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Integration and Test of Shuttle Small Payloads

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ABSTRACT

This paper is intended for consideration by developers of small shuttle payloads, including integration and test (I&T) managers, project managers, and system engineers. Recommended approaches for small space shuttle payload I&T are presented. Examples and lessons learned are provided based on the extensive history of 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 should be of special interest to those payload projects that have small budgets and few resources: that is, the truly "faster, cheaper, better" projects. All shuttle small payload I&T managers 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

1.1 Overview and Scope

Integration and test (I&T) of space shuttle small 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 enables a level of flexibility and responsiveness not possible with larger projects. Smaller team size, on the order of a dozen total, means each individual has a more significant role in the development, integration, and test of the spacecraft.

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

After 29 missions involving over 60 separate instruments, the Hitchhiker project team has gained a wealth of experience in integrating and testing shuttle payloads with a core cadre of I&T personnel. Although many details and examples presented here are based on the Hitchhiker program, the basic approaches are directly transferable to any small 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.

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

The focus of this paper is on payload-level integration and test. Therefore, details regarding design and qualification testing of individual components and subsystems are not presented.

1.2 Definitions

Carrier: The payload infrastructure that acts as a mechanical and electrical interface between the payload customer(s) and the orbiter. The carrier not only supports the customer hardware mechanically, but may also provide such services as power, command and data handling (C&DH), and thermal control. For example, carriers for Hitchhiker payloads are mounted in the payload bay, either on the side or cross-bay using Mission-Peculiar Equipment Support Structure (MPESS) "bridges."

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"). At Kennedy Space Center (KSC), however, 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 developed, assembled, and tested for flight. This includes I&T at the payload development facility, as well as that at the launch site (usually KSC).

I&T Manager: The person usually 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 person may be an engineer, technician, or other individual who is intimately familiar with the procedure, and who is fully qualified to lead the operation.

2. I&T MISCELLANEOUS

2.1 The I&T Team

2.1.1 Team Responsibilities

The I&T team for a given payload 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), personnel supporting disciplines such as attitude control and propulsion may also be involved.

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

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

2.1.2 I&T Manager Responsibilities

The following is a summary of responsibilities that fall under the purview of the I&T manager for shuttle small payloads:

- Leads the I&T team, including engineers, technicians, and customers
- Serves as the primary point of contact regarding integrated payload I&T issues
- Coordinates I&T operations, including resources, 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 the I&T team, project management, and individual instrument customers regarding I&T status and issues
- Provides input to payload design issues that may affect I&T
- Provides inputs to shuttle program documentation, such as the Payload Integration Plan (PIP), Interface Control Document (ICD), and safety data packages
- Serves as 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.

2.2 I&T Coordination

2.2.1 Meetings

Regular I&T meetings are suggested to 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. For example, hazardous operations usually require more intense team coordination than those that are nonhazardous.
- The level of I&T activity for the payload itself. That is, when the team is involved in an intense level of activity (e.g., multiday 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. This will be, in general, 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. A retreat provides an informal atmosphere in which the team can brainstorm regarding I&T flow and any design issues that 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 meeting location away from team members' offices usually helps facilitate uninterrupted participation.

2.2.2 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 on past experience. The schedule should be realistic: not overly ambitious, yet not overly conservative. In addition, some contingency in the schedule is usually prudent to allow for any unanticipated delays and problems.

For example, support and deliverables are not always provided in time to meet the established schedule. Delays may be caused by a variety of factors, including long lead-time component deliveries, test failures, and design enhancements. In these situations, the I&T manager can consider several options: step up the effort (e.g., via overtime or more people), revise the schedule to accommodate the delays, or recommend some redesign in order to maintain the schedule. In any case, everyone involved with the payload I&T process must understand the importance of maintaining the schedule in order to ultimately meet the launch date.

Use of Performance Evaluation Review Technique (PERT) charts is sometimes helpful in the early planning stages to help identify I&T flow. Maintaining the accuracy of large PERTs over time is, however, generally manpower intensive, particularly for smaller projects with limited resources. 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 may be useful. Ultimately, the I&T manager should utilize the scheduling tool that he or she finds most effective.

Ideally, project management should be provided an advance copy of the I&T schedule for review prior to general distribution. Schedules should be distributed in whatever form is most convenient for the team, such as electronic distribution or website posting.

The I&T team must understand that the I&T manager (by definition) manages the schedule. Any issues or conflicts should be brought to his or her attention as soon as possible after discovery, so that resources can be reallocated and the schedule can be adjusted, if necessary.

2.3 Handling of Flight Hardware

2.3.1 General I&T Practices

Members 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:

- Minimize, if not eliminate, debris ("foreign-object debris," or FOD) in I&T areas. This debris includes particulates, unneeded tools and equipment, extraneous paper and other consumables. Take the initiative to report facility cleanliness issues.
- Before entering a clean environment, utilize shoe cleaners when available and properly don all necessary garments prior to entering.
- 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.
- Do not lay tools, test equipment, paperwork, or other miscellaneous items on top of flight hardware.
- Fabricate or 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 when power is applied.

