DISCOVERY Planetary Mission *Operations* **Concepts**

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ABSTRACT

The NASA Discovery Program of small planetary missions will provide opportunities to continue scientific exploration of the solar system in today's cost-constrained environment. Using a multi-disciplinary team, the Jet Propulsion Laboratory has developed plans to provide mission operations within the financial parameters established by the Discovery Program. This paper describes experiences and methods that show promise of allowing the Discovery Missions to operate within the program cost constraints while maintaining low mission risk, high data quality, and responsive operations.

Planetary mission operations concepts are surveyed, with an emphasis on low-cost strategies and experiences. The major factors that determine mission operations cost are identified and approaches to management of mission operations costs are presented. A taxonomy of mission operations functions is described and examples of several Discovery-class organizational approaches are presented. Also described are multi-mission ground system services that will allow Discovery missions to share tracking, data capture, command, and navigation support.

The Discovery Program will encourage the development of missions with smaller, more focused, spacecraft. We in mission operations must respond with correspondingly small, efficient mission operations concepts and ground data systems.

1. Introduction

Mission operations include all the activities required to fly a spacecraft and execute a mission once the spacecraft is launched. Even at its simplest level, this activity requires complex data collection, data analysis, and data archiving. Ground operations provides data that allows the project members to do activities that are essential to the mission:

- Navigate the spacecraft to, and point the instruments at, the target of interest
- Assess the health, maintain the safety of, and control the spacecraft and its instruments
- Collect, process, distribute, and archive the scientific data

2. Mission Operations Services

Figure 1 is a stylized depiction of the set of operations services required of a typical mission. Mission operations for Discovery missions will not be organized along traditional lines where each service is typically provided by a team of people. On Discovery missions, there will be fewer teams; perhaps on some missions only one team. On some Discovery missions several services may be provided by a few individuals – or even one. Other missions may use a reduced set of services. Other Discovery missions may chose to delete part of a service. The full set of services are presented here to provide a reference for common understanding.

Mission Planning

Mission Planning is predominately a prelaunch activity. During operations this service is responsible for assessing adherence to the mission plan and maintaining and updating the plan. This service responds to unforeseen mission events, determines the effect on mission objectives, and, if required, performs replanning to optimize mission objectives.

Science Planning and Analysis

Science Planning and Analysis supports the PI/Science Team planning of science observations and the assessment of instrument health and performance. Personnel providing this service collect science observation requests into a single, integrated, activity plan based on mission science objectives. This function then generates activity requests required to implement the plan. Instrument engineering and science data are analyzed to ensure that the investigation is performing as expected.

Spacecraft Planning and Analysis

This service is responsible for the maintenance, health, safety, and repair of the spacecraft. This includes all uplink and downlink activities required to monitor, calibrate, and evaluate the performance of spacecraft subsystems . Additionally, this service maintains and updates flight software, and maintains and operates the flight system simulator (if one exists) . Generation and maintenance of flight system specifications (safe-operation envelope, operational constraints, etc.) required by operations are also functions of this service.

Navigation

This service is responsible for delivery of the spacecraft to its target(s) . This includes planning and gathering of radio metric data as well as determining and validating the spacecraft orbit/trajectory. To carry out this responsibility, this service also maintains knowledge of the ephemerides of the target body or bodies.

There are four primary factors that

Sequence Development

This service is the integrator of all uplink activity requests from Science Planning and Analysis, Spacecraft Planning and Analysis, and Navigation. It is within this service that conflicts are identified for resolution and sequences are validated. A major role of this service is to provide output products that can be used by the various Flight Team members as they work, collectively, to resolve conflicts and validate sequences.

Mission Control

This service is the real-time service for controlling, monitoring, and operating the mission. Both flight and ground elements of the mission are under the cognizance of this service.

Data Transport and Delivery

This service is responsible for transport of data to and from the spacecraft, and for delivery of data throughout the ground system. Provided as part of this service is a central data base for uplink and downlink data to accommodate easy access by Flight Team and science users. Radio signals from t-he spacecraft are processed to extract instrument science and spacecraft engineering data, which is then delivered to users and to the data base. Spacecraft commands are processed, modulated on the radio channel, and then transmitted to the spacecraft. This service encompasses those services provided by both the Deep Space Network (DSN) and the Advanced Multimission Operations System (AMMOS).

Science Data Processing

Science Data Processing extracts instrument data and constructs instrument data records. Experiment data records are created, after processing to the level specified by the PI, which include science instrument data and selected engineering and ancillary data. Hardcopy products are also available, if desired, through this service.

