GENERIC MISSION PLANNING CONCEPTS FOR SPACE ASTRONOMY MISSIONS

N94-23878

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ABSTRACT

The past two decades have seen the rapid development of space astronomy, both manned and unmanned, and the concurrent proliferation of the operational concepts and software that have been produced to support each individual project. Having been involved in four of these missions since the '70's and three yet to fly in the present decade, the authors believe it is time to step back and evaluate this body of experience from a macro-systems point of view to determine the potential for generic mission planning concepts that could be applied to future missions. This paper presents an organized evaluation of astronomy mission planning functions, functional flows, iteration cycles, replanning activities and the requirements that drive individual concepts to specific solutions. The conclusions drawn from this exercise are then used to propose a generic concept that could support multiple missions.

Key Words: Space astronomy, mission planning, generic functions, design drivers, operations.

1. INTRODUCTION

Recent trends toward subsystem commonality in astronomy spacecraft and the concurrent desire to drastically reduce ground system support costs set the stage for concomitant reductions in the resources required when developing new mission planning concepts. The time has come for a careful evaluation of astronomy missions flown during the last twenty years, including lessons learned, to determine the basic mission planning and scheduling functions and their commonality from mission to mission. A logical organization of the requirements for a generic astronomy mission planning system can and will materialize from this evaluation. The three main areas to analyze are: 1) mission planning functions, 2) functional flow considerations, and 3) design drivers. After examining the three areas thoroughly, it becomes very simple to describe the generic system and its core elements. A well-defined and implemented generic system will pay dividends by being able to support multiple satellites and by centralizing software maintenance and revisions.

2. MISSION PLANNING FUNCTIONS

The first step in this analytical approach is to look at each mission planning system (past, present, and future) and dissect it into its component functions. This process was done without regard for how the functions are packaged in software programs. The main generic functions that resulted from this analysis are described below.

2.1 Observation and Engineering Request Processing

The nature of astronomy mission planning requires a great deal of flexibility in receiving and processing observation requests. The astronomer using the system must be able to easily submit, edit, and track requests until implementation. In like manner, engineering requests arising from spacecraft health and safety considerations must also be developed by flight operations teams and entered into the scheduling stream where they can be merged with science requirements. This function may also serve as an executive driver for the other functions.

2.2 Orbital Mechanics

Because orbital mechanics is the foundation on which an astronomy mission plan is built, the mission planner should have easy access to the spacecraft ephemeris. The orbital mechanics function should be able, based on the ephemeris, to produce rise/set times for any point in the sky. Also, the mission planner will need to be able to calculate line-of-sight angles for the spacecraft and/or its pointings. These pointings are evaluated for compatibility with the spacecraft and instrument constraints. The orbital mechanics function must also be able to track other satellites, Sun, Moon, and planet positions, compute ground site and South Atlantic Anomaly (SAA) entry/exit times and earth occultation periods, and generate spacecraft ground tracks.

2.3 Guide Star Selection

Once a target is chosen, the spacecraft will need to be given some guide stars near the target to fine tune the pointing angles and lock on the correct target. This can be done by the mission planners in a very straight-forward fashion. Software that incorporates the pointing algorithm of the telescope and the very latest star catalogs can be used to facilitate this task. The software should allow the user to easily manipulate star tracker/aspect camera characteristics in case of a partial or complete sensor failure. Depending on mission-specific constraints, the guide star selection function may run independently or in response to the scheduling function.

2.4 Scheduling

With observation and engineering requests and orbit mechanics data as inputs, the scheduling function produces and verifies an integrated spacecraft and viewing schedule. Past experience suggests that this scheduler should be able to work in two modes, manual and automatic. For a generic system, scheduling constraints should be easy to create, edit, and decipher. The manual mode should employ graphics capabilities using a mouse to insert and move observations and other events throughout the schedule. The product of this function should be a mission schedule that is completely free of constraint violations.

2.5 Editing

Once a schedule is produced, the next task is to be able to edit it. This function is necessary because mission schedules are usually generated weeks before execution, making them vulnerable to contingencies and significant ephemeris prediction errors. The editor should employ extensive graphics using a mouse to drag events around on the screen. The editor will include ephemeris information and target position information to calculate rise/set times as needed. Once a target is inserted into the schedule, it can be selected to show information about it at that time in the schedule. Since the editing function actually changes the schedule, it must also have a comprehensive validation capability to assure that the results maintain the schedule's integrity.

2.6 Communications Planning

Communications scheduling depends greatly on the interaction among spacecraft attitude and trajectory and satellite/ground site availability. For unmanned missions, communication opportunities are determined 3-4 weeks ahead of time; however, on Space Shuttle missions, the schedule is more determined by spacecraft orientation rather than communication satellite availability. Either way, the mission planner must have a way of determining communication opportunities and be able to send contact requests to and receive schedules from the Space Network (SN) or the Deep Space Network (DSN).

