Integration and Test for Small Shuttle Payloads [1,2]

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Abstract—Recommended approaches for shuttle small payload integration and test (I&T) are presented. The paper is intended for consideration by developers of small shuttle payloads, including I&T managers, project managers, and system engineers. Examples and lessons learned are presented based on the extensive history of the NASA's Hitchhiker project.

All aspects of I&T are presented, including:

- I&T team responsibilities, coordination, and communication;
- Flight hardware handling practices;
- Documentation and configuration management;
- I&T considerations for payload development;
- I&T at the development facility;
- Prelaunch operations, transfer, orbiter integration and interface testing;
- Postflight operations.

This paper is of special interest to those payload projects which have small budgets and few resources: That is, the truly "faster, cheaper, better" projects. All shuttle small payload developers are strongly encouraged to apply these guidelines during I&T planning and ground operations to take full advantage of today's limited resources and to help ensure mission success.

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1. INTRODUCTION

Overview and Scope

Integration and test (I&T) of small shuttle payloads, such as those historically designated as "Class-D," is typically accomplished on a much smaller scale than most other human-rated space projects. The streamlined nature of these projects affords a level of teamwork and flexibility not possible with larger projects, such as Space Station or Hubble Space Telescope. Smaller team size, on the order of a dozen total, means each individual has a distinctly significant role in the development, integration, and test of the spacecraft.

Presented here are some guidelines and recommendations for small shuttle payload I&T based, in part, on lessons learned over the 18-year history of Hitchhiker payloads. Hitchhikers, along with Get-Away-Specials, are "in-house" projects of the Shuttle Small Payloads Project Office (SSPPO) at NASA's Goddard Space Flight Center (GSFC).

After 29 missions involving over 50 separate instruments, the Hitchhiker project has gained a wealth of experience integrating and testing shuttle payloads with a streamlined cadre of I&T personnel. Although many details and examples presented here are based on Hitchhiker, the basic approaches are directly transferable to any small shuttle payload project. Current or prospective payload developers, and in particular I&T managers, are encouraged to consider and apply these guidelines during I&T planning and ground operations.

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[2] IEEEAC paper #092, Updated October 1, 2001

In addition, I&T suggestions for small shuttle payload customers can be found in [1]. An example of a customer accommodations and services provided by the Hitchhiker carrier, as well as additional details regarding shuttle I&T, is in [2]. Some additional lessons learned can be found in [3].

Since the focus of this paper is on payload-level integration and test, details regarding design and qualification testing of individual components and subsystems is not included.

Definitions

Carrier—The payload infrastructure which acts as a mechanical and electrical interface between the payload customer(s) and the orbiter. The carrier not only supports the customer hardware, but may also provide services such as power, command and data handling (C&DH), and thermal control.

Customer—The user (principal investigator or other instrument representative) of the payload carrier who develops and delivers the instrument to the carrier organization. Often, "customer" is used synonymously to refer to the instrument hardware itself (as in "customer interfaces"). However, at Kennedy Space Center (KSC), the term "payload customer" typically refers to the overall integrated payload organization.

Experiment—The scientific research, technology demonstration, or other operation conducted during the mission using the instrument.

Instrument—The customer hardware subassembly, one or more of which are integrated onto the payload carrier.

Integration and Test—The process by which a payload is assembled and tested for flight. This includes I&T at the payload development facility, as well as that at the launch site (KSC).

I&T Manager—The person responsible for coordinating the I&T team, and for directing payload I&T from development through postflight deintegration.

I&T Team—A multidisciplinary group of engineers and technicians responsible for developing, integrating, and testing a payload to prepare it for flight. Areas of expertise may include such disciplines as mechanical, electrical, and thermal engineering, as well as ground data systems.

Payload—The integrated spacecraft assembly, composed of a flight carrier supporting one or more instruments. The term is also used here to refer to the payload development organization, responsible for delivering the integrated payload to KSC.

Task Leader—The member of the I&T team who is responsible for directing a particular operation. This may be an engineer, technician, or other individual who is intimately familiar with the procedure, and fully qualified to lead the operation.

2. I&T MISCELLANEOUS

The I&T Team

Team Responsibilities—The I&T team for a given spacecraft is generally composed of engineers and technicians representing a range of disciplines, such as mechanical, electrical, and thermal engineering. For some autonomous free-fliers (such as Spartans), the I&T team may also include disciplines such as attitude control and propulsion.

Prior to the start of I&T, all I&T personnel must understand their assigned responsibilities. Lead engineers must always be kept apprised of all significant developments and meetings, as they are the prime points of contact for their areas of expertise.

During I&T itself, personnel supporting a particular operation are responsible for assuring that all necessary equipment is on-hand, calibrated (if required), and properly configured. They should also be on-station prior to start of a procedure and be present (or at least on-call) until the operation is completed. This could be important if, for example, any troubleshooting is necessary that requires the support of specific individuals.

I&T Manager Responsibilities—The following is a summary of responsibilities which may fall under the purview of the I&T manager for small shuttle payloads:

- Primary point-of-contact regarding integrated payload I&T issues;
- Coordinates I&T team and operations, including subsystem, customer, facilities, and support services;
- Works with project management to prioritize and resolve conflicts regarding schedule, support and resources;
- Develops integrated payload I&T plan and procedures;
- Develops and maintains schedules for integrated payload I&T at the development facility and launch site;
- Informs I&T Team, project management, and individual instrument customers of I&T status and issues;
- Provides input to payload design issues which may affect I&T;
- Provides inputs to shuttle Payload Integration Plan (PIP), Interface Control Document (ICD), Installation Requirements Document (IRD), and safety data packages;
- Primary point-of contact with KSC for requirements, scheduling, procedures, and operations at the launch site;
- Develops "lessons learned" following each mission, as applicable.

Ultimately, the I&T manager's primary job is to facilitate the I&T of the payload in as safe and timely a manner as possible.

I&T Coordination

Meetings—Regular I&T meetings are suggested to help keep the I&T team informed. The frequency of I&T team meetings depends on many factors:

- The amount of time until start of I&T; that is, I&T meetings should be more frequent (e.g., once a week) as the start of I&T becomes imminent;
- The criticality of the operations at-hand; e.g., in general, hazardous operations require more intense team coordination;
- The level of I&T activity for the payload itself; i.e., when the team is involved in an intense level of activity (e.g., multi-day operations), daily I&T team meetings may be warranted; these can be as simple as stand-up status meetings in an off-line lab or "on the floor";
- The frequency of project-level meetings, which in general should be inversely proportional to the frequency of I&T meetings;
- The level of activity within the project as a whole; that is, the amount of time which the members of the I&T team have available to attend meetings while supporting other activities.

It may also be desirable, if time allows, to organize an "I&T retreat" for the team early during the payload design phase. This provides an informal atmosphere for the team to brainstorm regarding I&T flow and any design issues which may affect I&T. Success of such a retreat requires that the I&T team, especially the lead engineers, commit themselves to attend without interruptions. A remote meeting location generally helps facilitate uninterrupted participation.

Schedules—An I&T schedule is developed based on the KSC delivery and launch schedules, on inputs from the entire team and the customers, and finally on past experience. The schedule should be realistic: not overly ambitious, yet also not overly conservative. Even some contingency in the schedule is actually realistic, since there are <u>always</u> unanticipated delays and problems.

Use of Performance Evaluation Review Technique (PERT) charts is sometimes helpful in the early planning stages to help identify I&T flow. However, maintaining accuracy of large PERT's over time is generally manpower intensive, particularly for smaller projects. More basic scheduling tools are recommended for frequent tracking of I&T, such as one-page "Gaants" to highlight major I&T milestones. In the case of KSC I&T, which tends to be a short-duration, intense level of activity, a daily line-by-line summary of operations is useful. Ultimately, the I&T manager should utilize the scheduling tool which he or she finds most effective.

Ideally, the I&T schedule should be reviewed by the project management before general distribution to the team and customers. The I&T team must understand that the I&T schedule is managed (by definition) by the I&T manager. Any issues or conflicts should be brought to the attention of the I&T manager as soon as possible after they are discovered, so the schedule can be adjusted as necessary.

Handling of Flight Hardware

General I&T Practices—Each member of the I&T team, particularly those who will be directly handling the flight hardware, must be familiar with basic flight hardware handling practices. The following "common-sense" practices may seem trivial at first-glance, but may ultimately be the keys to mission success and safety:

- Before entering a clean environment, utilize shoe cleaners when available and properly don all necessary garments prior to entering clean area.
- Do not lay tools, test equipment, paperwork, or other miscellaneous items on top of flight hardware.
- Minimize, if not eliminate, debris ("foreign-object debris," or FOD) in I&T areas; this includes particulates as well as unneeded tools and equipment. Take the initiative to report facility cleanliness issues.
- Use gloves when handling cleaned flight hardware, including cable harnesses. Replace gloves as necessary to avoid contaminating clean hardware.
- Use conductive gloves and wrist-stats when handling any hardware containing electronic components or ordnance.
- Fabricate/rework hardware in an area away from flight hardware, preferably in a separate lab (if feasible).
- No personnel shall perform work on a powered-up payload, unless that work is required to support the operation being conducted. Those I&T team personnel who must work in the vicinity of the payload should be notified of payload activation.

