

## OUTLINE

- Charter
- Membership
- Methodology
- Schedule of Activities
- General Observations
- Faster, Better, Cheaper
- Review and Analyze Recent Mars and Deep Space Missions
- Relationships and Interfaces
- Scientist Involvement
- Mars Surveyor Program
- Conclusions

The Mars Program Independent Assessment Team (MPIAT) report follows this outline. There are three related reports produced under the direction of the MPIAT charter.

“Mars Program Independent Assessment Team Report” dated 3/14/00 (This Report)

“Mars Program Independent Assessment Team Summary Report” dated 3/14/00

“Report on the Loss of the Mars Polar Lander and Deep Space 2 Missions” dated 3/22/00

Three additional relevant reports have been produced external to the MPIAT activities.

“Mars Climate Orbiter Mishap Investigation Board Phase I Report” dated 11/10/99

“Report on the Loss of the Mars Climate Orbiter Mission” dated 11/11/99

“Report on Project Management in NASA by the Mars Climate Orbiter Mishap Investigation Board” dated 3/13/00

# CHARTER

---

- Review and Analyze Successes and Failures of Recent Mars and Deep Space Missions
  - Mars Global Surveyor
  - Pathfinder
  - Deep Space 1
  - Mars Climate Orbiter
  - Mars Polar Lander
  - Deep Space 2
- Examine Relationships Between and Among
  - NASA Jet Propulsion Laboratory (JPL)
  - California Institute of Technology (Caltech)
  - NASA Headquarters
  - Industry Partners

The charter for the MPIAT was established by the NASA Administrator. This charter includes examination of the multiple facets of the Mars Program, with emphasis on the strengths and weaknesses in individual projects, the overall program, and relationships among participants. A critical aspect of the charter is to identify lessons learned for use by the future Mars Program.

# CHARTER

---

- Assess Effectiveness of Involvement of Scientists
- Identify Lessons Learned From the Successes and Failures
- Review Revised Mars Surveyor Program to Assure Lessons Learned Are Utilized
- Oversee Mars Polar Lander and Deep Space 2 Failure Reviews
- Complete by March 15, 2000

## MEMBERSHIP

---

- Thomas Young, Chair
- James Arnold
- Thomas Brackey
- Michael Carr
- Douglas Dwoyer
- Gen. (Ret.) Ronald Fogleman
- Maj. Gen. (Ret.) Ralph Jacobson
- Herbert Kottler
- Peter Lyman
- Joanne Maguire
- Robert Pattishall
- Laurence Soderblom
- Peter Staudhammer
- Kathryn Thornton
- Peter Wilhelm
- Brian Williams
- Maria Zuber
- Kurt Lindstrom,  
Executive Secretary

4

Team membership is from a broad spectrum of organizations, including government, industry, and academia. Several engineering and science disciplines are represented as well as members with broad management experience in the aerospace community. Associations and biographies for the members appear at the end of this report.

## CONSULTANTS

---

- John Casani
- Brantley Hanks
- Bruce Murray
- Peter Norvig
- Robert Sackheim
- Steven Zornetzer

Consultants were important contributors to the MPIAT activities. John Casani chaired the Mars Climate Orbiter, Mars Polar Lander, and Deep Space 2 failure reviews.

## METHODOLOGY

---

- Structured Reviews
- Informal Sessions
- Executive Sessions
- Team Discussions

6

The team began work in early January 2000 with structured fact-finding reviews at the Jet Propulsion Laboratory (JPL) in Pasadena, California; Lockheed Martin Astronautics (LMA) in Denver, Colorado; and NASA Headquarters in Washington, D.C.

The structured sessions were followed by informal splinter sessions involving subsets of the team. These subsets met with representatives from a cross-section of managers and technical staff. The meetings focused on management and technical concerns raised in the structured reviews.

The informal sessions were complemented by executive sessions, involving the entire team with individual senior managers, technical personnel, and science leaders. Topics discussed included broad management and technical issues in the Mars Program.

The team met on a regular basis in discussions centering on its current understanding of the issues and identification of areas for further examination. Significant discussion and debate by the team resulted in this being an integrated report supported by all members.

## SCHEDULE OF ACTIVITIES

DATE	LOCATION	ACTIVITY
Jan 7	NASA Headquarters	Kickoff Meeting
Jan 11, 12, 13	JPL	JPL Review
Jan 20, 21	LMA	Lockheed Martin Astronautics Review
Jan 25, 26	NASA Headquarters	NASA Headquarters Review
Feb 2, 3, 4	JPL	Follow-up JPL Review
Feb 8, 9	LMA	Follow-up Lockheed Martin Astronautics Review
Feb 16	NASA Headquarters	Process Status Report to NASA Administrator
Feb 22, 23, 24	NASA Headquarters	Report Preparation/Follow-up NASA Headquarters Review
Feb 29, March 1, 2, 3	NASA Headquarters	Report Preparation/Architecture Preview
March 13	NASA Headquarters	Report Review
March 14	NASA Headquarters	Final Report to NASA Administrator

7

The team followed the schedule as outlined. Fact-finding trips were conducted between January 11, 2000, and February 9, 2000. The team spent the balance of the time on special topics and developing a common understanding of the issues and developing lessons learned.

## GENERAL OBSERVATIONS

- Mars Exploration Is an Important National Goal That Should Continue
- Deep Space Exploration Is Inherently Challenging; the Risks are Manageable and Acceptable
- NASA, JPL, and Industry Have Required Capabilities to Implement Successful Mars Exploration Program
- JPL Is a Center of Excellence for Deep Space Exploration with Unique Capabilities
- Faster, Better, Cheaper (FBC), Properly Applied, Is an Effective Concept for Guiding Program Implementation that Should Continue
- Significant Flaws Are Identified in Formulation and Execution of Mars Program
- All Identified Flaws Are Correctable in a Timely Manner to Allow a Comprehensive Mars Exploration Program to Successfully Continue

8

Throughout history, people have pondered whether there is life beyond Earth. Now, the United States has the ability to pursue this question. Mars is the only planet feasible for human exploration in the near term. It is the only planet that appears viable to sustain a human presence. The Mars Pathfinder landing on July 4th, 1997, demonstrated extraordinary public interest in Mars, setting a record number of visits (over a half billion) to a Web site. The Mars Program Independent Assessment Team found no reason that the exploration of Mars should not continue.

The United States has enjoyed unprecedented and unmatched technological achievements in space over the last four decades. Nevertheless, pioneering exploration of the planets remains a challenging enterprise and is inherently risky. The distances are immense, the environment is hostile, the tolerance for error is small, the spacecraft resources are limited, and navigation of the heavens is demanding. While the challenges are high, the extraordinary deep space successes demonstrate that the risks are manageable and acceptable.

The significant successes of the deep space program illustrate that the United States has the required capabilities to implement a successful Mars Exploration Program. While the MPIAT found numerous instances in which this capability was not effectively applied, the team believes that observation to be correct.

## GENERAL OBSERVATIONS

- Mars Exploration Is an Important National Goal That Should Continue
- Deep Space Exploration Is Inherently Challenging; the Risks are Manageable and Acceptable
- NASA, JPL, and Industry Have Required Capabilities to Implement Successful Mars Exploration Program
- JPL Is a Center of Excellence for Deep Space Exploration with Unique Capabilities
- Faster, Better, Cheaper (FBC), Properly Applied, Is an Effective Concept for Guiding Program Implementation that Should Continue
- Significant Flaws Are Identified in Formulation and Execution of Mars Program
- All Identified Flaws Are Correctable in a Timely Manner to Allow a Comprehensive Mars Exploration Program to Successfully Continue

8

For more than four decades, the Nation has consistently invested in the NASA Jet Propulsion Laboratory. JPL is a vital national asset—a focal point for implementing deep space exploration with unique capabilities. The utilization of these capabilities has resulted in successful programs ranging from the Mariners to Galileo to Magellan to Pathfinder. The MPIAT found situations in which the JPL deep space expertise was not properly applied, resulting in significant problems, and areas in which it was effectively utilized thereby contributing significantly to mission success.

NASA has been applying a new way of doing business, Faster, Better, Cheaper (FBC), for much of the decade of the 1990s. FBC was reviewed extensively by the MPIAT and found to be an effective concept for guiding program implementation, if properly applied. The team believes that the FBC concept should continue to be the approach utilized in the future Mars Program.

Significant errors in the formulation and execution of the Mars Program were evident. This will be discussed in detail in this report, including the identification of appropriate lessons learned to be incorporated in the future program.

While the flaws are serious, the MPIAT believes they are correctable in a manner that will allow a comprehensive Mars Exploration Program to continue.

## **FASTER, BETTER, CHEAPER**

"...tell us how we can implement our missions in a more cost-effective manner. How can we do everything better, faster, cheaper, without compromising safety?"

NASA Administrator's  
Remarks to JPL Employees  
May 28, 1992

9

This quote was part of a speech given by Daniel S. Goldin to employees at JPL, approximately 2 months after he became NASA Administrator. In this speech, he challenged the employees of JPL to revolutionize future NASA space missions to provide the American people with a more cost-effective space science program. In this challenge, he also made it clear that this new, revolutionary program was not intended to compromise safety. In this context, safety relates to mission success.

# FASTER, BETTER, CHEAPER

Mars Program Independent Assessment Team's

## Definition

- Create Smaller Spacecraft—More Frequent Missions
  - Increases Opportunities for Scientist and Public Participation
  - Distributes Risk
  - Provides More Frequent Opportunities to Incorporate Timely Results in Subsequent Missions
- Reduce Cycle Time
  - Eliminates Non-Value-Added Work
  - Utilizes Improved Management Techniques and Engineering Tools
- Utilize New Technology
  - Increases Opportunity to Utilize New Technology
  - Enhances Scientific Return and Public Interest
  - Reduces Spacecraft Size and Overall Mission Cost

10

Because the team could not find an established definition of FBC, the MPIAT developed the definition outlined on this and the following chart. The team used this definition in deriving findings and lessons learned.

The concept of smaller spacecraft and more frequent missions is intended to increase opportunities for scientist and public participation. It also distributes risk over a larger number of small missions as opposed to one large mission. The FBC strategy distributes the risk of achieving science objectives among more missions, minimizing the impact of a single mission failure. More frequent missions provide the opportunity to incorporate knowledge gathered (both science and engineering) into future missions in a more timely manner.

Faster does not mean arbitrarily reducing development and implementation time. It means reducing cycle time by eliminating inefficient or redundant processes. This must be done carefully to accomplish necessary tasks in the most efficient manner possible.

Utilization of new technology is integral to FBC success. FBC increases the ability to incorporate new technology into missions. New technology can be used to increase the scientific return of missions and/or reduce spacecraft size and overall mission cost. It is necessary that a new technology be adequately mature before it is incorporated in a flight program. Ideally, new technology (rover, virtual reality, etc.) can also serve to increase public interest in the program.

