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SPACE SHUTTLE PAYLOAD ACCOMMODATION
AND TRENDS IN CUSTOMER DEMANDS

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ABSTRACT

Current space policy limits the assignment of primary payloads on the Shuttle to those requiring manned presence or the unique capabilities of the Shuttle. While exceptions to these criteria have been allowed due to other compelling circumstances, it has essentially resulted in the removal of deployable satellites from the Shuttle manifest. In the pre-Challenger environment the Shuttle's performance capabilities were efficiently utilized by co-manifesting NASA science experiments with commercial deployable satellites. The absence of these commercial payloads has resulted in a Shuttle manifest primarily oriented to science and technology payloads. The diverse on-orbit operational requirements of these payloads results in future shared-cargo missions which are considerably lighter and more complex.

This paper will review payload demands for Shuttle resources and services in the pre-Space Station Freedom (SSF) time frame. Requests for flight in both the Orbiter cargo bay and middeck will be considered. Factors limiting more efficient use of the Shuttle will also be discussed.

INTRODUCTION

Demands for Shuttle services will be assessed according to the type of accommodations needed: cargo bay or middeck. Both of these areas have constraints limiting efficient utilization of resources available for payloads. While there has been some improvements in Orbiter payload accommodations allowing for increased payload capability, discussion of these services will be deferred until after review of customer demands and mission trends.

Assessment of demand is based on payloads manifested on the Shuttle in the August, 1991, Payload Flight Assignments NASA Mixed Fleet Manifest (PFANMF) and on secondary requirements submitted to the Office of Space Flight. The PFANMF contains only a small fraction of the payloads requesting flight. Only those payloads requiring significant integration activity or flight planning are shown for missions scheduled more than a year away. Simple sidewall mounted experiments, middeck payloads and GAS canisters are added to flights between 7-12 months before launch. While these simple payloads are not shown in the out years, they comprise over 80 percent of payloads flight requests.

CARGO BAY PAYLOAD DEMAND

Cargo bay demand will be divided into subclassifications based on payload requirements for assessment purposes. The first category is primary payloads. These are major payloads which alone or in combination with others, justify a Shuttle flight. The next classification is secondary payloads. These are typically smaller than 8,000 lbs and 7 1/2 feet in length and are manifested on a space available basis after the primary payload assignment. They are not to require more than quarter-bay services or drive the mission flight design. This is generally true today, but there is a trend towards more complex and operationally intensive cargo bay secondaries. The last payload category is the Get Away Special (GAS). These payloads are flown in canisters along the Orbiter sidewall or on an across-the-bay carrier called the GAS Bridge Assembly (GBA). GAS payloads are flown on a space available basis after primaries and secondaries are considered.

Primary Payloads

Primaries are flown on dedicated or shared Shuttle missions based on the payload resources required. Discounting SSF flights, 62 percent of the total payloads shown in the PFANMF are primaries. Less than a third of these need dedicated flights.

Though a small percentage of the total, the dedicated primaries do consume a large portion of the Shuttle's flight rate capability. Five of the seven flights in fiscal year (FY) 92 are dedicated; FY 93-96 average three dedicated flights; and starting in FY 96 when SSF assembly begins, there are only two non-SSF dedicated flights per year until SSF completion. After 1992, missions can be broken down into three categories: Spacelabs (primarily constrained to OV-102 for missions of greater than 13 days), Shuttle Radar Labs (SRL), and HST servicing missions. The latter two payloads desire OV-105 for its high performance capability, while allowing for mission duration of up to 10 days.

The main concerns associated with dedicated payloads are ascent performance and mission duration. The average weight for dedicated payloads is approximately 23,000 lbs. The Orbiter can easily lift this weight to the 160 nautical mile standard altitude, but most Spacelab flights are planned as Extended Duration Orbiter (EDO) missions and are impacted by approximately 10,000 lbs of additional EDO equipment. Additionally, OV-102 (weighing about 8,000 lbs more than the other Orbiters) is the only Orbiter currently configured to support EDO. The SRL and HST missions are performance limited because of their respective nonstandard inclination and altitude requirements. Mission duration concerns are due to a desire to maximize science by extending payload operations to 9 days or more on-orbit. Currently, only OV-102 and OV-105 have the fifth cryo tank set necessary to provide this capability.

