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 (MA) 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.

TABLE OF CONTENTS

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.

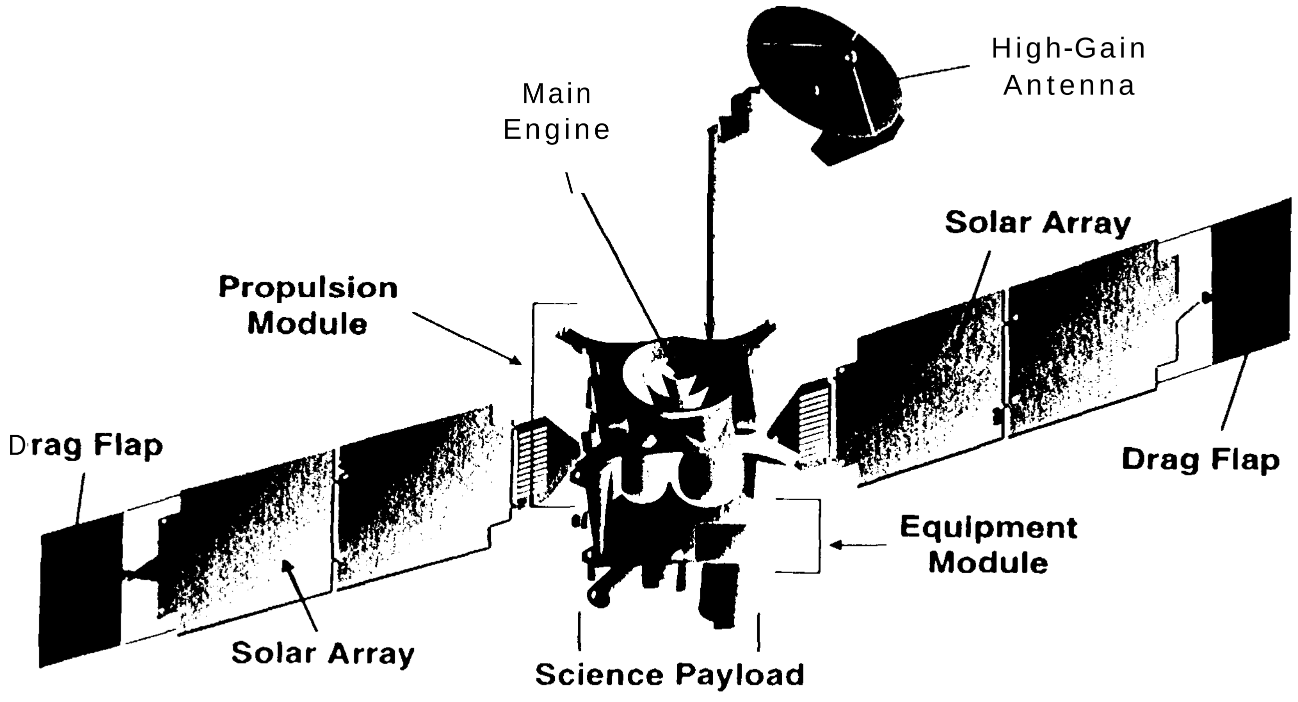

Figure 1. MGS in Mapping Configuration

After a rapid study period, the MGS spacecraft Request For Proposal (RFP) was released in April 1994 and Lockheed Martin Aeronautics (LMA) (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.

Table 1. MGS Project Milestones

System Requirements Review	4/12/94
Mission Preliminary Design 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	10/10/96
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 (MA) 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 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 11 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- -At the outset of the project, the Project Manager set the tone for the entire development by declaring that this project was to be implemented in a “cost-driven paradigm”.

This was implemented by project policy, which established that the primary decision criteria in all decision processes would 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. This is sometimes called Cost As an Independent Variable (CAIV).

Another manifestation of this paradigm was the project policy to approve changes only for the purpose to:

1) “make play”; required to make the design work or meet necessary margins of safety,
2) reduce costs,
3) improve schedule margins, or
4) manage risks relative to meeting mission or project objectives,

This cost-driven paradigm impacted all aspects of MGS development, including targeted application of resources, relatively stable requirements (e.g., 70 MGS waivers compared to 62 I MO waivers), limited implementation approaches, and value-driven selection of tasks to perform.

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 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.

The baseline for MGS development included significant attention to addressing potential issues from MO. The project development baseline developed by the MGS Project Manager included a comprehensive matrix of all actions to be taken as part of the MO Corrective Action Plan [1]. This list of actions was revisited throughout the development process to determine compliance and assess residual risk. Formal presentations of this compliance matrix were made at project reviews.

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 shown in Table 5.

