Mars Atmosphere and Volatile Evolution Mission

Mission Operations Requirements

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MAVEN
CU/LASP • GSFC • UCB/SSL • LM • JPL

Attachment J

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1.0 Introduction

1.1 Purpose and Scope

The purpose of this document is to:

1. Provide an overview of the Mission Operations System (MOS) and Ground Data System (GDS),
2. Delineate the GDS development and operations roles and responsibilities among NASA's Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), the spacecraft contractor (Lockheed Martin Space Systems Company), the Science Operations Center (SOC) at the University of Colorado Laboratory for Astronomy and Solar Physics (LASP), and Instrument Teams, and
3. Form a contractual relationship between these project elements and GSFC by flowing MOS-GDS requirements to Lockheed Martin (LM), the SOC, and the Instrument Teams.

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 Lockheed Martin's operations support requirements including Spacecraft Test Laboratory (STL) and Orbiter Analysis Software (OAS) requirements.

2.0 Operations/MOS/GDS Overview

2.1 Organization

2.1.1 Development Organizations

The development of the MAVEN MOS-GDS will be a joint effort among GSFC and multiple external organizations, including the science investigators, the SOC, and Lockheed Martin. General development activities are:

- Defining the MOS-GDS architecture and operations concept
- Establishing the MOS-GDS implementation plans and requirements
- Developing the preliminary and detailed designs
- Integrating and testing the end-to-end MOS-GDS, verifying the intra- and inter-component data products, and performing compatibility testing between the MOS-GDS and the spacecraft and instrument payloads
- Training personnel on the operational use of MAVEN MOS-GDS components MAVEN and the processes and procedures to be used during mission operations

The development responsibilities by organization are defined as follows:

A. MAVEN MOS-GDS Development at GSFC
The MAVEN project will provide the leadership of the overall MOS-GDS development activities including all activities at GSFC, JPL, Science Investigator facilities, and Lockheed Martin (LM). The MAVEN Project Office will be responsible for the management, systems engineering and coordination, operations concept development, operations processes, system integration, and test and training functions. MAVEN will also use a subset of existing services provided by JPL's Interplanetary Networks Directorate (IND) with minimal modification. The IND shall provide services to the MAVEN project based upon a set of negotiated requirements documented in Section xx of the Mission Requirements Document (MRD, GSFC-xx-xxx). The services include telecommunication, navigation and tracking.

B. MAVEN MOS-GDS Development at each Instrument Institution
Each Co-Investigator institution shall be responsible for the development of required science operations and data analysis capabilities, including hardware, software, facility, and procedures. Co-Investigator facility science operations procedures and data interfaces will be consistent with the overall MOS-GDS procedure and standard interfaces

C. MAVEN MOS-GDS Development at the Science Operations Center (SOC)
The SOC at the University of Colorado LASP will be responsible for development of required capabilities to receive, monitor, and display telemetry; monitor data quality and instrument status; build instrument operations timelines; transmit instrument command sequences for load generation and uplink; produce Level 0 and Level 1 science datasets; and transfer data to the Instrument Teams. This includes all hardware, software, facility, and procedures required to perform the above.

D. MAVEN MOS-GDS Development at Lockheed Martin (LM)
LM will be responsible for the development, verification, validation, and delivery of the OAS, STL, spacecraft operations tools, command and telemetry dictionaries, flight rules, spacecraft and payload operations procedures, contingency scenarios, and anomaly responses. LM will also support GSFC in the preparation and review of test sequences for Assembly, Test, and Launch Operations (ATLO) in addition to the flight sequences for use post-launch.

2.1.2 Operations Organizations

During operations, GSFC is responsible for leading MAVEN mission operations with support from the instrument teams, JPL and LM.

A. MAVEN Project Office
The MAVEN Project Office at GSFC will provide leadership of the overall mission operations and mission operations management. Specific functions

provided by the MAVEN Project include, but are not limited to, mission management, mission planning, and mission design.

B. JPL
JPL will support the MAVEN Project Office in the area of mission design and navigation

C. Instrument Institutions
MAVEN science operations at the instrument provider's home institution include items such as science command request generation, high-level data product generation, and analysis.

D. Science Operations Center (SOC)
The SOC will be responsible for integrating instrument-specific command operations into a cohesive Science Observing Plan, providing data to the Instrument Institutions for use in high-level data product generation, and monitoring instrument status by tracking limit violations, alarms, and alarm responses

E. Lockheed Martin (LM)
LM will perform spacecraft mission operations and provide engineering support including trend analysis, anomaly investigation and recovery, monitoring of spacecraft health and status, performance calibration, and command sequence generation and uplink.

