Mars Reconnaissance Orbiter

Mission Operations Requirements

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EXHIBIT IV

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1.0 Introduction

1.1 Purpose and Scope

The purposes of this document are to provide an overview of the Mission Operations System (MOS) and Ground Data System (GDS), and to describe the functional requirements on the MOS and GDS in sufficient detail to permit potential orbiter providers to propose implementation plans that are consistent with the Mars Reconnaissance Orbiter (MRO) project's resources, requirements from NASA, and management philosophies.

1.2 Document Structure

Section 1 provides an introduction to this document. Section 2 provides an overview of the MOS and GDS. Section 3 identifies Orbiter Contractor operations support requirements including Orbiter Testbed (OTB) requirements and Orbiter analysis software requirements.

1.3 Applicable Document

The following document apply to the extent specified in this document, with revision number/date of issue as specified in Exhibit II, Applicable Documents.

Document No.	Title
JPL D-17896	TMOD Security Requirements August 12, 1999

2.0 Operations/MOS/GDS Overview

2.1 Organization

2.1.1 Development Organizations:

The development of the MRO MOS/GDS will be a joint effort by both JPL and external organizations, including the science investigators and Orbiter Contractor. General development activities are:

- Defining and evolving the operations concept
- Establishing the MOS/GDS implementation plans and requirements
- Developing the preliminary and detailed designs
- Integrating and testing the MOS/GDS design and end-to-end information system interfaces both internally and with the Orbiter and payloads
- Training personnel on the MRO processes and procedures to be used during the flight operations.

The development responsibilities by organization are defined as follows:

A. MRO MOS/GDS Development at JPL
MRO Project will provide the leadership of the overall MOS/GDS development activities including all activities at JPL, at Principal Investigator (PI) facilities and at Orbiter Contractor's facility to meet the project's requirements. MRO Project will be responsible for the management, systems engineering and coordination, operations concept development, operations processes, system integration, test and training functions. MRO will use existing Deep Space Mission System (DSMS) services provided by JPL's Telecommunications and Mission Operations Directorate (TMOD) with minimum modification. The DSMS provides services to MRO Project based on the negotiation documented in the Detailed Mission Requirements document. The services include telecommunication, telemetry, command, sequence, navigation and tracking, image processing and others.

B. Science & Instrument Operations Development at PI's home institution:
PI will be responsible for the development of the science operations and data analysis capabilities, including hardware, software, facility, people and procedures. Investigator's science operations procedures and data interfaces will be consistent with the overall MOS/GDS procedure and standard data interfaces.

C. Orbiter Contractor:
The Orbiter Contractor will be responsible for the development, verification, validation and delivery of the Orbiter analysis software, Orbiter testbed, Orbiter operations tools, command, telemetry dictionaries, flight rules, Orbiter and payloads operations processes, procedures and contingency scenario and plan development, and anomaly responses. The Orbiter Contractor will also participate with JPL to prepare and review flight sequences for ATLO and testing.

2.1.2 Operations Organizations

During operations, JPL is responsible for the leading the MRO mission operations with support from the science investigator teams and the Orbiter Contractor.

A. MRO Project: MRO project provide the leadership of the overall mission operations and mission operations management. Specific functions will be provided by the MRO project including but not limited to mission planning, navigation, sequence and command generation, and real-time operations.

B. The Orbiter Contractor will provide Orbiter Engineering Operations support. The support includes trend analysis, anomaly investigation and recovery, Orbiter health and welfare monitoring, performance calibration, engineering sequence and command request generation, and other engineering support.

C. MRO Science Operations at PI's home institution provide science operations such as science command request generation, data processing and analysis.

2.2 Timeline & Activities

2.2.1 Development Phase:

During development phase a series of MOS/GDS development activities will occur to ensure that proper operations configuration and planning are implemented. The development activities are:

A. MOS/GDS organization definition and implementation planning

The MOS/GDS development will be led by JPL and supported by the investigator teams and the Orbiter Contractor. Staff position and operations team roles and responsibilities will be defined. The operation concept will be developed and plans for implementation of the MOS and GDS designs will be established.

