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ABSTRACT

The Kennedy Space Center (KSC) Payload Management and Operations Directorate is responsible for the processing of Space Shuttle payloads. KSC responsibilities begin prior to hardware arrival at the launch site and extend until the experiments are returned to the investigators after the flight.

KSC involvement with the integration and checkout of payloads begins with participation in experiment, Mission Peculiar Equipment (MPE), and integrated payload design reviews. This involvement also includes participation in assembly and testing of flight hardware at the appropriate design center, university, or private corporation. Once the hardware arrives at the launch site, KSC personnel install the experiments and MPE onto a carrier in the Operations and Checkout (O&C) building. Following integration, the payload is functionally tested and then installed into the orbiter. After the mission, the payload is removed from the orbiter, deintegrated in the O&C building, and the experiments are turned over to the mission manager.

One of the many payloads processed at KSC consisted of two space construction experiments: the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS). This paper addresses the details of EASE/ACCESS integration, testing, and deintegration and discusses how this mission can serve as a guide for future space construction payloads.

INTRODUCTION

With the advent of the Space Station era, large truss structures in space will become the framework for on-orbit operations. To develop optimal techniques for building truss assemblies in zero-gravity, construction experiments must be performed. Two space construction experiments, EASE and ACCESS, recently were flown aboard the Space Transportation System (STS). The Space Shuttle has carried many scientific experiments into orbit. The final integration and verification of all Shuttle payloads occurs at the Kennedy Space Center (KSC) in Florida.

The various elements that comprise a payload arrive at the launch site from their individual design centers and are assembled and verified at KSC. All assembly and testing of the components are performed by KSC personnel. Each experiment is installed onto a carrier, such as a Mission Peculiar Equipment Suppport Structure (MPESS) or a pallet, and then tested to verify proper function. The entire payload is then installed into the orbiter and final preparations for launch are completed. After the mission, the payload is returned to KSC for deintegration.

KSC ORGANIZATION

STS activities at KSC are separated into two general categories: Shuttle operations and payload operations. The KSC organizational chart is shown Figure 1. The Shuttle Operations Directorate is responsible for the processing, launching, and landing of the Shuttle. This includes refurbishing the orbiter after each flight and mating it to the external tank and solid rocket boosters. Lockheed Space Operations Company is the Shuttle processing contractor and performs the actual "hands-on" operations.

The KSC Payload Management and Operations Directorate, on the other hand, is responsible for all payload processing at the launch site, including payloads flown on expendable vehicles. Within this directorate, the STS Payload Operations Directorate handles the processing of both horizontal and vertical Shuttle payloads. Vertical payloads, such as the Space Telescope and all satellites, are installed onto a carrier in the vertical position. Horizontal payloads, such as Spacelabs and partial payloads, are integrated onto a carrier in the horizontal position. Horizontal payload processing is performed by the Spacelab and Experiments Division. Several other offices, such as the safety office and the quality assurance office, also provide support for payload integration.

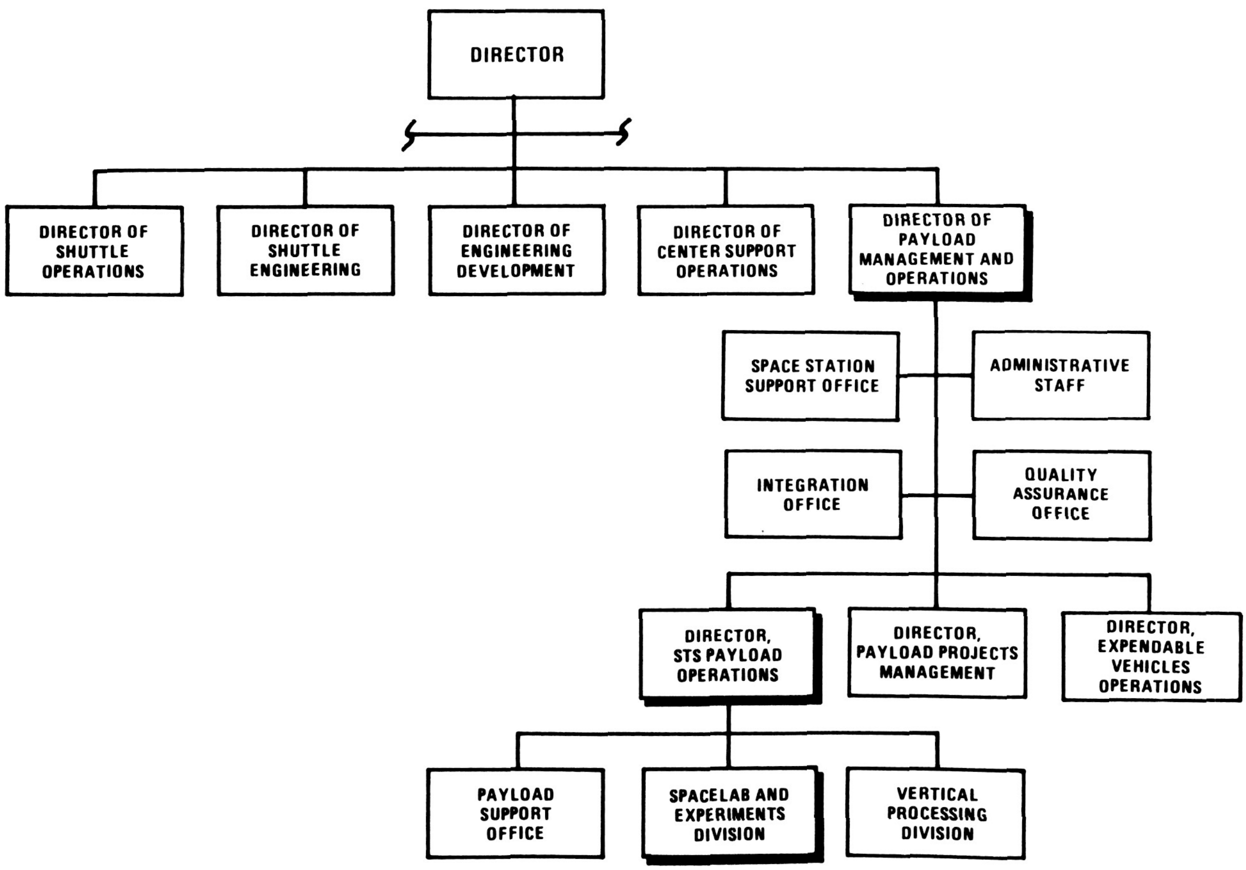


FIGURE 1 – NASA ORGANIZATIONAL CHART, JOHN F. KENNEDY SPACE CENTER

In the Spacelab and Experiments Division, NASA engineers perform hands-on work with flight hardware and ground support equipment. Figure 2 shows the breakdown of NASA and contractor roles in payload processing. NASA personnel are assisted by Boeing Aerospace Operations technicians. McDonnell Douglas Astronautics Corporation is the payload interface to the Shuttle organization and is also responsible for integrating Spacelab carriers.

