We're Here to Help You

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[Abstract] Air Force lore tells us that the two biggest lies you will ever hear on the tarmac are when the Inspector General steps off the plane and says to the Wing Commander, "We're here to help you," and the Wing Commander replies, "We're glad to see you." Not too surprisingly, a similar relationship is often perceived between a project manager and the mission assurance representative (especially for operations). This perception intensifies as budgets shrink and missions shorten, after all, where is the value added? That is the question we will examine for three small, short projects: Phoenix, WISE, and Grail (which is yet to launch). All have limited resources to devote to "niceties" and a very short mission to reap the benefits for their operations. We will examine how mission operations assurance evolved for each project, what worked well, what could have been improved, and how these lessons can be applied to ensure mission operations assurance is a value added function for Grail and future small missions.

I. Background

Mission Assurance has long been instantiated in project development at the Jet Propulsion Laboratory (JPL) as a necessary evil to ensure the quality of both hardware and software development. While the necessity of Mission Assurance (MA) and its constituent elements of Hardware and Software Quality Assurance (QA), reliability, and electronic parts are accepted, there is the perception that this overhead can potentially pose a risk to budget and

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schedule. Should the MA function impose higher standards than Project Management believes are necessary given the project's accepted risk posture, the perception is strengthened. The longevity of the MA function and the role of the Mission Assurance Manager (MAM) in leading a team that works with the project have aided in assuaging the fears engendered by this perception and served to mitigate the natural adversarial relationship between the two entities. On the other hand, the Mission Operations Assurance (MOA) function is a relative newcomer on the scene and is still trying to establish the proper rapport while maintaining independence and providing value added for achieving success once a project begins mission operations.

> When the Challenger exploded in 1986, one of the immediate results at JPL was the delay in the launch of the Galileo spacecraft to Jupiter. The ensuing accident investigation made it abundantly clear that there were residual risks from development activities that could affect flight operations. Consequently, JPL made the decision to extend the normal Mission Assurance function into flight operations to independently identify and assess residual development risks as well as perform an ongoing assessment of risk throughout the operational mission. Thus as Magellan (which was now scheduled to launch on the shuttle ahead of Galileo) and Galileo prepared for their interplanetary launches from the space shuttle, the concept of Mission Operations Assurance was born at JPL.[1]

As described in Ref. 1, the MOA concept evolved with time and received additional impetus with the Mars Climate Orbiter incident in 1999 and the review board made specific findings captured in the NASA Public Lessons Learned.[2]

1) Although a Mission Assurance Manager (MAM) was assigned to Mars Climate Orbiter (MCO) during project development, there was no independent mission assurance function established for the work performed at JPL following launch.
2) Discrepancies between the delta-Vs expected by the Navigation Team and those produced by the Angular Momentum Desaturation (AMD) file from the Spacecraft Team were observed during mission operations. However, no Incident/Surprise/Anomaly (ISA) or Problem/Failure Report (P/FR) was written on this issue.

In response to these findings, changes were made to JPL's Flight Project Practices which required an independent MA representative throughout operations of every flight project and required the projects to track and report post-launch anomalies using the ISA system. With this additional emphasis on MOA, the process evolved further with increasing rigor and integration into project flight teams.[1] For the most part, these were relatively long duration missions with significant critical events which easily justified the allocation of resources for the MOA function. As the emphasis shifted to more missions with smaller budgets, a number of shorter missions came into existence. We will examine some of these efforts from different perspectives to see if the nature of these projects led to a shift in the perception of potential risk to schedule and budget from an effective MOA function. The first project reviewed will be Phoenix from both the view of flight team members and from the perspective of JPL's industry partner for Phoenix, Lockheed Martin Space Systems. Following that we consider the evolution of MOA for Earth orbiting missions with emphasis on the relatively short operational mission known as the Wide-field Infrared Survey Explorer (WISE). Instruments developed and operated by JPL also provide a unique challenge in the arena of MOA which is considered here. Finally, the challenges of a small, short mission such as GRAIL are addressed from the perspective of a MAM who will transition to a MOAM and the challenges this presents.

II. Phoenix MOA from the Flight Team Perspective

Success doesn't come easy and from a flight team perspective, the MA/MOA function has an opportunity to both help and hinder in this regard. Preparation for flight operations actually starts before Assembly, Test & Launch Operations (ATLO). Putting together an integrated infrastructure to support Flight Operations is a huge job for a Ground Data Systems (GDS) Team. Coordinating teams, procedures, workstations, networks, software deliveries, documentation, and test activities to form a cohesive Mission Operations System (MOS) presents enormous challenges. Phoenix clearly had more than its fair share.

For the first time for a JPL mission, the hub of operations would be at a University rather than at JPL. The bulk of the operational functions would reside at the University of Arizona. While the center of operations would be located in Tuscon, the operational concept called for a truly distributed operational model. Phoenix flight and science operations were conducted by Project operations teams located at the University of Arizona Phoenix Science Operations Center (SOC) in Tucson, AZ with key support located at JPL in Pasadena, CA, and at Lockheed Martin Space Systems Operations (LMSSC) facilities in Denver, CO as illustrated in Figure 1.