An ancillary information system called SPICE is available to assist Discovery PI teams in mission planning, observation planning, and

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	MGN 2/92	MGN 2/93	MGN-LMGT 10/93
Mission Operations Management	22 - Mgmt. 63 - SE	13 - Mgmt. 3 - SE	7 - Mgmt. 0 - SE
Mission Planning and Analysis	7	3	1/2
Navigation	5	4	2
Sequencing	12	z 1/2	0 (incl. in S/C Team)
Science Planning and Analysis	24	5	1 1/2
Spacecraft Planning and Analysis	57	30	12
Ground Data System	12	4	2
Mission Control and Operations	42 (incl. MMCT ??)	35 (incl. MMCT ??)	5 1/2 (incl. MMCT ??)
Science Data Processing	48	22	1 1/2
	292	121	32

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Figure 2 Mission Operations Staffing

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MISSION	STAFFING LEVEL	MISSION DESIGN	SPACECRAFT	OTHER
Magellan	32	• Precision gravity-field mapping of Venus • No atmosphere science	• No radar ops • System-level staffing • Solar panels	• A/ O 'middle' management • Combined s/c and sequence teams • Combined mission planning and science teams
Ulysses	26	• Polar solar orbit	• Simple spacecraft • Body-fixed instruments • System-level s/c analysis • RTG powered	• No office managers • Sequencing done by s/c team • Science planning & analysis function done by s/c team • Relaxed Navigation reqmts
Voyager	24	• Two spacecraft in inter-stellar space • Relayed mission objectives	• ? instruments • UVS on scan platform • RTG powered	• 3-level organization • Uses continuous-running sequence w/ overlays • Sequence built from on-board blocks of pre-tested commands • Accepts data loss if DSN unavailable
SME	18 + Nav	• Studied ozone levels in upper atmosphere	• 6 science instruments • System-level s/c analysis	• Working-level Mission Directors • No mission planning • Sequencing done by science planning & analysis • Used some graduate students

Figure 3 Mission Operations Benchmarking

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5. Low-Cost Mission Operations Concepts

This set of low-cost mission operations concepts was assembled by researching techniques, tools, and practices that are currently in use as well as tapping the knowledge base and experience of the people who design and build the systems used for operations.

Mission Design Concepts

1. Provide repeat opportunities for science observations. Avoid single-opportunity events which can never be repeated. The concept is to design a mission which includes time margin in its data-taking srategy.

2. Plan to allow adequate time between events (maneuvers, data taking, etc.). Avoid fast-turnaround events which drive up staffing levels. This is another time-margin concept.

3. Plan for simple, non-time-critical tracking by ground stations. This means to avoid real-time downlink of data but also includes avioding multi-purpose passes containing complicated radio metric as well as telemetry/command data tasks, Planning and scheduling of ground tracking resources is a human-intensive task and often involves compromise. Flexible missions, will probably get more tracking time.

Flight System Design

1. Design the flight system with sufficient margins for parameters which have to be managed, monitored, or controlled by the ground system. Inadequate (or negative) margins drive ground system costs by requiring more precise models, more accurate trend monitoring, more precise maneuver placement, or more human-intensive decision making and scheduling.

2. Design automated flight system functions (e.g., memory management, attitude/pointing control). Truely automated functions may be automated on-board or on the ground but do not require careful monitoring, trending or predicting by the ground.

3. Reduce the number of commendable states. State tracking by the ground system requires considerable effort. This is one factor which defines a "simple" spacecraft.

4. Make the flight system insensitive to bad commands. Design the flight system so that the ground system does not have to produce zero-defect command sequences at all times. During critical periods, the ground system can be expected to produce zero-defect commands, but to expect that level of performance at all times is costly.

Management Policies

Management policies affect the entire conduct of the mission but those policies which most influence operations cost are risk avoidance policies, Here are some examples:

1. Try-again-tomorrow. Given a mission design which contains margin in its data gathering strategy, managment must still implement policies that take advantage of that fact.

2. Prioritized Risk Avoidance. Examine the entire mission timeline and assign a risk metric to each phase. Ground operations can then tailor or select its activities (verification, validation, modeling/simulation, etc.) to accomplish an appropriate level of risk avoidance.

3. Establish requirements for an on-board fault detection/recovery system which can be relied on, one that doesn't have to be exited from immediately. And then trust it.

4. Reduce performance modeling and predicting. Often we build automated systems (e.g., thermal, power, etc.) but then choose to monitor, model and predict the expected performance. Limit these type of activities to those phases that are high-risk.

Ground System Operations

1. Multi-tasking. our experience as we have "re-engineered" several mission operations teams is that multi-tasking is very beneficial, Multi-tasking allows the Mission Director to retain unique personnel by employing them in two tasks.

2. For relatively short missions, some of the traditional functions can be eliminated by assigning the task (if it is diminished because of the simplicity of the mission) to a team whose primary responsibility is some other function. For example, on simple missions, the PI/Science Team could take responsibility for

the in-flight mission planning and analysis function.

3. Operate the spacecraft at a "system-level" rather than retaining experts for each on-board subsystem. The system engineers must have a broad understanding of the spacecraft (ideally having been involved in design, development, and test phases). To accommodate system-level staffing, it is imperative that the spacecraft be designed with sufficient subsystem margins (e.g., memory size, power, etc.). It is also necessary to make some arrangement with the spacecraft builder to retain experts on each subsystem to respond when an anomaly occurs.

