Making Tracks on Mars
Mission Operations for Deep Space

Andrew Mishkin
Jet Propulsion Laboratory,
California Institute of Technology

January 11, 2006
Mars Science Microrover
Mars Science Microrover Technology Demonstration

- Mars mission issues addressed:
  - Communications time delay
  - Limited bandwidth
From technology demonstration to flight project…

- **Bandwidth**
  - Spacecraft have energy to downlink data only at very low rates (10’s to 1000’s of bits per sec)
- **Time delay**
  - Distances are so great that real-time interaction with spacecraft is impossible
- **Resource constraints: Mass, volume, power**
- **Schedule: “The planets don’t wait”**
- **Reliability: It’s got to work**
- **Limited communications opportunities**
  - Deep Space Network availability, planetary geometries, spacecraft resources or orientation all limit when communication is possible
- **Operability challenges**
  - Tensions between development constraints and operations needs
Characteristics of deep space robotic mission operations

- Direct teleoperation infeasible
  - Some degree of onboard autonomy required
- Reliance on stored sequences
  - Commands comprising all spacecraft activities for an extended period must be uploaded at one time
  - Sequences developed methodically and rigorously over time (often weeks or months)
  - Sequences carefully validated in testbed
- Rule #1: Don’t kill the spacecraft!
  - Spacecraft are severely resource-limited
  - Command errors are potentially mission-ending
  - No repairman in sight
- Onboard resources must be continuously managed
  - Energy
  - Thermal state
  - Data volume (onboard storage and downlink capacity)
  - Communications opportunities
- Limited visibility into spacecraft state
New Challenges for Mars Rover Missions

• Most robotic deep space missions allow for days or weeks to generate command loads
  – Long cruise phases punctuated by planetary encounters
  – Well-modeled trajectories
  – Known command execution durations
  – High cost to sequencing errors: usually no opportunity to recover missed observations

• Mars rover surface operations must be reactive, not pre-canned
  – Plans for tomorrow are contingent on the outcome of activities performed today
  – Operators must be able to respond to new information and discoveries
  – Results of planned rover traverse and instrument interactions with terrain are far from certain
    • Environment is poorly modeled
    • Duration of terrain interaction activities may be uncertain
    • Rover position at end of traverse will often not be exactly as desired
  – Feasibility and safety of instrument placement dependent on precise position of rover relative to target
  – Requires compressed command turnaround process and every day commanding
Mars Pathfinder and Sojourner

• **Pathfinder Mission Objectives**
  – Land on Mars in one piece
  – Take one set of observations
    · “Mission Success Panorama”
  – Deploy rover
  – Survive 30 days (prime mission)

• **Rover objectives**
  – Collect one APXS spectrum of soil
  – Collect one APXS spectrum of rock
  – Take one set of observations using suite of onboard technology experiments
    · Wheel Abrasion Experiment
    · Material Adherence Experiment
  – Image lander for engineering assessment
  – Survive 7 days
Sojourner Mission Operations
• Much more ambitious mission objectives
• Science-driven mission
• Increased complexity
  – MER would integrate rover and lander functions into a single spacecraft
• Like Pathfinder, MER would need to command every Martian day
# MER Mission Success Scorecard

