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PAYLOAD DESIGN GUIDELINES TO ENHANCE CARGO MIXING ON SPACE SHUTTLE FLIGHTS

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ABSTRACT

Payloads on Space Shuttle flights can be designed to enhance their potential to be integrated with other Shuttle payloads. Pertinent design guidelines have been identified in the areas of loads and dynamics, thermal and acoustic considerations, contamination, avionics and electromagnetic compatibility, ground processing and orbital operations. Consideration of these payload design guidelines throughout the design cycle can result in flight hardware with a high mixing potential. The resulting cargo manifesting flexibility provides earlier and more frequent flight opportunities for payloads, reduced costs, minimum post-design cycle modifications to accommodate cargo mixing and, ultimately, optimum utilization of the Space Shuttle.

INTRODUCTION

Cargo mixing is the process of assembling a compatible set of cargo elements to make up a Shuttle cargo manifest. Using appropriate guidelines during the design process will result in payloads with enhanced mixing potential permitting the fullest and most efficient use of the Space Transportation System (STS).

The requirement to integrate payloads effectively and thus optimize cargo mixes on the Space Shuttle is drawing increasing attention in the space community. The Space Launch Systems Division at Martin Marietta, Denver Aerospace, is a support contractor to Air Force Space Division for STS integration activities. At Martin Marietta we are working with DOD and other contractors to identify and analyze significant mixing issues and to develop guidelines to help payload designers produce hardware with an enhanced mixing potential. Many of these ideas did not originate with us but are included here because they are significant factors in cargo mixing. This is a report on the current status of our continuing effort to develop payload mixing guidelines based upon our payload integration experience.

Payload mixing enhancement is a challenge for the designer. To design for cargo compatibility he needs to know which issues are significant and to understand how to design hardware with a high mixing potential. The payload designer should plan to mix. Most payloads will mix. The designer must account for cargo environment effects and should consider mixing guidelines, as well as design criteria which are driven by mission requirements, early in design cycle analysis.

There are several pay-offs for payloads which are mixed into cargos. If sufficient attention is paid to enhancing mixability throughout the payload planning and design process, the developed payload will be a more compatible flying partner. If not, it may be preempted in the national competition for the Shuttle resource by a more mixable payload. A program manager with a mixable payload has an increased probability of a flight assignment for his payload when and as often as he wants it. Minimum post-design cycle modifications are also a consideration and reduced costs a stronger possibility. To fly alone in the cargo bay of the Shuttle is expensive and, except for a very few cases, results in waste of a unique national resource. Moreover, Shuttle flight managers may defer or delay incompatible payloads to later flights in order to utilize cargo bay space efficiently. Relatively full cargo bays will surely be one criterion for measuring the effectiveness of the Shuttle program.

Some of the payload integration efforts to date have involved mixing analysis on payloads which were designed for expendable launch vehicles (ELV) but which are now being transitioned to the Shuttle. These efforts clearly illustrate the difficulties encountered when trying to mix payloads which were not designed for compatibility. The guidelines in this report are primarily applicable to new spacecraft designed to fly on the Shuttle and share flights with other payloads. They may not apply to or be practical for spacecraft which are transitioning from expendable launch vehicles.

The baseline for enhancing mixability with other payloads is to first comply with NASA 07700 Vol XIV and ICD-2-19001 which define and control the interfaces and constraints between payloads and the Orbiter. In addition NASA has provided boilerplate Payload Integration Plans to provide guidance to the Program Offices during the early planning phases. Individual payloads are first responsible to understand and use the above documents in order to assure payload compatibility with the Orbiter. This report supplements the above documentation by providing additional guidelines to enhancing mixability between payloads. As we gain flight experience and build a proven data base, the compendium of payload to payload compatibility guidelines will be refined and expanded.

The significant mixability considerations we have encountered so far can be categorized into mission operations, physical, environmental and safety issues. These guidelines are factors to be considered and accounted for in the design process. They are not hard and fast rules but they should be accommodated throughout the payload design cycle to the maximum degree that is feasible consistent with program requirements.

