Improving Operations: Metrics to Results

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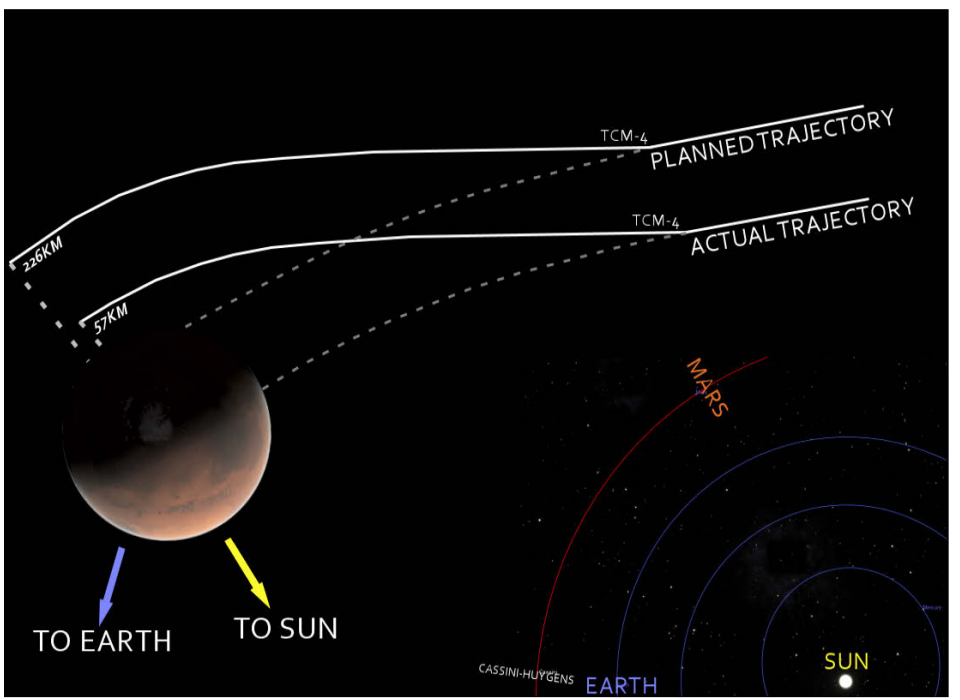
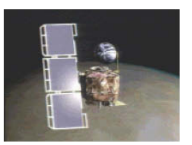
Mars Climate Orbiter Recommendations (1999)

- Revise JPL mission assurance policies and procedures to require an independent Mission Assurance representative during the operational phase of every flight project.

- Require all flight projects to report and track post-launch anomalies on ISAs. Project management should rigidly enforce this requirement and maintain a disciplined disposition, tracking, and resolution process.





Initial Operations Working Group Initiative (2001)

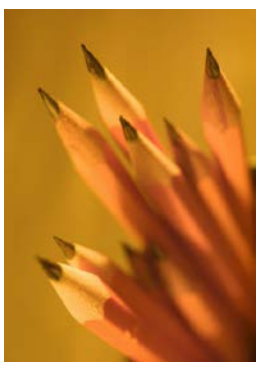
- The JPL Mission Management Office (MMO) established a joint JPL/Spacecraft Contractor working group to perform a comprehensive review of the command uplink process.

- The output of the working group was improvements to the process emphasizing command reliability which can be implemented across all supported projects.

Initial Operations Working Group Purpose/Charter

- Investigate root causes of commanding anomalies experienced by the supported projects (Mars Global Surveyor/Stardust/Odyssey/Genesis)

- Develop, refine, implement, and track improvements to the command uplink process which address these root causes.



