A High Efficiency System for Science Instrument Commanding for the Mars Global Surveyor Mission

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Abstract - The Mars Global Surveyor mission will return to Mars to recover most of the science lost when the ill fated Mars Observer spacecraft suffered a catastrophic anomaly in its propulsion system and was unable to attain orbital capture at the planet.

One of the major ground components of any planetary mission is its sequencing system. It is by use of this set of computer hardware, software and procedures that commands are sent to the spacecraft, resulting in control of the spacecraft and its activities. Daily real-time commanding usually requires many hours of team processing and review not to mention management scrutiny. All of these steps and built-in delays in the commanding processes mean that the flight team cannot be as responsive as necessary to spacecraft situations which might arise and that a large team is necessary to operate the system.

Mar-s Global Surveyor (MGS) will not have at its disposal either long lead times or large staffs. MGS has been defined to operate on a small, fixed budget. This implies small staffs and shorter lead times. In addition, the funding for development of speculative new technologies has been severely curtailed. MC, S has been directed to use as much of the old Mars Observer **ground system as possible. The MGS Sequence Team has responded to these requirements by developing new techniques and procedures for** using the **Mars Observer system.**

This paper will describe in detail the methods employed by the M G S Sequence Team to accelerate science command processing by use of the standard command generation process and standard UNIX control scripts. These scripts made possible the complete automation of what once was a very manual process. Increases in team efficiency and the resulting team staffing level reductions as dictated by NASA headquarters will be discussed. The MGS Sequence Team will operate with no more than six members versus the **Mars Ohserver Sequence Team which was ten members in size. Methods of risk mitigation employed during this development will be discussed. The greatest reduction in risk was accomplished by total automation of the process, Finally, a discussion of the applicability of these techniques to current and future planetary missions will he presented. These and other techniques being developed by JPL flight operations teams will make possible future planetary missions which can be flown within the tight budget constraints now being faced by NASA without compromising flexibility and responsiveness.**

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INTRODUCTION

The Mars Global Surveyor project has as its goal the mapping of the Martian surface in several spectral regions. Some arms are to be mapped in extremely high resolution. This will be accomplished by following a flight and operations strategy which uses the following design principles.

- The spacecraft will be a relatively simple device which will act as an orbiting platform from which to perform remote sensing of the planet's surface and atmosphere.
- The spacecraft will be placed in a low altitude (378 km), near circular, near polar orbit.
- The science instruments will be Nadir pointed with the remote sensing science instruments mounted on a rigid platform.
- Any and all instrument articulation will be performed internal to the instrument and be of a non-interactive, non-interfering nature.
- All control of the instruments will be managed and commanded by the remotely located science instrument teams. The JPL flight team will be a "port" through which commands move, but arc not interfered with.
- The flight team staffing will only be normal working hours.

These six basic design principles are intended to reduce complexity of operations, increase the autonomy of the Principle investigators over their instruments and, ultimately, reduce costs by reducing flight team workload and staffing requirements.

It became abundantly clear to management, the science teams and the operations team that the level of science commanding necessary to accomplish mission goals was not going to be possible given the conservative operations techniques used by night teams on other JPL missions. A totally new approach would be necessary to satisfy these needs. Radical new techniques in mission operations had to be developed if MGS was going to operate within the fiscal and staffing constraints dictated by Congress and NASA headquarters.

The tool which project management decided to use for accomplishing this goal was Reengineering. MGS project management assembled a group of experts in their respective fields and reengineered all functions performed by the flight operations team. As a result of these deliberations several major improvements were made to existing processes and several new processes and capabilities were identified as necessary to attain the reduced staffing levels dictated by NASA and previously referenced in the abstract to this paper. One of those improvements was to the method by which science instruments are commanded.

This paper will describe the Non-Interactive Payload Commanding (NIPC) process as it will be used during MGS flight operations. Following this will be a brief discussion of the application of these operations strategies to future projects.

TRADITIONAL NON-STORED SCIENCE INSTRUMENT COMMAND PROCESS
MARS OBSERVER: A CASE STUDY

The Mars Observer (MO) spacecraft was designed to allow command execution immediately upon receipt or for the storage of time-tagged commands into its onboard computer for later' execution. Stored commands Were referred to as "sequences," and the spacecraft was capable of simultaneously executing several stored sequences.

