SHARED MISSION OPERATIONS CONCEPT

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Abstract

Historically, new JPL flight projects have developed a Mission Operations System (MOS) as unique as their spacecraft, and have utilized a mission-dedicated staff to monitor and control the spacecraft through the MOS. NASA budgetary pressures to reduce mission operations costs have lead to the development and reliance on multimission ground system capabilities. The use of these multimission capabilities has not eliminated an ongoing requirement for a nucleus of personnel familiar with a given spacecraft and its mission to perform mission-dedicated operations.

The high cost of skilled personnel required to support Projects with diverse mission objectives has the potential for significant reduction through shared mission operations among mission-compatible projects. Shared mission operations are feasible if:

i. the missions do not conflict with one another in terms of peak activity periods,
ii. a unique MOS is not required, and
iii. there is sufficient similarity in the mission profiles so that greatly different skills would not be required to support each mission.

This paper will further develop this shared mission operations concept. We will illustrate how a Discovery-class mission would enter a "partner" relationship with the Voyager Project, and can minimize MOS development and operations costs by early and careful consideration of mission operations requirements.

Objective and Overview

The objective of this article is to describe a shared mission operations concept that provides for concurrent mission operations of two deep space Projects both utilizing a single MOS originally developed by the Voyager Project, but modified to accommodate shared support of a Discovery Project.

The Voyager Project is an existing JPL-operated interplanetary mission. Basically, the Voyager Project proposes to modify the Voyager MOS to enable shared operations support of a Discovery Project. The Discovery Project will benefit from savings achieved by avoiding development and operation of its own unique MOS. The Discovery Project will be responsible for costs associated with adapting the Voyager MOS for Discovery Project use, and for adding capabilities not part of the Voyager MOS baseline. For example, the Voyager Project is now operating in an extended cruise posture, has a well understood trajectory, and a fully developed and stable set of mission plans, thus Navigation and Mission Planning functions are not actively supported by the Voyager Project, are not part of the Voyager MOS baseline, and must be added for Discovery Project support.

Management Structure and Flight Team Organization

A Memorandum of Understanding (MOU) signed by both Project Managers will provide the basic ground rules governing shared flight operations, funding issues, resource utilization, priorities, conflict resolution, etc.

Development of the shared MOS will be undertaken by the Voyager Mission Director and the Voyager Flight Teams. The Voyager Mission Director will lead the effort to develop the shared MOS, and in this role, report to the manager of the Discovery Project. **Figure 1** depicts the Discovery Project development organization, and illustrates the relationship of the Voyager Project Mission Director to other elements of the Discovery Project development organization.

Figure 2 illustrates the relationship of the Voyager Mission Director to the Managers of both the Voyager and Discovery Projects, and expands the organizational structure beneath the Mission Director to reflect the supporting flight teams and staff, and to indicate where staff additions would be required for support of a Discovery mission. The MOS organizational structure shown in Figure 2 is organized into three process-oriented teams - the Uplink Team, the Downlink Team, and the Navigation Team.

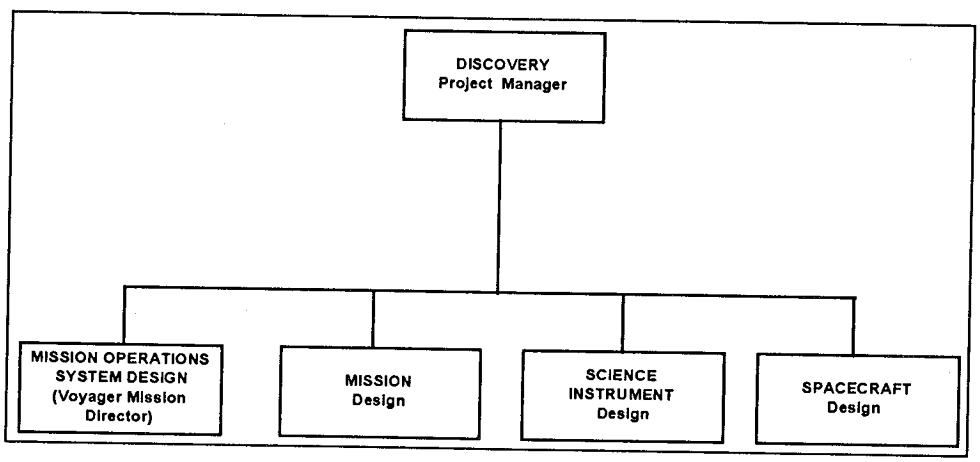

Figure 1

Uplink Team Description

The Uplink Team performs all functions required to generate spacecraft event sequences and send commands to the spacecraft. Two basic processes- the sequence generation process and the real time command process, provide the mechanism for accomplishing these functions.