Every horizontal experiment processed by the Spacelab and Experiments Division is assigned a NASA mechanical engineer and a NASA test conductor. These two engineers, along with the payload's launch site support manager,

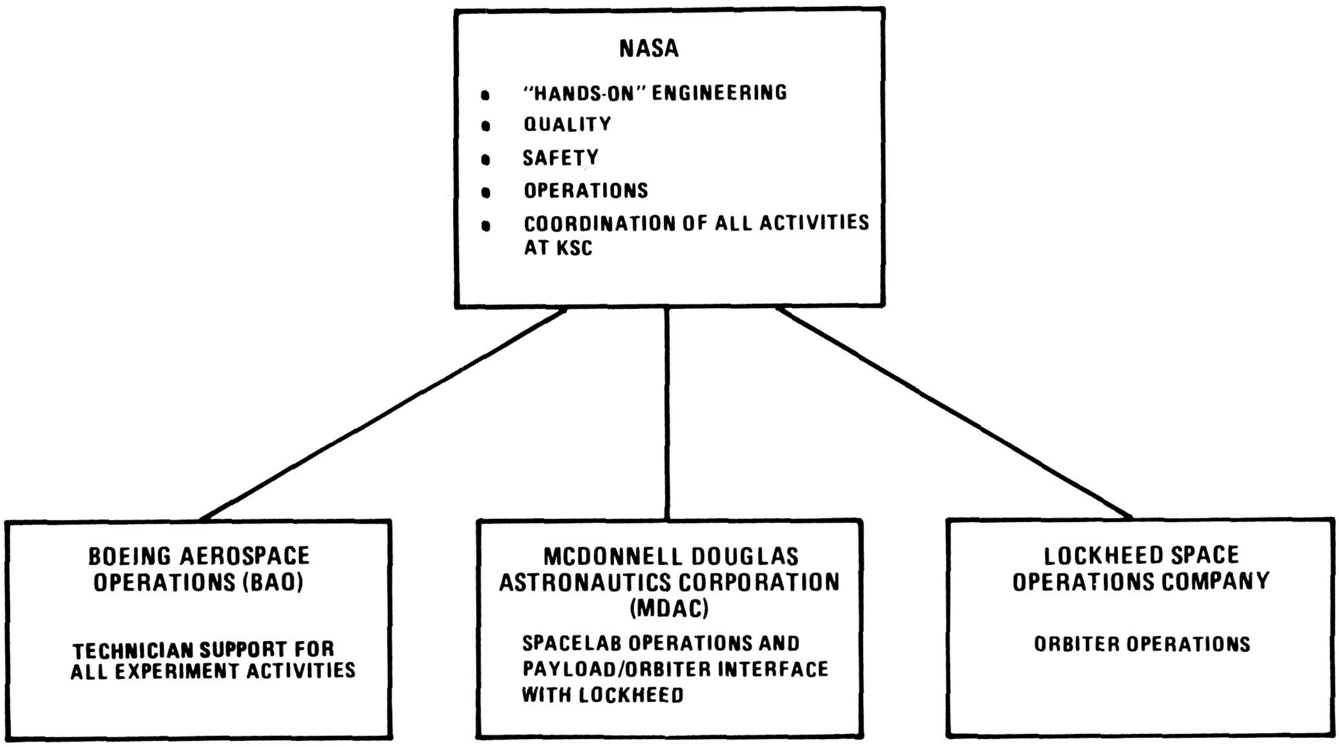


FIGURE 2 – NASA/CONTRACTOR PAYLOAD RESPONSIBILITIES AT KSC

serve as the primary contacts at KSC for the investigator as shown in Figure 3. The mechanical engineer is responsible for reviewing preliminary drawings of the experiment, participating in payload design reviews, installing the experiment onto the carrier, and removing the experiment after the flight. The test conductor is an engineer who is responsible for testing all experiment interfaces and for verifying that the experiment functions properly. The test conductor is also responsible for any additional tests that may be required, such as experiment calibration or periodic maintenance. The launch site support manager serves as the point of contact for the investigators before the experiment arrives at KSC.

Other personnel within the division are assigned additional tasks on a payload basis. For example, the electrical and mechanical branches each have an individual who coordinates the required effort from that office for each payload. In addition, an operations engineer is assigned to develop and track the payload schedule and to coordinate this schedule with those of other payloads also being processed at KSC simultaneously. To ensure that all top level payload requirements are met, a NASA payload manager is also assigned to each mission.

During the ground processing of a payload, KSC engineers work closely with the design center, the investigators, and orbiter personnel. For the EASE/ACCESS mission, the Marshall Space Flight Center was the mission management agency and was responsible for coordinating the integration of the two experiments onto the carrier. The EASE and ACCESS investigators were from the Massachussettes Institute of Technology and Langley Research Center,

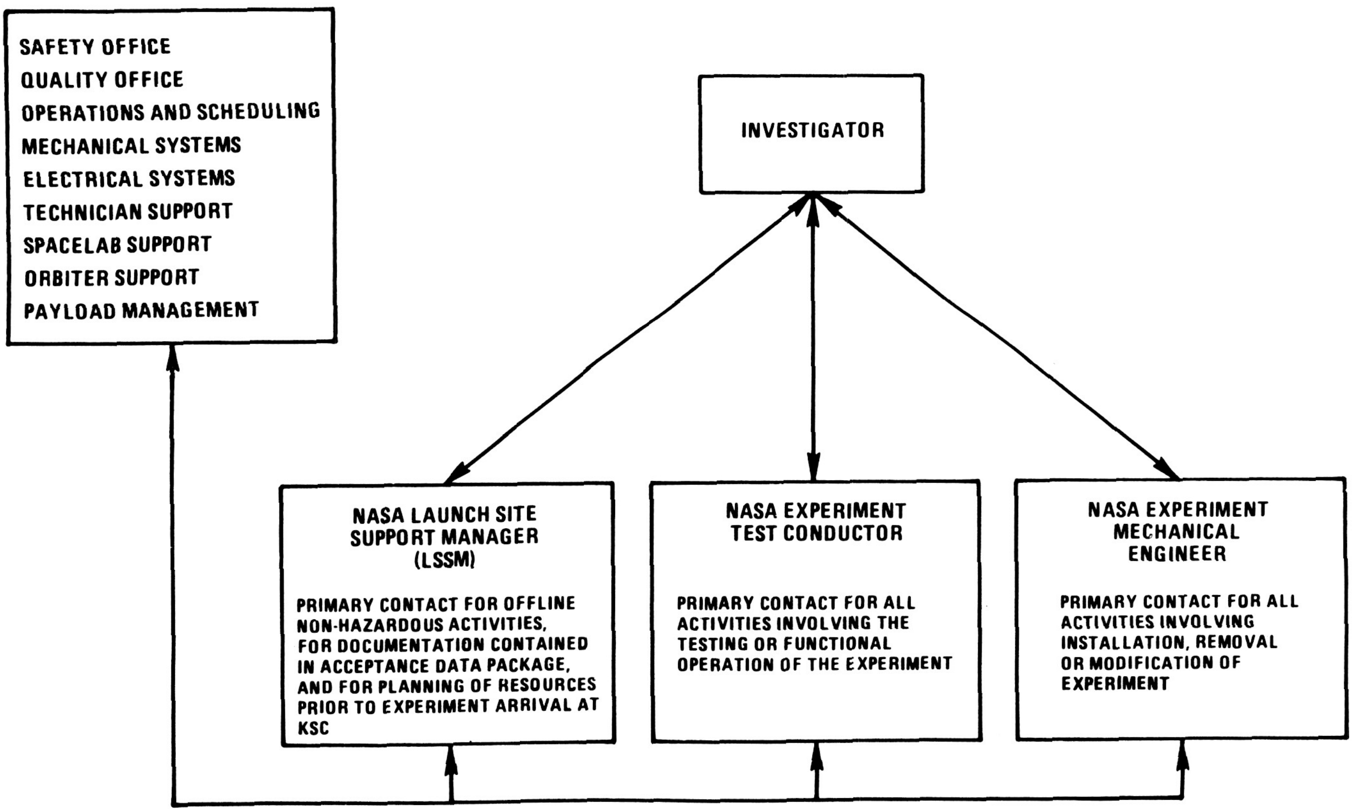


FIGURE 3 – INVESTIGATOR/KSC INTERFACES

respectively. As for all Space Shuttle missions, the Johnson Space Center was the interface for orbiter and crew operations.