The normal method of operating the MO spacecraft was to store one or more sequences onboard and to allow them to execute. Non-stored commands were scrutinized very carefully to assure that no adverse interaction with current sequences, spacecraft configuration or power and thermal conditions would occur.

The MO science instruments were specifically designed to minimize their interaction with all spacecraft subsystems. These included power, thermal or any other dynamic states of the spacecraft bus. The non-interactive nature of the payload commands made it possible to permit the science instrument operators maximum freedom in sending non-interactive commands to their instruments in real-time.

This concept of allowing the science teams to directly operate their own instruments was new to JPL. The Principle Investigators were located at their home institutions far from JPL. Communication between JPL and the PIs was accomplished electronically by use of computer networks. A central Project Data Base (PDB) was established at the JPL facility in Pasadena. This PDB served as a central repository for all files and telemetry exchanged throughout the flight team, including science requestors. Each science team had its own secure PDB "bin," or subdirectory, for depositing command requests to be processed.

in addition, other project teams had PDB bins. This partitioning of data file storage provided the necessary security to prevent erroneous commands from being transmitted to the spacecraft. It also provided members of the flight team logical locations to look when trying to locate command requests.

The actual process of submitting and transforming these files for transmission to the spacecraft involved significant amounts of paperwork and meetings, not to mention the technical work of actually processing the data. The meetings were early in the process as well as late. During the early meeting each requester would bring the required paperwork and present to the attendees the rationale for doing the commands. This would be followed by scrutiny of the paperwork to assure that all required information was present.

At the conclusion of this meeting all non-interactive science requests would be handed to the team responsible for the conversion of the file from mnemonics to bits, the Sequence Team (SEQ). Two members of the SEQ, the Sequence Integration Engineer (SIE) and the Software operations Engineer (SWOE) would retrieve the files from the PDB. The files would receive a brief visual scan and then be run through the sequencing Software to be checked for errors, reformatted and compiled. Some of the items checked during this stage of processing included:

- Checking to assure that only approved team members commanded their own instruments.
- Assuring that each command was routed to the appropriate instrument.
- Assuring, that each command was a non-interactive command.
- Checking that all requests were properly formatted and structured.

This process usually required 20-30 minutes per file. After processing was complete the SIE would review the log, files generated by the above processing. If errors were detected then the SIE would notify the requester and the request would be rejected. If no errors were found then the SWOE would install all resulting files pertaining to the request onto the PDB and the SIE would transcribe, by hand, pertinent data about the request and its processing onto a paper command request form. This part of the process required 30-45 minutes per request file. After the SIE and SWOE had completed all processing of a file, its paperwork was brought to the SEQ Team Chief (TC). The TC would make a quick look review of the command request form and sign-off the SEQ processing. Once signed by the TC the request was released by the SEQ and handed to the next team in the uplink process, the Mission Control Team (MCT).

The MCT was tasked with packaging the resulting SEQ generated binary representation of the request into a form which could be radiated through the DSN. They were also required to define uplink windows based on DSN allocations. In addition to these tasks, the MCT entered the remaining data onto the command request for-m and prepared the entire request package for presentation at a Command Radiation Approval Conference.

During this meeting operations management would review each request and, in some cases, scrutinize requests in detail. If operations management was satisfied that all processing had been executed properly and that the commanding was necessary then they would sign-off the request and approve it for radiation to the spacecraft. The MCI' would then queue the file(s) onto the command system for radiation and actually radiate the file(s). The MCT was also required to maintain logs of all uplink traffic.

The conservatism inherent in the above process was deemed necessary to avoid problems which might have been brought on by inappropriate commanding. It served the project vu-y well for the first few months of Mars observer flight operations. However, it became clear to project management, science requesters and flight operations personnel that the process was much too slow and labor intensive to support the predicted levels of commanding for the mopping phase of the mission. Plans were made to increase throughput by removing unnecessary steps and products. This increased performance by a factor of 2.5, and for Mars Observer this was acceptable. Unfortunately, the untimely loss of the MO spacecraft as it began orbit insertion prevented the flight team from ever implementing the new techniques. Flight operations would have to wait until a new project was begun before they could reap the advantages of the new process. That new project would be known as Mars Global Surveyor (MGS).

