110805 N95-17220

3777

p. 9

The Role of Mission Operations in Spacecraft Integration and Test

Raymond J. Harvey
Johns Hopkins University The Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20723

Abstract

The participation of mission operations personnel in the spacecraft integration and test process offers significant benefits to spacecraft programs in terms of test efficiency, staffing and training efficiency, test completeness, and subsequent cost containment. Operations personnel who have had real-time contact experience and have been responsible for the assessment of on-orbit spacecraft operations bring a unique view of spacecraft operations to pre-launch spacecraft test activities. Because of the unique view of the spacecraft/ground interface that experienced operations personnel have, they can propose optimum test approaches and optimum test data analysis techniques. Additionally, the testing that is typically required to validate operations methodologies can be integrated into spacecraft performance testing scenarios.

Introduction

Experienced mission operations personnel bring the unique view of operating a spacecraft to the integration and test (I&T) environment. Not only does the experienced mission operations person understand the functionality of the spacecraft at the system level, but also how the overall system will be operated after launch in the areas of mission planning, control, and assessment. Since these three functional areas of mission operations may be directly applied to integration and test, not only does this benefit the integration and test effort, but the mission operations effort as well, through validation of the operational concept, better training, and the practical experience of actually operating the spacecraft prior to launch. The participation of mission operations therefore benefits the entire program in both short and long terms in testing and operations efficiencies and the associated reduction in costs.

There are many different aspects where the mission operations personnel contribute to the integration and test effort from conceptual design of test procedures (planning), to the conduct of the test (control), and to the evaluation of the test (assessment). By involving these aspects of mission operations, the entire team may become involved in the various phases of testing. In addition to supporting the I&T effort, this process provides the opportunity to increase the coordination and communication within the mission operations team itself. In preparing for a spacecraft mission, the operations personnel are acquiring knowledge as to the capabilities which the spacecraft possesses, how these capabilities must be tested and validated during the early on-orbit checkout phase, and how to evaluate the performance of the spacecraft

Raymond J. Harvey is a member of the JHU/APL senior professional staff

throughout the mission. This knowledge and the experience from previous missions make operations personnel valuable assets to the integration and test effort.

Mission operations involvement also promotes spacecraft design optimization. The mission operations team knows how the spacecraft is "supposed" to operate. Their involvement in integration and test will demonstrate how the spacecraft will "actually" operate. In many fortunate cases, operations personnel can recommend subsystem modifications, if early enough in the process, such that on-orbit operations are more efficient and the mission operations development less complex. Obviously, for this to actually be effective, a certain amount of flexibility in the spacecraft design must exist, as well as a willingness on the part of program management to make modifications late in the spacecraft development process. From the program standpoint, however, it is often advantageous to implement the recommended changes, where time permits, to enhance the operational efficiency of the spacecraft over the course of the mission and potentially reduce lifecycle cost.

As summarized in Figure 1, there are many different aspects from which contributions may be made by the mission operations personnel in exchange for the invaluable experience gained by working with an operational spacecraft prior to launch. These aspects will be discussed below with practical examples provided where applicable.

