# MISSION OPERATIONS AND COMMAND ASSURANCE: FLIGHT OPERATIONS QUALITY IMPROVEMENTS

Linda L. Welz, Kristin J. Bruno, Sheri L. Kazz, Sherrill S. Potts, Mona M. Witkowski

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr., Mail Stop 125-233
Pasadena, CA 91109

N94- 33616

**Abstract**

Mission Operations and Command Assurance (MO&CA) is a Total Quality Management (TQM) task on JPL projects to instill quality in flight mission operations. From a system engineering view, MO&CA facilitates communication and problem-solving among flight teams and provides continuous process improvement to reduce risk in mission operations by addressing human factors. The MO&CA task has evolved from participating as a member of the spacecraft team, to an independent team reporting directly to flight project management and providing system level assurance. JPL flight projects have benefited significantly from MO&CA's effort to contain risk and prevent rather than rework errors. MO&CA's ability to provide direct transfer of knowledge allows new projects to benefit from previous and ongoing flight experience.

Key Words: Mission operations, command assurance, Total Quality Management, defect prevention, error management, system engineering

## 1. Introduction

A long-term program is in progress at the Jet Propulsion Laboratory (JPL) to reduce cost and risk of flight mission operations through defect prevention and error management. Flight mission operations require systems that place human operators in a demanding, high risk environment. This applies not only to mission controllers working in the "dark room" and Deep Space Network (DSN) operators configuring and monitoring DSN operations, but also to flight teams that plan the mission and develop the command sequences and to engineering teams responsible for analyzing spacecraft performance. The flight operations environment generally requires operators to make rapid, critical decisions and solve problems based on limited information, while closely following standard procedures (Refs. 1-3). This environment is, therefore, inherently risky because each decision made is potentially mission critical.

To contain this risk at JPL, flight mission operations procedures (as described in Refs. 4-5) currently require intensive human reviews. In addition, when an error does occur, rapid rework is required to ensure mission success. This strategy has worked well to reduce risk and ensure the success of JPL missions. However, the large human labor investment required for review and rework has substantially contributed to the overall cost of flight mission operations and has placed operators in stressful environments. Prevention of errors would greatly reduce both cost and risk of flight projects. Thus, the motivation of the long-term defect prevention/error management program is to contain risk in a more cost effective and human supportive manner by preventing errors rather than reworking them. The goal of this program is the management, reduction and prevention of errors.

A major element of this program is the Mission Operations and Command Assurance (MO&CA) function. MO&CA provides a system level function on flight projects to instill quality in flight mission operations. MO&CA's primary goal is to help improve the operational reliability of projects during flight. MO&CA occupies a unique position in the flight project organization, reporting to both flight project management and the Systems Assurance Division of the JPL Office of Engineering and Review. As a result, MO&CA is able to cross operational boundaries between teams and offices on a flight project enhancing inter-team communication and facilitating problem solving within the project.

This paper describes the development and evolution of the MO&CA function at JPL and the benefits provided to flight projects by MO&CA.

## 2. Evolution of the MO&CA Task

The MO&CA task began on the Voyager (VGR) project in 1985. In response to an increase in command related problems a study was conducted by the JPL Office of Engineering and Review to analyze the adequacy of procedures, operations and software involved in real-time commanding with the goal of reducing errors. Incident Surprise Anomaly (ISA) reports, problem reports written by flight team members when an anomaly occurs in flight operations, were analyzed from an eight year period