<table>
<thead>
<tr>
<th>Mission Success Criteria</th>
<th>MER-A Status</th>
<th>MER-B Status</th>
<th>Minimum Mission Success Achieved?</th>
<th>Full Mission Success Achieved?</th>
</tr>
</thead>
<tbody>
<tr>
<td># Sols of Operation</td>
<td>80</td>
<td>71</td>
<td>Yes</td>
<td>[1x90 t=0.5]</td>
</tr>
<tr>
<td># Sols of simultaneous operation</td>
<td>71</td>
<td>71</td>
<td>N/A</td>
<td>Yes [30]</td>
</tr>
<tr>
<td>360 deg color panorama</td>
<td>3</td>
<td>1</td>
<td>Yes</td>
<td>[One MER]</td>
</tr>
<tr>
<td>360 deg Stereo panorama</td>
<td>3</td>
<td>1</td>
<td>Yes</td>
<td>[One MER]</td>
</tr>
<tr>
<td>Image of rock</td>
<td>2</td>
<td>1</td>
<td>Yes</td>
<td>[One MER]</td>
</tr>
<tr>
<td>Complementary analysis of rock</td>
<td>1</td>
<td>1</td>
<td>[One MER, 1 instr.]</td>
<td>N/A</td>
</tr>
<tr>
<td>Freshly exposed rocks (RAT)</td>
<td>1</td>
<td>4</td>
<td>Yes</td>
<td>[Both MERs]</td>
</tr>
<tr>
<td>Image of freshly exposed rock</td>
<td>1</td>
<td>4</td>
<td>Yes</td>
<td>[Both MERs]</td>
</tr>
<tr>
<td>Complementary analysis of freshly exposed rock</td>
<td>1</td>
<td>4</td>
<td>Yes</td>
<td>[Both MERs]</td>
</tr>
<tr>
<td># Locations Investigated</td>
<td>11</td>
<td>3</td>
<td>Yes</td>
<td>[4]</td>
</tr>
<tr>
<td>Drive distance (m)</td>
<td>638</td>
<td>259</td>
<td>Yes</td>
<td>[300, One MER]</td>
</tr>
<tr>
<td>MER/MEX Demo (Forward)</td>
<td>1</td>
<td></td>
<td>Yes</td>
<td>[One MER]</td>
</tr>
<tr>
<td>MER/MEX Demo (Return)</td>
<td>1</td>
<td></td>
<td>Yes</td>
<td>[One MER]</td>
</tr>
<tr>
<td>Athena Payload Operation</td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Prepared by Jan Ludwinski
Date: 4/6/04

- N/A - Awaiting final confirmation/analysis

[Image of a table showing the mission success scorecard for MER mission with various criteria and status details, along with yes/no indicators and numbers for each category.]
Drivers on Design of MER Surface Operations (1)

- Presumed 90 sol lifetime for each rover
  - Rover is a wasting asset with limited time to accomplish specified objectives
- Two rovers must be operated simultaneously
- Critical telemetry to be fed through afternoon X-band session, with most non-critical telemetry relegated to UHF due to presumed latency
  - Critical telemetry defined as that data needed to plan the next sol
  - Some data not critical today may become critical tomorrow
  - Operational experience with ODY link eventually made reliance on UHF for critical telemetry commonplace
Drivers on Design of MER Surface Operations (2)

• Development Assumptions
  – One out of three sols is “margin”: operations scenarios assume that sols will regularly be lost due to inability to get a command load onboard (e.g., process or communications issues)
  – MER-A and MER-B tactical teams will be independent
  – MER strategic team will be integrated
  – Minimum mission success must be achievable under relay-only or X-band only scenarios
  – Rovers will support event-driven sequencing
  – Rover shuts itself down on a regular basis
  – Rover has robust communications response even in event of fault conditions
  – Rover is capable of limited conditionality
MER Prime Mission: Living on Mars Time

- MARS -
  MER-A 10:51:26 Sol 473
  MSD 46687.994
  23:51:22 MTC
  MER-B 22:50:17 Sol 452
  Ls 203.99°
  Early SH Spring

- EARTH -
  00:10:51 UTC 2005-123
  MJD 53493.008
  17:10:51 PDT 2005-122
  Light Dist. 11:26 min
Surface Operations Processes

- Surface operations divided into strategic and tactical processes:
  - Strategic multi-day planning and coordination (not tied to Mars cycle)
    - Mid- and long-range scenario development
    - Communications planning
    - Inter-mission coordination
    - Mission Success tracking
    - Model updates
    - DKF generation
  - Tactical “overnight” commanding (driven by Mars clock)
    - Time-critical science and engineering data product generation
    - Generation of individual sol activity plan
    - Rover traverse and IDD planning and sequencing
    - Activity plan review and approval
    - Science instrument sequencing
    - Rover engineering/housekeeping sequencing
    - Comm window updates
    - Command review and approval
Why Work Mars Time?