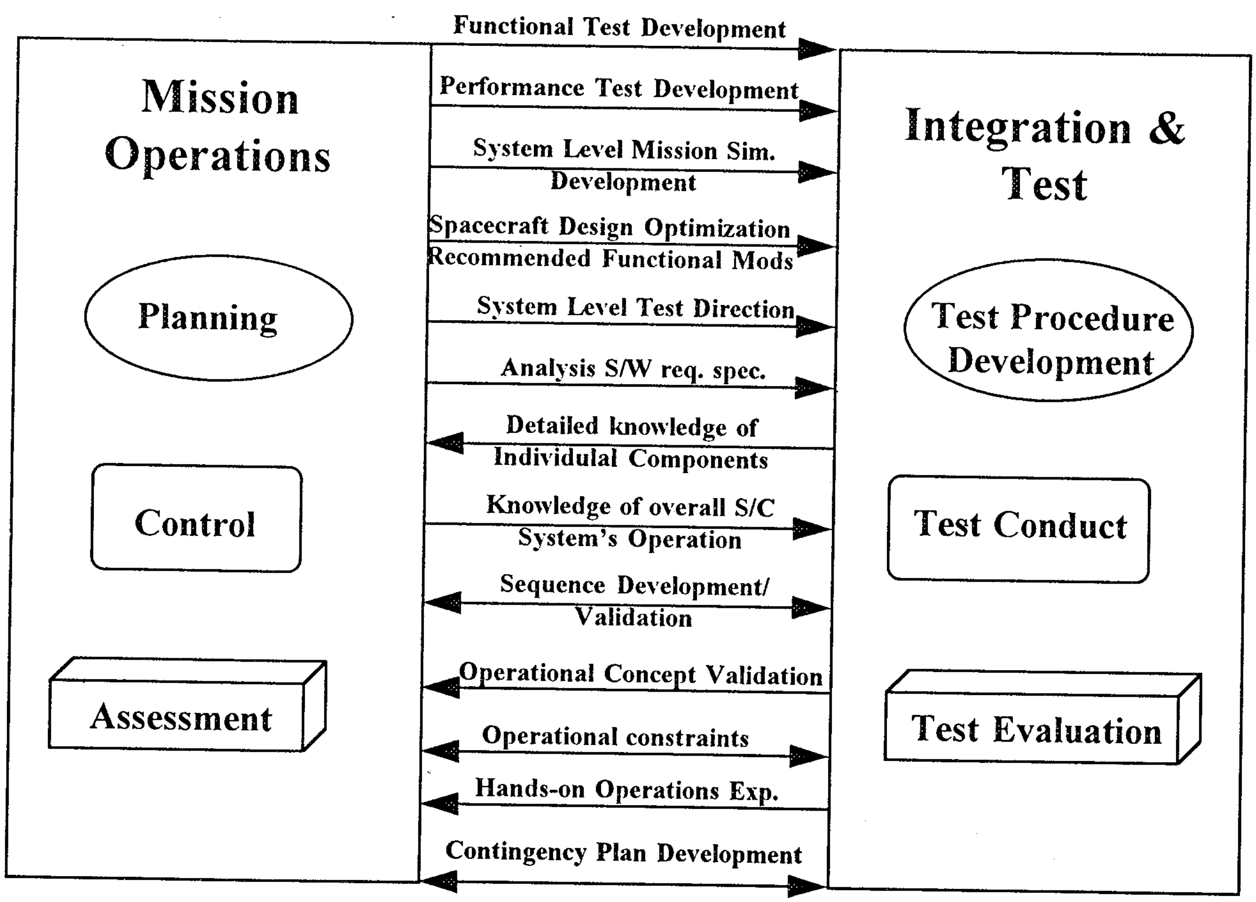

Figure 1: Mutual Benefits of Mission Operation's Role in Spacecraft Integration and Test

Mission Operations Involvement in I&T

Involvement of the mission operations team in I&T provides invaluable experience in many respects. It not only increases their knowledge of the spacecraft, validates their operational concept, capability, and command sequences, but it also benefits the I&T effort as well as the entire program. Many of the different roles within mission operations can be exercised by being involved with testing the spacecraft at the systems level. The different roles within mission operations are able to participate in the testing effort in different respects. These various roles come from the planning, control, and assessment teams. One of the planning team members is the "operations coordinator" (Marshall et al., 1992), who works with the program sponsor and PI teams to define how the spacecraft will be utilized on-orbit. Also from the planning team are "spacecraft specialists" who focus on the design and operation of the spacecraft and bring that knowledge to the mission operations team. The "spacecraft specialist" is the primary interface between the operations team and the spacecraft engineering design team. The mission operations control team provides the "mission controllers" who operate the consoles in performing the uplinks and downlinks to and from the spacecraft and monitor its state-of-health. During post-launch activities, the "spacecraft specialists" become the mission operations assessment team. The role of this team is to perform monitoring and trending of the spacecraft's health and status as well as to lead in the investigation and resolution of anomalies. This application to I&T is in test evaluation.

Participation of the "operations coordinators" provides the mechanism to use the mission operations planning system to design, develop, and generate command sequences that will subject the spacecraft to a post-launch type scenario. They also participate in the test evaluations to determine whether their instructions to the spacecraft produced the desired effect. This creates an optimum method of system level spacecraft testing as well as a chance to validate the planning team's capability of creating the scenarios and commanding the spacecraft to perform the scenario.

The involvement of the control team members include conducting the test, monitoring its progress in real-time, and identifying anomalies, just as they will be involved post-launch. Similarly, the assessment team members become involved in the real-time monitoring, post-test evaluation, and anomaly identification, investigation, and resolution. By the "mission controllers" and "spacecraft specialists" encountering actual spacecraft telemetry while the spacecraft is powered and operating within nominal ranges, they are able to experience how it responds to particular commands and sequences as well as how the spacecraft will operate within its design capabilities. This is especially advantageous when the involvement is during spacecraft environmental testing. This provides them with a baseline by which to evaluate the spacecraft's state-of-health, and to assess the performance of the spacecraft during post-launch operations. This information is highly critical to the mission operations team where they are a separate entity from the engineering design team, as is the case in many missions, including those at JHU/APL. In these cases where those who designed, built, and tested, do not operate the spacecraft, the "hands-on" experience is even more invaluable.

