Mars Exploration Rovers: Engineering Lessons Learned

Christopher Malow[1], Mr. David Lavery[2], Dr. Catherine Weitz[3]
[1] University of Virginia, Charlottesville, VA
[2] Mars Program Office, NASA Headquarters, Washington, DC
[3] Mars Program Office, NASA Headquarters, Washington, DC

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Mr. David Lavery *Dr. Catherine Weitz*
Dr. James Garvin *Virginia Space Grant Consortium*
University of Virginia Institute for Practical Ethics

Abstract

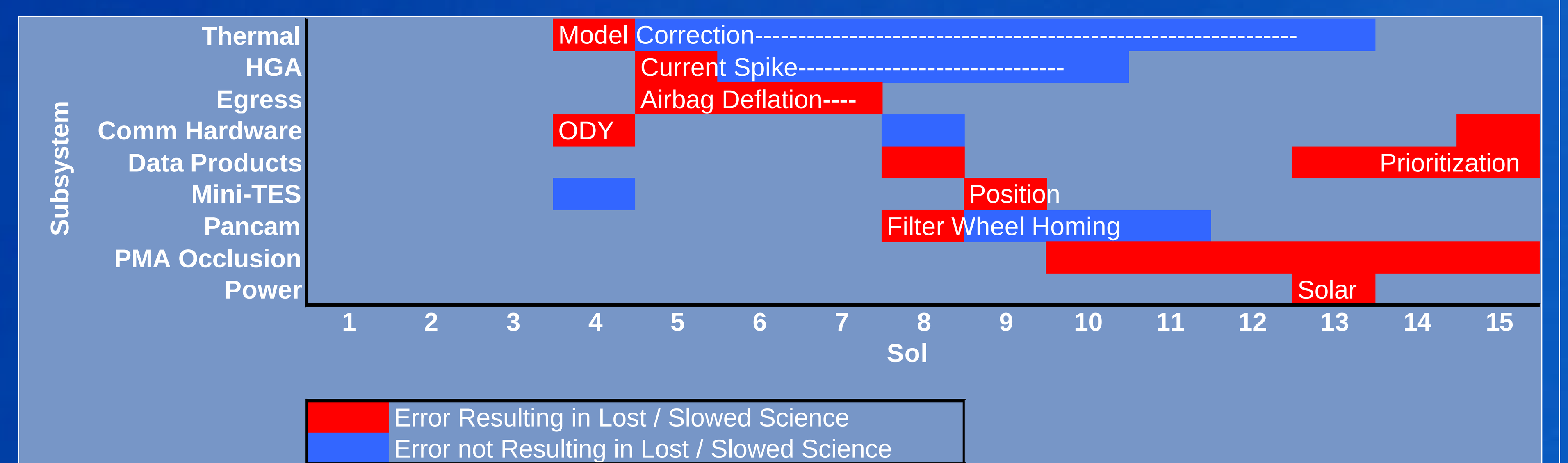
The Mars Exploration Rovers (MER) Spirit and Opportunity continue to operate beyond their expected lifetimes. Just as this extended operation increases the amount of science data gathered in the mission, more engineering data is gathered as project engineers confront and resolve engineering problems during operation. The lessons learned from resolving these engineering problems are important in designing future Mars missions, particularly the 2009 Mars Science Laboratory. This project will report the causes of these engineering problems, how they were resolved, and how this information might be applied to future Mars missions.

Research Method and Personal Contributions

In order to assess the magnitude of engineering problems and identify trends in the occurrence of engineering problems during the course of the Mars Exploration Rover missions, engineering problems will referenced to engineering subsystem and plotted for each Martian day. The sample time distribution chart at right shows the first fifteen days of the MER A: Spirit mission. Errors that resulted in a significant loss of science data or slowed the rover science mission on that day are indicated in red, while other errors that required the attention of the engineering team are indicated in blue.

Daily engineering information has already been gathered and compiled in the Daily MER Downlink reports assembled by the Jet Propulsion Laboratory. Engineering problems and daily concerns are not isolated from other operations information in these reports, so personal contributions to the project involve reviewing and analyzing the information contained in the Daily MER Downlink reports to identify engineering problems and lessons learned.

