The Mars Surveyor Operations Project Command Generation Process

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Abstract - The Mars Global Surveyor mission (MGS) will be the first in a series of Mars missions to return to Mars to recover 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.

A major characteristic of these Mars missions is their fixed and severely constrained budgets. NASA has provided a set anneal budget for flight operations and development. All spacecraft most be operated and pre-flight preparations made for developing missions on a single budget. This strategy has forced the JPL flight operations and development organizations to develop ncw and innovative methods for performing their functions. Onc logical outcome of this strategy has been to consolidate all Surveyor mission operations into one operations organization, the Mars Surveyor Operations Project (MSOP).

One of the major ground components of the MSOP is its command generation process. It is by usc of this set of computer hardware, software and procedures that commands arc sent to the spacecraft, resulting in control of the spacecraft and its activities. The MSOP command generat ion process is based on the Mars Global Surveyor process, which in turn was based on the Mars Observer process. However, the MSOI° process has been heavily automated so that the flight team can be staffed at levels commensurate with the restricted budget. In addition, new st rategies for commanding have been developed which farther streamline the commanding process.

This paper will describe in detail the methods employed by the MSOP flight team to accelerate the command generation process. The use of scripts has made possible the automation of what once were very manual processes. Increases in flight team efficiency and the resulting flight team staffing level reductions will be discussed. Methods of risk mitigation employed during this development will be discussed. 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

Flight operations at JPL has traditionally involved relatively complex spacecraft. These complex spacecraft required the flight teams for each mission to maintain rather large staffing levels to support the respective missions. in addition, each mission maintained its own flight team. In 1993 JPL embarked on a major reengineering of its flight operations processes. These changes were driven by the thrust to lower mission operat ions costs so that a greater number of planetary m issions could be flown more frequently, even in the face of dwindling budgets to support them. The approach taken by the laboratory for its Mars Surveyor Program was to develop a ground system which could simultaneously support as many as three spacecraft. in various phases of flight and two in development on the ground. The project which evolved from this effort is called the Mars Surveyor Operations Project (M SOP). This paper will discuss the uplink portion of MSOP. This process includes commanding of science instruments and the spacecraft bus using real-time commands as well as time-tagged stored sequences. Each will be discussed seperately.

THE BASIC SET OF COMMANDING TOOI ,S

The uplink process as practiced al JPL relics cm a specific set of software tools. These include:

SEQGEN: A spacecraft functional simulator.
SEQTRAN: Translates mnemonics to binary data. Similar to a computer language compiler.
SEG : Creates various tabular and graphical reports to aid in daily operations.
CO MAND: Used to operate the Deep Space Network (DSN).
ACT: Automated command tracking software. Allows flight team members to track command file status,
PDB: The Project Database. This data repository acts as the project's file server for flight operations and spacecraft development.

Beyond these special tools tbc uplink process also relics heavily on many standard UNIX functions as well as several small utility programs which help tie various pieces of the system together.

NON-INTERACTIVE PAYLOAD COMMANDING PROCESS

The most radical changes to JPL's traditional operational strategies occurred in the processing of non-interactive science instrument commands, also called non-interactive payload commands (N IPC). A basic tenet of tbc MSOP strategy for flight operations is that science instruments can be best operated by the science team responsible for developing cacb instrument. Each Principle investigator (PI) is responsible for proving that their instrument operates in a non-interactive, non-interfering mode. The testing necessary to prove th is operat ional mode is performed during spacecraft system test. If tbcy can show that their instrument dots operate in the aforementioned manner then they can take advantage of a command generation system which is almost completely automated and is available to them 24 hours pcr day, 7 days per week. This process is known as the NIPC process and provides cacb 1'1 with an extremely rapid mechanism for them to send commands to their own instruments. At tbc heart of the NIPC process is a fully automated script which runs in a Mission Planning and Sequencing Team (MP&S) computer. It makes use of the same tools as were used on Mars Observer for this function but uses them in a completely new fashion,

At a high level the NIPC process operates by allowing the requester to build a file containing the commands desired. This file is processed by a fully automated script which authenticates and validates its contents and then converts them from mnemonics to bits. This binary file is then scheduled for uplink 10 the spacecraft and is radiated through the DSN.

The first step in sending a NIPC type command to the spacecraft is for the Principle Investigator (PI) or Experiment Representative (ER) to use their Science operation Planning Computer (SOPC) which is remotely located at the 1'1's home facility to build their input file. They can usc the standard sequencing tool, SEQGEN, provided by the project, to build the file. This file is called a Spacecraft Activity Sequence File (SASF). Many science teams 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 arc 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). Each science site 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. Only approved members of each team are given write permission to these bins, This strategy provides one mechanism for command security.

