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SciBox, an end-to-end automated science planning and commanding system

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A B S T R A C T

SciBox is a new technology for planning and commanding science operations for Earth-orbital and planetary space missions. It has been incrementally developed since 2001 and demonstrated on several spaceflight projects. The technology has matured to the point that it is now being used to plan and command all orbital science operations for the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission to Mercury. SciBox encompasses the derivation of observing sequences from science objectives, the scheduling of those sequences, the generation of spacecraft and instrument commands, and the validation of those commands prior to uploading to the spacecraft. Although the process is automated, science and observing requirements are incorporated at each step by a series of rules and parameters to optimize observing opportunities, which are tested and validated through simulation and review. Except for limited special operations and tests, there is no manual scheduling of observations or construction of command sequences. SciBox reduces the lead time for operations planning by shortening the time-consuming coordination process, reduces cost by automating the labor-intensive processes of human-in-the-loop adjudication of observing priorities, reduces operations risk by systematically checking constraints, and maximizes science return by fully evaluating the trade space of observing opportunities to meet MESSENGER science priorities within spacecraft recorder, downlink, scheduling, and orbital-geometry constraints.

1. Introduction

Science operations planning requires coordination of many spacecraft and instrument teams (including subsystem engineers, orbit and pointing analysts, command sequencers, mission operators, and instrument scientists) and commonly calls for multiple iterations to coordinate, de-conflict, review, and test an operational command sequence. The process is iterative, time-consuming, and labor intensive. When a project schedule is tight, limited iterations can be performed, and spacecraft resources are frequently not optimally utilized. Missions tend to invest considerable time and effort in the development of mission-specific planning processes, adding to the mission development budget and schedule.

In this paper we describe SciBox, an end-to-end automated science planning and commanding system. The system begins with science objectives and operational constraints, derives the required observing sequences, schedules those observations, and finally generates and validates uploadable commands to drive the spacecraft and instruments. The process is automated, and there is no manual scheduling of science operations or construction of command sequences. SciBox has been developed

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and demonstrated incrementally over the last 10 years on several spaceflight missions. The current state of SciBox and its usage on MESSENGER are the focus of this paper.

2. Traditional science operation planning

Traditional science operations planning is a complicated and iterative process. It normally begins with scientists requesting observations from various elements of a suite of instrument subsystems, to image a planetary surface or sample an atmosphere or magnetosphere at specified geometries. A team of planners works closely with instrument scientists and guidance and control (G&C) analysts to search for appropriate observation opportunities and design the spacecraft pointing operations, and with highly skilled instrument sequencers to construct matching instrument command sequences. If there is a scheduling conflict between subsystems, the command sequence is further iterated, often with human-in-the-loop adjudication. When an acceptable command sequence to control the G&C pointing and drive instruments is constructed and tested, it is forwarded to engineers to validate that the sequence is within operational constraints. If there is no violation, the command sequence is then forwarded to mission operators for integration with an overall schedule. This process is illustrated in Fig. 1.

Usually there is more than one instrument team involved in a space mission. Collaboration between teams requires a more complex planning process to coordinate observations and avoid conflicts. Such cooperation can involve multiple iterations of planning [1–3], staggered to support continuous daily or weekly operation. The entire process can be labor intensive and requires multiple shifts of planning teams to manage the staggered phases. Multiple reviews and tests are conducted to ensure that science objectives are met and that operations sequences comply with all mission health and safety rules. The iterative coordination, review, and testing are time consuming, resulting in sequence development times of weeks or

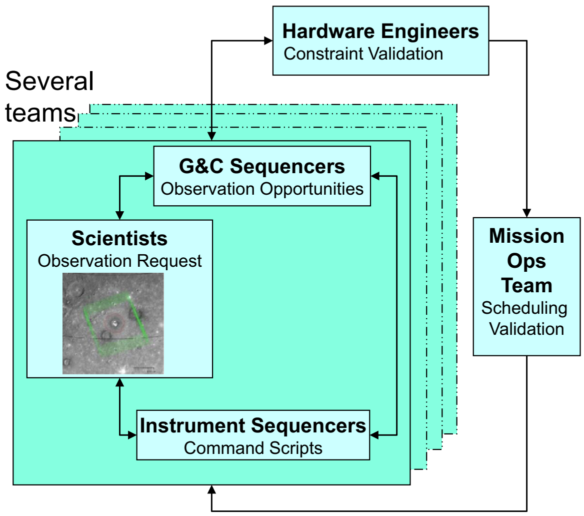

Fig. SEQ Figure * ARABIC 1. Traditional science operation planning process.

months. In cases where the sequence of operations is determined manually, it may not simultaneously achieve high data quality with minimized usage of key resources such as observing time, space on the solid-state recorder (SSR), or downlink bandwidth. When short-term changes in operating conditions occur, observations can be dropped, underutilizing available resources.

3. SciBox's streamlined planning process

SciBox's approach to improving planning efficiency is to treat the process as a series of streamlined steps, each with the objective of achieving the highest value science possible with available resources by optimizing the operations sequence using an integrated software system. The rearranged processes are illustrated in Fig. 2. They begin with science-observation *opportunity analyzers* customized to each type of science measurement. Instead of searching for single observing opportunities, the opportunity analyzers search all available opportunities, for example, to image a particular region at a defined observing geometry, or to acquire a spectrum at a given latitude and longitude. Opportunities are ranked by metrics that represent measures of data quality such as resolution or illumination. Through simulations, time- or altitude-phased thresholds are defined for instrument configurations (e.g., spatial pixel binning and allowable ranges of data-quality metrics) to accomplish measurement objectives within resource constraints. To minimize conflicts, periods are defined during which different instruments are given priority, although comparison of data-quality metrics between instruments allows interleaving of data acquisition to prevent "exclusion" of any instrument from key observing opportunities.

For each potential observing opportunity that is selected, an automated, rules-based *constraint checker* systematically validates the observing operation to ensure that it complies with all operational constraints. The validated observing opportunities are then sorted according to priority and by their data-quality metrics (weighted by the number of available observing opportunities). With the list of sorted, weighted observing opportunities, a software *scheduler* selects the best combination of observations, first placing the highest-ranked and then successively lower-ranked observations into a timeline until available resources are used up. An automated *command generator* then ingests the conflict-free schedule and generates spacecraft and instrument commands for uploading to the spacecraft.

4. SciBox development history

Development of the SciBox planning and commanding architecture was begun in 2001 [4] on the MESSENGER mission. In order to bring the proposed theoretical architecture into reality, key SciBox software modules were developed and demonstrated incrementally over 10 years on a variety of spaceflight projects at the Johns Hopkins University Applied Physics Laboratory. In 2001 the opportunity analyzer concept was demonstrated on the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) mission 〈http://www.timed.jhuapl.edu/〉, an Earth