Electrical I&T Practices—In addition to the recommended general practices, the following apply to personnel supporting electrical operations:

- Minimize connector mates and demates whenever possible, to avoid having to reverify interfaces and to help mitigate against connector failure. The latter can also be accomplished by using connector savers (if repeated demates are anticipated), or simply by exercising judicious consideration prior to demating. For example, if possible, perform electrical measurements from a ground support equipment (GSE) interface rather than a flight one.
- When using electrical test equipment, such as power supplies and break-out boxes, use proper leads and jumpers to minimize discontinuities and inadvertent shorts. If leads or jumpers are not available, fabricate new ones to support the job.
- Label all cables and connectors. This includes correct cable and connector information on all ends of flight and GSE harnesses, and temporary labels (e.g., tape) on test equipment when appropriate.
- After mating GSE cables or test equipment, provide adequate strain-relief support to harnesses. For example, non-flight ty-raps can be used to temporarily secure cables to brackets or dollies.
- When demating connectors on any flight or ground

equipment, grasp the connector, not the cable.

- Cap unused connectors on flight cables, and on GSE when appropriate, using anti-static caps (if available).

Formal Training—Beyond basic flight hardware handling practices are formal training courses for certification, such as electrostatic discharge (ESD) awareness, ordnance handling, soldering, crimping and harnessing. Those involved with flight hardware fabrication and handling must be certified, and I&T engineers should consider certification themselves in case their hands-on services are required. Flight certifications also provide the engineer with the knowledge necessary to evaluate proper flight hardware fabrication and handling performed by others.

Ordnance Operations—Handling of ordnance is usually performed by the lead engineer or technician for the system using the ordnance. For example, in the case of Hitchhiker ejection systems, the carrier mechanical team usually retrieves NASA Standard Initiators (NSI's) from the storage facility and installs them into the bolt cutter assemblies. Proper handling of ordnance includes utilizing wrist-stats, even when contacting hardware in which NSI's are installed. Hardware should be tagged with "ordnance installed" signs or streamers. The hazardous operations area should be cordoned off, inside which only those directly involved with the operations may enter.

While the actual ordnance operations are being performed, the I&T manager or task leader should monitor the immediate area for nonessential personnel or activities. If it takes yelling to get someone's attention to prevent a hazardous situation, so be it; better this than to have a hand blown off by an explosive device like an NSI.

Regardless of whether the ordnance system is flight or not, the individual handling the ordnance must be properly trained and certified to do so. Those performing operations with the ordnance system following integration (such as installing arm plugs) must also be certified in ESD awareness and pyrotechnic operations. Unfortunately, good courses for ordnance handling are difficult to find; the only pyrotechnic training covering operations for shuttle operations are offered by KSC.

Troubleshooting Anomalies—All anomalies should be fully investigated and understood. However, it is recommended to start with a troubleshooting plan to proceed in an orderly manner and, for example, to avoid unnecessary violation of interfaces.

Some rules of thumb for troubleshooting itself:

- Avoid deactivation of the payload or instrument, or rebooting of software, until as much information as possible is obtained about the problem.
- It is usually best to start troubleshooting the ground system first, and then those flight items which are least intrusive to the flight configuration.
- Only one change to the flight or ground configurations should be made at a time, to help isolate the problem.
- Don't assume that the released engineering accurately reflects the current hardware configuration. Drawings should simply be considered a troubleshooting tool.
- As much detail as possible should be recorded in the logbook (or on the procedure), regardless of how insignificant it may seem. This data may prove useful later on, for example, to help determine the exact configuration at any point in the troubleshooting.
- Notes and data should be recorded real-time, rather than reconstructed after the fact.

Once a problem is isolated, consider deliberately repeating the problem (if safely possible), for conclusive proof. Every effort should be made to fully explain any anomalies, especially those which are intermittent. Any that are deemed "unexplained" may come back to haunt you.

I&T Manager Communications

With I&T Team—Communication among the I&T team is of utmost importance for the smooth and safe performance of payload I&T. The focal point for this communication is the I&T manager, who is the single-point contact for payload I&T at both the development facility and launch site. In this capacity, the I&T manager can disseminate information regarding individual payload subsystems and customers among the entire I&T team. This role of the I&T manager also helps to avoid multiple requests for support and resources throughout I&T.

It is the responsibility of the I&T manager to keep the team informed of I&T schedule and status on a regular basis. Conversely, to do his/her job effectively, the I&T manager must likewise be kept informed of any changes to the I&T schedule, and be notified of any delays or support conflicts as soon as possible. If updates for each subsystem are not periodically received, the I&T manager may need to "poll" the I&T team for status.

Prior to a significant operation, such as a payload test procedure, a pretest briefing should be held with all participants. This short meeting, usually hosted by the task leader, includes:

- Distribution of copies of the released procedure and any deviations ("devs"), from which participants can work or follow along;
- Identification of key personnel and responsibilities, with task leader as primary contact for all operations;
- Discussion of potential hazards and controls (e.g., emergency power down);
- Directing that no unrelated work is to be performed on the payload while power is applied.

Finally, the good communication with the I&T team depends on the I&T manager's openness to alternative suggestions, whether solicited or not. Personal opinion should take a back seat to "doing what makes sense."

With Payload Customers—Besides communication among the I&T team, that with the payload customers is also important. Customers should be encouraged to communicate with the I&T manager on a regular basis, in an "open door" like policy. The I&T manager should be informed well in advance about any planned customer operations or requirements, and be notified as soon as possible regarding any unplanned activities. Again, customers should approach the I&T manager for any requests for support or I&T-related issues.

In the case of KSC operations, customers should be reminded to go through the I&T manager for special requests to KSC. This approach helps to minimize redundant, multiple requests to KSC personnel and helps keep the I&T manager informed about customer operations.

With KSC—As mentioned earlier, the I&T manager is considered the single-point contact for all integration and test activities at both GSFC and KSC. As such, the I&T manager must be kept informed of all carrier and experiment plans and activities. This will help ensure availability of resources, proper operational sequencing, and safe implementation.

The Future Payload Manager (or FPM, formerly the "Launch Site Support Manager") is considered the I&T manager's contact for communications with KSC. This communication path helps to minimize extraneous and erroneous communications. Of course, some technical details will still require direct discussion between specific discipline engineers.

The I&T manager is usually in frequent contact with the FPM during the final weeks leading up to delivery to KSC. Part of this information exchange includes regular updates regarding the expected arrival date, as well as any unique support requirements. This allows the FPM to keep the KSC payload processing team (PPT) informed and therefore better prepared to receive the Hitchhiker payload and personnel.

The I&T manager may also participate in weekly PPT meetings via telecon. However, since most of these meetings involve discussion of topics unrelated to secondary payloads, participation is usually optional for small payload teams.

3. Process Documentation and Configuration Management

Payload Project Configuration Management

Scope—Even before the introduction of ISO-9000 requirements, process documentation and configuration management (CM) has played an important part of NASA flight projects. Process documentation includes things like certification logs, as-run procedures, problem reports, and other "quality records." Configuration management includes maintaining a system of as-built hardware and software configuration, including requirements, procedures and drawings. Compared to some larger projects, CM for small payloads should be a more streamlined and user-friendly system, due to more limited resources.

In the case of Hitchhiker, a CM office and Configuration Control Board (CCB) has been established to track configuration, release documentation, and process Configuration Change Requests (CCR's). CCR's are required for all changes to the baselined flight configuration. Verbal approval may be obtained prior to written approval for changes which can be "reversed," that is, if the hardware can be restored to its original configuration if ultimately disapproved by the CCB.

Each small payload project must decide to what extent CM will be established and enforced. However, some form of CM is advisable for accountability and tracking as-built configuration for all human spaceflight projects.

I&T Considerations—Depending on the CM approach established by the small payload project, it is the responsibility of the I&T manager to ensure that:

- All new hardware is fabricated to released drawings;
- All modifications are documented and approved;
- All operations are worked to a released plan, drawing, and/or procedure;
- All as-run procedures are fully annotated and then maintained in an I&T logbook, for example;
- All anomalies are documented and maintained in the I&T logbook.

As an example of realistically tailoring documentation to the project's needs, Hitchhiker has historically not recorded electrical connections and disconnections in a "mate/demate log." This is primarily due to the streamlined documentation warranted by Class-D payload operations, and necessitated by the limited manpower available. In fact, despite the relatively large number of connection cycles over the years, functional testing of those electrical interfaces to be used for a particular flight is deemed sufficient for mission success.

Nonconformances—Any nonconformances or anomalies encountered should be documented, to allow tracking as well as provide an historical record. The level and extent of problem documentation depends on the individual project. As mentioned earlier, any troubleshooting should be deliberate and well-documented.