• Provides maximum number of workhours between afternoon downlink and morning uplink
  – Provides opportunity for teams (which will inevitably be insufficiently-trained at landing) to get up the learning curve

• Key spacecraft and ground events are tightly coordinated
  – Sol n afternoon downlink triggers uplink planning process (downlink analysis, science planning meetings, activity plan approval, command and radiation approval) which must complete in time for sol n+1 uplink
  – Spacecraft and ground activities happen at a consistent time on the Mars clock

• Personnel have clear understanding of when spacecraft events will occur
  – Easy to know what’s happening on Mars right now
When do I come into work?

- Shifts start 40 minutes later each (Earth) day
- Personnel generally worked 4 days on / 3 days off
- Mars watches were very popular…

<table>
<thead>
<tr>
<th>Name (Primary)</th>
<th>Name (Shadow)</th>
<th>Role</th>
<th>Day</th>
<th>Date</th>
<th>Time</th>
<th>PST</th>
<th>Sol #</th>
<th>LST-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mishkin</td>
<td></td>
<td>TUL1</td>
<td>Sat</td>
<td>1/3/04</td>
<td>5:36</td>
<td>AM</td>
<td>1</td>
<td>0:00:00</td>
</tr>
<tr>
<td>Dias</td>
<td>Fox, Kanef</td>
<td>TAP</td>
<td>Sat</td>
<td>1/3/04</td>
<td>3:52</td>
<td>PM</td>
<td>1</td>
<td>10:00:00</td>
</tr>
<tr>
<td>Maxwell</td>
<td></td>
<td>Rover Planner 1</td>
<td>Sat</td>
<td>1/3/04</td>
<td>7:26</td>
<td>PM</td>
<td>35</td>
<td>15:00:00</td>
</tr>
<tr>
<td>Kornfeld</td>
<td></td>
<td>SIE1</td>
<td>Sun</td>
<td>2/8/04</td>
<td>2:38</td>
<td>AM</td>
<td>35</td>
<td>22:00:00</td>
</tr>
<tr>
<td>Bonitz</td>
<td></td>
<td>Rover Planner 2</td>
<td>Sun</td>
<td>2/8/04</td>
<td>2:38</td>
<td>AM</td>
<td>35</td>
<td>22:00:00</td>
</tr>
<tr>
<td>Talley</td>
<td></td>
<td>TUL2</td>
<td>Sun</td>
<td>2/8/04</td>
<td>3:40</td>
<td>AM</td>
<td>35</td>
<td>23:00:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>START SOL36</td>
<td>Sun</td>
<td>2/8/04</td>
<td>4:41</td>
<td>AM</td>
<td>36</td>
<td>0:00:00</td>
</tr>
<tr>
<td>Mishkin</td>
<td></td>
<td>On-Call SIE</td>
<td>Sun</td>
<td>2/8/04</td>
<td>4:41</td>
<td>AM</td>
<td>36</td>
<td>0:00:00</td>
</tr>
<tr>
<td>Dias</td>
<td>Fox, Kanef</td>
<td>TAP</td>
<td>Sun</td>
<td>2/8/04</td>
<td>6:06</td>
<td>PM</td>
<td>36</td>
<td>15:00:00</td>
</tr>
<tr>
<td>Leger</td>
<td>Maxwell</td>
<td>Rover Planner 1</td>
<td>Mon</td>
<td>2/9/04</td>
<td>3:17</td>
<td>AM</td>
<td>36</td>
<td>22:00:00</td>
</tr>
<tr>
<td>Kornfeld</td>
<td></td>
<td>SIE1</td>
<td>Mon</td>
<td>2/9/04</td>
<td>8:06</td>
<td>PM</td>
<td>36</td>
<td>15:00:00</td>
</tr>
<tr>
<td>Wright</td>
<td></td>
<td>Rover Planner 2</td>
<td>Mon</td>
<td>2/9/04</td>
<td>3:17</td>
<td>AM</td>
<td>36</td>
<td>22:00:00</td>
</tr>
<tr>
<td>Talley</td>
<td></td>
<td>TUL2</td>
<td>Mon</td>
<td>2/9/04</td>
<td>4:19</td>
<td>AM</td>
<td>36</td>
<td>23:00:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>START SOL37</td>
<td>Mon</td>
<td>2/9/04</td>
<td>5:21</td>
<td>AM</td>
<td>37</td>
<td>0:00:00</td>
</tr>
<tr>
<td>Eelkema</td>
<td></td>
<td>SIE2</td>
<td>Mon</td>
<td>2/9/04</td>
<td>7:24</td>
<td>AM</td>
<td>37</td>
<td>2:00:00</td>
</tr>
<tr>
<td>Ghandchi</td>
<td></td>
<td>On-Call SIE</td>
<td>Mon</td>
<td>2/9/04</td>
<td>5:21</td>
<td>AM</td>
<td>37</td>
<td>0:00:00</td>
</tr>
</tbody>
</table>