The invocation of the MP&S script is instigated by a science representative, usually a Principle Investigator (PI) or an Experiment Representative (ER). After installing an SASF onto the PDB the requester uses a project provided script to compose an electronic NIPC trigger. This trigger contains data which uniquely ident ify the tile to be processed and is in a specific format. The script aids the requester in building this trigger and then sends it using standard UNIX c-mail to the MP&S computer running the NIPC script.

The MP&S script then performs several tasks. They arc:

- Immediately notify the requester that it has received their trigger.
- Read the trigger and extract the file named within from the PDB.
- Copy the file into the MP&S NIPC workstation.
- Check for the legitimacy of the request source as one permitted to be a source of NIPC commands.
- Check the legitimacy of the user requesting the command. Assure that the person making the request has permission to make the request.
- Build its own SASF composed only of those commands approved for a given requester,
- Check that the command is, in fact, a NIPC type command.
- Check for proper formatting, structure and field values.
- Translate the mnemonic request file into a binary equivalent of the file.
- Check all software runlog files for errors. If errors occurred then notify requester.
- If no fatal errors occurred then install all appropriate command data files onto the PDB.
- Populate the automated command tracking (ACT) software data files with pertinent data.

The performance of the MP&S script is extremely fast requiring between thirty seconds and two and a half minutes to process an average sized 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, this portion of the NIPC process requires no operations personnel to run it and is available around the clock.

After the MP&S script has completed its processing the binary file waits on the PDB for radiation. At this point the ACT electronically notifies the Real-time Operations Team (1{ '1 '0'1) of the file's existence. The RTOT is the team which controls the DSN and actually sends the command to the spacecraft. Upon receipt by the RTOT of an ACT message that a file is waiting to be sent t he team member responsible for sending, commands (called the Controller) will extract the file from the PDB and install it onto their local command system workstation. The Controller will use the ACT to schedule the time to radiate the command based on antenna availability and conflicting command activities. Once the time of radiation has been determined then the Controller waits for the appropriate time and the command is transmitted using the CO MANI) system.

N IPC type commands arc considered to be the lowest priority of all commands sent to the spacecraft and may be sent several hours after their original request time or may never be sent, depending on the amount of uplink traffic, DSN availability and activities reboard the spacecraft. NIPC commands arc given an expiration t imc by the person making the request. If a request has not been sent by the expiration time then it will not be sent and the original requester will be notified of its status. If they wish to send the same file again then they must resubmit the original SASF for processing. The science investigation teams have estimated that at least 85% of all science instrument commanding will be of this type.

EXPRESS COM MAN]) PROCESS

The Express Command (EC) process is equivalent to the NIPC process described above bat is usable only by the Spacecraft Team (SCT) for spacecraft bus commands which arc determined to be mm-interact ive. Examples of this type of command arc command loss timer resets, onboard star catalogs and onboard ephemerides. Rigorous checking of this command type is done before a request is submitted. Downstream software like SEQGEN anti SEQTRAN arc incapable of checking these files for errors in content except in so far as formats and limits arc concerned.

The EC process onl y differs from the N I PC process in that the requester is now a member of the Spacecraft '1'cam, specifically, a Systems engineer. Only the Systems people arc authorized by project policy to send Express Commands. 'Ibis means that the Systems engineer on duty at any given time must gather their inputs from any team subsystems members, combine these inputs as appropriate and then create an SASF (or several SASFs) which contains the desired commands. They then use the same script used by the science team members to install their SASF(s) onto the PDB and create a trigger for the MP&S NIPC script. From this point to the file's radiation to the spacecraft the process is identical to the NIPC process. This commonality bet ween the two processes has made development of these processes much quicker and easier.

The Spacecraft Team has estimated that approximately **75%** of all commands they will send to the Mars Global Surveyor (MGS) spacecraft will be of this type, thus reducing the need for a large ground support team to support clay-to-day spacecraft housekeeping activities.

COORDINATED COMMAND PROCESS

'The Coordinated Command (CC) process is by far the most rigorous of the non-shred commanding types offered by the MSOP. As their name implies Coordinated Commands require some amount of coordination for either spacecraft resources, ground resources or both. in the case of spacecraft resource utilization the commands usually require the integration of the desired commands with the currently ongoing stored sequence onboard the spacecraft. This integration may be necessary so that flight team members may obtain an integrated activity plan for the spacecraft or to assure that all spacecraft resources arc properly modeled and checked prior to executing the requested commands.