4. Sequence development cost can be reduced by introducing a number of approaches :

- Reduce the number of sequences.
- Minimize sequence iteration opportunities (no late updates) .
- Dedicate segments of the timeline to specific activities (e.g., science observations, engineering, maneuvers) ,
- Develop recallable "blocks" of sequences.

5. Take advantage of existing multi-mission ground system capabilities. Examples include:

- Telemetry/science data Processin9
- Command/sequence planning and development tools
- Networking and remote science data terminals
- Multi-mission teams (mission control, archiving, navigation)

6. Additional Information

Additional inforamtion regarding Discovery low-cost mission operations concepts may be obtained by requesting the following publications:

1. *Discovery* Mission *Operations Design Handbook,* JPL D-11351

2. *Discovery Mission Operations Reference Guide,* JPL D-11668

These publications may be obtained from Esker Davis, manager of JPL's Discovery Office:

- Telephone (818) 354-4343
- Fax (818) 354-0712
- E-mail ESKER_K_DAVIS@JPL.NASA. GOV

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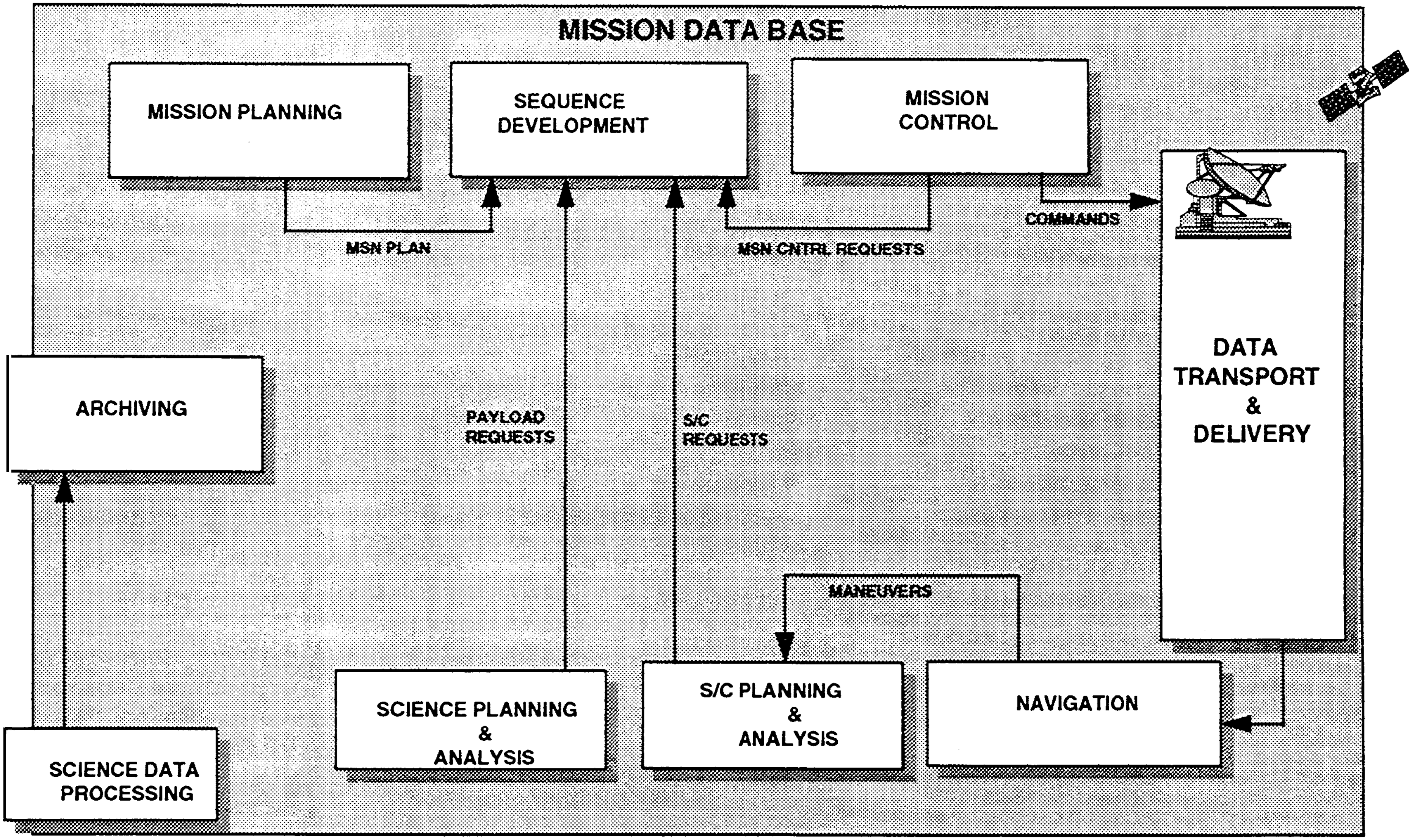

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Figure 1 Traditional Mission Operations Services