# FASTER, BETTER, CHEAPER

Mars Program Independent Assessment Team's

## Definition (cont.)

- Accept Prudent Risk Where Warranted by Return
  - Accept Risk of New High-Return Technology and Innovation
  - Accept Risk of Pursuing High-Value Science
- Utilize Proven Engineering and Management Practices to Maximize Mission Success
  - Clear Definition of Responsibilities and Authority
  - Prudent Use of Redundancy
  - Test-As-You-Fly/Fly-As-You-Test
  - Efficient, Competent, Independent Reviews
  - Fault Tree Analysis/Failure Effects and Criticality Analysis
  - Oversight to "Eliminate" Single Human Mistake Causing Mission Failure

11

FBC implies taking prudent risks. Rather than using more limiting, flight-proven technologies, programs should incorporate new technologies that show promise of enabling new capabilities and increasing performance. With proper testing and validation, the benefits of technology infusion can be enormous. Likewise, the value of obtaining certain science data may justify additional risk for the mission. In all cases, risks should be evaluated and weighed against the expected return and acknowledged at all levels.

Over the decades, the space program has developed proven engineering and management practices, many of which are shown on the chart above and are applicable to FBC missions. This is not an exhaustive list but rather important examples. Clear lines of responsibility and authority should be established at the initiation of each project. Competent and efficient reviews of projects by experts from outside the projects and outside the implementing institutions should provide overall assessment of the projects and a thorough evaluation of risks. Membership on review panels should remain constant throughout the development and implementation of each project.

## FASTER, BETTER, CHEAPER

### Findings

- Effective New Way of Doing Business if Properly Implemented
- No Established Definition or Implementation Policy/Procedure
- Project Managers Left to Establish FBC Policy for Their Projects
- Significant FBC Successes
- High Mars Projects FBC Failure Rate
- Technology Insertion, Though Limited, Has Proved to Be Enabling
- New Technologies Have Not Been a Cause of Failure

12

FBC is the right path for NASA's present and future. FBC has produced highly successful missions, such as Mars Pathfinder. More importantly, no other implementation philosophy can affordably accomplish NASA's ambitious future goals within a feasible budget and schedule.

However, NASA, JPL, and LMA have not completely made the transition to FBC. They have not documented the policies and procedures that make up their FBC approach; therefore, the process is not repeatable. Rather, project managers have their own and sometimes different interpretations. This can result in missing important steps and keeping lessons learned from others who could benefit from them.

The failure to effectively implement FBC has contributed to an unacceptably high failure rate in recent Mars missions. The team believes, that while 100 percent mission success is not a realistic target, with the right policies and procedures in place, and with a commitment to follow them, the vast majority of future FBC missions will be successful.

New technology is an essential part of FBC. The most positive example is Pathfinder. Of the missions studied, none of the failures was the result of new technology. Despite these findings, technology insertion has been too limited to date.

# FASTER, BETTER, CHEAPER

## Lessons Learned

- Transition to Faster, Better, Cheaper Requires:
  - Freedom to Introduce New Ideas and Methods
  - Discipline to Retain Sound Management and Engineering Principles
- A Respected Leader at Each Implementing Institution Is Essential to Manage New Processes
- Risk Must Be Assessed and Accepted by Accountable Parties
- New Technologies Are Required to Enhance FBC Missions

13

Like all major changes, converting to FBC is a serious leadership and management challenge. First, each participating institution must demonstrate leadership commitment to FBC through the Center Director or CEO and from a respected champion for FBC at the institution. Second, each institution must have a careful, disciplined plan for implementing the FBC approach across the institution and on each project.

The increased mission risk on FBC missions resulting from the use of new technology, innovation, or through the pursuit of important science objectives is acceptable when justified by the return. Increased risk is not acceptable when it is caused by inadequate design and review, incomplete testing, or mission goals that are unachievable within the allowed budget and schedule. Management must conscientiously and accurately assess, report, and manage risk throughout the course of a project.

Without new technology, the FBC approach can produce only incremental improvements. New technology, such as improved scientific instruments, solar-electric propulsion, autonomous navigation and fault diagnosis, automatic software synthesis and verification, aeroassist, and hazard avoidance during landing, can enable a new class of missions. New technology insertion should be encouraged on all FBC missions, and should be drawn from the best national sources.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

Mission	Successes	Failures
Mars Global Surveyor	x	
Pathfinder	x	
Deep Space 1	x	
Mars Climate Orbiter		x
Mars Polar Lander		x
Deep Space 2		x

14

The team evaluated the six Mars and deep space projects listed on this chart. They represent JPL's deep space FBC missions to date. The track record reflects several significant successes but also an unacceptably high failure rate.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars Global Surveyor - Successful

- Experienced Project Manager
- Stable Requirements
- Adequately Staffed Project Office
- Adequate Margins
- Effective Project-Contractor Relationship
- Appropriate Use of JPL Institutional Capability
- Extensive Inheritance From Mars Observer
- Utilized Sound Engineering Principles
- Continuity From Development to Operations

15

Mars Global Surveyor represents a transition between a traditional project approach and FBC. The mission of MGS was to globally survey Mars and later to function as a communications satellite to relay information from other Mars spacecraft back to Earth. Despite a problem with the solar array damper arm that delayed the aerobraking phase of the mission, MGS is an enormously successful project with a high science return that has significantly changed the global understanding of Mars.

The mission was led by an experienced project manager. The project was undertaken with margins commensurate with the risk, and a stable requirements baseline was maintained. Other contributions to success included appropriate application of institutional expertise, a thorough test program, and continuity from the development to operations phases.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Pathfinder - Successful

- Experienced Project Manager Eminently Capable of Leading an Inexperienced but Bright, Motivated Staff
- Stable Requirements
- Adequately Staffed Project Office
- Adequate Margins
- Effective Use of NASA Centers, Sandia, and Industry Capabilities
- Appropriate Use of JPL Institutional Capability
- Utilized Sound Engineering Principles
- Continuity From Development to Operations

16

Pathfinder was the first truly representative implementation of FBC in the conduct of a Mars mission. It represents the most significant success to date in implementing the FBC concept for Mars missions and has set the standard for future FBC deep space missions. The mission was primarily driven by technology objectives while accomplishing limited but exciting Mars science results.

Attributes of Pathfinder success include adequate margins, an experienced project manager coupled with a capable but inexperienced staff, sensible application of innovative technology and processes, and the judicious use of institutional expertise at JPL, NASA Langley, NASA Ames, Sandia, and LMA. Pathfinder was also an unprecedented public relations success because of the real-time release of surface images, the public's fascination with the Sojourner rover on the Martian surface, and the public's feeling of participation while watching the exciting and dynamic personalities involved in the challenging exploration of Mars.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Deep Space 1 - Successful

- Complex Management, Multiple-Source Funding Structure, and Ambitious Technology Mission
- Technology Mission Complicated by Addition of Science Requirements
- Inexperienced Project Manager
- JPL Management Effectively Employed Institutional Capability After Initial Problems
- Leveraged Capabilities of Partners—NASA Centers, Other U.S. Government Organizations, and Industry
- Effective Use of Schedule and Scope Flexibility

17

Deep Space 1 pushed the envelope as it successfully demonstrated 12 new technologies. Among these are ion propulsion, autonomous operations, and onboard optical navigation.

After an initially difficult development with many problems, effective application of institutional capability created a highly successful mission. Issues arising from competent but inexperienced project management and too much emphasis on science goals were mitigated by the effective involvement of technology partners and institutional expertise. Perhaps even more importantly, the mission could and did maximize the use of schedule and scope flexibility. The schedule was delayed several months, and the requirements were appropriately descoped. As will be discussed subsequently, a planetary mission typically does not have this flexibility, making adequate margins so critically important.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars Climate Orbiter - Failure

#### Failure Cause

- Navigation Error—Spacecraft Entered Atmosphere Instead of Going Into Orbit
  - Spacecraft Operating Data Needed for Navigation Provided in Wrong Units
  - Software Testing Inadequate
  - Navigation Team Inadequately Trained—Did Not Understand Spacecraft
  - Navigation Anomalies Observed During Cruise Phase Not Adequately Pursued to Determine Cause
  - Preparation Inadequate for Trajectory Correction Maneuver #5 Opportunity

18

MCO was lost as a result of a navigation error that went unresolved. It caused the spacecraft to enter the atmosphere of Mars, rather than achieve orbit. Spacecraft operating data needed for navigation were provided to the navigation team by prime contractor Lockheed Martin in English units rather than the specified metric units.

In developing complex space systems, errors are inevitable. Consequently, it is essential that development and operational processes be resilient enough to detect and correct errors when they occur. This is accomplished by a system of checks and balances built into the processes and by a discipline that follows established engineering practices. In the Mars Climate Orbiter mission, the system of checks and balances failed, allowing a single error to result in a mission failure. Multiple failures in system checks and balances included lack of training, software testing, communication, and adherence to anomaly reporting procedures, as well as inadequate preparation for contingencies. All of these contributed to the failure.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars Polar Lander - Failure

- Spacecraft Design Provided No Entry, Descent, and Landing Data

### Candidate Failure Modes

- Loss of Control Due to Dynamic Effects or Propellant Migration
- Landing Site Not Survivable
- Parachute Draped Over Lander After Touchdown
- Lander Engines Prematurely Shut Down Due to Spurious Touchdown Sensor Signal

19

MPL was the companion mission developed concurrently with the Mars Climate Orbiter as the Mars '98 project. The design of MPL did not include telemetry to provide entry, descent, and landing data. This was a major mistake that prevented an analysis of MPL performance and eliminated the ability to reflect knowledge gained from MPL in future missions. Given the absence of flight data, MPL failure analysis focused on reviews, analyses, and tests. The result was the identification of numerous possible failure modes. Several of the likely candidates are given in this chart, with the most probable scenario on the next page.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars Polar Lander - Failure (cont.)