B. MOS/GDS Requirements Definition:

MOS/GDS Requirements will be established that are traceable to higher-level project objectives and requirements. The requirement flow-down will include the MOS and GDS located at JPL, capabilities and services provided by the DSN, deliverables and support provided by the payload teams and Orbiter Contractor. Consistency and compatibility of requirements within the MOS/GDS as well as with the Orbiter will be insured. Requirements will be established to maximize the use of and compatibility with existing flight and ground hardware, software and procedures.

C. MOS/GDS Design and Development:
System and subsystem designs will be established that satisfy the requirements for the MRO MOS/GDS. Architectural trade studies and detail analysis will be conducted to establish the ground system and subsystem designs necessary to operate the mission. Project unique designs, DSMS capabilities, DSN services, payload teams and Orbiter Contractor deliverables and support will be integrated into the MOS/GDS system and detailed designs. Designs will be reviewed at the project and system preliminary and critical design reviews.

D. Mission Planning and Sequence Development:
A detailed MRO mission plan will be developed by JPL that satisfies the project objectives and science requirements. Detailed flight sequences will be generated to support Orbiter ATLO testing and mission compatibility testing. Critical mission sequences, such as Mars Orbit Insertion shall be developed and tested on the Orbiter during the ATLO activities.

E. I&T/ATLO Support:
This activity includes GDS deliveries to support flight software integration tests, Orbiter testbed tests, and ATLO activities. The OTB will be utilized during ATLO activities for testing mission scenarios and flight sequences, training personnel and developing fault responses and contingency plans

F. MOS Test & Training:
The MRO MOS/GDS will be tested before launch using nominal and fault -injected flight sequences. Test cases will include representative mission activities and all mission critical events. Orbiter-MOS compatibility testing will be used to help train operations personnel.

2.2.2 Operations Phase:

This phase starts with initial acquisition. The details of the operations activities and timeline will be documented in the Mission Plan. In general, it includes launch operations support (including Initial DSN Acquisition), Orbiter and Instrument Post-Launch checkout, cruise operations, orbit insertion, aerobraking, primary science, and relay operations, in-flight anomaly investigation and anomaly management.

In addition to the special events mentioned above, the day-to-day routine operations and maintenance activities including, configuration management, resource management, test and training for future events, and GDS maintenance are part of the operations phase activities.