Time Distribution of Early MER A Engineering Problems by Subsystem



Thermal Systems

- MER instrument temperature must be carefully monitored
- Thermal systems engineers use heat transfer models to predict instrumentation temperature and plan activities
- Initial ambient temperature was 10 C higher than expected for Spirit, requiring extra precautions
- Initial temperature measurements did not match heat transfer model predictions

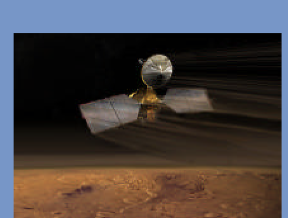
The thermal model was improved with four additional factors:

1. **Lander Effect** – Used Lander temperature profile instead of ground temperature profile
2. **Wind Effect** – Added continuous wind speed to model
3. **Tau Effect** – Tau value was higher than predicted, reducing atmosphere maximum temperature and increasing atmosphere minimum temperature
4. **CO_2 Effect** – Insulation effect of CO_2 gas between REM and Mini-TES

Improved thermal model allows engineers to plan activities that will not overheat the science subsystems

Application to Future Missions

2005 Mars Reconnaissance Orbiter



Comm Hardware, Data Products, Power

2007 Phoenix Scout

Thermal, HGA, Comm Hardware, Data Products, Power

2009 Mars Science Laboratory

All Subsystems

Communications Failure Chronology

The most visible engineering error in the Mars Exploration Rover mission began on Sol 18 and continued for eleven days before the Spirit rover returned to normal operation:

Sol 18 – Uplink and downlink information is not received and high-priority communications window receives no data.

Sol 19 – Multiple attempts to establish communication through commanded and fault communications windows fail, but the ability to command is established when a response beep is received from the rover.

Sol 20 – Demonstrated modulation and received an update packet from the rover.

Sol 21 – Engineers successfully boot the system into "crippled" mode, placing the rover in a low-power standby state.

Sol 22 – Rover communications indicate that repeated system resetting created backlog of flash data.

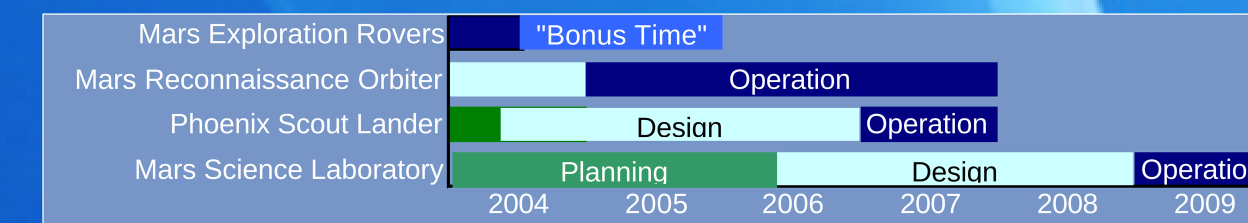
Sol 23 to 27 – Portions of flash system are dumped to enable further communications, and a task trace of rover commands is completed.

Sol 28 – Normal communications pattern is re-established

Sol 29 – Return to normal operations

The communications failure and its subsequent recovery demonstrated the importance of maintaining communications system health, the difficulty of clearing backlogs of data, and the durability of the rover emergency systems.