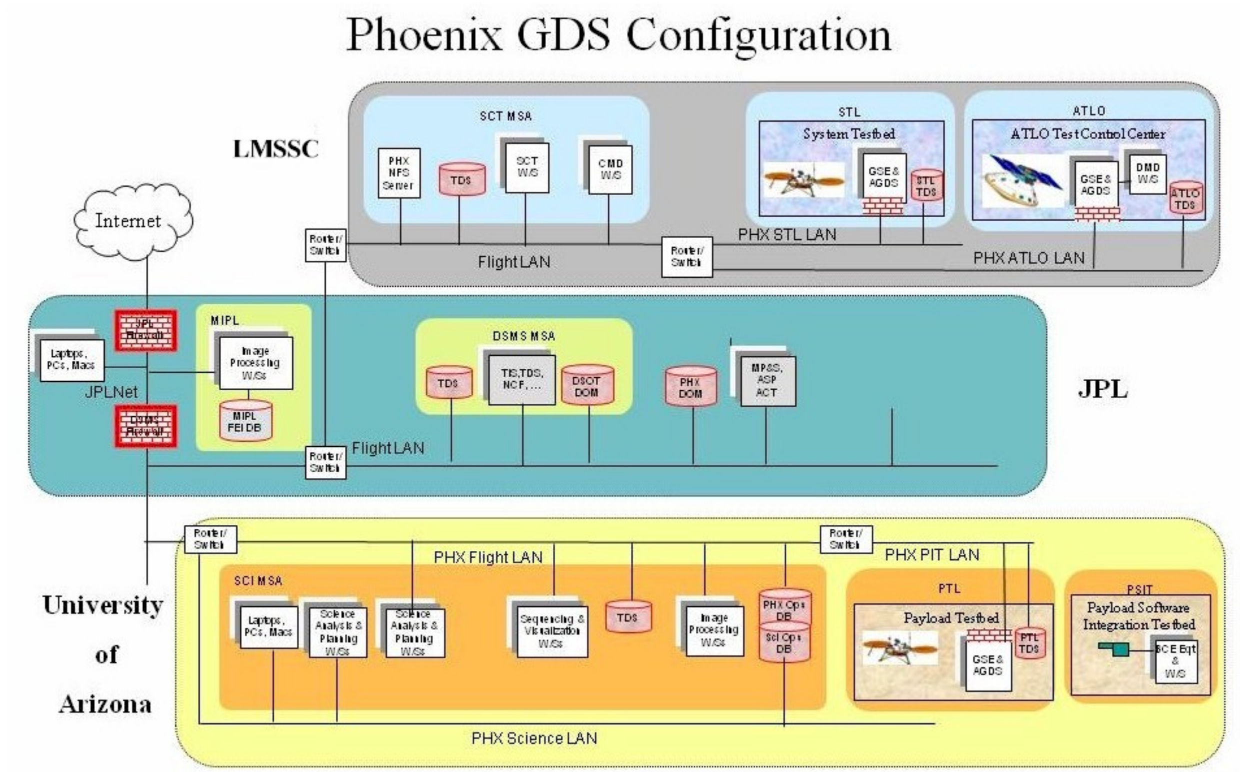

Figure 1. Phoenix Distributed Operations

While, as a surface mission, the Phoenix operations were more complex than many orbital missions, this complexity was not what made Phoenix so unique. The intensity of the daily time-line, tied to the Martian day and multiple daily overflights of two Mars orbiters, was the governing structure for the MOS team to complete their tasks. It was this continual intense pressure that made this mission more stressful and exhaustive. As we consider below, it was thesomewhat transparent pressures of the operation that contributed to issues the flight team had with aspects of the MA function.

A. Mission Assurance Management

During the Phoenix Project, there was a succession of MAMs and MOAMs throughout the development and operations phases. Each MAM/MOAM injected their own experience and preferences into the problem reporting and resolution process. From the Phoenix flight team perspective, standardization in problem reporting and resolution during operations between MOAMs would have facilitated consistent implementation of the Problem Reporting System (aka Incident, Surprise, Anomaly (ISA) reports) by the flight team. While the value of Mission Assurance is understood, the Phoenix flight team believed that the MOAMs also needed to recognize and fulfill a specific role within the team. The MOAM cannot directly impact either the flight team's schedule or their ultimate goal of meeting the mission milestones. It is important for the MOAM to establish a role as a team player within the flight team.