DESCRIPTION OF MARS GLOBAL SURVEYOR NON-INTERACTIVE PAYLOAD COMMANDING PROCESS

The Mars Global Surveyor project rose as the Phoenix from the loss of Mars Observer. JPL has been given the responsibility for developing and implementing MGS. Because of the short development cycle (about 2.5 years from inception to launch) MGS was directed to adhere to certain guidelines. Among these was a directive to make maximum use of MO Ground Data System (GDS) elements. To this end the MGS Mission Operations System (MOS), of which the GDS is a portion, set about reengineering the old MO processes and system to fit within the constraints defined by NASA headquarters. One element of the GDS which responded very agressively to these constraints was the Sequence Team (SEQ).

The SEQ is responsible for generating all uplink products for transmission to the spacecraft. The NASA budget for MGS provided for a staffing level not to exceed 60% of the equivalent team's MO staffing level. This requirement, in turn, forced the MOS to completely reassess the techniques it would use to command the spacecraft. Using the same tools as were used on MO, the SEQ has developed a completely new strategy for commanding. One of the new techniques, the Non-Interactive Payload Commanding (NIPC) process, is, for JPL, a radically new way of commanding science instruments.

The suite of science instruments to be flown on the MGS spacecraft is a subset of those flown on MO. They are non-interactive in nature and are constructed so that they cannot, by their own internal commanding, affect any other subsystems on the spacecraft. Each instrument carries its own internal Computer' which is capable of being programmed by the scientists responsible for its operation. The mechanism by which the scientists program their instruments is the NIPC process.

For the NIPC process to be feasible the flight team had to define a set of restrictions which, when satisfied, would qualify a command as a non-interactive payload command. These restrictions were:

- Command could not use spacecraft resources, including power, thermal, orientation, exceeding defined limits. All commands to be used as non-interactive payload commands are required to be qualified as such prior to launch.

- Command could not require use of ground resources beyond the use of the NIPC process and simply sending the command when DSN resources are available. No specified timing or order of transmission would be permitted.

- The execution by the instrument of a Non-interactive Payload Command is not mission critical and if a command request is not sent, then the requester will simply resubmit the command or replan their strategy.

With these restrictions defined and accepted by the project, the NIPC process could be implemented. The NIPC process is a fully automated command generation process. It requires no flight learn staff to operate it. It is available 24 hours per day, 7 days per week but is only guaranteed available on standard workdays, Monday through Friday, 8:00 am to 4:45 pm Pacific time, excluding legal Federal holidays, This means that it is always operating in the SEQ computer on which it resides, but if that computer experiences a failure, then the process will be unavailable until the next standard work period begins.

The implementation of the NIPC Process was to be done using, to the maximum extent possible, existing UNIX and MO tools. These tools included UNIX c-shell, UNIX e-mail, PERL, AWK and the standard set of sequencing tools which verify, validate and check command requests and then convert them from mnemonics to bits for radiation to the spacecraft. In fact, the final tool is composed of almost **95%** pre-existing tools, with the remaining 5% being composed of small, simple utilities written in the C programming language. These utilities are needed to tie the various modules of the sequencing system together or perform small housekeeping tasks not performed by the larger programs,

The invocation of the NIPC process is instigated by a science representative, usually a Principle investigator (PI) or an Experiment Representative (ER), from a project provided Science Operation Planning Computer

(SOPC). The SOPC is remotely located at the PI's home facility, **usually** a university. This person can use the standard sequencing tool, SEQGEN, provided by the project, to build an ASCII file containing the commands being requested. This file is called a Spacecraft Activity Sequence File (SASF). In fact, most requesters don't build these SASFS using SEQGEN directly. They use software which analyses previous data downlinked from their instrument, develops an observation plan based on those data and builds an SASF for them automatically. This SASF is then used as input to SEQGEN, which merely checks the SASF for syntactical and format errors. If errors are identified by SEQGEN, then the requester can use SEQGEN to correct them or can edit the file with any convenient text editor.

