Mars Global Surveyor Mission Assurance: Key Approaches for Faster, Better, Cheaper Missions

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Abstract- Future space missions are required to deliver significant results with new technology and substantially reduced development cost and schedule. Among the first of the recent Faster, Better, Cheaper (FBC) missions for Jet Propulsion Laboratory (JPL), the National Aeronautics and Space Administration's (NASA's) Mars Global Surveyor (MGS) was launched to Mars on November 7, 1996 after spending $148M and 27 months in development. A phoenix risen from the ashes of Mars Observer (MO), MGS combined significant heritage with key enabling new technologies to meet its ambitious programmatic and technical goals. This development was characterized by significant teaming between JPL and its development partners.

The MGS mission assurance program was tailored from its MO baseline to capitalize on previous heritage, use development partners' assurance approaches, balance technical risk and implement new assurance approaches consistent with the significant development constraints. The key approaches included teaming, heritage, personnel consistency, concurrency, collocation, task value analysis, communication, peer review, rapid closure, appropriate attention to detail and education. This paper will outline the MGS mission assurance requirements and describe the key mission assurance approaches.

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1. INTRODUCTION

Project History

MGS (see Figure 1) was created to capture a significant part of the MO science after contact was lost with MO on August 21, 1993. After a rapid study period, the MGS spacecraft Request For Proposal (RFP) was released in April 1994 and Lockheed Martin Aeronautics (then Martin Marietta Aeronautics) was selected as the spacecraft industrial partner in July 1994. Some key project milestones that culminated in the launch of MGS on November 7, 1996 are shown in Table 1.

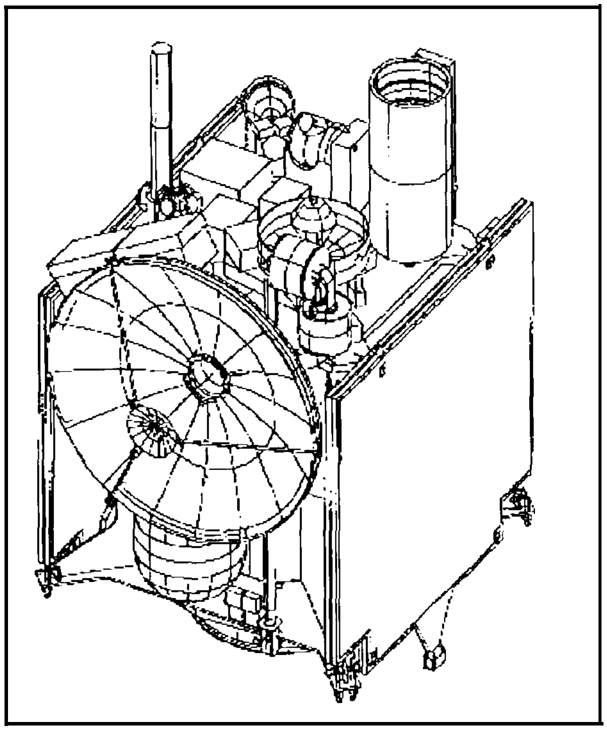

Figure 1. MGS in Launch Configuration

Table 1. MGS Project Milestones

System Requirements Review	4/12/94
Mission Preliminary Desire Review (PDR)	9/15/94
Spacecraft PDR	10/26/94
Spacecraft Critical Design Review (CDR)	5/4/95
Project CDR	5/23/95
Mission CDR	9/26/95
Mission Success Review	3/7/96
Spacecraft Pre-Ship Review	8/1/96
Mission Readiness Review	10/1 0/96
Flight Readiness Review	11/6/96

MO Heritage

Significant portions of MGS were inherited from MO, including staff, documentation, hardware and software. Many of the JPL Project staff were MO veterans bringing significant understanding of the overall mission, heritage hardware/software and lessons learned. The Project documentation set was largely composed of modifications to existing MO documentation to satisfy variant MGS needs and approaches. Many hardware elements from MO (typically MO flight electronics spares) were used with little or no modification. Most of the MGS flight software was modestly modified MO flight software. The Ground Data System (GDS) element of the MO Mission Operations System (MOS) was used on MGS.