For Mission Assurance to add value the place to start is to present the flight team with a clear definition of the MOAM's roles and the responsibilities which the team can understand and accept. Day-to-day operations during the flight operations/science phase of a mission follow a slightly different hierarchy than during the development phase. After launch the Mission Manager (MM), the Sub-System Leads (SSLs), and the Team Chiefs (TCs) are responsible for the operation of the mission and the people on their teams. On a small, cost-capped mission, everyone wears more than one hat and handles a lot of responsibilities and tasks. Therefore, perceived changes in MOA requirements and process due to changes in MOAMs add an extra burden on the flight team and hinder a good working environment.

On the Phoenix mission there was a contentious relationship between the MOAM and the flight team because the MOAM failed to understand that SSLs and the TCs had the responsibility for their specific sub-system and also that they were the 'experts' in that area. SSLs and TCs report to the MM who collects the information from the flight team to make an assessment regarding spacecraft health and safety. While the Project Manager (PM) is the ultimate decision-maker for the project, he/she relies on the MM for the day-to-day operation of the spacecraft. As viewed by the flight team some criticisms with MOA is that the MOAM does not understand how the spacecraft works, or the intricate details of the uplink and downlink systems thus bring into question the value of the MA function.

Another problem from the flight team perspective is some MOAMs hold themselves 'separate' to maintain 'independence'. This independence by separation is not necessarily a good thing. It prevents a true integration into the flight operations team. Significant bonding happens during long hours of critical operations which is where trust is built. Relationships and trust are important components in any team dynamic in addition to knowledge and experience. Building relationships and having trust in your team is not something found on a checklist. It takes time and working through difficult situations as a team that fosters this element. This element also helps a team get through the tough times and promotes an appreciation of others and how to support them and work with them. For example, when there is a spacecraft anomaly that suspends science data collection the science team needs to trust the engineering judgment of the sub-systems and the sub-systems have to appreciate the urgency on the part of the science team to get the instruments collecting data again. An organization chart cannot create trust relationships, working side-by-side through good times and bad times are the only way trust will grow. While a MOAM is responsible for providing and independent assessment of risk from anomalies, process changes, procedural changes, and proposed new operational activities, this does not mean they must separate themselves from the flight team. Rather they need to understand the MOS and its processes in order to adequately assess new risks to the mission. This means working with the team as a member, not as a separate outside entity.

It's unrealistic to expect a single individual to be an expert in all areas of a mission, and during the flight operations/science phase of the Phoenix mission the MOAM may have tried to cover too much territory. Each SSL and TC has ownership of their specific area and team members will work as many hours as needed and basically do whatever it takes to contribute to the success of the mission. This dedication to mission success drives the flight team.

So the question from the flight team perspective is what is the MOA function during flight operations? Should it be re-defined to narrow the scope since the SSLs, TCs, and MM perform a mission assurance function as part of their daily routine by continually assessing the risk to the mission of each planned activity? Might the role of MOA during flight operations be scaled back to reviewing the entries into the problem reporting system and having a regularly scheduled quiet hour with the Mission Manager? Is it part of a MM's job to interface with the flight team and follow up on issues or slowness in closing out the problem reports during operations? These questions certainly need clear answers to facilitate understanding and mutual respect between the MOAM and other flight team members and to develop a true sense of teamwork between MOA and those implementing mission operations.

B. Herding Cats

To complicate matters the Phoenix lander had no High Gain Antenna so it was completely relay dependent. This meant that the MOS and GDS teams must also plan and coordinate with two obiter spacecraft, Mars Reconnaissance Orbiter (MRO) and Odyssey depicted in Figure 2. Both spacecraft would have overflights every two hours. Yikes! Managing both uplink and downlink relays during surface operations was, as the heading suggests, like hearing cats.

To manage and deal with such a plethora of options requires a fully functioning and reliable infrastructure. JPL GDS support services personnel provided this and ensured that the MOS GDS hardware, software, local area networks (LANs), and operations facilities remained operational and properly configured during the entire mission operations lifecycle.