Another significant benefit from mission operations team participation in the testing efforts is in the area of contingency plan development. In many cases during spacecraft testing when anomalies are encountered, contingency plan development occurs on the spot, in real-time. From there it is a matter of refinement.

Another important aspect involves acquiring knowledge and understanding of spacecraft operational constraints. The operations personnel also are in a better position, while participating the I&T, to recognize operational constraints and requirements at the system level. The "spacecraft specialists" typically maintain this type of information and have a better appreciation and understanding of what occurrences in the I&T process should be construed as operational constraints and work-arounds.

Mission Operation's Involvement in Functional, Performance, and System Level Test Design and Conduct

The acquired knowledge of the complex spacecraft design and operation by the mission operations personnel give them a distinct advantage over the integration and test team. By the time integration and testing begins, the I&T personnel typically have not concentrated on how to operate the spacecraft as a system, but as individual components. This insight on the part of the mission operations personnel provides them with the broader view of the spacecraft's capabilities and their intended use on-orbit. This is valuable when defining the functional and performance related tests which will be performed throughout the testing process. Since the capabilities of the spacecraft are understood by the operations personnel, they provide a unique perspective on which capabilities exist, the fact that they should be tested, and recommend how they should be tested. On a previous mission, numerous meetings were held to determine how to test the various components when delivered to the spacecraft. The lead subsystem design engineers were to present the testing requirements. In many cases it was difficult for the lead engineers to recall all of the subsystem capabilities without including the entire design team in the discussions - a very time consuming process that distracts the team from completing the final design. In these meetings, it proved beneficial to involve the mission operations personnel because they understood all of the capabilities required of the spacecraft after launch, thus requiring pre-launch testing.

For the definition of system level tests, mission simulations provide an optimal method of including the entire spacecraft. These mission simulations involve placing the spacecraft through the same sequence of events that would be required of it in collecting data post-launch. These mission simulations may be generated by the mission planning team's operations coordinators who have been working with the program sponsor and Principal Investigators (PI) in defining how the spacecraft will actually be used post-launch. They can bring this point-of-view to the testing effort and provide actual command sequences to perform the mission simulations. This not only tests out the planning system's ability to accurately generate these command sequences, but it also subjects the spacecraft, at the system level, to typical scenarios it will experience throughout the mission. This also demonstrates to the I&T team and design engineers supporting the effort, how the spacecraft will be used post-launch. In many cases on a previous mission, this type of exposure to actual operations, made the experts re-evaluate how their systems were actually commanded. This resulted in command sequence modifications in the I&T effort as well as the mission operations area.

An interesting aspect of mission operations participation in testing arose on a previous mission where the planning team's test scenarios were not constructed exactly as intended. In some cases the spacecraft was subjected to a more stressing case, thus actually improving on the test. The planned cases were eventually run; however, the slight deviation served as a more optimum test. This was initially thought of as a negative aspect, but when it was realized that no harm could be done to the spacecraft, it was viewed as a positive feature.

On a previous mission, certain more stressing test scenarios developed by the mission operations team were incorporated into the formal spacecraft baseline performance test that was conducted at various times throughout the I&T process, to prove that the spacecraft met the on-orbit mission requirements.

Mission Operations Involvement in Test Evaluation

Evaluation of the tests defined by the mission operation's "spacecraft specialist" team is analogous to post-launch performance assessment. Again, these tests are system level tests and require evaluation by individual support teams as well as mission operations. However, in order to evaluate the test, knowledge of the objectives is essential. The person developing the test case must convey to the supporting teams these objectives and coordinate accumulating the results and disseminating this information to the appropriate teams. In filling this role, mission operations personnel are not only directly involved with the performance assessment of the spacecraft itself, but also the evaluation of how close the planning process came to modelling how the spacecraft would perform that particular case. This provides the "operations coordinators" with feedback on their planning models and the "spacecraft specialists" with additional insight into what is involved in assessing spacecraft performance.