MISSION OPERATIONS GUIDELINES

Payload mixing is enhanced if programs design flexibility into required launch windows and use standard mission design parameters such as parking orbit altitudes and inclinations. Required altitudes or inclinations which are significantly different from standard missions impact mixability adversely. On the other hand, programs should be flexible enough to adjust to necessary changes in standard mission parameters.

Launch Window. To minimize the launch window impact on mixing, programs should design for the widest possible Shuttle launch window. A specific requirement such as a daylight launch, a night launch or a specific launch date constrains mixing potential. A requirement for maximum Beta angle would constrain the launch window to roughly two days twice each year.

Programs should evaluate stay-time on orbit in the cargo bay to enhance launch window opportunities and still meet orbital placement constraints. Stay-time should be traded off with the size of the launch window to minimize impact on possible sortie partners. Launch window flexibility is of particular significance when mixing with launch-on-need payloads.

Inclination. The standard inclinations for the two launch sites are 28.5 degrees and 57.0 degrees at the Eastern Launch Site (ELS) and 98.0 degrees at the Vandenberg Launch Site (VLS). Non-standard inclination requirements may result in added costs for special Orbiter software or cause a delay in launch availability while waiting for other payloads with similar requirements. Using standard inclinations will promote easier mixing.

Altitude. Standard circular low earth parking orbit altitudes are 150 and 160 nautical miles. Non-standard altitude requirements may cause a delay in launch availability or added costs for special software also.

Deployment Opportunities. The deployment phase of the mission is constrained by safety considerations and involves clearance envelopes, separation velocities, tip-off rates, use of the Remote Maneuvering System (RMS), propulsion system enable/disable discretes and integrated Orbiter to payload separation timelines until the payload is a safe distance from the Orbiter.

Cargo mixing is enhanced if the payload does not have specific deployment requirements such as needing to be the first payload out of the bay, to deploy in either earth shadow or Orbiter shadow or to require operations to be within range of a Remote Tracking Station (RTS) site. Due to the complexity of the Orbiter and other payloads, all payloads should be able to withstand extended stays in the Orbiter bay while any subsystem problems are being resolved. The payload should be able to withstand some direct sun exposure, some direct deep space exposure and continuous payload bay toward earth exposure without degradation. Mixing is also enhanced if crew activity and deployment timelines are easily integrated and back-up deployment opportunities are maximized.

Programs should minimize special Orbiter attitude-hold requirements, payload sensitivity to deployment tipoff rates, special requirements for crew monitoring or support, continuous ground track requirements and requirements for post-deployment payload operations while in the Orbiter hazard envelope.

A payload which is designed to its own mission requirements but not for compatibility with other payload's operations may burden the Shuttle with conditions and timelines that are difficult to integrate. Some pre-deployment checkouts require several ground station contacts of several minutes duration each. DOD payloads which mutually use the RTS system for pre-deployment checkout should plan to share RTS capabilities and carefully integrate their communications timeline to increase the probability for mixing and for mission success. The seven RTS stations have an effective range of approximately 500 miles, which provides a maximum link time of six or seven minutes for each pass along the orbital path. Using the RTS system only, there are certain times when it is possible to orbit for nearly two revolutions without communication coverage. The Tracking and Data Relay System (TDRS), in addition to the RTS system, should be utilized to the maximum extent possible by DOD payloads due to the virtually continuous coverage provided by TDRS.

Alignment. Payload mixing which causes positioning changes in the cargo bay could result in differences in the deflections or rotations of the Orbiter bay structure. If a payload is sensitive to mis-alignments in pointing, the payload designer should consider emphasizing internal payload alignment for installation and flight and providing payload-mounted sensing equipment that can be correlated to the Orbiter guidance and control system.

Pre-launch alignment procedures should be minimized to enhance mixing. Some spacecraft which have a critical requirement for accurate attitude and orientation may need to trade post-deployment pointing accuracy with pre-deployment procedures to determine payload mis-alignment.