Initial Operations Working Group Composition

- Project and Line Management
- Mission Management
- Mission Operations Assurance
- System Engineering
- Real-time Operations
- Mission Planning and Sequencing
- Ground Data Systems

Initial Command File Error Definition

A command file error was initially defined as:

- An error directly related to on-console processing of a Command File for Radiation.
- An error that can be traced directly to an uplink process that wasn't followed correctly or that should have been caught in that process.
- An unexpected result on-board the spacecraft directly related to a command file or files. The appropriate uplink process was followed and adhered to as well as possible.
- Unexpected results in instrument or instrument related behavior as a result of Science Team command file(s) errors

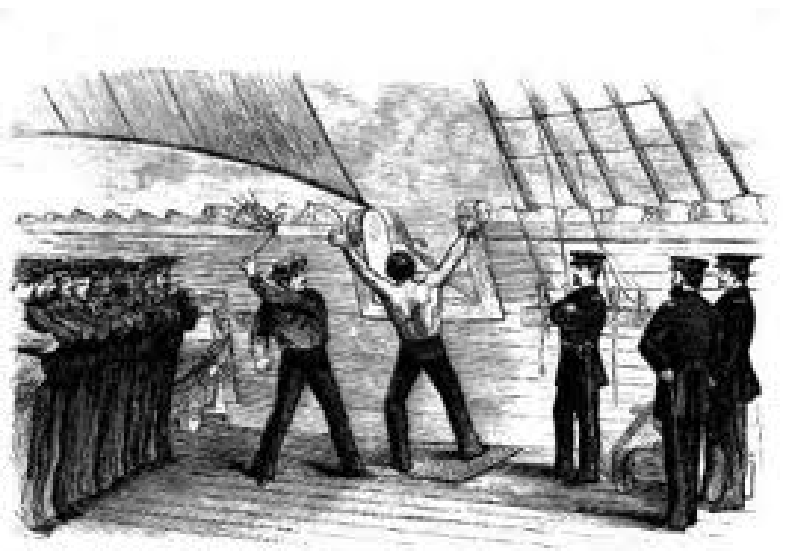
Summary of Causes

- Command File Error Causes Included:
  - -- Inexperience/Lack of Knowledge/New Spacecraft Startup Transient
  - -- Inadequate Command Product Review
  - -- Incomplete Command Uplink Process

- Root Causes Include:
  - -- Erosion of Technical Expertise/Experience
  - -- Testbed Fidelity/Capability
  - -- The “pressure” to do it now

Corrective Actions Implemented

- 16 Process improvements implemented as part of the ISA closure process
- 40 action items identified to be worked
- Quarterly flight team training scheduled
- Command file error prevention training conducted



Overall Recommendations

- Take more time to plan and review - even if you slow down the command uplink process
- Minimize the use of the real-time command process - plan to incorporate into the sequence development process, whenever possible
- Aggressively bring in past personnel expertise during critical events, new activities, recovering from anomalous situations, transitioning from one mission phase to another, etc.
- Use the test-bed capability more - when in doubt, err on the side of too much testing
- Use the standardized command uplink process

Command File Error Definition Refined (2008)

A command file error is:

- an error in a command file that was sent to the spacecraft;
- an error in the approval, processing, or uplinking of a command file that was sent to the spacecraft;
- the omission of a needed command file that was not uplinked to the spacecraft;

Regardless of the consequence on the spacecraft

Command File Error Template Development (2009)

As the effort continued a command file error template was developed as shown below and a working group was formed to evaluate and document each error in the standard format:

Project: G	ISA # ZXXXXX Incident Date: XX/XX/2009 Command File Error Category: X Command File Error Criticality: X
Command File Error Description (Undesired outcome) including a generic and more detailed description.	The background sequence set the downlink data rate to a value not expected for a specific antenna configuration.
Proximate Cause (The event(s) that occurred, including any condition(s) that triggered the undesired outcome.)	Incorrect Data Rate set.
Contributing Cause (The event(s) or condition(s) that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence.)	Desire to increase data rate and obtain more telemetry on the ground.
Root Cause (The event(s) or condition(s) that led to the proximate cause and subsequent undesired outcome and, if eliminated, or modified would have prevented the undesired outcome.	Error in inputting an updated downlink data rate change into sequence. Process review did not identify error in command product.
Corrective and Preventive Actions (include immediate and long-term), and Recommendations across projects.	Mission Manager now requires items approved in schedule approval to be verified as implemented by the requesting party/team during the Review Process. Diligence must be maintained for all product reviews – especially to approved changes.