Once a corrective action is determined, this should also be documented by whatever mechanism has been established by the project (problem record, logbook, etc.). If a modification is required which affects released engineering drawings, this should also be formally documented.

Customer "CM"

Documentation—Although individual customers are not always bound by the payload project's CM requirements, it is still important (particularly for flight safety) to ensure that the instrument as-built configuration is consistent with the documentation. For the purposes of I&T, accurate, organized, and complete documentation provides an invaluable source of information if troubleshooting becomes necessary.

For these reasons, instrument developers should keep logs and drawings showing the as-built configuration of their system. This documentation can help ensure that the payload safety review process, as well as I&T itself, proceeds smoothly.

Documentation which is useful to maintain during the course of instrument development includes:

- Test and assembly logs, including records of any anomalies and modifications;
- Certificates of compliance for materials and components, including those provided by vendors;
- Record of Mandatory Inspection Points (MIP's) to verify safety items and as-built configuration;
- Up-to-date mechanical drawings and electrical schematics, including fuse and wire sizes;
- Parts and materials lists, with Material Safety Data Sheets (MSDS's) for hazardous materials (hazmats);
- Fastener certifications and logs, including torque levels;
- Summary of open items or problems, if any, to be addressed following delivery to GSFC.

The CCCR—Besides the as-built configuration and certification data mentioned, post-delivery configuration management of the instruments is also important. For example, customer hardware or software is sometimes modified following delivery in order to effect enhancements or correct problems. Such changes must be brought to the attention of payload project personnel to ensure that even seemingly benign modifications will not compromise flight safety or mission success. Since small payload projects generally do not maintain configuration of customer hardware or software, other means should be established to help identify and track customer changes.

The SSPPO has instituted a process by which modifications by the customer can have greater visibility and review for potential impacts. Following delivery to GSFC, customers are requested to complete and submit a Customer Configuration Change Request (CCCR) for any changes to flight or non-flight hardware or software from that originally approved for use. Since the CCCR is used simply as a communication tool, it imposes no CM requirements on the customer. The sample form can be found in the SSPPO's "Customer Accommodations and Requirements Specifications" (CARS) document [4].

4. Payload Development

Payload Carrier

I&T Considerations—From the very beginning of payload carrier development, all aspects of I&T must be considered. Therefore, I&T personnel must participate in the design of new carrier systems, so that the final product design takes into account real-world integration issues. Experienced I&T input will help ensure that, once the new carrier is developed, it can be integrated as efficiently and safely as possible. For example, test connector brackets are now installed on some Hitchhiker canisters to allow easier access for testing in the orbiter.

An important point regarding design for electrical interface verification is that all final electrical connections must be verified for flight, either functionally or by continuity measurement. This means that interfaces which cannot be powered following final connection, such as arm plugs for ordnance circuits, must be designed with a parallel test connector to allow verification that all circuits are intact after mating.

Finally, all items to be handled in the orbiter, such as dust covers or safe/arm plugs, must be designed to be tetherable for handling, and secure when installed. In the case of one Hitchhiker payload, a customer's dust cover was only pressure-fit onto an instrument aperture. When the payload was on the pad and a Titan was launched a few miles away, the cover vibrated loose, impacting and damaging another payload installed in the bay below.

New Hardware Testing—Requirements for environmental testing of new components or subsystems should be clearly defined in a test plan. For SSPPO payloads, requirements are based on specifications defined in the Goddard Environmental Verification Specifications (GEVS) document [5] and the Shuttle "Core" ICD [6].

Environmental testing performed on new components or subsystems typically includes vibration and thermal-vacuum. In the case of Hitchhiker, the only environmental testing performed at the integrated payload level is electromagnetic compatibility (EMC). For payloads involving safety-critical circuits, all inhibits are enabled during environmental testing to ensure safety is maintained during worst-case conditions.

For flight mechanical components being developed, preintegration fit-checking is recommended whenever possible. History has shown that, despite the best drawings, actual hardware may not always fit properly.

Flight Hardware Reuse—The Hitchhiker project has the luxury of reusing the majority of its carrier hardware from mission-to-mission. Carrier components which already exist are selected for reflight, with fabrication of new hardware only as necessary. Existing hardware to be reused is obviously not required to undergo requalification testing. However, some hardware (such as limited-life items) must at a minimum be thoroughly inspected prior to reflight.

In the case of Hitchhiker electronics assemblies, typically only those circuits to be used for the assigned mission are refurbished and tested. This includes replacing fuses and performing bench-level functional testing. Electrical harnesses are selected from an extensive "library" of previously flown cables. Of course, as more payloads are flown, more cables become available from which to choose.

Flight and Ground Software—Flight software for small shuttle payloads may include C&DH software internal to the payload itself, or that installed as part of the Payload and General Support Computer (PGSC) flight load. Verification usually involves testing with the hardware (either a simulator or flight). The payload-unique flight software is then sent to JSC to be included in the PGSC flight load for the mission.

Although initial PGSC software testing may be conducted with a laptop simulator, final testing with the integrated payload should be performed using a JSC-provided, flight-like PGSC. PGSC loaners are requested from JSC via a Request For Support (RFS) form, for periods of two weeks at a time.

If a ground command and telemetry system is being used to support payload I&T, any displays and procedures are (ideally) baselined by the start of testing. Periodic training for test team personnel is recommended. Utilizing the same ground system for both I&T and mission operations, as is done for Hitchhiker, is obviously preferable and most efficient.

Customer Instrument

Customer-to-Carrier Interfaces and Requirementss—Small payload customer interfaces and requirements, including those for ground operations support, must be clearly identified and well-defined in advance. These are usually specified in a payload-to-customer ICD, based on a customer requirements document. Details of mechanical and electrical interfaces are usually included in drawings referenced in each ICD.

Some examples of requirements included in the payload-to-customer ICD (or on referenced drawings) are:

- Electrical interfaces: command, telemetry, video, recording, PGSC;
- Mechanical interfaces: mounting locations, orientation, handling;
- Thermal interfaces: heaters, blankets, mission thermal modeling;
- Ground support equipment: GSE, slings, and containers;
- Servicing: purging, battery charging, accessibility;
- Safety: hazmats, operations;
- Misc. I&T issues: cleanliness, tethering, temperature & humidity limits, radiation sensitivity (e.g., x-rays).

Those requirements involving KSC operations are included in PIP Annex 8 (Launch Site Support Plan, or LSSP), and possibly Annex 9 (Operations and Maintenance Requirements and Specifications Document, or OMRSD) if any involve interface verification, unique environmental constraints, or stand-alone payload operations in the orbiter. The latter include testing, battery top-charging, cover removals, etc. It is important that a customer's requirements are clearly understood as either mandatory, or simply recommended or "highly desired." Customers may need to be reminded that small shuttle payloads are usually "secondary" payloads, and as such have little clout when it comes to driving KSC operations such as payload-bay door opening at the pad.

I&T Considerations—As with the payload carrier, I&T issues related to the customer should be considered during the development phase. First, customer hardware design and flight configuration should be formally documented on released engineering drawings. This is especially important for those components which could be integrated with the carrier in more than one orientation.

For customer hardware requiring late access in the orbiter, accessibility must be considered in the design phase, as mentioned earlier for carrier hardware design. For example, connectors for battery top-charging, inhibit verification, and other prelaunch operations should be accessible from step-ups, "pic" boards, or platforms. The same is true for "remove-before-flight" items such as lens covers and drag-on purge lines. Use of the Orbiter Processing Facility (OPF) "bridge bucket" for access to the payload is strongly discouraged, since bucket operations depend on the availability of both the bucket and an operator.

Preintegration Testing—It is strongly recommended that customers complete all environmental testing prior to delivery to the payload organization for final flight integration. Once the entire payload is integrated, it is difficult or impossible to correct any problems or shuttle ICD exceedances, such as might be discovered during EMC testing. Not only will the customer hardware be virtually inaccessible within the integrated payload, but the KSC delivery schedule may not allow time to modify hardware late in the flow.

Besides the usual qualification and acceptance testing, customer preintegration testing with the carrier is also recommended. Preintegration testing provides customers an opportunity to verify function of both flight and ground system interfaces well in advance of flight integration. It is usually performed early enough to allow time to make any modifications, if necessary, prior to final delivery.

Preintegration tests can be performed using customer prototype or flight hardware (or software) in development. Any testing of the customer interfaces with the carrier prior to delivery is helpful, even if just to check ground test system interfaces.

Preintegration testing also provides an opportunity to verify the accuracy of procedures prior to final delivery. In any case, performing the test using a written procedure not only serves as a dry-run of the flight integration procedure, but also documents the as-run operation for future reference.

5. PAYLOAD INTEGRATION

Carrier Integration Sequence

Integration of individual payload components should be performed in the most logical sequence. However, the implementation of a logical integration sequence depends on several factors, including the availability of hardware, the accessibility of components once integrated, and functional interdependence.

