground station hardware, including the radio transceiver, antenna and related equipment. This will include updating computer records of spacecraft orbital elements and operating the software that commands the antenna tracking hardware. This also involves communicating with real-time operations personnel to keep them apprised of the status of the communications link, as well as communication with remote ground station personnel at the Fairbanks, Alaska site being used for remote operations. The Communication Operator will be required to serve at the same times as real-time operations personnel and will be required to obtain an amateur radio license, as he/she will be the person directly in control of the ground station radio equipment.

Science Operations / Analysis

For analysis of the CX-1 science data, two people from the Science subsystem team will be required daily to analyze downlinked science data, verifying the data by comparing it to data from other sources, and analyzing engineering data related to the science instruments to determine the performance of the instruments. This activity could involve more students in order to educate more participants, or, if the need arises to divert personnel resources to other projects, the minimum of two could be maintained.

Systems Analysis

Two Systems Engineering personnel will be available on-call to deal with any problems with the spacecraft that cannot be solved by real-time personnel through application of project fault management procedures (fault trees). This includes determining the cause of symptoms evident in engineering telemetry data, consulting subsystem team personnel is necessary, finding a solution, and consulting with the MOM, planner, and real-time personnel to develop remedy or work-around procedures as soon as practical. It is desirable that this be accomplished prior to the subsequent communications pass, such that the problem could be solved as soon as possible, thus minimizing any deleterious effects on the spacecraft. This would be similar to mission control "back rooms" present in NASA mission operations. While the active operations personnel can in all likelihood deal with the majority of spacecraft problems, other personnel are often needed to research a problem and develop solutions while real-time operations personnel continue to operate the spacecraft.

Data Processing and Systems Maintenance

Each of these positions will include one person working daily in the case of Data Processing and weekly in the case of Systems Maintenance. Data Processing personnel will be responsible for maintaining and processing Ground Operations software, including the systems that collect and store data from remote ground sites and archive telemetry data. Systems maintenance personnel will maintain the mission-critical computer systems used for operations, including the workstations on which the graphical user interface and other operations software will be run. Both these tasks are critical for keeping the mission operations system stable, reliable, and complete. Systems maintenance personnel will also be available on-call, in the event that computer systems fail in such a manner as to potentially hinder operations.

Early Orbit Support

For the initial portion of mission operations, additional support may be necessary during this period of potentially more frequent spacecraft and operations problems. One additional person at minimum should be present for real-time operations during this period for general assistance to the Flight Director and Command Controller. Often in spacecraft operations the number of personnel involved in operations decreases as the mission progresses and the situation becomes increasingly stable. Commonly, the more senior personnel continue to other projects, while junior personnel hone their skills and increase their experience with stable and mature programs. This would be an ideal educational and training scenario in a university environment, in that subsequent projects could be undertaken and systems designed while operations on the current project continues. This follows the history of the NASA manned space flight program, in which mission operations personnel routinely moved on to evolving projects in the later stages of a previous project, as in the case of the transition from Gemini to Apollo.[5]

Training and Mission Simulation[4]

Prior to conducting mission operations, each member of the Mission Operations team (including supporting personnel as described above) should complete a course of training regarding spacecraft systems, operations procedures, use of operations systems, and other information specific to each operations role. This would consist of a series of lecture sessions, mission simulations, informational readings, and certification testing. Lectures would cover both general spacecraft and operations information useful to every member of the team, as well as smaller sessions focusing on specific operations roles, such as procedures for conducting real-time operations or holding planning meetings. Additional training would include the operations team member reading documentation about various software and hardware systems, both in ground systems and on-board the spacecraft. This could include working through tutorials or completing worksheets as well. While this training will be in addition to regular schoolwork, it provides a hands-on education that is seldom encountered in classes. Training will provide immediate feedback to students regarding the applications of subjects being taught, which would likely increase students' interest.

In addition to its role in system verification and validation testing, mission simulation serves as an invaluable training tool. Simulation ensures that mission operations personnel will be prepared for actual operations, including many possible non-nominal scenarios. In nearly all spacecraft programs, both manned and robotic, training involves dealing with many different types of operations scenarios that might be encountered. To save personnel resources, insertion of anomalies into the simulation system could be automated, rather than the manual system that has been used in the past. In current and past NASA programs, several test conductors have operated the simulation from remote consoles in an attempt to foil the operations trainees, but, due to limitations both in personnel and in computer resources, this can easily be performed by preprogrammed scripts to insert simulated anomalies.

Because CSGC does not currently have any method of accurately simulating CX-1 independent of the flight hardware, the initial simulation will consist of actual interaction with the spacecraft, but this will provide valuable experience with the same systems to be used in operations, as well as finding systems problems before launch.

The final stage in training for a given operations role will be certification of the trainee to serve under that role without supervision. This will include a series of oral, written, and practical (mission simulation) examinations, conducted by senior team personnel, including the team lead (likely the MOM), or other previously certified personnel. Oral exams would include a series of questions regarding procedures and systems knowledge, where the desired responses would reflect a sample all information presented during training. Written examinations would cover similar topics, while practical tests would consist of a portion of an operations shift, including a representative portion of the training material. Practical examinations will include both nominal operations and troubleshooting scenarios in order to assess the trainee's responses to varying conditions and spacecraft responses. While this testing might seem to simply be additional exams during the school year, but the value of this type of certification cannot be overstated. It is essential that every person operating the spacecraft be trustworthy with the systems involved, such that additional personnel would not be needed for supervision. The savings in personnel resources that would otherwise be spent training operator candidates during actual operations would more than make up for the work spent conducting this training program. Additionally, in an institution for which each program is so important, one cannot risk mission failure due to inadequate training and competence of operations personnel. In industry, government, or education, training such as described above is considered extremely valuable, and exposure to this material at the undergraduate level would be a rare and important contribution to students' experiences and education.

Conclusions

The plan outlined in the preceding sections can provide a mission operations and training system for small satellite operations, utilizing a minimum of personnel resources while maintaining the level of technical and organizational competence crucial to mission success. This plan also minimizes cost to the educational institution, in that each participant, trainee and manager alike, is a student, as well as the fact that this plan does not require extensive facilities or equipment beyond that necessary for basic spacecraft operations. The only additional equipment would be basic presentation materials and classroom resources common to any institution of higher education. No computing resources beyond those used for real-time operations would be necessary, in that those tasks performed at other times could easily use the same workstations. The launch and subsequent operations of the CX-1 mission in late 2002 will show the effectiveness of this system, and a similar system will be used for operations of the Three Corner Satellite project, to be launched in 2002 or 2003, also to be operated by CSGC.

References

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