The uplink process begins with the collection of spacecraft activity requests (science and engineering), which are combined into a conflict free sequence design (a timeline of sequence events). Based on this sequence design, a time ordered listing of all spacecraft events is generated and a sequence simulation and validation performed. A parent command file is then generated which is conditioned, validated for correctness and then segmented into separate ground command files for radiation to the spacecraft.

There are three types of sequences the Uplink Team builds and/or updates: mini, overlay and baseline. The mini sequence is composed

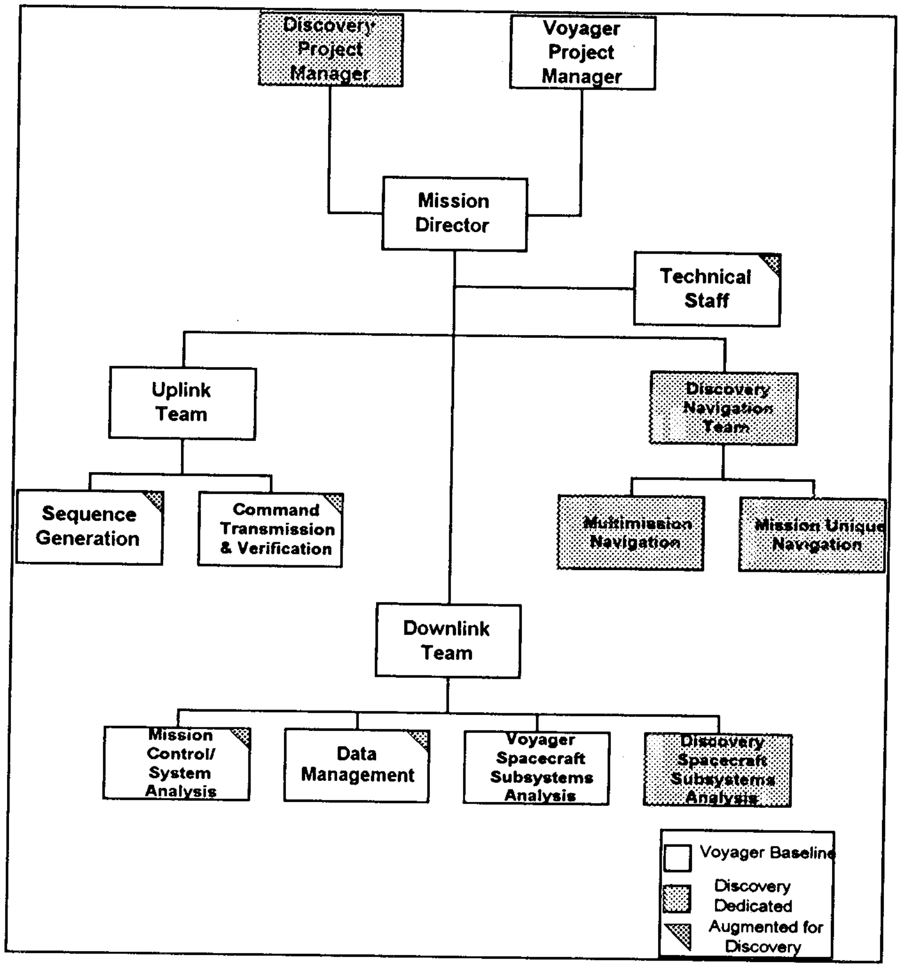

Figure 2

of one or more stored commands which are required to respond to an unplanned event or anomaly. The overlay sequence consists of non-repeating or special science and engineering observations. The Uplink Team's primary sequencing function is building these overlay loads. The baseline sequence is a looping sequence aboard the spacecraft consisting of repeating science and engineering activities. The baseline sequence operates autonomously. Modifications can be made to the baseline sequence at pre-determined restart points.