When the system level tests described in the previous section were to be executed, there was not one person on the integration and test team who completely understood the objectives of the test and therefore no one could realistically evaluate how the spacecraft system performed. The mission operations personnel understood the objectives since they defined the test, and therefore stood in a good position to direct the test development, execution, and evaluation. Particularly during the conduct of the test, when anomalies arose, someone understanding the test was required in order to be able to assess the situation and decide if particular anomalies could possibly be show-stoppers. In these cases, the mission operations person was relied upon for such evaluations. This not only increased the knowledge of the mission operations person, but provided an added benefit to the integration and test team, in that they were not required to dedicate a systems level person to learning and understanding the fine details of each test. In many cases, the mission operations representative kept the effort progressing when anomalies arose. By knowing the detailed objectives of the test from a systems perspective, the mission operations person was able to search for work-arounds to continue testing, as opposed to one team investigating the anomaly and the other teams watching and waiting. This allowed portions of the testing to proceed amongst the other teams while troubleshooting continued. The "hurry-up and wait" mode not only wastes valuable testing time of the spacecraft itself, but also that of the engineers and technicians providing support. If the mission operations person, with their unique perspective, can provide recommendations and suggestions on how to proceed, they again benefit the entire testing effort.

Mission Operations Contributions to Ground Support System Development

A basic understanding and knowledge of how the spacecraft is operated, previous operations experience, and the ability to foresee how the spacecraft will actually be used on-orbit, enable the mission operations personnel to assist in the development of ground support system requirements, mainly in the areas of software. (The ground support system refers to the hardware and software used by the I&T team to test the spacecraft. It consists of the necessary elements to develop test scripts and command sequences, conduct tests, and to monitor and evaluate the performance of the spacecraft). Obviously, for every capability that a spacecraft possesses, there should be a way of testing that capability, and evaluating the performance of that test. In many cases, special ground support software must be developed to provide the capability to control the spacecraft a particular way.

Because of their viewpoint of how the spacecraft could and would be operated, mission operations personnel on a previous mission specified requirements for software tools to be used mostly in the areas of test evaluation and performance assessment. These types of tools were used in the integration and test effort not only to validate the spacecraft capability but also in troubleshooting anomalies. Some particular examples are described below:

<u>Command Execution Verification</u> - A post-launch requirement of verifying that every command in a stored sequence executed as expected, drove a software requirement for such a utility. This utility, in development for post-launch operations, was used extensively in evaluating system level performance tests. This software read a planned command sequence and for each command, accessed a look-up table for the appropriate telemetry parameters required for functional verification of each command. The software then accessed telemetry parameters from an archive file of raw telemetry and converted that telemetry from the appropriate time frame to engineering units for verification of proper command execution.

<u>Command History Decoder</u> - This tool was developed for mission operations such that command replicas downlinked in telemetry were reconstructed into a readable format. The mission operations personnel, recognizing the need for such a tool after launch, proceeded to have software developed to perform this task. This software was in turn made available on the GSS for the I&T team's use during testing to verify proper command system functionality.

<u>History Buffer Decommutation</u> - On a previous mission, there were several buffers which contained historical information concerning the health and status of the spacecraft. At the I&T level however, there was not an easy method of determining the contents of these buffers after they were downlinked (the only method consisted of manually decommutating raw data formatted in hex separated by minor frames). These tools, once in place, were used during the I&T process not only to verify the functionality of the buffers, but in reconstructing events on the spacecraft, particularly in the area of anomaly investigations. Particular buffers for which display capabilities were developed are briefly discussed below:

Autonomy - on this spacecraft, the command system had the capability of being programmed with rules which instructed it to monitor raw telemetry and perform comparison operations to determine if the telemetry showed to be in violation of a rule. If it was determined to be in violation, then the command system would execute a pre-defined command or command sequence. Rules were defined to safe-guard the spacecraft. The only method of determining the contents of these autonomy rules were to downlink a particular region of the command system's processor memory. There was no method of visualizing the contents of the rules without decommutating the raw data. Software was developed to read this raw data and convert it to a readable table. This tool was essential, in that the only way to determine which rule "fired" was to dump this region of memory and compare several counts. This software tool performed this comparison.

Orbit Memory - this buffer stored a subset of critical housekeeping telemetry parameters on a routine basis, to provide a continuous record of performance assessment trending. This buffer was downlinked through a particular telemetry format. The operation of this buffer was verified by the I&T team by using the manual method of decommutating raw data. This was acceptable for testing this capability, but not acceptable for using the data after launch to perform trending of these critical parameters. At the request of mission operations, this capability was designed into the GSS and was used in the I&T process to test the buffer's capability and used post-launch, for performance assessment trending.