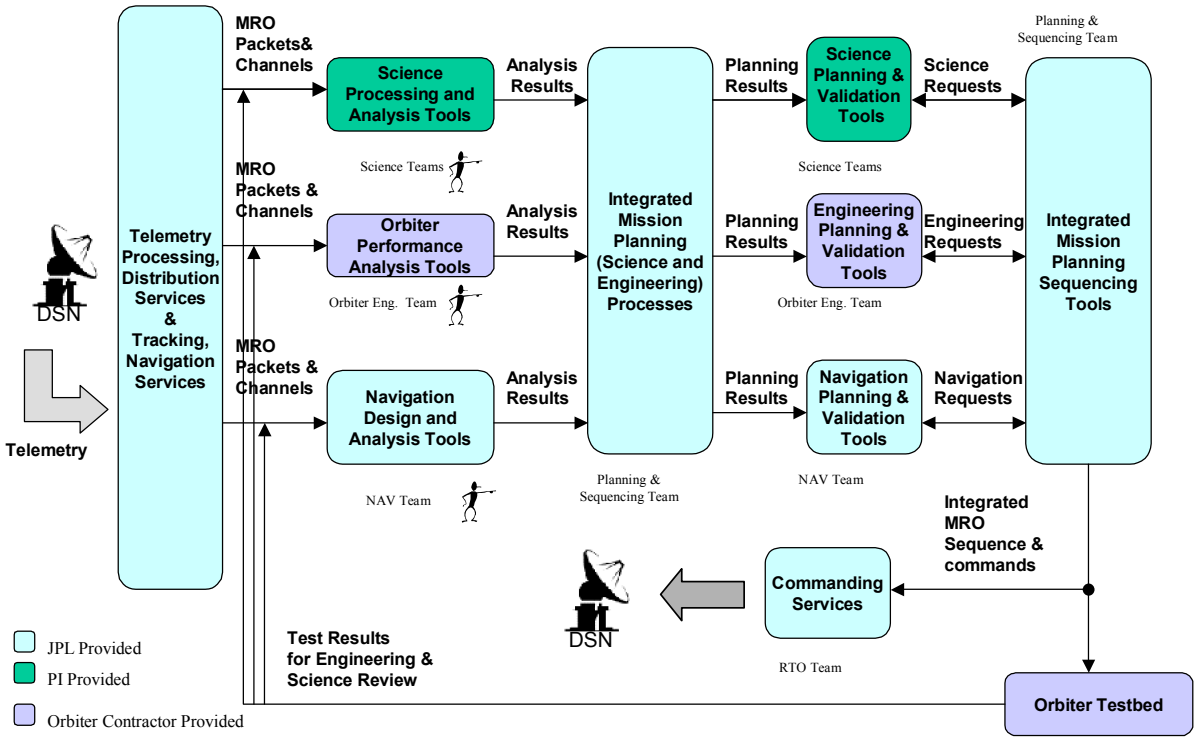
2.3 MOS/GDS Architecture

The MOS/GDS includes the following two major elements to support mission operations functions defined in previous section – the MOS and the GDS. The GDS contains the hardware, software, facilities and networks that support the operations team accomplish activities such as telemetry processing, sequence and command processing, and Orbiter analysis. The MOS segment includes mission operations process and procedures, teams and personnel for teams to perform those aforementioned activities.

Overall MOS/GDS capabilities will need to support functions such as Orbiter uplink, science instrument uplink, sequencing, commanding, data acquisition and real-time monitoring, data storage management and distribution, Orbiter analysis, payload analysis, navigation and related ancillary information generation, science data processing and distribution, data archival, and status and team coordination.

Figure 1 contains a simplified functional block diagram to show the basic data flow.

Figure 1 -Flight Information Flow



The team structure and flight support architecture of the MOS organization to accomplish the above functions will be as follows.

A. Mission Management and Systems Engineering
   1. Manage overall mission operations activities including all participants

2. Coordinate detailed activities among all teams
3. Coordinate observations and mission resource usage

B. Orbiter Engineering:
   1. Operate and manage Orbiter engineering activities
   2. Analyze telemetry for Orbiter health and performance
   3. Maintain flight software on-board
   4. Anomaly resolution planing and implementation
   5. Operate the Orbiter testbed to validate engineering sequences and commands
C. Mission Planning, Sequencing and Execution
   1. Plan mission activities
   2. Develop and integrate Orbiter and instrument activities
   3. Generate sequences and commands for radiation and testing
   4. Operate the Orbiter testbed to validate integrated engineering and science sequences and commands
D. Navigation
   1. Determine and maintain Orbiter trajectory
   2. Plan and manage maneuvers
E. Science operations
   1. Monitors instrument health and performance
   2. Plans instrument activities
F. Real-time Operations
   1. Coordinate real-time activities between projects and multimission teams
   2. Radiate commands and monitors real-time data system and Orbiter health
G. Data Management
   1. Manage the science data processing and distribution systems
   2. Produce data distribution products and performs data distribution function
   3. Archive science data products

3.0 Orbiter Contractor Support Requirements

3.1 Orbiter Operations Support Development Requirements

3.1.1 Orbiter Analysis System (OAS)

Design, develop, document, certify and deliver Orbiter system and subsystem analysis tools (software and hardware), which allow the analysts to:

A. perform health and status analysis,
B. perform performance predictions and trending including uncertainties,
C. perform life prediction,
D. perform anomaly investigation of unpredicted performance,
E. generate Orbiter command requests.

This system should include subsystem disciplines such as flight software maintenance, thermal analysis, power analysis, structures and mechanisms, propulsion/maneuver operations and analysis, attitude, articulation and control, C&DH operations and analysis, and telecom subsystem performance.