Waivers to project requirements fell into seven categories as follows:

1) Mission Critical Single Point Failures (MCSPFs): 22,
2) Part classification/screening level: 14,
3) Performance of required tests: 11,
4) Meeting derived specification limits: 11,
5) Demonstrating design margin: 8,
6) Implementing design methodology: 3, and
7) Degradation (slight) in mission performance: 1.

Mission Critical Single Point Failures (MCSPFs)

Mission Critical Single Point Failures (MCSPFs) received a significant degree of attention in light of their severity and MO history. A Critical Items List (CIL) was derived that contained approximately 100 items that provided continuity between MO MCSPF concerns and the MGS design. It contained all known MO MCSPFS, new MGS MCSPFs and certain MO process and programmatic issues considered relevant to loss of mission by a single cause. MCSPF items fell into three categories: MO MCSPFS that were retained, MO MCSPFs that were eliminated and new MGS MCSPFS. The CIL was used throughout development to identify and address all MCSPFs that remained in the MGS design. For those that remained as MGS MCSPFS, waivers were approved by the Project Manager after a thorough risk review, mitigation and assessment process. The MCSPF Project Policy also provided a list of exceptions that were not amenable to typical or cost-effective redundancy. The CIL was used as the foundation for the Single Point Failure Review conducted in December 1994. The MCSPF discovery process utilized numerous sources from MO and MGS, including System Fault Tree Analyses (FTAs), Failure Modes, Effects and Criticality Analyses (FMECAs), Failure Review Board reports, heritage design analysis review records, and prior waivers.

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 [2], and the lessons learned portion of this matrix is provided as Table 6 at the end of the paper. In this table, the columns provided are lesson number, priority (in the author's opinion), lesson area and specific lesson learned or recommendation. Several presentations and discussions [3][4][5] 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 teamed and common themes, a set of key approaches to Faster, Better, Cheaper (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.

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-I); no mission critical single point failures without Project Manager (PM) approval; required design analyses; formal Problem/Failure Report (PFR) system; Failure Modes, Effects, Criticality Analysis (FMECA) focus.
Quality Assurance	Spacecraft quality assurance (QA) satisfies NASA Handbook (NHB) 5300.4 (l C); instrument QA assures interface requirements compliance.
Electronic Parts	MIL-STD-975 Grade 1 equivalence; Nonstandard Part Approval Requests (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 per FED-STD-209D (<100,000 particles >0.5 microns in 1.0 cubic foot of air)
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 (K SC) GP- 1098; Missile System Pre-launch Safety Package (MSPSP); Project Safety Plan; spacecraft partner safety program compliance with intent of JPL D-1 141 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 (1 A-1); waiver of single point failures; reliability assurance plan; reliability analyses: functional/interface FM ECAs, 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 (1B) and NHB 5300.4 (1C); 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 park; review non-standard 'parts; ASIC/Hybrid/Custom part special requirements; backward traceability; screening data availability; *lot* QCI; post-programming bum-in; Destructive Physical Analyses (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 ressure 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 Eastern Range Regulation (ERR) 127- 1/ Kennedy Space Center (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; Problem/Failure Reports (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 (1/1 1) 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 of command/sequence requests; command/sequence verification
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, Ground Data System (GDS) and Mission Operation System (MOS)