New Technologies

Despite significant MO heritage, many new development process approaches were utilized and significant new elements were qualified and flown. New development process approaches included electronic documentation, communication and requirements tracking using shared servers, electronic mail, teleconferencing, limited World Wide Web-based video and various database systems. Other new development process approaches will be described throughout this paper. New elements included composite spacecraft structure, Nickel-Hydrogen batteries, Solid-State Recorders (SSRs), Silicon and Gallium-Arsenide Solar Arrays, Traveling-Wave-Tube Amplifiers (TWTAs), Low-Gain Antennas, combined X-band and Ka-band antenna feed, propulsion components and mechanisms. The mission system re-engineered its processes to minimize required resources and embed assurance into its implementation.

Notable Project Characteristics

In addition to significant heritage used for MGS, there were several other project characteristics that influenced the development and corresponding mission assurance program. The most notable of these included a focus on teaming and constraints on mass, cost, and schedule. Teaming provided a positive development environment and the constraints served to focus development effort on prioritizing and performing the most value-adding work.

Teaming-- Throughout the spacecraft development process, there was a significant degree of teaming between the Project team at JPL and the spacecraft prime industrial partner, Lockheed Martin Astronautics (LMA). This manifested itself in a multitude of ways, including:

1) Acceptance and use of partner implementation approaches to meet performance requirements versus blanket imposition of customer implementation approaches,
2) Reduction and elimination of "oversight" functions, activities, or perception,
3) Each team member brought "contribution" to the team (e.g, expertise, specific tasks)
4) Joint meetings, work, reviews, tests and interactions at all levels during all phases, thereby facilitating "insight", and
5) Some attention and specific activities targeted at team building and maintenance.

Mass- The launch capability of the Delta II (7925) imposed a mass constraint that influenced many facets of MGS system development, including aerobraking, composite structure use, and instrument selection. There was a constant scrutiny and management of margin to avoid unrealistic "stacking" of uncertainties, especially where this imposed development constraints. The instrument payload selection was fine-tuned to get the highest return "global" science that would form a solid foundation for the remainder of the Mars Surveyor Program within the tight payload accommodation mass budget.

Cost- The project cost-driven paradigm impacted all aspects of MGS development, including targeted application of resources, stable requirements (see Figure 2), limited implementation approaches and value-driven selection of tasks to perform. The driving project policy provided for the primary decision criteria in all decision processes to be the minimization of cost and the maintenance of the project's development and operations cost caps. Mission technical performance could be altered to satisfy this policy.

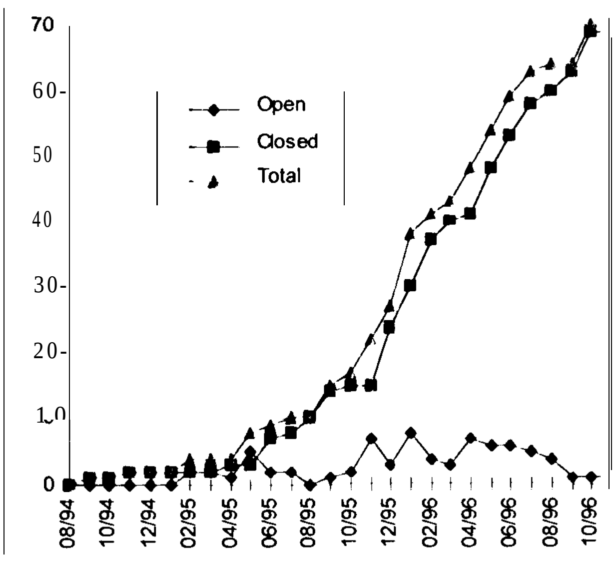

Figure 2. MGS Requirement Waivers Metric

Schedule- Finally, the schedule of 27 months from spacecraft partner selection through launch played a significant role in development, including task concurrency (related tasks), parallelism (different tasks), phasing (sequence) and selection (existence). Schedule margin was monitored on a weekly basis and adherence to task milestones was paramount.