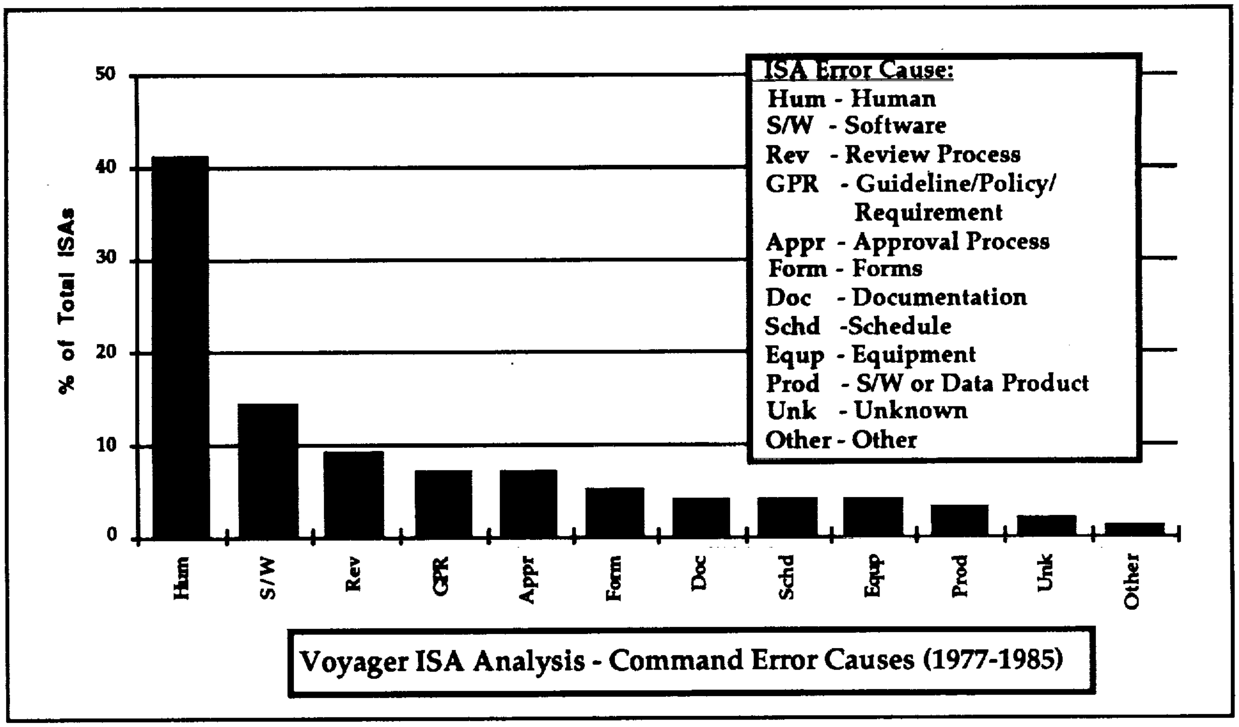


**Figure 1**
**Voyager ISA Analysis**

(1977 - 1985) to determine the causes of command errors. This study showed that the major cause for real-time command errors was human error (Figure 1).

Based on this analysis, recommendations were made to the VGR project for improvements including: 1) upgrading the command development software to improve readability of command printouts thereby facilitating command reviews and approvals; 2) providing traceability between command forms and ISAs to facilitate analysis and correction of command incidents; 3) reducing real-time commanding by improving the coordination of real-time and sequence commanding and including as many commands as possible in command sequences; and 4) updating flight team training to include command awareness issues to inform flight team members of potential command problems and how to avoid them. Command development procedures were updated to incorporate these recommendations. Real-time command anomalies decreased from 60 in 1985 to 40 in 1986, and to 24 in both 1987 and 1988.

When an opening occurred in the spacecraft team, the position was filled by a MO&CA engineer who became the Systems Lead for real-time commanding for the VGR Project. This placement allowed MO&CA to not only recommend changes to command procedures, but also to implement these changes with project management concurrence. MO&CA also continued to analyze ISA reports and make recommendations for continuous improvement to the commanding process. MO&CA provided both a system engineering function for the spacecraft team and a systems assurance function for the VGR Project.

Following VGR, a MO&CA team was activated on the Magellan (MGN) Project in March 1989, just two months prior to launch. The main MO&CA task for MGN was to detect, analyze and correct defects that existed in flight operations and procedures. One of the major efforts of the MGN MO&CA team was assisting the flight project to upgrade the real-time command process and related operational procedures. The initial real-time command process in place at launch included only a handful of steps. Systems coordination and inter-team communication were not included in the procedures.

In the first few months following launch extensive operational workarounds and real-time commanding were required to compensate for the spacecraft hardware problems. Because of the level of commanding and a lack of coordination in the real-time command process, command problems occurred.

MO&CA recommended improvements to the command process which included: 1) review of commands by all subsystems prior to development; 2) system level coordination of all commanding; 3) management approval prior to command development; 4) traceability of commands from initial request to final approval for transmission; 5) development of rigid test requirements for all commands; 6) required representation by all operations teams at command review and approval meetings; 7) spacecraft team support of the command coordination meeting and 8) training for all flight team members with the newly developed command procedures.

By December 1989, an updated real-time command process was in place on MGN. Improved communications enabled the flight team to function well as a unit and respond quickly to anomalies. Real-time command incidents decreased dramatically despite the fact that the flight team continued to face spacecraft anomalies.