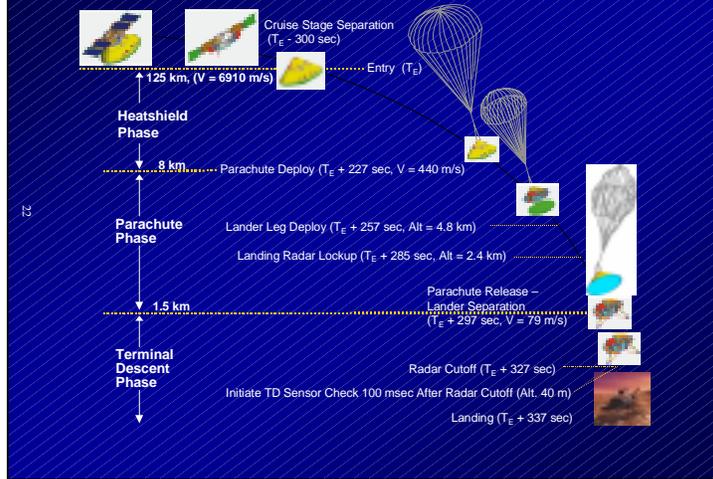
**Most Probable Failure Cause** – Lander Engines  
Prematurely Shutdown – Lander Crashed Into Mars Surface

- Touchdown Sensing System Was Vulnerable to Spurious Signals Generated at Leg Deployment, Causing Premature Engine Shut Down
- Mars Polar Lander Test Program Flaw
  - Touchdown Sensors Wiring Error in System Test
  - System Test Not Repeated With Wiring Correction
- Software Design Did Not Include Protection for Spurious Signals

20

The most probable cause of the MPL failure is premature shutdown of the lander engines due to spurious signals generated at lander leg deployment during descent. The spurious signals would be a false indication that the lander had landed, resulting in premature shutdown of the lander engines. This would result in the lander being destroyed when it crashed into the Mars surface. In the absence of flight data, there is no way to know whether the lander successfully reached the terminal descent propulsion phase of the mission. If it did, extensive tests have shown that it would almost certainly have been lost due to premature engine shutdown. The following chart provides a pictorial of the MPL entry and landing sequence. Lander leg deployment is at Entry +257 seconds. Initial sensor interrogation is at an altitude of 40 meters. It is at this point that the spurious signals would have prematurely shut down the lander engines. As with MCO, the most probable failure of the Mars Polar Lander resulted from inadequate checks and balances that permitted an incomplete systems test and allowed a significant software design flaw to go undetected.

## MPL Landing Sequence



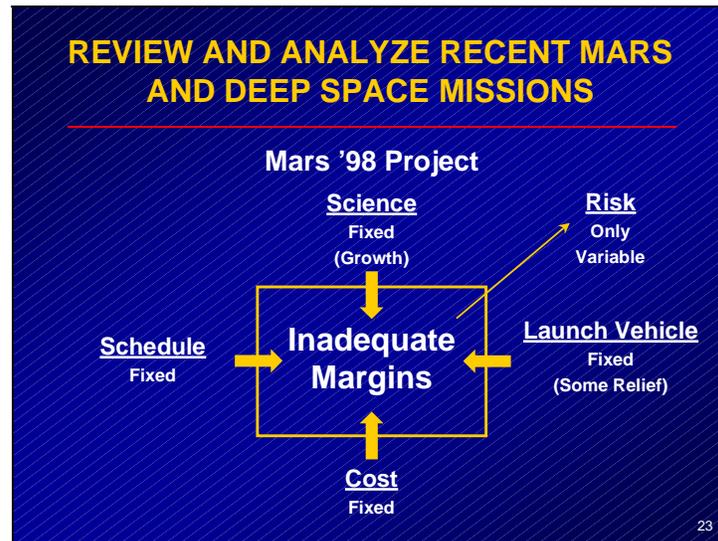
## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars '98 Project (Mars Climate Orbiter–Mars Polar Lander) Implementation

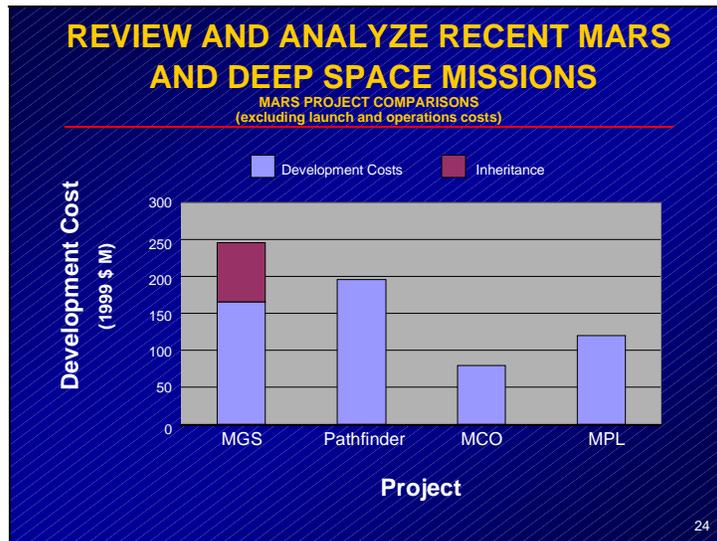
- Inadequate JPL Management Oversight
- Inadequate Margins From the Start
  - Only Variable Was Risk
  - Overly Aggressive Lockheed Martin Astronautics Cost Proposal
  - Excessively Optimistic Project Office/LMA Implementation
  - Single Individuals Implementing Many Important Engineering Activities, Preempting the Normal Checks and Balances and Technical Interchange
- JPL Management Perception That No Cost Increase Possible
- Requirements Creep on MPL
- No Entry, Descent, and Landing Telemetry
  - Impedes Failure Analysis
  - Limits Ability to Implement Corrective Action in Follow-on Missions

22

Mars '98 had inadequate resources to accomplish the requirements. Through a combination of perceived NASA Headquarters mandates and concern for loss of business, JPL and LMA committed to overly challenging programmatic goals. The JPL management perception was that no cost increase was permissible and the aggressive pricing strategy adopted by LMA exacerbated the problem. The pressure of meeting the cost and schedule goals resulted in an environment of increasing risk in which too many corners were cut in applying proven engineering practices and the checks and balances required for mission success. Examples include incomplete systems testing, lack of critical event telemetry, and requirements creep. JPL and LMA also failed to ensure adequate independent reviews and adherence to established policies and practices.



This diagram illustrates the overly constrained situation that characterized the Mars '98 project. Schedule, cost, science requirements, and launch vehicle were established constraints and margins were inadequate. The only remaining variable was risk. Accordingly, project management was faced with managing excessive risk. Lack of adequate risk identification, communication, management, and mitigation compromised mission success.



This diagram illustrates the striking contrast in cost between successful and unsuccessful FBC Mars projects. Mars Global Surveyor benefited from significant hardware spares and software inheritance from Mars Observer. Pathfinder was successful in part because of adequate margins. Pathfinder sets the standard for an FBC mission. In effect, the Mars '98 project attempted to deliver two spacecraft for the price of a Pathfinder. If efficiencies from shared development and operations are factored in, it appears that the Mars '98 project was underfunded by at least 30 percent.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Pathfinder–Mars '98 Development Cost Comparison

(1999 \$ M)

Element	Pathfinder	Mars '98 (MCO & MPL)
Project Management	11	5
Mission Engineering and Operations Development	10	6
Flight System	134	133
Science and Instrument Development	14	37
Rover	25	
Other	2	7
Total	196	188

25

This comparison breaks down the aggressive cost goal for the Mars '98 project. Project management and mission engineering and operations costs on Mars '98 were approximately half of that for Pathfinder. In addition, flight system costs were equivalent in the two programs. This is striking, given the fact that the Mars '98 project was delivering both an orbiter and a lander as well as three times the amount of science.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Mars '98 Project Implementation (cont.)

- Inadequate JPL Project Office Staffing
- Inadequate LMA Staffing Early in Project
- Inadequate Application of JPL Institutional Capability
- Deficient Analysis/Testing at LMA
- Inadequate Mission Operations Involvement and Preparation During Development
  - Development Project Manager Only Responsible Until Launch
  - Mission Operations Inadequately Prepared and Staffed for Simultaneous Operations of:
    - MCO/MPL
    - MGS
    - Stardust
    - Future Planned Missions

26

Inadequate project staffing and application of institutional capability by JPL contributed to reduced mission assurance. Pressure from an already aggressive schedule was increased by LMA not meeting staffing objectives early in the project. This schedule pressure led to inadequate analysis and testing.

The desire to reduce cost led to the decision by JPL to create a multimission operations project separate from the flight project. The result was to bypass the traditional cradle-to-grave responsibility of the project manager in most projects. This led to a discontinuity of expertise in the development and operations handover, characterized by a lack of understanding of navigation and operations issues by the development team and a lack of understanding of the spacecraft by the operations team.

Another important factor was that the operations team was managing four spacecraft (MGS, MCO, MPL, and Stardust) simultaneously with limited resources. Additionally, unplanned effort was required to respond to aerobraking delays due to the damaged solar panel on MGS.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Deep Space 2 - Failure

- Microprobe Technology Applied to Exploring Another Planet Is High Risk, High Return
  - Risk Consistent With FBC Concept
- Failure Cause
  - Unknown (No Data)
- Project Implementation
  - Ineffective JPL Management Oversight
  - Inadequate Time for Acceptable Mission Success Probability
  - Inadequate Test Program
  - Inadequate Risk Assessment
  - Inconsistent JPL Institutional Support
  - No Knowledge of Probe Status After Integration on MPL Cruise Stage
  - New Aeroshell Technology Introduced but Not Flight Validated
  - Microprobes Not Ready for Launch

27

Deep Space 2 was designed as a high-risk project to demonstrate a new capability for landing on Mars and other solid bodies of the solar system. This capability could ultimately result in high scientific return when used in future applications. The new technology could deliver a network of small payloads to the surface of Mars. Although the failure mechanism is unknown because there was no post-launch telemetry, the mission likely failed as a result of deviation from fundamental management and engineering principles. The inadequacies listed above indicate that the microprobes were not ready for launch.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Lessons Learned

- Senior Management Attention Needs to Be Highest When New Ways of Doing Business Are Being Implemented
- Experienced Project Management or Mentoring Is Essential
- Unique Constraints of Deep Space Missions Demand Adequate Margins
- Clearly Defined and Stable Program Requirements Are Important to Mission Success
- Commitment Is Important, but Senior Management Intervention Is Required When Risk Is High—Don't Abandon the Project Manager

28

The dominant Mars '98 problem was inadequate funding to accomplish the established requirements. The Mars '98 project was in the FBC category, and the project management team was given insufficient guidance as to proper implementation of FBC. It is important in such a situation that institutional management closely monitors project implementation.

The challenges associated with deep space exploration drive the need for innovation and critical evaluation of conventional approaches to project implementation. At the same time, certain fundamental engineering and management principles must be maintained: involvement of experienced project management, adequate margins, stable requirements, and adherence to sound engineering principles. This combination of inadequate management oversight and violations of fundamental engineering and management principles became the underlying contributor to mission failure.

Commitment, while important, must not overshadow an objective assessment and reporting of risk. This requires responsible intervention by senior management.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Lessons Learned (cont.)