Mission Assurance Program

The MGS mission assurance program "core" included the concurrent engineering development support disciplines of mission assurance management, circuit/system reliability, environmental compatibility, quality assurance (QA), electronic parts reliability/radiation, and system safety. This core was defined by specific resources (budgets) allocated by the project in the JPL mission assurance program. Additional activities that contributed to mission assurance included materials and processes control, configuration management, risk management, contamination control, software quality assurance, reviews and performance verification. Due to the unique history of MGS, the mission assurance program was a blending of the inherited MO mission assurance program, resolution of failure review board findings, and new approaches to satisfy the severe technical, cost and schedule constraints.

2. REQUIREMENTS

The project mission assurance requirements were documented in the MGS Project Plan at a high level and are summarized in Table 2.

The spacecraft mission assurance requirements were documented primarily in the Spacecraft Performance Assurance Provisions and are summarized in Table 3.

The instrument mission assurance requirements were documented in the Science Investigation and Instrument Development Policies and Requirements and are summarized in Table 4.

The Mission Operations System (MOS) mission assurance requirements were documented in the Mission Operations Specification volumes as requirements for successful delivery of mission products while the explicit mission operations assurance requirements are summarized in Table 5.

3. KEY APPROACHES

Based on a quick survey of the development team after the MGS launch, a spreadsheet of 125 lessons learned inputs was compiled [1]. Several presentations and discussions [2][3][4] were held during and after development of this list to share the mission assurance process and elicit common themes from the MGS development and mission assurance program. From these lessons learned and common themes, a set of key approaches to FBC development processes and mission assurance programs began to emerge from the MGS experience. This section will provide a summary of these key approaches, which include teaming, heritage, personnel consistency, concurrency, collocation, task value analysis, communication, peer review, rapid closure, appropriate attention to detail and education.

Teaming

A leading Faster, Better, Cheaper (FBC) approach in the mission assurance program was the significant degree of teaming. Throughout the development process, as skills were needed and resources constrained, each partner (including JPL) would step up to the challenge by providing needed capabilities and effort. It was important to strike an appropriate balance between the responsibility and support. The partner receiving help needed to maintain responsibility for the task results and work with the helping partner to establish clear deliverable dates, products and costs. The helping partner had to assume shared responsibility for satisfying these agreements. Lastly, costs were important to keep track of, since there were contractual commitments that had to be managed.

The MGS mission assurance program was a significant "proving ground" for the replacement of "oversight" functions and perceptions with "insight" and partner contribution, since traditional mission assurance programs have often had significant oversight activities embedded in them (e.g., inspection, analysis review) and traditional customer-supplier relationships have often stressed the "oversight" role for the customer. In large part, this challenge was met.

Teaming support was provided for individual tasks, in a particular discipline for specific capabilities, and cross-cutting general experience. Many assurance areas benefited from teaming, most notably parts, materials, radiation, EMC, magnetics, quality assurance, and reliability.

Parts teaming included JPL providing component specialist support, parts from JPL inventory, parts failure analysis, parts radiation effects expertise/testing, automatic GIDEP Alert processing, and Web-based Electronic Parts information Network System (EPINS) parts lists. JPL materials consultation was provided for some issues resolution and materials list item knowledge.

Radiation teaming included JPL natural space radiation environment modeling, micrometeoroid analysis, and radiation transport analysis support. EMC teaming from JPL included testing support, issues resolution support, and design consultation. Magnetics control processes, procedures and issues resolution support was provided by JPL.