The CC process begins in a manner very similar to the EC process described above. An SCT Systems engineer obtains inputs from subsystem members of the team. The Systems engineer reviews the requests and may convene an internal SCT meeting to discuss the reasons for the requested commands. once the Systems engineer has been satisfied that the commands arc needed then they create an SASF containing the commands and install it onto the PDB. They then invoke the ACT to begin the processing of the command request. The ACT is populated with pertinent information about the file and the commands it contains. This information will include such items as the SASF file name, its creation date and time, the name of the Systems engineer responsible for the request and a rationale or justification for the request. Once these data have been properly entered then the ACT will notify a Sequence 1 ntegrat ion Engineer (S1 E) on the MP& S '['cam that a CC request has been submitted for processing.

Upon receiving the notification from the ACT, the SIE will extract the SASF from the PDB. They will then gather all of the most current sequence data products to be merged with the request. These files will contain the current l y executing onboard stored sequence and any interact ive non-stored commands executed to that point in time.

Once all data products arc ready the SIE merges the requested commands into the current spacecraft sequence files. SEQGEN is used to check the effects of the requested commands and sequence data products arc generated. The SIE uses various software tools to review the integrated simulation for errors or flight rule violations. If errors are detected then the SIE must take corrective action to remedy the situation. This may include making simple modification s to the original input or working closely with the Systems engineer to arrive at a resolution to the problems. This process is iterated through as many times as is necessary until a clean simulation is obtained.

Once the SIE has generated a clean merge of the commands with the ongoing sequence they release the resulting simulat ion to the Systems engineer for their final review. If errors are detected during this review then the SIE will rerun the merge with the necessary modifications to correct the errors. If no errors arc found by the Systems engineer then the SIE installs all sequence data products for the command file onto the PDB. After this they invoke the ACT and enter the information pertinent to the command request. Finally, the SIE releases the resulting command files using the ACT.

Once the command files arc released by the SIE the ACT notifies project management that a Coordinated Command is awaiting their approval. Project managemen t convenes a command approval meeting which is attended by the Operations Manager, the various team leads, tbc SIE who processed the request and the

Systems engineer who made the original request, about six attendees. During this meeting the Operations Manager will ask any clarifying questions they may have about the request. At tbc end of the meeting they will either approve or disapprove the request for transmission. If tbc request is disapproved then they specify so in tbc ACT and the command file is never radiated. If it is approved then the Operations Manager indicates so electronically using the ACT. After this approval the process is the same as for the other types of mm-stored commands. The RTOT extracts the binary file containing the request, it is scheduled for uplink, loaded into the command system at the appropriate time and radiated to the spacecraft using the DSN.

This process is more labor intensive than the NIPC or EC processes described earlier. Care must be taken to avoid causing damage to the spacecraft or disrupting activities taking place onboard when the command is to execute or afterward. These arc the reasons for extra rigor being applied to these commands. The length of time required to complete this process for any given request file depends on the types of commands it contains, but for an "average" file containing well understood commands this process will require no more than two hours to complete. Actual radiation time will depend on availability of the DSN.

STORED SEQUENCE PROCESS

The preceding command generation processes arc used to generate commands which arc sent to the spacecraft and executed immediately upon receipt or stored in a science instrument for later execution. The final commanding process provided by the MSOP is the Stored Sequence (SS) process, A stored sequence is a time-lagged, time-ordered set of commands which are loaded into the spacecraft's onboard memory and allowed to execute, much as a piece of software dots in a computer. This sequence may perform activities as simple as changing a downlink data rate or as complex as a major maneuver. In any case, the commands must be executed at very specific times and require extreme scrutiny before they arc executed to avoid damage to or loss of the spacecraft.

The MSOP stored sequence process is a two pass process. The first pass involves planning the sequence, building the SASF which contains the sequence and integrating the various activities contained in the sequence into a working entity. The second pass is used to correct errors found during the flight team review of the sequence and incorporating any late updates. At the end of the second pass the sequence is approved for transmission and radiated to the spacecraft.

The first step in pass one is planning tbc sequence. This is accompli ished using various data pertaining to the sequence. The Mission Sequence Plan (MSP) is a project document which provides high level guidelines for the activities required to be performed during various periods of the mission. This document describes functionally which events arc necessary and when they should occur. The DSN allocation file contains data describing when any given DSN antenna is allocated for usc by the mission. There arc also any change requests which have been approved by project management for implementation in the sequence. With these data at their disposal the SIE proceeds to construct an SASF which contains the block calls which will make the required sequence activities occur. The SIE solicits specific input data from the other teams on the project to populate data fields in the SASF for activities requiring, them.

