

ISS PAYLOAD OPERATIONS: THE NEED FOR AND BENEFIT OF RESPONSIVE PLANNING

Ed Nahay* and Mandee Boster**

**Teledyne Brown Engineering
P.O. Box 070007, Huntsville, Alabama, USA 35805
FAX: +1-256-544-5405**

***E-mail: ed.nahay@pobox.tbe.com**

****E-mail: mandee.boster@pobox.tbe.com**

Abstract

International Space Station (ISS) payload operations are controlled through implementation of a payload operations plan. This plan, which represents the defined approach to payload operations in general, can vary in terms of level of definition. The detailed plan provides the specific sequence and timing of each component of a payload's operations. Such an approach to planning was implemented in the Spacelab program. The responsive plan provides a flexible approach to payload operations through generalization. A responsive approach to planning was implemented in the NASA/Mir Phase I program, and was identified as a need during the Skylab program.

The current approach to ISS payload operations planning and control tends toward detailed planning, rather than responsive planning. The use of detailed plans provides for the efficient use of limited resources onboard the ISS. It restricts flexibility in payload operations, which is inconsistent with the dynamic nature of the ISS science program, and it restricts crew desires for flexibility and autonomy. Also, detailed planning is manpower intensive.

The development and implementation of a responsive plan provides for a more dynamic, more accommodating, and less manpower intensive approach to planning. The science program becomes more dynamic and responsive as the plan provides flexibility to accommodate real-time science accomplishments. Communications limitations and the crew desire for flexibility and autonomy in plan implementation are readily accommodated with responsive planning. Manpower efficiencies are accomplished through a reduction in requirements collection and coordination, plan development, and maintenance.

Through examples and assessments, this paper identifies the need to transition from detailed to responsive plans for ISS payload operations. Examples depict specific characteristics of the plans. Assessments identify the following: the means by which responsive plans accommodate the dynamic nature of science programs and the crew desire for flexibility; the means by which responsive plans readily accommodate ISS communications constraints; manpower efficiencies to be achieved through use of responsive plans; and the implications of responsive planning relative to resource utilization efficiency.

Introduction

Payload operations' planning encompasses the definition of the sequence and timing of payload operations to occur onboard the ISS. Results of planning drive the implementation and control of the ISS science program. When necessary, the plan is maintained in real-time to accommodate unexpected or requested changes to the course of planned events. Examples of unexpected changes include sudden resource non-availability and unanticipated results of science program implementation.

A payload operations plan can be defined at any level of fidelity. A detailed plan provides a refined level of definition. It specifies the exact sequence and timing of individual components of each payload's operations. A responsive payload operations plan provides a less refined level of fidelity. It

combines individual components of a payload's operation into groups. These groups become the individual components that comprise the plan.

The type of plan implemented onboard the ISS, whether responsive, detailed, or some variation thereof, has a direct impact on the ability to accomplish science. Through assessment of the characteristics of detailed and responsive plans, it becomes readily apparent responsive planning is the most feasible approach to science onboard the ISS.

Characteristics of ISS Payload Operations

The ISS is a continuously operating on-orbit facility, with a ten to fifteen year life span. The primary purpose of the ISS is to provide a laboratory for conducting long duration science in a microgravity environment. Onboard operations are conducted through automation, commanding, and crew activity. The payload operations plan defines the sequence and timing of the payload operations to occur onboard the ISS.

The long duration operations environment of the ISS provides unique opportunities with regard to accomplishing science. On previous space-based science programs, such as Spacelab, opportunities for science were limited in duration, defined by the length of the individual Spacelab mission. The ISS, as a long duration space-based platform, provides the opportunity to define, plan, and implement long duration science programs. These programs are afforded the opportunity to adjust operations based on results, rather than strictly adhering to predefined sequences of operations. This is due to the payload hardware being resident onboard the ISS for periods sufficiently long enough to accommodate such changes.

The long duration operations environment of the ISS also poses challenges. The onboard crew, resident for periods of 3 to 6 months, must be afforded the privilege of managing their daily course of activity. Such a concept is counter to the mode of operation on Spacelab. There the crew adhered to a detailed schedule to ensure completion of all defined science objectives.

