6. ENGINEERING APPROACH

The following sections describe the engineering elements for which the EO-1 Mission was responsible for implementing.

6.1 Mission Assurance Requirements

The Mission Assurance Requirements were established to increase system reliability and reduce life-cycle cost while managing risk, consistent with the EO-1 Mission scope and the complexity of available technology. The EO-1 Mission had a *Mission Assurance Requirements (MAR)* document that flowed down to both the spacecraft and instrument contractors along with the EO-1 technology developers. This document addressed the overall mission requirements in the following areas:

- Quality System;
- Review Program;
- Materials;
- Verification;
- Workmanship;
- Safety;
- Reliability;
- Contamination;
- Failure Reporting;
- Parts;
- Software.

6.2 Contamination Control

6.2.1 Spacecraft

As documented in *SAI-PLAN-138*, the spacecraft contractor employed active contamination monitoring and control procedures to ensure the successful validation of the EO-1 technologies. Before delivery to the spacecraft, the ALI, the Hyperion, and the Atmospheric Corrector instruments were governed by their own contamination control plans. The spacecraft selected materials that conformed to the outgassing requirements of *NASA-JSC-SP-R-0022-A*, and was integrated and tested in at least a class 100,000 environment. When outside of a class 100,000 facility, a protective enclosure surrounded the spacecraft and the instruments. The ALI and Hyperion instruments employed a dry nitrogen purge to maintain internal cleanliness.

6.2.2 ALI, Hyperion, and Atmospheric Corrector Instruments

The ALI, Hyperion, and Atmospheric Corrector are imaging instruments operating in the visible and near-infrared spectrums. Though no data was collected in the ultraviolet short of 0.4 micron, the instruments were pointed at the Sun occasionally for calibration purposes. The "Sun look" illuminated a small fractional area of the primary mirror in each instrument before being dispersed by a diffuser. The instrument developers were concerned with both particulates and condensates. The former has a major impact on calibration by way of dissimilar throughput change as well as spectral distortion.

The general approach to contamination control for the instruments involved a number of thrusts. Each design created contamination barriers through control of venting and sealing of apertures. Materials were selected carefully to ensure components had low particulate release and outgassing. Components were cleaned and kept clean before assembly. During assembly, the telescope was kept under constant high-quality purge. Personnel were trained in appropriate cleanroom and instrument handling procedures. Finally, opening an instrument aperture after assembly, when required for examination or performance test, was performed in a class 100 local environment.

6.3 Integration and Test

Each element of the EO-1 Mission was tested individually by its developer. This included functional and environmental testing per the *EO-1 Mission Assurance Requirements*, and it also included mechanical, electrical, and radiation environments.

Major electrical subsystems (e.g., C&DH, ALICE, and WARP) were delivered to the spacecraft along with pre-tested ASIST (Advanced Spacecraft Integration & Systems Test) software procedures for the verification of aliveness, functionality, and performance. This allowed an aggressive spacecraft-level integration schedule using pre-tested subsystem procedures for the basis of the system-level testing.

Time was allocated within the I&T schedule for operational ground system testing, RF compatibility testing, and launch and early orbit simulations. The spacecraft was delivered by SAI directly from GSFC to the Western Space Missile Center (WSMC) for launch on a Delta 7320 vehicle. Launch occurred on November 21, 2000.

7. MISSION MANAGEMENT

The following sections describe the management organization and responsibilities, management strategy, and evaluation process.

7.1 Management Organization

The EO-1 Mission organization is shown on Figure 11.

7.1.1 Mission Manager

The Mission Manager was responsible for all aspects of the EO-1 Mission including: mission planning and evaluation; personnel management; configuration management; systems integration, tests, and reliability; mission assurance; launch vehicle integration; the ground system; validation of mission requirements; scheduling/schedule management; health, safety, and security; and budgetary and financial planning, contract, monitoring and reporting.

The Mission Manager had full authority to carry out these functions, subject to limitations established by the EO-1 Program Manager, Director of Flight Projects, and the GSFC Director. The Mission Manager discharged these responsibilities with the assistance and support of individuals and organizations assigned administratively or functionally to the mission management organization.

7.1.2 Mission Scientist

The Mission Scientist was provided by the Earth Sciences Directorate (Code 900) and was responsible for ensuring the satisfactory accomplishment of the scientific validation of the Mission's technologies. The Mission Scientist reviewed the implementation of the mission to ensure that the mission was consistent with the science validation objectives. The Mission Scientist ensured that the scientific data was effectively used and that the scientific results of the mission were expeditiously produced. The Mission Scientist evaluated all scientific validation requirements placed on the mission and provides guidance to The Mission Management Team.