ACTIVITIES PRIOR TO HARDWARE ARRIVAL

At the same time that an experiment is being finalized at its design center, the investigator begins to work with KSC personnel to ensure that all of the experiment requirements will be satisfied. One of the most important steps for the investigator is to state all planned experiment activities in the Ground Integration Requirements Document (GIRD). This document is printed by the payload mission manager and one GIRD exists for each payload; thus, the requirements for all experiments on the same flight are included in the same GIRD. All payload activities and support services at KSC must be requested in the GIRD. This includes installation of the experiment onto the carrier, testing of the experiment, any required calibration, and any necessary maintenance. If any activity is not listed in the GIRD, it will not be performed at KSC, unless it results from an unforeseen problem. Therefore, the investigators must be certain that they have listed every planned event in the GIRD.

In addition to listing the payload requirements, the GIRD contains a deliverable items list identifying all payload equipment to be delivered to KSC. This information enables KSC to plan for equipment storage space on center and to keep track of all items stored at KSC. The GIRD also contains a section on contingency landing requirements. The list of deliverable items and the contingency landing requirements are both used by KSC to develop the Off-Site Plan, Annex 21 to the NASA/Johnson Space Center Payload Integration Plan (PIP). The Off-Site Plan includes all payload support equipment that needs to be shipped to a contingency landing site if the orbiter does not land at the primary landing site.

KSC's formal response to the GIRD is the Launch Site Support Plan (LSSP), Annex 8 to the PIP. The LSSP addresses each GIRD requirement with a KSC response and commitment. KSC may not be able to fulfill some requirements based on existing capabilities. If a requirement is agreed to by KSC, a specific procedure or other commitment source will be identified in the LSSP. By working together with the investigators and the mission management team on finalizing the GIRD, KSC personnel are usually able to respond affirmatively to every requirement in the LSSP. This was the case with EASE/ACCESS. If KSC is unable to meet a specific requirement, this will be thoroughly discussed with the investigator and the mission manager before the experiment arrives at KSC.

In addition to the GIRD, another document exists which lists requirements involving orbiter support. This document is called the Operations and Maintenance Requirements Specifications Document. For space construction payloads, such as EASE/ACCESS, the only requirement involving orbiter support would probably be a bonding check of the carrier to the orbiter.

Prior to flight hardware arrival, KSC personnel participate in ground operations reviews and in integrated payload design reviews. Approximately a year before the EASE/ACCESS launch, KSC participated in the Integrated Payload Final Design and Operations Review at Marshall. KSC reviewed the data package, which included the payload integration drawings and the payload GIRD. Areas of interest were accuracy and completeness of hardware installation details and requirements. For every incomplete or questionable item, KSC submitted to Marshall a discrepancy notice which identified the problem. All notices were resolved by the mission management team and appropriate action resulted.

Payload planning meetings such as payload ground operations working group meetings and technical exchange meetings are held at KSC for most payloads. These meetings enable the experimenters to become familiar with KSC operations and allow KSC to learn more about the payload. Schedules, procedures, and other concerns are discussed at these meetings.

Another type of meeting scheduled at KSC consists of a series of ground safety reviews. These reviews are sponsored by the KSC safety office and attended by the mission manager. If a particular experiment has many hazardous operations or uses equipment that can be hazardous, then the mission manager can request that the investigators also attend. The purpose of these meetings is to identify and analyze all hazardous operations that will be performed at KSC during payload ground processing. Specialized handling instructions and precautions are agreed upon by all attendees. This information is then forwarded to the NASA engineer who will be performing the operation and will be responsible for ensuring the safety of the task.

In addition to reviewing the GIRD, addressing any applicable discrepancy notices, and participating in KSC-sponsored payload meetings, an investigator also interacts with KSC/NASA personnel by providing written procedures for all experiment activities specified in the GIRD. Also, the assigned NASA engineers usually travel to the experiment design center to learn first-hand how the equipment functions and how it should be integrated.

For the EASE/ACCESS payload, KSC/NASA engineers participated in the integration of mock-up EASE and ACCESS experiments and Mission Peculiar Equipment (MPE) onto a non-flight MPESS at Marshall. NASA personnel also participated in the integration and testing of the flight ACCESS experiment at Langley Research Center. These activities enabled KSC engineers to obtain detailed information from the investigators about their experiments. This participation also enabled KSC to estimate more accurately the integration time and the resources that would be required at the launch site. Using this information, NASA generated an EASE/ACCESS processing schedule for the entire payload flow at KSC.

Schedules are used at KSC as planning tools and as a method for implementing procedures and utilizing resources. The payload master schedule shows the payload flow at KSC from arrival on-dock (O/D) through deintegration. The payload integration schedule shows major milestones and a detailed breakdown of all payload work performed. This schedule is formulated prior to hardware arrival and is updated throughout the processing flow to reflect the as-run activities and any necessary changes for remaining work. Figures 4 and 5 show the as-run EASE/ACCESS master schedule and integration schedule, respectively.

Based on integration drawings, GIRD requirements, experience with hardware integration and testing at the design center, and experimenter inputs, the KSC/NASA engineers develop procedures for all planned activities. These documents are called Test and Assembly Procedures (TAP's). The purpose of an assembly procedure is to implement pre-planned payload activities. These procedures are written well in advance of the actual activity. The first draft of an assembly procedure is written several months prior to the use date. After being reviewed by the mission manager, the experimenters, KSC quality engineering, and the KSC safety office, the procedure is finalized and released for use. Up to three drafts of a document may be published before the final version is released. Several test and assembly procedures were written specifically for the EASE/ACCESS payload. These procedures included EASE installation, ACCESS installation, MPE installation, and ACCESS functional testing.