- MER-A IST Staffing 2/7/04
- START TIME
- END TIME
- Earth Time
- Mars Time
- Name (Primary)
- Name (Shadow)
- Role
- Day
- Date
- Time
- PST
- Sol #
- LST-A
- Day
- Date
- Time
- PST
- Sol #
- LST-A
Why Not Work Mars Time?

• Although sustainable from a physiological perspective, incredibly disruptive of team members' personal lives

• Easily leads to fatigue-related symptoms

• What time is it on Earth?

• Who are those people living in my house making noise when I’m trying to sleep?
Opportunity: SOL 272 SKELETON -1.3 Ahr
Predicted Energy Margin
no deep sleep/2nd Switchback Drive
Thursday
Start End DUR CPU
HGA 22720 10:40:00 11:00:00 0:20:00
Eng Keepout/MTES 11:02 11:15 0:13
Comm Blip 11:04 11:09 0:05
Drive 11:15 11:45 0:30
visodom 11:45 13:15 1:30
Post drive imaging + Tau 13:15 14:00 0:45
Shutdown 14:00 0:09
NAP 14:00 16:44 2:44
VME on 0:06
ODY Mtes & Disable D.S. (e2023) 16:44 17:09 0:25
RUHF 42721 14:59:52 15:12:53 0:13
RUHF 42723 (30Mb) 16:52:32 17:08:45 0:16
Shutdown 17:12 0:09
NAP 17:12 3:36 10:23
Wakeup 0:14
RUHF 42730 (60Mb) 3:36 3:52 0:15
RUHF 42732 5:22 5:35 0:13
Shutdown 3:52 0:09
Wakeup 0:06
SA stomp- heating - cloud observation 8:00 8:45 0:45
Shutdown 8:45 0:09
Wakeup 0:06
AM Science (note: late HGA = longer science) 10:35 11:19 0:44
HGA 22730 10:59:59 11:19:59 0:20:00
## MER Nominal Surface Tactical “Overnight” Timeline at Landing

1/04

| Activity Name                              | Location | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|--------------------------------------------|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| UHF Passes                                 |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| DTE                                        |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Night Time Rover Operations                |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sleep                                      |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Pre-Comm Session Sequence Plan Reviews     |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sol n-1 Day Sequence Plan Review          | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Science Sol n Context Meeting             | 264-450  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sol n-1 Night Sequence Plan Review        | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Real-Time Monitoring                      | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Downlink Product Generation...            |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Tactical Science Assessment/Observation Planning | 264-450  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Science DL Assessment Meeting             | 264-450  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Tactical End-of-Sol Engr. Assessment      | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Engineering Skeleton Activity Plan Update | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Engineering Leads Tagup                   | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| DL/UL Handover Meeting                    | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| SCWG Meeting                              | 264-650  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Refinement / Sequence Assignment | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Selected Activity Expansion / Constraint Cleanup | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Carving                          | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Plan Integration & Validation   | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Plan Tagup                       | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Plan Product Generation          | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Activity Plan Approval Meeting            | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sequence Plan Design                      | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sequence Development                      | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Master/Submaster Walkthru                | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Integrate Sequences                      | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Command Product Generation               | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sequence Validation                      | Testbed   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sequence Review Product Generation       | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Review of Review Products                | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Command & Radiation Approval             | 264-425  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Margin                                    |          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sol n Radiation                          | SMSA     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