Table 2. Project Mission Assurance Requirements

AREA	REQUIREMENT
General	NASA Management Instruction (NMI) 8010.1 defined Mission Class A Spacecraft; Class B Instruments; and Class A Mission Ops System. Review all heritage waivers, Problem/Failure Reports (PFRs), Nonstandard Part Approval Requests (NSPARs), incident/Surprise/Anomaly (ISAs) and deviations against MGS requirements.
Reliability	Satisfy NASA Handbook (NHB) 5300.4 (1A-1); no mission critical single point failures without Project Manager (PM) approval; required design analyses; formal Problem/Failure Report (PFR) system; FMECA focus.
Quality Assurance	Spacecraft quality assurance (QA) satisfies NHB 5300.4 (I C); instrument QA assures interface requirements compliance.
Electronic Parts	MIL-STD-975 Grade 1 equivalence; NSPARs/waivers if not approved in parts list review nor MO approval; all new parts lists require JPL reliability and radiation review; review all parts against Government-Industry Data Exchange Program (GIDEP) Alerts.
Materials and Processes Control	Spacecraft uses partner's standards for high-reliability projects; Instruments require Class 1 change from MO baseline and updated materials list at instrument delivery.
Performance Verification	Verify compliance with requirements for design, performance, interfaces, margins, environments, science objectives; delta verification from prior related verification.
Contamination Allowance and Control	Maintain Class 100,000 control.
Software Assurance	Software management plan, software documentation, configuration management, margin management, delivery review and testing.
Maintainability	Reduce life cycle costs, modem software engineering practices, and "good software documentation.
Risk Assessment	Risk management program includes cost, schedule and technical risk identification, integrated risk assessments for decision-making and communication to NASA management the risk significance and decisions.
Safety	Institutional industrial safety; range safety compliance with Eastern Range Regulation (ERR) 127-1, Kennedy Space Center (KSC) GP- 1098; Missile System Pre-launch Safety Package (MSPSP); Project Safety Plan; spacecraft partner safety program compliance with intent of JPL D-1141 I; instrument safety compliance using safety plan, safety analysis and other safety support as required.
Reviews	System Requirements Review (SRR), Critical Design Review (CDR), System Acceptance Review (SAR) / Operational Readiness Review (ORR), Flight Readiness Review (FRR); Agency Reviews: Quarterlies, Independent Assessment, Independent Readiness

Table 3. Spacecraft Mission Assurance Requirements (partial)

AREA	REQUIREMENT
Reliability	Meet intent of NHB 5300.4 (1A-1); waivers of single point failures; reliability assurance plan; reliability analyses: functional/interface FMECAs redundancy switch, parts stress, mech. stress/Fault Tree Analysis (FTA), worst-case; Problem/Failure Report (PFR) system; GIDEP Alert review
Quality Assurance	Satisfy NHB 5300.4 (1 B) and NHB 5300.4 (l C); Hardware escort for >$100k equipment
Electronic Parts	Standard parts are MO and Grade 1 equivalent parts; evaluate for Total Ionizing Dose (TID), Single Event Effects (SEE) and new application of MO parts; review non-standard parts; ASIC/Hybrid/Custom part special requirements; backward traceability; screening data availability; lot QCI; post-programming bum-in; DPAs; derating; forward traceability; failure analysis
Materials & Processes	Use industrial partner standards; MO materials acceptable
Performance Verification	Verification tests at assembly, interface and system levels; Prelaunch ops; environmental protoflight testing: dynamics margin 4dB, sine vibration, acoustics, random vibration, pyro shock, thermal margin 25C, thermal/vacuum, large area/appendage thermal shock, launch pressure profile, ElectroMagnetic Compatibility (EMC) test margin 6dB (9dB design margin)

Table 3. Spacecraft Mission Assurance Requirements (cent'd)

AREA	REQUIREMENT
Contamination Control	1 % obscuration on external surfaces (Spacecraft contract Exhibit III--Spacecraft Requirements)
Software Assurance	Software management plan; documentation; margin management; software assurance activities applied to critical software/documents; configuration management; testing
Configuration Management	Identification; control; status accounting: as-designed, as-built, change status
Safety	Industrial partner safety engineer; safety steering committee; interfaces safety; compliance with ERR 127-1/ KSC GP-1098; Safety Technical Interchange Meetings (TIMs); tank log books; factors of safety; ionizing/non-ionizing radiation safety; pressure vessels; pyrotechnics (pyres); handling; one-fault tolerant safety critical functions; safety reviews
Reviews	Spacecraft: PDR, CDR, Operability and Fault Protection; Subsystem: Heritage, PDR, CDR; Reliability assurance participation in reviews

