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Shuttle Operations Era Planning for Flight Operations

John D. Holt
Chief, Payload and Operations Support Branch, NASA Lyndon B. Johnson Space Center, Houston, TX 77058

David A. Beckman
Payload and Operations Support Branch, NASA Lyndon B. Johnson Space Center, Houston, TX 77058

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Payload and Operations Support Branch
NASA Lyndon B. Johnson Space Center
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David A. Beckman
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Abstract

The Space Transportation System (STS) provides routine access to space for a wide range of customers in which cargos vary from single payloads on dedicated flights to multiple payloads that share Shuttle resources. This paper describes the flight operations planning process from payload introduction through flight assignment to execution of the payload objectives and the changes that have been introduced to improve that process. Particular attention is given to the factors that influence the amount of preflight preparation necessary to satisfy customer requirements. The partnership between the STS operations team and the customer is described in terms of their functions and responsibilities in the development of a flight plan. A description of the Mission Control Center (MCC) and payload support capabilities completes the overview of Shuttle flight operations.

Introduction

The STS is an integrated system consisting of the Space Shuttle vehicle (Orbiter, external tank, and solid rocket boosters) upper stages, payload(s), and any associated flight hardware and software. Operation of the system requires launch, landing, and turnaround processing facilities; the flight control facilities of the MCC; and the STS communications network which will be a combination of the tracking and data relay satellite system (TDRSS) and the space tracking and data network of ground stations.

The key element to opening this new era of routine space operations is the Space Shuttle system. The Orbiter can accommodate many standard or unique payloads in its large cargo bay and deliver them to orbit.

Four types of upper stages are planned to deliver payloads beyond the Orbiter's Earth orbit. Satellites headed for geosynchronous, elliptic, and higher circular orbits can use the solid inertial upper stage (IUS). Deep space or planetary probes will employ the "wide-body" Centaur stage which is under development. Satellites of the Delta or Atlas-Centaur weight and volume class can use payload assist modules (PAM's) capability to effect a smooth transition from existing expendable launch vehicles. Another solid propulsion stage, the transfer orbit stage, is under development and will fill the gap between PAM and Centaur or IUS.

The details of the STS operator and customer relationship is best described in terms of the basic flight operations concept for the operations era of the Shuttle that was envisioned in 1980.

Flight Operations Concept

In Shuttle operations planning, the key words are "standard" and "adaptable." To provide cost-effective access to space and to support the projected flight rates with the flexibility required by the traffic model requires an evolution from the flight operations approach employed in past programs. Every aspect of the flight operations process was examined in the light of new STS goals and the functions were simplified and standardized where possible without compromise of crew safety or undue reduction of mission success probability.

The foundation of the operations concept of the STS consists of standard plans and equipment, using standard interfaces (both human and hardware), a few basic types of flights, and a building block set of flight phases. Figure 1 illustrates the concept.

The customer can select among several options in equipment, thereby tailoring a flight to his needs. The experiment hardware then interfaces with a total hardware and procedural system. On-orbit, many operational adaptations of standard techniques and procedures are available. Because of the standardized concepts, customers are now able to plan and concentrate on the design and effectiveness of their own payloads, assured that these payloads will be compatible with the Shuttle and its flight operations.