- Institutional Management Must Take Responsibility for Policies and Procedures That Assure High Level of Mission Success
- Institutional Management Must Be Accountable so That Project Implementation Is Consistent With Required Policies and Procedures
- Appropriate Application of Institutional Expertise Is Critical for Mission Success
- A Thorough Test and Verification Program Is Essential for Mission Success
- Telemetry Coverage of Critical Events Is Necessary for Analysis and Ability to Incorporate Information in Follow-on Projects

29

An additional important role for senior management, whether at NASA, JPL, or LMA, is to ensure the establishment of, and compliance with, policies that will assure mission success. For example, these policies should address design (at the component, system, and mission life cycle level), test and verification, operations, risk management, and independent reviews.

The technical expertise required for deep space exploration is a national resource. Successful missions must draw upon the top talent for the task regardless of organizational boundaries. Equally important to mission success is a thorough test and verification program.

Each involved organization should establish a policy requiring telemetry coverage of mission-critical events.

## REVIEW AND ANALYZE RECENT MARS AND DEEP SPACE MISSIONS

### Lessons Learned (cont.)

- Project Manager Must Be Responsible and Accountable for All Aspects of Mission Success
- Focus Technology Projects on Technology Objectives and Requirements
- Accept Risk Inherent to Use of New High-Payoff Technology or in Quest of High-Value Science
- Do Not Accept Risk Associated With Deviating From Sound Engineering and Management Principles
- **IF NOT READY—DO NOT LAUNCH**

30

Development and operations are tightly coupled in complex projects. It is critical that engineering expertise be included in operations and operational insight in design. This is best achieved by assigning the project manager cradle-to-grave responsibilities.

New technology can represent significant risk in science-driven missions. Separate technology demonstration missions can play a significant role in validating new enabling technologies. If technology is the primary objective of a specific mission, science objectives should not conflict with or compromise the achievement of technology objectives.

While risk is a fact of life in deep space missions, it is important to clearly understand what risks are appropriate and what risks are reckless. Accepting higher risks to achieve high return is appropriate. Accepting risk that deviates from sound engineering and management principles is never prudent.

In the final analysis, mission readiness must take priority over launch window.

## RELATIONSHIPS AND INTERFACES

### Findings

- NASA Headquarters–Caltech
  - Contract
  - Annual Evaluations
  - Fee
  - Mission Success Impact ~ Neutral
- Caltech–JPL
  - Financial
  - Intellectual
  - Mission Success Impact ~ Neutral

31

The following six charts discuss the nature of the interfaces among the key organizations involved in the Mars Program.

The Jet Propulsion Laboratory is a Federally Funded Research and Development Center managed by the California Institute of Technology under contract to NASA. Annual performance evaluations of JPL are performed by NASA Headquarters, and an annual fee is determined and awarded to Caltech. The team finds that this interface had no impact on mission success.

JPL is managed by Caltech as a division headed by the Laboratory Director, who is also a Vice President of Caltech. The Caltech–JPL interface is focused on financial management and an effective intellectual relationship. There is no appreciable involvement by Caltech in JPL technical activities; therefore, the impact of the interface on mission success is neutral.

## RELATIONSHIPS AND INTERFACES

### Findings (cont.)

- JPL–Lockheed Martin Astronautics
  - No Formal Identification of Risk or Deviations From Standard Practice by LMA Management
  - Positive Project Management Relationship
  - Insular Approach in Accepting Excessive Risk
  - Mission Success Impact ~ Mixed
- NASA Headquarters–JPL
  - Ineffective
  - Multiple Interfaces for Mars Program
  - Mission Success Impact ~ Negative

32

The JPL–Lockheed Martin Astronautics interface for Mars '98 was characterized by a positive, close working relationship between the JPL and LMA project managers and their offices. However, this relationship had a negative, insular effect when accepting excessive risk. The insular relationship was characterized as “circling the wagons” around some of the risk issues of the spacecraft development process. There was no formal identification of risk nor of deviations from standard practice by LMA management. The nature of this interface seemed to work well for most of the activity, but had a mixed result on mission success, with the risk management issues a clear negative.

The NASA Headquarters–JPL interface was found to be ineffective as the result of a failure to clearly communicate. Examples of the communication failure will be found on the next page.

Multiple interfaces at NASA Headquarters for the JPL Mars Program Manager caused difficulty at both organizations. The nature of the multiple interfaces will be illustrated on the Office of Space Science organization chart. The ineffective nature of the interface is judged to have had a negative impact on mission success.

## RELATIONSHIPS AND INTERFACES

### Findings (cont.)

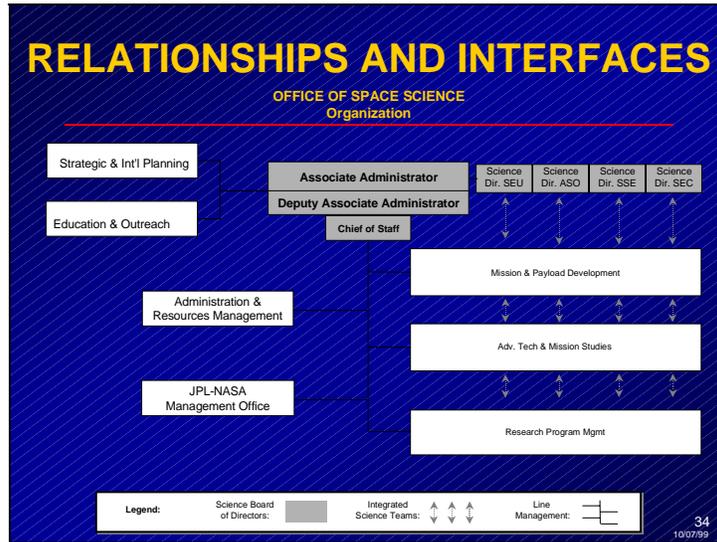


- NASA Headquarters Viewed Program Objectives, Requirements, and Constraints as Mutually Agreeable
- JPL Viewed Launch Vehicle, Cost, Schedule, and Performance as Non-negotiable Mandates
- Ineffective Interface Did Not Resolve Issues or Manage Risk

33

Ineffective communication between JPL management and NASA Headquarters contributed to an unhealthy interface and significant misunderstandings in conducting the Mars Surveyor Program. NASA Headquarters thought it was articulating program objectives, mission requirements, and constraints. JPL management was hearing these as non-negotiable program mandates (e.g., as dictated launch vehicle, specific costs and schedules, and performance requirements).

The team believes that JPL management was intending to convey general program advocacy and to promote a positive customer relationship, motivated by fear of losing business. The result was that JPL management did not convey an adequate risk assessment to NASA Headquarters. What NASA Headquarters heard was JPL agreeing with and accepting objectives, requirements, and constraints. This communication dynamic prevented open and effective discussion of problems and issues. JPL management did not effectively express their concerns to NASA Headquarters about programmatic constraints, and NASA Headquarters did not seem receptive to receiving bad news. Consequently, frank discussions identifying and managing program risks and problems did not occur.



This chart illustrates the complexity of the Mars Program interface at NASA Headquarters. For the formulation phase of the program, the JPL Program Manager deals with the Advanced Technology and Mission Studies Division. For the implementation phase of the program, the JPL Program Manager deals with the Mission and Payloads Development Division. For the operations phase of the program, the JPL Program Manager deals with the Research and Program Management Division. For all, there is critical involvement with the Science Board of Directors. Not shown is the involvement with other organizations, such as the Human Exploration and Development of Space Enterprise.

## RELATIONSHIPS AND INTERFACES

### Lessons Learned

- Caltech Should Provide Top-Level, Independent Oversight of JPL's Performance
- Contractor Responsibilities Must Include Formal Identification to Customer of Project Risk and Deviations From Acceptable Practice

35

The JPL–Caltech relationship has not historically included technical issues. Caltech could contribute to JPL’s overall performance by providing limited top-level, independent oversight through a “visiting committee”-type activity.

The team found multiple examples of ineffective risk identification and communication by both JPL and LMA. Compounding this, JPL and LMA each deviated from accepted and well-established engineering and management practices. Risk identification and any significant deviations from acceptable practices must be communicated to the customer in an open, timely, and formal fashion.

## RELATIONSHIPS AND INTERFACES

### Lessons Learned (cont.)

- NASA Headquarters – JPL
  - Frank Communication of Objectives, Requirements, Constraints, and Risk Management Throughout All Phases of the Program Is Critical to Successful Program/Project Implementation
  - Senior Management Must Be Receptive to Communications of Problems and Risk
  - Mars Program Needs Dedicated, Single Interface at NASA Headquarters Reporting to the Associate Administrator for Space Science (Responsible for All Requirements and Funds, Including Human Exploration Requirements)

36

Successful program/project management requires frank and candid communication at all levels. Ineffective communication is a major contributing factor to mission failure. In this case, JPL and NASA Headquarters communications were inadequate, in part because JPL was concerned that Headquarters would perceive JPL concerns about programmatic constraints negatively; JPL did not want to antagonize the customer. NASA Headquarters was rigid in adhering to unrealistic constraints.

Communication between JPL and NASA Headquarters was impeded by a cumbersome and poorly defined organizational structure within the Office of Space Science (OSS). Multiple interfaces and points of contact within OSS contributed to confusion and dilution of effective communication. A single dedicated point of contact within OSS reporting to the Associate Administrator for Space Science is essential to ensure effective and timely communication.

# SCIENTIST INVOLVEMENT

## Findings

- Involvement of Scientists in Mission Development Represents Significant Contribution to Mission Success
- Extent and Effectiveness of Participation of Scientists in Broad Aspects of Project Implementation Varied Considerably
- Scientists Not Always Involved in Decisions That Would Affect Conduct of Scientific Experiments
- Commitment of Science Teams to Rapid Release of Mars Data Is Critical Factor in Public Involvement and Interest

37

All mission characteristics, such as power, telemetry rates, payload mass, and orbital parameters, affect the achievement of science goals. Thus scientists must participate in all stages of project implementation to ensure that science goals are understood and taken fully into account. The actual extent of scientist involvement varied considerably from project to project. In a few instances, major decisions were made without formally consulting the scientists affected. The inevitable result was that some of the science eroded. Despite experiences like this, for the most part, participation of the scientists in the missions has been very good.

The missions examined differed considerably in the extent to which they succeeded in engaging the public. The Pathfinder mission was very successful, whereas some aspects of Mars Global Surveyor, although enormously scientifically successful, have been ineffective in this area. The Pathfinder success was achieved by promptly releasing the acquired data to the news media and making it available to the public at large on the Web. Scientists and engineers gave frequent press briefings. In contrast, release of parts of the Mars Global Surveyor data were delayed, and communication with the media was hindered by the wide dispersal of the scientists involved.