Table 4. Instrument Mission Assurance Requirements

AREA	REQUIREMENT
Reliability	Interface FMECA; parts stress analysis; PFRs, Electrostatic Discharge (ESD) control
Quality Assurance	Interface requirements verification: pre-ship data review, acceptance test witness, interface verification check witness, physical inspection
Electronic Parts	JPL D-5357 Appendix A (Class A) parts requirements; review prior waivers; Grade 1 equivalent standard parts; nonstandard part approval; screening demonstration for 3 year mission
Materials & Processes	Changes from baseline approved by Class 1 waiver; updated materials list at Delivery Review
Environmental Test	Heritage waivers inapplicable; assembly and instrument level protoflight tests tailored to degree of redesign and reuse of MO spare hardware; 500 hours operation prior to spacecraft integration; random vibration; sine vibration; thermal/vacuum; EMC (including specific instrument interactions); magnetic field characterization; non-ionizing radiation characterization; retest requirements; test authorization; test reporting
Software Assurance	Follow Project Software Management Plan; documentation set; progress reports; configuration control; software readiness review
Configuration Management	Identification: functional requirements, Interface Control Documents (ICDs), Science Requirements Document (SRD), baseline documentation (i.e., MGS submittals of updated documentation only); Control: baseline, change classification (I/II) and processing; Accounting: record and report configuration identity with changes
Safety	Safety Plan (or update) with Experiment Implementation Plan; interfaces; hazards; regulatory conformance: ERR 127-1 conformance: MSPSP inputs; safe power-on state
Reviews	Reviews for implementation (initial plan), programmatic, pre-environmental test, delivery, software, mission operations

Table 5. MOS Mission Assurance Requirements

AREA	REQUIREMENT
Command Assurance	Completely integrated into doing processes; use command/sequence requests; command/sequence verification ' f
Configuration Management	Use of change requests; impact analysis; change authorization; change impact assignments and configuration management status
Anomaly Management	Anomaly reports: Spacecraft (PFRs), Operations/Initial (ISAs), Deep Space Network (DSN) Discrepancy Reports (DRs); Mission Operations System Failure Reports (FRs); anomaly assignments and anomaly status
Project Reporting	Status reports for downlink, configuration management, anomalies, uplink, GDS and MOS

Collocated JPL quality assurance reps and reliability engineers were involved in daily teaming through a variety of tasks throughout the development period. The quality assurance reps shared many inspection responsibilities with LMA quality reps. The reliability engineers performed many design analyses for PIEs and supported issues resolution.

Heritage

A significant contributor to FBC mission assurance on MGS was the significant use of heritage hardware and software. These elements had "been through the development wringer" once and this contributed to significant savings on re-use, even with the extra effort that had to be expended to determine heritage status and perform variance work necessary to achieve MGS requirements.

There is a tremendous amount of development work and issues resolution that occurs in the prior design, fabrication and testing of hardware and software destined for flight application, This proved to be true for MGS heritage elements as well. In large part, design analyses had been completed, application issues resolved, parts utilization approved, interface compatibility established and MO requirements compliance verified. Since many of the MGS requirements were enveloped by MO requirements, this meant that all these assurance activities were completed. Remaining requirements were satisfied with variance design, analysis and testing, as opposed to comprehensive verification from scratch.

Additionally, there were many other issues uncovered (and some resolved) as a result of the MO in-flight experience and subsequent failure review processes. The MGS development process was therefore able to focus its limited resources on addressing those identified, yet unresolved heritage issues and on new problems discovered in the MGS development. Particular care had to be taken to ensure complete understanding of changes to determine applicability y of heritage effort.

On the flip side, heritage elements required significantly more effort than originally planned in order to understand and disposition heritage issues. This was driven significantly by the LMA and Project focus on mission success, which did not accept unresolved issues in either heritage or new elements. An additional driver was the degree of effort required to recreate the heritage element history. Recreating this history will become even more difficult as increased numbers of projects adopt FBC methods, such as reduced historical-value-only documentation.

Purely performance-based specification for developed elements is another FBC approach, although there are no real good examples of this extreme in MGS. This would reduce the heritage history process to interface issues alone. Successful use of this approach will depend largely on the state of the art for specifying and verifying performance requirements (e.g., mission reliability, space environments, non-testable requirements) that don't currently lend themselves to verification.

A significant lesson learned was the amount of detailed understanding the user must have when applying heritage hardware. It is important to allow sufficient resources to conduct detailed interviews with prior developers, utilize prior developers in the re-application development (especially for peer level reviews), and allow new developers to review and understand all heritage drawings, specifications and characteristics.

Personnel Consistency

Consistency in the development personnel from early conceptualization through launch (and into mission operations if possible) is an essential ingredient in FBC development. This saves tremendous resources often spent towards communication, learning, and documentation, all of which have a direct impact on the mission assurance program.