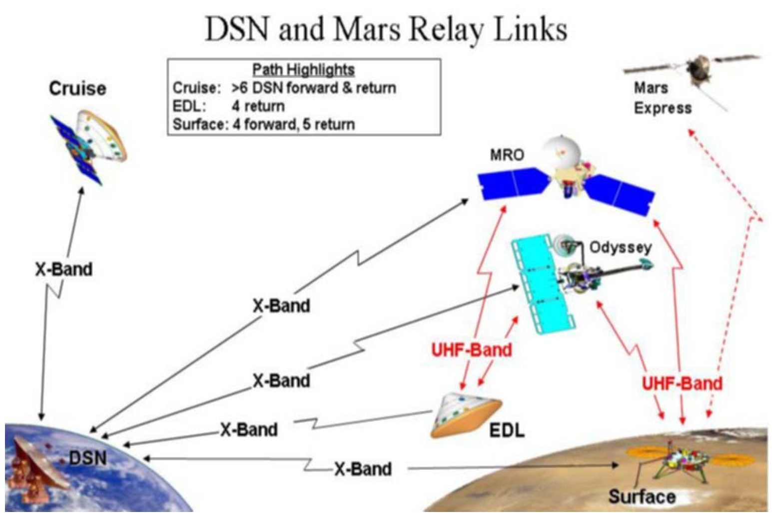

Figure 2. Phoenix Relay

C. The Lesson the Flight Team Learned

Lessons learned are a key component to contributing to the mission success as well providing a better roadmap for lower risk during flight operations. One lesson learned from Phoenix that was implemented on Juno is to set up, standardize, and start using the operational problem reporting process from the first ground software delivery. As discussed above, one issue on Phoenix was that were was no apparent standardization on problem reporting. Each MAM had his/her own reporting preferences. While the transition from development MAMs to operations MOAMs is normal and even personnel changes during phases of the mission, it is crucial that the MOAM be involved throughout the implementation of the operational problem reporting process and that the standards be clear and consistent throughout operations. The MOAMs need to strive to avoid the situation where some MOAM's had a laissez-faire approach while others turned the problem reporting aspect of the mission assurance function into a cottage industry. The "cottage industry approach" alluded to in Figure 3 is to be avoided as any horticulturist will tell you, it's great for the fungi, but not good for building a team. A better approach is described in the discussion of MOA partnering with Industry on Phoenix in the next section.

Figure 3. Cottage Industry?

III. What Future Missions Can Learn from Phoenix

Mission Operations Assurance (MOA) is performed independently from the Engineering Operations Team to ensure the reduction of risk to mission success by performing assessments of project risks and operational readiness. This is true, not only at JPL, but also at JPL's industry partners, such as Lockheed Martin Space Systems Company (LMSSC) on Phoenix. An open line of communication is set up early within a project with all teams and sites to establish a uniform system of quality practices that is essential for mission assurance operation functions. Team partners, contractors, and remote sites follow and implement the same standards agreed upon during contract and project initiation. Contractor MOA is an extension of the JPL principles and practices for projects.

The highly successful Phoenix Mars Lander mission is an excellent example of collaboration between JPL and industry partner LMSSC for MOA operations. The role of MOA has been practiced and proven in past and current missions such as Mars Reconnaissance Orbiter, Odyssey, Genesis,Stardust NExT, and Spitzer Space Telescope by Lockheed Martin. The Phoenix mission was able to pull the experiences and lessons learned from the previous missions and established strong standards for the Mission Operations function.

The Phoenix mission was faced with some unique challenges. Support schedules between the different organizations in different time zones were driven by the Martian day. Operation activities were also mandated not by Earth time but Martian time. What this scenario presented was schedules that were changing on a daily basis for support personnel. Each day personnel were required to come into work at a forward shifting time of around twenty minutes. Personnel life and work schedules were slowly migrating from a day shift to a swing shift though out the mission. The mission was planned for ninety days of science but actually lasted over an unbelievably 150 days. The shared responsibility for each MOA was to identify fatigue, stresses, and distractions within the team as operations carried into the later stages to minimize operator errors and project risk. JPL required MOA coverage from off sites during this critical time of surface operations.

Another challenge for Phoenix personnel was to perform against a hard time constraint. The mission was in a race against the clock to complete the required science before the Martian winter arrived and shadowed the solar arrays starving the lander for power. Daily operations and planning for Phoenix were dependent on science results and spacecraft health of the previous day. Activities had to be reviewed, planned, processed, and sequences uploaded prior to the next Martin Day. The results from science operations needed to be considered before the next science task was to proceed. This demanded continued focus and coordination from operation engineers, scientist, and test lab operators. The MOA performed Space Craft Upload Manager (SCUM) duties reviewing the upload packages for errors, process deviations, completeness, and consistencies. MOA ensured compliance to the problem reporting system to capture anomalies for lessons learned, tracking risk posture, and closure of outstanding issues. JPL relied on the onsite MOAs to perform and report status and risk for project operations.

What worked well for the Phoenix team's success were the preparations before launch, teamwork between multiple sites, and a uniform Mission Assurance groups both at JPL and Lockheed Martin. Operational Readiness Test (ORT) was performed to train engineers for upcoming events and possible anomalies that might occur. The team was prepared for unscheduled events and how to react to them. Decision trees were outlined based on possible outcomes of an activity. Sequence design anticipated changes and alternative paths of operations by having 'on the shelf' products to react to the changing environment. Open and frequent communication for MOA between JPL and off site representatives kept the whole team aware of any risk and status.

Phoenix provided real time lessons learned throughout the operations stage for the operations team and MOA. The spacecraft health is the highest priority for the mission operations team. Without a space craft there can be no science. Health monitoring, spacecraft engineering data, and software patches are time consuming to review but are an absolute necessity for mission success. Engineers must balance the required time to adequately complete each task prior to the processing of the next day's planning. In an event that an anomaly occurs such as a space craft safe mode which puts the space craft in a safe configuration, no science can be performed. When it is determined that a software modification is required such as a patch, the turnaround time is of essence for a mission on a finite time schedule. The normal patch process is rigorous involving experts in engineering and quality control to ensure that software modification is correctly implemented and tested, and all risks have been identified and resolved. With missions with a restrictive time table, it is paramount that the solution is quickly processed and correct with the lowest risk profile acceptable. A design with a streamlined process is needed to address time sensitive issues without compromising process and product integrity. It is the responsibility of MOA to provide the independent assessment to ensure a successful operation.