# SCIENTIST INVOLVEMENT

## Lessons Learned

- Scientists Participating in Projects Should Be Full Partners in Project Development and Operations
- Public Engagement with Mars Mission Results and Prompt Release of Data Should Be Hallmarks of the Mars Program
  - A Successful Public Outreach Effort Requires Active and Sustained Involvement of Scientists and Public Affairs Experts and Should Be an Integral Aspect of Mission Science Investigations
  - Preliminary Results Should Be Released Immediately as a Means of Involving the Public in the Discovery Process

38

Mars mission success is largely a measure of how well the project has achieved the science goals. Scientists are in general the people best able to assess the science impact of pending decisions and make the accompanying scientific tradeoffs. They should, therefore, not only be consulted about the science impact of pending decisions, but they must also be active partners in making the decisions relating to science during all phases of a mission. This helps protect the science goals and maintain an appropriate balance among all of the different goals.

The Mars Program has a high public profile. One crucial part of satisfying public interest is the prompt release of science data. However, the release of data is not sufficient; an effective process for the delivery of mission results to the public is critical. In some situations, science data have been released only after a protracted period during which the scientists on the project have exclusive access to the data. Public affairs needs should be carefully balanced in any such restrictions. Scientists and engineers must also be available to explain the scientific significance of the results and to provide engineering background. They can energize the public and make them “see” the results of missions.

## MARS SURVEYOR PROGRAM

---

- Definition
- History
- JPL Program Implementation
- JPL Organization
- Future Missions (Architecture)
- Lessons Learned

39

Earlier sections of this report have largely focused on individual projects. This section reviews the Mars Program. To aid the MPIAT evaluation, a program definition has been constructed.

A review of the history of the Mars Program since 1994, including program implementation approach and organizational structure at JPL, is presented.

Findings are then presented, related first to the implementation of the program at JPL and then to the organizational structure at JPL.

Lessons learned are presented, which the team believes will lead to a healthy and resilient Mars Exploration Program.

# MARS SURVEYOR PROGRAM

Mars Program Independent Assessment Team's

## Definition

A Program Is an Integrated Framework in Which Projects Fit to Accomplish More Than the Sum of the Individual Projects

- Achieve Long-Range Goals
- Provide Resilience to Failure and Take Advantage of Success
- Assure Technologies Available to Meet Needs

40

A program is more than the sum of the individual projects. There are long range program goals that require the contributions of multiple projects. For example, an orbiter mission may be required to gather data on potential landing sites for future lander missions. A program is the synergistic result of cooperative, interacting projects.

# MARS SURVEYOR PROGRAM

## History

- Program Responsibilities



- JPL Organization



- Architecture

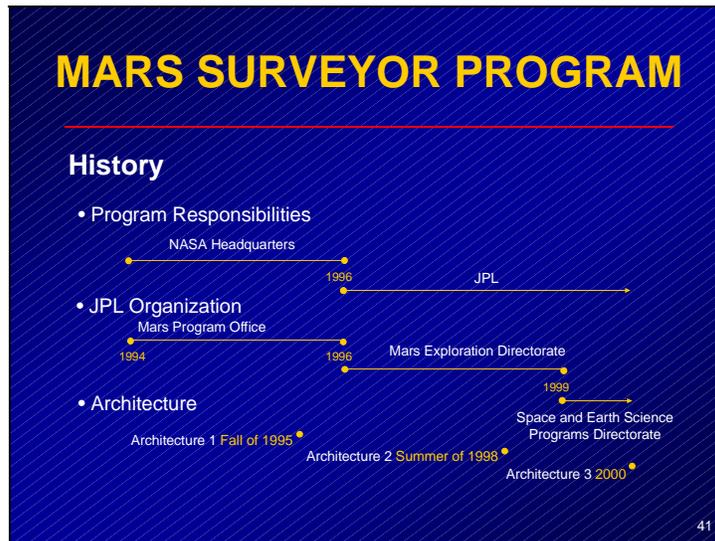


41

Historically, NASA Headquarters had management responsibility for all of the Agency's programs. This was generally true through 1996. At that time, the NASA Administrator directed that program management responsibilities be moved from Headquarters to the appropriate Field Center. Accordingly, program management for the Mars Program was transferred to JPL.

In recognition of the importance of the Mars Program, JPL created a new organizational element, the Mars Program Office, in 1994. This office was responsible for the individual Mars projects and provided study and architecture support to the NASA Program Management Office at Headquarters. The manager of the Mars Program Office reported directly to the Director of JPL.

The first Mars Program architecture was defined in the fall of 1995. It consisted of a series of modest scale landers and orbiters on small launch vehicles. Sample return from Mars was included as a potential out-year program possibility, but was not within the planning horizon of Architecture 1.



Program responsibility was moved from NASA Headquarters to JPL in 1996. The Laboratory responded by creating a new organization, the Mars Exploration Directorate, which replaced the Mars Program Office. In addition to the functions and responsibilities of the earlier office, the new organization took on additional program responsibilities, including allocation of funds and developing collaborative relations with other NASA participants and international partners.

With the announcement of the “Mars Rock” (Alan Hills 84001) in August 1996, interest in an accelerated sample return mission required a change in the Mars Program architecture. Architecture 2, undertaken in the summer of 1998, was the response. The new architecture provided a sample return from Mars to Earth by 2008. This was to have been facilitated in large part by participation of the French.

Following the launch of the MCO and MPL, the Mars Exploration Directorate was merged with the Space and Earth Sciences Programs Directorate, a move intended to promote more effective use of resources and processes common to both organizations. It was also designed to leverage on the past successes of the Space and Earth Science Programs Directorate.

The MCO and MPL failures, as well as the recognized deficiencies in Architecture 2, require a new architecture. Architecture 3 is being developed as this report is being completed. This has allowed the MPIAT to comment on the process but not review the completed product.

# MARS SURVEYOR PROGRAM

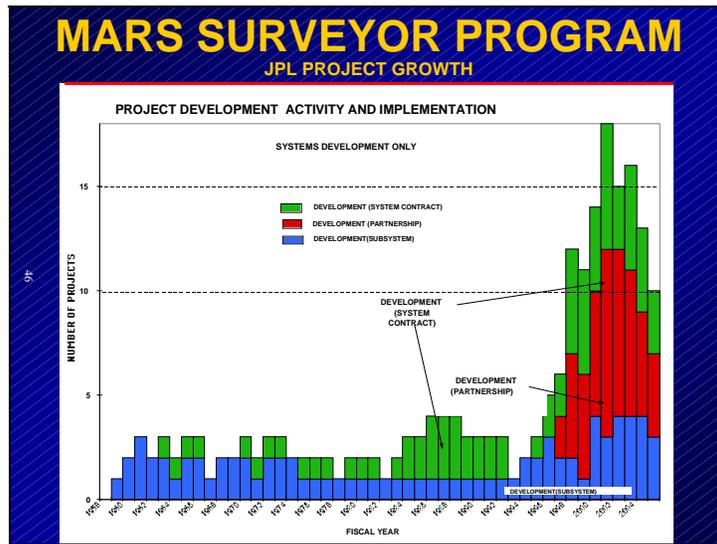
## JPL Program Implementation

- Number of Flight Projects Has Increased Significantly
- Significant Loss of Experienced, Successful Project Managers Through Retirement
- Current Project Managers Are Competent—Inexperienced—Little Mentoring
- Mars Program Has Been a Group of Individual Projects Instead of Integrated Program

42

The nature of the program implementation task changed significantly at JPL in response to the FBC initiative. The number of flight projects to be managed by the Laboratory greatly increased over a few short years. Furthermore, the nature of the projects changed from very large projects with budgets of a billion dollars or more to small projects with tightly constrained budgets. The Mars Program was only a part of this increased activity.

These changes, combined with the retirement of a significant portion of the experienced project leadership population, resulted in a demand for many new project managers. The demand was filled by the appointment of very capable, but inexperienced, people to project management positions. There was little mentoring for these managers in their new positions, especially in the use of project management principles and engineering practices such as reviews and testing. Simultaneously, the new leaders were required to meet the challenge of change to Faster, Better, Cheaper while not being well-grounded in prudent risk management. At the program level, these projects were not integrated and managed as a group. As a result, it was very difficult for the newer project managers to obtain outside help, to learn from each other, or to define interdependencies among their projects.



The tremendous and rapid growth in the number of projects at JPL is clearly shown in this chart. Over a period of approximately 3 years, JPL went from its long history of normally managing two large projects simultaneously to managing more than a dozen significantly smaller projects.

# MARS SURVEYOR PROGRAM

## JPL Organization

- 1994–1996 Mars Program Office (MPO)
  - Reported to Laboratory Director
  - Mars Projects Reported to MPO Director
  - Conflicted With NASA Headquarters Program Management Role
  - Oversight of Projects Was Ineffective
  - Collection of Individual Projects as Opposed to Integrated Program

44

The Mars Program organization at JPL between 1994 and 1996 is described on this chart. The Mars Program Office was responsible for the mission planning, program advocacy, and flight project development. It was under this organization that the Mars '98 project was initiated. Several difficulties were encountered. The roles and responsibilities of the program office relative to program direction and control were interpreted differently in the JPL Mars Program Office and the NASA Headquarters sponsoring office. This led to conflicts and protracted resolution activities, which diluted the attention needed to accomplish the missions. The result was that oversight of individual projects was inadequate and integration of ongoing and proposed projects into a unified program vision was not effective. The individual projects were not developed or managed within a clearly defined overall framework that identified interdependencies and risk management strategies. During this period, the integrated Mars Program architecture was developed, which included the early planning for the Mars '01 project.

## MARS SURVEYOR PROGRAM

### JPL Organization (cont.)

- 1996–1999 Mars Exploration Directorate (MED)
  - Program Responsibility Delegated to JPL
  - Mars Projects Reported to MED Director
  - No Single Point of Contact Existed at NASA Headquarters
  - Major Expansion and Redirection of Program Goals after “Mars Rock”
  - Human Exploration Requirements Led to Increase in Program Complexity
  - Oversight of Projects Was Ineffective
  - Collection of Individual Projects as Opposed to Integrated Program

45

In 1996, NASA Headquarters delegated full program management authority to the NASA Centers. To implement this direction, JPL reorganized its Mars Program management as described on this chart. A Mars Exploration Directorate (MED), which reported to the Laboratory Director, was created. The MED was responsible for all program management functions, including those previously executed at Headquarters. With the change came the loss of a single point of contact at Headquarters for the Mars Surveyor Program. This situation was further complicated by the “Mars Rock” announcement in August 1996, resulting in a heightened public interest in Mars. Major redirection was given to JPL to include planning for robotic exploration related to the long-term needs of Human Exploration (managed by a different part of Headquarters) in its Mars Program plans. This led to a revision of the Mars architecture in 1998. The increased complexity and the deluge of new requirements was such that the ongoing projects were still not integrated at the program level. They operated as independent entities. Oversight of the projects was ineffective.