Another challenge facing payload operations, given the long duration ISS operations environment, pertains to the availability of space to ground communications. Because the ISS is a long duration-orbiting platform, communications assets, such as TDRSS, are not devoted to ISS; they are shared with other space-based platforms. Restricted communications limit the ability of the ground function to monitor and control ISS payload operations in real-time.

As with any long-term operations program, manpower expenditures are a continuous challenge. The ten to fifteen year lifespan of the ISS demands an efficient approach to operations; neither budgets nor personnel can sustain a rapid and meticulous approach to operations planning and plan maintenance. Instead, the ground control function must be streamlined, which in turn affects the approach to payload operations planning.

Payload Operations Planning

The payload operations plan can be specifically structured to accommodate the unique characteristics of the ISS operations environment. Payload activities can be defined at a high level to accommodate responsiveness based on science results. Unscheduled payload activities can be included with the plan to accommodate the crew's desire for flexibility in operations implementation. Activities which require space to ground coordination can be scheduled in accordance with all known communications asset restrictions. The fidelity of payload operations plans can be adjusted to accommodate plan development and maintenance manpower budgets.

The extent to which the unique characteristics of the ISS operations environment are accommodated in the payload operations plan is dependent on the specific approach to planning. Where the objective is maximizing the quantity of science, independent of the need for flexibility in operations, a detailed

payload operations plan is developed. Where the objective is maximizing the quality of science while accommodating flexibility in operations, a responsive payload operations plan is developed.

The current approach to ISS operations is to develop and implement detailed payload operations plans. Such an approach ensures the expected payload operations manifested on the ISS are completed, provided there are no payload or onboard system failures. However, the detailed plan does not provide for a robust science program; significant changes in the proposed course of payload operations, based on science results, are not readily accommodated. Also, the crew desire for managing their daily activity is not fulfilled.

As the ISS payload operations program progresses, a transition to responsive payload operations planning will be mandatory. Scientists will push for quality of science over quantity. Crew operations will have become routine, leading to crew requests for flexibility in defining their daily course of activities. And the push for "better, faster, cheaper" will have driven ground control functions to streamline their manpower requirements. Further justification for this need to transition from detailed to responsive planning is provided through an in-depth assessment of the characteristics of these two types of planning.

Detailed Payload Operations Plans

The primary difference between detailed and responsive payload operations plans is the level of fidelity of planned payload operations. A secondary difference pertains to the need to provide the crew with the ability to manage their daily activity. Other differences pertain to communications coverage availability and ground support required to develop and maintain the plans.

Detailed payload operations plans are characterized by a highly refined timing and sequencing of payload operations, with few, if any, payload operations left unscheduled. Figure 1, Detailed Payload Operations Activity Requirements, depicts the characteristics of payload operations requirements specifications that comprise a detailed plan.