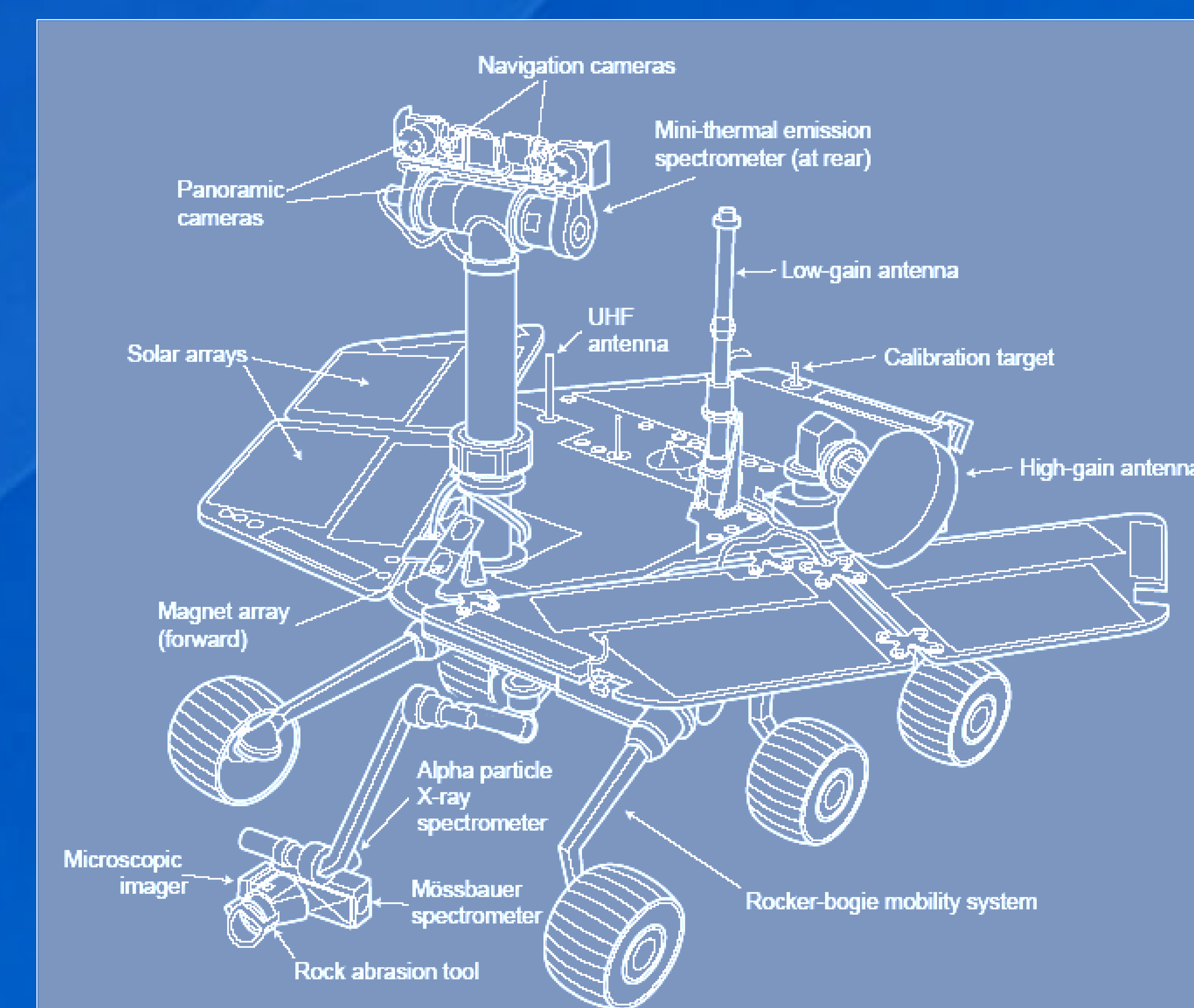
MER "Bonus Time" Overlaps with Future Mission Planning



As the operation of the Mars Exploration Rovers is extended, the amount of engineering information gathered continues to grow. At the same time that this pool of engineering information is growing, however, the amount of time to review this information and apply it to future Mars robotic missions decreases. In particular, the 2005 Mars Reconnaissance Orbiter, the 2007 Phoenix Scout Mission, and the 2009 Mars Science Laboratory can all use the engineering lessons learned from the Mars Exploration Rovers in planning, design, or operations phases. Continued MER operation also leaves less resources available to review this engineering information.

Mars Exploration Rover Subsystem Layout

The diagram below shows the layout of science and engineering subsystems on the Mars exploration rovers. The positioning of the high-gain antenna behind the pancam mast assembly is particularly important because occlusion from the assembly decreased the performance of the communications antenna.



Future Work

- Complete review of mission manager's reports for all available downlink reports and identify all major engineering problems encountered to date
- Investigate the causes and resolution of these engineering problems, using daily subsystem reports as necessary
- Identify trends in the occurrence of engineering problems and prioritize engineering problems based on relevance to future missions
- Apply this engineering knowledge to future missions such as the 2009 Mars Science Laboratory
- Report relevant information in an MER Engineering Lesson Learned document