Shared primaries average considerably less in weight (11,100 lbs each), thus, the shared cargo missions are rarely constrained by ascent performance. These payloads are increasingly difficult to manifest because of other resources, particularly on-orbit operations time. While shared primaries in the pre-Challenger time frame made up approximately the same percentage of demand (67 percent), the main service required was lift capability. The operational duration of each payload in that era averaged slightly over one day. Today, operations average 3.5 days. It is not difficult to see that if payloads are unable to operate simultaneously then mission duration will limit the number of payloads that can be co-manifested.

Unfortunately, operational duration is not the only requirement that negatively impacts efficient utilization of the Shuttle. Approximately, 1/3 of the shared primary payloads require Remote Manipulator System (RMS) operations. This typically indicates a rendezvous with an already free-flying spacecraft or a deploy and retrieval of a spacecraft on the same mission. Ground-up rendezvous of a free-flying spacecraft is not usually feasible until the middle or latter part of a mission due to phasing requirements. However, rendezvous maneuvers or burns are normally required earlier in the mission. This often constrains or disrupts operations of other co-manifested payloads. In addition, Orbiter propellants may not be sufficient to support the scheduling of two retrievals on the same mission. Sequential operations necessary for multiple retrievals are typically prohibitive due to mission duration limitations. The improbability of supporting multiple rendezvous on a single mission significantly reduces manifest flexibility. Greater than 3/4 of the shared flights already contain retrievals, and a schedule perturbation resulting in the remanifesting of a rendezvous payload onto another mission almost certainly impacts subsequent rendezvous payloads.

The most significant change in payload requirements from missions flown to date is the need for active cooling. Only 10 percent of the shared primaries already flown have required active cooling. However, these payloads now represent over half of the shared primary demand. This results in an actively cooled payload on over 80 percent of the shared missions. While the combined cooling requirements of two actively cooled payloads would normally be within the Shuttle's payload heat dissipation capacity, there are a number of problems to be resolved prior to manifesting them on the same flight. Previously, such payloads have been manifested with one in the cargo bay and one in the middeck. But, the heat rejection needs of middeck payloads are significantly less than typically required by those in the bay. Two cargo bay primary payloads which could benefit significantly by being co-manifested are Spacehab (water cooled) and USMP (freon cooled). Both payloads request a series of flights and require micro-gravity operations. An Orbiter modification allowing for multiple cargo bay payloads to be connected to the Orbiter cooling system can be installed. However, two other factors restrict the assignment of these payloads on the same flight. First is the degradation of the payload heat exchanger from different payload coolant fluids, and

second is the joint operational timeline required to support both payloads cooling needs. The latter could be mitigated through extension of on-orbit duration to allow for sequential operations.

Although not as problematic as payload cooling requirements, telemetry and power consumption requirements contribute to the reduction in manifest flexibility and to the appearance of Shuttle under-utilization. The Orbiter is designed to support 4 quarter-bay allocation payloads. This standard allocation allows for 16 kilobits per second of telemetry and 1.75 kilowatts (kw) maximum continuous power for each quarter-bay payload in the cargo bay. Primary payloads often exceed this allocation, significantly reducing the opportunities for other primaries or secondaries to be manifested on the same flight. This often results in under-utilized shared missions with excess ascent performance margins of 10,000 lbs or more.

Given that compatible cargoes can be defined to satisfy payload on-orbit requirements, there are number of other constraints not immediately obvious. Launch/retrieval intervals, payload ground hardware and telemetry processing constraints, carrier turnaround, and international commitments are often as large a factor in determining shared cargo flights as is Shuttle performance capability.

Secondary Payloads

The cargo bay secondaries manifested in the PFANMF are only slightly less operationally demanding on-orbit than the shared primaries (2.6 days). Weighing an average of 2,800 lbs, they are of little consequence when assessing ascent performance capability. Approximately 1/3 of these payloads have attitude requirements and as many require the RMS. Overall, these are the most difficult payloads to manifest. The near-dedicated nature of the shared primary payloads leaves little time available for secondary operations unless conducted simultaneously. Secondaries fly on a space available basis and, hence, do not have the manifest priority to assure schedule stability. Sufficient opportunities exist at the present moment to meet demand. However, a flight rate reduction will result in some schedule delays and reduced opportunities for new payloads.