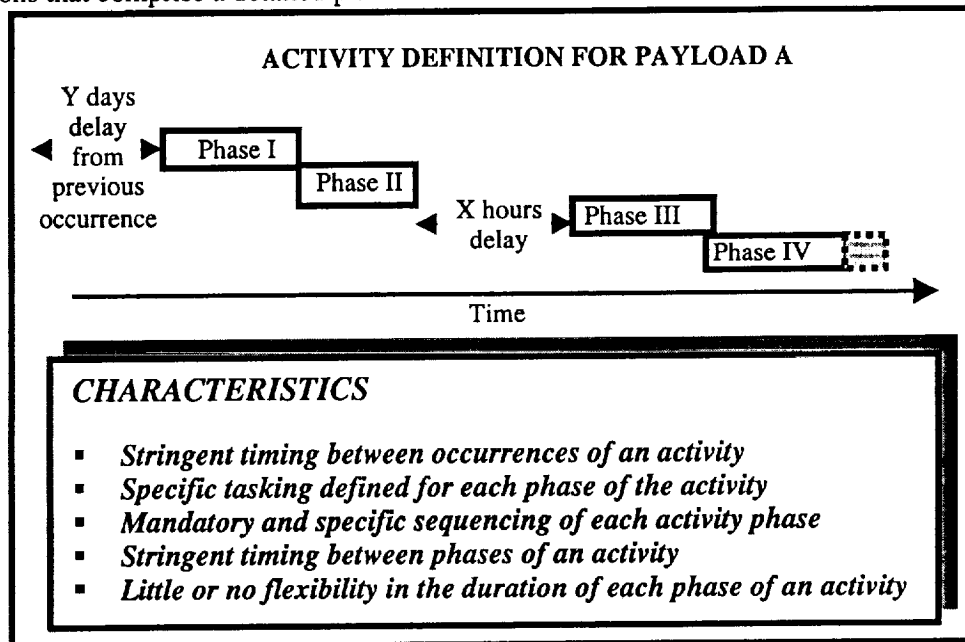


Figure 1, Detailed Payload Operations Activity Requirement

To accomplish detailed payload operations planning, the activities that comprise individual payload operations are defined in significant detail. Principle investigators responsible for defining payload operations requirements may prefer this level of specification for the following reasons: it conserves their budget of available resources by specifically identifying when and how resources are used; and it accommodates payload operations that must adhere to critical timing constraints to ensure success.

Payload operations during the ISS assembly phase mandate detailed requirements specifications. This is due to the significant number of assembly operations that occur in parallel with payload operations. Given the need to maintain critical timing of these assembly operations, there is no latitude for flexibility in payload operations. Given the limited resources available to payloads during the ISS assembly phase, there is little tolerance for the inefficient use of onboard resources. Once the payload operations are defined in detail, a plan is developed which integrates the payload operations with the station assembly operations.

A detailed payload operations plan is characterized by the intricate interweaving of payload activities with assembly activities. There is little flexibility as to when a specific portion of a payload's operations can start or end. Adjusting either the start time or the end time of a payload operation in real-time will probably impact the ability to start or complete an assembly operation on time. Given the high priority of assembly operations, such a change to a payload operation plan is not likely. Therefore, detailed payload operations planning is appropriate only during the ISS assembly phase. Once the bulk of assembly operations are complete, detailed payload operations plans become inconsistent with the preferred mode of operations onboard the ISS.

Detailed payload operations planning does not readily accommodate the needs of the steady state (post assembly phase) ISS for the following reasons:

- Payload operations response is limited – The detailed payload plan is not responsive to the results of real-time payload operations. A primary consideration in the implementation of science is evaluating and responding to results. Detailed payload planning, driven by detailed requirements specifications, assumes specific operational outcomes. Plans are built in accordance with these assumed outcomes. However, science is not inherently predictable; time and resources must be available to continue exploration of unexpected results. The detailed payload operations plan, with its intricate interweaving of payload operations, restricts the ability to respond to unexpected results without adversely affecting other operations.
- Little or no crew flexibility in operations implementation – Consistent with the limited payload operations response to results is detailed planning's inherent limited opportunity for crew flexibility. As previously stated, payload activities in detailed plans are intricately intertwined. Placement of the activities on the detailed plan is dependent on stringent operations constraints and resource limitations. As a result, science programs are optimized with respect to resource utilization. This means there is little resource availability to support crew flexibility. With detailed planning, crew flexibility is usually limited to payload activities with few operations constraints or resource requirements. Given these activities amount to mundane chores, they do not satisfy the crew request for flexibility in operations. The crew prefers to have the opportunity to manage their daily activity with regard to science program implementation. To do so means opening the opportunity for flexibility to include activities with specific science objectives. This translates into maintaining a margin of resource availability to accommodate the flexibility, which is counter to the objectives of detailed planning.
- Limited access to communications resources – The need to share communications assets with other space based programs limits communications resource availability to the ISS. As time progresses, more space-based platforms will be vying for the already limited communications assets, further eroding availability to the ISS. Limited communications restricts space to ground communications, minimizing the ability to control and monitor onboard payload operations. Instead, payload operations have to occur independent of the ground, either through crew control or onboard-automated processes. The detailed payload operations plan does not provide the opportunity for flexibility required to control operations independent of the ground. A more robust plan, which provides for flexibility in operations, is required to accommodate the reduced communications asset availability.
- Manpower intensive operations planning and plan maintenance – Detailed payload operations planning is in direct conflict with the specific push for “better, faster, cheaper”, as it relates to ground support personnel. The detailed activity requirements specifications required for detailed payload operations planning must be coordinated between the planning function and the principle

investigator that defines the requirements. This coordination ensures the specific requirements for payload operations are properly modeled in the planning system software, and therefore properly represented on the detailed plan. The more refined the activity requirement specification, the more time the ground support personnel must spend in coordination and modeling. Once the activity requirement specifications are defined, coordinated, and modeled, they must be placed on the timeline. This is a manpower intensive activity considering the various timing and sequencing constraints associated with each component of the activity definition. Maintaining the plan in real-time is also manpower intensive; any change in one payload's operations is likely to affect another.