3.1.2 Orbiter Testbed

Design, develop, integrate, document, certify and deliver the Orbiter Testbed (OTB) that meets the following requirements:

A. OTB Functionality
   1. Includes flight-functional-equivalent Orbiter processors, clocks and buses,
   2. Executes Orbiter flight software (object code) without special modifications,
   3. Includes EM and software simulations for Orbiter subsystems, payloads and environment,
   4. Supports timed software parameter modification and fault injection,
   5. Supports bit-serial telemetry and command interfaces with the GFE Telemetry and Command System for testing,
   6. Execute GDS-generated uplink command sequences and generates flight-like telemetry content.
   7. Provides visibility into (and capture of) flight system command/telemetry activity and interface activity, with ASCII output options and formatted Orbiter-clock time tags.
   8. Includes a hardware/software infrastructure including racks, cables, power, GFE workstations, Graphical User Interface, MRO flight network access, database, and hooks for external models & external data input,
   9. Includes editable start-up, and initialization files and operating procedure,
   10. Includes a halt/checkpoint/restart capability,
   11. Supports unattended operation during sequence execution,
   12. Support remote operations,
   13. Support closed loop dynamic simulation capability,
   14. Support redundancy management testing.

B. OTB Performance
   1. Supports real-time flight-processor speeds,
   2. Supports flight-system command & telemetry rates,

3. Supports (housekeeping) time jumps (as an option),
4. Includes sufficient online storage for all potential input and output data associated with ten 24-hour simulations.
5. The OTB shall support flight-like Orbiter redundancy
6. The OTB shall support flight-like telemetry content, flight-like software and command sequence execution, flight-like fault protection response, flight-like serial command & telemetry interfaces in support of flight software integration and troubleshooting, GDS/MOS development, ATLO test sequence validation, flight sequence validation and in-flight anomaly investigation.

C. OTB Operations
1. Operate and maintain the OTB, locally, beginning with pre-ATLO flight software integration,
2. Execute MRO-provided sequences,
3. Configure and initialize the OTB for MRO-specified simulations and anomaly investigations,
4. Deliver an OTB to JPL before Orbiter shipment to KSC,
5. Train JPL employees for OTB operations.

3.1.3 Software Simulator

Design, develop, integrate, document, certify and deliver the Software Simulator that meets the following requirements:

A. Provide flight-functional-equivalent capability
B. Executes Orbiter flight software (object code) without special modifications,
C. Includes software simulations for Orbiter subsystems, payloads and environment,
D. Supports timed software parameter modification and fault injection,
E. Supports compatible interfaces with the GFE Telemetry and Command System for testing,
F. Execute GDS-generated uplink command sequences and generates flight-like telemetry content.
G. Provides visibility into (and capture of) flight system command/telemetry activity and interface activity, with ASCII output options and formatted Orbiter-clock time tags.
H. Includes editable start-up, and initialization files and operating procedure,
I. Support faster than real time execution, the speed depends on the hosting computing performance,
J Supports unattended operation during sequence execution,
K The software simulator shall be capable of executing on commercial UNIX workstation.

3.1.4 Orbiter Operations Development

Provide Orbiter operations development support:

A. Provide a management lead for the Orbiter engineering support,
B. Maintain an integrated schedule for all development and activities,
C. Participate and present at Monthly Management Reviews,
D. Provide a system engineering lead for Orbiter engineering support during development and during operations,
E. Support MRO MOS/GDS requirements, design, development and reviews,
F. Provide MOS and facility requirements for Orbiter Engineering Team (OET) operations,

G. Provide inputs to OTB requirements,
H. Provide preliminary and final OET operations design specification,
I. Provide inputs to the MRO MOS Test & Training Plan,
J. Provide a Orbiter operations handbook,
K. Provide inputs to the MRO Mission Sequence plan,
L. Provide inputs to the DSN Initial Acquisition Plan,
M. Provide a Orbiter and instrument initial Checkout Plan,
N. Provide inputs to the MRO Aerobraking Operations Plan,
O. Provide MRO MOS personnel with training regarding operational characteristics of the Orbiter, the use of OET-maintained portions of MRO operations database, and interfacing with OTB (data and operations),
P. Support preparation, execution and analysis of tests associated with GDS deliveries, ATLO, Launch Operations, and Flight Operations including MOS-Orbiter compatibility testing at Orbiter Contractor facilities and the launch site,
Q. Support preparation, execution and analysis of operations dataflow and operations readiness tests (ORT's),
R. Support development of command sequences for ATLO and Flight Operations using GFE sequencing software.