In contrast to the VGR project, the MGN team was not integrated directly into an existing team on the flight project, but instead formed an independent unit. While this enabled the MGN MO&CA team to maintain a systems view of flight operations, it did not provide the same ability to implement changes. MGN MO&CA instead provided recommendations for change based on ISA analysis and direct participation in working, review and approval meetings. The flight team, directed by project management, implemented the changes to operations procedures and processes.

Due to the success of the VGR and MGN MO&CA teams, MO&CA teams were placed on the Mars Observer and TOPEX/POSEIDON projects. Both of these new projects experienced immediate benefits through the direct transfer of MO&CA's knowledge and experience from the previous two projects. These MO&CA teams were the first to be in place on the flight project an extended time prior to launch. The teams were therefore able to implement "lessons learned" and process improvements early. This opportunity allowed MO&CA to instill quality into the flight procedures in a pro-active manner, rather than work reactively to update processes and procedures after completion of mission operations development.

Mars Observer MO&CA, like the MGN MO&CA team, was established as an independent unit making recommendations for improvements and updates to command processes and procedures. A prime target for improvement by the Mars Observer MO&CA team was operations communications.

The Mars Observer project had strong real-time and sequence commanding processes in place when MO&CA began working with the project. MO&CA, however, noted problems with inter-team communication and use of ancillary command data. Four separate operations teams, Spacecraft, Planning and Sequencing, Mission Control, and MO&CA, maintained separate command related data files that resulted in redundant and incongruous data. Manual transcription and interpretation errors occurred frequently and unnecessarily increased risk. MO&CA gathered the file structures and reports from each team and identified redundant data usage. MO&CA also initiated and led a working group that analyzed each team's data needs and identified and prioritized requirements for the development of a single command data system. The working group passed recommendations for system implementation to the Uplink Manager. An effort is currently underway to implement an on-line, real-time command data system to be in place by August 1993.

Another communications issue that Mars Observer MO&CA addressed was the result of an unique aspect of the Mars Observer project. The principle investigators have direct control of commanding the science instruments. The remote science teams are situated at several different locations throughout the United States. Therefore, maintaining communications between the science teams and the flight operation team located at JPL is a challenge. Also, the science teams need to have access to real-time spacecraft and instrument status for development of command requests. To facilitate communication, MO&CA recommended that the audio VOCA (Voice Operations Assembly Communications) net be made available to all flight team members, keeping both science and operations teams informed of current spacecraft status.

A third communication problem noted by Mars Observer MO&CA was the definition of the command uplink window, the time period available to transmit commands to the spacecraft. Alignment of the command requester's requirements, the availability of the scheduled commanding windows, and the Mission Control Team's coordination with commanding station hand-overs was complex and prone to errors. MO&CA recommended that a tool be developed to allow the Mission Control Team to interpret, implement and verify the command requester's requirements for uplink windows. This tool was developed by the Mission Control Team and is now being used for flight operations.

Similarly to the Mars Observer Project, the MO&CA task was also well received by the TOPEX/POSEIDON Project. A MO&CA engineer was placed on staff to the TOPEX/POSEIDON Flight Operations System Manager. The

TOPEX/POSEIDON MO&CA task combined elements from the VGR and MGN MO&CA experience. Like the MGN MO&CA team, TOPEX/POSEIDON MO&CA functions as an independent unit, and, like VGR MO&CA, TOPEX/POSEIDON MO&CA has the ability to implement improvements in flight operations procedures.

Once in place on the project in November 1991, MO&CA quickly assessed existing flight operations plans and noted that an additional process for the development and approval of unplanned real-time commands was required. MO&CA worked with the flight team to define inter-team interfaces for the unplanned real-time command process and develop the necessary procedures and process descriptions. While the flight teams were preparing individual team operating procedures, MO&CA was able to provide a system level overview and develop the additional process and procedures that cross team and division boundaries.

As the project planned to use the real-time command process extensively, MO&CA coordinated the development of a Real-time Command Library. This library consisted of all pre-defined real-time command files developed for repeated utilization throughout the life of the mission. The most beneficial portion of the Real-time Command Library proved to be the Contingency Commands. When spacecraft anomalies occurred early in the mission, the Contingency Commands facilitated recovery operations during a high activity period. The value added by the MO&CA Real-time Command Library is also visible daily during mission operations. The majority of planned real-time commands in the TOPEX/POSEIDON Sequence of Events are pulled "off-the-shelf" from MO&CA's Real-time Command Library.