Table 6. MGS Lessons Learned

#	Pri	Area	Lesson Learned/Recommendation
7	1	Cognizance	Provide right mix of technical disciplines (w/ ownership) to review and monitor development approaches and progress (e.g., Electrical Engineers (EE's) for electrical aspects of mechanisms, heaters, etc.; Mechanical Engineers (ME's) for mechanical parts of electrical boxes like thermal & packaging).
70	1	Management	Keep the same people on the program from beginning to the end; it improves continuity of design and ATLO efforts for the least cost.
5	2	Analysis	Collocate reliability engineer with designers.
6	2	Analysis	Perform Redundancy Verification Analyses (RVAs) on all internally redundant assemblies to drive out Single Point Failures (SPFs) as opposed to rigorous FMECAs.
10	2	Cognizance	Incorporate meaningful alarm limits into ATLO telemetry monitors as early as possible and ensure every telemetry point has a cognizant person assigned to it.
13	2	Communication	Ensure good communication from the beginning between subsystems and flight software developers to decrease issues uncovered late in the program. Collocate software developers with supported subsystems, especially attitude control.
17	2	Contamination	Ensure conformance to all contamination requirements throughout development and testing, especially in facilities known to violate requirements. Make someone responsible for implementation of Contamination Control Plan. Evaluate facility procedures early.
19	2	Contract mgmt	Establish a standard subcontract weekly/monthly reporting mechanism that addresses all deliverables, drawing, procedures, and open items. Plan on Product Integrity Engineers (PIEs) meeting with sub's at least monthly/bi-monthly and more during contract testing phases.
20	2	Contract mgmt	Include in Subcontract Data Requirement Lists (SDRLs) the delivery of all relevant subcontract documentation to the detailed level (e.g., Parts, Materials and Processes (PMP) lists, drawings, and certifications). Perform detailed review of all subcontracted component documentation with appropriate specialists.
23	2	Design	Analyze entire grounding tree (including structural paths) through to end circuits including noise thresholds. Use dedicated returns/differential channels for sensitive circuits/telemetry. Work grounding architecture and issues early. Assign Grounding PIE.
25	2	Design	For Nickel-hydrogen batteries, 1) reduce charge rates as full charge is achieved, 2) ensure no excess electrolyte, 3) mount batteries to minimize electrolyte "pooling".
26	2	Design	Use twisted shielded pair wiring on telemetry and digitally clocked signal interfaces to reduce cross talk. This should not be sacrificed for mass. Allow for future growth in the number of these signals.
27	2	Design	Combine X and Ka feeds in antenna design.
29	2	Design	Design in enough attitude control authority margin to accommodate modest off-nominal conditions, like partial deployments
33	2	Design	Eliminate potentiometers from deployment designs unless intermediate positioning is essential (and even then, consider whether this is your only capability for establishing position).
36	2	Design for Testability	Avoid inadvertent "hot" mates and demates of connectors by disconnecting (via switch) the battery power leg.
38	2	Design for Testability	Increase degree of modular design to increase schedule flexibility
39	2	Design for Testability	Locate power interrupt (e.g., Main Enable Plug) in the high side of power system with appropriate safety features. Design to avoid sneak paths (e.g., telemetry & GSE) when power system intended to be off. (Note: this is a heavily debated design approach with good rationale for either leg).
44	2	Documentation	Close PFRs within 30 days. Process should include discipline-cognizant reliability engineer involved right after the anomaly who supports analysis, ensures cross-discipline review. helps with minimal documentation and CLOSES it when solved (no other review).
51	2	GSE	Ensure GSE has manual mode of operation in addition to automated modes, and that adequate procedure control exists when varying from automated process.
66	2	Management	Maintain a single data bank of open items controlled by Quality Assurance
67	2	Management	Mirror the JPL and partnering organizational structures to provide significant economy in communication, cognizance and reporting.
68	2	Management	Conduct weekly programmatic and technical status meetings

Table 6. MGS Lessons Learned (cent'd)

#	Pri	Area	Lesson Learned/Recommendation
74	2	Materials	Perform detailed review of all Spacecraft (S/C) and Ground Support Equipment (GSE) soft goods (e.g., propulsion line o-rings, valve seats) considering exposure duration and performance effects. Perform component-level qualification testing with actual fluids and exposure duration seen in flight. Allow for in-flight isolation without MCSPFs.
75	2	Metrics	Establish metrics for all development activities at the subsystem or box level, as appropriate. Software development metrics should include status for each task in a build, percent complete for requirements, design, walkthroughs, unit test, Integration and Test (I&T), Version Description Document (VDD) preparation, module error rates, etc. Hardware development metrics should include for each board in the box percent complete for requirements, design/released engineering, tabletop (peer) reviews, FMEA/analyses, parts procurement, compatibility analyses, fab, test, etc. Schedule metrics for analytical activities should include percent complete of algorithm development, performance analysis, parameter definition, tabletop reviews, etc. Schedule metrics for testing should include for each test the percent complete of procedures, tabletop, dry run, final run, post test data processing, analysis, buyoff, etc.
89	2	Parts	Perform parts list reviews early, document results, track issues resolution and complete this process by CDR. NSPARS are not required if this is done.
96	2	Resources	Apply one subsystem engineer per Assembly, Test and Launch Operations (ATLO) shift plus one more who can support troubleshooting and paper closing. This includes flight software engineers.
101	2	Reviews	Use informal reviews that address interactions with other elements, fault protection, plan to get the job done, plan to track status, key technical issues or design concerns, and plan for verification.
103	2	Safety	Provide for positive confirmation that hazardous commands cannot be acted on when not intended BEFORE commands are sent.
104	2	Safety	Ensure adequate understanding of facility test control redundancy. This should be a significant part of the pre-test procedure walkthrough.
108	2	Teaming	Maximize teaming between JPL and industrial partner by identifying and providing direct JPL support for requested activities.
109	2	Testing	Testing personnel must be thoroughly trained in oscilloscope measurement and exercise extreme caution when making any measurement on flight hardware. Consider isolating scopes with isolation resistor/transformer and making only differential measurements.
116	2	Testing	Develop a suite of minimum, essential software tests to be done, stick to them, and only add "nice" tests later as time permits. Document unit testing well to buyoff requirements. Phase test personnel training and testing to support schedule.
119	2	Testing	Ensure component level testing is rigorous enough to sufficiently screen out problems.
120	2	Testing	Phase component and interface testing based on prior experience and changes. Schedule testing of new components and changed interfaces earlier. Schedule heritage components and unchanged interfaces later, but verify no subtle changes.
123	2	Testing	Perform System Thermal Vacuum (STV) earlier in the program, specifically, prior to vibration testing, to allow more time for fixes. Outweighs flight order of environments. Requires instrument deliveries earlier so complete system will go through System Thermal Vacuum (STV) test.
1	3	Analysis	Define required design analyses early, track weekly, assess impact to other areas (e.g., hardware, software, cabling), continually evaluate value added, and stick to plan. Complete analyses and issues resolution by CDR. Prioritize issues by risk (impact and probability)
2	3	Analysis	Design Analysis Status Reports provide a comprehensive tracking method for design issues resolution. Implement a simple mechanism for tracking these issues to ensure resolution early enough in the design process (e.g., before CDR).
3	3	Analysis	Ensure that preventive measures identified by Mechanical Fault Tree Preventive Measures Matrix are performed and tracked.
4	3	Analysis	Ensure prudent use of significant design margin, which can lead to substantial cost, schedule and performance savings by mitigating the need and impact of labor-intensive design analyses that discover design inadequacies late in the development process.