3.1.5 Ground Data System Development

Provide Ground Data System Development Support:

A. Develop a OET (at the Orbiter Contractor) GDS, including GFE workstations, networks and software, as well as Orbiter Contractor supplied equipment and software,
B. Provide a small subset of the local GDS, for in-flight OAS software development and to support in-flight MRO ground software/hardware/network transitions,
C. Support the development of data interfaces between MRO and Orbiter Contractor facilities,
D. Participate in the MRO System Administration and Configuration Management processes,
E. Participate in the MRO GDS delivery process,
F. Provide GDS requirements for OET GDS and OAS tools,
G. Provide inputs to OTB requirements,
H. Provide preliminary and final OET GDS design specification,
I. Provide inputs to the MRO GDS Test Plan.

3.1.6 Orbiter Engineering Facilities

A. Provide facilities that meet the JPL D-17896 ”TMOD Security Requirements” for the OET function, including workspace, power, telephone, administrative computers and software, and secure local networks and data facilities,
B. Provide facility engineering support for installation of GFE equipment.

3.2 Orbiter Operation Support Requirements

Orbiter Contractor shall provide an OET during the mission operations phase to support the mission.

3.2.1 Orbiter Engineering Management & System Engineering

A. Management
   1. Provide a management lead for the Orbiter engineering support,
   2 Maintain an integrated schedule for all development and operations activities,
   3. Participate and present at Monthly Management Reviews.

B. System Engineering
   1. Provide a system engineering lead for Orbiter engineering support during operations,
   2. Support MRO MOS/GDS change assessment and review for requirements and design changes,
   3 Participate in MRO project activity reviews such as Mars Orbit Insertion (MOI) readiness review.

C. Operations Reports
   1. Provide weekly Orbiter engineering reports, during flight operations, summarizing Orbiter status and activities,
   2. Provide special summary reports for key Orbiter activities (e.g. Launch and initial acquisition, Orbiter and instrument checkout, MOI, and aerobraking).

3.2.2 Orbiter Engineering Operations

A. Orbiter Performance Monitoring
   1. Monitor, status and perform trend analysis Orbiter subsystems (ACS, Thermal, Power, Propulsion, C&DH, Telecom), payloads, and the telecom link during prime shift and critical events such as MOI,
   2. Maintain and provide Orbiter alarm limits and subsystem lead contact information to the MRO Mission Manager,
   3. Respond to alarm conditions, both on-hours and off-hours, when notified of an alarm state,
   4. Monitor ACS momentum buildup/unloading and submit uplink requests for momentum unloading (if needed),
   5. Monitor Orbiter Telecom performance and Telecom Link performance,
   6. Monitor the execution of approved command sequences,
   7. Monitor onboard storage utilization, predict telecom link capability (in terms of supportable rates), and participate in planning for telecom operations,
   8. Maintain ACS parameters and catalogs and submit appropriate uplink requests,
   9. Maintain Orbiter flight software and software parameters,
   10. Participate in the MRO configuration management process,
   11. Operate and maintain the OTB in support of JPL-approved flight activity plans (Initial checkout, Cruise, MOI/Aerobraking, Science Operations, Relay Operations) and in-flight anomaly investigations.

B. Anomaly Investigation & Management
   1. Report suspected flight system anomalies to MRO system engineering,
   2. Investigate suspected Orbiter anomalies, and support investigation of suspected Orbiter anomalies,
   3. Participate in the MRO anomaly management process,
   4. Provide expert, on-call support for the investigation of suspected Orbiter anomalies, as needed,
   5. Develop operational workarounds to compensate for degraded Orbiter capabilities.