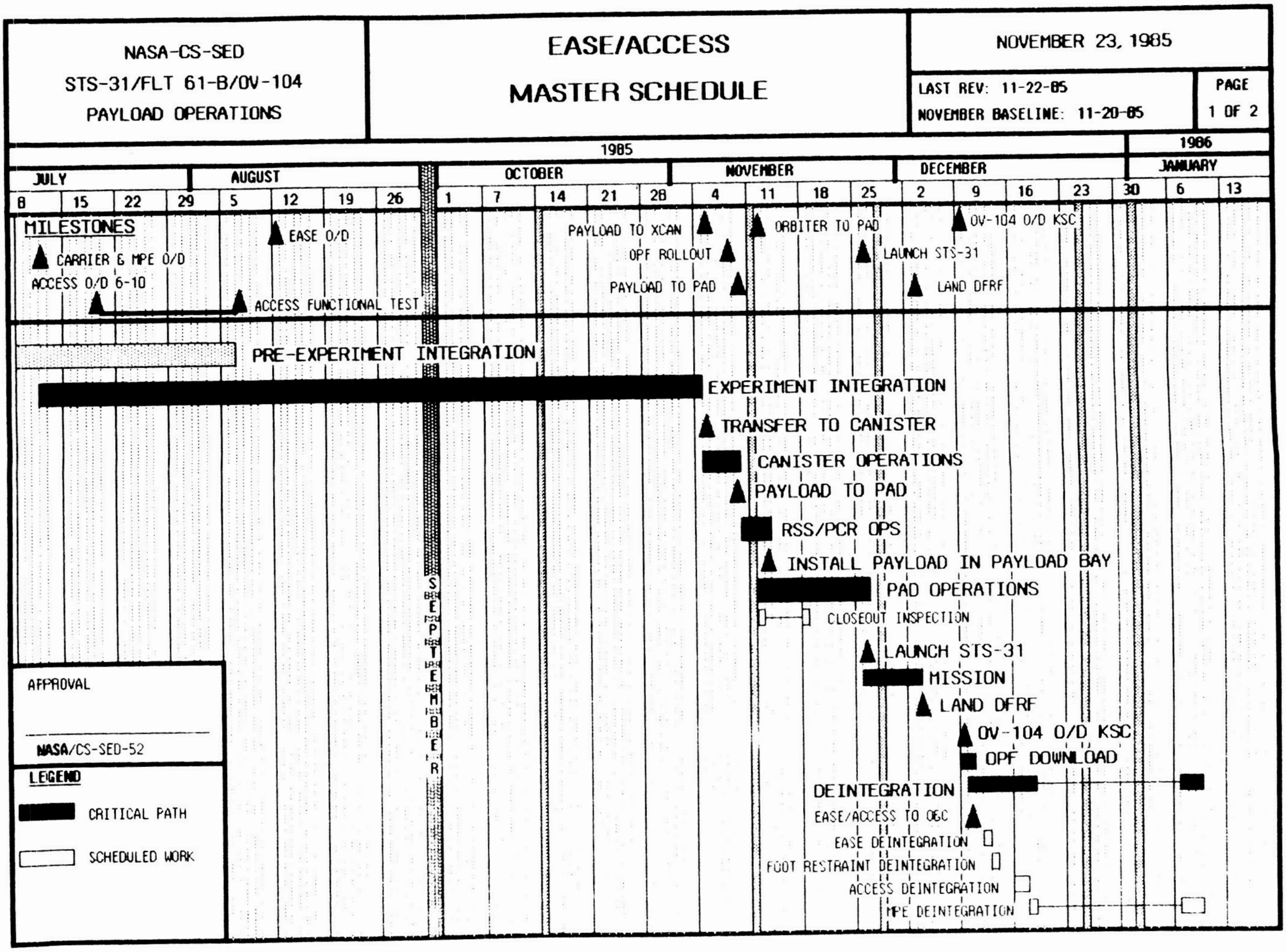


FIGURE 4 – EASE/ACCESS MASTER SCHEDULE

A number of generic test and assembly procedures exist which can be performed on more than one payload. Standard procedures used for EASE/ACCESS processing included weight and balance determination, payload clearance checks, and MPESS/pallet payload closeout inspection. These same procedures can be used for processing future space construction experiments.

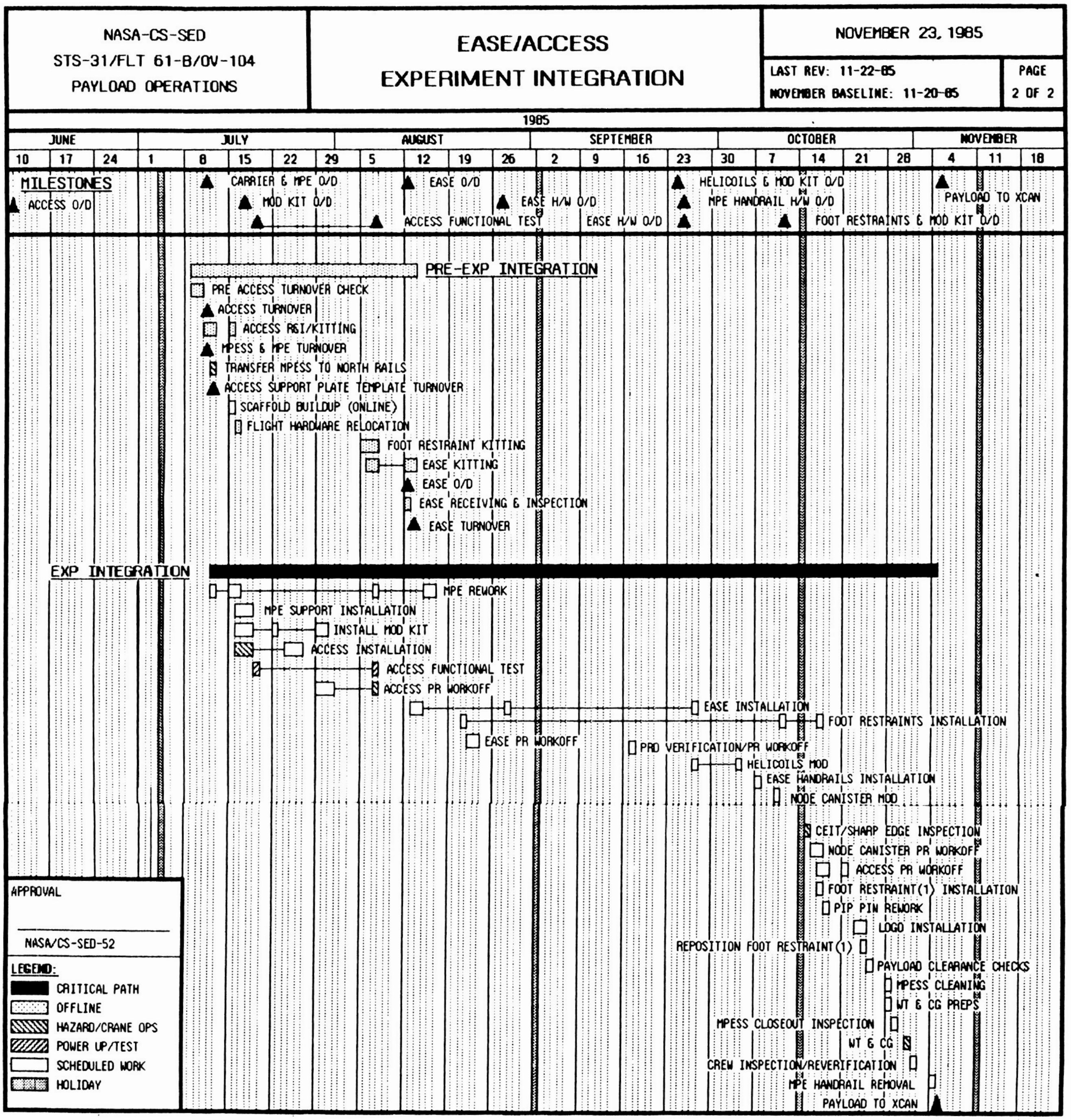


FIGURE 5 – EASE/ACCESS INTEGRATION SCHEDULE

OFFLINE PAYLOAD PROCESSING

Once the experiments and the mission peculiar equipment begin to arrive at KSC, all activities appear in the KSC Payload Integrated Control Schedule. This is a detailed 72 hour/11 day schedule and is published daily. Hardware deliveries, experiment installations, functional tests, and facility requirements are all listed in the schedule. The time required to perform a scheduled activity is indicated in hours for the first 72 hour period and in shifts for the following 11 day period. The technician and Quality Assurance support required for an activity is also indicated, as well as any other necessary support. Figure 6 is an example of a page from the schedule.