**Note:** All times in Mars hours
Working Mars Time Early in the Mission

- **Operations at landing**
  - ~18 hour turnaround time
  - 3 shifts per sol (1 “downlink” shift, 2 “uplink” shifts)
  - Minimum of 4 personnel trained for each position
    - 2 rovers x 7 day support
  - In some cases, 8 personnel per uplink position
    - 2 rovers x 7 day support x 2 shifts

- **Team Roles**
  - Mission Manager (2)
  - Science Operations Working Group Chair
  - Tactical Uplink Lead (2)
  - Tactical Activity Planner
  - Rover Planner (2)
  - Sequence Integration Engineer (2)
  - Payload Uplink Leads (for each instrument)
  - Uplink Verification Lead (2)
  - Tactical Downlink Lead
  - Science Uplink Rep.
  - Subsystem Engineers
  - Flight Director
  - ACE
Sample Issues for Planning a Sol

Tactical Operations Technical Challenges

- How choose rock?
- Plan within rover resources?
- Complexity of plan within human resources?
- Instrument conflicts w/UHF comm
- Traverse plan safe?
- Target in IDD (rover arm) workspace?
- Trade comm pass for science?
- Critical data fits into downlink?
- Turn rover for comm feasible?
- Position rover to maximize solar energy?
- Enough energy for next sol?
Kicking Off the Process

- Rover finishes its critical activities (e.g., driving, post-drive imaging, instrument placement) by mid-afternoon, Mars local time (LST)
- Rover transmits critical telemetry direct-to-Earth for an hour or more (~1300 - 1500 LST)
- Key downlink products (including corrected images and terrain meshes) generated within ~30 minutes of end of downlink
- Engineering downlink assessment complete by 1800 LST
  - Identify any rover state issues impacting the nominal planning process
- Science downlink assessment complete and competing proposed observations defined by 1800 LST
Science Activity Planning
(1800-2000 Mars LST)

Science Operations Working Group Meeting
- Led by SOWG Chair
- Competing science activity proposals integrated into tentative plan
- Resources (time, energy, data volume) estimated
- Priorities for uplink and downlink specified
- Feasibility assessed by engineering team (MM, TUL, Rover Planner, TAP, SIE)
Science Activity Planner (SAP)

- Used primarily by science team members and instrument sequencers (PULs) to:
  - Specify science activities and their priorities
  - Designate science targets
  - Estimate data volume and duration for activities
TAP (Tactical Activity Planner) generates validated activity plan
- Activity constraints defined in Constraint Editor
- MAPGEN tool incorporates automated scheduler, high fidelity resource models
- TAP schedules activities, may delete activities as necessary
- Integrated plan includes rover wakeups, shutdowns, comm sessions, science and engineering activities
Activity Plan Approval Meeting
(0000 - 0045 LST)

- Review final plan
  - Consistency of implemented plan with original science intent
  - Resources
    - Battery energy
    - Data volume acquired, stored in flash, downlinked
    - Critical data
    - etc.
  - Warnings/errors
- Review rover motion plan
- All review products online
Rover Motion Planning & Sequencing
(2000 - 0230 LST)

- Rover Planners plan rover activities and generate motion sequences
  - Assess feasibility of activity, modify if necessary
  - Provide resource estimates to TAP during activity planning
  - Perform all tasks in RSVP (Rover Sequencing and Visualization Program)
  - Simulate all rover motion in RSVP
All sequence builders (Rover Planners, PULs, SIE) use RSVP-RoSE (Rover Sequence Editor) to generate command sequences.

Sequences validated prior to delivery.