### 3. Human Factors Benefits of MO&CA

MO&CA originated in response to a rise in command errors. As was shown in subsequent error analysis (Ref. 6) the largest group of errors was human error (Figure 2). Thus, addressing human factors in flight mission operations has been the overriding benefit of MO&CA. The enumeration of these benefits follows.

The most important of these benefits is a direct transfer of knowledge. Originating from the Systems Assurance Division at JPL, MO&CA is able to transfer knowledge between current missions in addition to providing valuable "lessons learned"

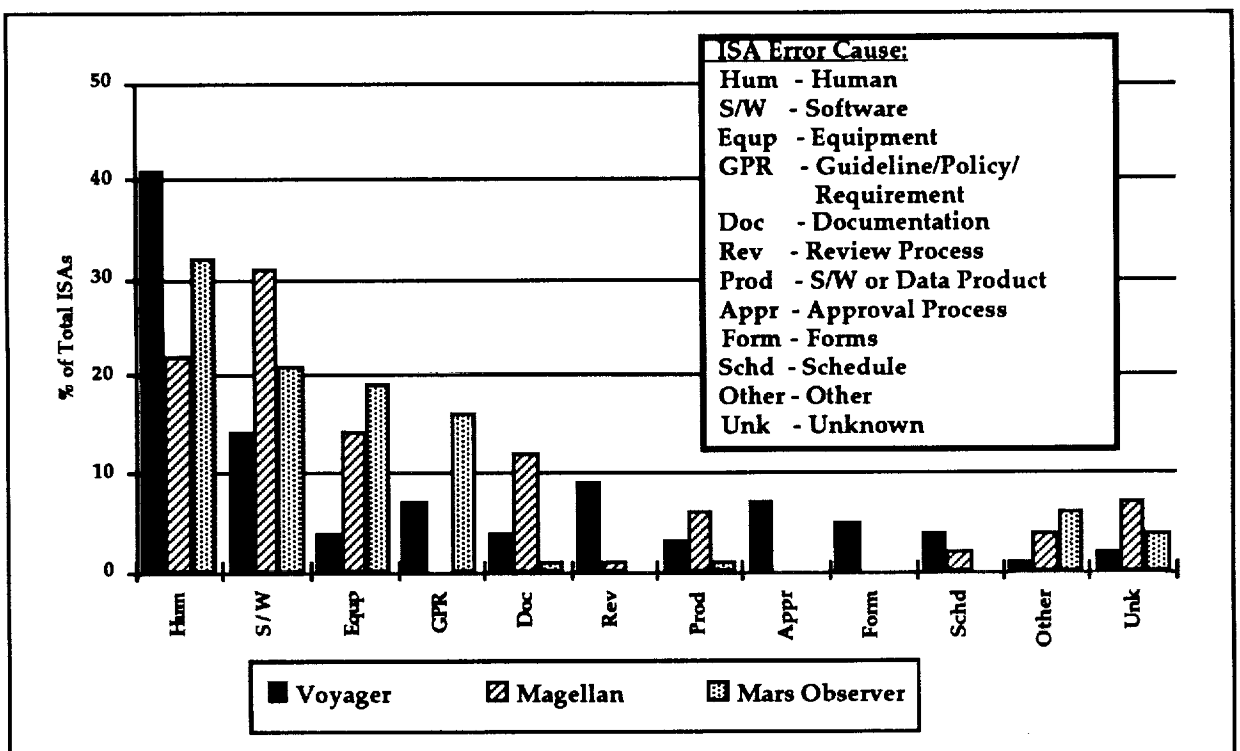


**Figure 2**
**Comparison of ISA Analysis - Voyager, Magellan, Mars Observer**

experience to new flight projects. New projects are able to thus benefit directly from both previous and ongoing mission operations experience. Lessons learned can be incorporated early into project requirements, thereby eliminating the amount of necessary rework on flight operations procedures. The real-time command process and library on the TOPEX/POSEIDON project are examples of this direct transfer of knowledge.

Another major benefit is process improvement. Process improvement activities require the ability to measure and evaluate a process. MO&CA teams collect and analyze error data from the ISA reports written by flight teams on operational problems. Many of MO&CA's recommendations for process improvement are based on these reports. This error analysis results in improvements not only to the project that wrote the report, but also to other flight projects via transfer of knowledge. The error analysis information is also used for analysis in the overall defect prevention/error management program that identified human errors as the largest category (Figures 1 and 2).