NASA - MDAC/KSC
PAYLOAD OPERATIONS

LEGEND: NON HAZARDOUS / HAZARDOUS / POWER UP/TEST

72 HOUR / 11 DAY
PAYLOAD OPERATIONS SCHEDULE

LEGEND: H = HARDWARE, W = WAD, M = MDAC, L = NASA/LV 4, P = MSFC, J = JSC, A = ARC, G = GSFC

PG. 3 DATE: 8-7-85

TUE 8-6-85 (3 1 2) | WED 8-7-86 (3 1 2) | THUR 8-8-85 (3 1 2)

F 9 | S 10 | S 11 | M 12 | T 13 | W 14 | TH 15 | F 16 | S 17 | S 18 | M 19

	TIME OR T/O	ORG	*MIXED CARGO*
1			**GENERAL MEETINGS**
2		L	SIR-C TELECON (RM2141)(EVERY OTHER FRI.)(BLAND)
3			
4			*STS-27/51-I PVTOS 8-27-85*
5			**DELIVERIES**
6			PVTOS EXP O/D 8-13
7			
8			**OFFLINE**
9	2M/1	L	XFER PVTOS EXP. FR LOAD/DOCK TO RM2245
10			**EG&G HVY/EQUIP & MANPOWER
11	2M/1	L	XFER PVTOS EXP. FR RM2245 TO PAD (SEIS VAN)
12	2M/1	L	INSTL. PVTOS EXP.
13	1Q	L	PVTOS R&I
14	1E/1M/1	L	PVTOS EXP OPS (RM2245)
15			-- WILTECH/He LEAK CHECK/EG&G/MASS SPEC
16			
17			*STS-31/61-B EASE/ACCESS 11-26-85*
18			**GENERAL MEETINGS**
19	1100	L	EASE T/O MTG (RM 2141) (MOATES)
20			
21			**DELIVERIES**
22		J	FOOT RESTRAINTS (4 ea) O/D TBD
23		P	EASE EXP O/D 8-12
24		P	MPE BOLTS (26 ea) O/D 8-9
25			
26			**ONLINE**
27	1M/1	L	T1-EASAC-0002 ACCESS FUNCTIONAL TEST (VILLAMIL)
28	5M/1	L	T1-EASAC-1101 EASE INSTL(MOATES)
29	1M/1	L	--EASE KITTING
30	1M/1	L	--MPE KITTING
31	2M/1	L	PR-EASAC-MPE-STR-009 SHARP EDGES ON MPE PLATES(VILLAMIL)
32			**W CRANE 0830-1100
33	2M/1	L	T1-EASAC-1104 FOOT RESTRAINTS INSTL (MOATES)(ESD 8-21)
34	1M/1	L	--MPE KITTING
35			
36			**OFFLINE**
37	2M/1	L	XPORT EASE FROM (RM1469) TO (RM1485)(MOATES)
38	1M/1	L	EASE R&I
39			

FIGURE 6 – KSC PAYLOAD INTEGRATED CONTROL SCHEDULE

ORIGINAL PAGE IS
OF POOR QUALITY

All horizontal payloads follow the processing flow outlined in Figure 7. Payload hardware arrives at the O&C building located in the industrial area of KSC, shown in Figure 8. After the hardware is offloaded from the plane or truck, a quality inspector performs a receiving and inspection. This process includes a visual verification that no shipping damage has occurred and a check that all items and applicable documentation have been received. Afterwards, the experimenter is free to perform any offline activities that are necessary, if such a request had been previously stated in the GIRD. Offline labs are available for experimenters on an individual basis, and KSC can provide limited resources, such as darkrooms, laminar flow benches, centrifuges, sinks, and certain common fluids and gases. In all cases, the request for an offline lab or for supporting equipment must be included in the GIRD, and KSC's response as to whether or not the service can be provided is listed in the LSSP.