2.3.2 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, nonflight 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 GSE, when appropriate, using anti-static caps (if available).

2.3.3 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 persons 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 knowledge necessary to evaluate proper flight hardware fabrication and handling performed by others.

2.3.4 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 (NSIs) from the storage facility and installs them into the flight hardware.

Handling of ordnance requires the use of "wrist-stats," even when contacting hardware in which NSIs are installed. Hardware should be tagged with "ordnance installed" signs or streamers. The hazardous operations area should be cordoned off and restricted to only those directly involved with the operations.

While 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.

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, with the exception of KSC's training, good courses for ordnance handling are difficult to find.

2.3.5 Troubleshooting Anomalies

All anomalies should be fully investigated and understood. It is recommended, however, to start with a troubleshooting plan to proceed in an orderly manner and to avoid unnecessary violation of interfaces.

Some rules of thumb for troubleshooting are:

- 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 that are least intrusive to the flight configuration.
- To help isolate the problem, only one change to the flight or ground configurations should be made at a time.

- Although hardware should be "built to print," occasionally drawing errors occur. Therefore, do not always assume that the released engineering accurately reflects the current hardware configuration.
- As much detail as possible should be recorded in the logbook (or in 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 in real time rather than reconstructed after the fact.

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

2.5 I&T Manager Communications

2.5.1 Communication With I&T Team

Communication among I&T team members 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 regularly inform the team regarding the I&T schedule and status. Conversely, to do his or 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.

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 the task leader as the 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, 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 safety and doing what makes sense.

2.5.2 Communication With Payload Customers

Besides communication with 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" 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 with 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.

2.5.3 Communication 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 information 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 or erroneous communications. Of course, some technical details will still require direct discussion among 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 payload, support equipment, and personnel. The I&T manager may also participate in weekly PPT meetings via teleconference.

3. PROCESS DOCUMENTATION AND CONFIGURATION MANAGEMENT

3.1 Payload Project Configuration Management

3.1.1 Scope

Even before the introduction of ISO-9000 requirements, process documentation and configuration management (CM) have played an important part in NASA flight projects. Process documentation includes certification logs, as-run procedures, problem reports, and other “quality records.” CM involves maintaining an archive system of as-built hardware and software configuration, including requirements, procedures, and drawings. Compared to some larger projects, CM for small payload projects should be a more streamlined and user-friendly system.

In the case of the SSPPO, a CM office and Configuration Control Board (CCB) have been established to track configuration, release documentation, and process Configuration Change Requests (CCRs). CCRs are required for all changes to the baselined flight configuration.

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

3.1.2 I&T Considerations

Depending on the CM approach established by the 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
- All anomalies are documented and maintained in the I&T logbook.

3.1.3 Nonconformances

Any nonconformances or anomalies encountered should be documented to allow tracking, as well as to provide a 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.

A corrective action should be documented by whatever mechanism the project has established (problem record, logbook, etc.). A required modification that affects released engineering drawings should also be formally documented.

3.2 Customer “CM”

3.2.1 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 that 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 (MIPs) 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 (MSDSs) for hazardous materials (hazmats)
- Fastener certifications and logs, including torque levels
- Summary of open items or problems, if any, to be addressed following delivery for payload integration.

3.2.2 The CCCR

Besides the as-built configuration and certification data mentioned, post-delivery CM of the instruments is also important. For example, customer hardware or software is sometimes modified following delivery 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 customer modifications can have greater visibility and review for potential impacts. Following hardware delivery to GSFC, customers are requested to complete and submit a Customer Configuration Change Request (CCCR) for any changes to flight or nonflight 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

4.1 Payload Carrier

4.1.1 I&T Considerations

From the very beginning of payload carrier development, all I&T aspects 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, on some Hitchhiker payloads, test connectors are strategically placed to allow easy access for testing in the orbiter.

There is one important point regarding design for electrical interface verification: All final electrical connections must be verified for flight, either functionally or by continuity measurement. This means that interfaces that 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 of the flight circuit.

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 shuttle payload, a customer's dust cover was only pressure-fit onto an instrument's horizontal-oriented 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.

4.1.2 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, at a minimum, vibration and thermal-vacuum tests. 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.

4.1.3 Flight Hardware Reuse

The Hitchhiker project has the luxury of reusing the majority of its carrier hardware from mission to mission. Carrier components that already exist are selected for reflight, with new hardware fabricated only as necessary. Existing hardware to be reused is usually not required to undergo requalification testing but 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 work 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.

4.1.4 Flight and Ground Software

Flight software for shuttle small 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 Johnson Space Center (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 2 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 of 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.