Other time constrained missions in the future can benefit from the lessons Phoenix has taught the operations team. Early establishment of relations and communication methods between all MOA must be established. A problem reporting system that is easy to use and accessible to both JPL and contractors is important to share status and risk to the mission. It also provides a vehicle for other missions to track common problems and risk. Processes need to be reviewed for completion in a time constrained manner without compromising the quality of the product and controlling risk.

Resources are always a risk in any project. It is important to understand that unplanned events are going to happen, be it personnel, hardware, or software related items. Plans and contingencies should be evaluated and reviewed before the start of operations. ORTs are an essential part of this assessment process. Performing ORTs requiring a practice of a worst case scenario will expose weaknesses that can be corrected before assets and mission objectives are at risk.

It is the MOA responsibility to ensure that practices, principles, and process are in place and are being followed to maximize the rate of success. All MOA must act as one entity across different agencies to ensure commitment to quality. For a successful mission, Mission Operations Assurance is performed by the whole project team and industry partners. Next we look to see how this was applied and evolved for Earth orbiting missions supported at JPL.

IV. TOPEX to WISE, MOA for Earth Orbiters

In 1990, development began in earnest for the TOPEX/POSEIDON mission operations phase. TOPEX/POSEIDON launched in 1992 and Mission Operations Assurance (MOA) was involved in the project. In the late 1990s, the Jason-1 project began and development of the mission operations phase at JPL built on the lessons of TOPEX/POSEIDON. The Jason-1 Ground System was an update of the TOPEX/POSEIDON Ground System and Mission Operations incorporated the lessons learned during TOPEX/POSEIDON's early years (TOPEX/POSEIDON project ended in January 2006), including the involvement of Mission Operations Assurance. The Ground System developed for Jason-1 (called the Jason Telemetry, Command, and Communications System [JTCCS]) was deliberately built so that it could easily be modified for another mission. Jason-1 launched in 2001, and JTCCS successfully supported the mission (still flying today). As time went on, the JTCCS model was used for other projects (Jason-2 at NOAA and WISE at JPL).

Similarly, MOA also built on the lessons of the previous and lessons learned during the TOPEX/POSEIDON operations were incorporated into the Jason-1 Mission Operations design. And so on to WISE.

Many of the tasks that were still-new to MOA on TOPEX/POSEIDON or Jason-1 had become standard parts of MOA activities on Wise. During operations development, MOA was involved in ensuring that operations requirements are implemented to the maximum extent practical in hardware, software, and operations designs. MOA participated in operations peer reviews, Operations Readiness Tests (ORTs) and the Operations Readiness Review to help assess the ability of the WISE Mission Operations System (ground software/hardware and personnel) was ready to perform operations.

As operations began in earnest on WISE, MOA was present to ensure that activities were happening as expected and that procedures that worked in the abstract during ORTs truly worked in the reality of flight operations. Timing to get activities accomplished is not as critical on an Earth Orbiter as they are on a planetary mission (whether to Mars or somewhere beyond), but they are still a factor. During satellite check-out, timing of individual activities relative to each other may not be critical, but timing within the activities often is. Some elements of early operations and satellite check-out may be deemed as "Critical Events" requiring extra reviews with high visibility, much like the "critical event" of "Entry, Descent, and Landing" of a Mars lander such as Phoenix; others might simply be important activities in a long list of activities to check off to ensure proper satellite operations in the proper orbit around the Earth. In the case of WISE, the ejection of the cover over the telescope was deemed as a "Critical Event" requiring these extra reviews, while the maneuvers necessary to move from the injection orbit (the orbit provided by the launch vehicle boost) to the operational orbit were not.

Once these early operations and satellite check-out are complete, MOA still has a vital role in what often are repetitive activities, ensuring that complacency does not lead to mistakes (more likely on a long-duration mission than a shorter mission such as WISE or Phoenix). If mistakes are made, observations may be lost or data not returned from the satellite to the ground – all things avoidable if care is taken and everyone, not just the MOAM, remains aware of the possibility of said mistakes.

Additionally, the MOAM has the role of assisting in, if not leading, anomaly resolution when the anomaly is not an error that began on the ground (whether a commanding error, ground station failure, or processes taking too long) leading to missed opportunities on the satellite. Luckily, anomalies of this type have been relatively minor on WISE. When something does go wrong on the satellite, the MOAM works with the flight team, the engineers and anyone else necessary (e.g., satellite or subsystem manufacturer) to determine if the anomaly is recoverable or undoable and the steps needed to do that activity (including any activity on a test bed to validate the actions planned). If the anomaly is determined to not be recoverable, but rather something that needs to be addressed for the rest of the mission (such as a lost reaction wheel (not something that has happened on WISE, but something that did happen on Jason-1), the MOAM helps the flight team not only take the immediate steps needed to recover to nominal operations, but assists the team in reviewing flight procedures to take the failure into account, whether extra commanding, avoiding certain actions, or reworking fault protection settings on the satellite.