2.7 Spacecraft Management

Following schedule development, the spacecraft subsystem responses to execute scheduled events must be defined. Good design practice in modern astronomy satellites makes it more feasible to separate this increasingly independent function from the scheduling process. Events planned in the timeline, such as maneuvers and target pointings, dictate corresponding support from spacecraft appendages and subsystems. Solar array and high gain antenna movement and gimbal positions as well as data storage and communication device activities are included in this function.

2.8 Flight Operations Team Support

The mission planning and scheduling process by its very nature produces much information that is useful to flight operations teams. Typically, this information is displayed on a large screen in a control center and/or fed to TV monitors and workstations to provide a focus or reference for mission operations.

2.9 Command Management

Although not a mission planning function per se, command management is included here for completeness because in some projects it is combined with mission planning as a matter of convenience or as the result of organizational responsibilities. On Spacelab missions, it is not a part of the mission planning and scheduling system.

MISSION PLANNING FUNCTIONS
• Observation and Engineering Request Processing
• Orbital Mechanics
• Guide Star Selection
• Scheduling
• Editing
• Communications Planning
• Spacecraft Management
• Flight Operations Team Support
• Command Management (optional)

Table 1. Mission Planning Functions

3. FUNCTIONAL FLOW CONSIDERATIONS

3.1 Modularity/Flexibility

As a mission planning concept becomes more generic, its component functions must be more modular and flexible. This is particularly true of the orbit mechanics and scheduling functions, which must satisfy the biggest share of project requirements and constraints. Each astronomy mission flown in the past has had its own unique set of science observation requirements and spacecraft operations, and although there is a tendency now towards some commonality, new software and science instrument advances will in the future spawn new requirements and options unforeseen today.

To posture itself for this onslaught of unknowns, the generic system must strive for a clean separation of the mission planning functions described above. Mission unique features can be modeled as input rules, algorithms and logic options in a scheduler with a standard user interface. Constraints that arise late in project development or due to flight contingencies can often be satisfied by clever manipulation of orbit mechanics data. Functional modularity pays extra dividends by allowing standalone analysis of special operational problems and by making it possible to easily reorder functional flows whenever mission experience or contingencies dictate a change in the mission planning functional flow process.

3.2 Flow Sequence Optimization

One of the most important considerations in mission planning concept design is the order in which individual functions are performed. Careful attention to the sequence of activities involved assures an efficient, smooth-flowing system and saves many hours of extra effort during mission operations. A poorly designed flow, on the other hand, will cause many unnecessary iterations, confusion and added risk of error. For example, the checking of target visibility constraints after an observation has been scheduled instead of before is an open invitation to an endless iteration loop. The authors have noticed two errors in mission planning task flow that are common to many past and existing systems. One of the most ubiquitous mistakes is mixing orbital mechanics constraint calculations with scheduling algorithms in a minute-by-minute "sneak up on the limit" procedure. This approach is very repetitious and wasteful of computational resources. It is far more efficient to analytically solve for constraints such as target rise/set times one time in the orbit mechanics function and feed this information to the scheduling function.

Another common mistake is the early computation of spacecraft support events and commands in the scheduling process, long before they are actually needed. Combining these three independent functions creates a large amount of data that normally must sit around for several weeks before execution, making it vulnerable to contingencies and last minute changes. Changes to such volumes of data are labor-intensive and prone to error.

This last point illustrates another strong consideration in flow sequence optimization. External planning cycles, such as TDRSS resource scheduling, often dictate the generation