The Uplink Team is also responsible for all real-time command operations. Real-time commanding is used to load spacecraft event sequences and modify the on-board spacecraft configuration and/or the executing sequence. These operations consist of generating the real-time command request, coordinating and reviewing the request, negotiating the Deep Space Network (DSN) coverage for uplink/downlink, generating the command file, transferring it to the DSN, and monitoring the uplink/downlink.

The Discovery Project sequence development process will be similar to Voyager Project's where possible so as to use established procedures and interfaces.

Downlink Team Description

The Downlink Process begins at the spacecraft where state, status, and instrument observation samples are integrated into a formatted data stream for transmission to ground-based receiving stations. The Downlink Process ends with delivery of committed data products to science investigators.

The Downlink Team is responsible for the capture, conditioning, and delivery of science and ancillary data committed by the project to experimenters, as well as, all data required for monitoring the status of both the Voyager and Discovery Project spacecraft.

The Downlink Team also provides analysis of spacecraft and science instrument performance and health. This team evaluates spacecraft and instrument status against expected performance and initiates recovery actions for all spacecraft failures. The Downlink Team will provide inputs for the uplink process as necessary to generate engineering calibration and performance data needed to evaluate spacecraft performance and health, and will provide any necessary spacecraft state and status data to predict spacecraft behavior.

In support of the Discovery Project, the Downlink Team will support concurrent development of spacecraft and Ground Data System (GDS) capabilities during the period preceding launch. This will include: support to test and demonstrate spacecraft and ground system compatibility; development of capabilities needed to display and evaluate spacecraft and instrument performance and health; support for development of fault protection algorithms and other programmable spacecraft capabilities; definition of spacecraft alarm limits and recovery procedures; and other activities necessary to assure knowledge of the state and status of both the Voyager and Discovery spacecraft and instruments.

Navigation Team Description

The Discovery Navigation Team estimates, predicts, and controls the spacecraft trajectory and updates the planetary and satellite ephemerides. Navigation personnel for systems engineering, orbit determination, maneuver analysis, optical navigation support, trajectory analysis, and software maintenance will comprise the Discovery Navigation Team. Radiometric orbit determination analysis and related operations support will be provided by the Multimission Navigation Team under funding by the Telecommunications and Mission Operations Directorate (TMO). Discovery Project funding will provide for trajectory analysis, maneuver design and analysis, and optical navigation support functions.

Mission Scenario

As mentioned earlier, the Voyager Project is operating in an extended cruise phase. Operations are routine and consist of daily spacecraft contacts for science and engineering data collection and spacecraft performance monitoring. Sequence operations are based on use of a baseline sequence composed of repeating spacecraft activities. Non-repeating or time-varying activities are controlled by periodic transmission and execution of overlay sequences.

Discovery project mission operations will consist of multiple mission phases beginning before launch with System Test/Pre-launch Operations. Typical mission operations phases, operation activities, and mission phase duration are:

System Test/Pre-launch Operations

Support of system test and pre-launch operations consists of:

i. Generating all commands to be executed by the Discovery Project spacecraft during system test and pre-launch operations using the Sequence System.

ii. Monitoring subsystem and instrument telemetry data in real time for test support and evaluation purposes using the operational GDS and Mission Support Area (MSA).

This support will require that the GDS, including Sequence System development, be complete prior to the start of system test and that the combined Voyager / Discovery flight team be staffed to near launch-operations level prior to the beginning of system test support. This includes having the remote science locations connected to provide test data to the science teams for instrument checkout.

Flight team activities during this phase will also include personnel test and training for launch and near earth operations.

Launch And Near Earth Phase

DSN support for the first three weeks is assumed to be continuous 24 hour per day coverage using 34 meter stations. The second three weeks will require 1-2 passes per day using 34 meter stations resulting in 8 to 16 hours per day coverage.

Spacecraft telemetry data are monitored during launch, parking orbit, interplanetary injection, and spacecraft separation. Following separation and initial spacecraft acquisition by the DSN, spacecraft telemetry data are monitored for subsystem and science instrument checkout purposes, radiometric navigation data are acquired, and the post-injection trajectory estimated. A Trajectory Correction Maneuver (TCM) is designed and executed correcting any launch injection errors. Additional radiometric navigation data are collected and processed to confirm a successful trajectory correction, or to design an additional cleanup TCM if necessary.