It is because of these shortfalls the detailed payload plan should not be used during steady-state ISS operations. Its inability to accommodate responsive payload operations and the drive for flexibility in crew operations implementation requires a transition to a plan that is more accommodating: the responsive payload operations plan.

Responsive Payload Operations Plans

A responsive payload operations plan is characterized by the ability to accommodate flexibility in operations and the opportunity for the onboard crew to manage their daily activities. A responsive payload operations plan also readily accommodates the implications of limited communications resource availability. Also, responsive payload operations plan development is less manpower intensive than is detailed payload operations planning.

The ability to accommodate flexibility in operations through responsive payload operations planning is based on the development and implementation of high-level operations requirement specifications. Figure 2, High-level Payload Operations Activity Requirement, depicts the characteristics of such a specification. The same operations requirement specification exemplified in Figure 1, Detailed Payload Operations Activity Requirement, is displayed in Figure 2 as a high-level specification. Notice the primary difference is the fidelity of defined operations. Where the detailed requirements specification provides the specific timing and sequencing of individual components, the high-level requirements specification defines the operation as fewer but larger components.

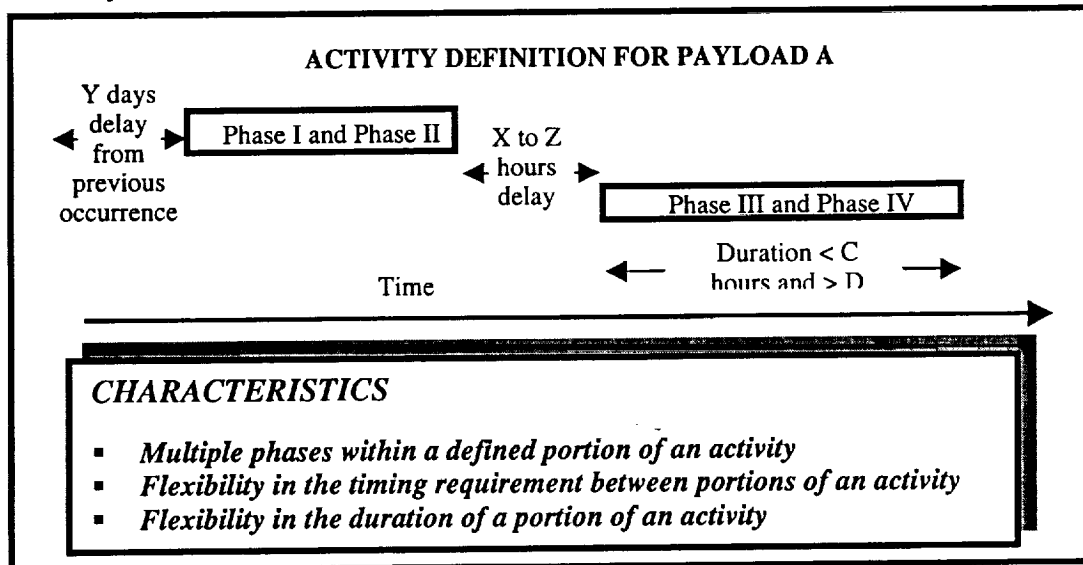


Figure 2, High-level Payload Operations Activity Requirement

Implementation of the responsive payload operations plan, comprised of high-level specifications, affords flexibility in operations based on science program status. Figure 3, Flexible Payload Operations, depicts the means by which flexibility in payload operations is achieved through high-level specifications. It compares payload operations, as planned, to a possible implementation of payload operations, given the use of high-level payload operations requirements specifications. The

primary tradeoff, compared to detailed specifications, is the potential for inefficient resource usage. Where science operations proceed as expected, with little or no required change in operations sequencing or timing, the resources made available to accommodate flexibility are not needed. These same resources however may provide the onboard crew the flexibility to manage their daily activities.