Science representation throughout process.
Sequence Integration & Validation
(0230 - 0700 LST)

- Sequence Integration Engineer (SIE) integrates sequences from all developers
  - Up to 30 or more individual sequences
  - Flight rule checking of integrated set
  - Sequence management
  - Generate all command and review products
Watching the Clock: Schedule Tracking on MERBoard

- Dynamic display reminds team of time remaining
- Consequence of missed deadlines may be lost sol of operations
Command Approval
(0700 - 0800 LST)

- Review key sequences
  - Master/submasters
  - Rover motion sequences
- Confirm flight rule checks
- Confirm command files load and begin execution in software sim
- Review radiation sheet
- After approval, deliver documentation to ACE
- Each position documents its part of uplink plan for communication to next shift
Documenting the plan for the next shift...

Sol 143: MER B Uplink Report

RAT PUL [History] [Edit]

Summary - enum 2004-06-19 09:32:17 GMT

RAT PUs:
Jack Wilson 946.824.1156
Sergiu Stracescu
Erik Maun

Sol 143: mostly a RAT sol, 2 hrs brushing and grinding on the target named Cobble Hill, layer B within the Kentucky feature inside Endurance Crater.

The position of the Rover is such that the front wheels are at a steeper angle (front right 23.3 deg and front left 0 22.5 deg) than the back wheels (29.3 deg). This situation raised significant concern amongst Rover planners. The main argument was that preloading the RAT B 200N, in this particular configuration, could endanger the integrity of the Rover and the IDD in particular. The Rover planners were leaning towards backing up and repositioning the Rover to a different spot within the same area of interest, where both front and back wheels will yield similar readings of the terrain slope they are on. The implication of spending another sol for repositioning the Rover led to a slightly different than the SOWG meeting RAT activity plan: there will be an initial 2 minute brushing of the target, followed by 1 hour and 26 minutes RAT-ing attempt (approx 5 m deep into Kentucky), followed by a final 11 minutes brushing. The rationale behind this new sequence is the idea that even if the RAT fails at the beginning of the grinding operation, we will still have a brushed spot and probably something to learn about the sidereal stiffness and limitations of the IDD and the Rover. The final IDD preload value is the one that the Rover planners felt comfortable with, was 10N, at which the RAT team can only hope for the best.

The RAT team generated a new sequence number, 402515, similar to the conditional RAT-ing sequence (402514) with a brushing added at the beginning of the sequence, before the conditional grinding. The parameters used were similar to those applied on Humphrey (see Spirit Rover).
• Now do it all again tomorrow…
Extended Mission: Returning to Earth

• How to stop working Mars time:
  – Step 1: Shorten the tactical timeline (i.e., build up time margin)
    · Many hours (>6) removed from tactical process through evolution of automated scripts to simplify TAP/SIE functions
    · Build-up of libraries of reusable sequences
    · Increased understanding of critical tasks for each role
  – Step 2: Burn margin to stay closer to a normal schedule
  – Step 3: Be willing to build some plans with stale (sol n-2) data
Evolution of the Tactical Timeline (1)

- **Operations at landing**
  - Mars-time staffing
  - ~18 hour turnaround time
  - 3 shifts per sol (1 “downlink” shift, 2 “uplink” shifts)
  - Minimum of 4 personnel trained for each position
    - 2 rovers x 7 day support
  - In some cases, 8 personnel per uplink position
    - 2 rovers x 7 day support x 2 shifts

- **Operations during extended mission**
  - Sliding Earth-time schedule
  - ~8 hour turnaround
  - 1 shift per day
    - Enables consolidation of uplink positions (8 drops to 4)
    - Some roles combined (e.g., TAP and SIE merged)
  - 7 day-a-week staffing
Evolution of the Tactical Timeline (2)

• Operations during later extended mission
  – 5 day-a-week staffing
    • Plan 3 sols on Fridays (10-12 hour Friday shifts)