Following a complete spacecraft checkout and resolution of any subsystem or science instrument abnormalities, the spacecraft is configured for cruise operations. The cruise configuration should be established around L+3 weeks with the next three weeks devoted to characterizing spacecraft performance in the cruise configuration. At nominally L+6 weeks, cruise begins with reduced DSN tracking support consisting of either one 8 hour pass per week or two 4 hour passes per week using 34 meter stations.

Cruise - Spacecraft Health Monitoring And Maintenance

The spacecraft health monitoring and maintenance phase includes the time period from L+6 weeks to encounter/orbit injection-6 months. DSN support during this phase is nominally one 8 hour or two 4 hour passes, (34 meter stations), per week for spacecraft health monitoring. Navigation requirements may result in additional tracking passes being required.

Spacecraft control will be via a long-term baseline type of sequence that is augmented with periodic overlay sequences. The baseline sequence contains antenna pointing information for maintaining communications with the ground and any spacecraft events that are repetitive and can be planned in advance. Overlay sequences consisting of non-repetitive activities will be generated and transmitted to either Voyager or Discovery spacecraft on a schedule consistent with mission requirements and Uplink Team staffing; nominally this will be no more frequent than once every three months for any Voyager or Discovery spacecraft. Anomaly responses or special events will be handled by mini-sequences generated as required. This baseline/overlay sequencing strategy will be maintained throughout the cruise phase until 6-months before the start of the Discovery Project encounter/orbit operations.

Flight team staffing during the cruise time period is minimized by maximum utilization of shared flight team personnel. With the exception of periodic detailed spacecraft checkout, the entire Discovery Project effort during cruise is spacecraft health monitoring and maintenance, and navigation. While the combined flight team staff needs to maintain a knowledge base in each spacecraft subsystem area for normal cruise operations, the ability to respond quickly to spacecraft anomalies will be limited by this minimum staffing approach. In the event of a significant spacecraft anomaly, a link will be established to the spacecraft contractor's facility for support of the contractor's spacecraft team. The spacecraft team will provide diagnostic support and will be responsible for recommending recovery actions.

Encounter/Orbit Insertion Preparation

The test and training phase for the Discovery mission includes the time period from encounter/orbit insertion-6 months to encounter/orbit insertion-4 months. DSN support will increase as final preparations for the start of the encounter/orbit insertion sequences are implemented and increased navigation support is necessary for starting the ephemeris updates of any early encounter sequences.

During this final portion of spacecraft cruise, preparations for the start of the Discovery Project encounter/orbit operations are completed:

- The acquisition and processing of navigation data is increased for sequence updates and approach TCMs.
- Final checkout and configuration of the spacecraft for the start of encounter/orbital operations is accomplished.
- Training exercises are conducted to verify and refine flight team operational readiness.
- Sequences are updated and loaded onboard the spacecraft.

Encounter (& Gravity Assist Flyby)/Orbital Operations

Flight team activities during this period are directed at:

- Acquiring the planned science data.
- Maintaining spacecraft health.
- Achieving the trajectory knowledge and control to provide the viewing conditions necessary to successfully accomplish the planned science observations (includes necessary TCMs).
- Updating the sequences based on the latest trajectory information.
- Capturing, processing, and delivering science data that are downlinked during the encounter operations.

In the special case of a gravity assist flyby without any science data acquisition, the operations emphasis is on the acquisition and processing of navigation data and the execution of approach TCMs. Following the flyby, there will be additional navigation data acquisition and processing for a post-encounter TCM to correct trajectory errors resulting from the flyby.

Mission Operations System Description

The MOS is defined to be the collection of systems (hardware and software), personnel, facilities, and procedures required to remotely monitor and control a spacecraft and deliver data products to users. The MOS may extend to a remote scientific investigator's site to support science instrument control and scientific data delivery. However, the MOS does not include data processing elements, personnel, or procedures utilized by scientific investigators for scientific data analysis.