Integration of payload carrier components should be completed prior to interfacing with customer hardware. I&T should be performed in a sequence which allows ease of accessibility for certain operations (such electrical measurements), yet also minimizes risk to the flight hardware. Routing of harnesses for flight should be performed only after all functional testing of the particular end item is complete. Thermal blankets may or may not have to be installed prior to final flight connections, depending on whether they have been designed to allow installation over connected cables.

Regardless of the I&T sequence, the I&T manager must understand all the subtle requirements of the I&T flow. He or she should make the I&T flow clear to the I&T team (via meetings, schedules, I&T plan, etc.), yet remain open to suggestions of alternatives from other team members. Again, the important point is to do what makes sense.

Customer I&T

Customer Predelivery Preparations—Customer procedures (planned and contingency) required for I&T should be submitted to the payload organization no later than one month prior to delivery. This will ensure adequate time for review and modification (if necessary) prior to customer arrival. Customers should be strongly encouraged to perform dry runs of the procedures they plan to perform following delivery. This will not only provide familiarization with the procedures themselves, but may also help reveal problems or discrepancies with the hardware or software which may need to be addressed.

Customers should be advised to avoid last-minute design changes to hardware or software. This is particularly important with respect to changes involving mechanical and electrical interfaces to the carrier. This also applies to customer commands required to be sent during the payload-to-orbiter interface verification test (IVT), since these will have been previously defined in the PIP Annex 4 (Command and Data Annex). If late modifications to hardware or software are deemed necessary, then the as-built documentation must be updated accordingly, including any inputs to the safety data packages.

The customer-to-carrier ICD should also reflect the latest payload interface and I&T requirements. Any last-minute changes to the ICD should be approved by the payload carrier and customer prior to customer hardware delivery.

To support payload-level I&T, customers should be reminded to bring their instrument test and assembly logs, schematics, unique tools, test equipment, and consumables. Customers should also bring flight-qualified spares for critical components, as these may have a long-lead delivery time.

Customer Delivery—Unless prior arrangements have been agreed to, the customer is expected to deliver the instrument and GSE ready for integration with the payload carrier. The only operations to perform prior to carrier I&T are typically receiving and inspection, and any postship functional testing of the instrument.

Shortly after the customer arrives, a "turn-over" meeting with the customer and I&T team is held. Some I&T-related items which should be addressed during the meeting are:

- General customer status/summary;
- Open customer work to be performed (before or after start of carrier integration);
- Anomalies (explained or unexplained);
- Deviations to procedures previously identified (planned or contingency);
- Distribution of customer and payload procedures;
- Status of carrier flight and ground systems;
- Plan for integration and test: schedule, location, personnel, hazards;
- Unique customer requirements, if any (alignment, purge, calibration, charging, etc.);
- Customer support area (i.e., office space);
- Customer responsibility for shipping, handling, and storage of their own equipment.

Customer-to-Carrier I&T—Following completion of any post-ship stand-alone functional testing, the customer hardware is mechanically integrated with the payload carrier.

Prior to electrical connection to the carrier power and C&DH subsystems, resistance measurements should be taken at the customer interface to verify proper continuity and isolation, as applicable. Following electrical connections for flight, a functional test should be performed. Since the purpose of this test is to ensure the final flight mates, it may be abbreviated if a full functional was performed during initial electrical I&T.

It is advisable to restrict activation of individual instruments to times when there is a customer representative present to monitor instrument status.

Payload-Level I&T

Final Integration—After all hardware is installed, the payload should be configured as close as possible to flight. This includes securing all thermal blankets and cable harnesses. It may be desirable to delay installation of lock-wiring and staking, in case removal of hardware is required for whatever reason.

IVT Simulations—To ensure that the orbiter IVT sequence is correct, as well as familiarize the team with the IVT procedure, IVT simulations are conducted. These sims are performed with the payload in the flight configuration, with the latest version (or draft) of the IVT procedure. Generally, IVT sims are performed upon completion of payload integration at the carrier facility, and then upon completion of Payload Processing Facility (PPF) testing at KSC just prior to orbiter integration.

For those payloads utilizing a PGSC, it is important to use the latest mission software available from JSC. However, the "training load" software is usually not available until L-110 days, and the final flight load is not released until approximately L-40 days.

Since the PGSC software used during the IVT sim may not be the final version, JSC should notify the payload of any changes to the flight load following initial release. This notification should allow enough time for the payload-unique software to be modified and tested, if necessary, prior to the orbiter IVT.

All individuals who plan to support the actual orbiter IVT should participate in the IVT sims. This includes members of the I&T team as well as any customers involved. Having the same people for both tests is especially important for subjective verifications, such as those for closed-circuit television (CCTV) images. It also helps ensure that everyone is familiar with the procedure and associated verifications prior to the orbiter IVT.

If crew is available, such as a payload specialist, then he/she should also participate in the IVT sims for the familiarization opportunity. In this case, the crew should be kept informed of the test schedule, which may need to be adjusted to accommodate availability.

Transfer to EMC—Upon completion of customer-to-carrier integration, the payload is transferred to an EMC test facility. Performing EMC testing on the payload in flight configuration is important to accurately test for emissions and susceptibility. Testing is based on the latest EMC limits identified in the shuttle "core" ICD.

For payloads involving safety-critical circuits, all inhibits must be enabled during EMC testing to verify no susceptibility. For example, any ordnance should be installed and connected, and the system fully armed. Ordnance integrity should be verified at regular intervals during susceptibility testing (such as the end of each test day), to limit the amount of retest required if susceptibility is discovered.

EMC test data which indicates any exceedances is provided to JSC for review. Exceedances which are approved for flight are eventually documented in the payload-to-orbiter ICD. Those not approved are mitigated through redesign (such as incorporation of electromagnetic interference filters) or operationally (e.g., not activating the emissions-producing hardware).

Telemetry Recording—If a small shuttle payload has any telemetry interfaces, data should be recorded during I&T for later playback during mission simulations. Ideally, this telemetry reflects payload configurations expected during the mission, and therefore requires that each of the subsystems and instruments be operated in various on-orbit modes.

For any ground data GSE to be used both during I&T and the mission itself, two sets are recommended. This will allow support of mission sims during prelaunch I&T, as well as provide an back-up set if the prime has a failure.

6. Preparations for Launch Site Operations

Documentation

Payload Procedures—Although the format for payload procedures is generally up to the payload provider, it is preferable to have payload procedures in the same format as KSC procedures. This helps not only to translate to KSC format if needed for KSC work authorization documents (WAD's), but also helps familiarize the payload team with the KSC format.

Hazardous procedures usually require KSC-specific wording and formatting. The distinction between hazardous and non-hazardous procedures is outlined in KHB-1700.7 [7], with which the I&T team should be familiar.

Currently, all payload procedures (planned and contingency) are due to KSC 45 days prior to first use.

KSC Documentation—Like payload procedures, KSC should provide to the payload for review drafts of all documentation related to processing the payload. This includes the Launch Site Support Plan (LSSP), Program Requirements Document (PRD), Test Preparation Sheets (TPS's), Operations and Maintenance Instructions (OMI's), and prelaunch switch lists, as applicable. All of these must be reviewed thoroughly for accuracy during the draft phase, to avoid having to mod or dev a document after it is released. As with payload inputs to KSC, procedures should be submitted to the payload for review 45 days prior to first use.

For procedures involving payload connections or disconnections, explicit steps and respective "OK's" for each mate/demate should be included. A table or checklist with each mate/demate, which can then be signed-off when completed, may also be helpful. Each step should be referenced in only one procedure (either payload or KSC), to avoid confusion regarding who should perform the operation and whether it has been completed.

Even before the KSC procedures are written, payload requirements must be specified in the LSSP and OMRSD. Facility, consumable, and other support requirements are included in the PRD. Also, any hazardous operations requiring KSC support (e.g., pad clears, RF silence, etc.) should be explicitly identified in the LSSP and/or PRD.

Orbiter Documentation—Usually before the Cargo Integration Review (CIR), approximately one-year prior to launch, the payload provides initial inputs to such programmatic documentation as the PIP and annexes, detailed orbiter schematics, and the IRD. The latter is most important for side-mounted payloads, and should identify departure lengths for any payload-to-payload cables which are fabricated by the payload provider and sent to KSC for preinstallation into the orbiter. The I&T manager should thoroughly review this documentation for accuracy.

In the case of the PIP Annex 4, confirmation of command bit patterns is especially important. This is because KSC uses the Command and Data Annex to generate Payload Signal Processor (PSP) commands sent via the Launch Processing System (LPS) during the orbiter IVT. Any discrepancies are difficult to identify and correct while the IVT is in progress. Therefore, the command tables should be thoroughly reviewed for accuracy prior to Annex 4 release.