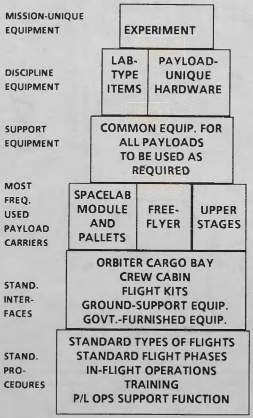


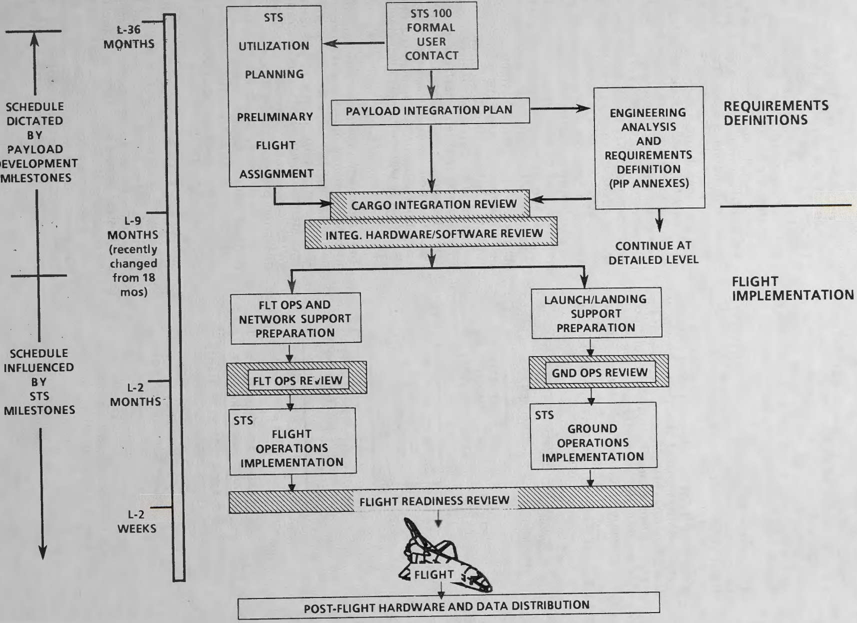
Figure 1 - The standardized building blocks of the STS operations concept

In developing this flight operations support concept, it was important that the responsibilities of the STS flight operations elements and the customer responsibilities be well defined since the flight operations is conducted as a partnership. Of utmost importance to STS flight operations was the responsibility to streamline the interface between customer and the STS and to provide continuity of support personnel from the initial planning through flight. It was deemed necessary to provide for customer-controlled payload operations while retaining STS management visibility and control of operations resources. In addition, it was recognized that management of STS flight operations had to assure adequate support for payload operations activities which includes providing Orbiter attitude and pointing control, power, thermal control, communications and data retrieval, and consumables management to guarantee accomplishment of customer objectives. As important was the responsiblity to manage the Orbiter systems in a manner which allows the crew to concentrate on payload activities. In all cases, an effort has been made to strike an effective balance between standardized interfaces, procedures and schedules, and accommodation flexibility. For operations issue resolution, a payload operations working group was chartered to deal directly with customers on behalf of the STS.

The fundamental customer responsibility was to provide management and direction of all payload activities, both preflight and in-flight. All payload mission planning requirements and identification of STS services required were also customer-provided. The payload operating procedures, flight operations decisions to be followed for confirmed failure and payload training for the flight crew are all customer responsibilities. The customer must also provide his own payload operations team and training for this team.

The STS flight operations team is composed of the flight controllers in the MCC at the Johnson Space Center (JSC) and the basic flight crew made up of a commander, pilot, and mission specialists. There are also many other people at JSC associated with the planning and preparation of a successful flight operation. These people are involved in the development of the flight profile, the implementation of the mission control facilities,

FIGURE 2 STS/PAYLOAD INTEGRATION PROCESS



and the training and simulations associated with preparation of the flight operations team for the mission.

The payload customer team is responsible for the activities within the flight having to do with the operation of the payload. Through this team, the customer's requirements, payload objectives, and constraints are reflected in the payload mission plan and payload-specific procedures which will be integrated with the Shuttle flight operations planning.

Flight Operations Planning

The flight operations activities in support of a mission normally begin with receipt of the payload integration plan, approximately 2 to 3 years prior to the scheduled launch date. During this early timeframe, one or more compatibility assessments may be performed for the purpose of identifying and evaluating potential impacts associated with supporting the proposed payload (Figure 2). The payload may be the sole reason for a flight or part of a cargo consisting of other payloads.

