Wake Cycle Robustness of the Mars Science Laboratory Flight Software

Jet Propulsion Laboratory

California Institute of Technology

Space Grant

Robert Whitehill

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Robert Whitehill

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Danny Lam, Project Mentor

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Acronyms

ELT	Electra-Lite Transceiver
FSW	Flight Software
IMU	Inertial Measurement Units
IPA	Integrated Pump Assemblies
JPL	Jet Propulsion Laboratory
LCC	Load Control Card
MCA	Motor Control Assembly
MSL	Mars Science Laboratory
PAM	Power Analog Module
RCE	Rover Compute Element
REU	Remote Engineering Unit
SDST	Small Deep Space Transponder
SSE	Support and Simulation Equipment

Introduction

The Mars Science Laboratory (MSL) is a spacecraft being developed by the Jet Propulsion Laboratory (JPL) for the purpose of in-situ exploration on the surface of Mars. The objective of MSL is to explore and quantitatively assess a local region on the Martian surface as a habitat for microbial life, past or present. This objective will be accomplished through the assessment of the biological potential of at least one target environment, the characterization of the geology and geochemistry of the landing region, an investigation of the planetary process relevant to past habitability, and a characterization of surface radiation. For this purpose, MSL incorporates a total of ten scientific instruments for which functions are to include, among others, atmospheric and descent imaging, chemical composition analysis, and radiation measurement.

The Flight Software (FSW) system is responsible for all mission phases, including launch, cruise, entry-descent-landing, and surface operation of the rover. Because of the essential nature of flight software to project success, each of the software modules is undergoing extensive testing to identify and correct errors.

Background

Of particular interest to the flight software test team is the wake cycle robustness of MSL software to changes in hardware state configurations. Because the wake cycle response of MSL software is a direct function of rover hardware state and health information, this data is stored in on-board, non-volatile memory banks before the rover enters sleep. During wake activities, the last known state of each hardware element is read and compared to the expected state. In the case of off-nominal configuration scenarios, FSW invokes fault response scripts and/or safing commands to preserve MSL integrity.

Hardware elements that directly influence wake cycle activities include the Power Analog Modules (PAM), the Rover Compute Elements (RCE), Small Deep Space Transponders (SDST), and Electra-Lite Transceivers (ELT).

Ideally, wake cycle testing could take place on one of the MSL hardware test beds; however, because of budget and time constraints a Work Station Test Set (WSTS) has been developed to allow many individuals the ability exercise simulated functionality. For this reason, Simulation and Support Equipment (SSE) commands may be issued to the WSTS environment to artificially place the rover in any configuration. The SSE command dictionary is rather extensive; however, there are limitations to its functionality that will be discussed in subsequent sections of this report. Fortunately, a majority of the desired simulation functionality for this investigation is accessible through SSE commands that manipulate hardware registers and memory banks.

That is, via direct interaction with hardware registers and memory, at the bit level, it is possible to configure rover elements to simulate a desired scenario. In addition, several SSE commands are available that indirectly configure rover elements such as power and relay switches.

In addition, there exists element information that is not accessible through SSE commands, specifically, the health state of individual elements. Each of the elements considered in this study may be thought of existing in one of the following health states: healthy, sick, dead, or suspect. This information is stored in rover non-volatile memory

Scenarios considered in this study include any combination of the following elements in any of the listed state and/or health conditions.

Remote Compute Element

There exists two RCEs onboard MSL, a preferred and a secondary. An RCE is, in the simplest term, the flight computer. This being said, the RCEs onboard MSL are specially developed for space operations and protected against the associated dangers of operating in harsh conditions, i.e. – radiation, extreme temperatures, etc.

Originally, the pair of RCEs was designed to operate in concert; however, mission requirements proved individual operation a more advantageous configuration. Designation of RCE preference is made through bit manipulation of the Power-Management Power-On-Enable Register

Power Analog Module

Two elements of particular importance to wake activities inside each PAM are the Remote Engineering Unit (REU) and the Load Control Cards (LCC). Power commands are generated via the REU and distributed via the LCCs. For this reason, a PAM may be thought of as existing in one of the following health states: healthy, LCC-inhibited, REU-inhibited, or isolated. It is worth noting, there are system limitations to the possible combination of health and state information for each PAM. For example, a prime PAM cannot be isolated nor can both PAMS be REU inhibited.

Wake Type

There are a variety of wake methods available to the rover in an effort to provide flexibility during wake operations. Wake up types available to MSL include Cold Start, Primary Alarm expiration, Cross-String wakeup, Hail, Ground Support Equipment (GSE) wakeup, Under-voltage (UV) trip, and Backup Alarm expiration.

Each wake type initiates scripted response behavior to prepare MSL for activity. Examples of such actions include, but are not limited to, un-inhibiting the Load Control Card (LCC), turning on the preferred RCE, and resetting the primary alarm clock.