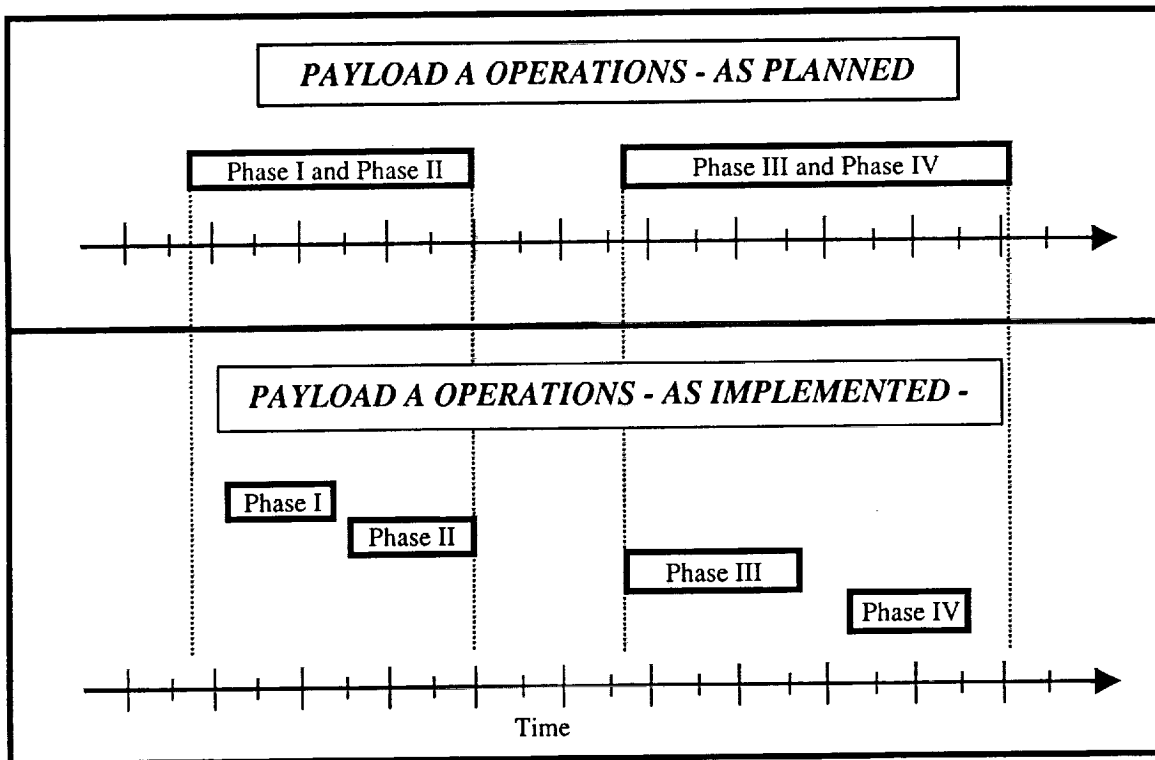


Figure 3, Flexible Payload Operations

The crew prefers to manage their daily course of activities, independent of intervention or oversight from the ground control function, once they become familiar with the routine of onboard operations. The responsive payload plan affords this opportunity through resource availability. It has already been determined the high-level resource requirement specification concept may lead to resource utilization inefficiencies. Any available resources can be used at crew discretion to conduct operations selected from a predefined list, thus enabling the crew to decide their daily activity. The list of payload operations to be implemented at crew discretion would identify the resources required to complete the operation. Figure 4, Crew Flexibility in Operations, depicts the means by which the onboard crew can select activities they prefer to implement, based on resource availability. The list of payload operations to be implemented at crew discretion would be limited to those that do not require significant resource requirements or stringent timing and sequencing constraints. Obviously, the more detailed the operation, the less likely the crew would find the opportunity for its implementation. Included on the list would be the resource requirements corresponding to each operation.

Responsive payload planning readily accommodates communications resource limitations. Given the flexibility corresponding to use of high-level requirements specifications, the crew has the ability to adjust science operations independent of a real-time interface with the ground control function. This is critical for periods where communications assets are not available to the ISS, but decisions must be made in real-time.

A final consideration regarding responsive payload plans pertains to manpower. Payload operations requirements specifications defined at a high level require little coordination between the requirement developer and the planning function. Developing a plan comprised of high level requirements is less manpower intensive than developing a plan comprised of detailed requirements. Also, implementation

of changes to the plan can occur independent of ground control function intervention, because resources are available to accommodate flexibility in operations. This reduces the manpower required to support real-time responses to requested payload operations plan changes.