The OMRSD is used to ensure that a requirement is formally levied on KSC. Compared to the LSSP, the OMRSD affords greater visibility and tracking, especially in the orbiter world. Also, keep in mind that the OMRSD is meant to specify what requirements need to be fulfilled, not how they are to be implemented -- those details are left for the procedures.

As orbiter integration becomes imminent, tech orders (TO's) will be generated by orbiter engineering to document the details necessary to integrate a particular payload. It is important that the individual discipline engineers review the TO's to ensure technical accuracy, well in advance of orbiter integration.

Personnel Training and Badging

Note: As of the date of paper submission, security requirements at NASA facilities were being revised. It is recommended that the I&T manager verify the latest KSC security requirements, and ensure payload team compliance prior to payload delivery.

Types of Badging—All payload personnel, NASA and non-NASA, must be properly trained and badged to enter and work in facilities at KSC. Two types of badging are in force at Kennedy. The first allows access onto government property, and basically requires a either a permanent picture badge or a temporary "machine pass." The second allows entry into designated areas and facilities, and requires an area permit which can be either permanent (for which a Personnel Access Control Accountability System, or PACAS, badge is issued) or temporary (for which a Temporary Area Authorization, or TAA, is issued). The latter can be either for escorted or unescorted access.

It is recommended that the entire payload support team obtain unescorted access, not only since they will probably require periodic, long-term access to KSC facilities, but also because they can help escort customers if necessary. For payload customers, escorted badging is usually sufficient since most are only one-time visitors and no special training is required in this case. For those customers with anticipated long-term or multiple visits to KSC, unescorted access is recommended.

Training Requirements—Those requiring unescorted access to KSC facilities must also be trained in emergency egress, including use of the Emergency Life Support Apparatus (ELSA) and the respective facility "walk-downs" (usually on video). General safety videos must also be viewed, including: Ammonia Hazard, Pad Debris Damage, Space Shuttle Safety, and General Processing Safety.

Unescorted access also requires that a full Personnel Reliability Profile (PRP) security investigation on the individual be conducted. Unfortunately, the process is quite lengthy, requiring personal history details submitted usually a year in advance. Although one's PRP approval can be renewed, if it lapses for an extended period (i.e., over a year or so), then the entire investigation process must be reperformed.

In addition, anyone requiring access to elevated platforms must be trained in fall protection, which involves use of body harnesses tethered to support structures. Anyone involved in use of hazardous materials (including solvents and staking compounds) must be trained in "hazardous waste handling." Finally, anyone requiring access to the orbiter must view the midbody and crew module familiarization; it is required that these videos be viewed at KSC for training to be considered valid.

Training/certifications must be kept up-to-date, such that personnel are certified for the duration of scheduled operations. As much training as possible should be completed before start of KSC operations, so time at the Cape can be used most effectively. Major operations or meetings should not be rescheduled to accommodate training.

Shipping

Arrangements—About a year before going to KSC, the I&T manager (or designee) should initiate DOT approval for shipment. Requests must begin this early to allow for DOT processing time, especially if there are hazmats involved, such as hazardous chemicals, radioactive substances or explosives. If shipping via highway is ultimately denied, alternatives modes of transport include plane and barge. The latter was necessary to ship CAPL-1 Hitchhiker (STS-60), due to its relatively large quantity of ammonia. Since then, Goddard has obtained a global DOT exemption for shipping up to 0.25 pounds of ammonia per heat pipe.

Some other issues which need to be addressed prior to shipment include:

- Generation of shipping list, including up-to-date MSDS's and hazmat checklist;
- Contracting and scheduling of the truck;
- Arranging for truck driver badging at KSC, and providing specific directions to driver;
- Generation of shipper, and verifying against items loaded onto truck.

More on Hazmats—All hazardous materials must be identified in advance, for GSFC and KSC processing safety, as well as shipment. Those items which should be assumed hazardous until proven innocent include: chemicals, gases, radioactive materials, and ordnance. Small, commercial, off-the-shelf batteries are not considered hazmat items.

Hazmats contained within payloads which have been approved for shipment from GSFC to KSC must again be properly classified as a hazardous material on shipper, with an MSDS included. Hand-carrying of hazmats is prohibited. Special requirements may also apply for radioactive materials.

Loading and Shipment—Although shipping requirements depend on such things as payload size and sensitivity, the payload and GSE can usually be shipped in an environmentally controlled moving van.

The actual day of shipment to KSC depends on the amount of time required for post-ship I&T prior to orbiter integration. To take most advantage of the work week at KSC, it is usually advantageous to ship on a Saturday for arrival first-thing Monday morning. The FPM should be contacted to arrange for entrance of the truck and personnel onto KSC.

Finally, it is traditional to have plenty of payload stickers or other "goodies" on-hand for the movers and any other support personnel.

Miscellaneous Preship Considerations

GSE Certification—Mechanical ground support equipment (MGSE), such as lifting slings, must be proof-loaded and certified to lift flight hardware. This certification is valid for only one year, which is usually sufficient to support both prelaunch and postlanding operations for small payloads. Therefore, it is desirable to have the MGSE proof-loaded as late as possible just prior to shipping, with a couple of weeks added for contingency.

Also, electronic test equipment (such as meters) should be calibrated prior to shipment. Since meters and other electrical GSE (EGSE) are readily available at KSC, last-minute calibration of these is not as critical as for MGSE.

Payload Bay Cabling—Some Hitchhiker cables, such as "cross-bay" cables, are installed by KSC into the payload bay prior to payload installation. These should be shipped down to KSC well in advance of being required for integration into the orbiter. If time allows, the cables should be transported with the payload; otherwise, they must be shipped in advance (along with the flight certification documentation). Unless another contact is designated, the FPM can be the point-of-contact for receiving the cables at KSC.

Preship and Configuration Reviews—For Hitchhiker, an "in-house" preship review is conducted prior to shipment to KSC, to verify that there are no hardware configuration issues, or nonconformances or anomalies to be addressed. Ideally, the preship review is scheduled immediately following the EMC test so any exceedances can also be presented. The review is also the last opportunity to verify all documentation is up-to-date: certification logs, problem records, procedures, ground safety verification items, etc.

Also prior to the preship review, a review is conducted to identify any configuration discrepancies between the hardware and orbiter documentation. Conducting this configuration review before shipment allows enough time to correct any discrepancies before orbiter integration. A final survey is conducted at the PPF, just prior to transfer to the orbiter, to cover any items integrated in the field.

Things to Bring—The following is a non-exhaustive list of items which the I&T manager should bring (or arrange to be shipped) to KSC:

- Latest versions of procedures (payload stand-alone or KSC), including any redlines;
- Latest payload drawings, including all cable assembly drawings and carrier schematics;
- Excerpts from the payload-to-orbiter ICD, especially electrical pin-outs;
- Latest Annex 4, OMRSD, LSSP, PRD, and IRD (if applicable);
- Certification logs and as-run copies of procedures performed during payload I&T at the development facility;
- List of key contacts at home and KSC (KSC phonebook may be obtained via the FPM);
- Badges (picture and KSC Area Permit) and any certification cards;
- Beeper, if deemed necessary;
- Stickers, pins, or patches, for KSC support personnel.

7. Prelaunch Operations

General

The I&T Manager's Role at KSC—While at KSC, the I&T manager fulfills several functions. First, he/she continues to be the focal point for payload I&T operations. The I&T manager works closely with the FPM, through whom KSC support and resources are requested.

Second, the I&T manager serves as the payload test conductor (or TC, not to be confused with KSC's PTC). As such, the I&T manager is the primary payload contact during the orbiter IVT and other integrated operations.

Third, the I&T manager also has the role of launch site safety representative for the payload. Therefore, he/she must be familiar with all safety issues associated with processing the payload at KSC.

Finally, the I&T manager has payload signature authority for approval of KSC WAD's and sign-off of as-run procedures. In this capacity, he/she may also sign-off on the payload closeouts for flight.

Miscellaneous I&T Considerations—Following arrival at KSC, daily I&T meetings with a summary of operations for the week are usually helpful. Depending on the number of participants and space available, these can be relatively informal, stand-up meetings with the team. Pretask briefings, especially for major tests and hazardous ops, should be considered mandatory. KSC personnel who are involved in the operations should also attend.

Any overtime, whether it be on a daily or weekly basis, should be coordinated through KSC and payload management in order to comply with work restrictions. More importantly, personnel fatigue increases the risk of accidental injuries or damage to flight hardware. Any extension or rescheduling of operations should be decided upon with due consideration to the payload I&T team, which is typically "single-string."

Ordnance Operations—During testing and arming of ordnance (such as NSI's) in the orbiter, the I&T manager must ensure that the operation has been identified as a hazardous ordnance operation. This includes scheduling RF-silence and requesting a local clear area (typically 10-feet from the hardware). Unless KSC requires it, an entire "pad clear" during ordnance operations is not necessary; a local clear is sufficient, with only a cordoned-off area in the immediate vicinity of the operation. RF-silence and clear area should be called out in the associated WAD.