MO&CA's unique position as an independent unit in the flight project organization provides a third major benefit to flight projects: the ability to facilitate communication and problem solving. Problems that span many teams and offices within a flight project can be effectively addressed by MO&CA. Coordinating real-time command processes is an example of this task. Flight project members who are faced with problems that impact several teams often bring the issue directly to the MO&CA engineer when they cannot be addressed solely by their team. MO&CA is also able to improve the efficiency of data reporting that crosses team boundaries. On Mars Observer MO&CA worked with the teams to eliminate data duplication and ensure correct data was reported.

## 4. MO&CA and TQM

The MO&CA function is one example of a Total Quality Management (TQM) process at JPL. Specifically, MO&CA embodies the TQM principle of Continuous Process Improvement (CPI) in which processes are continuously examined and analyzed for opportunities for improvement. Figure 3 shows how MO&CA implements CPI in two ways. First, within ongoing projects, the flight mission operations environment is established and MO&CA participates as a team member. In the course of day-to-day operations, anomalies are documented as ISA reports. The ISAs then serve as data that is analyzed by MO&CA engineers for process improvement opportunities. When these opportunities are identified, MO&CA provides reports and data to support recommendations for improvement to project management. Finally, based on management approval, MO&CA helps the project implement the changes back into the day-to-day mission operations environment. This technique was successfully implemented on the JPL projects.

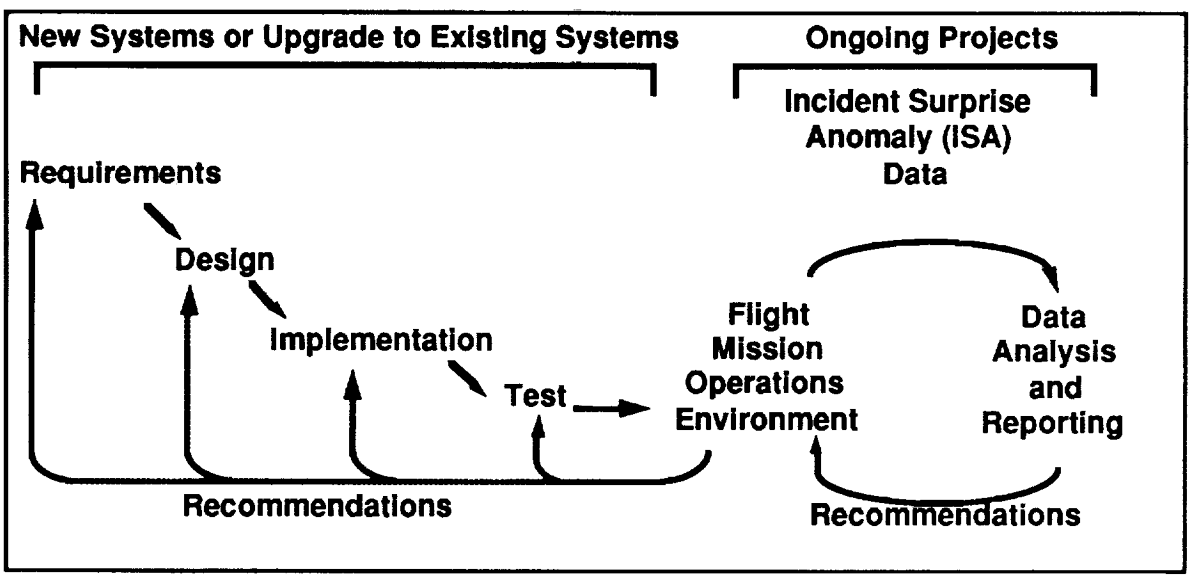


**Figure 3**
**TQM Model of MO&CA**

The second way in which MO&CA implements CPI on JPL projects is on new projects or upgrades to existing projects. The recommendations that are developed from the ISA data analysis on ongoing projects are used as input to system requirements on new projects. This allows new projects to benefit from improvements made on past projects as TOPEX/POSEIDON benefited from the experience gained on VGR and MGN.