4.2 Customer Instrument

4.2.1 Customer-to-Carrier Interfaces and Requirements

Small payload customer interfaces and requirements, including those for ground operations support, must be clearly defined in advance. These items 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 (including software)
- Mechanical interfaces: fasteners, 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
- I&T issues: cleanliness, tethering, temperature and humidity constraints, radiation sensitivity (e.g., x rays).

Any customer requirements not documented in advance should be considered new requirements. These must be assessed for whatever additional support or resources may be required, and may be an "optional service" not normally provided by the carrier organization. The ICD or requirements documents should then be modified to include the new requirements.

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 "highly desired." Customers may need to be reminded that shuttle small 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.

4.2.2 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 that 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, interfaces for test connections, purges, and other prelaunch operations should be accessible from step-ups, "pic" boards, or other 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 due to its operational complexity, limited availability, and increased risk of damage to flight hardware.

4.2.3 Preintegration Testing

It is strongly recommended that customers complete all environmental testing prior to delivery 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 could 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 system interfaces.

Preintegration testing also provides an opportunity to perform a "dry run" of I&T procedures, to verify the inaccuracy prior to final delivery. This also serves to document the as-run operation for future reference during flight I&T.

5. PAYLOAD INTEGRATION

5.1 Carrier Integration Sequence

Integration of individual payload components should be performed in the most logical sequence. Implementation of a logical integration sequence, however, depends on several factors. These include hardware availability, integrated component accessibility, and functional interdependence.

For example, integration of payload carrier components should be completed prior to interfacing with customer hardware. Also, 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 alternative suggestions from other team members. Again, the important point is to do what makes sense.

5.2 Customer I&T

5.2.1 Customer Predelivery Preparations

Customer procedures (planned and contingency) required for I&T should be submitted to the payload organization no later than 1 month prior to delivery. This deadline allows adequate time for review and modification, if necessary, prior to customer arrival. Customers should be strongly encouraged to perform dry runs of their procedures at their home facilities. These "rehearsals" will not only provide familiarization with the procedures themselves, but may also help reveal problems or discrepancies with the hardware or software that may need to be addressed.

Customers should also 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 restriction also applies to customer commands required to be sent during the payload-to-orbiter interface verification test (IVT); this is because such commands are defined in advance in the PIP Annex 4 (Command and Data Annex) and incorporated into KSC's Launch Processing System (LPS) software. 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 involve a long-lead time for delivery.

5.2.2 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 is held with the customer and I&T team. Some I&T-related items that should be addressed during the meeting are:

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

5.2.3 Customer-to-Carrier I&T

Following completion of any postship stand-alone functional testing, the customer hardware is mechanically integrated with the payload carrier. This may be as simple as bolting a small box to a mounting plate, or as complex as crane-lifting a large sensor onto a pointing subsystem requiring subsequent optical alignment.

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 is performed to verify the final flight interfaces between the customer and carrier.

It is advisable to restrict activation of individual instruments to times when a customer representative is present to monitor instrument status. One exception to this rule is when the customer is able to monitor the instrument telemetry from a remote Payload Operations Control Center (POCC).

5.3 Payload-Level I&T

5.3.1 Final Integration

After all hardware is installed, the payload should be configured as close as possible to flight. This work 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 to address any problems encountered during payload testing.

5.3.2 IVT Simulations

To ensure that the orbiter IVT sequence is correct, as well as to familiarize the team with the IVT procedure, IVT simulations (“sims”) are conducted. These sims are performed with the payload in the flight configuration, with the latest version (or draft) of the IVT procedure. IVT sims should be 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. The “training load” software is usually not available, however, until launch (L)-110 days. 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 allows 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, including members of the I&T team and any customers. 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 familiarize everyone with the procedure and associated verifications prior to the orbiter IVT.

If crew is available, such as a payload specialist, then he or 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 their availability.

5.3.3 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 that indicate any exceedances are provided to JSC for review. Exceedances 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).

5.3.4 Telemetry Recording

If a payload has any telemetry interfaces, data should be recorded during I&T for later playback during mission simulations. Ideally, this telemetry should reflect payload configurations expected during the mission, and therefore requires that each subsystem and instrument be operated in various on-orbit modes.

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

6. PREPARATIONS FOR LAUNCH SITE OPERATIONS

6.1 Documentation

6.1.1 Orbiter Documentation

Usually before the Cargo Integration Review (CIR), approximately 1 year prior to launch, the payload provides inputs to such programmatic documentation as the payload-to-orbiter ICD, the PIP and annexes, and detailed orbiter schematics. The I&T manager and engineers 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 LPS during the orbiter IVT. Any discrepancies are difficult to identify and correct while the IVT is in progress.

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. It is also important to remember 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 (TOs) are generated by orbiter engineering to document the details necessary to integrate a particular payload. The individual discipline engineers should review the TOs to ensure technical accuracy, well in advance of orbiter integration.