The detailed flight operations preflight planning activities are initiated after the cargo integration review (CIR) when the manifest is approved. The CIR assures that the payload complement is physically and operationally compatible with the STS. The complexity involved in conduct-ing the detailed preflight planning activities is a function of the mission complexity as well as the number of times a given type of flight and/or payload has already been flown. These planning activities consist of four independent functions: (1) flight design, (2) crew activity planning, (3) flight operations support planning, and (4) training planning and development. As shown in figure 3, each of these functions, which will be discussed subsequently, is accomplished through the joint efforts of both the JSC flight operations team and the payload or customer team.

Figure 3 - Flight Operations Planning

Flight Design

The end result of the flight design activity is a detailed trajectory and flight profile that includes such information as maneuver sequences, attitude and pointing, orbital parameters, consumables analyses, and communications coverage. The detailed trajectory and flight profile is prepared by JSC approximately a year before launch for complex and new types of flights, and is based on customer requirements such as approximate launch date, mission duration, altitude, and inclination. It then becomes the basis for much of the other planning activities.

Crew Activity Planning

Crew activity planning is the analysis and development of required activities to be performed by the crew. Crew activity timelines (referred to as the crew activity plan (CAP)) plus any necessary procedures and reference data to accomplish the flight are developed by both the JSC STS operator and customer and stowed onboard in the STS and payload flight data file (FDF).

The STS summary CAP is developed in a timeframe compatible with the CIR. This document incorporates the reference flight profile and schedules crew activities for the STS flight phase (launch, rendezvous, entry, etc.), crew work/rest cycles, and crew personal and system maintenance periods. The STS summary CAP is coordinated with the customer to create a single integrated summary CAP. Those STS activities required to support the payload activities are also scheduled. Also accomplished during this planning period are detailed STS and consumables analyses for the flight, using the reference flight profile and the CAP as the basis for the analyses. As a result, consumables budgets and redlines for the flight are produced.

The customer then develops payload documentation consistent with STS constraints and schedules which is required to accomplish payload flight objectives. The payload operation procedures, malfunction analysis procedures, and payload decision criteria are submitted through the PIP flight operations support annex and are translated into flight crew procedural documentation by STS flight operations personnel. This assures a standard format and consistent nomenclature.

Operations Support Planning

The involvement of the customer in real-time flight operation must be considered in formulation of the operations support plan. The range of options is enormous and varies from monitoring a single action to activate a small middeck experiment to complex interactions of crew activities and ground commanded functions to accomplish payload objectives. Factors which must be considered are customer location, amount of payload command and telemetry available, and the time-critical nature of the activity. Where payload ground analysis is required at a remote customer location, network support must be arranged consistent with the crew activities.

Training

The training preparation task for a specific flight begins with the determination of training requirements. If new facilities or capabilities are needed, they must be identified far enough in advance to allow funding and design work. Once the training requirements have been identified, standardized training plans will be modified to fit the flight requirements, the training facilities will be scheduled, the simulation scripts written, and the actual training performed to support both flight crew and flight controller tasks. All STS-related training, both for onboard and flight control personnel, is the responsibility of JSC. All payload-related training is the responsibility of the customer. Close coordination is therefore required to achieve a compatible and balanced training plan.

Effort is made to validate each FDF element with the training or simulation facility which is most representative of the in-flight environment. The flight crew and flight controller training process is also the means of final operational integration of the mission and develops the necessary confidence in the flight plan and procedures.

Mission Control Center and Payload Operations Control

During actual flight conduct, flight operations support is provided jointly by the flight control team and the payload operations team.

Flight operations command and control facilities are provided in the MCC which is located at JSC. Facilities for the use of payload operations teams are in the same complex. For all flights, the MCC provides systems monitoring and contingency support for all STS elements, provides two-way communications with the crew and onboard systems, performs flight data collection to a central site, and provides a preflight and in-flight operational interface with the payload operations team to coordinate flight operations.

The customer options available to support payload activities are to either come to JSC for the flight and simulations or to establish an interface from a customer remote payload operations complex (POCC). JSC has some capability to house customer representatives in the MCC to provide proximity to the flight control team. This will be allocated on a per-flight basis as a function of the amount of command and telemetry associated with the payload. The JSC POCC is dedicated to Spacelab support.