Table 6. MGS Lessons Learned (cent'd)

#	Pri	Area	Lesson Learned/Recommendation
8	3	Cognizance	Assign a Pyro PIE and Telemetry PIE to handle these functions to ensure that these cross-subsystem functions get worked adequately. At a minimum, assign transducer/telemetry responsibility to Command and Data Handling (C&DH) and pyro responsibility to Power.
9	3	Cognizance	Provide enough time for subsystem review of Spacecraft Test Laboratory (STL) / Enhanced Real-time ADA Interactive Debugger (ERAID) / ATLO results, test procedures, test sensor installation drawings and test conditions to ensure compatibility with all component test limits and adequate validation of requirements, interfaces and redundancy.
11	3	Communication	Ensure a closed-loop process for communicating issues to all users. Assigning discipline-cognizant PIEs as long-term owners for each component (may require multiple PIEs on a box) facilitates this.
12	3	Communication	Use email, Meet-me teleconferencing, live camera pictures on Web page and mirrored computer servers to facilitate communication between non-collocated parts of design team, like JPL and an industrial partner.
14	3	Configuration control	Ensure that engineering changes are promptly entered into documentation (e.g., drawings, specifications)
15	3	Configuration control	The change process must include reverification as one of its gates before approval and implementation
16	3	Configuration control	Ensure good flight software configuration control and code librarian functions to facilitate rapid software builds, anomaly processing, and efficient development for rapid projects.
18	3	Contract mgmt	Develop standard Statement Of Work (SOW) / Procurement Document (PD) with consistent SDRLs, reviews, PDR/CDR support, I&T support, detailed environment, contamination, parts, packaging and shipping requirements, Product Assurance (PA) and Configuration Management (CM) requirements. Deletions should be well understood by all disciplines and risk accepted.
21	3	Contract mgmt	Scale vendor surveillance based on vendor experience (design, fab, etc.), product uniqueness, and activity (e.g., fab step) criticality to performance. Conduct in-depth initial survey to understand this and develop detailed surveillance plan WITH vendor.
22	3	Design	Maintain detailed Radio Frequency (RF) budget that includes all RF components
24	3	Design	Establish and validate adequate margin when using set screws in rotational torque designs
28	3	Design	Review harness layout for current loops in the harness, structure and electronic assemblies to ensure compatibility with program magnetics requirements.
30	3	Design	Obtain all instrument/sensor calibration curves and ensure application requirements are satisfied over the operating region, especially for nominal conditions.
31	3	Design	Complete ALL environmental design analyses (radiation, micrometeoroid, charging, etc.) and review prior to PDR.
32	3	Design	Eliminate thermal cavities from design.
34	3	Design	Develop command and telemetry dictionaries prior to ATLO for maximum savings. Negotiate format of these between ATLO, MOS and Ground Software.
35	3	Design	Develop reliable methods to terminate, handle and protect small cables and connectors.
37	3	Design for Testability	Allow for low risk access to replace failed parts. In general, for less mature areas; allow for greater rework access.
40	3	Design for Testability	Ensure adequate inspection process for non-testable items. in general, establish testability measures for components, assemblies, redundancy and requirements. Ensure adequate review of risk and mitigation approach for non-testable items. Test all Fault Protection (FP) in ATLO
41	3	Design for Testability	Size all relays to take derated in-rush current. Consider effects of inadvertent power down states in design (e.g., may want to allow ON relay to be able to be switched open independent of ENABLE relay state).
42	3	Design for Testability	Establish design approach that allows for late Safe Mode program incorporation and/or early interaction with all subsystems and testing to identify issues.
43	3	Documentation	Focus documentation efforts to primarily facilitate real-time communication and secondarily the minimum required to support future recall of critical events and conditions. Document as you go along (don't save till end).
45	3	Documentation	Time spent documenting design analyses once pays for itself in efficient issue resolution
46	3	Documentation	Keep an ongoing lessons learned list, issues list and significant events throughout the program (rather than only at the end).