• Operations during second extended mission
  – Most of science team participates remotely
    • Co-located science/engineering team was essential during prime mission operations
    • Remote team participation became highly feasible in late mission
      › Team members know their jobs, and necessary tools and products are in place, so communications overhead is reduced
      › Some SOWG chairs went remote on 9/1/04
      › Open conference line in sequencing room throughout planning process
Evolution of the Tactical Timeline (3)

• Operations during later second extended mission
  – Modified 5 day-a-week staffing
    · Work Saturdays when required
    · Options:
      › Plan 3 sols on Fridays (no Saturday shift)
      › Plan 1 sol on Friday, 2 sols on Saturday
        » Permits more traverse activities per week
      › Plan 3 sols (including two drive sols) on Friday
        » Rover Planners review results of first sol’s drive, provide go/no-go for second sol of traverse
        » Most of team does not work Saturday
### MER Earth-Time Tactical Timeline

**8/04**

<table>
<thead>
<tr>
<th>Activity Name</th>
<th>Location</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactical Science Assessment/Observation Planning</td>
<td>264-450</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science DL Assessment Meeting</td>
<td>264-650</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsystem Poll (End-of-Sol Engr. Assessment)</td>
<td>SMSA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDL Tactical Engr. Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Tagup</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOWG Meeting</td>
<td>264-650</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity Refinement / Sequence Assignment</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity Plan Integration &amp; Validation</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity Plan Product Generation</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity Plan Approval Meeting</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence Plan Design</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence Development</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Master/Submaster Walkthru</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrate Sequences</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Command Product Generation</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence Review Product Generation</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review of Review Products</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Command Approval Meeting</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare sol n+1 Skeleton Plan</td>
<td>264-425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: All times in Earth hours*
Challenges of Earth Time (1)

• Working on Earth Time
  – Logistics complexity in staffing and scheduling Earth time ops for Mars-clock mission is greater than managing Mars-time schedule
  – “Earth-time” schedule still has walking of shifts (earliest start 7 am; latest end 10 pm)
  – Spacecraft and ground operation activities are often only loosely synchronized
    ∙ Downlink/uplink may occur off-shift
    ∙ Exceptions occur when downlink drifts into Earth-day shift or when uplink must occur early in Earth day shift
  – Easy to lose lock on what’s happening on Mars
  – Use of alternating “restricted” and “un-restricted” sols to enable planning based on stale data
    ∙ Required when downlink occurs too late in Earth-day to support Earth-time schedule
    ∙ Preclude key state changes (i.e., rover motion or instrument placement) on restricted sols so uplink team may rely on telemetry from the prior un-restricted sol to plan the next un-restricted sol
• Working on Earth Time (cont.)
  – Significantly reduced disruption of personal lives compared to Mars-time schedule (duh!)

• From a scheduling standpoint, working on Mars-time--every sol is the same; working on Earth-time every day is different

• Working 5 days a week
  – Tools had to be adapted to:
    · Be robust to gaps between command cycles and to produce projected initial conditions files
    · Support multi-sol plans and command loads
  – Decreased mission return
Continuing Challenges of MER Ops

- For presumed 90-sol mission life, ops team had development experience
  - Still evolving training mechanisms for new personnel coming onboard
  - Inevitable loss of corporate knowledge
- Automation tools speed up execution, but disconnect personnel from underlying process
- Attrition as personnel move on to new challenges
- Upcoming challenge: UHF-only mission for short time periods
  - Multi-hour uplink latency
  - Assumed unavailability of morning relay passes due to rover energy constraints
Backup
Things don’t always go smoothly…

- **A sampling of anomalies**
  - Spirit sol 18 anomaly
    - Too many data products in flash memory fills RAM
  - Opportunity: IDD heater stuck on (mitigate with Deep Sleep)
  - Spirit (mostly): Low-probability software collisions
  - Spirit: High current in right-front wheel drive (healed!)
  - Spirit: RAT grinding bit has worn out (after many grinds)
  - Opportunity: Mini-TES instrument intermittent problems
  - Opportunity: Right-front steering drive failure
  - Opportunity: Immersed in sand ripple