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# MISSION OPERATIONS AND COMMAND ASSURANCE: INSTILLING QUALITY INTO FLIGHT OPERATIONS

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## 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 the probability of radiating incorrect commands to a spacecraft. 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 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). The mission operations 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 has ensured 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. Prevention of errors would greatly reduce both cost and risk of flight projects. The motivation of the long-term defect prevention/error management program is to contain risk in a more cost effective 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's effort focuses directly on continuous process improvement to reduce the probability of radiating incorrect commands to a spacecraft. MO&CA occupies a unique position in the flight project organization, reporting to both flight project management and the System 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. This system level view enables MO&CA to enhance inter-team communication to facilitate 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 review

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 a seven year period (1978 - 1985) to determine the causes of command errors. Based on this analysis, recommendations were made to the project for improvements in flight procedures including: upgrading the command development software to improve readability of command printout thus facilitating command reviews and approvals; providing traceability between command forms and ISAs to facilitate analysis and correction of command incidents; 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 updating flight team training to include command awareness issues making flight team members aware of potential command problems and how to avoid them. Command development procedures were updated to incorporate these recommendations.

When an opening occurred in the spacecraft team the following year, the position was filled by a MO&CA engineer who became the Systems Lead for real-time commanding for the VGR Project. 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. Although not included in the project at launch, the MO&CA function was successfully integrated into the spacecraft team. This placement allowed MO&CA to not only recommend changes to command procedures, but also to implement these changes, with project management concurrence, for the spacecraft team.

Following VGR, a MO&CA team was activated on the Magellan (MGN) Project just two months prior to launch, on May 4, 1989. The main MO&CA task for MGN was to detect, analyze and correct defects that existed in flight operations and procedures. Tasks to detect and analyze defects included: review of flight operations processes and documentation; participation in operational readiness training exercises; assessment of command process compliance with requirements and procedures; analysis of ISA reports; and participation in software testing. Activities associated with defect correction included: command awareness training; real-time support to the command development process; participation in the analysis and correction of

command incidents; implementation of an Anomaly Reporting and Tracking System (ARTS); and support for investigation and development of workarounds for hardware failures.

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. Commands were initiated within one subsystem of the spacecraft team, passed to another subsystem for coding, and submitted to project management for approval to transmit. No system level effort for review or coordination was in place.

In the first few months following launch the real-time command system was in constant use due to several hardware problems on the spacecraft. Extensive operational workarounds were required to compensate for these problems. Because of the anomalies and a lack of coordination in the real-time command process, command problems occurred. MO&CA recommended improvement to the command process which included: review of commands by all subsystems prior to development; system level coordination of all commanding; management approval prior to command development; traceability of commands from initial request to final approval for transmission; development of rigid test requirements for all commands; required representation by all flight teams at command review and approval meetings; spacecraft team support of the command coordination meeting; 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. This well-structured process 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 MO&CA team to maintain a systems view of flight operations, it did not provide the same ability to implement changes. MO&CA instead provided recommended changes 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 first MO&CA teams, the MO&CA function was proposed to the management of the TOPEX/POSEIDON Project. The concept was well received by the Project and in November 1991, a MO&CA engineer was placed on staff to the TOPEX/POSEIDON Flight Operations System Manager to facilitate development of the Real-time Command Process.

A unique aspect of the TOPEX/POSEIDON Project is the amount of planned real-time command activity. Due to the nature of the mission, TOPEX/POSEIDON is very dependent on real-time command activity. For example, tape recorders are played back via real-time commands three times per day. Once in place on the project, 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 required 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 that were planned for repeated utilization throughout the life of the mission.

In addition to the Real-time Command Process and Library, MO&CA also developed the Operations Coordination Process, Anomaly Reporting Process and aided in development in the Configuration Management Process. As a portion of the Operations Coordination Process, MO&CA documented the types and level of necessary Flight Operations meetings.

By January 1992, the TOPEX/POSEIDON Real-time Command Process and Library were in place. The transition to test and training activities went smoothly. The flight team readily adapted to, and exercised the Real-time Command Process, the Real-time Command Library, and the Anomaly Reporting Process. With a functioning pre-launch Anomaly Reporting Process for ISA reporting, MO&CA was able to gather and present detailed statistics to the project on recurring problem areas encountered during test and training.

Since launch on August 10, 1992, MO&CA's efforts have been focused on coordination of the real-time command process, coordinating approval and uplink. MO&CA also plays a key role in sequence review and validation of all planned real-time commands.