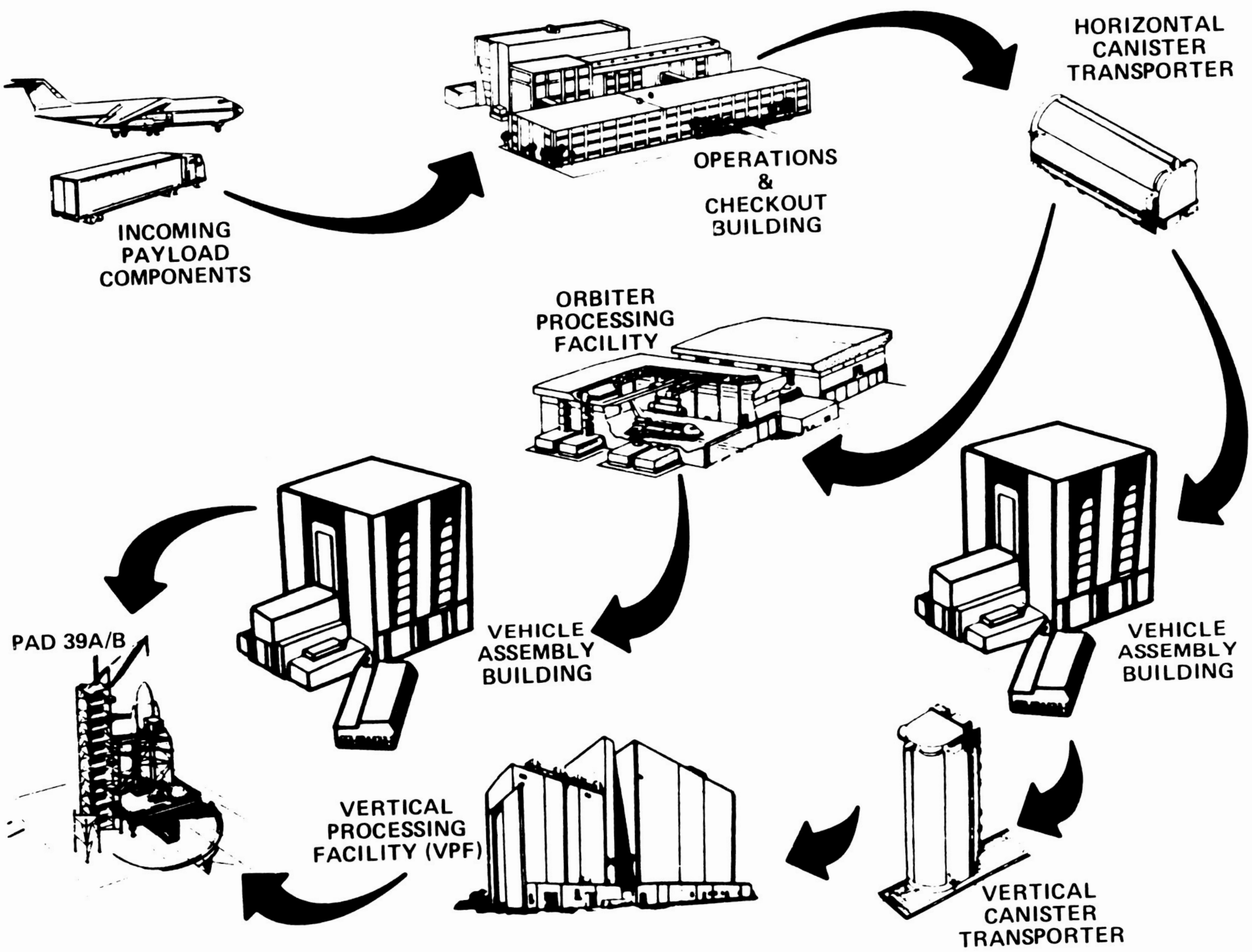
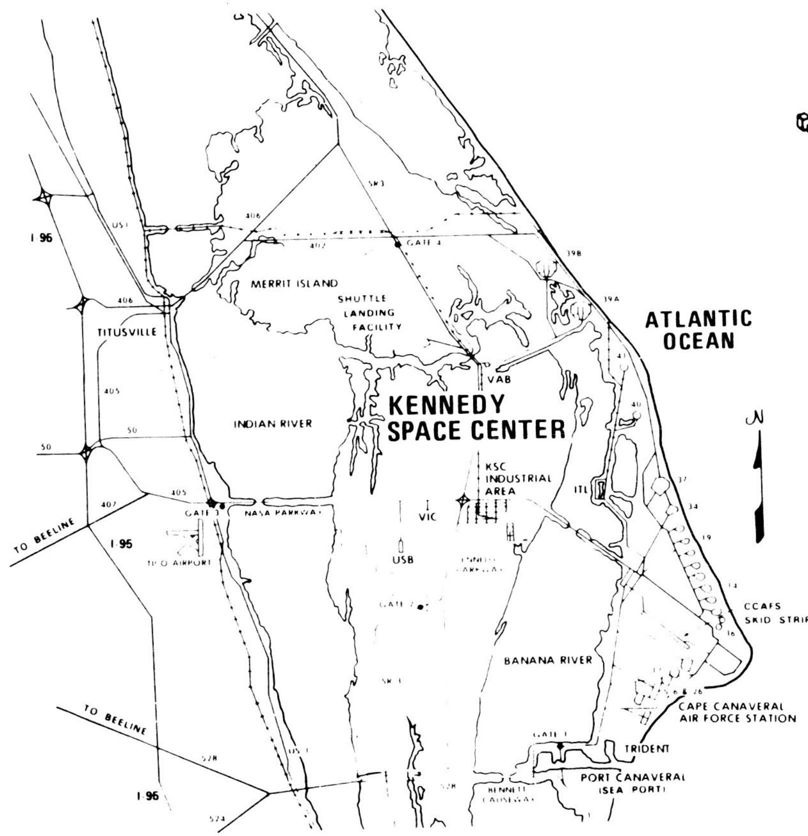
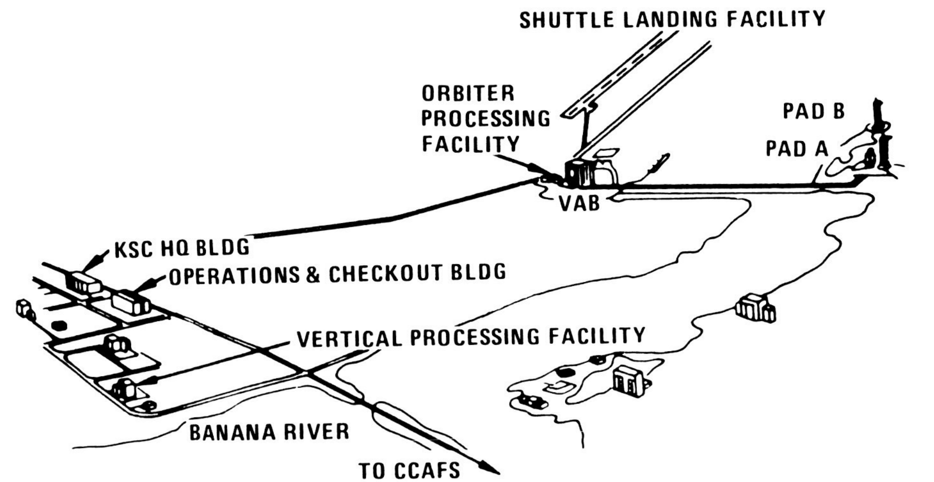


FIGURE 7 – HORIZONTAL PAYLOAD PROCESSING FLOW



KSC AND SURROUNDING AREA



FACILITIES USED FOR
HORIZONTAL PAYLOAD PROCESSING

FIGURE 8 – KSC AREA MAP

Many experiments arrive at KSC ready for installation and require no offline activities. This was the case with the EASE experiment. The ACCESS experiment, on the other hand, went first to an offline lab where the experimenter checked out the operation of the struts and the nodes.

The offline labs can also be used for other activities, such as loading film or pressurizing an experiment. Investigators perform all work under their own paperwork system if there are no hazards involved. If any of the offline activities are hazardous, such as a crane lift or an operation involving high pressure, then a NASA engineer will be responsible for writing a Test Preparation Sheet (TPS) to perform the operation. This procedure will be reviewed by the safety office and the activity will be performed under the NASA task leader's direction.

In addition to being used for offline hazardous activities, test preparation sheets are also used for unplanned online activities and for events that do not require any significant support beyond a NASA engineer, Boeing technicians and NASA quality assurance. The major differences between a test preparation sheet and an assembly procedure are that the first is less formal and that no preliminary drafts are published. Therefore, a test preparation sheet is usually written just prior to use and needs to be reviewed only by the appropriate KSC personnel. Most hardware changeouts, modifications, and deintegrations are performed using a test preparation sheet.

After offline activities, the next step in the processing flow is hardware turnover to KSC. A quality engineer reviews the acceptance data package which accompanies every item of flight hardware that arrives at KSC. The data package contains updated drawings for the flight hardware, a list of non-flight items that are currently installed on the flight hardware (such as ground lifting rings), any required certifications (such as proofload data), any existing waivers or deviations, a list of open work that still needs to be completed, and any problem reports documenting nonconformance items. Quality engineering verifies that all of the required material is present. Quality personnel also write a KSC problem report for every nonconformance item and for any open work that was not previously scheduled to be performed at KSC. In addition, the quality engineer logs all non-flight hardware in the payload's non-flight equipment/red streamer log, and a red "Remove Before Flight" streamer is attached to each of these items. At this point, the payload has been officially turned over to KSC and is considered to be online. All further experiment operations are performed by NASA/Boeing personnel and all activities are documented in the KSC paperwork system.