Problem avoidance and rapid issue resolution are the most significant effects in the mission assurance program from personnel consistency. Many problems are simply avoided since personnel are familiar with element history, sensitivities, constraints and idiosyncrasies. This manifests itself in correct design application, test procedures, appropriate cautions, and immediate identification of non-issues. Issues are quickly resolved since the learning process is skipped by personnel familiar with the elements involved. Like a good process design, the handoffs required to perform a task or resolve an issue are minimized.

Effective selection of the "right" team is paramount in FBC efforts. The probability of development "success" is directly related to the quality of the team in both technical and management arenas. It is often easier to attract the best and brightest when the development cycle is relatively short (e.g., 2-3 years). The end of the development cycle produces additional challenges for personnel retention since the end of the development motivates the search for the next challenge. Partnerships, management attention and careful planning between line organization and project organization can minimize this issue.

Concurrency

In FBC developments, it is critical to have a high degree of concurrency between development and mission assurance activities. Some examples of MGS mission assurance concurrency included concurrent design analyses (worst-case, parts stress, FMECA), parts list review (reliability, radiation, availability, application), quality review (subcontract RFP documentation, in-process inspection), problem resolution, testing verification, requirements compliance, and deviation disposition.

FBC processes have to eliminate the "transom-tossing" where each contributor performs their complete task, and then and only then, "tosses it over the transom" to the next person to operate on the results. When this next person inevitably finds some crucial piece of information missing, it is "tossed" back over to the first person for completion. The FBC implementation of this is to "open the door" below the transom and work hand-in-hand on the task, operating on intermediate results as applicable and providing immediate feedback on required inputs and outputs.

Concurrency combined with teaming is a powerful approach for FBC developments. Examples of this for MGS included parallel review by JPL and its partners (especially LMA) of Problem/Failure Reports (PFRs), Engineering Change Requests (ECRs) and waivers. Relative to LMA waivers, JPL Cognizant Engineers (CogEs), Project Element Managers (PEMs), specialists, System Manager and Project Office would concurrently review the waiver and associated documentation in parallel with their LMA counterparts, culminating in a joint telecon with the LMA and JPL change boards to provide disposition and approval. Instrument PFRs underwent a similar parallel review by both the instrument team and JPL reliability engineering.

Collocation

Collocation of mission assurance personnel provides a significantly increased capability for the tight coupling between the mission assurance activities and the core development processes. Collocation can be an enabling vehicle for effective communication and concurrency. Even with enabling communication technology and processes, there is no substitute for the "hallway" and "deskside" interaction that comes with collocation. Ready availability of mission assurance personnel enhances the involvement in critical development interactions and meetings, which are often informal and ad-hoc in their nature.

Collocated personnel should be mostly dedicated to the development team in which they are collocated. They should retain ready access to their "home" functional organizations and exercise this access periodically to provide cross-fertilization, increase external information flow and capitalize on possible synergies and common activities in the project and line organizations.

Collocated personnel must have the "right" mix of technical and people skills to successfully implement this strategy. Successful personnel attributes include the ability to function autonomously, understand project mission assurance requirements, understand project and developer positions and constraints, have a good understanding of mission assurance practice effectiveness in addressing and preventing development issues, interpret requirements from a technical basis, identify and assess issues relative to risk magnitude and provide realistic solutions.

Task value analysis

The resource limitations on MGS focused the effort in the mission assurance program to those tasks that added the most value to the development. Value trades included verification method (e.g., analysis, test, inspection), degree of verification (e.g., margin, sample size), and level of verification (e.g., system, assembly, component). Factors that went into these trades included criticality, failure/degradation impact, failure/degradation probability, and resources required for the task.

There were explicit and implicit approaches to arriving at this Most-Value-Adding (MVA) task set. Examples of explicit approaches included:

1) concern rating (e.g., l-high, 2-medium, 3-low) for design analyses, and
2) risk rating for PFRs (e.g., 1/1 - known cause / certain corrective action) and waivers (e.g., low, medium, high risk).