Once an error free SASF has been generated it is installed onto the Project Data Base (PDB). The PDB is a large repository (several gigabytes) of data storage space maintained by the project. Each PI is connected to JPL and the PDB by high speed data lines. The PDB is divided into "bins" or subdirectories. Each instrument team has its **own** bin into which it may deposit its SASFs containing commands. Only approved members of each team are given write permission to these bins. This strategy provides one mechanism for command security.

After installing an SASF onto the PDB the requester uses a project provided script to compose an electronic file release form (EFRF). This EFRF contains data which uniquely identify the file to be processed and is in a specific format. The script aids the requester in building this EFRF and then sends the EFRF to the SEQ computer running the NIPC process.

The first job performed by the NIPC process is to immediately notify the requester that it has received their EFRF. The NIPC process then reads the EFRF and extracts the tile named within from the PDB. The file is copied into the NIPC workstation and processing begins.

Processing is composed of several checks to assure the safety of the spacecraft is not compromised. First, the process checks for the legitimacy of the request source as one permitted to be a source of NIPC commands. This is performed by the Daemon by comparing the e-mail source to a SEQ maintained list. The request must have **come from** an approved SOPC or the request is rejected.

Next, the legitimacy of the user requesting the command is determined. In this case, it is necessary to assure that the person making the request has permission to make the request. It is done by the Daemon and a program called MERGE . Both of these modules check the requester from the e-mail address vs the PDB bin from which the request was extracted vs the bus interface unit address for the command, which is contained in the body of the SASF vs the command mnemonic itself. Each requester is approved to only send commands to a specific instrument. The NIPC process builds its own SASF composed only of those commands approved for a given requester. Any commands not available to a requester are rejected and not written onto this NIPC generated SASF. This strategy may sound a bit odd,' however it is useful for instrument teams when they wish to coordinate activities within their own instruments. This type of internal coordination between instruments is expected to occur during MGS mapping operations. The next check performed by the NIPC process is to check that the command is, in fact, a NIPC. The MGS spacecraft has a large list of commands it can process. NIPCs are only a small subset of those commands. SEQGEN, a functional spacecraft simulator, compares each command requested to a list of allowable commands. SEQGEN's list only contains allowable commands. Any commands not contained in SEQGEN's command list are rejected as unrecognized and not written onto the NIPC generated SASF.

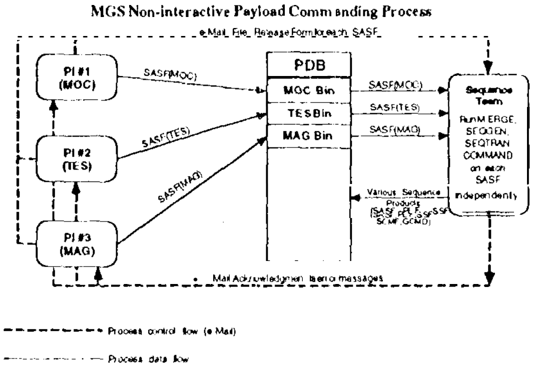

Figure 1

SEQGEN also checks each requested command for proper formatting, structure and field values. If errors of these types are encountered, then the NIPC process rejects the entire request and ceases processing. The reason for this resulting in a fatal error is because the NIPC process cannot determine with certainty how to correct the error. An incorrect modification to a request could cause an instrument to operate improperly or, in a worst case scenario, cause damage to an instrument by placing it in a mode inappropriate for observing conditions.

If at any time during the preceding processing an error occurs, the NIPC process notifies the original requester of the circumstances surrounding the failure. If no errors occur, then the request proceeds through the final steps of the NIPC process, converting the mnemonics in the SASF into binary data which can be transmitted through the DSN to the spacecraft for eventual execution. Figure 1 is a graphic representation of the NIPC process.

As a final protective measure to the NIPC commanding process, all SEQ software and hardware are maintained by the project under formal configuration management. All files are protected from intruders by UNIX operating system security and network security. The MGS network which connects all SOPCs to JPL is a closed network, with no accessibility from the outside world, including the INTERNET.

The performance of the NIPC process is extremely fast. in tests performed using the process as it will be used during flight operations the NIPC process can operate on two files simultaneously. In timing tests it requires between thirty seconds and two and a half minutes to process an average sized (as compared 10 similar MO files) file from extraction of the original SASF from the PDB to writing the final binary output files onto the PDB and notifying the requester of the completion of processing. As mentioned earlier, the process requires no operations personnel to run it and is available around the clock.