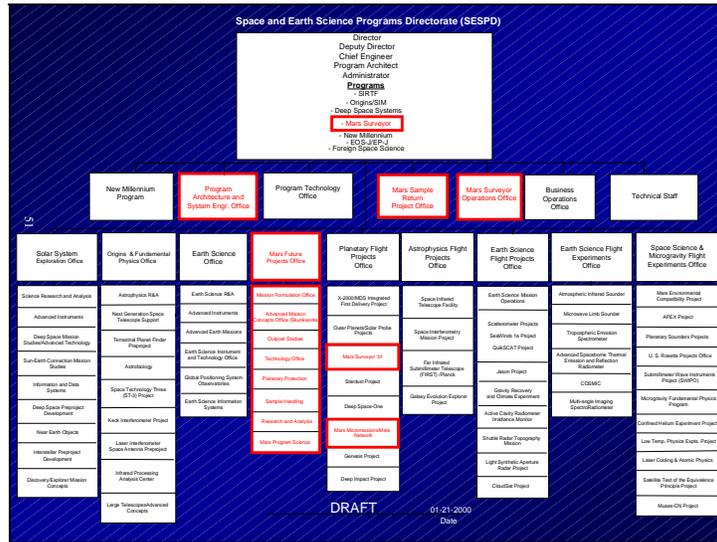
# MARS SURVEYOR PROGRAM

## JPL Organization (cont.)

- 1999–Present Mars Surveyor Program
  - Responds to Program Management Deficiencies
  - Program Manager Reports to Director for Space and Earth Science Programs
  - Mars Project Reporting Level Reduced
  - Confusing Lines of Responsibility and Accountability Created
  - Mars Program Separated Into Multiple Elements
  - Organization Is Inconsistent With Major High-Visibility Program
  - Current Organization Is Not Appropriate to Successfully Implement the Mars Surveyor Program in Combination With Other Commitments

46

In 1999, JPL reorganized its entire space and Earth science effort into one directorate. This was done to better manage the significantly increased number of programs and projects in both science areas. Within this new organization, the Mars Program Manager no longer reports to the Laboratory Director as a separate entity. Projects report at a lower level, and many related program functions are distributed to other parts of the organization. The result is a serious loss of visibility and management focus on the Mars Surveyor Program as an entity. Complex lines of authority and communication abound, rendering a successful management of the Mars Program unlikely.



The JPL Space and Earth Sciences Programs Directorate (SESPD), illustrated in the accompanying figure, is intended to combine all management and planning functions for space and Earth sciences. It is an extremely broad organization that includes responsibilities for project management, program management, advanced studies, program planning and architecture, science experiments, and instrument and technology development.

The Mars Surveyor '01 Project Office is embedded in this structure at the third level. Thus it is far removed from senior JPL management. Further, it is on par with a large number (68) of other equivalent level units, most with substantially smaller scope. This organizational position makes it difficult for the project to have visibility and ready access to management. In the team's opinion, it invites project isolation, as happened in the Mars '98 project.

The SESPD structure raises even more questions relative to the management concept for the Mars Program. Various parts of the program responsibilities are scattered throughout SESPD, as highlighted in the organization chart. Program organization elements report at various levels and appear to have overlapping, and even conflicting, responsibilities. An example is the Program Architecture and Systems Engineering Office. Its systems engineering overlaps with the Mars Future Project Office, the Mars Sample Return Office, and the current flight projects.

The Mars Program Office must have the visibility and stature to oversee the planning and implementation of the entire Mars Program throughout the NASA Centers, industry, and the science community.

## MARS SURVEYOR PROGRAM

### Future Missions (Architecture)

- The MPIAT Concur With the NASA Decision Not to Fly the '01 Lander in 2001 and to Consider Its Use at a Later Opportunity
- The MPIAT concurs With the NASA Decision to Fly the '01 Orbiter
- The Architecture for the Future Mars Surveyor Program Is Still Under Development; Therefore, a Review to Assure That Lessons Learned Are Utilized Will Be Performed at a Later Date
- The MPIAT Has Reviewed and Provided Comments on the Process and Preliminary Architecture

48

The MPIAT extensively reviewed the planned Mars '01 Project and concurs with the NASA decision not to fly the Mars '01 Lander in 2001 and to consider its use at a later opportunity. The MPIAT also concurs with the NASA decision to proceed toward flight of the Mars '01 Orbiter in 2001.

The new architecture is in an early stage of development; therefore, a detailed evaluation is not currently feasible. MPIAT has reviewed and provided comments on the preliminary architecture and its development process. The MPIAT believes that the new architecture is critically important to a successful Mars Surveyor Program.

A substantive review will be conducted at a later time.

# MARS SURVEYOR PROGRAM

## Lessons Learned

- Responsibilities Must Be Reasonably Balanced Across Total Institution
- Clear Responsibility and Accountability Are Necessary for Program Success
- Effective Program Management Requires an Integrated Framework in Which Projects Fit to Accomplish More Than the Sum of the Individual Projects
- Importance of Project Managers Must Be Emphasized
- Mentoring Is Critically Important for Competent, Inexperienced Project Managers

49

The Mars Surveyor Program was a difficult assignment for JPL. It came at a time of major internal changes involving simultaneous downsizing in personnel and growth in the number of projects. Though the formal Program Office title was transferred to JPL, the lines of responsibility among programs, projects, and the science community were not clearly delineated. Critical program requirements were set without adequate resources. The Program Office did not perceive that it had the flexibility to balance program elements or to deal with risk, except within individual projects. As a result, the JPL Program Office was unable to establish and play an effective role in implementing the Mars Program.

The lessons learned summarized herein are fundamental. They are basic to good program and project management and need to be part of the foundation of all future Mars Program activities.

Responsibilities must be accepted and balanced across all parts of the institutions involved. Clear lines of responsibility and attendant accountability are necessary.

# MARS SURVEYOR PROGRAM

## Lessons Learned

- Responsibilities Must Be Reasonably Balanced Across Total Institution
- Clear Responsibility and Accountability Are Necessary for Program Success
- Effective Program Management Requires an Integrated Framework in Which Projects Fit to Accomplish More Than the Sum of the Individual Projects
- Importance of Project Managers Must Be Emphasized
- Mentoring Is Critically Important for Competent, Inexperienced Project Managers

49

Effective program management must provide a framework in which all program elements are balanced and optimized in light of NASA's overall objectives. The Program Office must have the flexibility to realign and to adjust various science, technology, and flight project elements.

Equally important is the capability and experience of project managers. Project management is one of the most demanding professional skills. It can only be acquired through years of experience. NASA, its Centers, and its contractors are challenged to provide managers capable of executing the series of complex projects required in the Mars Program. The success of the Mars Program is critically dependent on first-class project managers, and it is the responsibility of the respective institutions to assure their full training and mentoring.

# MARS SURVEYOR PROGRAM

## Lessons Learned (cont.)

- A Strong, Single Point of Contact Reporting to the Associate Administrator for Space Science Is Critical to Successfully Implementing the Mars Program
- An Integrated Mars Program Office at JPL Reporting to the Director Is Consistent With Major High-Visibility Program
- An Organization at the Directorate Level Dedicated to Implementing Major Flight Projects Would:
  - Provide Clear Responsibilities and Accountability
  - Effectively Balance Responsibilities
  - Emphasize Project Management Importance
  - Provide Mentoring for New Project Managers
  - Provide a Consistent Standard for Implementation of Projects

50

Relative to the overall structure of the Mars Program, the Mars Program Independent Assessment Team offers three points for consideration:

First, NASA Headquarters needs to clearly define the overall framework and direction of the Program. What does NASA want to accomplish in the long run? What should the products be for science, for human exploration, for technology, and for the public imagination? What are the near-term and long-term budget targets? All of these must be based on inputs from a wide range of constituencies, but must be compatible with what is technically feasible, and of scientific value. The program must be firmly based on well-thought-out studies performed under the auspices of the Program Office. Further, it is critical that there be a single point of contact at NASA Headquarters setting the overall framework. This person must also be responsible for the resolution of major issues and for authorization of program redirection, should that become necessary. It also should assure that national resources are being fully utilized.

Second, at JPL, the Program Office needs the stature and visibility of reporting directly to the Laboratory Director. The Program Office will deal with multiple entities, both inside and outside of JPL. The Program Office needs the access to, and the authority of, the Laboratory Director.

Given the importance of Mars exploration, both as an established national goal and as an engaging program of enormous public interest, the Mars Program Office requires very high visibility.

## MARS SURVEYOR PROGRAM

### Lessons Learned (cont.)

- A Strong, Single Point of Contact Reporting to the Associate Administrator for Space Science Is Critical to Successfully Implementing the Mars Program
- An Integrated Mars Program Office at JPL Reporting to the Director Is Consistent With Major High-Visibility Program
- An Organization at the Directorate Level Dedicated to Implementing Major Flight Projects Would:
  - Provide Clear Responsibilities and Accountability
  - Effectively Balance Responsibilities
  - Emphasize Project Management Importance
  - Provide Mentoring for New Project Managers
  - Provide a Consistent Standard for Implementation of Projects

50

Third, the Mars flight projects along with other major flight projects need a highly visible profile. They also need the opportunity to share in the rich heritage resident at JPL and ongoing experience among all flight projects. A way to accomplish both objectives is to create a Flight Projects Directorate. Such a directorate would provide direct and clear lines of responsibility and accountability. It would have the overall resources of the Laboratory at its disposal to balance the needs of various projects. It would also provide a home for the training and growth of project managers and would assure that consistent standards of implementation, review, and corrective action are taken across all projects.

The MPIAT believes that merging the Mars Exploration Directorate with the Space and Earth Sciences Programs Directorate is ill-suited to the successful implementation of the Mars Program.

## CONCLUSIONS

---

- Significant Flaws Have Been Identified in Formulation and Execution of Mars Program
- Lessons Learned Are Provided in Response to All Findings
- All Identified Flaws Are Correctable
- A Comprehensive Mars Exploration Program Can Successfully Continue

51

The MPIAT believes the flaws identified in this report can be corrected in a timely manner to allow a comprehensive Mars Exploration Program to continue successfully.

# **Appendix**

## **MPIAT Membership Biographies**

## **Biographies of the Mars Program Independent Assessment Team**

### **Thomas Young – Chairman**

Tom Young retired as Executive Vice President of Lockheed Martin in 1995. He had previously served as President and COO of Martin Marietta and President of the Martin Marietta Electronics and Missiles Group. Prior to joining Martin Marietta, he had held positions at NASA including, Director, Goddard Space Flight Center; Deputy Director, Ames Research Center; Director, Planetary Program at NASA Headquarters; and Mission Director for the Viking Project at Langley Research Center. He is the recipient of NASA's highest award, the Distinguished Service Medal, for his work on the Viking Project. He received BSME and BSAE degrees from the University of Virginia, and a Masters in Management from MIT, which he attended as a Sloane Fellow. Mr. Young is a Senior Fellow of the American Institute of Aeronautics and Astronautics (AIAA), a Fellow of the American Astronautical Society (AAS), and a member of the National Academy of Engineering. He is a member of the NASA Advisory Council, and Chairman of the National Academy of Engineering Committee on Technology Literacy.