The baseline Voyager MOS is composed of a GDS, two flight operations teams, and a collection of fully demonstrated operating procedures. Voyager management actively pursues a continuous improvement process to assure that the operational MOS is based upon the latest available technology, and incorporates new tools and processes as they become available. This continuous improvement process has kept the Voyager Project at the cutting-edge of mission operations engineering, and has resulted in the Project pioneering the operational use of new multimission capabilities, often becoming the prototype user for new capabilities developed for future flight projects.

The systems that comprise the Voyager Project GDS are Telemetry, Command, Sequence, Spacecraft Analysis, Data Records, Tracking, Monitor and Control, and Simulation. The TMO Directorate provides multimission subsystems that constitute significant portions of the GDS.

Development of the Discovery MOS will require modification of the Voyager GDS to add the capability to process Discovery spacecraft command and telemetry data. This will be done in a manner that minimizes the addition of new hardware, and exploits existing software capability.

GDS Design and Development

The design of the Discovery Project GDS will be approached from the perspective that a minimum cost design will maximize use of existing capabilities. This implies that requirements will be imposed on the Discovery Project spacecraft data system design to avoid unnecessary incorporation of new data format definitions, spacecraft clock design, decommutation schemes, etc. that would cause significant rework of current ground system capabilities. A design team of ground system developers and Discovery contractor spacecraft engineers will be tasked with identifying and developing a set of minimum impact requirements and detailed design specifications that will likely require some compromise on both sides of this interface. A process for concurrent spacecraft data system-GDS design will maximize communications and shorten the development life cycle.

The Discovery GDS will include:

- a telemetry front-end processing capability providing: recovery from lost, noisy and disorganized data; detection and removal of data handling and transmission artifacts; removal of redundant data; distribution of data for display, analysis, and storage.
- a sequence development, validation, and command generation and transmission capability.
- a science data processing capability including: full-capability science data processing providing for data manipulation, editing, enhancement, archival storage, remote access and retrieval, Experiment Data Record production, and Planetary Data System

hand-off; or as preferred by the experimenter, quick access to science data processed only to eliminate recoverable gaps and add any required ancillary data.

- a spacecraft navigation capability providing: pre-launch tracking requirements analysis; conventional radiometric navigation; maneuver design and analysis; when required, optical navigation.

Recommendations for Low Cost Mission Operations

MOS Development

i. Minimize life cycle costs by maximizing re-use of existing capabilities. This is feasible if: the sharing Projects do not have missions that conflict with one another in terms of peak activity periods; a unique MOS is not required; and greatly different skills are not required to operate each mission.

ii. Design the spacecraft data system to meet existing ground system interfaces, and avoid requiring unusual data formats, data modes, derived parameters, etc.

iii. Foster a concurrent MOS-spacecraft engineering process. Utilize a simulation capability to develop and demonstrate ground system/spacecraft interfaces and compatibility as the spacecraft evolves. Extend the GDS to the investigators home institution, and to spacecraft developer facilities. These same ground system nodes will later serve to support delivery of science data, support inputs to the uplink process, and support spacecraft subsystems analysts in event of a spacecraft anomaly.

iv. Build ample margin into the spacecraft subsystems. This includes adequate onboard storage to avoid frequent and mandatory data playback, adequate power margin such that science instrument power sharing will not be required, adequate telecommunications link margin to avoid reliance on scarce large aperture ground antennas, etc. There will be trade-off decisions that affect spacecraft margins, and it must be kept in mind that the smaller these margins become, the more complex and costly operations will become.

Flight Operations

i. Develop a sequencing strategy that is compatible with your partners. Voyager Project will utilize a repeating baseline sequence with periodic overlay sequences. Do not plan a strategy that either requires a separate sequencing capability, or drives operations costs by adding complexity to the sequence process.

ii. Utilize extensive cross training of personnel to provide increased availability of operations support personnel to both missions with a minimum of additional staffing.

iii. Minimize cruise activities, such as cruise science. Use onboard autonomy to reduce tracking coverage required for spacecraft performance and health monitoring.

Conclusion

Flight projects that do not have overriding requirements for unique MOS capabilities or for standalone operations can reduce operating costs by reusing rather than inventing, and by partnering with compatible projects to share MOS expenses. Voyager Project is actively pursuing this concept with a Discovery-class partner, and is planning to demonstrate the practicality and cost benefit of our shared operations concept.