NIPC PROCESS REDUNDANCY

The NIPC process is a doubly redundant process. Figure 2 shows the functionality of this redundancy. The redundancy is accomplished by actually having the requester send their EFRF to three SEQ workstations, the primary NIPC computer and first and second backup machines. This is handled by the aforementioned script which builds the EFRF. Each backup machine keeps its list of EFRFs until the primary NIPC computer informs them that it has finished processing a particular request. The primary does this as the final step in its processing, immediately after it writes the resultant files onto the PDB. The primary machine also sends a periodic “ME OK’ signal to both backup machines. The backup machines each run a small script which maintains its EFRF list and checks to make sure that it has received the “ME OK’ signal from the primary machine. If at any time the first backup machine doesn’t receive three consecutive “ME OK” signals from the primary then it will assume that the primary has failed and will begin running the NIPC process itself. The loss of signal from the primary will also tell the secondary backup that it should watch the first backup, much as the first was watching the primary. The first backup sends “ME OK’ signals to the secondary backup and, if the secondary does not receive this signal as expected, then it begins running the NIPC process. Finally, all three NIPC machines periodically interrogate all SOPCs to make sure that the project network is functioning and that the machines are alive. If any NIPC machine senses that a SOPC or the network is down it will notify the appropriate people at JPL.

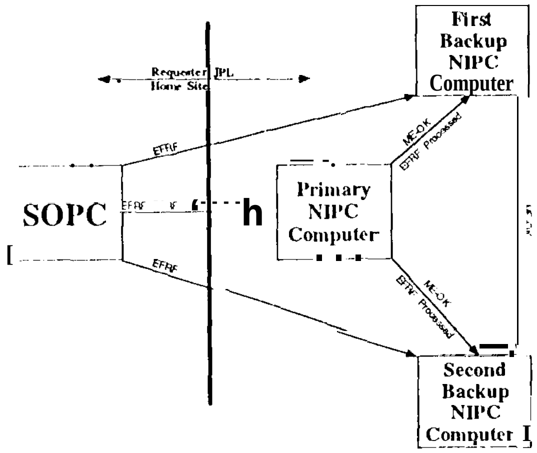

Figure 2

APPLICATION OF RESULTS TO FUTURE FLIGHT OPERATIONS

With federal budgetary constraints as severe as they have become, NASA’s budget can no longer support the large planetary missions of the past. Flight projects must operate with extremely small staffs while at the same time provide operational systems robust enough to mitigate risk of loss of the mission. There is no indication that these restricted budgets will be relieved any time in the near future. Processes must become more automated and flight teams must become more efficient if the small to moderate sized missions NASA is proposing are to become reality.

Automation of the type described herein is essential if these future missions are to be sucessful. Large, expensive and lengthy development cycles for sophisticated uplink tools is no longer feasible nor necessary. The development of the NIPC process required approximately four total workweeks of effort. It requires little maintenance since it is composed of components which have been extensively tested during other mission's flight operations. All of these characteristics have resulted in almost nonexistant development costs, extremely rapid development periods and enormous operational savings. The NIPC process alone accounts for half of the Sequence team staff reduction from MO as mandated by NASA.

However, the use of this strategy for science commanding is not its only application. Traditionally, all spacecraft bus commands are treated as interactive commands. During MO flight operations the flight team discovered that several of the most frequently used bus commands were, in fact, non-interactive in nature. Upon this realization the flight team altered its software and procedures to permit more rapid processing of those commands. These types of commands will exist on MGS and on all of the spacecraft expected to be flown as part of the Mars Exploration Program (MEP). The spacecraft to be flown during MEP will be more sopisticated than even MGS and will have greater autonomy implemented in onboard flight software and hardware. This, in turn, will make possible even greater automation of the ground uplink system. A more autonomous spacecraft implies that the spacecraft will be able to better care for itself than did previous spacecraft. With reduced risk of commands sent from the ground being able to injure the spacecraft (thanks to onboard autonomy) less scrutiny by the ground crew will be necessary. This leads to faster turn-around times for commands when they are requested and for fewer, if any, staff being needed to perform the processing.

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