Table 6. MGS Lessons Learned (cent'd)

#	Pri	Area	Lesson Learned/Recommendation
47	3	Documentation	Use Industrial partner's problem reporting system exclusively. JPL review should be through the contractor's system (e.g., flags, Central Martin Anomaly Reports (CMARs))
48	3	Documentation	Document software requirements well and maintain them. It pays off in the long run when troubleshooting and performing verification. Needs to be performed early and resources allocated.
49	3	Fabrication	Don't allow welding currents to flow through electrical components and overstress them when using a welded-wire interconnection technique.
50	3	GSE	Allow sufficient time for PIEs/ Cognizant Engineers (CogEs) to be cognizant of Electrical GSE (EGSE) development
52	3	GSE	Connect EGSE and workstations to an Uninterruptable Power Supply (UPS) so testing can continue, especially during critical events.
53	3	GSE	Ensure adequate clearance between RF radiating elements and reflective material
54	3	GSE	Ensure early enough testing of all GSE to identify operational and technical issues and resolve well in advance of need.
55	3	GSE	Ensure early test bed capability to support project needs. Ensure ready access to development test environments (e.g., ERAID) to free up more formal test beds and even more limited spacecraft test environments.
56	3	Handling	1) Compare hardware capability, transportation environment and instrumentation, 2) Hand-carry flight hardware for air transport, 3) Ground transport on air-ride if sufficiently weighted, 4) Transportation experts review shipping containers & move approach
57	3	Handling	Define early all flight critical hardware and incorporate into Move-Safe procedures
58	3	Heritage/GFE	Establish early specific plan for review of heritage hardware that provides enough resources, including detailed interaction between heritage/GFE developers and new users, as well as direct Project support from prior developers. Identify review criteria and intent.
59	3	Heritage/GFE	Analyze impact of all possible application changes for heritage hardware, including off-nominal conditions since these are typically not tested as thoroughly.
60	3	Interfaces	Clearly specify intended Interface Control Drawing (ICD) requirements early on and monitor implementation throughout development. ICDs should contain schematics of actual end circuits for each interface. Perform detailed ICD walkthrough with all stakeholders.
61	3	Interfaces	Develop and maintain a database for all flight and GSE interfaces to the bit/value (e.g., voltage, current) level for software, commands, telemetry, harness connections and box pinouts.
62	3	Interfaces	Implement a systematic method (e.g., compatibility analysis, checkout drawing review, circuit data sheets, interface database) for identifying interface issues from the beginning and apply resources as needed to identify and fix issues early in the design phase.
63	3	Management	Maintain a single issues and concerns list that captures all reliability concerns,
64	3	Management	Implement a formal Risk Management program
65	3	Management	Margin should be managed as a line item on schedules based on planned work to be performed versus required need date.
69	3	Management	Establish clear responsibility for mission success for each contributor and for all hardware/software elements.
71	3	Management	Track development progress at the lowest level of detail practicable to avoid downstream surprises that are hard to recover from.
72	3	Management	Incorporate minimal software Independent Verification and Validation (IV&V) where close communication between requirement developers and coders exist, developers understand the implemented software, and adequate development discipline processes exist (configuration control and independent review).
73	3	Materials	Ensure that Planetary Protection requirements are compatible with other Project requirements
76	3	Ops Training	Provide sufficient time and priority for rehearsals/Operation Readiness Tests (ORTs)
77	3	Ops Training	Ensure that launch procedures are in hand before Launch & Initial Acquisition Rehearsals/ORTs are conducted.
78	3	Ops Training	Conduct Rehearsals/ORTs on mature software.
79	3	Ops Training	Conduct test and training on ground software in advance of Rehearsals/ORTs
80	3	Ops Training	Provide sufficiently detailed and meaningful telemetry to Rehearsal/ORT team to adequately simulate spacecraft performance