Data Processing. Data processing hardware should be designed to not be adversely affected by Ku-Band emanations. Payloads should maximize the use of stored program commands in lieu of real time ground support and minimize the use of non-standard capabilities. The General Purpose Computer (GPC) on the Orbiter is a large flexible resource available to payloads. It has a large mass memory and can support payloads with its capabilities to store and play-back data, to star scan and update state vectors and to transmit on-board commands.

Ground Processing. Ground processing of payloads at both the Kennedy Space Center (KSC) and the Vandenberg Air Force Base (VAFB) launch sites follows the same general flow. Payload design will have no direct impact on mixing until the point in the flow where cargo build-up takes place. Ground Support Equipment (GSE) design and testing procedures characteristics can affect the physical and operational interactions between DOD cargo elements in the Shuttle Payload Integration Facility (SPIF). Design characteristics that affect payload mixing during ground operations include access, systems test support and environmental control requirements.

Payload programs should become familiar with the ground facilities and operation at the launch site as early as possible, preferably prior to space vehicle design. Program personnel should visit the launch site to gain familiarity with its facilities, systems and procedures for communications, ordnance handling, safety and other shared resources. The better the ground processing system capabilities and limitations are understood, the easier it is to design GSE and develop test procedures which will fit into the ground processing flow easily and thereby mix more readily.

Payloads should maximize the completion of preliminary activities prior to cargo build-up to enhance mixing. We should be looking for ways to reduce the load on and streamline the processing flow through the SPIF. The SPIF will become a serious processing bottleneck if too many preliminary activities such as spacecraft build-up, subsystem assembly, checkout, handling, access and storage are attempted in its facilities. To the maximum extent possible activities in the SPIF should be restricted to cargo build-up and integration, interface verification testing and other final testing. A payload which can be processed through the SPIF easily makes a better mixer.

When one payload is engaged in hazardous operations in the SPIF, all other payloads' crews must stop their own processing activities and vacate the cell. Cargo element procedures should be designed such that all cargo element and cargo mechanical and electrical checks are complete prior to propellant loading. Propellant loading should be the last scheduled activity prior to departing for the pad to reduce the hazardous condition period for the cell.

GSE commonality enhances mixing and simplifies the use of the SPIF. Programs should consider using standard GSE rather than unique equipment items which drive up costs and generate storage and interface problems.

The number of payloads which are candidates for mixing with a given payload is related to the interactions and interfaces applicable to each combination of payloads. Minimizing the number and extent of interactions and interfaces with other cargo elements will maximize the number of compatible payload mixing candidates. Minimizing cargo element handling, servicing and interface verification requirements will enhance mixing. A payload of minimum size and weight, requiring no access or servicing after cargo build-up, and which is effectively inert from cargo build-up through pre-deployment activation will have a maximum number of payload mixing opportunities.

PHYSICAL GUIDELINES

Mass Properties. Spacecraft mass properties data are required in order to evaluate center of gravity (c.g.) conditions as part of the cargo mixing process. C.G. stability must be considered for all expected cargo mix combinations. The c.g. location for the total cargo must fall within acceptable bounds for three Orbiter entry conditions: return-to-launch site (RTLS) abort, abort-once-around (AOA) and nominal entry at the entry interface. Nominal entry c.g. constraint criteria must be satisfied for return with the total cargo, return following deployment of any combination of cargo elements or return following deployment of all cargo elements. These conditions could lead to changes in in-bay location from flight to flight for payloads with multiple launches. In an emergency a payload may have to be dumped out of the cargo bay to satisfy c.g. criteria.

In-Bay Location. A payload which satisfies all interfaces with the Orbiter can still be incompatible with potential mixing partners. Mixability is enhanced if a payload can be designed for any location as well as 180° rotation in the cargo bay. Suppose that a payload is required to be moved and rotated to accommodate the combined center of gravity constraints for the payload and its mixing partner in the Orbiter bay. If this is not possible due to structural limitations of the spacecraft, then addressing this issue in initial design probably would have made the spacecraft more mixable with no appreciable increase in weight or complexity.