The Mission Scientist worked with NASA HQ to release a NASA Research Announcement (NRA) to create a Science Validation Team (SVT) approximately one year before launch. The SVT was a team of scientists that performed the scientific validation of the imaging technologies in the ALI, Hyperion, and LAC instruments flown on EO-1. The Mission Scientist led the SVT.

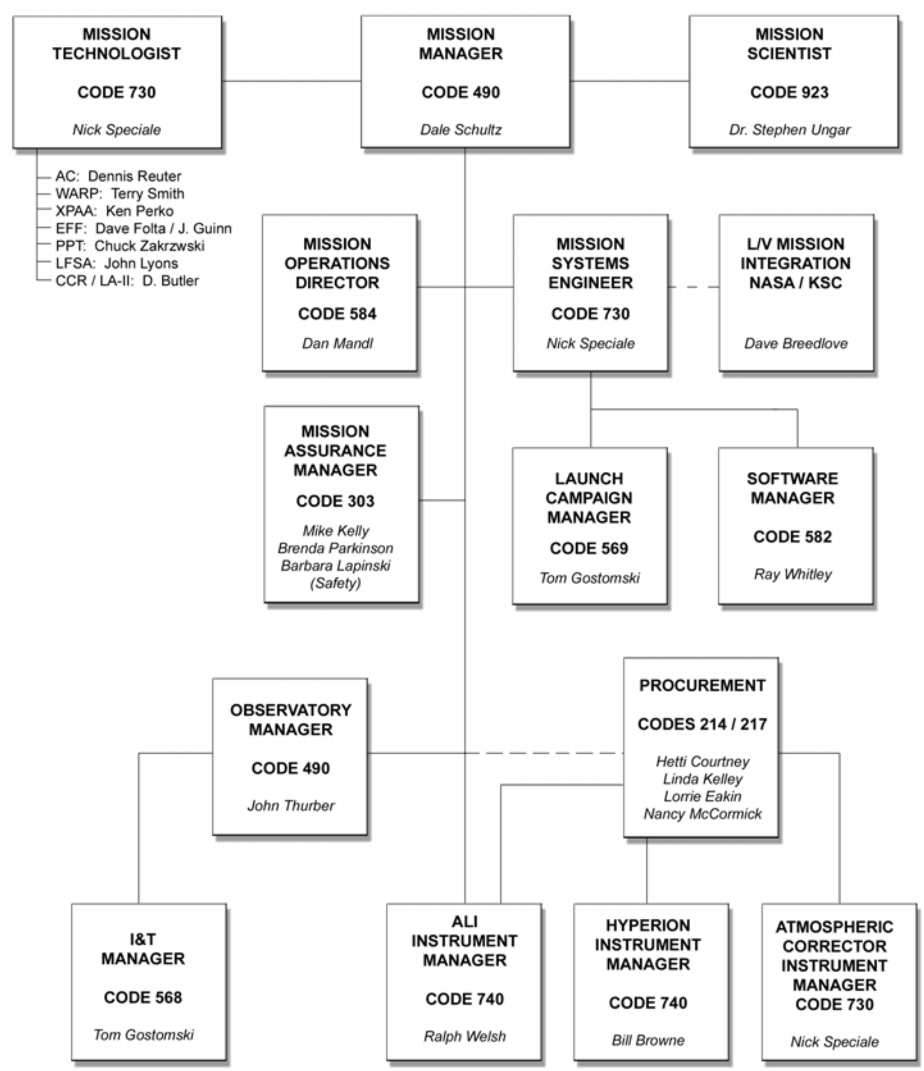

Figure 12 - Management Organization

7.1.3 Mission Systems Engineer

The EO-1 Mission Systems Engineer reported to the Mission Manager for all systems aspects of the flight and ground elements including the technologies validated on this mission. The Mission Systems Engineer was responsible for developing the systems design of the total mission, including the integrated satellite, launch vehicle, and ground systems. The Mission Systems Engineer established interface constraints and requirements for mission elements, resolved interface and mission system-level performance issues and assured mission system compatibility with project reliability objectives. The Mission Systems Engineer reviewed performance data and measurements throughout the mission to ensure that flight and ground systems met stated requirements and objectives. The Mission Systems Engineer was responsible for reviewing design specifications, all major test plans and procedures, performing risk assessments and evaluating design margins and inadequacies, comparing predicted and actual performance of systems and reporting the status of system engineering activities to the Mission Manager. The Mission Systems Engineer chaired the mission-level Configuration Control Board. In the absence of the Mission Manager, the Mission Systems Engineer was permitted to act for the EO-1 Mission Manager.