Small Deep Space Transponder

In an effort to ensure communication with the spacecraft throughout the duration of its mission, there is a SDST located on both the Cruise and Rover flight segments. Unlike many of the other elements on board, there is only one device per flight segement. During wake activities, the SDST is powered on to ensure communication channel is established. Each SDST may be thought of as existing in one of the following health states: healthy or dead.

Electra-Lite Transceivers

The Electra-Lite transceiver is a UHF radio for the purpose of communication between MSL and orbiter relays (MRO and Odyssey). Similar to the SDST, it is powered on during wake activities to ensure a communication channel is established with rover. There is an A-side and B-side for redundancy purposes and they may be designated as prime or backup.

Objective

It is the intent of this investigation to provide confidence in the wake cycle robustness of MSL FSW to expected and unexpected changes in hardware states. A comprehensive collection of nominal and off-nominal configurations is to be generated to simulate potential wake cycle scenarios; however, an exhaustive collection of configurations is outside the scope of this study due to time considerations. Of particular interest to this investigation is the wake behavior of spacecraft elements during nominal cruise conditions, off-nominal rover conditions, and fault detection/response behavior scenarios.

In addition, the test team is to deliver a test environment for which the MSL FSW team is able to expand upon or modify for additional testing. Included in the test harness are the necessary scripts to parse the desired input configuration, initialize flight software, extract the output configuration, and report anomalies.

A successful investigation will yield no unexpected behavior in the flight software *or* will indentify one or more problems with the wake cycle for which action must be taken.

Approach

Test scenarios are to be generated through a series of simulation commands chosen to model a desired hardware configuration. Flight software will utilize the command list during the wake cycle to introduce modified hardware values to what may be considered a nominal system. Resultant state parameters may be checked against the expected values in an effort to identify unexpected software behavior.

In an effort to validate the test suite is functioning properly, a collection of well-documented scenarios are to be tested. For this purpose, approximately 1000 cruise configurations are generated with a wide variety of PAM health states, wake types, and instrument settings.

Pending successful completion of the nominal test cases, more elaborate, off-nominal configuration scenarios may be considered. Note: for the nominal test cases only, a successful test will be one which yields *no* unexpected behavior in the flight software.

Off-nominal is a rather broad qualifier when considering complex systems such as MSL. For the purpose of this investigation, off-nominal may be considered any configuration for which FSW recognizes an unexpected state and performs corrective actions to safe the vehicle or continue operation. Approximately 50 test scenarios will be generated that examine FSW response to dead-prime PAM units. An additional 50 test scenarios will be generated that examine FSW fault detection. Fault detection includes the recognition and response to scenarios such as an unexpected RCE swap, an REU-inhibited prime PAM, or UV alarm. For reference purposes, an example of an off-nominal input configuration, as accepted/read by the test suite is presented below.

scmode, cruise, cruise
wakeup, primary_alarm
RCEpreferred, b
RCEsecondary, a
rpama, backup, healthy, lcc_inhibited
dpama, prime, healthy, lcc_inhibited
cpama, prime, healthy, uninhibited
rpamb, prime, healthy, uninhibited
dpamb, backup, sick, lcc_inhibited
cpamb, backup, healthy, uninhibited
cipaa, prime, healthy
cipab, backup, healthy
dimua, prime, dead
dimub, backup, healthy
elta, prime, healthy
eltb, backup, healthy

Assuming a successful boot of FSW, the returned values for each device and instrument is compared to an expected value given scripted behavior is available. In addition, some scenarios require confirmation that certain actions were performed by FSW. For this purpose, the Event Report (EVR) log is examined automatically for specific reports.

In the case of off-nominal scenarios, a successful test may return discrepancies in the expected state of hardware elements if an examination indicates that it is the result of a limitation in the simulation software as opposed to a fault in FSW.

Results

As mentioned previously, the test suite is to be delivered to the FSW team for continued testing. For this reason, the results of this investigation will be an ongoing process for the life of MSL. This being said, approximately 97% of the scenarios considered in this study cleared testing with zero errors or discrepancies in the expected behavior.

Of the approximately 3% that failed with one or more errors or discrepancies, it is hypothesized that continued investigation will reveal the causality is a function of the limitations in the simulation software.

In addition, the test environment was successfully merged with the MSL FSW directory for 'checkout' by other developers. This allows individuals to access and utilize the test suite to perform continued testing.

Conclusion

The results of this investigation are successful in increasing the confidence of FSW robustness during the wake cycle; however, as mentioned previously, there are some cases for which continued investigation is suggested. For this reason, a special test vector has been generated which contains configurations which failed testing but under suspicious circumstances. It is assumed at this time that FSW failure of these scenarios is a function of limitations in simulation software as opposed to flight software.

The test suite is available to MSL FSW developers for which this investigation team suggests continued study of the boot cycle be performed. Furthermore, because of the relatively lengthy test duration of even a single scenario (5-6 minutes), completing a test vector of thousands of configurations typically takes several days. For this reason, the test team suggests the utilization of one of the JPL supercomputers or computing clusters for a reduction in test time.

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