Because standard wiring provisions in the Orbiter bay are not symmetrical, dual orientation design should also take into consideration redundant cable connections or locating the spacecraft junction box on a centerline so that by rerouting cables the spacecraft can be rotated 180 degrees in the bay. Many design considerations such as alternate cable configuration are fairly easy and inexpensive to incorporate at the front end of the design cycle. Later on they can escalate into major problems of cost, Orbiter Processing Facility (OPF) schedule impacts, revised testing procedures and requirements to return the Orbiter to its standard configuration at mission termination.

Structural/Mechanical Attachments. Cargo mixing is enhanced by designing such that ICD limitations are not exceeded for a wide range of cargo placements. Mixability is also improved if payload attachment points are designed to line up with multiple attachment points in the cargo bay.

Field of View. Payload design should consider the available field of view resulting from potential constraints that are due to variations in mixed installation configurations. Potential obstructions include blockage by a larger diameter payload, extension of appendages, payload sensors, and solar panels as well as obstructions due to such Orbiter equipment as the Remote Maneuvering System (RMS), payload guides and retention fittings, television cameras and handrails.

Lighting and TV Viewing. To minimize potential constraints for a payload with multiple optional cargo bay locations, optional use of dedicated cargo-mounted TV and lights should be considered in relation to deployment sequence, cargo bay location, environment and blocked view.

Crew Compartment. Payload design should consider minimizing stowed equipment and judicious use of console space based on cargo load factor allocations. Integration and configuration trades between cargo elements should be coordinated.

Electrical Power. Providing power isolation and regulation internal to the payload enhances mixing. Minimum use of non-standard accommodations will enhance potential mixing opportunities. Power sharing trades between cargo elements should be coordinated.

Wiring Harness. To enhance mixability payloads should utilize the standard harness and use standard power, control, signal and data interfaces to allow multiple installation points. Power isolation and regulation should be provided internal to the payload and non-standard accommodations should be minimized.

Resources. Standard or optional flight systems and payload accommodations provided by NASA such as standard switch panels, electrical cables, latches, pallets and additional OMS kits should be used whenever feasible. Programs will have a better chance to mix if they use common flight-proven equipment rather than program-unique equipment which has non-standard interfaces with the Orbiter. Flying with standard and optional flight systems should result in fewer and less costly surprises. Late surprises encountered in unique hardware development and qualification adversely impact schedule restraints and hinder mixability. The knowledge acquired as standard equipment and options are used will result in a continuously improving data base and thus provide greater mixing guidelines reliability.

Orbiter avionics and electrical power and control capabilities which are available to payloads as defined in JSC 07700 Vol XIV should be exploited to the maximum extent feasible. During various phases of the mission programs need to be aware of available Orbiter resources such as electrical power and GPC computational capabilities. A payload can conserve its own battery power and increase its operational flexibility, reliability and probability of mission success by using the Orbiter electrical power system. The added electrical interface requirement has to be weighed against these advantages.

Sharing Orbiter capabilities is required for mixing. A program should not plan to use more than its available share of an Orbiter resource. If the payload occupies a single section of the bay it is not likely that all of any given resource will be available to it. During design the program must distinguish between total Orbiter capabilities and its own pro-rata share of them. Additional telemetry capabilities, for example, may become available to a single payload at some point in the mission but the payload should be able to operate on its pro-rata share during the mixed segment of the mission.

ENVIRONMENTAL GUIDELINES

Contamination. Programs should determine early in the design phase through hardware susceptibility analysis whether their systems are highly sensitive, moderately so, or essentially not sensitive at all to contamination. Tolerable levels of contamination should be identified. As soon as potential mixing partners are established, a set of contamination cleanliness and control criteria should be developed based on mixability guidelines.