GAS payloads

The one payload category that is now seeing significantly increased opportunities is the GAS. These experiments, first flown in March 1982 on STS-3, are, as mentioned earlier, small payloads in canisters flown on the GBA or on the Orbiter sidewall. Each experiment is self-powered and provides its own heating and data recording equipment. Designed as an inexpensive, accessible avenue into microgravity experimentation, the demand in the pre-Challenger era became so great that flight requests were no longer accepted. The light nature of current shared cargo flights combined with the need for forward center-of-gravity relief on many Shuttle missions has provided more opportunities than there are GAS payloads ready to fly. Projections

for the GBA alone support 24 GAS canisters a year. However, many customers with GAS payload reservations are no longer active and the GAS queue needs to be opened again. A new GAS policy is in final review, and the queue should be opened again shortly thereafter.

MIDDECK PAYLOADS

All middeck payloads are categorized as secondary payloads and will not be subdivided into further detail.

The utilization of middeck lockers for payloads in the pre-Challenger timeframe was dominated by NASA sponsored life science and materials processing experiments, as well as, by payloads exploring the commercial aspects of space. This period also introduced the Student Experiment Program designed to pique interest in the Shuttle program by actively involving high school and college students in the development and study of experiments flown on the Shuttle. The demand for space was minimal and was easily accommodated. In the early fall of 1988, the first reflight saw increased competition for middeck space within NASA as well as the DoD. The demand for secondary flight opportunities resulted in a NASA policy that regulated how and when these payloads would be manifested. From STS-26 through STS-48, the middeck has been largely used by NASA's Office of Commercial Programs (OCP) and Office of Space Science and Applications (OSSA). The influx of commercial payloads was initiated by the formation of the Centers for the Commercial Development of Space (CCDS) in 1985. This consortium between industry, government and academia "allows a broad industry base to participate in the development of specific product oriented technologies"[1].

Middeck emphasis continues in the areas of life sciences and materials processing. Necessary locker space undersupports demand and the OCP has leased 200 Middeck Locker Equivalents (MLEV's) from SPACEHAB to supplement their allocation of middeck space. While these additional MLEV's provide enough volume to meet NASA's current requirements for middeck experiments (over 460 lockers through 1996,) the key resource limiting middeck opportunities is not space or ascent performance. The life science and materials processing experiments of major interest to NASA and the CCDS typically require late transfer of biological specimens or materials to the Orbiter (Launch-24 hrs) and that near-continuous power be provided through all phases of flight. The maximum number of payloads needing these "premium" resources that can be accommodated is subject to the prelaunch flow process. The payloads need to be turned over to NASA, weighed and packaged, transferred to the pad, installed and then undergo an integrated verification test (IVT) upon installation into the middeck to ensure proper payload operation. Payloads requiring late access and power are typically limited to no more than four per flight. An example of a life science payload with "premium" resource requirements is the Protein Crystal Growth (PCG) experiment, a multi-flight payload

designed to conduct experiments which will supply information on the scientific methods and commercial potential for growing large high quality protein crystals in microgravity. Required hardware is the Refrigeration/Incubation Module (R/IM) to ensure proper experimental temperature for growth of the sensitive crystals. Subsequently, power is necessary throughout the flight. The PCG cannot go unrefrigerated for longer than 24 hours which necessitates the late access requirement.

Since return-to-flight in 1988, the number of payloads requiring "premium" resources has steadily increased. From STS-26 through STS-48, only 37 percent of middeck payloads needed these resources. However, current projections through FY 97 indicate more than 60 percent of the requested payloads will require late access and power. Based on a Shuttle flight rate of 10 a year, only half of these requests can be accommodated. Obviously, the middeck resources are insufficient to handle current requests in this area and customers have been advised to design middecks that do not necessitate the use of Orbiter power.

While late access for powered payloads is currently the greatest concern for middeck payloads, other constraints will likely limit full utilization of middeck lockers. STS-50 is carrying 4 R/IM's. This relatively small number of payloads results in the noise level reaching maximum acoustic limitations. An Acoustics Working Group has been formed to study and seek solutions in reducing the noise emanating from middeck experiments. Additional areas of concern in manifesting middecks are the 0.4kw limit for total middeck power on ascent (previously 0.0kw until fall 1991) and the Orbiter cabin forced air and passive cooling limitation of 1.8kw for payloads.