3.2.3 Orbiter Engineering Uplink

A. Submit Orbiter engineering uplink requests to the MRO Uplink Process,
B. Participate in the generation of command sequences, to be uplinked to the flight system,
C. Participate in the command approval/tracking process,
D. Verify receipt (by Orbiter) of all ground commands, and input command accounting data to MRO command tracking database.

3.2.4 Orbiter Engineering Downlink

A. Monitor downlink data transport performance and participate in accounting of receipt of telemetry packets at the MRO telemetry database,
B. Retrieve telemetry packets and engineering channels from the MRO telemetry database, as input to Orbiter engineering functions,

3.2.5 Orbiter Navigation & Maneuver Operations

A. Provide prediction of Orbiter thruster events (Delta-V vector and epoch) for all maneuvers (including AMD's, TCM's and ACS burns during aerobraking drag passes) to the MRO Navigation Team based on a combination of Orbiter configuration and operating characteristics/plans,
B. Provide actual Orbiter thruster events (Delta-V vector and epoch) for all maneuvers (including AMD's, TCM's and ACS burns during aerobraking drag passes) to the MRO Navigation Team based on Orbiter engineering telemetry (momentum unloading, attitude changes, etc.),
C. Provide predicted maneuver performance/profile data to the MRO Navigation Team, based on maneuver requirements (delta-V) from the MRO Navigation Team,
D. Generate uplink requests for execution of approved propulsive maneuvers,
E. Provide reconstructed maneuver performance/profile data to the MRO Navigation Team, based on analysis of engineering telemetry,
F. Generate uplink requests for execution of approved attitude maneuvers,
G. Provide reconstructed Orbiter attitude (quaternion) in a Navigation Ancillary Information Facility (NAIF) C-Kernel format.

3.2.6 Orbiter Engineering Databases

A. Local OET Operations Database - Populate and maintain a local OET database containing all local data products, including:
    1. All uplink requests and commands verified,
    2. Orbiter engineering channels (retrieved from MRO telemetry database),
    3. Key Orbiter performance analysis products.
B. Inputs to MRO Operations Database - Populate and maintain Orbiter Engineering portions of (flight-team-accessible) MRO Operations Database, including (but not limited to):
    1. Command and Telemetry Definitions, Schema & Maps,
    2. Standard Orbiter Activity, Sequence or Block definitions,
    3. Flight Rules,
    4. Key Operational Orbiter Parameters & Constraints,
    5. Telemetry Alarm Limits,
    6. Orbiter / UTC time correlation.

3.2.7 Ground Data System (GDS) Maintenance

A. Maintain a OET-local (to the Orbiter Contractor) GDS,
B. Provide a small subset of the local GDS for in-flight OAS software maintenance and to support in-flight MRO ground software/hardware/network transitions,
C. Provide local system administration support,
D. Support the maintenance of data interfaces between MRO and Orbiter Contractor facilities,
E. Participate in the MRO System Administration and Configuration Management processes,
F. Participate in the MRO GDS delivery process,
G. Support MRO GDS software/hardware/network transitions,

3.2.8 Orbiter Engineering Facilities

A. Maintain facilities at the Orbiter Contractor site throughout the operations phase.

4.0 Acronym List

ACS Attitude Control Subsystems
ATLO Assembly, Test, Launch Operations
CDR Critical Design Review
DSMS Deep Space Mission System
DSN Deep Space Network
GDS Ground Data System
GFE Government Furnished Equipment
I&T Integration and Testing
JPL Jet Propulsion Laboratory
MRO Mars Reconnaissance Orbiter
MOI Mars Orbit Insertion
MOS Mission Operations systems
NAIF Navigation Ancillary Information Facility
NAV Navigation
ORT Operations Readiness Tests
OTB Orbiter Testbed
PDR Preliminary Design Review
PDS Planetary Data System
PI Principal Investigator
OAS Orbiter Analysis Software
OET Orbiter Engineering Team
TMOD Telecommunication and Mission Operations Directorate