Specific types of payloads require variations in the interface support provided by the MCC. The MCC operation has sufficient flexibility to accommodate all types of missions with varying degrees of customer participation and STS services to payloads. The operations concepts are intended to provide cost effective and convenient services in response to individual customer needs.

Coordination between the MCC and the payload operations team is conducted primarily by the flight director and the payload officer located in the flight control room. The flight director will provide the management interface for all real-time decisions which involve joint STS and payload interests. The payload officer is the primary working interface for coordinating payload operations with the STS flight operations. Dedicated flights involving a single customer typically have clear lines of communication with tradeoffs made by the customer and decisions presented to the STS. Mixed cargoes require that priority be established prior to the flight since the STS operations team must integrate the requirements of multiple customers.

The responsibility for managing and staffing the payload operations teams lies with the customer ; thus, the organization structure is flexible and may vary somewhat from one flight to another. However, the customer is expected to designate a spokesman who has overall responsibility for all payload operations decisions.

A subset of the same data that are available to the STS controllers within the MCC can be made available to the customer. All commands through the Orbiter to payloads will pass through or be initiated at the MCC. The intent of the Shuttle command system (onboard and ground system) is to provide for maximum transparency to payload commands, while retaining adequate control for crew safety. Some specialized preflight planning with the customer is necessary to achieve this goal.

Where ground initiated command is a principal method of operating, an STS/payload command plan is developed and jointly agreed upon by JSC and the customer, with particular attention given to the countdown, launch, insertion, and payload activation sequences. All payload commands that constitute a hazard to the Orbiter are identified jointly by the customer and JSC before the flight and the protocol for these commands is carefully coordinated during the preflight planning. The customer may add to the list any commands considered hazardous to the payload operations. The joint command list is entered in a special "safed" MCC command software category requiring multilevel checks before the command can be sent to the Orbiter.

<u>Current Planning Experience</u>

The flight experience to date has established an impressive array of tools to increase man's effectiveness in space. EVA is becoming an acceptable method for some operations. The MMU is expected to expand this capability significantly. The remote manipulator system (RMS) has proven to be an effective means of handling payloads. Spacelab has shown that the shirt sleeve environment in the module can provide the capability for round-the-clock operations. The Orbiter has demonstrated excellent flexibility as orbital laboratory and orbital launch platform. These tools will continue to be refined in an effort to provide increased flexibility in design of flights and payloads within the range of STS services.

The previous Shuttle flights have proven the STS planning process to be an effective means of meeting the payload customer's requirements. The PIP and annex process has allowed the customer to state requirements and have them translated into crew procedural checklists, facility requirements, and flight plans. For repeat payloads, every effort has been made to standardize the PIP annexes and checklists by developing generic documents. Payload operations working groups have given a forum for resolving operational issues, developing support plans, and clarifying customer requirements.

Cargo Manifest Experience

The original flight operations concept was based upon a high flight rate, standard trajectories, flights dedicated to single customers or compatible customers, Shuttle consumables margins sufficient to avoid optimization, and with reflight as an alternative. With this as the baseline, it is obvious that the cargo integration process has presented a challenge to operations planning. There is a strong desire by NASA to obtain maximum return on investment for a flight and to provide the maximum flight opportunity for customers with available payloads. In general, the cargo manifest approaches the capability of the Shuttle launch performance, mission duration capacity, and/or telemetry data capacity. Mission duration limits may be either attitude control propellant or cryogenic consumables needed for power demand and life support.

Where these situations exist, it has been necessary to use optimization techniques to insure that Shuttle safety margin is preserved while customer requirements are satisfied. This optimization is typically very sensitive to trajectory considerations, such as, launch date, ground station coverage, lighting considerations, and pointing requirements. Launch delays usually require extensive revision of existing plans and flight crew documentation. Another contributor is the late addition of a payload which requires extensive crew operation, addition of the RMS, and EVA, or telemetry processing. This can require a complete revision of all preflight analyses.