Table 6. MGS Lessons Learned (cent'd)

#	Pri	Area	Lesson Learned/Recommendation
81	3	Ops Training	Dedicate time and resources to team building for the entire Mission Operations team (e.g., LMA, JPL, Science)
82	3	Ops Training	Dedicate sufficient planning for green cards (randomly handed out simulated anomaly conditions) as a training tool
83	3	Ops Training	Incorporate the entire Operations team inputs in planning and enlist its support during conduct to make Operations training tests as efficient and effective as possible
84	3	Ops Training	Consolidate Operations software interfaces
85	3	Parts	Perform all parts testing (life test, DPA) and failure analysis early enough in program for fixes if problems are serious.
86	3	Parts	Perform early DPA of all parts, especially commercial parts to screen for potential problem parts. Perform early DPA on all ceramic capacitors to screen out porous dielectric; susceptible to this failure mode.
87	3	Parts	Start early on formal parts program weekly tracking. Allow sufficient time for procurement process. Have a dedicated parts expediter.
88	3	Parts	Establish specific actions to prevent connector disconnection such as avoiding blind mates, quality checks, unique keying, Scoop-Proof connectors, unique labeling, label both sides of connection, procedures, stray voltage, and ringout.
90	3		Develop plan early in the Project that identifies resources required and organizations for these resources. Work with these organizations (including other Projects) to develop solutions for both the short run (Project) and long run (core capabilities).
91	3	Resources	Estimate resources required for the modification of existing software to include a significant effort to understand the total existing software design (especially for critical modules and fault protection) and software development platform/tools.
92	3	Resources	Phase the thermal analysis effort (top level down to details) so that it can be accomplished sufficiently early to respond to issues, and apply adequate resources. This is an area that is often understaffed and late.
93	3	Resources	Increase emphasis on early and accurate estimation of mass in thermal and harness areas.
94	3	Resources	Provide adequate resources to drive out all Single Point Failures before CDR.
95	3	Resources	Don't spread cognizant engineers too thin. Two boxes per PIE is often an appropriate staffing level. This extends to payload accommodation engineers as well.
97	3	Resources	Staff STL testing similar to ATLO staffing through launch. Establish plan to verify known/understood requirements using STL. Involve subsystem engineers in STL verification tests.
98	3	Resources	"Provide a software development workstation for each software developer.
99	3	Resources	Ensure that all flight software development tasks are identified and planned for from the beginning. Often overlooked tasks include telemetry list, command list, and development of early testing data such as bina ephemeris and star catalogs.
100	3	Reviews	Ensure that subsystem PDRs and CDRs have presentations and complete participation by subcontractors, Systems, verification, reliability, thermal, stress, mechanical, electrical, and PMP. Put subcontractor participation in each SOW.
102	3	Reviews	Have homeshop (functional organization) review Basis Of Estimates (BOEs) during preposal and during program. Bring them in for 1-4 hour briefing on plan/BOE.
105	3	Spares	Provide enough spares to maintain schedule flexibility required for fast projects. Can reduce spares requirements by using box-level redundancy. Develop a specific plan early for rapid repair and replacement with hard agreements in place.
106	3	Spares	Treat flight spares as if you were going to fly it. Clean and store assuming long-term storage and eventual flight use. Close all paperwork and capture history/rationale for those left open.
107	3	Teaming	Perform buyoffs by instrument teams at major testing milestones (like begin/end of tests, major configuration changes), including verification of instrument configuration. Unusual requirements like magnetics and electrostatics may require closer tracking.
110	3	Testing	Perform powered on vibration testing to detect intermittent failures (even if this isn't the launch power mode).
111	3	Testing	Perform long, hot assembly level thermal test to drive out time and temperature dependent failure modes.

Table 6. MGS Lessons Learned (cent'd)

#	Pri	Area	Lesson Learned/Recommendation
112	3	Testing	Perform Electromagnetic Interference (EMI) testing in an electromagnetically controlled facility with well-understood test objectives and pass-fail criteria. Test known EMI victims and sources as early as possible (e. g., component level). Track EM I characteristics of all components.
113	3	Testing	Expect some errors when using air link from spacecraft facility to M1L71 (NASA KSC RF facility) due to multipathing.
114	3	Testing	Thoroughly test software at subsystem level and system tests off-line from spacecraft before delivery. Allow sufficient time and people to review off-line tests (e.g., STL) prior to spacecraft execution. Document fault protection flow diagrams.
115	3	Testing	Establish specific plans and agreements for lab/fab/test facilities prior to CDR.
117	3	Testing	Consider prudent use of subsystem level testing to decrease schedule risk of System level test anomalies
118	3	Testing	Perform end-to-end phasing tests of all spacecraft articulation modes. Don't assume because phasing is proper for one software mode that it is proper for all modes.
121	3	Testing	Consider facility power interruptions when developing test contingency plans and FMEAs for GSE. In this case specifically, include an extra solenoid valve that closes when power is removed.
122	3	Testing	Ensure that test procedure writer reads entire requirement to be tested and obtains test method and pass/fail criteria from PIE. If time early on, try to capture this linkage in the requirements tracking database.
124	3	Testing	Provide close coordination between Flight Software (FSW) development and ATLO to support just-in-time software deliveries for ATLO.
125	3	Testing	Make use of all the protection features offered in the hardware. Develop hardware and procedures with features to protect the hardware.