V. Do Instruments Need MOA?

JPL's institutional requirement to assign a MOAM to support JPL managed flight instruments includes the situation where a JPL developed instrument is delivered to a project managed by another NASA center. In this case, the JPL instrument team operates the instrument as part of the project managed by another NASA center. A MOAM is routinely assigned to instruments flying on other agency/country spacecraft (examples: AMR, GPSP on OSTM/Jason-2 (CNES), M3 on Chandrayaan-1 (ISRO)). The MOAM works with the instrument flight teams to help them understand spacecraft anomalies whether they impact the instrument (and hence are treated in part at least as instrument anomalies, since the instrument has to take actions) or not. The MOAM has the responsibility of setting up and managing the Problem Failure Reporting System (PFRS) in support of instrument flight operations. She/he interfaces with the project in coordinating failure reports between the project and instrument team. Additionally, he/she supports the instrument team during instrument anomaly investigations. Typical support includes electronic parts consultation along with radiation susceptibility and environments. One final MOAM option we want to examine is when the development MAM continues on to be the MOAM during operations. This is particularly practical on a small mission such as GRAIL.

VI. Taking MOA from Development into Operations on GRAIL

GRAIL (Gravity Recovery and Interior Laboratory) is a Discovery mission designed to map the gravity of the moon in 2012 during a 3-month science collection period. Much as for GRACE mission orbiting Earth, the GRAIL mission will orbit the moon with two spacecraft flying in a coordinated fashion to obtain ranging data between the spacecraft. The ranging data constitutes the science data set that is then reduced to create a three dimensional density map of the interior of the moon from crust to core. The GRAIL spacecraft are both largely single string, requiring that they have high reliability. The short data collection window of 3 months requires that the spacecraft also have high availability during the data collection period.

During the development phase of the GRAIL mission, the project team has conducted a proactive reliability program led by Safety and Mission Assurance working closely with System Engineering and Mission Operations. A primary consideration has been assuring the reliability of the largely single string flight system, as guided by the unique GRAIL mission risk classification, Class C Enhanced. This classification emphasizes the important reliability drivers in the risk matrix (e.g., parts, reliability analysis, quality assurance, and test) as Class B activities to assure the system reliability needed for mission success with two single string spacecraft.

One of the key events in the proactive reliability program was a June 2008 visit the STEREO Mission Operations Center at APL. Similarities between STEREO and GRAIL (largely single string, two spacecraft, both have to work, many maneuvers, one LV) make it an excellent case study on building reliability into a single string flight system and operating it successfully and reliably in transition to flight. In this section the planning for successful GRAIL transition to flight and the role of Mission Operations Assurance in assuring GRAIL mission success is explored.

A. GRAIL Mission Operations Assurance Challenges

Mission Operations Assurance is a vital component of the GRAIL project team with its unique challenges, which include:

- Roughly forty maneuvers within six months to achieve formation flying of two S/C in lunar polar orbit to obtain the required science data in three months, to be accomplished prior to the lunar eclipse in June 2012
- Flight-like testing considering both spacecraft operating simultaneously and the ability to handle anomalies, potentially on both spacecraft simultaneously
- Successful separate lunar orbit injection (LOI) of two spacecraft a day apart
- Avoid science data collection interruption in the three-month science collection period, especially in the middle third which is particularly important to the most challenging science objectives related to core detection and characterization
- Spacecraft and the MOS team training needs to be fully accomplished before launch as there are maneuvers to be conducted and little time in cruise for training
- Aggressive Thread Test, ORT, SVT schedule

B. GRAIL Operations Assurance Overview

The GRAIL Mission Assurance program as the project transitions from development to flight operations and continues through the end of the mission has the objective of enhancing the likelihood of mission success by proactively contributing to the identification, assessment and mitigation of risks through the implementation of MOA processes for the GRAIL project.

Of particular importance to the success of the Mission Operations Assurance plan is the transition from development assurance to operation assurance and the involvement of the entire flight operations team in the MOA process. The Mission Assurance Operations Manager (MOAM) implements the process elements by providing leadership to the management, payload, spacecraft, ground system, and support teams in the MOA process. The GRAIL Mission Operations Assurance Plan (MOAP) provides the guidance and description of the MOA process specifically for GRAIL. It starts with requirements and provides a roadmap for the MOAM to contribute to assuring GRAIL mission success. Key elements addressed in the plan are covered in the sections which follow.