7.1.4 Mission Technologist

The Mission Technologist was responsible to the Mission Manager for successfully integrating and validating all technologies approved for the EO-1 Mission. The Mission Technologist was a member of the NMPO and was responsible for maintaining a smooth working relationship between the NMP IPDTs and the EO-1 Flight Team. The Mission Technologist was responsible for preparing and maintaining technology validation plans, descriptions, spacecraft resource requirements, budgets, schedules, verification procedures and any agreements necessary for their acquisition. The Mission Technologist developed and disseminated appropriate informational documentation to the EO-1 Flight Team and other interested parties in order to facilitate a broader understanding of the EO-1 technologies and their potential role in future science missions. After launch, the Mission Technologist organized and supervised implementation of the validation plans, analysis of the validation data and preparation of the technology transfer plans.

7.1.5 Mission Assurance Manager

The Office of Flight Assurance (Code 300) provided the Mission Assurance Manager. The Mission Assurance Manager was responsible to the Mission Manager for all flight assurance disciplines of the mission to ensure that the spacecraft, instruments, and ground system equipment (e.g. hardware and software) met their intended performance objectives. These disciplines included mission assurance, design review, reliability, system safety, parts, materials and processes, verification testing, contamination, verification and software. The Mission Assurance Manager coordinated GSFC resident or Government Inspection Agency (GIA) personnel activities.

7.1.6 Observatory Manager

The Observatory Manager was responsible to the Mission Manager for ensuring the performance of the spacecraft development activity. The Observatory Manager identified and specified the mission-imposed spacecraft systems requirements; managed the spacecraft development and spacecraft integration and test efforts; and ensured that proper steps were taken to demonstrate that the spacecraft system and its components met their performance requirements in the launch and space environments. Responsibilities included planning and managing these tasks so that they were completed on schedule and within the available resources.

7.1.7 Instrument Managers

One Instrument Manager was responsible to the Mission Manager for ensuring the performance of the Advanced Land Imager (ALI) instrument being developed by MIT/LL, and a second Instrument Manager was likewise responsible for the Hyperion being developed by TRW. The Instrument Managers identified and specified the mission-imposed instrument systems requirements, managed their development, oversaw spacecraft integration and test efforts, and ensured that proper steps were taken to demonstrate that the instruments met their functional performance requirements in the launch and space environments. The Instrument Managers ensured through coordination and technical review of designs that the instruments met the technical performance, cost, and schedule parameters of the mission requirements. They were responsible for coordinating the spacecraft bus/instrument interfaces and for ensuring that the related ground support equipment (GSE) was provided.

7.1.8 Mission Operations Director

The Mission Operations Director was responsible to the Mission Manager for developing and implementing mission operations requirements for both the space and ground elements. The operational ground system consisted of the Mission Operations Center (MOC), the flight data capture/processing system and all hardware, software, and communications support necessary to command and control the EO-1 satellite. Before launch, the Mission Operations Director was responsible for ensuring that operational requirements were met, including the conduct of all tests necessary to verify and validate the operation system. After launch, the Mission Operations Director was responsible for the operation of the satellite.

8. MANAGEMENT STRATEGY

8.1 Life-Cycle Costing

All of the costs associated with the EO-1 Mission were calculated from a life-cycle perspective such that there were no known outstanding costs. The GSFC Resource Analysis Office (Code 152) prepared an independent cost estimate for the mission. This estimate was compared to the Mission Team’s cost estimate and the deviations were addressed at the Confirmation Review. Also, if there were any significant mission changes, the Resource Analysis Office's estimate was appropriately updated so that any cost impact could be validated.

8.2 Design-To-Cost

Once the preliminary definition of the mission was completed, the EO-1 Mission adopted a Design-to-Cost (DTC) approach and set appropriate DTC targets for all mission elements. The Mission Team considered a number of alternative designs, until an approach was identified that would achieve the desired performance within the DTC target and the planned schedule. Some DTC targets contained no reserves for such mission elements as Mission support, the science budget, and the EO-1 contribution to the launch vehicle. All of the DTC targets for flight hardware and software contained reserves that were reported monthly to the EO-1 Mission. The degree of risk, the criticality to the mission, and the nature of the contract determined the size of the reserve. To reduce the reserve requirements, the EO-1 Mission made the fullest use of fixed price contracts.