6.1.2 KSC Documentation

The payload organization works with KSC on most of the documentation related to processing the payload. This includes the LSSP and Program Requirements Document (PRD), as well as work authorization documents (WADs) such as Test Preparation Sheets (TPSs) and Operations and Maintenance Instructions (OMIs). All of these must be reviewed thoroughly for accuracy during the draft phase to avoid having to modify 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.

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.

6.1.3 Payload Procedures

Although the format for payload procedures is generally up to the payload provider, it is preferable to write payload procedures in the same format as KSC procedures. This approach helps not only to translate to the KSC format if needed for KSC WADs, 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 nonhazardous 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.

6.2 Personnel Training and Badging

Note: As of the date of publication, 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.

6.2.1 Types of Badging

All payload personnel, NASA and non-NASA, must be properly trained and badged to enter and work at KSC facilities. Two types of badging are in force at KSC: the first allows access onto Government property, and basically requires either a permanent picture badge or a temporary "machine pass." The second allows entry into designated areas and facilities, and requires an area permit that 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 because 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; no special training is required in this case. For those customers with anticipated long-term or multiple visits to KSC, unescorted access is recommended.

6.2.2 Training Requirements

Those persons 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). There are also several general safety videos that must be viewed.

Unescorted access also requires that a full Personnel Reliability Profile (PRP) security investigation of 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, the entire investigation process must be reperformed if it lapses for an extended period.

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 video.

Training and 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.

6.3 Shipping

6.3.1 Arrangements

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

Other issues that need to be addressed prior to shipment include:

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

6.3.2 More on Hazmats

All hazardous materials must be identified in advance for GSFC and KSC processing safety, as well as for shipment. Those items that 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, although other larger batteries may need to be identified.

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

6.3.3 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 postship I&T prior to orbiter integration. To take the most advantage of the work week at KSC, it is usually advantageous to ship over a weekend for arrival early 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.

6.4 Miscellaneous Preship Considerations

6.4.1 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 1 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, their last-minute calibration is not as critical as for MGSE.

6.4.2 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 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). If advance shipment is required, and additional payload testing (such as EMC) is to be performed, then a second set of cables is necessary.

6.4.3 Preship and Configuration Reviews

As is usual for flight projects, an "in-house" preship review is conducted prior to shipment to launch site. This serves as a forum to verify that there are no hardware configuration issues, 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 that all documentation—certification logs, problem records, procedures, ground safety verification items, etc.—is up-to-date.

Usually prior to the preship review, a separate 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.

6.4.4 Things to Bring

The following is a nonexhaustive list of items the I&T manager should bring (or arrange to be shipped) to KSC:

- Latest versions of procedures (payload stand-alone or KSC), including any modifications
- Latest payload drawings, including all cable assembly drawings and carrier schematics
- Excerpts from the payload-to-orbiter ICD, particularly the technical details
- Latest PIP and annexes
- Certification logs and as-run copies of procedures performed during payload I&T
- Contact information for key personnel at home and at KSC
- Badges (picture and KSC Area Permit) and any certification cards
- Stickers, pins, or patches for KSC support personnel.

7. PRELAUNCH OPERATIONS

7.1 General

7.1.1 I&T Manager's Role at KSC

While at KSC, the I&T manager fulfills several functions. First, he or 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. In this capacity, the I&T manager is the primary payload contact during the orbiter IVT and other integrated operations. As such, he or she is the communication link between the payload and KSC teams on the Operational Intercommunication System (OIS) "net."

Third, the I&T manager also has the role of launch site safety representative for the payload. Therefore, he or 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 WADs and sign-off of the as-run procedures. In this capacity, he or she may also sign off the payload closeouts for flight.

7.1.2 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 operations, should be considered mandatory. KSC personnel involved in the operations should also be invited to attend.

Any overtime, whether daily or weekly, should be coordinated through KSC and payload management 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 I&T team, which is typically "single string" for small payloads.

7.1.3 Hazardous Operations

During hazardous operations, such as testing and arming of ordnance, the I&T manager must ensure that the operation has been identified as hazardous. This effort includes scheduling RF-silence (if necessary) and requesting a local clear area (typically 10 feet from the hardware). For some hazardous operations a local clear is sufficient, with only a cordoned-off area in the immediate vicinity of the operation. RF-silence, clear areas, and any emergency steps should be called out in the associated WAD.

The KSC payload operations (ops) representative is responsible for ensuring that other personnel are notified about hazardous operations in the clear area. The area should be monitored for unauthorized entry and questionable activities. Those directly involved with performing hazardous operations must be trained and certified.

7.1.4 Data Transfer

Occasionally, data must be transferred from the payload organization to KSC. This data includes final payload weight and center of gravity (cg), and any information 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.

Likewise, as-run data from KSC WADs must sometimes be transferred from KSC 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.