Teaming

A leading 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 "proving ground" for the replacement of "oversight" functions and perceptions with "insight" and partner contribution. 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 crosscutting 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 (http: //parts.jpl.nasa.gov). 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.

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 Product Integrity Engineers (f'IEs) 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 (o 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.

A tremendous amount of development work and issues resolution 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. Most 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.

Many issues were uncovered 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 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 significant 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. By paying attention to these activities, use of heritage can have a profound effect on decreasing the schedule, budget and technical risk for the heritage-using project.

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 personnel familiar with the elements involved skip the learning process. Like a good process design, the handoffs required to perform a task or resolve an issue are minimized.

MGS capitalized on personnel consistency throughout the development process. Most of the development team stayed with the project from spacecraft proposal phases through launch. This provided significant savings in time, as people were intimately familiar with development issues and idiosyncrasies. This was especially helpful in resolving discrepancies by focusing effort on the "real" issues, resulting in rapid understanding and resolution by both design and mission assurance personnel.

F, ffective 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, FM ECA), 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 a 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. For LMA waivers, JPL Cognizant Engineers (CogEs), Project Element Managers (PEMs), specialists, System Managers and the 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. The rapid results of this intense parallel activity are shown in Figure 2. Instrument PFRs underwent a similar parallel review by both the instrument team and JPL reliability.

Collocation

Collocation of mission assurance personnel significantly increases the coupling between the mission assurance activities and the core development processes. Collocation enables 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 primarily 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 implement this strategy successfully and be able to:

1) function autonomously,
2) understand project mission assurance requirements,
3) understand project constraints,
4) understand designer constraints,
5) understand mission assurance practice effectiveness,
6) understand the technical basis for mission assurance practices and be able to communicate this, and
7) 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 task resources required.

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., I-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 to 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 (RVAs),
.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 Mission Critical Single Point Failures (MCSPFs), heritage and environmental requirements compliance matrix.

Generally, this task value analysis did an excellent job of focusing the limited resources on the most significant development issues and activities. One example that provides some insight into the risk with this approach is where an analysis rated as a "2" (medium) priority that was never performed (since these were on a "as time permits" basis) might have indicated an overstress condition for a misapplied heritage temperature controller. This same example provided a lesson learned about cross-discipline design cognizance.