Explicit ratings were used to scale the effort applied to tasks. Attention to detail, completion and resolution were directly proportional the concern rating. As an example, design analyses with a high concern rating (1) were targeted (and satisfied) for completion the earliest, while low concern items (3) were specifically not addressed.

Implicit approaches were those activities which, although not quantitatively assessed, were conscious efforts to perform the MVA tasks. Examples of implicit approaches included:

1) informal spreadsheet analyses,
2) analyses memorandum (as opposed to reports),
3) Redundancy Verification Analyses (as opposed to systematic FMECAs),
4) system fault tree "brainstorming" sessions (as opposed to a formal system level fault tree),
5) parts list reviews for Alerts (most readily available reliability measure) and radiation issues only, and
6) one day reviews for MCSPFS, heritage and environmental requirements compliance matrix

Communication

Effective communication is crucial to FBC mission assurance programs. A number of approaches were used on MGS that contributed significantly to effective communication:

1) Mission assurance participation in weekly JPL/LMA status telecons (vs. formal monthly management reviews),
2) Two dedicated teleconference "meet-me" phone nets, used throughout development for both formal and informal meetings between non-collocated mission assurance team members,
3) Collocation of JPL quality assurance reps and reliability engineers at LMA,
4) Significant travel and direct interaction by JPL mission assurance team members with development partner organizations, especially LMA,
5) Electronic mail between team members,
6) Computer file server space shared between team members, and
7) World-Wide-Web page access to parts lists, Central Martin Anomaly Reports (CMARs), PFRs and Cape operations video, which all provided remote access to crucial information.

Peer review

A highly effective FBC development and assurance approach is informal detailed design reviews by peers within the technical discipline as well as all mission assurance disciplines. When these reviews are conducted at higher levels of assembly, it also becomes important to involve the lower assembly level developers, including technical subcontractor personnel to identify possible misapplications.

Formal programmatic reviews by heavily experienced technical and project management personnel are most effective as forcing functions for development milestones and programmatic status assessment. A powerful FBC alliance is to couple these with less formal, detailed peer reviews.

All of these reviews are conducted in the most beneficial and cost-effective manner when the review board members are the same throughout the development period. Another contributor to review efficiency and added value was to limit active participation in the review to the review board members. This had to be carefully balanced to ensure identification of all relevant issues and not use the review as a substitute for nominal development issue resolution. The last significant contributor to review effectiveness was documentation of the board report and action items before the board was released from the review.

Rapid closure

FBC development and mission assurance efforts require rapid closure of tasks and issues. It is extraordinarily costly in many dimensions (technical, schedule and cost) for tasks and issues to dwell for long periods of time. This serves to focus analysis efforts, optimize trade study factors and duration, clarify test objectives, and achieve "good enough" closure. One approach to rapid closure is effective task management, including establishment of clear subtasks, required decision data, concrete decision points and specific accomplishment milestones.

One MGS example of rapid closure was the PFR process. For almost all PFRs, the critical information gathering and decision-making period occurred within the first few weeks after the event. With direct mission assurance involvement during this period, mission assurance disciplines added value in the issue resolution and were able to close the PFR shortly after the corrective action was implemented and verified (typically, within 30 days). Reported metrics (see Figure 3) helped 'motivate rapid closure.

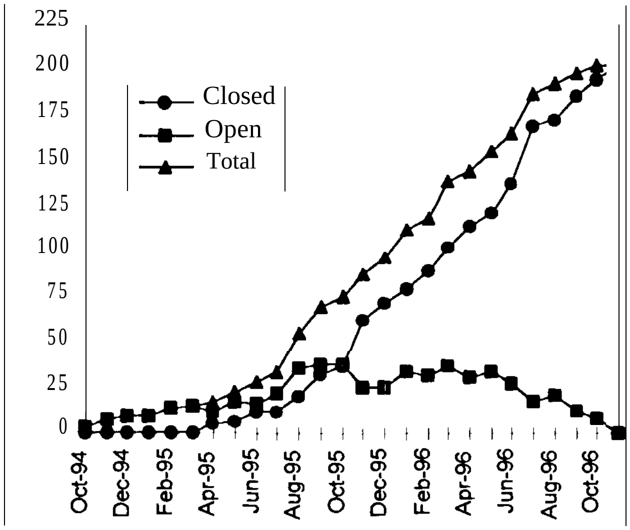

Figure 3. MGS Cumulative PFRs

An important corollary to this approach is the effective closure of issues to minimize the chance and impact of opening the issue later in the development cycle. Many times, this is one of the driving reasons for "sufficient" documentation, which contains enough information to determine why the decision was made.