Each element's budget was evaluated monthly to assess conformance with established obligation and cost plans. Variances were analyzed to determine if the progress of work was being affected or if there was a potential for cost overrun. If so, then mitigation options were developed and the best one was selected for implementation. The potential for developing additional budgetary reserve was constantly watched due to inherently conservative management processes that lend themselves to overestimating cost or time to develop a task. Any cost or schedule reserve increase was factored into the assessment of the element's programmatic health.

8.3 Schedule Management

The Mission had an aggressive schedule management approach. It included developing a detailed schedule for each element of the mission, with a critical path and critical development milestones. Each schedule was reviewed bi-weekly by the respective development team and monthly with the EO-1 Management Team. The review included an analysis of the critical path for any changes. If changes were identified, then alternatives to minimize the impact to the critical milestones were developed and the lowest cost option, having the least impact, was chosen. Also, progress on the critical milestones was established. If any were falling behind, then mitigation options were again evaluated and the best one selected for implementation. As the development of an element continued, the time estimated to complete near-term tasks was constantly challenged to see if more schedule reserve could be created in the critical path.

8.4 Software Management

The EO-1 Mission had software in the flight segment, the I&T Phase, and the Operations Ground System. The Mission was responsible for the coordination of these elements. Each software package was developed according to the respective software management plans.

8.5 Risk Management

A robust risk management plan was developed for EO-1. It allowed potential risk to be identified, along with a risk mitigation plan for each identified risk. Trigger points were also identified and were used to implement the risk mitigation plan when any risk materialized.

8.6 Mission Success Criteria

The EO-1 Mission Success Criteria was to consist of meeting the Top-Level requirements, namely, to successfully flight-validate the EO-1 technologies and science objectives, to launch in the 3rd quarter of CY00, and to complete the mission within the allocated budget.

The EO-1 Minimum Mission was to consist of flying and successfully validating the Category I technologies, which were the basis of the ALI instrument. Any inability to develop a Category I technology would result in a restructuring of the EO-1 Mission. Failure to successfully restructure the mission would result in a Cancellation Review.

9. EVALUATION PROCESS

9.1 Performance Assessment

Each mission element was assessed monthly by the EO-1 Mission Team in terms of technical, cost, and schedule performance, and was reported monthly to the Program Office and to the GPMC. Technical performance was assessed through insight gained from teaming with the element development teams. This involved working with them to identify and solve problems, reviewing internal documentation, reports, etc. Every effort was made to gain insight using a constructive versus an interfering process. Element team leads were encouraged to seek help from GSFC when they had problems. Each element was required to report schedule progress weekly and cost status monthly. Each month, the EO-1 Management Team evaluated the technical, cost, and schedule status at the mission level. Also, the Mission Systems Engineer evaluated the technical performance of each element with its respective programmatic performance to determine an element level assessment for inclusion in the mission assessment. If problems were identified for any, then the Mission Systems Engineer developed options (which could effect other elements) for correcting the situation and then recommended them in programmatic priority order to the Mission Manager. Every attempt was made to minimize the impact to the Mission's top-level requirements.

9.2 Reviews

The following mission-level internal reviews were conducted.

Requirements Reviews:
- Spacecraft
- Advanced Land Imager
- Ground System

Design Convergence Reviews:
- Spacecraft
- Advanced Land Imager

Confirmation Reviews:
- Primary Confirmation Review
- Delta Confirmation Review

Critical Design Reviews:
- Advanced Land Imager
- NMP Technologies
- Spacecraft
- Mission-Level
- Hyperion
- Delta Mission-Level

Pre-Environmental Reviews:
- Thermal /Vacuum Readiness I
- Thermal/Vacuum Readiness II
- Thermal/Vacuum Readiness III
- Advanced Land Imager
- Hyperion
- Mission-Level

Pre-Ship Reviews:
- Advanced Land Imager
- Hyperion
- Spacecraft
- Delta Spacecraft
- Delta Mission Operations Review

Operational Reviews:
- Mission Operations Review
- Operational Readiness Review

Launch Reviews:
- Launch-1 Year Review
- Mission Readiness Review
- Delta Mission Readiness Review
- Flight Readiness Review
- Launch Readiness Review

In addition, the following external reviews were conducted:

- Littles' Committee Review
- External Independent Readiness Review (EIRR)
- EIRR Joint EO-1/SAC-C Review
- EIRR WARP Review
- Senior Manager's Review
- Red Team Review
- Red Team Follow-Up Meeting
- Final Red Team Review
- Red Team ELV Review
- Red Team He/IRU Review
- Flight Software Independent Assessment

10. Lessons Learned

During the course of conducting the EO-1 Mission, there were many "lessons learned" experienced. The most significant of these are listed below.