7.1.5 Customer Access to Orbiter Facilities

Understandably, many payload customers may want to tour the various orbiter integration facilities (OIFs), as well as the orbiter itself. Such tours may be acceptable during a break in I&T, for example, or with only a couple of visitors. For larger groups, a separate tour is recommended as schedules permit.

During critical integrated operations, however, such as orbiter installation or IVT, visitors not involved with the operation itself should not be permitted in the area. Finally, no visitors should be allowed inside the orbiter crew compartment unless there is sufficient justification. This restriction is based on the high density of critical components in the crew module, as well as to "man-loading" limits.

7.1.6 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 connections for payload GSE.

A summary of general categories of operations and the primary responsible party for each is shown below:

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 payload-to-payload or payload-to-GSE interfaces	Payload
Payload close-outs and postlanding operations involving direct contact with the payload	Payload

7.1.7 KSC I&T Flow

The general shuttle small payloads I&T flow at KSC is shown in figure 1.

7.2 Postship Operations at the PPF

7.2.1 Responsibilities at the PPF

Since operations at the 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 shipment back to the home facility.

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

7.2.2 Facilities

Several KSC facilities are used as PPFs for small payloads, including the Multi-Payload Processing Facility (MPPF), Space Station Processing Facility (SSPF), Radioisotope Thermoelectric Generator Facility (RTGF), and Multi-Operations Support Building (MOSB). Historically, even off-site facilities (such as the SpaceHab facility and Cape Canaveral Air Force Station hangars) have also been used as PPFs. Each facility requires separate familiarization training for access and crane operation.

In recent years, the MPPF has been used for shuttle small payloads. The relative isolation of the MPPF affords users a certain level of autonomy. For example, payload technicians can be easily trained and certified to operate the MPPF crane. One drawback, however, is that the MPPF is still considered a secure area and requires proper badging for access. There is also some level of competition from multiple payload organizations requiring use of the MPPF.

If a larger facility such as the SSPF is used, several points should be considered. First, the payload should be cordoned off if it is not in a separate secure area. Second, only KSC technicians are qualified to operate the overhead bridge cranes; therefore, 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 is usually at a premium, so small payload representatives may be relegated to remote locations.

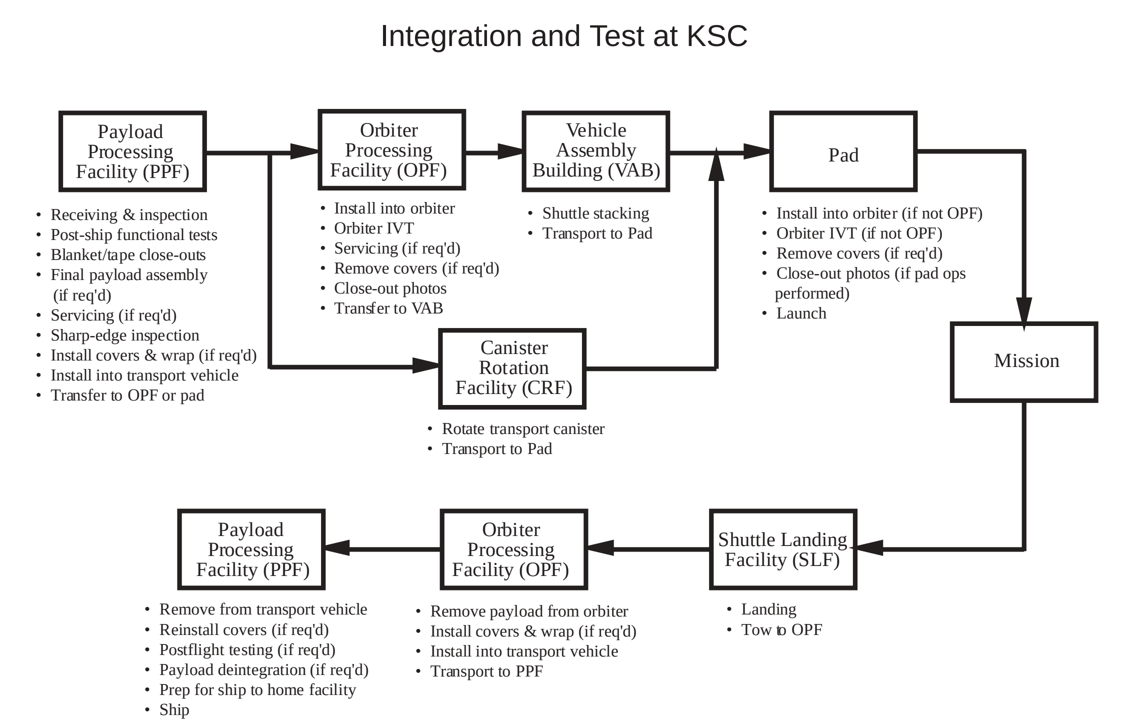

Figure 1.