1. Risk Management

The Mission Operations Assurance team will provide an independent assessment of the project's risk posture (risks, mitigations, system failures, failure reports, corrective actions, and lessons learned) directly to the project manager, Mission Assurance Management Office Manager, Mission Assurance Division Manager, and Director for Safety and Mission Success. The project risks identified during development will be carried forward in transition to Mission Operations without interruption of the project risk management process, and will continue to include consideration of open PFRs, Red Flag PFRs, Waivers (especially to JPL's Flight Project Practices (FPP) and Design Principle (DP) documents), test as you fly (TAYF) exceptions, the Project's risk list, any risks identified by the Mission Assurance Manager, and any risks that are on System Manager lists that are not on the Project's risk list. The risk management plan extends, or is updated to extend throughout the entire mission

The MOA team looks to future operational events to identify any residual risk applicable to operations, particularly for critical and first time events. For GRAIL, the pair of Lunar Orbit Insertion (LOI) burns (one for each spacecraft), separated by one day are the post launch critical events. Preparation for LOI will include a special review process for the project culminating in a Critical Events Readiness Review (CERR). An independent review and assessment of the Project's risk posture and operational readiness will be performed to facilitate the mitigation of risks to LOI operations. Residual risk posture will be reported at the Project's CERR and to the Center Management Council (CMC). Mission trades will be assessed for potential risk in preparation for LOI. MOA responsibility includes review of plans/procedures/scripts for Mission Operations demonstrations (EEIS tests and Operations Readiness Tests (ORT) as a minimum) to assess if the objectives are sufficient to fully validate functionality and operational readiness, thus contributing to risk reduction. The breadth of these tests is broad, encompassing processes, procedures, software tools, personal, ground system reliability, flight/ground system compatibility, health and safety assessment, performance trending, status reporting, uplink products, uplink product validation, spacecraft constraints and flight rules, and simulation tools.

2. Incident, Surprise, Anomaly (ISA) Resolution

In preparation for start of Assembly Test and Launch Operations testing GRAIL ISA processing for the GRAIL Ground Data System is already fully implemented in the JPL Institutional Problem Reporting System. With the initiation of Mission Operations Thread Testing the MOA team will begin providing independent assessment of the Project's implementation of their anomaly resolution process as well as the risks relevant to any recovery action or decision not to take action.

The ISA process will assure that

1) problem reporting standards and guidelines are implemented throughout flight operations,
2) The flight team has access to and is properly trained in the use of the system,
3) The flight team understands the need for initiating an ISA whenever an anomaly, surprise, or unexpected event occurs,
4) ISAs are initiated in a timely manner
5) ISAs are analyzed and resolved prior to impacted mission events, and
6) Corrective actions are reviewed prior to the ISA closure for adequacy to preclude the recurrence of the anomaly.

C. Key Review Board Findings Where MOA Must Be Involved From a Risk Management Perspective

3. Mission Design Trades

The number of maneuvers in preparation for the science Phase poses an operational challenge with 44 planned in the nominal mission. The Project delta V margin may allow for a reduced number of maneuvers. It may be desirable to consider the trade of using delta V margin to reduce the number of planned maneuvers in phase E

4. Dual Spacecraft ORTs and Table Top Exercises

The GRAIL system needs to be tested operating both spacecraft simultaneously and exercising the interaction between the two spacecraft in both nominal and anomalous situations where you may be working simultaneous anomalies on both spacecraft. MOA assesses ORT plans to ensure the ORTs are planned for exercising the interaction of the two spacecraft configuration.

5. Risk reviews and risk reduction testing

The top-level phase E schedule did not include risk reviews and spacecraft risk-reduction testing leading up to the LOI CERR. MOA should provide a recommendation on scheduling risk reviews and spacecraft risk reduction testing in preparation for the CERR.

6. Fault Protection Strategy for the Science phase (82 days) is key to risk reduction

There are a limited number of days (82) to complete the science collection. In order to accomplish the mission, two primarily single string spacecraft need to be operating nominally and collecting data. This is particularly critical during the second cycle when critical science objectives will be met. A different approach to spacecraft fault protection strategy may be in order where cycle 2 may be viewed more as a critical longer duration event and the spacecraft fault protection responses set up to limit the possibility of science data collection disruption except under the most serious situations. MOA will be involved in the evaluation the fault protection strategy for the Science Phase of the mission, which will consider how to minimize the possibility of science data collection disruption during the 82 day period with particular emphasis on the second cycle.

7. Mission Operations to Deep Space Network (DSN) Interface

The DSN scheduling process is very dynamic, with ongoing future-week negotiations, proposals, real-time station anomalies, station maintenance, and possible launch contingencies. In 2011 and 2012, significant contention for DSN use is expected. While some of the project-related effort can be delegated to the GRAIL DSN scheduler, there is a need for a project representative knowledgeable in the operations and science quantity and timing requirements for DSN contacts to review proposals and evaluate them with respect to mission-specific requirements. Experience from previous multiple S/C missions (e.g., STEREO) has shown that a mission operations staff member should be dedicated to the DSN interface, not only for scheduling, but also to work with the Network Operations Project Engineer (NOPE) to optimize each track for the success of the mission. The need for adequate DSN coverage to reduce the risk of losing science data makes the project's approach another area where the MOAM will need to provide specific risk assessment.