2.2 Timeline & Activities

2.2.1 Development Phase

A series of MOS-GDS activities will occur during the development phase for procuring and developing the hardware and software to prepare the ground segment for operations. This includes the MOS, spacecraft simulators, and associated elements of Mission Support Area (MSA) and STL infrastructure. LM will perform all preparations for MAVEN mission operations including the development of plans, procedures, databases, and the implementation of training and Operations Readiness Tests (ORT):

A. MOS-GDS Organization Definition and Implementation Planning
MOS-GDS development will be coordinated by GSFC and performed by the investigator teams, the SOC, and LM. Staff positions and operations team roles and responsibilities will be defined. The operations concept will be developed and plans for implementation of the MOS-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 as defined in the Mission Requirements Document (MRD, MAVEN-PM-RQMT-0005) and the Mission Plan (MP, GSFC-xx-xxxx). The requirement flow-down will include the distributed MOS-GDS, capabilities and services provided by the Deep Space Network (DSN), and the deliverables and support provided by the SOC, LM and Instrument teams.

Consistency and compatibility of requirements among individual MOS-GDS components as was well as the spacecraft shall be ensured. Requirements will be established to maximize the use of and compatibility with existing flight and ground hardware, software, and procedures

C. MOD-GDS Design and Development
System and subsystem designs will be established that satisfy the requirements for the MAVEN MOS-GDS. Architectural trade studies and detailed analyses will be conducted to establish the ground system and subsystem designs necessary to perform MAVEN mission operations. Project-unique designs, mission interfaces, DSN services, payload teams, and LM deliverables and support will be integrated into the overall MOS-GDS system. Designs will be reviewed at the project Preliminary Design Review (PDR) and Critical Design Review (CDR).

D. Mission Planning and Sequence Development
Detailed flight sequences will be generated to support the activity as required by the GSFC Mission Plan (MP, GSFC-xx-xxx). Sequences will be run extensively during spacecraft and mission compatibility tests with the MOS-GDS prior to and during mission operations.

E. I&T/ATLO Support
This activity includes GDS deliveries to support flight software integration tests, STL tests, and ATLO activities. The STL will be utilized during ATLO activities for testing of mission scenarios and flight sequences, as well as for the training of personnel and the development of fault responses and contingency plans.

F. MOS Test and Training
The MAVEN MOS-GDS will be exercised extensively prior to launch using nominal and fault-injected operations scenarios. Test cases will include representative mission activities and all mission critical events. Spacecraft-MOS compatibility testing will be used to help train operations personnel.

2.2.2 Operations Phase

This phase technically begins with initial post-launch acquisition of the MAVEN spacecraft, though the mission operations team will also monitor the spacecraft configuration via pre-launch telemetry flow. The details of the operation activities and timeline are documented in the Mission Plan (MP, GSFC-xx-xxxx). The operations phase includes spacecraft and instrument post-launch check-out, activation, Trajectory Correction Maneuvers (TCM), Mars Orbit Insertion (MOI), primary mission science, relay operations, in-flight anomaly investigation and anomaly resolution management.

In addition to the mission-critical and one-time events mentioned in the preceding paragraph, day-to-day operations and maintenance activities including configuration management, resource management, testing and training for future events, and MOS hardware and software maintenance are part of the operations phase activities.

2.3 MOS-GDS Architecture

The GDS element of the MOS-GDS consists of all hardware, software, facilities and networks that support the distributed team in accomplishing MAVEN operations, from telemetry acquisition to science data processing and high-level product generation. The MOS element includes the specific hardware and software for conduct of the core command and control activities including spacecraft and instrument command integration; command uplink; data downlink; housekeeping telemetry decommutation; real-time health and safety monitoring; spacecraft and instrument trending and performance analysis; data storage and management; data distribution; navigation; science data processing and data archival; and the mission archive of downlinked housekeeping telemetry. The operations teams and support personnel responsible for performing the described activities are also considered to be a component of the MOS-GDS.

Figure 1 below provides a functional block diagram of the MOS-GDS facilities.