The KSC payload ops representative is responsible for ensuring that other personnel are notified about hazardous operations in the clear area. As during all ordnance operations, the area should be monitored for unauthorized entry and questionable activities. Finally, as mentioned earlier, those directly involved with handling ordnance or systems connected to ordnance must be trained and certified.

Data Transfer—Occasionally, data must be transferred from the payload organization to KSC. This data includes final payload weight and center-of-gravity (c.g.), and that required for safety verifications and OMRSD requirements.

Since there is no formal mechanism to handle data transfer between the payload and KSC, it is recommended that the payload develop a form similar to SSPPO's "GSFC Data Transfer Form." A copy of this form may be obtained from the SSPPO CM Office at GSFC; see the SSPPO website (http://sspp.gsfc.nasa.gov) for contact information.

Likewise, as-run data from KSC WAD's must sometimes be transferred from KSC to the payload. Unfortunately, there is no easy mechanism currently in place to transfer information to the payload. In this case, it behooves the I&T manager to request any required KSC data via the LSSP. At a minimum, KSC should be provided with advance notice that the as-run data will be needed.

Customer Access to Orbiter Facilities—Understandably, many payload customers may want to tour the various orbiter integration facilities (OIF's), as well as the orbiter itself. This may be acceptable during a break in I&T, for example, or with only a couple of visitors. However, during critical integrated operations, such as orbiter installation or IVT, visitors not involved with the operation itself should not be permitted in the area.

This is an even greater concern if a large number of customers (e.g., more than a couple) want to tour simultaneously. Instead, a separate tour when things are not as busy is recommended. Finally, unless there is sufficient justification, no visitors are allowed inside the orbiter crew compartment.

Operational Responsibilities at KSC—Depending on the nature of the operation involving shuttle payloads, either KSC or the payload has primary responsibility, with the other acting in a support role. KSC personnel have primary responsibility for performing most of the payload-to-orbiter integration operations. The payload representatives are responsible for performing those operations that involve payload-to-payload interfaces. These include not only payload flight interfaces, but nonflight ones such as test connectors for payload GSE.

Here is a summary of general categories of operations and the primary responsible party for each:

Operation	Primary Responsibility
Payload operations at the payload processing facility	Payload
Integration and deintegration involving payload-to-orbiter interfaces	KSC
Integration and deintegration during orbiter operations involving payload-to-payload interfaces	Payload
Payload testing involving payload-to-orbiter interfaces	KSC
Payload testing during orbiter operations involving PGSC or payload-to-GSE interfaces	Payload
Payload close-outs and postlanding operations involving direct contact with the payload	Payload

Postship Operations at the PPF

Responsibilities at the PPF—Since operations at the payload processing facility (PPF) are off-line and stand-alone, the payload shall have the primary responsibility for performing this work. Generally, this includes prelaunch functional testing, payload preparations for orbiter integration, and any postflight operations prior to ship back to the home facility.

KSC personnel are responsible for providing payload support and resources, as defined in the LSSP and PRD.

Facilities—There are several facilities at KSC which are used as PPF's for small payloads, including the Multi-Payload Processing Facility (MPPF), Space Station Processing Facility (SSPF), and Multi-Operations Support Building (MOSB). Historically, even off-site facilities (such as the Astrotech and SpaceHab buildings) have also been used as PPF's prior to orbiter integration. Each facility requires separate familiarization training for access, as well as hands-on training for crane operation.

In recent years, the MPPF has been used for small shuttle payloads. The relative isolation of the MPPF affords users a certain level of autonomy. For example, payload technicians can be trained and certified to operate the MPPF crane. However, one drawback is that the MPPF is still considered a secure area and requires proper badging for access.

If the SSPF is used, several points should be considered. First, the payload should be cordoned-off if not in a separate, secure area. Second, only KSC technicians are qualified to operate the overhead bridge cranes in the high-bay, so at least two KSC crane operators must support major lifts. Third, the proximity to KSC payload personnel helps in obtaining KSC support resources, yet also invites more intense scrutiny. Finally, office space in the SSPF is usually a premium, so small payload representatives may be relegated to remote locations.

Receiving, Inspection, and Set-Up—Following arrival at the PPF, the payload and GSE are off-loaded from the truck, usually in the reverse order from loading. For flight hardware on small dollies, only hydraulic lift gates and fork-lifts may be used to unload. Use of truck platforms supported by chains is prohibited, since these have failed in the past (CryoHP Hitchhiker on STS-53), resulting in damage to the dolly and potential damage to the payload.

If an elevated truck lock is unavailable, off-loading of cross-bay payload hardware has been performed using a combination of flatbed truck and portable crane. However, the use of roll-backs (or "Jerr-Dans") has more recently been approved by KSC safety for off-loading large payloads. One issue which has come up in the past (regarding commercially rented roll-backs) is proof-loading of the cable used to hoist the payload onto the flatbed. However, this issue is reportedly no longer considered a safety issue.

As the hardware is off-loaded, the individual who coordinated the shipping from the home facility verifies all hardware has been received and signs-off the bill-of-lading. After unloading, the flight hardware and GSE are usually rolled into an intermediate truck-lock area for unpacking and cleaning. Once inside the main cleanroom, the hardware is configured for post-ship testing and any additional integration required before transfer to the orbiter.

Mechanical Integration—Depending on the type of payload, off-line mechanical integration at the PPF can be relatively simple or complex. For example, side-mounted payloads typically remain on dollies until orbiter integration. The price for this simplicity is paid during orbiter integration, when individual components must then be mounted and connected sequentially.

For larger payloads, such as cross-bay Mission-Peculiar Equipment Support Structure (MPESS) bridges, PPF operations may require more mechanical integration. There may also be some instruments which are shipped on dollies separately, which would then have to be installed at the PPF.

Electrical I&T—Once the payload is set up and connected to the EGSE, post-ship functional testing may commence. This includes activation of the carrier and all instruments, depending on customer support available.

Usually, the final test performed at the PPF is a final IVT sim. Like the sim performed prior to shipment, the test at Kennedy is based on the IVT OMI, except this is the final released procedure to be run during the orbiter IVT.

If the IVT involves using a PGSC, the payload (i.e., the I&T manager) is again responsible for obtaining a PGSC loaner from JSC. However, this last sim should be run using the latest flight software load from JSC, not only to verify software compatibility but to verify the orbiter IVT sequences with the released OMI.

Unfortunately, the <u>final</u> flight load is usually unavailable for the IVT sim or even the IVT itself. However, as mentioned earlier, JSC should at least notify the payload organization of any changes to the mission software, to avoid surprises either during the IVT or on orbit. There should also be a mutually agreed-upon limit to the extent of any changes to the JSC flight load, to ensure the payload-unique software will not be affected.

Upon completion of electrical I&T, any customer GSE can be packed for shipment to the Payload Operations Control Center (POCC), if needed to support the mission, or left at KSC if required to support the IVT.

Transfer to Orbiter

Preparations for Transfer—As mentioned earlier, a final configuration review is performed by a payload representative at the PPF. This is usually performed just prior to transfer to the orbiter. Although this check will have been performed just prior to shipment to KSC, this last-minute verification is to check the final flight configuration following PPF operations.

A Vehicle Integration Test Team (VITT) representative usually performs the sharp-edge inspection; any areas of concern must be addressed prior to payload closeout for transfer. A contamination inspection is also performed, with any required cleaning supported by payload mechanical and thermal technicians. In general, the cleaner the payload is prior to transfer to the orbiter, the cleaner it will be on orbit.

Transfer from PPF—After all off-line operations are complete, a final weighing of the payload is usually performed prior to transfer and the data is provided to KSC. The payload is then either double-wrapped (in the case of side-mounted payloads) or loaded into the transport canister (cross-bay payloads).

For lifting larger payloads, KSC's Integrated Partial Payload Lifting Assembly (IPPLA) is the MGSE of choice since it allows for c.g. adjustment. However, if the IPPLA is used, prelift inspections of both the bridge trunnions and

IPPLA trunnion supports are recommended to ensure no damage will be incurred.

Occasionally, customers require a continuous drag-on purge for their instruments. This may be accommodated on a case-by-case basis. Otherwise, periodic interruptions of the purge may be necessary during transfer.

CITE Testing—The horizontal CITE stand is a high-fidelity orbiter avionics simulator located in the SSPF. The purpose of CITE is to verify new payload electrical interfaces to the orbiter, prior to orbiter integration.

Reusable payload carriers such as Hitchhikers are typically exempt from CITE testing, since electrical interfaces to the orbiter usually do not change from mission to mission. However, since CITE is required by default, KSC conducts a "CITE bypass study" to assess whether the test is actually necessary.

The CITE IVT procedure is basically the same as the orbiter IVT, and is a good dry-run for the final orbiter test. A CITE test typically adds about a month to the prelaunch flow, including transfer operations.