- Technology validation missions have unique, high-risk mission requirements and cannot be treated and staffed like a small science mission because of the following factors:
  - Maturing the technologies;
  - Architectural risks;
  - Developing the technologies;
  - Flight-validating the technologies;
  - Infusing the technologies.

- Mitigating these risks requires:
  - Greater reserves of time and money ($\geq$20%);
  - More capable people;
  - Robust Risk Management (Full time risk manager);
  - Strong System Engineering. This is ABSOLUTELY ESSENTIAL in orchestrating a successful NMP mission;
  - Ready and repeated routine access to the best engineering talent.

- NMP missions are not important in and of themselves, BUT where they lead;

- Enabling future science missions is the primary function of any NMP mission;

- OMB expects infusion to be direct and obvious;

- To be effective, programs need to have some influence on technology development and validation prior to infusion;

- Infusion must become more sophisticated than "Build it and they will use it";

- Infusing into a single large mission will rarely save enough money to pay for the NMP mission;

- Infusing into multiple missions works best at the box level;

- Hence, the NMP is being turned into a Multi-mission Box Program;

- The NMP must become much smarter about its infusion targets;

- In the end, technology validation missions are justified because they are programmatically necessary and not because they are cost-effective;

- Mission requirements should be traceable to Validation Plans that need to be completed early in the definition phase and strong science input is essential in drafting good plans;

- "Light touch" management does not work for an NMP mission. Due to the technical complexity of an NMP mission, in-depth, experienced staffing is needed from the outset;

- An "insight" not "oversight" management style is required across the entire management structure;

- Be prepared to assist and supplement a contractor's work force;

- It is essential to have an experienced engineer serve as the Mission Technologist who will develop and maintain the Validation Plans. In addition, the Mission Technologist is needed to manage development of the technologies, take ownership of the mission after on-orbit checkout, supervise the implementation of Validation Plans, develop technology transfer documents, and organize and implement technology infusion;

- Techniques to keep the required budgetary reserve manageable are as follows:
  - Optimize "category" architecture to minimize programmatic risk;
  - Maintain a robust, nimble schedule to preserve programmatic flexibility;
  - Establish a design-to-cost strategy from the outset;
  - Utilize fixed price contracting for SOTA elements;
  - Establish incentives for Technology contracts keyed to schedule;
  - Quickly off-load a technology if it does not meet maturity milestones.

- With capable scheduling, a +15% funded schedule slack should be adequate.

11. CONCLUSIONS

The EO-1 mission has been an unqualified success and additionally has demonstrated the success of the NMP concept. All NMP mission objectives were met or exceeded within 13 months of launch as planned, and EO-1 continues to be fully functional after 19 months on-orbit. Excluding a critical failure, the spacecraft has adequate consumables to permit the mission to last at least into year 2005. Contained within the validation reports, which follow, are specifics that give convincing evidence to this success. Also, the validation reports show that a plentiful number of technology infusion opportunities have resulted. The EO-1 Science Validation Studies have revealed numerous scientific applications for the Advanced Land Imager and Hyperion images thereby creating a substantial increase in customer interest when coupled with reduced cost of images.

Publicly available EO-1 reports, published papers, and meeting/workshop presentations charts, as well as general information about the EO-1 Mission, can be viewed on the NASA EO-1 website http://eo1.gsfc.nasa.gov. The reports, papers, and presentations can be either downloaded from the website or obtained from the given source listings.

A listing of ICD and requirements documents is contained in the Index of EO-1 Baseline Documents as presented in the Appendix to this Part.

APPENDIX

INDEX OF EO-1 BASELINE DOCUMENTS

MSO TO MOC ICD.pdf
LVL_II_Tech_rqt1.PDF
LVL_II_Space_rqt1.PDF
LVL_II_ground_reqt1.PDF
ICD-67-S-Band WARP.pdf
ICD-65 HYPERION.PDF
ICD-57 WARP to AC.PDF
ICD-47-X Band .pdf
ICD-25 GPS.PDF
ICD-23 SC to GRND.PDF
ICD-070 LEISA AC TO SCIENCE DATA PROD.pdf
ICD-056 ALI-RS422.PDF
ICD-055(B) RADIOMETRIC CALIBRATION.pdf
ICD-028 Carbon Carbon.PDF
ICD-026 SC to WARP .PDF
ICD-021 LEISA-AC.pdf
ICD-020 LFSA.pdf
ICD-019 SC to PPT ICD.PDF
ICD-018(A) SC to ALI.PDF
EO-1 Landsat 7 icd.pdf
EO-1 ICD-04 TRW GSFC INTFC.pdf
E0-1_DMR7.pdf