To reduce contaminant transfer to other cargo elements while installed in the cargo bay, each payload should be designed for easy cleaning and maximum accessibility. Payload design should minimize contamination interaction between cargo elements. Design which reduces outgassing and venting in the bay or during deployment will enhance mixing capability. Contamination source geometry should be designed such that spacecraft vent and leakage sources are located to minimize direct impingement on other cargo elements. Nonmetallic materials selected for use on each mixing partner should comply with the outgassing criteria set forth in JSC SP-R-0022A. No active vents are allowed into the bay during launch or reentry.

Sensitive payloads should evaluate the use of protective devices. Some programs may not be able to mix without protection from outgassing, active venting and engine contaminants. Protective covers, caps, shrouds, heaters or purge systems for sensitive spacecraft surfaces and optical systems should be considered in the design to minimize contamination degradation from the Orbiter, other cargo elements and ground facilities.

Design or selection of materials that protect against contamination and go beyond the formal STS interface criteria will enhance mixability and may be cost effective in the long run. System overdesign of a solar array, for example, may be the best approach to compensating for power degradation due to contamination and thereby contribute to both mission success and mixability.

Electromagnetic Compatibility (EMC). To say that payloads are electromagnetically compatible really means two things. First, it means that the payload will not interfere with the Orbiter and other cargo elements. Second, it means that the payload will not be interfered with by the Orbiter and the other cargo elements. The interference referred to here is any type of electromagnetic interference (EMI) including electrostatic, magnetic, conducted and radiated. It includes any and all frequencies that could result in a problem.

A payload which meets the ICD-2-19001 specifications for EMC might still exceed the tolerances for ride-sharing payloads. The ICD defines the RF environment in terms of overall energy levels whereas spacecraft transmitters and receivers are sensitive to specific frequencies, many times at very low energy levels. Major EMC design objectives are to minimize time and power levels while near the Orbiter with the doors open and to maximize receiver and electronics resistance to RF radiations from the Orbiter and the other payload transmitters. To keep as EMI inert as possible and transmit and receive as little as possible while in or near the Orbiter is to be more mixable.

A payload can be designed to be more compatible if the electromagnetic environment produced by and the susceptibility of the Orbiter and other cargo elements are known. While most of this information is documented in the NASA ICD-2-19001 for the Orbiter it is unlikely that any data exist for other cargo elements unless they are of existing design. To work this problem most spacecraft are required to design to a common specification. In this way the emissions and susceptibilities are controlled to known values that will be compatible.

The only time this approach will result in problems is if a waiver to requirements is granted without a complete evaluation of the impact which the waiver might have on other cargo elements. Waivers have to be addressed as they are encountered. They cannot very well be evaluated for a general design guideline and should be avoided if possible.

At present the best EMC specification for DOD spacecraft design is MIL-STD-1541. These requirements along with the interface requirements contained in the NASA ICD represent the best design-to data available for future spacecraft. If all cargo elements design to these requirements they will minimize the areas where incompatibilities exist and those will have to be resolved as they are identified.

Loads and Dynamics. Since a payload program which will mix does not usually know with certainty either the other cargo elements or its own final in-bay location, the payload should consider that it may be located anywhere it can reasonably fit in the bay. To optimize cargo mixing opportunities the payload should be designed for placement over a wide range of locations in the cargo bay. During design dynamic loads analyses, loads should be computed with two, three or four (depending on size and weight) models of the same payload placed at several locations in the cargo bay to maximize potential compatibility. This accomplishes two things. First, the payload can now be designed to an envelope of loads from each of the models. Second, the basic dynamic interaction between payloads or pallets is accounted for since the presence of another cargo element in the bay is reflected.

It is anticipated that a mini mixing loads analysis cycle incorporating the actual cargo elements for a specific flight will be initiated at the Payload Mixing Review (PMR). The results will be used to support the Cargo Integration Review (CIR). However, a payload which follows the above guidelines will probably not have any difficulty in satisfying the criteria of the mixing loads analysis cycle. An uncertainty factor is generally applied to early analysis results to cover increases in loads which may occur in later analyses due to changes in payload model characteristics, STS model and forcing function updates and possible adverse effects of the final cargo mix.