### **James O. Arnold**

Jim Arnold's career with NASA spans nearly four decades. Currently, he serves at NASA Ames Research Center as Chief of the Space Technology Division. His service has included research engineering, branch management, a tour of duty at NASA Headquarters (aerothermodynamics program manager), and division and directorate management. Dr. Arnold received the NASA Medal for Outstanding Leadership and the NASA Medal for Outstanding Scientific Achievement. He was a recipient of the Senior Executive Service (SES) Meritorious Executive Award and of the SES Distinguished Executive Award. He received his B.S. at the University of Kansas, his M.S. from Stanford University, and his Ph.D. from York University, Toronto, Canada. He is a Fellow of the AIAA.

### **Thomas A. Brackey**

Thomas Brackey serves as Executive Director, Technical Operations, and as a Chief Technologist for Hughes Space and Communications Company. In more than three decades of service to Hughes, he has gained extensive experience in line, project, and program management and business development encompassing all aspects of the space and communications business. He also has in-depth technical expertise in the areas of advanced technology, design, analysis, test, systems engineering, and operations for large, complex systems. He is a Distinguished Graduate of The Ohio State University, where he received a B.E.E., M.S., and Ph.D. in Electrical Engineering. He currently serves as a member of the NASA Advisory Council, Chairman of the NASA Technology and Commercializing Advisory Committee, and a member of the Air Force Scientific Advisory Board. He is a senior member and Distinguished Lecturer of the AIAA and is a member of many other organizations.

### **Michael H. Carr**

Michael Carr is a geologist with the U.S. Geological Survey, Menlo Park, California. He is an Interdisciplinary Scientist on the Mars Global Surveyor mission and a member of the Galileo Imaging Team. Since joining the Geological Survey in 1962, he has been involved almost exclusively in lunar and planetary studies. After participating in the selection of the Apollo landing sites and analysis of returned lunar samples, he focused mainly on Mars. He was a member of the Mariner-9 imaging team and leader of the Viking Orbiter Imaging team. He received a Distinguished Service Award from the Department of Interior, the G. K. Gilbert Award from the Geological Society of America, and the National Air and Space Museum Medal for Lifetime Achievement in Air and Space Science and Technology. Dr. Carr received a B.Sc. from the University of London and a Ph.D. from Yale University, both in Geology. He has written over 150 papers about Mars and two widely used books, the *Surface of Mars* and *Water on Mars*. He has chaired many planning groups, most recently one looking into how NASA should prepare for return of samples from Mars. Dr. Carr is a Fellow of the Geological Society of America and the American Geophysical Union.

### **Douglas L. Dwoyer**

Doug Dwoyer is the Associate Director for Research and Technology Competencies at the NASA Langley Research Center. At Langley he has previously served as Director, Research and Technology Group; Chief, Fluid Mechanics Division; Aerospace Technologist; and head of the Hypersonic Technology Office and of the Computational Methods Branch. Prior to joining NASA, he held positions at the Virginia Polytechnic Institute and State University, United Aircraft Research Laboratories, and the U.S. Air Force Aerospace Research Laboratories. He is the recipient of the U.S. Air Force Commendation Medal, the NASA Exceptional Engineering Achievement Medal, the NASA Outstanding Leadership Medal, and the SES Meritorious Executive Award. He received his B.S., M.S., and Ph.D. in Aerospace Engineering from Virginia Tech. During his research career in Computational Fluid Dynamics, he has had over 40 publications and edited four books. Dr. Dwoyer is a Fellow of the AIAA and a member of the Committee of 100 of the Virginia Tech College of Engineering. He serves on the Advisory Boards of the Department of Aerospace and Ocean Engineering of Virginia Tech and the Aerospace Engineering Department of the University of Maryland.

### **Gen. (Ret.) Ronald Fogleman**

Ron Fogleman retired from the U.S. Air Force on September 1, 1997, after serving as the Chief of Staff. He is now President and CEO of a holding company that includes an aerospace consulting firm and several small businesses. As a member of the Joint Chiefs of Staff, General Fogleman served as a military advisor to the Secretary of Defense, the National Security Council, and the President. He has extensive operational experience having served as Commander-in-Chief, U.S. Transportation Command; Commander, Air Mobility Command; Commander, 7<sup>th</sup> Air Force; and Commander, Air Component Command, U.S./R.O.K. Combined Forces Command. He received his B.S. from the U.S.A.F. Academy and an M.A. in Military History/Political Science from Duke University.

General Fogleman serves on the editorial board of the *Strategic Review*. He has published numerous articles in the defense arena and frequently lectures at leading academic institutions. He donates considerable time to national security affairs and serves as the director of several aerospace companies.

### **Maj. Gen. (Ret.) Ralph Jacobson**

Ralph Jacobson retired as President and Chief Executive Officer of the Charles Stark Draper Laboratory, Inc., in July 1997. He had held this position since his retirement from the U.S. Air Force as a Major General ten years earlier. Throughout his career, he had a variety of assignments involving the space program. His final Air Force post was as Director of Special Projects, Office of the Secretary of the Air Force. Among his awards are the Distinguished Flying Cross and the Defense, National Intelligence Community, and Air Force Distinguished Service Medals. General Jacobson graduated from the U.S. Naval Academy with a B.S. in Engineering and a commission as a Second Lieutenant in the U.S. Air Force. He earned an M.S. in Astronautics from the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, and a second M.S. in Business Administration from The George Washington University. General Jacobson is a Fellow of the AIAA and a trustee of the U.S. Naval Academy Foundation. He is a member of the Strategic Advisory Group for the U.S. Strategic Command, the NASA Advisory Council, the U.S. Naval War College Board of Advisors, and several others.

### **Herbert Kottler**

Herbert Kottler is Associate Director of Lincoln Laboratory. He is responsible for the ballistic missile defense activities at the Laboratory; space activities for the Air Force, NASA, and NOAA; and interactions with Congress and the Office of the Secretary of Defense. Dr. Kottler has been with Lincoln Laboratory since 1969. Previous positions include Associate Head and Head of the Aerospace Division, Manager of the Re-entry Systems Program, Leader of the Advanced Systems Group, and Leader of the Countermeasures Technology Group. He is the recipient of a NASA Public Service Group Achievement Award. Dr. Kottler received a B.S. in Electrical Engineering from Drexel Institute and an M.S., and Ph.D. in High Energy Physics at Case Institute. Dr. Kottler has written extensively in the areas of sensor system design, testing and development. He is a member of the AIAA, Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi.

### **Peter T. Lyman**

Peter Lyman retired as the Deputy Director of the Jet Propulsion Laboratory, a NASA facility operated by the California Institute of Technology. In his 29 years at JPL, Dr. Lyman served as a spacecraft development specialist, as Director of spacecraft operations for several NASA deep space missions, and as Deputy Project Manager of the Voyager project. Additionally, he has managed the JPL Applied Mechanics Division and the Information Systems Division. As Assistant Laboratory Director for Telecommunications and Data Acquisition, he was responsible for the overall management of the NASA worldwide Deep Space Network, including long-range planning, advanced development, implementation, and operation of the network. Dr. Lyman was awarded the NASA

Outstanding Leadership Medal twice, the NASA Equal Employment Opportunity Medal, the NASA Exceptional Achievement Medal, and the NASA Distinguished Service Medal. Dr. Lyman holds degrees in Mechanical Engineering and Naval Architecture from the University of California at Berkeley. He co-chaired several task forces for NASA. In addition, he is a consultant to the Lawrence Livermore National Laboratory. He is a Fellow of the AIAA, a Fellow of the AAS, and a member of the International Academy of Astronautics.

### **Joanne M. Maguire**

Joanne Maguire is Vice President and Deputy General Manager for core business development in the TRW Space & Electronics Group (S&EG). In this role, she leads the group's pursuit of strategic business opportunities encompassing responsibility for marketing, planning, and discretionary investments. Her past positions at TRW include Vice President and General Manager of both the Space and Laser Programs Division, where she led the S&EG NASA programs, including the Chandra X-ray Observatory, and previously the Space & Technology Division, the S&EG spacecraft engineering and technology organization. Since joining TRW in 1975, Ms. Maguire has held a succession of increasingly responsible technical and management positions. She received the 1999 Outstanding Leadership Award from Women in Aerospace. She has a B.S. from Michigan State University and an M.S. in Engineering from UCLA.

### **Robert A. Pattishall**

Bob Pattishall is the Director of the National Reconnaissance Office (NRO) Advanced Systems and Technology Directorate. He is responsible for conducting an aggressive, customer-focused R&D program to provide enabling technologies that will revolutionize global reconnaissance. During his 24-year career in the NRO, Mr. Pattishall served in a variety of engineering management positions involving development and operations of state-of-the-art reconnaissance satellite systems. Previous to his appointment as Director of Advanced Systems and Technology, Mr. Pattishall was the Director, S Program Group. As such, he was responsible for the design, manufacture, and operation of a multiple satellite integrated architecture that provided critical intelligence to national decisionmakers and military commanders. Mr. Pattishall successfully managed the development and deployment of a new generation collection system and consolidation of two existing National Space Reconnaissance programs into a combined program. Prior to the NRO, he worked as an aerospace engineer for McDonnell-Douglas and Fairchild Space and Electronics Company. Mr. Pattishall has received numerous awards and recognition including the National Intelligence Certificate of Distinction, the Intelligence Medal of Merit, and the Joseph Charyk Award for Contributions to the National Intelligence Space Program. He received a B.S. in Aerospace Engineering from the University of Maryland.

### **Laurence A. Soderblom**

Larry Soderblom is a geophysicist with the U.S. Geological Survey. He has been involved in numerous scientific investigations on NASA planetary exploration missions, including the Mariners 6, 7, and 9; Viking; Voyager; Magellan; Galileo; Mars Pathfinder;

Mars Global Surveyor; Cassini; and New Millennium missions. He twice served as Branch Chief of Geological Survey's Astrogeology Program. Dr. Soderblom has received the NASA Public Service Award and twice received the NASA Exceptional Scientific Achievement Award. He was awarded the Department of Interior Meritorious Service Award and Distinguished Service Award. Dr. Soderblom attended New Mexico Institute of Mining and Technology, receiving dual B.S. degrees in Geology and Physics, and later Caltech, from which he received a Ph.D. in Planetary Science and Geophysics. He served as President of the Planetology Section, American Geophysical Union, and has led a number of NASA advisory committees, including the NASA Space Science Advisory Committee, NASA Space and Earth Science Advisory Council, and the NASA Solar System Exploration Subcommittee. He was a Sherman Fairchild Distinguished Scholar in residence at the California Institute of Technology.