Attitude History - this buffer routinely stored the spacecraft's attitude, such that while the on-board recorder was not in use and the spacecraft was outside of a station contact, the attitude would be known for that instant. This could be used to assess whether the spacecraft was maintaining the proper attitude orientation throughout the orbit. A capability was also designed into the GSS at the request of mission operations to access this data through a particular downlink telemetry format for use in verifying the spacecraft capability during I&T and for post-launch performance assessment.

Ephemeris Load Data Structure - although not particularly a buffer, this data structure contained the latest ephemeris that was uplinked to the attitude determination and control system. During system level testing, the spacecraft was loaded with an ephemeris such that the attitude system could be used in a mission simulation. These ephemeris loads were critical to the testing effort and therefore were routinely downlinked for verification of proper storage on-board. Again, the mission operations team defined the requirements and method of decommutation of this information such that it could easily be displayed and interpreted on the GSS.

Other software tools developed in support of the mission operations team were supplied to the I&T effort. These included a method to construct autonomy rules from a table which defined the input parameters. The format for these rules was complex such that a tool was required in order to create the rules with confidence of correctness. Another tool allowed for the autonomous comparison of a loaded rule with an image on the ground as opposed to inspection, to verify that it had been installed properly. A similar tool was developed to monitor the status of the rules. In providing these various tools to the I&T team, testing efficiency was increased.

Mission Operations Contribution to Spacecraft Design Enhancements

The involvement of mission operations personnel in the integration and test effort can result in an improved spacecraft. With their previous experience and their pre-launch involvement in the I&T process, the members of the mission operations team are in a good position to recommend modifications to components, where applicable and possible, to enhance the performance of the spacecraft post-launch.

On a previous mission, this proved to be particularly beneficial in several areas. Because of the mission operations "spacecraft specialists'" involvement in the system level operation of the spacecraft, they could anticipate the effect of one subsystem's capability on the entire system's performance. In a particular case, it was known that the solar arrays rotated at a particularly slow rate. The attitude system was designed to control the position of the arrays such that they could independently track the sun within a certain range. It became apparent during I&T simulations that solar array position control ceased while the spacecraft was in eclipse. This was because the attitude system positioned the arrays based on the measured sun direction derived from sun sensor inputs. This would require the arrays to be positioned upon exit from eclipse. This could require several minutes because of the rate at which they rotated. The mission operations personnel could envision the affect of this on power recovery and requested that the attitude software be modified such that the arrays could be positioned based on calculated sun direction as well as measured. In this way, the arrays would be at an optimal angle upon exit from eclipse, thus allowing maximum power recovery time.

A similar situation was identified during I&T where the arrays were not positioned when the spacecraft was maneuvering. For particular scenarios, positioning the arrays could require several minutes after the spacecraft position stabilized, but prior to actual data collection. Once again, it was requested that a modification be made such that positioning during maneuvers would be possible in order to maximize solar array rotation time.

Conclusion

The participation of experienced mission operations personnel in spacecraft integration and test has proven to be beneficial to spacecraft programs not only in the areas of mission operations system and team development, training efficiency, operational concept validation, and command sequence validation, but also in the areas of testing efficiency and completeness. The experienced mission operations personnel bring the unique point-of-view of having operated a spacecraft on-orbit to the testing effort. This results in more effective system level testing. It is advantageous for the entire mission operations team to become involved in that their planning, control, and assessment teams may assist in the areas of test development, conduct, and evaluation.

If the involvement of the mission operations team in the integration and test area can be coordinated at the onset of a program where particular responsibilities and authorities are given to the mission operations personnel, the benefits could be even more abundant. However, when these responsibilities are not established early, mission operations personnel may be constrained by their commitments to their own system development and validation activities at the time I&T officially begins. Planned mission operations personnel participation can also assist the I&T team in that their responsibilities and team size may be reduced. An added advantage to the early involvement of mission operations is that an operation's perspective can influence the capabilities and efficiency of spacecraft pre-launch testability and post-launch operability. If this is taken into account at the beginning of a program from both teams' perspective, it will result in associated cost savings from the outset.

References

Marshall, M. H., & Landshof, J. A. (November 1992). Connecting Science and Operations: The Operations Coordinator. *Proceedings of the Second International Symposium on Ground Data Systems for Space Mission Operations (SPACEOPS 92)* (JPL Publication 93-5) (pp. 267 - 271). Pasadena, CA.