Payloads should be designed for sufficient structural stiffness to avoid internal frequency ranges that create loads or deflection problems in the payload or stability problems with the Orbiter through dynamic coupling. Frequencies below 6-7 Hz can cause Orbiter pitch control problems. Payload construction materials should be selected to provide the required degree of structural stiffness. For payloads which are oriented longitudinally in the cargo bay the separation between forward and aft trunnions should be maximized to keep moment arms from becoming excessive.

Vibro-Acoustics. Vibrations are transmitted to cargo elements through the Orbiter longeron and keel fittings. The cargo element vibration level is a function of the vibration level and mass loading on the individual fittings. Cargo effects on empty bay acoustic levels can produce payload levels that are above empty bay levels for frequencies below 125 Hz with small (less than 10-foot diameter) payloads. A larger diameter payload will produce a larger increase above the empty bay levels. A 14-foot diameter payload can produce levels that are significantly above the specified empty bay levels for frequencies below 250 Hz. Mixed cargo payloads must account for these total cargo effects when deriving test levels for their programs.

The critical phases of flight for vibro-acoustics have short lifetimes, about 30 seconds at liftoff and another 10 seconds or so going through maximum dynamic loading (max Q). Severe vibration levels can be induced by a design which encompasses small closed volumes bounded by cargo and Orbiter surfaces. Compatibility is enhanced if free air passages around payloads are included in their design, permitting a reasonable flow of air in all directions. The most critical direction is forward and aft in the cargo bay. The worst vibro-acoustics environment in the bay is in the near field of the aft bulkhead due to the acoustic field generated by the STS engines.

Thermal. The thermal environment of combined payloads may create a worse condition than standard ICD specifications for single payloads. For the cold case, however, the overall spacecraft thermal balance will be warmer in the mixed configuration due to the increased thermal capacitance in the cargo bay. Also, the presence of a cargo element forward of another element generally results in warmer pre-launch and post-landing purge air being supplied to the downstream element. Cargo elements dependent upon cold purge air may have compatibility problems with heat-producing cargo elements.

The payload should be designed to minimize thermal interactions with adjacent payloads by making adjacent surfaces adiabatic and non-reflecting and avoiding solar entrapment cavities between payloads where possible. Local temperatures exceeding ICD specifications are possible with solar entrapment, which occurs when the cargo bay doors are open and solar energy is directed into the bay. Designing to withstand high local temperatures by material selection or by safely absorbing the heat for the required solar exposure times enhances mixability. If a payload can be inert for extended periods and does not have to leave the cargo bay quickly, it is more mixable.

Unique thermal requirements generally constrain mixability and should be avoided. A design which requires deployment in the shadow of the earth or the Orbiter constrains mixability. Requirements such as thermal maneuvering, an orbit with a high Beta angle, or immediate deployment upon reaching low earth orbit reduce cargo compatibility. Payload design should attempt to neutralize sensitivity to the above thermal considerations or include provisions such as heaters or insulation for protection from the thermal environment. Unique thermal requirements tend to overcomplicate integrated timelines and reduce operational flexibility.

Suppose, for example, that in a Z local vertical (ZLV) attitude one payload could not stay within its temperature constraints long enough to permit another payload to deploy ahead of it. The payload either would have to go out first or else it would require the Orbiter to perform thermal maneuvering, which increases crew activity, propellant consumption and complexity of the mission timeline. Such a negative mixing impact by a payload program only reduces its own flight assignment potential as well as the overall probability of mission success.

SAFETY GUIDELINES

Energy sources such as pyrotechnics and RF transmissions generate the majority of safety issues. To the extent that they can be minimized, controlled or protected against, mixability will be enhanced. In order to avoid mixing constraints due to hazards or accident risks, payload design should preclude hazardous propagation of failures from one cargo element to the environment of the Orbiter or another cargo element. Design should also preclude interactions or sequencing operations with other cargo elements or the Orbiter which could lead to critical or catastrophic hazards. For example, radiated and conducted heat energy must be considered in respect to its distance from sensitive components of companion spacecraft.