The paperwork system used at KSC ensures that all payload activity is coordinated and that results are properly recorded. The documents show fulfillment of GIRD requirements and indicate any configuration changes performed at KSC. From these documents, all payload work performed at KSC can be reconstructed and verified. Regardless of the type of document used for a payload activity, each step is stamped by a technician or signed by an engineer and stamped by a quality inspector as appropriate. This method of tracking the work performed enables any reader to identify what steps were successfully completed and which personnel were involved. If at any point in the processing flow a problem or potential problem arises, a problem report is generated by the quality inspector. This report tracks the nonconformance item and is used to return the hardware to flight configuration. When either a procedure is completed or a problem documented on a problem report is solved, then the appropriate procedure or report is officially closed. This means that all necessary operations have been accomplished and that no open work remains. If the experiment cannot be returned to the originally planned flight configuration because of a problem, then the condition must be approved by the appropriate personnel before the problem report can be closed.

Throughout all payload processing, KSC personnel evaluate experiment operations to determine and predict possible problems that may occur. Many times, a specific item of experiment hardware may not appear to be problematic to the investigator but may, in fact, interfere with the operations of another nearby experiment. KSC personnel keep in mind the operation of the entire payload when working with individual experiments. This helps to identify potential problems before they occur.

During the review of the EASE acceptance data package, material usage agreements and deviations that had not yet been fully approved were found. A problem report was written to track these nonconformance items. The problem report could not be closed until several months later when proper documentation was received from Marshall. During receiving and inspection of EASE, minor paint scratches on the cradle assemblies were discovered. The problem was resolved the following week by performing touch-up painting of the hardware.

No problems were encountered during the ACCESS experiment turnover. Several red "Remove Before Flight" streamers had to be attached to ACCESS, however, since non-flight lifting hardware arrived installed on the experiment.

ONLINE PAYLOAD PROCESSING

Shuttle payloads go through a maximum of three levels of processing: Level IV, a combined Level III/II, and Level I. Reference Figure 9. Level IV

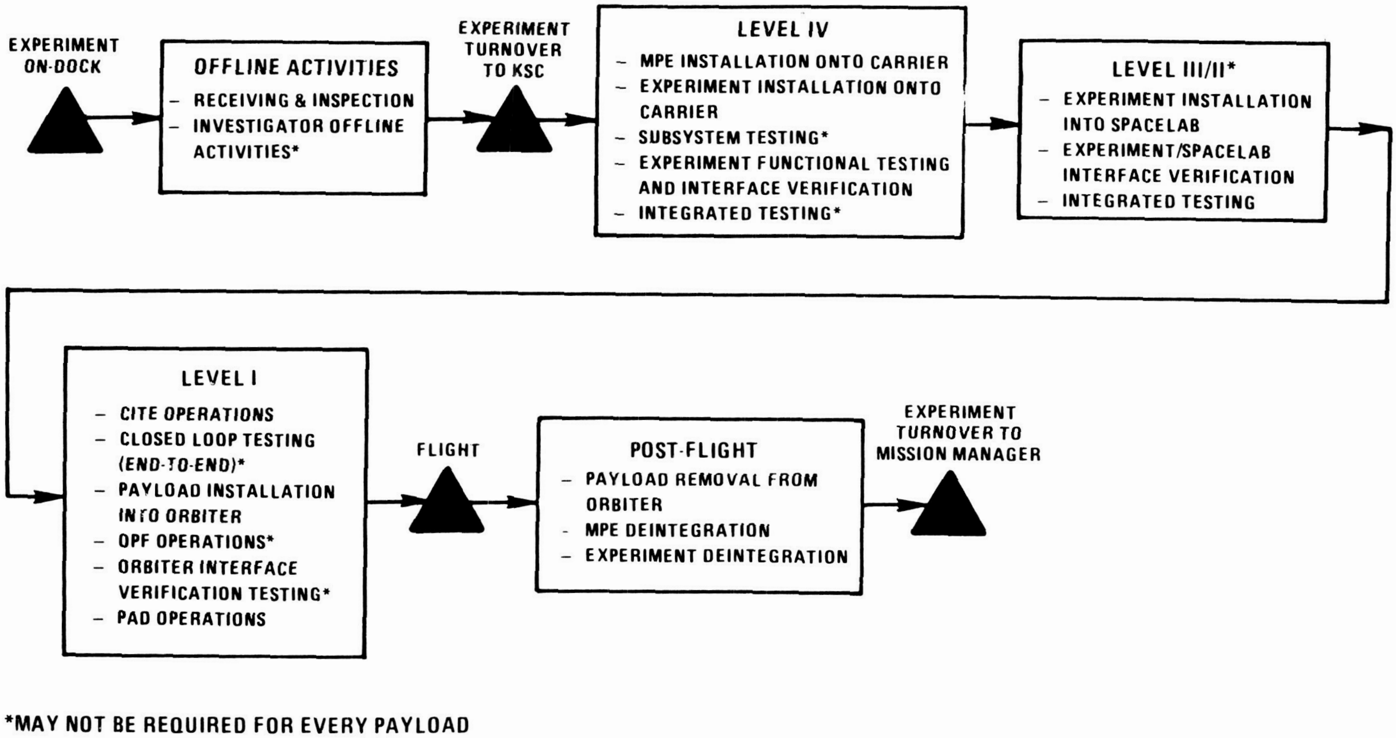


FIGURE 9 – EXPERIMENT INTEGRATION LEVELS FOR HORIZONTAL PAYLOADS

includes the installation of the experiment onto the carrier, the functional testing of the experiment, and the integrated testing of all experiments on the same carrier. Level III/II verifies experiment to carrier interfaces and only involves Spacelab missions. EASE/ACCESS bypassed this level, as would most future space construction experiments. Level I includes all simulated and actual orbiter testing and all payload/orbiter operations.

The majority of online payload operations occurs in the O&C low bay, a class 100,000 clean area (airborne particles). Clean room garments must be worn in the proximity of flight hardware. The low bay is a secure area, and personnel entering the area must be badged appropriately. Two 27.5 ton capacity cranes are available for use during payload processing.

Located at one end of the O&C low bay are the Level IV test stands, followed by the Level III/II test stands, and finally the CITE stand (Cargo Integration Test Equipment). The low bay is shown in Figure 10, with the Level IV stands in the foreground. CITE simulates the orbiter and allows