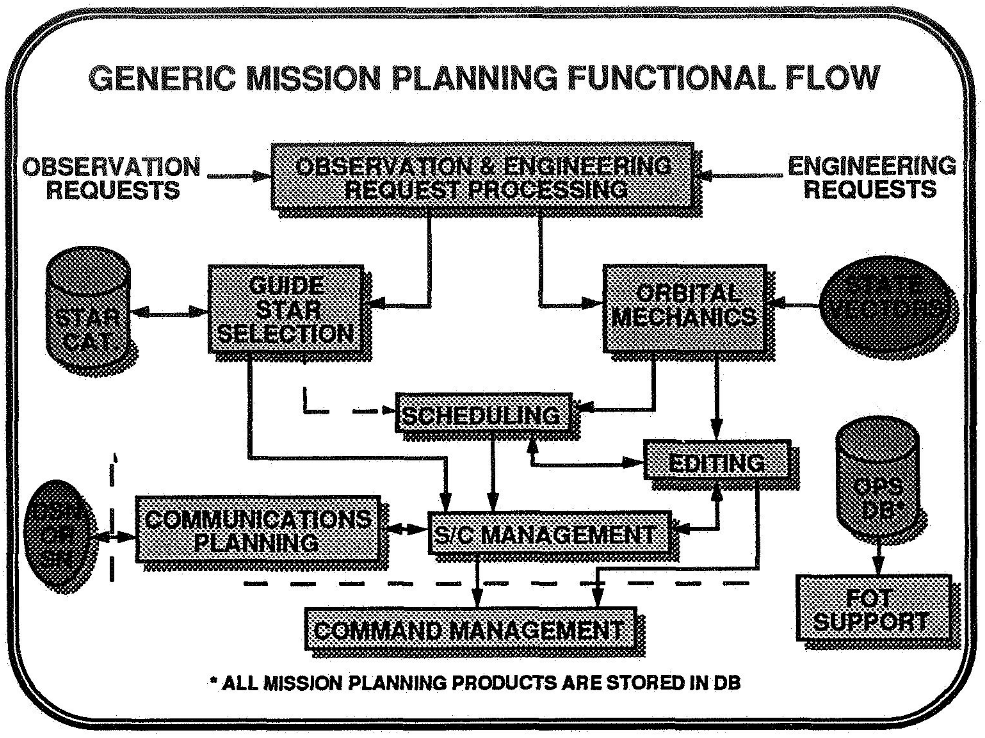

Figure 1. Generic Mission Planning Functional Flow

of observation schedules several weeks before they are required by a control center. This factor also leads to the conclusion that data should be generated when it is needed to minimize vulnerability and control center workload.

In summary, the two most important mission planning flow optimization principles are (1) perform the functions in the most efficient order to minimize iterations and (2) generate the mission planning products at the right time to minimize editing workload.

4. DESIGN DRIVERS

4.1 Science Instrument and Spacecraft Complexity

Fortunately, the major design drivers that affect astronomy mission planning concepts are relatively few (See Table 2). Of these, one of the most important is the complexity of science instrument and spacecraft design and the interaction between them. The pickle-shaped fields-of-view of the Hubble Space Telescope (HST) Fine Guidance Sensors (FGS), for example, created a dependency among spacecraft attitude, guide-star selection and seasonal variations in target availability. Likewise, the dynamic rate of data production from its science instruments, ranging from micro-seconds to hours, sometimes makes it necessary to make a trial run through the command management system to assure that on-board memory and/or uplink restrictions will not be violated by projected observation schedules.

4.2 Real-time Requirements

Another closely related design driver is a requirement for real-time interaction with the spacecraft. This situation usually arises from the necessity to pinpoint faint object location and field orientations that are not well-known. To provide this capability, a link must be established between communication schedules done 3-4 weeks in advance and observation schedules. Last minute changes in planned contacts cause complex schedule interactions and require preplanned contingency procedures.

4.3 Manned vs. Unmanned

Compared with unmanned operations the advent of manned astronomy with the Astro-1 mission brought a new set of problems that significantly affect mission planning system design. Actually this design driver is composed of a number of different factors, but for purposes of this analysis they can all be attributed to having a "man in the loop." Two of these factors involved in Space Shuttle operations are the relatively short mission durations and frequent occurrences of launch delays, both of which dictate the independence of the orbital mechanics function, and the strong need for an efficient schedule editor and flexible scheduling software.

DESIGN DRIVERS
• Science Instrument and Spacecraft Complexity
• Real-Time Requirements
• Manned vs. Unmanned
• Interfaces
• Orbit Type

Table 2. Design Drivers

4.4 External Interfaces

Although rarely the result of any definitive requirement, the external interfaces with a mission planning system often have a significant effect on shaping its design. Organizational structure, roles and responsibilities, operational philosophies and the practicalities associated with shared facilities play an important part in concept development. These factors are normally assumed rather than being explicitly derived. For example, an organization responsible for both spacecraft and science operations will typically merge these independent functions together for convenience. Also, scheduling and command management are commonly combined if these responsibilities reside under a common directorate.

4.5 Orbit Types

The last, but definitely not least, design driver is orbit type. Because of the more rapid progression of environmental constraints, low earth orbit (LEO) missions are much more complex to plan than high earth orbit (HEO) missions. Similarly, highly elliptic orbits present more ephemerides prediction and timing problems than do circular orbits.

5. CONCLUSIONS

5.1 The Generic System

After examining the component functions involved in a number of mission planning concepts, it appears that, if not one, at least a small number of generic systems are feasible. In fact, a first step towards a common concept might well be generic systems for certain types of missions. If this approach is taken, the authors recommend dividing the systems by orbit type and manned/unmanned operation. In any case, heavy emphasis should be placed on making the component functions as independent as possible, so that they can later be linked into one generic system. The generic system proposed by the authors is illustrated in Figure 1.

5.2 Core Elements

The key to making the transition from these interim generic systems to one system is the identification of "core" elements that change very little (or not at all) from mission to mission. Once these elements are standardized and used on several missions, the other elements can be examined one at a time to determine how they could be incorporated into the next-generation system. This close scrutiny will bring about new innovations in concept design and implementation, eventually leading to one generic system. Even if it doesn't make sense to provide a function that works for all missions, it is very possible to hook alternatives into the system. A prime example might be a different scheduler for manned and unmanned missions.

In like manner, functions and subfunctions not required for certain missions could be unplugged from the generic system. Spacelab missions, for example, don't need the spacecraft management element since the Shuttle Mission Control Center at Johnson Space Center performs this function.

In any case, all space astronomy missions share much common ground in the planning activities that must be performed to implement observation requirements. The time has come to examine these commonalities in search of a generic system to support future missions.

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