MISSION TRENDS

While the missions since return-to-flight have been heavier than previously flown (35,100 lbs), upcoming missions will average considerably less (22,700 lbs). The lighter cargoes are partly attributed to the loss of commercial satellites but, also because NASA has flown a majority of the backlog of major NASA science and national security payloads which were almost exclusively dedicated in nature. The change from dedicated to shared flights is significant. Only three of the last 19 missions have been shared cargoes, while 60 percent of the upcoming missions prior to SSF assembly will be shared. Due to the complexity of the shared missions, increased flight production manpower will be required per flight and additional time needed for crew training.

The average flight duration of upcoming missions is projected at over eight days. This is primarily due to the addition of the Extended Duration Orbiter (EDO) pallet on OV-102 which provides up to 16 day mission capability. Also OV-105 was delivered with a fifth cryo tank set giving it 10 days of mission capability. With the exception of

Spacelab-J, all the Spacelabs currently manifested request at least a nine day mission, thereby dominating usage of OV-102 and OV-105. Detailed mission timelines for the shared cargo flights in 1994 and 1995 have yet to be worked out, though it is expected that flights with durations of greater than seven days will be needed to preclude the deferral of secondaries. Clearly, flight duration is a key to increased manifest stability. Flight duration also impacts the affect a reduced flight rate has on manifesting the current cargo bay payload requests. Like the late access constraint in the middeck, resolving this barrier may not necessarily result in a marked increase in manifest efficiency. The large number of actively cooled payloads requesting flight mentioned earlier and the ability to support multiple cooled payloads on a single mission is perhaps the next barrier limiting cargo combinations.

Orbiter Enhancements

The two major Shuttle enhancements affecting near-term payload capability are based on increased energy availability. The most obvious of which is the EDO pallet. The other is the addition of the Middeck Accommodations Rack (MAR).

The EDO pallet provides the capability to extend mission duration up to 16 days on-orbit. The first flight with this capability is scheduled for summer of 1992, on OV-102. It significantly increases the science return from a single mission and allows for new research not previously feasible on the shorter missions. While the first flight is constrained to 13 days, mission duration will later be extended up to the full 16 days when it is assured the longer stay on-orbit is not detrimental to the crew's health. There is however, no backup EDO capability and OV-102 becomes a schedule risk to the payloads requiring EDO. OV-105 has been modified to accommodate the EDO pallet, but additional hardware is needed to make it fully functional.

The MAR provides an equivalent space of up to five lockers in the middeck through the repackaging of the current crew galley. Additionally, the MAR provides the capability to actively dissipate heat through the Orbiter's payload heat exchanger. While the additional lockers provide much needed stowage space for EDO missions and the active cooling capability allows for a new class of payload in the middeck, the major benefit of the MAR is the Middeck Utility Panel (MUP). This panel provides an additional 4 power outlets for middeck payloads. This is especially significant on ascent and descent because only one outlet was previously available in the middeck for payloads. Without this capability on all the Orbiters further reductions in payloads requiring "premium" middeck resources would be needed.

There has been an increase in total power available to the payloads on-orbit, up from 7.0kw to 8.0kw maximum, and increases to power available to payloads in the cabin. These upgrades, however, have not

significantly changed the manifest, as did EDO and the MAR.

SUMMARY

Until the SSF timeframe when ascent performance again becomes the dominant factor constraining capability, Shuttle manifest efficiency should be assessed through other factors. Mission duration is the primary constraint limiting manifest efficiency in the near-term.

The addition of a fifth cryo tank set on OV-103 and OV-104 would greatly increase manifest stability by providing redundancy to missions scheduled on OV-105 and OV-102. In addition, this could result in the savings of future Shuttle flights by allowing more combinations of payloads to be considered. While the Space Shuttle Program is assessing the addition of a fifth cryo tank set to OV-103 and/or OV-104 and is looking at options to allow for support of multiple cooled payloads capability, other programmatic/financial considerations may preclude immediate implementation of these enhancements. However, the benefits of the enhancements in terms of increased manifest flexibility would make the investment worthwhile. The long lead time necessary to build hardware and perform Orbiter modifications requires direction to incorporate these modifications be given soon to maximize payload support prior to SSF assembly.

It is imperative the implementation of the MAR scheduled for OV-103 and OV-104 later this year be accomplished. Deferral of this enhancement significantly impacts customer support. Additionally, any means of increasing late access capability in the middeck would provide considerable benefits. One additional "premium" resource middeck per flight results in a 25 percent increase in capability.

1. Dan Hedin & John Temple, "Manifest: Payloads and Accommodations", AIAA-90-3530, Space Programs and Technologies Conference, September 1990, Huntsville, AL.