Using this technique, not only do ongoing projects continuously improve, but each new project starts with a better set of requirements and better processes than the last one. At JPL this continuous improvement feedback loop has improved flight mission operations processes from the Voyager Project, to the Magellan Project, and to the Mars Observer and TOPEX/POSEIDON projects. Additionally, this Continuous Process Improvement reduces both cost and risk of flight mission operations.

## 5. The Future of MO&CA

Future flight missions at JPL will have smaller spacecraft and flight teams (Refs. 7-8). Development times will be reduced and the teams that design and build the spacecraft will also staff the flight mission operations teams. MO&CA will need to evolve to adapt to this changing flight operations environment. With smaller flight teams the MO&CA engineer will be taking on additional duties such as command procedure development and system lead functions, as did the engineers on VGR and TOPEX/POSEIDON.

MO&CA will also participate during the early phases of the project, enabling MO&CA to implement "lessons learned" and process improvements during development. MO&CA will continue to provide both system assurance and engineering assistance to operations. MO&CA can assist in developing operational procedures and participate in flight team training, especially enhancing flight team communications and problem solving. This participation will streamline procedure development and eliminate late changes and upgrades thus reducing rework and cost.

Automation of ISA data tracking and analysis by MO&CA will help to make operations process monitoring and error analysis more efficient and timely. With automation, MO&CA will be able to address problem areas quickly. Finally, ISA data will be used in a parallel error analysis study. The findings of this study (Ref. 6) will enable prevention of errors through improved requirements development on new projects.

## 6. Summary

JPL flight projects have benefited significantly from MO&CA's effort to contain risk and prevent rather than rework errors. MO&CA's ability to provide direct transfer of knowledge allows new projects to benefit from previous and ongoing flight experience. The system level view of project operations provided by MO&CA enhances communication to facilitate problem solving within a flight project.

MO&CA will continue to evolve to meet flight project needs. Early involvement with developing projects will ensure that quality is incorporated into mission operations during operations development and training.

The MO&CA function at JPL has built quality into mission operations, enabling flight teams to operate efficiently and effectively in the dynamic flight operations environment. Since error analysis has shown human error to be the largest error category, human factors improvements have, thus far, proved to be the major benefit. MO&CA, as a TQM effort, focusing on continuous process improvement and elimination of rework, will continue to provide benefits to flight projects.

## 7. Acknowledgment

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

The effort of many people from the JPL Office of Engineering and Review went into the MO&CA work on JPL projects. The authors would like to acknowledge their efforts by recognizing the participants: Al Brejcha, Anna Bruhn, Grant Faris, Larkin Hamilton, Sara Hyman, Kil-Sun Kang, Mark Kennedy, Farinaz Kavousirad, Young Kim, Robyn Lutz, George Nichols, Irwin Plitt, Anne Phu, Richard Santiago, Mitch Scaff, John Schlue, Hui-Yin Shaw, William Shipley, Lowell Thompson, Greg Welz.

## 8. References

1. Horvath, J.C., and Perry, L.P. 1990. Hypercubes for critical spacecraft verification. In Proceeding of AIAA Second International Symposium on Space Information Systems, Pasadena, Ca., 1285-1291.

2. Linick, T.D. 1985. Spacecraft commanding for unmanned planetary missions: the uplink process. Journal of the British Interplanetary Society, 38:450-457.

3. Muratore, J.F., Heindel, T.A., Murphy, T.B. Rassmussen, A.N. and McFarland, R.Z. 1990. Real-time data acquisition at mission control. Communications of the ACM, 33(12):18-31.

4. Haynes, N.R. 1985. Planetary mission operations: an overview. Journal of the British Interplanetary Society, 38:435-438.

5. McLaughlin, W. 1987. How to feed a spacecraft. Spaceflight, 29: 38-40.

6. Bruno, K.J., Welz, L.L., Barnes, G. M., and Sherif, J.S. 1992. Analyzing human errors in flight mission operations. A Paper presented at the Sixth Annual Space Operations, Applications, and Research Conference, NASA Johnson Space Flight Center, Houston, Texas, August 4 - 6.

7. Cassini, K., and Spear, A.J. 1992. Low Cost Spacecraft: The Wave of the Future [Videotape]. Pasadena, Ca.: Jet Propulsion Laboratory.

8. Stone, E.C. 1992. Total Quality Management Seminar [Videotape]. Pasadena, Ca.: Jet Propulsion Laboratory.

## Session H2: ENHANCED ENVIRONMENTS

---

**Session Chair: Maj. Gerald Gleason**