7.2.3 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. Only hydraulic lift gates and forklifts may be used to unload flight hardware from small dollies. Use of truck platforms supported by chains is prohibited, since these have failed in the past, resulting in damage to GSE and potential damage to flight hardware.

If an elevated truck lock is unavailable, cross-bay payload hardware has been off-loaded using a combination of flatbed truck and portable crane. The use of roll-backs (or "Jerr-Dans") has more recently been approved by KSC safety for off-loading large payloads.

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 clean room, the hardware is configured for postship testing and any additional integration required before transfer to the orbiter.

7.2.4 Mechanical Integration

Depending on the type of payload, off-line mechanical integration at the PPF can be relatively simple or very 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, and their electrical interfaces verified during the IVT.

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

7.2.5 Electrical I&T

Once the payload is set up and connected to the EGSE, postship functional testing may commence. This testing includes activation of the carrier and all instruments, depending on customer support available.

Usually, the last 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 that the latest version of the KSC procedure is used.

If the IVT involves using a PGSC, the payload organization (i.e., the I&T manager) is again responsible for obtaining a PGSC loaner from JSC. 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 latest OMI.

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

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

7.3 Transfer to Orbiter

7.3.1 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 checks the final flight configuration following PPF operations.

A sharp-edge inspection is usually performed by a representative from the Vehicle Integration Test Team (VITT). 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.

7.3.2 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 (for 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. 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. Unless optional service accommodations are negotiated with KSC, periodic interruptions of the purge are usually necessary during orbiter transfer operations.

7.3.3 CITE Testing

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

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. Since CITE is required by default, KSC conducts a "CITE bypass study" to assess whether the test is 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.

7.4 Orbiter Integration

7.4.1 I&T Responsibilities at the OIF

KSC shall have the primary responsibility for integration (and deintegration) involving payload-to-orbiter interfaces. This task 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 that must be routed within the payload bay structure. The payload organization is responsible for providing support for such operations, as required.

The payload team shall be responsible for performing integration (and deintegration) involving payload-to-payload interfaces during orbiter operations. This work 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 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 team shall be responsible for performing all stand-alone operations involving payload-provided GSE. This work 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.

7.4.2 PGSC Operations

As mentioned above, KSC has primary responsibility for performing those operations involving payload-to-orbiter interfaces, and the payload provider performs operations on payload-to-payload interfaces. There are, however, other tasks involving interfaces for which the responsible parties are less clearly defined. A case in point is when a payload-provided PGSC is being used during orbiter integrated operations. These operations include tests such as the payload-to-orbiter IVT and other procedures involving payload activation using orbiter power.

Such operations involving the PGSC and payload-provided software are usually conducted by KSC personnel. However, since the payload customer provides any payload-unique software, and is therefore most familiar with its operation, a payload representative should monitor all PGSC operations. This is especially important for payloads with PGSC commands which, for example, initiate an irreversible experiment sequence. Having an experienced payload representative overseeing the PGSC operations helps to ensure that all payload commanding is properly executed.

Finally, if any flight crew support payload testing at KSC, they generally perform any orbiter or payload keyboard and switch operations. This is also a good opportunity for the crew to gain valuable training with the actual mission hardware and software in the flight configuration.

7.4.3 Operations Scheduling

Once in the orbiter flow, the payload is at the mercy of the orbiter integrated schedule. The I&T manager must remain cognizant of potential schedule impacts, especially those that require contiguous multishift operations–often a challenge for small-payload teams.

At KSC, it is sometimes unclear who is the single-point contact for payload operations during orbiter integration: a representative from the KSC Payload Ground Operations Contractor (PGOC), someone from the Shuttle Flight Operations Contractor (SFOC), or the NASA payload manager. If on hand, the PGOC payload ops person is usually considered the single-point contact for scheduling payload operations. While at the OPF, however, the SFOC payload ops person is a more direct line to the orbiter world.

Unfortunately, while quite helpful in providing support, payload ops personnel have little authority over prioritizing operations. Ultimately, it is left to the payload I&T manager to advocate on behalf of the payload for KSC support to allow payload operations to remain on schedule.

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-op, such as crane and access preparations, the day before a major task is also helpful.

7.4.4 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 full clean room garments.

Therefore, the I&T manager should request that all personnel in the vicinity of the payload wear proper clean room 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 a concern particularly during installation of side-mounted payloads because this effort typically requires frequent handling of fasteners and tools. Since noncaptive fasteners cannot be tethered, one suggestion is to install a temporary tarp or other FOD capture device directly below the hardware being installed. This precaution is especially important in bays where the payload bay liner has been removed. It also helps to have spare fasteners on hand so that integration can continue if a fastener is temporarily lost.

Another problem encountered during installation of side-mounted payloads is the risk of contamination from fastener grease. Orbiter technicians are usually not required to wear gloves to install fasteners, thus introducing the risk of transferring grease to the payload. Even if gloves are worn, grease can still be transferred to flight surfaces if the gloves are not replaced after becoming soiled.