Institutional Operations Working Group Charter (2010)

- An institutional operations working group was established:
  - to provide a forum for the review of command file and operational errors;
  - to discuss how overarching corrections and process improvements over a broad range of operational issues could be implemented across JPL institutional boundaries.

Institutional Operations Working Group Membership

- System verification, validation and operations
- Planning and execution systems
- Ground System Engineering
- Project development and operations support
- Multimission ground systems and services
- Mission assurance management
- Mission management

Institutional Operations Working Group Implementation

- Initial meeting held on 18 November 2010 with follow-up meetings on approximately two week intervals
- Focused on the higher criticality 2009 command file errors (criticality 1&2)
- Continued to review 2009/2010 command file errors along with new ones in 2011
- Disseminated results to the flight team community with emphasis on upcoming launch and early phase E activities (JUNO, GRAIL, MSL, NuSTAR)

Proximate/Root Causes

- Loss of rigor
  - Inattention to detail, complacency, inadequate review, procedures not followed, miscommunication, distraction, multi-tasking
- Situational Awareness
  - Inadequate knowledge of the spacecraft state as a function of time
- Flight Team work overload
  - Stress, fatigue, rush in getting tasks done
- Non-standard activities
  - Doing activities in different ways, first time events on the spacecraft

Themes/Findings – Nine Major Categories

- Test-bed/Simulation/Modeling
- Spacecraft State/Parameter Tracker
- Operations Sustainability
- Operations development
- Operations Training
- Human Factors
- Configuration Management
- Operability Infusion
- Expert Systems

Example Findings

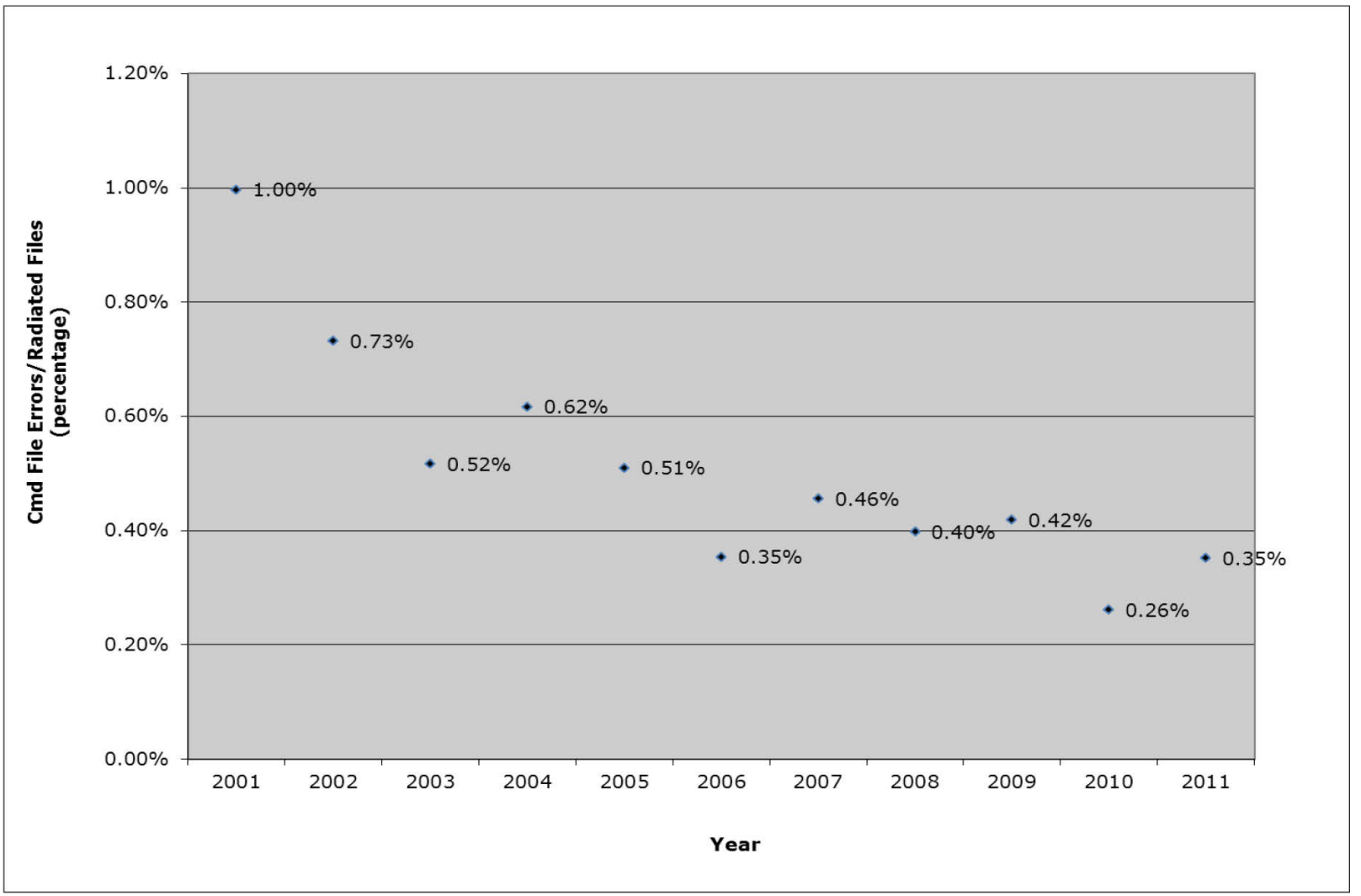
- Perform and document a thorough tabletop planning session at the beginning of each uplink activity to include as a minimum beginning/ending spacecraft states, detailed verification/validation plans, transmission constraints, and contingency commands.