### **Peter Staudhammer**

Peter Staudhammer is Vice President and Chief Engineer of TRW Inc. Prior to this position, he worked in rocket engine combustion at the Jet Propulsion Laboratory for two years before joining TRW. He was one of the principal architects and chief engineer for the development of the Lunar Module Descent Engine. He later managed space instrument development, including the Viking Mars biology and meteorology instruments, the Voyager Jupiter/Saturn Ultraviolet spectrometer, the Pioneer Venus atmospheric analysis, and several Earth radiation and climatology instruments. Dr. Staudhammer subsequently directed the TRW Central Research Staff. He was named Vice President for classified space systems before being named to his present position as the TRW Chief Technical Officer. He received B.S., M.S., and Ph.D. degrees in Engineering from UCLA. He is a member of the National Academy of Engineering.

### **Kathryn Thornton**

Kathryn Thornton, a former astronaut, is currently Assistant Dean for Graduate Programs at the University of Virginia School of Engineering and Applied Science; a professor in the Division of Technology, Culture, and Communication; and the director of the University of Virginia Center for Science, Mathematics, and Engineering Education. Selected by NASA in May 1984, Dr. Thornton is a veteran of four space flights, including the first Hubble Space Telescope Service Mission. She has logged over 975 hours in space, including more than 21 hours of extravehicular activity. Prior to becoming an astronaut, Dr. Thornton was employed as a physicist at the U.S. Army Foreign Science and Technology Center in Charlottesville, Virginia. She has received numerous awards, including NASA Space Flight Medals, the NASA Distinguished Service Medal, and the National Intelligence Medal of Achievement. Dr. Thornton received her B.S. in Physics from Auburn University and her M.S. and Ph.D. in Physics from the University of Virginia. She is a member of the National Research Council Aeronautics and Space Engineering Board, the U.S. Air Force Air University Board of Visitors, and the National Academy of Sciences Committee on Technological Literacy.

### **Peter Wilhelm**

Peter Wilhelm is the Director, Naval Center for Space Technology, at the Naval Research Laboratory. The Center's mission is to "preserve and enhance a strong space technology base and provide expert assistance in the development and acquisition of space systems." The Center is unique within the Department of Defense and has provided its expertise to a wide variety of customers, including the Naval Service, Army, Air Force, NRO, NASA, BMDO, and NPOESS. Several satellites, currently under development, will raise the Center's total to over 90 satellites in the past 40 years. Mr. Wilhelm's role in this field has been recognized by many awards and honors over the years, including the Robert H. Goddard Astronautics Award. He was elected into the National Academy of Engineering.

### **Brian C. Williams**

Brian Williams is the Boeing Associate Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT) and is a member of the Space Systems and Artificial Intelligence Laboratories. His research concentrates on model-based autonomy—the creation of long-lived autonomous systems that are able to diagnose and repair themselves through common-sense reasoning. Prior to joining MIT, he formed the Autonomy and Robotics area at the NASA Ames Research Center, noted for the development of the remote agent autonomous control system for the Deep Space 1 probe. At Xerox Palo Alto Research Center, he co-invented the GDE and Sherlock model-based diagnosis systems. Dr. Williams holds an S.B., S.M., and Ph.D. in Computer Science from MIT. He is on the editorial boards of *AAAI Press* and the *Journal of Artificial Intelligent Research*, and he has been a guest editor for the *Artificial Intelligence Journal*. He has won several best paper prizes for his research in model-based and qualitative reasoning.

### **Maria T. Zuber**

Maria Zuber is the E.A. Griswold Professor of Geophysics and Planetary Sciences at the Massachusetts Institute of Technology. She is Deputy Principal Investigator of the Mars Orbiter Laser Altimeter on the Mars Global Surveyor spacecraft; Team Leader of the laser ranging investigation on the Near Earth Asteroid Rendezvous mission; a member of the geophysics team of the Clementine mission to the Moon; and lead of the geophysics investigation of the MESSENGER mission to Mercury. Previously, Dr. Zuber held a faculty position at Johns Hopkins University and a staff position at the Goddard Space Flight Center. She is a recipient of the NASA Exceptional Scientific Achievement Medal. Dr. Zuber received a B.S. from the University of Pennsylvania and M.S. and Ph.D. degrees in Geophysics from Brown University. She currently serves on the editorial board of *Science*. She serves as President of the Planetary Sciences Section of the American Geophysical Union and is a member of the NASA Space Science Advisory Committee, the American Astronomical Society, and the American Association for the Advancement of Science.

## **Kurt Lindstrom**

Kurt Lindstrom, Executive Secretary for the MPIAT, has been at NASA since 1983. Mr. Lindstrom is currently a program executive in the NASA Advanced Technology and Mission Studies Division. He is responsible for the process of technology integration across the Office of Space Science activities. Mr. Lindstrom is the former Director of the NASA Management Office at JPL. In this position, he was responsible for the institutional management of the NASA Jet Propulsion Laboratory. Prior to that, Mr. Lindstrom directed the Program Analysis Branch in the NASA Office of Space Science and Applications and was the Development and Operations Contract Manager for the Numerical Aerodynamic Simulation Program at Ames Research Center. He began his career at NASA as a Presidential Management Intern.

## **Consultants**

### **John Casani**

John Casani retired in 1999 after 43 years with the Jet Propulsion Laboratory. He spent the majority of his career in systems engineering and project management. He was Project Manager for three major space missions at JPL: Voyager, Galileo, and Cassini. He held senior project positions in several early space programs, including Explorer, Pioneer, Ranger, and Mariner. He is a recipient of several NASA awards, including the Distinguished Service Medal, the Exceptional Achievement Medal, and the Medal for Outstanding Leadership. He received the AIAA Space System Award and the von Karman Lectureship, the National Space Club Astronauts Engineer Award, and the AAS Space Flight Award. He received a BSEE and an Honorary Doctor of Science degree from the University of Pennsylvania. He is a Fellow of the AIAA and is a member of the National Academy of Engineering and the International Astronautics Academy.

### **Brantley Hanks**

Brantley Hanks is the Special Assistant for Framework and Metrics, Intelligent Synthesis Environment Programs Office, NASA Langley Research Center. He has 37 years of experience in leading and conducting spacecraft technology development at Langley, including serving as the Leader, Spacecraft Technology Thrust Office and Head, Spacecraft Dynamics Branch. He has had temporary assignments to NASA Headquarters as Deputy Chief Engineer, Technical, responsible for integrated engineering and technology planning, and in the Space Technology Directorate, assisting in the planning of the Small Spacecraft Technology Initiative. His experience in spacecraft/space systems technology development focused on Apollo, Viking, Voyager, the Space Shuttle, the New Millennium Program, and the International Space Station. Mr. Hanks received the NASA Exceptional Service Medal. He received B.S. and M.S. degrees in Engineering Mechanics at Virginia Tech; his post-M.S. study was in Aerospace Engineering at Purdue University. He is an Associate Fellow of the AIAA and past Chairman of the AIAA Structural Dynamics Technical Committee.

## **Bruce Murray**

Bruce Murray is Professor of Planetary Science and Geology at the California Institute of Technology (Caltech) in Pasadena, California. He has been at Caltech since 1960 and currently teaches courses in Global Environmental Science and Planetary Surfaces, and he supervises graduate student research. Dr. Murray was Director of the Jet Propulsion Laboratory for 6 years, which included the Viking landings on Mars and the Voyager mission through the Jupiter and Saturn encounters. Dr. Murray was a member of the science teams of the early Mariner Mars flights. More recently, he was a science team member of the Russian Phobos 1 mission, the Russian Mars 96 and the U.S. Mars Observer missions, the Mars Global Surveyor mission, the New Millennium Mars Microprobe (DS-2), Mars Climate Orbiter, and Mars Polar Lander. In 1979, he and the late Carl Sagan founded The Planetary Society, a 100,000-member international organization dedicated to exploring the solar system and the search for extraterrestrial intelligence.

## **Peter Norvig**

Peter Norvig is Chief of the Computational Sciences Division at NASA Ames Research Center and the Thinking Space Systems Thrust Area manager in the Cross-Enterprise Technology Development Program. Prior to these positions, he was Chief Scientist for Jungle Corp., where he helped develop an industry-leading database-backed comparison shopping service. He was a Senior Scientist at Sun Microsystems Laboratories, where he did research and development in information retrieval and helped set Sun's strategic Internet policy. He was a faculty member at Berkeley and the University of Southern California. Dr. Norvig has over 40 publications in artificial intelligence, natural language processing, and software engineering, including the leading textbooks *Artificial Intelligence: A Modern Approach* and *Paradigms of AI Programming*.

## **Robert L. Sackheim**

Bob Sackheim is the Assistant Director and Chief Engineer for Propulsion at the NASA Marshall Space Flight Center. He is responsible for providing technical leadership for all of the Center's flight propulsion systems and for research and development of new propulsion technology for advanced space transportation systems. He has been an instructor in Space Propulsion at UCLA for 9 years. He recently retired from TRW Space and Electronics Group after 35 years in various management positions, the most recent being Manager of the Propulsion and Combustion Center. Mr. Sackheim is the recipient of numerous awards for contributions to space propulsion, including the AIAA Wylde Propulsion Award, the AIAA Sustained Service Award, three NASA Public Service Awards, and three TRW Chairman's Awards for Innovation. He received a B.S. in Chemical Engineering from the University of Virginia, received an M.S. in Chemical Engineering from Columbia University, and completed all coursework towards a Ph.D. at UCLA.

Mr. Sackheim holds seven patents and has published over 120 technical papers on propulsion for launch, missile, and space vehicles. He is a Fellow of the AIAA, a recently elected member of the National Academy of Engineering, a member of the International Academy of Astronautics, and a member of many other organizations. He has participated on numerous NASA, Department of Defense, National Research Council, AIAA, and university advisory boards and committees.

**Steven F. Zornetzer**

Steve Zornetzer is Director of Information Sciences and Technology at NASA Ames Research Center. Previously, he served as Director of Life Sciences at the Office of Naval Research. A principal focus of recent interest and effort, for both NASA and the Navy, has been the improvement of technology infusion into operational settings. Prior to joining the Senior Executive Service, Dr. Zornetzer was a Professor of Neuroscience at the University of California at Irvine College of Medicine and the University of Florida College of Medicine. He was a recipient of a Presidential Rank Award for Senior Executives. Dr. Zornetzer received his B.A. from the State University of New York, Stony Brook; an M.S. from the University of Wisconsin, Madison; and a Ph.D. in Biological Sciences from the University of California at Irvine. He has published over 70 research papers and co-authored two books. Dr. Zornetzer served as Vice-Chair of the White House Planning Committee for the Decade of the Brain and numerous other national committees and review teams.