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),

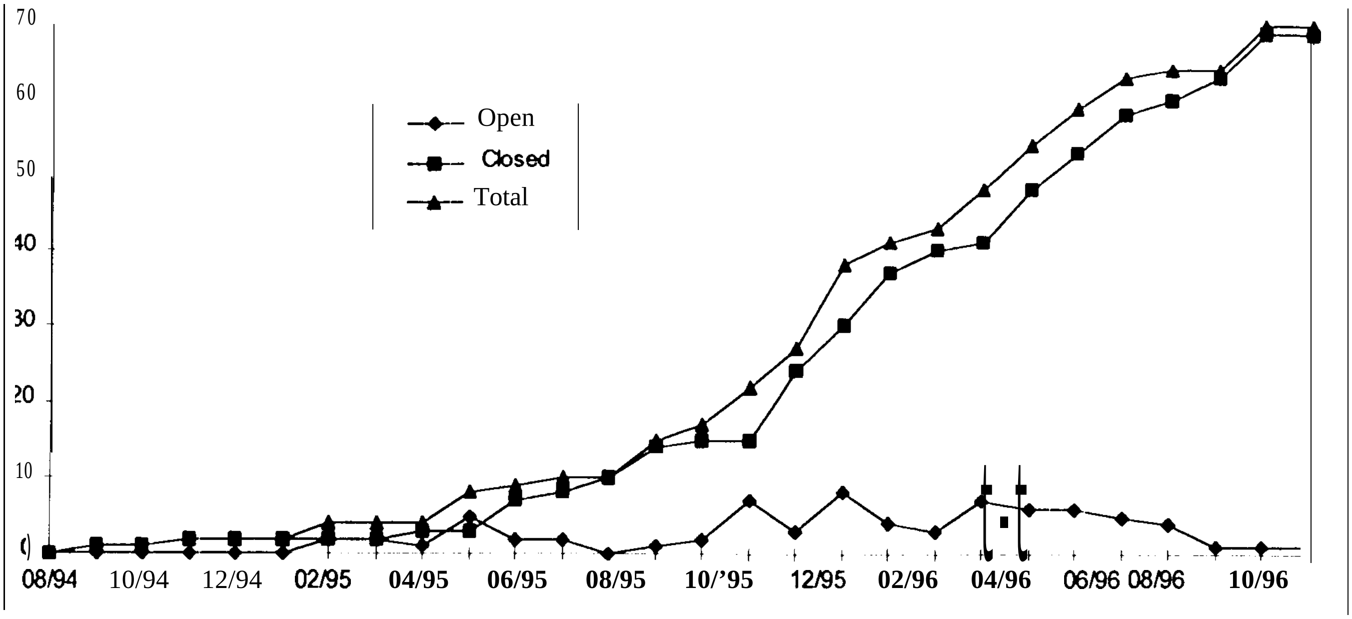

Figure 2. MGS Waivers

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.

Peer review

A highly effective FBC development and assurance approach is informal detailed design reviews by peers within the technical discipline as well as with 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 highly 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.

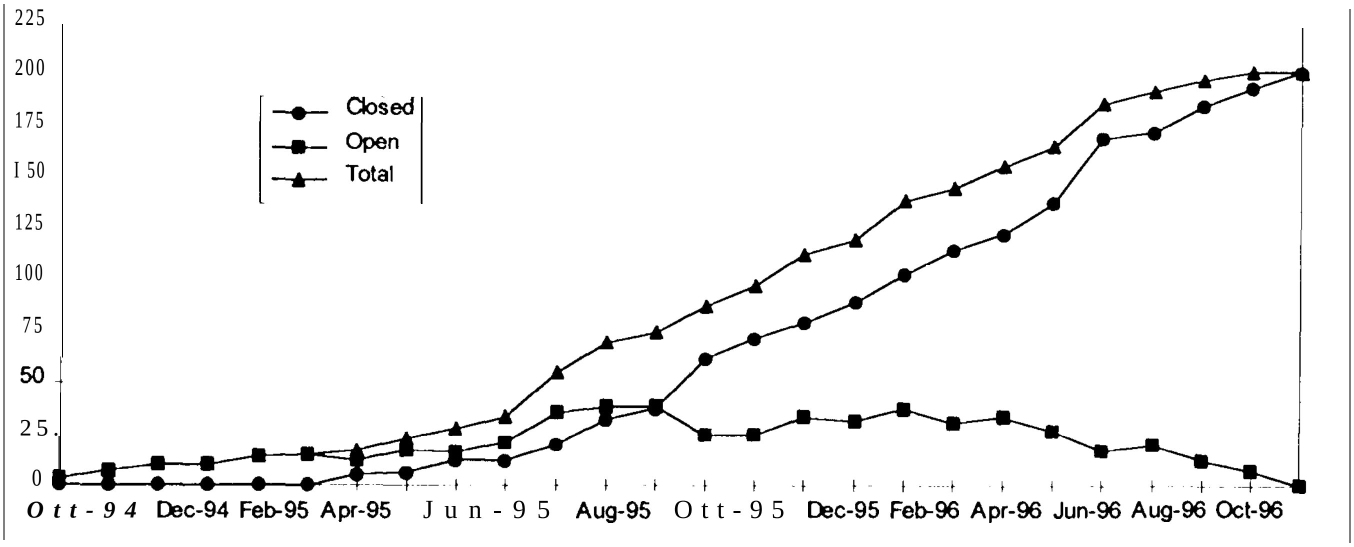

Figure 3. MGS Cumulative PFRs

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.

An example of this challenge is provided by the apparent failure of the -y solar array viscous damper shaft that occurred during the deployment of the solar array in flight, The shock loads of the outer panel deployment latching event transmitted through the inner panel to this damper shaft were well within apparent design and test margins for this flight-proven design. However, the information that this shaft was cast rather than forged, which makes this failure credible, was buried deep within the damper manufacturing details. Surfacing this type of detail with a cost-effective design methodology is a challenge for FBC projects.

Based on MGS experience, there are several areas that may require special attention to detai 1. 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. They are based on the MGS mission assurance experience and should be

tailored to the unique characteristics of each mission. These results are based on 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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APPENDIX I FORMATTED ABSTRACT FOR THE CONFERENCE DIGEST

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, 19% 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. Tire 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.