The most beneficial portion of the Real-time Command Library proved to be the Contingency Commands. The Contingency Commands were invaluable when spacecraft anomalies occurred early in the mission, facilitating 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.

The TOPEX/POSEIDON Project experienced an immediate benefit through the direct transfer of MO&CA's knowledge and experience from previous projects. The 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. TOPEX/POSEIDON MO&CA was the first MO&CA team to be in place on the flight project an extended time prior to launch. The team was therefore able to implement "lessons learned" and process improvements early while flight operations procedures were being developed. 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.

### 3. Benefits of MO&CA

The MO&CA function has evolved from participating as a member of one flight team on the VGR project; to an independent unit providing assessments and recommendations based on a systems view to the MGN project; and finally to its current state as a combination of both direct flight team participation and system level assurance on the TOPEX/POSEIDON project. MO&CA's unique position, with both a high level systems view and the direct ability to develop and implement changes as necessary, enables MO&CA to provide flight projects the benefits of both the assurance and system engineering functions.

Originating from the Systems Assurance Division at JPL, MO&CA provides a direct transfer of

knowledge between current missions in addition to providing valuable "lessons learned" experience to new flight projects. New projects are able to thus benefit directly from both previous and ongoing mission operation experience. Lessons learned can be incorporated early on, 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.

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 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.

MO&CA's unique position as an independent unit in the flight project organization provides its 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. The newest MO&CA team on the

Mars Observer (MO) project noted that identical data was being reported by several of the flight teams, and that the data was often erroneous if it originated in one team and was reported by another. MO MO&CA worked with the teams to eliminate this 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 1 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 which 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 VGR, MGN and TOPEX/POSEIDON projects.

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

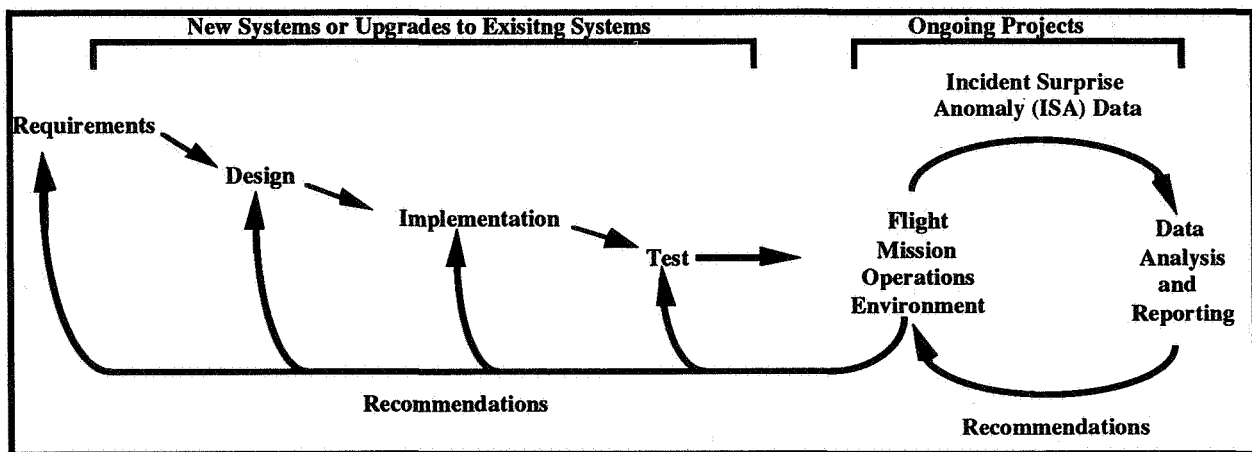


Figure 1  
TQM Model of MO&CA

developed from the 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 TOPEX/POSEIDON project. Additionally, this continuous process improvement reduces 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. 6-7). Development times will be reduced and the teams that design and build the spacecraft will also staff the flight mission teams. MO&CA will need to evolve to adapt to this changing flight operations environment

MO&CA will continue to provide both system assurance and engineering assistance to operations. The MO&CA function will be implemented during project development so that MO&CA can assist in developing operational procedures and participate in flight team training. This will streamline procedure development and eliminate late changes and upgrades thus reducing rework and cost.

Automation of data tracking and analysis by MO&CA 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. 8) 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 a dynamic space flight operations environment. Since MO&CA, as a TQM effort, focuses on continuous improvement of processes and elimination of rework, MO&CA will continue to provide benefits to flight projects.

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