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 PCR ventilation system. This risk can be mitigated through the use of a debris shield installed directly above the payload in the PCR, as requested via the LSSP and PRD.

There are, however, a couple of issues associated with a debris shield. First, installation of the shield itself can increase the risk of contaminants falling onto the payload or the payload being accidentally contacted. Second, the shield is not a contiguous piece of material and therefore may not 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.

Regardless of whether a debris shield is used or not, the payload should be fully inspected during pad closeouts and cleaned for flight, as necessary.

7.4.5 Payload Handling Issues

Over the years, many incidences of damage to payload flight hardware, particularly during orbiter integration, have been reported. 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.

Special handling requirements can be addressed in the LSSP, but they 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 sometimes not readily available in the OIFs.

7.4.6 Physical Interfaces

Mechanical and electrical interfaces between the payload and orbiter are integrated per WADs such as TOs and TPSs. If the hardware does not match the documentation, however, some form of nonconformance paperwork (such as a problem report) is 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 a wrong keel trunnion installed, a problem not discovered until orbiter installation.

One payload electrical interface that causes recurring difficulties is the zero-gauge Standard Mixed Cargo Harness (SMCH) power cable. In several instances, the payload-to-orbiter ICD has referenced a cable length or routing that was physically impossible to implement. Also, 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 ensure 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 is often required.

7.5 Payload-to-Orbiter IVT

7.5.1 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 IVTs.

Since the IVT is considered a copper-path verification, no functional testing is usually performed. Despite this, occasionally some limited amount of functional testing is performed in conjunction with IVT. This activity 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 test 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. This is the means by which KSC officially acknowledges and allocates resources for support.

7.5.2 Procedure Development

The I&T manager, or designee, typically provides KSC with inputs required for IVT OMI development. These inputs are usually provided several months prior to delivery to KSC. Any steps performed in the OMI should have a corresponding OMRSD requirement that 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. Such a procedure can be cumbersome, however, 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, 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.

7.5.3 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. Prompt completion of the IVT 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 is 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 2 months later.

7.5.4 Near-term Preparations

A day or so prior to the IVT, KSC usually conducts a pretest briefing during which a timeline and deviation package are distributed. The I&T manager and any other payload personnel supporting the IVT should attend this meeting.

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

- KSC orbiter and payload personnel supporting the IVT are aware of their respective responsibilities
- If IVT is to be performed as the OPF, dedicated bridge bucket support (if required) will be available; bucket operators should be available on-station from pre- to post-ops, as necessary
- 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
- Payload access platforms (if required) will be installed the day prior to 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 the call-to-stations
- 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 meeting typically includes 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. Further, the payload team should be reminded of their OIS call signs, proper on-net etiquette, and test team discipline.

Performing the pre-IVT survey of the payload ("walkdown") on the day before (versus the day of) the test is also highly recommended. Early completion of the walkdown allows at least one shift to address any issues discovered. For example, in the case of MightySat/SAC-A Hitchhiker (STS-88), the walkdown was scheduled only 2 hours prior to call-to-stations. During the walkdown, the payload-to-orbiter interface cables were found to have been routed too tightly in the bay. 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 PGSCs, 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. Receiving PGSCs (from JSC) may need to be coordinated with the flight crew equipment representatives at KSC. The final flight software load (or as close to it as possible) should be used during the orbiter IVT to ensure that the payload-unique software operates properly during the mission.

7.5.5 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, where the carrier and customer C&DH GSE is located. This proximity allows easy communication with the customers and viewing of telemetry and video monitors (if applicable). Extraneous observers should also be located at the PPF.

The Hitchhiker mission manager usually supports from the LC-39 firing room, where the KSC PTC and engineers are stationed. At that location, he or she is able to provide any payload customer signatures required on any OMI deviations or problem reports.

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 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 discussions unrelated to the IVT.

As mentioned earlier, payload test team discipline must be maintained, especially during the IVT which may involve a hundred or so KSC personnel. One notable situation was when most of the payload test team (stationed at the OPF) decided to take a dinner break in the middle of the IVT, without notifying the rest of the team. As a result, the IVT was on hold for almost an hour, awaiting the return of the payload personnel. In situations like this, the I&T manager (or test conductor) should remind the payload team of their responsibilities to complete the test as efficiently and safely as possible.

Upon completion of all testing, any payload GSE can be packed for shipment to the POCC, if required to support the mission. Any flight crew equipment (such as PGSCs) may be dispositioned by the flight crew representative.

7.6 Closeouts and Launch

7.6.1 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 and verify 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 and cleanliness, and that all nonflight items have been removed
- Taking close-out photos.

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

7.6.2 Launch

Unless the payload is powered during launch or utilizes a “T-0 interface,” 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 is usually not required to support the mission. The I&T manager should, however, be on-call in case a problem develops which requires his or her expertise.