Since cargo requirements are the sum of all payload requirements and payload requirements are negotiated before the cargo is defined, optimization may be required to satisfy the customer requirements. Crew activity plans can become extremely complicated and offer little or no opportunity to recover from anomalies. In several instances, a customer, who will be part of a mixed cargo, has developed an operating timeline and then built scheduling requirements which would, in effect, force an inflexible timeline on the STS. This results in wasted effort for the STS and the customer when the manifest is established since conflicts invariably result and require much late rework.

Small payloads of opportunity require much the same attention as more expensive payloads. If the payload has acceleration constraints or sun pointing restrictions, scheduling can be very complex.

Customer Experience

The planning for a mission can be rather complex, particularly for customers encountering the process for the first time. In response to this situation, the STS operations elements will concentrate their limited resources toward assisting first-time customers and rely upon the self-sufficiency achieved by experienced customers and integration contractors for repeat business.

The key to providing effective customer service within flight operations is to maintain continuity from the initial preflight contact (as early as possible) through the flight. For first-of-a-series payloads, FDF product development is scrutinized so that the repeat payloads can use generic documents. This has been very successful with the Hughes 376/ McDonnell-Douglas PAM series.

Cargo Integration Process Changes

NASA has instituted some schedule modifications in an attempt to establish a cargo which is more likely to fly as manifested. In the original baseline, a cargo baselined at the CIR held 18 months before launch was frequently changed until Orbiter performance limits were reached, or changes to the Orbiter hardware or software could not be accommodated. The CIR and integrated hardware/ software reviews are now scheduled at 9 months prior to launch in an attempt to define a cargo which has better understood requirements, better guarantees of hardware available, and a better chance of launching within the planned launch window. This is expected to reduce the extensive replanning cycles and the heavy resource expenditure that accompanies it.

Trends Affecting Operations Planning

McDonnell-Douglas Aerospace Corporation includes the services of a PAM flight operations team in the contract for a PAM. After several flights of over-the-shoulder monitoring for safety compliance, STS flight operations has now accepted the PAM team as the flight control team element for PAM support. This has proven to be an effective technique for acquiring indepth experience and knowledge for preflight planning and flight execution. There are other possible applications for this type of customer-provided services which may be developed in the future.

There is work under way to provide an alternative to payload use of the Orbiter flight software. The flight software has substantial capability but the configuration must be frozen well before flight to permit the final integration and verification to be performed. These steps are necessary since the payload software is resident in the same computer as Orbiter support systems software. A payload microprocessor separated from the Orbiter data processing system is viewed as an alternative and several concepts have emerged in industry and within NASA.

Spacelab 1 was a resounding success. It was also one of the most complicated flights to plan and execute. Future Spacelab flights are planned to be dedicated to a scientific discipline to reduce the exotic tradeoffs of a multiple discipline flight.

The planning for Department of Defense flights involves national security and is conducted in a classified environment. There are obvious inefficiencies involved. In addition, flight operations has historically been conducted in an unclassified mode which has required an attitude change on the part of the STS operator. Actual flight experience must be gained before the process can be completely assessed.

Centaur greatly enhances the payload delivery capacity of the Shuttle, but requires Orbiter software modification to dump the cryogenics during launch aborts. As a result, JSC will assume time critical safety responsibility while Lewis Research Center will retain responsibility for mission success and spacecraft-to-stage integration.

Summary

The record of STS successes is testimony to the effectiveness of the operations planning process - a process, however, that is continuing to evolve in response to experience and other factors. Although multiple payload manifests and the manned vehicle necessarily introduce some complexity, the planning process is intended to reduce its impact on customers while at the same time retaining the primary objectives of mission safety and flexibility. Teamwork is the key. Each team member, whether customer, government, or aerospace manufacturer must understand and be sensitive to the roles and responsibilities of the other members. Such a team can make the most effective use of the STS and open the benefits of space to all.

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