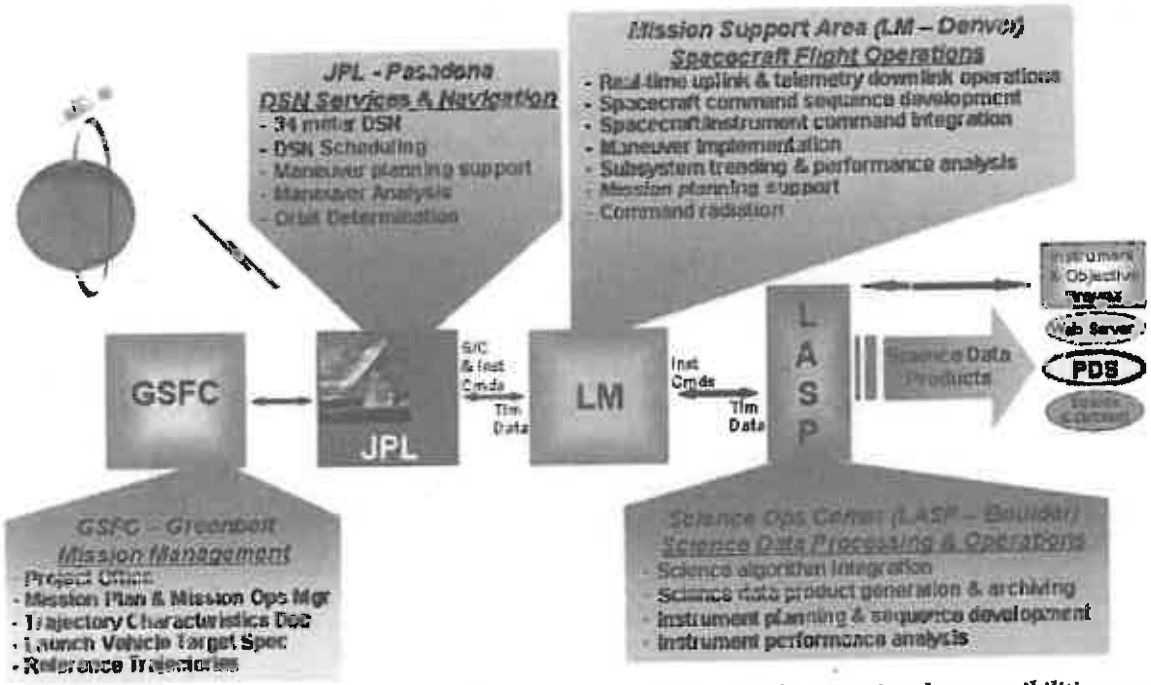

***Figure 1.** The MAVEN MOS-GDS is a distributed system in which specific operational responsibilities are allocated to the partner institution at which key expertise in the specific discipline is concentrated.*

The team structure and flight support architecture of the MOS-GDS organization will be as follows:

A. Mission Management and Systems Engineering
   a. Manage overall mission operations activities to include all participants
   b. Coordinate detailed activities among all teams
   c. Coordinate observation and mission resource usage

B. Spacecraft Engineering
   a. Operate and manage all spacecraft engineering activities
   b. Analyze telemetry for spacecraft health and status
   c. Maintain on-board flight software
   d. Anomaly resolution planning and implementation
   e. Operate the STL to validate engineering sequences and commands

C. Mission Planning, Sequencing, and Execution
   a. Plan mission activities
   b. Develop and integrate spacecraft and instrument activities
   c. Generate sequences and commands for radiation and testing
   d. Operate the STL to validate integrated engineering and science sequences and commands

D. Navigation
   a. Determine and maintain spacecraft trajectory
   b. Plan and support implementation of maneuvers

E. Science Operations
   a. Monitor Instrument health and performance
   b. Plan instrument activities

F. Real-Time Operations
   a. Coordinate real-time mission activities
   b. Radiate commands and monitor real-time data systems

G. Data management
   a. Manage the science data processing and distribution systems
   b. Produce data products and perform data distribution function
   c. Archive science data products

3.0 Spacecraft Support Requirements

3.1 Spacecraft Development Requirements in Support of Mission Operations

3.1.1 Orbiter Analysis System (OAS)

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

a. Perform health and status analysis
b. Perform performance predictions and trending

c. Perform life prediction
d. Perform anomaly investigation of unpredicted performance
e. Generate spacecraft command requests

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

3.1.2 Spacecraft Testbed

Design, develop, integrate, document, certify, and deliver two (2) Spacecraft Test Laboratories (STL) that meet the following requirements:

A. STL Functionality
   a. Includes flight-functional-equivalent spacecraft processors, clocks and buses
   b. Executes spacecraft flight software (object code) without special modification
   c. Includes EM and software simulations for spacecraft subsystems, payloads and environment
   d. Supports timed software parameter modification and fault injection
   e. Supports bit-serial telemetry and command interfaces with Government-Furnished Equipment (GFE) telemetry and command system for testing
   f. Executes 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 spacecraft-clock time-tags
   h. Includes hardware/software infrastructure including racks, cables, power, GFE workstations, Graphical User Interface, MAVEN flight network access, database, and hooks for external models & external data input
   i. Includes editable start-up and initialization files and operating procedures
   j. Supports unattended operation during sequence execution
   k. Supports remote operations
   l. Supports closed loop dynamic simulation capability
   m. Supports redundancy management testing

B. STL Performance
   a. Supports real-time flight processor speeds
   b. Supports all flight-system command and telemetry rates
   c. Supports time jumps
   d. Includes sufficient on-line storage for all potential input and output data associated with ten 24-hour simulations
   e. The STL shall support flight-like spacecraft redundancy
   f. The STL 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, MOS-GDS development, ATLO test sequence validation, flight sequence validation and in-flight anomaly investigation

C. STL Operations
   a. Operate and maintain the STL, locally, beginning with pre-ATLO flight software integration
   b. Execute instrument provided sequences
   c. Configure and initialize the STL for MAVEN-specific simulations and anomaly investigations

3.1.3 Software Simulator

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

a. Provides flight-functional-equivalent capability
b. Executes spacecraft flight software (object code) without special modification
c. Includes software simulations for spacecraft subsystems, payloads, and environment
d. Supports timed software parameter modification and fault injection,
e. Supports compatible interfaces with GFE Telemetry and Command System for testing
f. Provides visibility into (and capture of) flight system command/telemetry activity and interface activity, with ASCII output options and formatted spacecraft-clock time-tags
g. Includes editable start-up and initialization files and operating procedures
h. Supports faster than real-time execution
i. Supports unattended operations during sequence execution
j. The Software Simulator shall be capable of executing on commercial workstations.

3.1.4 Spacecraft Operations Development

Provide Spacecraft operations development support as follows:

a. Provide a management lead for the spacecraft engineering support
b. Maintain an integrated schedule for all development and operational activities
c. Participate and present at Monthly Management Reviews
d. Provide a system engineering lead for spacecraft engineering support during development
e. Support MAVEN MOS-GDS requirements, design, development and reviews
f. Support MOS and facility requirements for Flight Operations Team (FOT) activities
g. Provide input to STL requirements
h. Develop Level 3 MOS-GDS requirements document

i. Provide input to the MAVEN MOS Test and Training Plan,
j. Provide a spacecraft operations handbook
k. Develop mission operations products (commands, blocks, sequences, and parameters) necessary to execute the mission as described in the Mission Plan (MP, GSFC-xx-xxxx)
l. Provide MAVEN MOS personnel with training regarding operational characteristics of the spacecraft
m. Support preparation, execution and analysis of tests associated with GDS deliveries, ATLO, Launch Operations, and Flight Operations including MOS-Spacecraft compatibility testing at LM and at KSC
n. Support preparation, execution and analysis of operations dataflow and Operations Readiness Tests (ORTs).

3.1.5 Ground Data System Development

Provide Ground Data System Development Support:

a. Develop a flight operations GDS at LM, including networks and software
b. Provide a subset of local GDS capabilities for in-flight OAS software development and to support in-flight MAVEN ground software/hardware/network transitions
c. Support the development of data interfaces between MAVEN and LM facilities
d. Participate in the MAVEN Systems Administration and Configuration Management processes
e. Participate in the MAVEN GDS delivery process
f. Provide GDS requirements for the flight operations GDS and OAS tools
g. Provide input to STL requirements
h. Provide a flight operations GDS design specification
i. Provide inputs to the MAVEN GDS Test Plan

3.1.6 Spacecraft Engineering Facilities

a. Provide facilities that meet the GSFC-xx-xxx Security Requirements for the flight operations 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 Spacecraft Operation Support Requirements

3.2.1 Spacecraft Engineering Management & Systems Engineering

A. Management

a. Provide a management lead for Spacecraft engineering support during Mission Operations
b. Maintain an integrated schedule for all development and operations activities,

c. Participate and present and Monthly Management Reviews

B. Systems Engineering

a. Provide a systems engineering lead for Spacecraft engineering support during mission operations

b. Support MAVEN MOS-GDS change assessment and review for requirements and design changes

c. Participate in MAVEN project activity reviews such as Mars Orbit Insertion (MOI) readiness review