Pyrotechnic system design should be sensitive to ordnance location and potential orientation with respect to other cargo elements. Explosive separation bolts, for example, must be adequately isolated from shock sensitive elements in other payloads.

RF transmissions have a potential for triggering unwanted and sometimes catastrophic events. They can fire ordnance, gimbal engines, deploy appendages or provide erroneous input signals to Orbiter crew analog displays such as caution and warning indicators. Waiver requests for planned RF transmissions on ascent or for relief from two fault tolerance for an inadvertent turn-on should be avoided.

Mechanisms such as deployment tilt tables and latches are difficult to design to provide the required level of redundancy. Extravehicular activity (EVA), sometimes contemplated as a fault tolerance aid, complicates integrated timelines and impacts mixability adversely.

Waivers to safety requirements generally concern such issues as pyrotechnic system design requirements, RF transmissions on ascent, pressure vessel testing requirements and failure tolerances for various mechanisms. Waivers are usually requested during the time frame between the Preliminary Design Review (PDR) and the Critical Design Review (CDR), and they should be resolved no later than CDR. However, a waiver is approved based upon a particular environment and the addition of a second spacecraft can change that environment and cause an incompatibility. Waivers may be necessary in certain cases but should be avoided to enhance mixability.

OTHER CONSIDERATIONS

Sorties in the cargo bay tend to vie with each other for available resources such as operations time, orbital parameters and solar radiation configurations. Consequently, it is frequently easier to mix a sortie with a free flyer than with other sorties.

Does mixability always reduce costs for payloads? Not necessarily. For some large payloads which only fly once, the cost of paying for the whole cargo bay for a flight may not be as expensive as designing for mixability. Compatibility will, however, nearly always provide an advantage in terms of earlier available flights and more frequent flight opportunities. Stated another way, incompatibility may cause a payload to be bumped or result in its having to fly alone due to the competition over the Shuttle resource.

CONCLUSION

Most payloads will not have the cargo bay to themselves. The single most important factor impacting mixability is a conscious, deliberate decision by the payload program to plan to mix, to consider mixing guidelines very early and throughout design cycle analysis and as a result to be more mixable. That decision alone will eliminate many long poles and bottlenecks and minimize the effort required to maximize payload mixing opportunities.

Early familiarization with the launch site and ground operations will help in designing a payload around potential mixing problems. Early identification and assessment of potential mixing partners provides more time for coordinating the use of shared resources and thereby enhances mixability. A prospective mixer also should be prepared to do some additional analysis after the cargo mix is determined.

Perhaps the shortest road to incompatibility derives from payload-unique requirements. To the maximum extent possible payloads should utilize standard mission design and standard available equipment and avoid the use of unique, constraining or uncommon requirements.

Careful consideration of mixing enhancement guidelines throughout the design cycle will minimize the post-design modifications required to make a payload compatible with its cargo partners. By making his payload more compatible, the designer can increase the chances for easier and more frequent flight opportunities. With more compatible payloads flight manifesting can be accomplished more easily and efficiently by flight managers, resulting in better utilization of the capabilities of the Shuttle and reduced costs per flight.

As we gain experience, learn lessons and gather a large empirical data base we will be looking for ways to improve cargo mixing planning and analysis. Parametric analysis will be used to establish bounds that will streamline payload mixing processes and provide greater reliability with fewer surprises. We will continue to develop and improve cargo mixing guidelines for consideration in trade studies conducted during payload design so that compatibility problems will be resolved when a payload program gets to the Shuttle and wants to fly.

Within ten years the STS should be operating something like an airline. Our ultimate goal should be to fly cargo elements on the Space Shuttle somewhat like we fly cargo on an airline. We should aim for an operation which is relatively hazard-free and in which a payload program can fly whenever and wherever it is needed.