Orbiter Integration

I&T Responsibilities at the OIF—KSC shall have the primary responsibility for integration (and de-integration) involving payload-to-orbiter interfaces. This includes payload installation into (and removal from) the orbiter, as well as connection (and disconnection) of payload-to-orbiter interfaces. It also includes installation (but not connection) and removal (but not disconnection) of any payload-to-payload cable harnesses which must be routed within the payload bay structure. The payload is responsible for providing support for such operations, as required.

The payload shall be responsible for performing integration (and de-integration) involving payload-to-payload interfaces during orbiter operations. This includes installation (and removal) of payload components, such as remove-before-flight items, drag-on purges, and payload-to-payload electrical connections. It also includes connection (and disconnection) of any payload-to-payload cable harnessing which are routed within the payload bay structure. KSC is responsible for providing support for such operations, such as platforms or bridge-bucket support for payload customer access.

During integrated orbiter operations, KSC shall be responsible for performing payload testing involving payload-to-orbiter interfaces. This includes tests such as the payload-to-orbiter IVT and other integrated procedures involving payload activation via orbiter power. The payload provides test support for any integrated procedures requiring payload activation.

The payload shall be responsible for performing all stand-alone operations involving payload-provided ground support equipment (GSE). This includes tests such as the payload-to-orbiter IVT and other integrated procedures involving payload activation. It also includes tests involving payload activation via stand-alone power supplies or internal batteries, i.e., not requiring orbiter activation. KSC provides support for payload testing, as required.

PGSC Operations—As mentioned above, KSC has primary responsibility for performing those operations involving payload-to-orbiter interfaces, and the payload performs operations on payload-to-payload interfaces. However, there are other interfaces for which the responsible party is less clearly defined. A case in point is when a payload-provided PGSC is being used during orbiter integrated operations. This includes tests such as the payload-to-orbiter IVT and other procedures involving payload activation.

Such operations involving the PGSC and payload-provided software should be conducted by payload representatives, rather than KSC personnel, for two significant reasons. First, since the payload provides the PGSC for IVT, the payload is ultimately responsible for it.

Second, since the payload customer also provides any payload-unique software, the customer is most familiar with its operation. This is especially important for payloads with PGSC commands which, for example, initiate an irreversible experiment sequence. Having an experienced payload representative operating the PGSC helps avoid any accidental mission-critical commanding which could ruin an experiment before it even leaves the ground.

Operations Scheduling—Once in the orbiter flow, the payload is at the mercy of the orbiter integrated schedule. It is helpful to have KSC provide advance notification when work is delayed or scrubbed. Since the small payload team typically cannot support contiguous multi-shift operations, the I&T manager must remain cognizant of potential schedule impacts. Ideally, any rescheduling of payload operations should be discussed with all parties involved before being finally decided and implemented.

It is sometimes unclear who is the single-point-contact for payload operations during orbiter integration: the payload ops representative from KSC Payload Ground Operations Contractor (PGOC) or from the Shuttle Flight Operations Contractor (SFOC). If on-hand, the PGOC payload ops representative is usually considered the single-point contact for scheduling payload operations. However, while at the OPF, the SFOC payload ops person is the contact of choice, since he/she is a more direct line to the orbiter world.

Unfortunately, while quite helpful in providing support, payload ops personnel have any authority over prioritizing operations. Ultimately, it is left to the payload I&T manager to advocate for KSC support on behalf of the payload. In this respect, the I&T manager should not be timid. It behooves the I&T manager to diplomatically "lobby" for payload operations to remain on schedule as much as possible, through discussions with key KSC operations personnel.

To help mitigate against potential support discrepancies, a pretask briefing should be held with all participants the day prior to (not morning of) the operation. Having KSC complete pre-ops (such as crane and access preps) the day before a major operation is also helpful.

Contamination Control—Contamination control during orbiter integration, particularly in the OPF, is somewhat less stringent than in the PPF. In the case of side-mounted payloads, staging in the relatively unclean OPF transfer isle can introduce contamination. Here, and even in the payload bay itself when payloads are not installed, KSC personnel are not required to wear cleanroom garments.

Therefore, the I&T manager should request that all personnel in the vicinity of the payload wear proper cleanroom attire. The LSSP and OMRSD should also include explicit cleanliness requirements, if applicable. These measures not only help mitigate risk of contamination, but also help instill a more diligent level of awareness in the handling of flight hardware.

Also at the OPF is the risk of FOD being introduced inside the payload bay. This is particularly a concern during installation of side-mounted payloads, which require frequent handling of fasteners and tools. Since non-captive fasteners can not be tethered, one suggestion is to install a temporary tarp or other FOD capture device directly below the hardware being installed. This is especially important in bays where the payload bay liner has been removed. It also helps to have spare fasteners on-hand, so integration can continue if a fastener is temporarily lost.

Another problem encountered during installation of side-mounted payloads is the fact that orbiter technicians usually do not wear gloves to install fasteners. This introduces the risk of transferring fastener grease to the payload. Even if gloves are worn, grease can still be transferred to the payload if they are not changed-out after handling fasteners.

At the pad, Payload Changeout Room (PCR) cleanliness is significantly better than at the OPF. The primary concern at the pad is debris from operations or other payloads situated above, as well as occasional incidences involving the Payload Changeout Room (PCR) ventilation system. This can be mitigated through the use of a debris shield installed directly above the payload in the Payload Changeout Room (PCR), requested via the LSSP and PRD.

There are, however, a couple of issues associated with a debris shield. First, the installation of the shield can increase the risk of contaminants falling onto the payload, or the payload being accidentally contacted. Second, the shield itself is sometimes not a contiguous piece of material, and therefore doesn't always fully protect the payload from falling dust and debris. Third, the proximity of an adjacent payload installed above may not allow enough clearance for a debris shield.

In summary, there are cases when a debris shield is not feasible nor desirable. In these situations, the best one can do is to fully inspect the payload during pad closeouts, and clean as necessary for flight.

Payload Handling Issues—Over the years, many incidences have been reported of damage to payload flight hardware, particularly during orbiter integration. In addition, some practices which have become almost standard for flight hardware development (e.g., use of wrist-stats and gloves) are not usually implemented during orbiter processing.

Some of these handling requirements can be addressed in the LSSP, but should also be noted in the applicable WAD to ensure visibility. For operations involving payload-to-payload interfaces, the I&T manager must be diligent about ensuring that only payload personnel execute them.

In cases where the payload contains ordnance, everyone working with the hardware should be reminded that ESD protection is mandatory when handling the hardware. It is also helpful to have extra conductive gloves on-hand during orbiter operations, since these are difficult to come by in the OIF's.

Physical Interfaces—Mechanical and electrical interfaces between the payload and orbiter are integrated per WAD's such as TO's and TPS's. However, if the hardware does not match the documentation, some form of Problem Reporting And Corrective Action (PRACA) paperwork is usually opened, and a real-time modification with follow-up documentation is required.

Performing a configuration verification on the payload hardware, as mentioned earlier, can help avoid some conflicts prior to orbiter integration. For example, one Hitchhiker payload had the wrong keel trunnion installed, which wasn't discovered until orbiter installation.

One payload electrical interface which causes recurring difficulties is the 0-AWG Standard Mixed Cargo Harness (SMCH) power cable. In several instances, the payload-to-orbiter ICD has referenced a cable length or routing which was physically impossible to implement. If the payload has any cross-bay cables (provided in advance to SFOC for installation), routing should be verified by the payload as soon as possible to insure the cables can be connected properly prior to IVT. Since the actual routing of payload cables is difficult to define prior to orbiter integration, a change to the ICD and/or IRD is often required.

Payload-to-Orbiter IVT

Scope—Strictly speaking, the orbiter IVT is limited to exercising only those power and signal functions required to verify copper path interfaces between the payload and orbiter, or payload-to-payload interfaces connected after orbiter installation. It should be noted that because side-mounted payloads typically involve more payload-to-payload mates during orbiter integration, more interfaces need to be verified during their IVT's.

Since the IVT is considered a copper-path verification, no functional testing is usually performed. Despite this, there is occasionally some limited amount of functional testing performed in conjunction with IVT. This may be acceptable if there is sufficient technical justification, such as a late, prelaunch instrument calibration. Even if justifiable, scheduling and access are usually the most significant issues associated with functional testing. It should be noted that every additional payload command (sent via LPS) can require as many as a half-dozen additional OMI steps to implement, as well as additional bit patterns defined in PIP Annex 4.

An alternative to performing payload functional testing within the context of the IVT is to conduct a stand-alone test independent of orbiter power. This is typically performed via a payload test connector and external, drag-on power supply.

Regardless of the approach, all requirements for testing in the orbiter must be documented in the OMRSD in order for KSC to officially acknowledge and support them.

Procedure Development—The I&T manager, or designee, typically provides KSC with inputs required for IVT OMI development. This is usually done several months prior to delivery to KSC. Any steps performed in the OMI should have a corresponding OMRSD requirement which is ultimately fulfilled through their implementation.