C. Operations Report

a. Provide weekly Spacecraft engineering reports which summarize Spacecraft status and activities

b. Provide special summary reports for key spacecraft activities (e.g., Launch and Initial acquisition, Spacecraft and Instrument checkout, and MOI)

3.2.2 Spacecraft Engineering Operations

A. Spacecraft Performance Monitoring

a. Monitor status and perform trend analysis spacecraft subsystems, payloads, and the telecom link during prime shift and mission critical events

b. Maintain and provide spacecraft alarm limits and subsystem lead contact information to the MAVEN Mission Operations Manager

c. Respond to alarm conditions, both on-hours and off-hours, when notified of an alarm state

d. Monitor spacecraft telecom performance and telecom link performance

e. Monitor the execution of approved command sequences

f. Monitor on-board storage utilization, predict telecom link capability (in terms of supportable rates), and participate in the planning for telecom operations

g. Maintain Attitude Control Subsystem (ACS) parameters and catalogs and submit uplink requests

h. Maintain spacecraft flight software and software parameters

i. Participate in the MAVEN configuration management process

h. Operate and maintain the STL in support of activities included in the Mission Plan (MP, GSFC-xx-xxx) and other activities approved through Mission Change Request (MCR)

B. Anomaly Investigation & Management

a. Report suspected flight system anomalies to MAVEN systems engineering and the GSFC Mission Operations Manager

b. Investigate suspected spacecraft anomalies

c. Support the MAVEN anomaly management process, providing expert, on-call support for the investigation of suspected spacecraft anomalies as needed

d. Develop operational workarounds to compensate for degraded spacecraft capabilities.

3.2.3 Spacecraft Engineering Uplink

A. Submit spacecraft engineering uplink requests to the MAVEN 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 (at the spacecraft) of all ground commands, and input command accounting data to the MAVEN command tracking database

3.2.4 Spacecraft Engineering Downlink

A. Monitor downlink data transport performance and participate in accounting of receipt of telemetry packets,
B. Retrieve telemetry packets and engineering channels for the MAVEN telemetry database, as input to spacecraft engineering functions

3.2.5 Spacecraft Navigation and Maneuver Operations

A. Provide prediction of spacecraft thruster events (Delta-V vector and epoch) for all maneuvers to the JPL navigation team based on a combination of spacecraft configuration and operating characteristics/plans
B. Provide actual spacecraft thruster events (Delta-V vector and epoch) for all maneuvers to the JPL navigation team based on spacecraft engineering telemetry
C. Provide predicted maneuver performance/profile data to the JPL navigation team based upon maneuver requirements (delta-v) from the JPL navigation team
D. Generate uplink requests for execution of approved propulsive maneuvers
E. Provide reconstructed maneuver performance/profile data to the JPL navigation team based upon analysis of the engineering team
F. Generate uplink requests for execution of approved attitude maneuvers
G Provide reconstructed spacecraft attitude (quaternion) to the JPL navigation team

3.2.6 Spacecraft Engineering Databases

A. Local flight operations database – Populate and maintain a local database containing all required products including:
  a. Uplink requests and commands verified
  b. Spacecraft engineering channels (retrieved from MAVEN telemetry database)
  c. Key spacecraft performance analysis products

B. Inputs to MAVEN operations database – Populate and maintain spacecraft engineering portions of the MAVEN operations database including:
  a. Command and Telemetry Definitions, Schema and Maps
  b. Standard Spacecraft activity, sequence or block definitions
  c. Flight rules
  d. Key operational spacecraft parameters and constraints
  e. Telemetry alarm limits
  f. Spacecraft UTC time correlation

3.2.7 Ground Data System (GDS) Maintenance

A. Maintain a flight operations-local GDS
B. Provide a small subset of the local GDS for in-flight flight operations software maintenance and to support in-flight MAVEN ground software/hardware/network transitions,
C. Provide local system administration support
D. Support the maintenance of data interfaces between MAVEN and LM facilities
E. Participate in the MAVEN System Administration and Configuration Management processes
F. Support MAVEN GDS software/hardware/network transitions

3.2.8 Spacecraft Engineering Facilities

A. Maintain operations facilities at LM throughout the operations phase