- Include as part of a project's closeout activities a thorough review and possible changes to the spacecraft states with a view towards a follow-on mission (The spacecraft should be placed in a known and documented configuration in anticipation of follow-on activity)

- Include operations personnel on the project systems engineering team early and throughout the project development phase, to facilitate a flight system design that is less error-prone to operate.

Command File Error Metrics

Aggregate Command File Error Rate For Each Mission Year of Operations



Command File Error Metrics

Aggregate Command File Errors by Criticality for Each Mission Year of Operations

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Criticality 1	11	0	7	11	7	3	5	2	3	0	0
Criticality 2	26	16	12	23	19	3	14	13	16	1	13
Criticality 3	22	21	26	46	38	43	43	54	30	27	30
Criticality 4	1	2	5	4	2	1	1	0	0	0	2
Total Command File Errors	**60**	**39**	**50**	**84**	**66**	**50**	**63**	**69**	**49**	**28**	**45**
Total Command Files Transmitted	**6019**	**5331**	**9682**	**13618**	**12944**	**14131**	**13834**	**17339**	**11700**	**10709**	**12798**
# Projects included	**5**	**5**	**7**	**9**	**9**	**9**	**10**	**10**	**9**	**9**	**13**
Aggregate Command File Error Rate	**1.00%**	**0.73%**	**0.52%**	**0.62%**	**0.51%**	**0.35%**	**0.46%**	**0.40%**	**0.42%**	**0.26%**	**0.35%**
Command File Errors/# of projects	**12.0**	**7.8**	**7.1**	**9.3**	**7.3**	**5.6**	**6.3**	**6.9**	**5.4**	**3.1**	**3.5**

Observations/Conclusions

- The aggregate command file error rate has been roughly cut to a third from 2001 to 2011 but increased from 2010 to 2011 (0.26% to 0.35%)

- Experience suggests that the command file error rates increase with launch and early cruise operations.

- Additionally, increased operational tempo around such activities as comet encounters and orbital operations often times cause a spike in the error rate along with the execution of first time spacecraft activities.

- As projects approach periods of high operational activities, the chances of committing command file errors increase and the projects should take steps to reduce their likelihood within the budget and schedule constraints of the operations.

- This paper has outlined some of the steps a project might consider in order to reduce the likelihood of command file errors causing an impact to meeting their mission success criteria.