8. POSTFLIGHT OPERATIONS

8.1 At KSC

8.1.1 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. A non-KSC landing usually does not involve secondary payloads unless some unique requirement has been prenegotiated. 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.

8.1.2 PPF Operations

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

In some cases, customers request that specific postflight operations, such as data retrieval or even instrument deintegration, be performed at the PPF. It is recommended, however, that customer hardware be deintegrated after return to the home facility, unless there is sufficient technical justification otherwise. Performing work at KSC beyond the minimum required to ship the payload back home requires more procedures to be run at KSC. This approach 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), one customer requested that his instrument be removed from the payload at the PPF. Although this had not been the original plan, the consensus was that early deintegration would expedite experiment sample removal, as well as eliminate the need for the customer to travel to GSFC. Unknown to all was that one of the sample vials, which contained a hazardous substance, had broken within the canister. When the can 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.

8.2 Back at the Ranch

8.2.1 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 can remain installed if required to support a subsequent mission. Generally, however, all mission-unique hardware is removed from the payload and returned to storage for future use.

8.2.2 Documentation

Following postmission activities, the I&T manager should compile and distribute a summary of any “lessons learned.” This report should include any significant I&T-related issues experienced, as well as suggestions for improvement. Specific team members should also be commended for their efforts.

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

Payload customers should be asked to submit some form of customer survey to the payload carrier organization. This feedback can help the payload team gain insight into improving customer support and payload processing. The format for the customer survey used for Hitchhikers can be found in the CARS document [4].

Finally, all payload documentation and logbooks (including as-run procedures) should be closed and archived to make them available for future reference.

9. CONCLUSION

A successful shuttle mission depends on the safe and efficient integration and test of the payload. This, in turn, depends on the diligent efforts of the I&T manager and I&T team.

Although small payloads often go unrecognized, and are usually undervalued, these represent the most cost-effective means of accomplishing space missions. Following the guidelines and recommendations included in this document, I&T managers can help continue this legacy of safety and efficiency well into the new millennium.

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ACRONYMS AND ABBREVIATIONS

CARS	Customer Accommodations and Requirements Specifications
CCB	Configuration Control Board
CCCR	Customer Configuration Change Request
CCR	Configuration Change Request
CCTV	Closed-Circuit Television
C&DH	Command and Data Handling
CIR	Cargo Integration Review
CM	Configuration Management
DOT	Dept. of Transportation
EGSE	Electrical Ground Support Equipment
ELSA	Emergency Life Support Apparatus
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
FOD	Foreign-Object Debris
FPM	Future Payload Manager
GEVS	Goddard Environmental Verification Specifications
GSE	Ground-Support Equipment
GSFC	Goddard Space Flight Center
ICD	Interface Control Document
IPPLA	Integrated Partial Payload Lifting Assembly
I&T	Integration and Test
IVT	Interface Verification Test
JSC	Johnson Space Center
KSC	Kennedy Space Center
L	Launch
LPS	Launch Processing System
LSSP	Launch Site Support Plan
MGSE	Mechanical Ground Support Equipment
MIP	Mandatory Inspection Point
MOSB	Multi-Operations Support Building
MPESS	Mission-Peculiar Equipment Support Structure
MPPF	Multi-Payload Processing Facility
MSDS	Material Safety Data Sheet
NSI	NASA Standard Initiator
OFI	Opportunity For Improvement
OIF	Orbiter Integration Facilities
OIS	Operational Intercommunication System
OMI	Operations and Maintenance Instructions
OMRSD ments	Operations and Maintenance Require- and Specifications Document
OPF	Orbiter Processing Facility
PACAS	Personnel Access Control Accountability System
PCR	Payload Changeout Room
PERT	Performance Evaluation Review Technique
PGOC	Payload Ground Operations Contractor
PGSC	Payload and General Support Computer
PIP	Payload Integration Plan
POCC	Payload Operations Control Center
PPF	Payload Processing Facility
PPT	Payload Processing Team
PRD	Program Requirements Document
PRP	Personnel Reliability Profile
PSP	Payload Signal Processor
RFS	Request For Support
RTGF	Radioisotope Thermoelectric Generator Facility
SFOC	Shuttle Flight Operations Contractor
SMCH	Standard Mixed Cargo Harness
SSPF	Space Station Processing Facility
SSPPO	Shuttle Small Payloads Project Office
TAA	Temporary Area Authorization
TC	Test Conductor
TPS	Test Preparation Sheets
VITT	Vehicle Integration Test Team
WAD	Work Authorization Document

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13. ABSTRACT *(Maximum 200 words)*

Recommended approaches for space shuttle small payload integration and test (I&T) are presented. The paper is intended for consideration by developers of shuttle small payloads, including I&T managers, project managers, and system engineers. Examples and lessons learned are presented based on the extensive history of 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 that 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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