Appropriate attention to detail

Issues discovered late in the development process can kill a FBC project. At a minimum, they can substantially reduce the solution space, resulting in unplanned/uncontrolled risk increase or resource violations. Balancing the mission assurance focus on the appropriate level of detail becomes paramount in identifying these issues within resource constraints. Resolving the issues requires the diligence to expeditiously follow through to solution.

Based on MGS experience, there are several areas that may require special attention to detail. These include heritage knowledge transfer, subcontractor status, software development and testing status, issues resolution, cross-discipline or cross-cognizance interfaces (e.g., test sensors on special surfaces, electrical circuits in mechanical devices/applications), phasing and interface compatibility.

Education

A significant role for mission assurance in a FBC development is to ensure the deployment of the wealth of past applicable experience. Approaches that support this role include:

1) Effective instantiation of past applicable lessons learned in the development processes and tools,
2) Availability of applicable lessons learned to development personnel,
3) Presentation of mission assurance disciplines to development personnel to ensure knowledge of potential issues,
4) Infusion of mission assurance knowledge through direct involvement with the development process, and
5) Direct support of development processes by mission assurance personnel (e.g., analyses, test support).

4. CONCLUSIONS

Faster, Better, Cheaper (FBC) missions require significantly innovative, responsible and cost-effective mission assurance programs. Mission assurance requirements must be focused towards problem avoidance, tailored to the mission constraints and understood in terms of the value they add. Key approaches must focus the implementation of these requirements to achieve maximum added value. For MGS, these key approaches included teaming, heritage, personnel consistency, concurrency, collocation, task value analysis, communication, peer review, rapid closure, appropriate attention to detail and education.

These approaches can be utilized by future FBC missions to decrease the cost of mission success. It is based on the MGS mission assurance experience and should be tailored to the unique characteristics of each mission. These results are based on empirical experience on one project. Extensibility and enrichment of this FBC mission assurance approach set will come through other projects' lessons learned, cross-project communication and controlled research into various mission assurance practices effectiveness and coupling.

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References

[1] Kevin Clark, "MGS Lessons Learned Spreadsheet", January 21, 1997.

[2] Kevin Clark, "MGS Mission Assurance Lessons Learned", ***Stardust Mission Assurance Advisory Board presentation,*** December 17, 1996.

[3] Kevin Clark, "MGS Mission Assurance Program Lessons Learned", ***JPL Reliability Section Lunchtime Seminar presentation,*** January 29, 1997.

[4] Charles Whetsel, "Mars Global Surveyor Development Lessons Learned", ***MGS Lessons Learned Presentation to JPL Flight System Section,*** August 25, 1997.

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APPENDIX 1 FORMATTED ABSTRACT FOR THE CONFERENCE DIGEST

Mars Global Surveyor Mission Assurance: Key Approaches for Faster, Better, Cheaper Missions

Kevin P. Clark, Jet Propulsion Laboratory

Abstract- Future space missions are required to deliver significant results with new technology and substantially reduced development cost and schedule. Among the first of the recent Faster, Better, Cheaper (FBC) missions for Jet Propulsion laboratory (JPL), the National Aeronautics and Space Administration's (NASA's) Mars Global Surveyor (MGS) was launched to Mars on November 7, 1996 after spending $148M and 27 months in development. A phoenix risen from the ashes of Mars Observer (MO), MGS combined significant heritage with key enabling new technologies to meet its ambitious programmatic and technical goals, This development was characterized by significant teaming between JPL and its development partners.

The MGS mission assurance program was tailored from its MO baseline to capitalize on previous heritage, use development partners' assurance approaches, balance technical risk and implement new assurance approaches consistent with the significant development constraints. The key approaches included teaming, heritage, personnel consistency, concurrency, collocation, task value analysis, communication, peer review, rapid closure, appropriate attention to detail and education. Ibis paper will outline the MGS mission assurance requirements and describe the key mission assurance approaches.