Historically, some payloads have had an "IVT support procedure" to be run by payload support personnel in conjunction with KSC's IVT OMI. However, this can be cumbersome, not only to maintain as procedurally consistent with the OMI, but also to run in parallel with the IVT. If the IVT is written accurately, then no other support procedure should be required. Possible exceptions include pre- or post-ops, or those payload-specific operations outside the scope of the IVT itself.

Scheduling—It is most beneficial if KSC schedules the payload-to-orbiter IVT as soon as possible following payload installation and connection to the orbiter. This helps small payload teams minimize travel, since many of the same people who support installation also support IVT and subsequent close-outs.

In addition, delaying the IVT a week or more beyond installation introduces potential risks to the overall schedule. One example was the IEH-1 Hitchhiker IVT (STS-69), which was originally scheduled about a week after installation into the orbiter. Unexpected circumstances (including roll-back due to a hurricane) delayed the IVT until two months later, potentially impacting the launch schedule.

Near-Term Preparations—A day or so prior to the IVT, KSC usually conducts a pretest briefing, during which a timeline and dev package are distributed. This meeting should be attended by the I&T manager, who typically acts as the payload TC during the IVT. In this capacity, he/she is the primary payload contact during the test and is the communication link between the payload and KSC teams on the Operational Intercommunication System (OIS) "net."

During the briefing, the I&T manager should also verify with KSC that:

- All KSC equipment required to support IVT (e.g., MGSE, bridge bucket) is on-hand and functionally tested no later than the day before IVT;
- Those networks required during IVT, such as OIS and CCTV, will be functionally tested end-to-end the day before IVT (if earlier, then patching could be inadvertently changed; if later, then systems may not be ready in time for call-to-stations);
- Payload access platforms (if required) will be installed, also the day prior to IVT;
- Dedicated bridge bucket support (if IVT at the OPF) will be available; bucket operators should be available on-station from pre- to post-ops, as necessary;
- KSC orbiter and payload personnel supporting the IVT are aware of respective responsibilities, particularly with regards to PGSC operations (if applicable);
- For ordnance operations, local clear and RF silence will be established at the proper point in the procedure.

In addition, the payload TC should hold a separate pretest briefing with the payload team, usually after the KSC pretest briefing. This would include payload-specific details such as personnel assignments and stations, and any customer support issues. Everyone supporting the IVT in the OIF should have the proper training and certifications, and any necessary escorts should be prearranged. Finally, the payload team should be reminded of their OIS call-signs, and proper on-net etiquette.

Performing the pre-IVT walkdown the day before (vs. the day of) is also highly recommended. This allows at least one shift to address any issues discovered during the walkdown. For example, in the case of MightySat/SAC-A Hitchhiker (STS-88), the walkdown was scheduled only two hours prior to call-to-stations. During the walkdown, the orbiter/payload interface cables were found to have been routed in the bay too tight. The payload activation was delayed several hours while KSC technicians adjusted the cables.

Finally, the I&T manager is responsible for ensuring that all payload-provided test equipment is available, such as PGSC's, scopes, meters, and any payload-unique GSE. In the case of the PGSC, a flight-like unit is borrowed from JSC via the RFS form, as is done for stand-alone testing. The final flight software load (or as close to it as possible) should be used during the orbiter IVT, to help ensure that the payload-unique software will operate properly during the mission.

Performing the IVT—As mentioned earlier, the same individuals who participated in the IVT sim should participate in the actual orbiter IVT. In the case of Hitchhikers, the payload TC is usually stationed at the PPF. This allows easy communication with the customers and viewing of telemetry and video monitors, as applicable.

Any extraneous observers should also be located at the PPF.

The Hitchhiker mission manager usually supports from the firing room, where the KSC payload test conductor and engineers are stationed. At that location, he or she is able to provide any payload customer signatures required on any devs or PRACA.

For orbiter aft flight deck operations, crew support is the first choice, if available. If a PGSC is required for IVT, the operator should be the payload software engineer when crew is unavailable. In any case, it is up to the payload TC to decide who is best qualified to operate the PGSC, with concurrence from project management. Of course, the operators should have all the training and certifications required for crew module access.

Payload personnel may also be required to support from the payload bay. They should arrive at the OIF early enough to allow time to check-in all test equipment and tools with the access monitor. As usual, any test equipment required to support IVT in the payload bay must be tetherable and secured.

All personnel supporting the IVT should be on-station at least one-half hour prior to start of their pre-ops or call-to-stations, as applicable. The payload team should utilize the separate, preassigned OIS channel for any off-line discussions during the IVT. On-line communications are restricted to responses as called out in the procedure itself, with the payload TC responding for the rest of the team unless otherwise specified. Telephones should be used for extended conversations or those unrelated to the IVT.

Upon completion of all testing, any payload GSE can be packed for shipment to the POCC if required to support the mission.

Closeouts and Launch Operations

Closeouts—Some payload operations must be performed as late as possible prior to launch. This typically means no later than a day or so prior to final payload bay door closure either at the OPF or pad. Late payload operations generally do not involve orbiter power; therefore, any testing requires stand-alone power supplies. Testing may include, for example, a last-minute instrument calibration or battery top-charge.

Payload closeouts are those operations required to finally configure the payload for flight, including:

- Removing "remove-before-flight" (or "red-tag") items, such as dust covers and purge lines;
- Installing arm plugs for ordnance or other functions, such as enabling satellite batteries;
- Verifying armed circuits, for example, via continuity measurements at a test connector;
- Performing a walkdown of the payload to verify configuration, cleanliness, and that all nonflight items have been removed.

Payload closeout requirements, whether at the OPF or pad, must also be predefined in the OMRSD. Since these are generally performed by payload personnel, they are usually specified in a separate payload procedure.

Launch—Unless the payload is powered during launch, or a "T-0 interface" is utilized, payload personnel are usually not required to support launch at KSC. Instead, payload representatives should be stationed at the POCC for payload activation.

The I&T manager may or may not be required to support throughout the mission. I&T may just be on-call in case a problem develops which requires his or her expertise.

8. Postflight Operations

At KSC

Postlanding and Orbiter Deintegration—As with launch, payload personnel are generally not required to support landing. Any postlanding operations are performed in the OPF following payload bay door opening. The only postlanding, stand-alone operations for small payloads are usually dust cover reinstallations and safing of ordnance circuits, if necessary. Again, any requirements for operations in the orbiter must be documented in the OMRSD.

Electrical disconnections are performed in the OPF, usually in the reverse order of connection, with the same respective KSC and payload responsibilities noted earlier. Payload transfer back to the PPF is also performed in essentially the reverse order of prelaunch integration. Any payload-provided cables removed from the payload bay should be returned to the payload organization.

PPF Operations—Once the payload arrives back at the PPF, it is generally prepared for shipment back to the home facility. For Hitchhikers, no activation of the payload is performed at the PPF postflight.

In some cases, customers request that specific postflight operations, such as data retrieval or even instrument deintegration, be performed at the PPF. However, it is recommended that customer hardware be deintegrated after return to the home facility, unless there is sufficient technical justification. Performing work at KSC beyond the minimum required to ship the payload back home requires more procedures to be run at KSC. This tends to increase the time in the field, as well as the probability of encountering unforeseen problems.

For example, following the flight of IEH-1 (STS-69), the CONCAP-IV/03 customer requested that the canister be removed from the payload and deintegrated. Although this had not been the original plan, the consensus was that it would help expedite experiment sample removal, as well as eliminate the need for the customer to travel to Goddard. Unknown to all was that one of the sample vials, which contained a hazardous substance, had broken within the can. When the canister was opened the noxious gas escaped, resulting in a hazardous situation inside a KSC facility. Fortunately, no one was injured, but a valuable lesson had been learned at a risk to human health.

Back at the Ranch

Deintegration—Upon return to its home facility, the payload and GSE are off-loaded and inspected for damage. Any postflight troubleshooting deemed necessary should be performed before any hardware is deintegrated from the payload.

As with integration, deintegration is performed in the most logical sequence. Removal of customer hardware depends on accessibility of the hardware, as well as availability of the customers themselves. For Hitchhikers, carrier hardware remains installed if necessary to support a subsequent mission. However, generally all mission-unique hardware is removed from the payload and returned to storage for future use.

Documentation—Following post-mission activities, at his/her earliest convenience, the I&T manager should compile and distribute a summary of any "lessons learned." This includes significant I&T-related issues experienced and any suggestions for improvement. Specific team members should also be commended for their efforts.

In addition, the I&T manager should provide some feedback to KSC regarding operations in the field. This may include a KSC payload customer survey, Opportunity For Improvement (OFI) form, or simply a summary to key individuals.

Payload customers should be asked to submit some form of customer survey to help the payload team gain some insight for improving customer support and payload processing. The format for the customer survey used for Hitchhikers can be found at the SSPPO website.

Finally, all payload documentation and logbooks (including as-run procedures) should be archived, to make them available for future reference. Of course, all problem records should be dispositioned and closed prior to archiving.

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