Once the SASF has been constructed the SIE uses the SEQGEN software to functionally simulate the events which will occur during the sequence and to model their effects on the spacecraft subsystems. SEQGEN produces several output files which ate reviewed by the S1 E for flight rule violations and to assure that the intent of the sequence is being met. Any errors or problems with the sequence are resolved by the S11; through interactions with the other teams on the project. The final output from this part of the process is a fully integrated sequence. The sequence data products generated by this process arc installed onto the P])] 3 by the SIE. They then enter various pieces of information about the sequence into the ACT and release the sequence for flight team review using the ACT to notify the reviewers of its readiness.

At this point in the process members of the flight team may retrieve the sequence files from the PDB and make use of them for various tasks. Examples would be loading the sequence into the project's hardware simulation device to verify the sequence's actions. It may also include the creation of preliminary data products used by other elements of tbc flight team. 1 lowever, specific members of the team will be required to provide review comments to the SIE on a very specific schedule. Comments are submitted using tbc AC']'. Upon receipt of review comments tbe S1 E will review each comment and take action as appropriate. In some cam the comment will require a minor or insignificant change to the sequence and the change will be made by the S1 E. Some comments may require updated inputs from a member of the flight team and those updates will be provided to tbe SIE with the comments. Still other changes will be a change in scope for the sequence and will require the person requesting the change to make a formal request to project management for tbc change. An electronic change request process bas been incorporated into the MSOP system and would be used to submit tbc change request. If tbe change is not approved then the S1 E simply won't make tbc change. If it is approved then the SIE will make all necessary modifications to the SASF and rerun SEQGEN to resimulate the modified sequence. Once again, tbc SIE iterates the sequence through the sequencing software until the simulation produces no errors or problems.

At this point the SIE installs tbc sequence products onto the PDB and releases them to the flight team for review, using the ACT to make notifications. This final review is intended for tbc flight team to verify that all required corrections and changes to the sequence as reflected in the comments have been properly incorporated into the sequence. This milestone is only a very few days prior to uplink of the sequence to the spacecraft and only errors which endanger spacecraft health or mission success will be corrected. It is expected that any comments at this point will be of a benign nature and the sequence will be ready for uplink to tbc spacecraft after approval. A very short contingency rerun of the sequence is provided in the schedule for each sequence however this reran is expected to be used seldom if ever.

When the sequence is deemed acceptable by tbe flight team then the S1 E releases it to project management for approval. A sequence's approval is made in a sequence approval meeting hours before it is scheduled to be radiated to the spacecraft. Project management, team leads, the SIE responsible for tbc sequence and the Systems engineer attend this meeting and make their final inputs to project management regarding the sequence. If the sequence is disapproved then the sequence will not be radiated to the spacecraft. The MGS spacecraft does not require a stored sequence to be resident in its memory to function properly. A contingency rerun would be required if it were disapproved and possible elimination of sequence activities may be required to accommodate the late rerun. If it is approved then the process for actual radiation through the DSN antenna is the same as for the above described non-stored commands. The sequence is loaded onto the spacecraft and execution is begun.

SUMMARY

The automation of the above processes to the extent described in the preceding paragraphs has resulted in enormous savings in flight operations costs while not increasing risk to or compromising the safety of the spacecraft being flown or tested. This has been accomplished by carefully analyzing each process and then choosing which processes to automate based on whether the work being performed was merely a matter of transforming data or actually required a person to validate the effects of a request. In most cases where automation was implemented the scripts used to perform the tasks were built based cm the original manual procedures for that task. Before any actual scripts were written each manual process was analyzed and reengineered to make sure that only necessary work was being performed. In addition, the tools used to perform the tasks within the scripts already existed as part of the nominal ground data system.

One requirement which tbc M S01' placed on the software developers was that each piece of software used in the commanding process provided a command line interface to that software. This made possible the kind of total automation being used by the MSOP. Many of these programs provide a graphical user interface as an option to the user but all must be controllable via a command line interface. Other standards of practice include using a standardized naming convention for all commanding files, modularization of the software tools used during the process, making all software components table driven and partitioning of the PDB into logical subdirectories to provide file security. This overall approach to software tools and procedures has made the Mars Surveyor Operations Project an extremely efficient, robust and responsive organization for operating interplanetary spacecraft.

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