8. System Test Laboratory (STL) Use

The STL is in high demand and is critical to Verification and Validation (V&V) of each spacecraft(S/C). The GRAIL mission is different from past LM/JPL missions in that it is very intensive, with over 40 deterministic maneuvers in the first six months to achieve an unprecedented formation flying of two S/C in lunar polar orbit to obtain the required science data in three months, before the mission-ending lunar eclipse on June 4, 2012. Both S/C and the MOS need to be fully trained, tested, and certified before launch. MOA needs to provide a risk trade to the project when they consider developing another STL dedicated for mission operations use.

9. Environmental Testing

No time is allocated to testing flight operations systems, procedures, and flight activities in the most "flight-like" environment. Given that personnel involved in environmental testing will later serve on the mission operations team and hence learn from the ATLO testing, the project appears to be missing an excellent opportunity to piggyback on to environmental testing to validate operational systems and products to be used after launch. Again, an MOA risk trade is appropriate to assess the options for adding operations sequence testing to the environmental testing.

10. Operations Readiness Test (ORT) "Flight-Like" Fidelity Limitations

As per GRAIL's Test Plan, GRAIL ORTs are conducted over the course of the development to "take the concept of thread-testing into the complete, final operational environment." "They demonstrate MOS readiness in the execution of activities in a flight-like environment." At present, plans seem to fall well short of this goal in these areas.

1) Number and type of ORTs: There are very few ORTs.
2) Flight and ground software not final: Of those ORTs planned, only the Launch ORT is conducted after June 2011, when the final version of flight and ground software is available.
3) No ORTs are conducted with the two actual spacecraft; all are conducted on the STL, which does not include EMs for the bulk of the systems, including payload--hence many fidelity limitations.
4) Facilities: It is not clear that ORTs are conducted in the final operations facility; the MSA is established in the final months before launch.
5) Incompressible Test List: Only the Launch ORT is on the ITL. Others not deemed critical enough.

In mitigation, Sequence Verification Tests (SVTs) address items #2 and #3, with all performed on the S/C with the latest FSW. Also, more SVTs are on Incompressible Test List (#5). Moreover, the MOS ground software and personnel are used to build SVT sequences. Other "flight-like" fidelity improvements may be addressed in SVT tests. MOA should provide a risk trade assessment on whether planning the SVTs to be run by mission operations and satisfy all fidelity requirements to "test as you fly" or some of the other recommended options provide the best bang for your buck in risk mitigation.

11. Mission Operations Review

The next potential independent review with GRAIL mission operations will either be at the Test Readiness Review in March 2011 or the Operations Readiness Review in July 2011 (one year from now). However, all mission operations thread tests are due to be completed by January 2011. In addition, the first of two major rounds of Sequence Verification Tests (SVTs) are due to be completed by November 2010. Hence, significant information will be available by that time to assess feasibility of completing remaining preparations for launch on time. It would be valuable for the MOAM to support a mission operations peer review in January 2011 to assess operations progress to date, and expectations for completing development and execution of remaining operations products and tests required to fully prepare for launch and validate the MOS prelaunch within available resource and schedule constraints.

D. MOA Going Forward to Launch

There are numerous opportunities for the MOAM to contribute to the readiness and risk reduction as GRAIL proceeds to launch. The continuation of the development MAM into operations, especially given the short duration of this mission, makes excellent sense given the carryover of development risk into operations and the need to be an integral part of the team as discussed above for Phoenix. It seems clear that while an independent risk assessment is part of the MOAMs charter, the theme of the need to be integrated into the flight team is repeated on mission after mission, especially the short and high intensity efforts.

VII. Conclusions

Small and/or short missions present some interesting challenges for Mission Operations Assurance. If the development MAM doesn't continue on as the MOAM, can the team involvement, so key to projects such as Phoenix, be realized? The answer to that question is probably, it depends. Some individuals can easily immerse themselves in an operational environment and become a team member. Others have no idea what operations is about, thus making a transition more challenging. In these cases, especially for short missions, it can be beneficial for the development MAM to continue on the be the MOAM. It is certainly a recurring theme as we look at projects from both the flight team and the MOA perspectives, that teamwork is key to the success of operations. Without the MOAM being able to assimilate into and become a valuable team member, the stereotypical adversarial perspective of the Air Force Inspector General and Wing Commander will prevail. This integration while maintaining an objective perspective to provide Project and Institutional Management with the independent assessment they are expecting, is not easy. It is a challenge for each MOAM, and certainly points out the importance of really meaning it when, as a MOAM, you say, “We’re Here to Help You.”

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