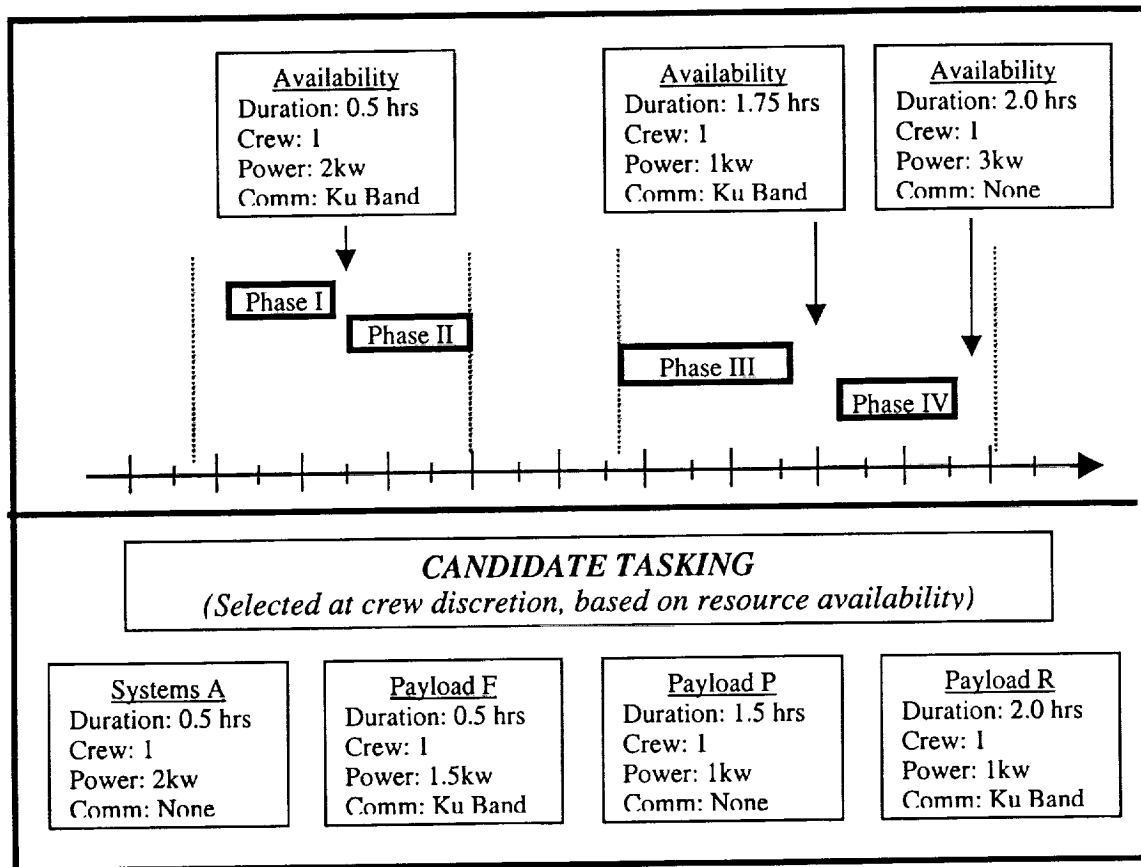


Figure 4, Crew Flexibility in Operations

The responsive payload plan provides for a responsive science program and crew flexibility in performing operations, while minimizing dependence on communications assets and ground control function manpower. But these advantages come at a cost. Development, planning, and implementation of high level requirements can lead to a reduction in the quantity of science performed, in comparison to that of detailed planning. The responsive payload plan can also lead to resource utilization inefficiencies. However, these costs have to be weighed against the advantages of science program quality and the ability to accommodate the crew request for autonomous operations.

Transition from Detailed to Responsive Payload Operations Plans

The detailed payload operations plan is compatible with the assembly phase of operations. There are sufficient timing constraints and resource limitations to justify the tradeoff between the quality and quantity of science accomplished. However, as the ISS program transitions from the assembly to the utilization phase, the approach to payload operations should transition to the development and implementation of responsive payload plans. This will provide the test bed for evaluating the affects of high level requirements specification on science program quality and the crew desire for flexibility. By the time assembly operations are complete, and the ISS is steady state, the responsive payload operations plan should be fully implemented. This will ensure a quality science program while meeting the needs of the crew.