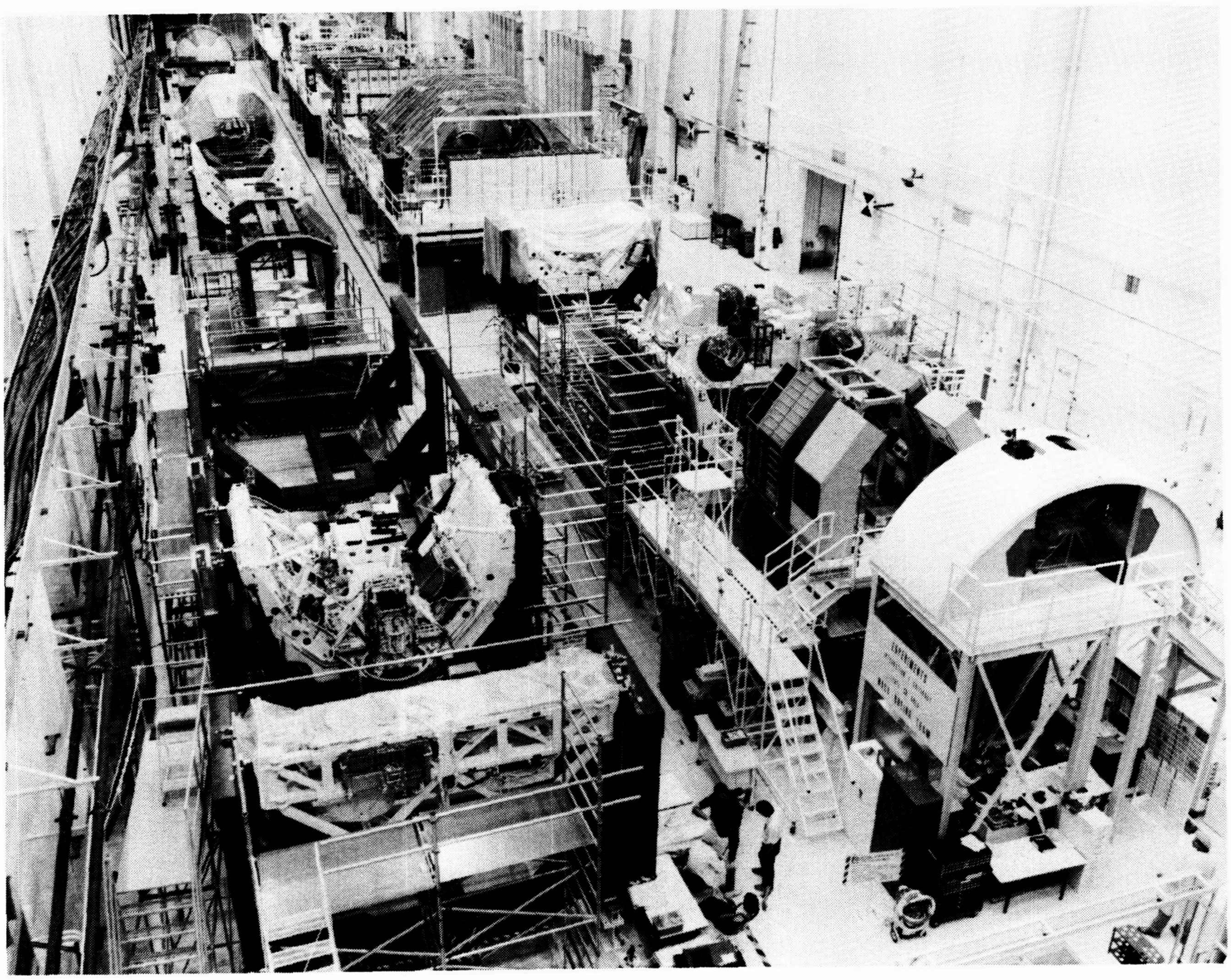


FIGURE 10 – OPERATIONS AND CHECKOUT BUILDING LOW BAY

payload-to-orbiter electrical interfaces to be verified. CITE marks the beginning of Level I. Level I continues when the payload is installed in the payload canister and taken to either the Orbiter Processing Facility or the pad, at which point the payload is installed into the Space Shuttle orbiter. All further payload operations until launch are also included as part of Level I processing.

MISSION PECULIAR EQUIPMENT INSTALLATION

Level IV integration begins with MPE installation onto the carrier. The carrier can be an MPESS (Mission Peculiar Equipment Support Structure), a Spacelab pallet, or other such structure. These carriers are flown inside the payload bay of the orbiter, as shown in Figure 11. The EASE/ACCESS payload used an MPESS. Normally, KSC's first task would have been to install the MPE

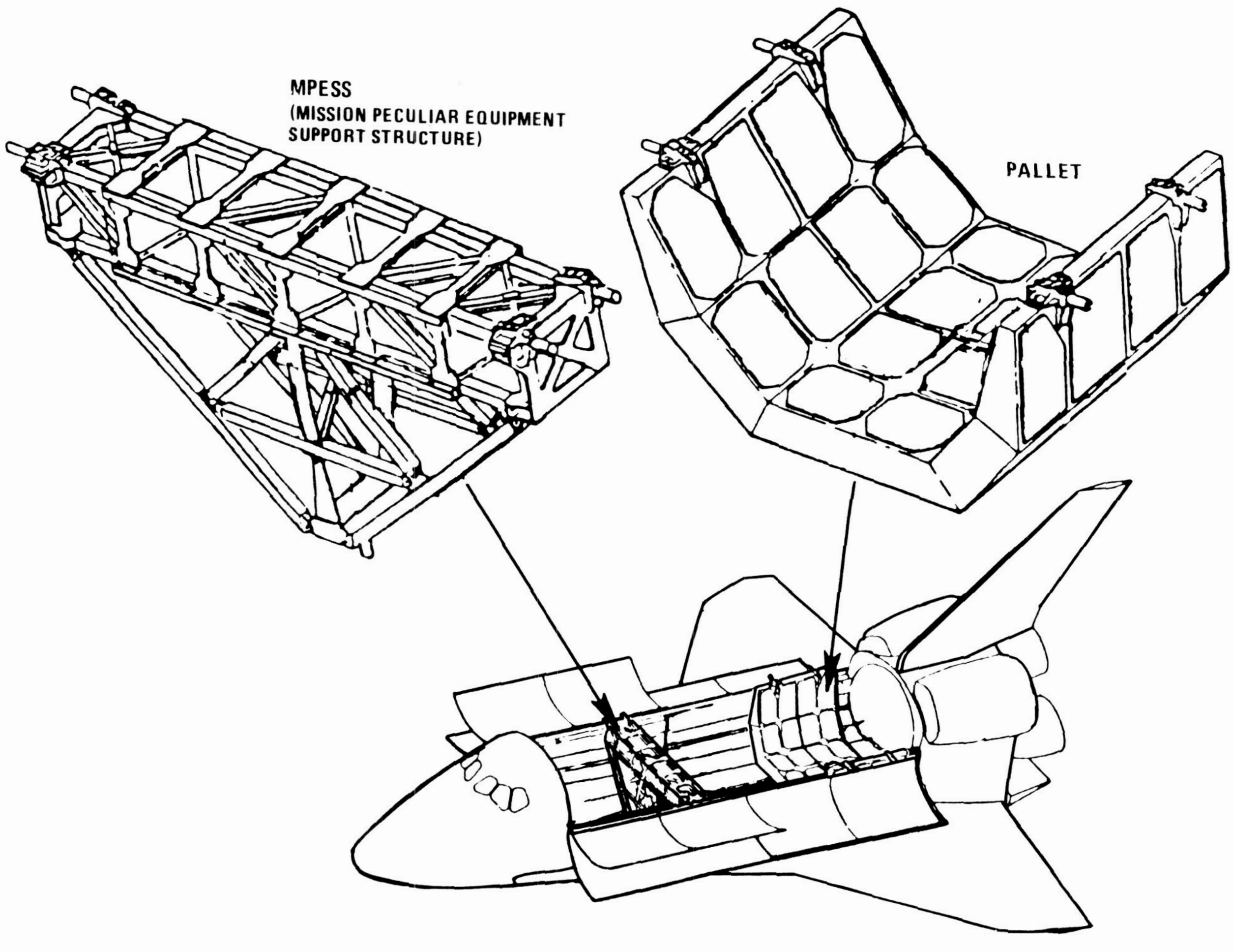


FIGURE 11 – ORBITER PAYLOAD BAY WITH CARRIERS INSTALLED

saddle and plates. Since the specific MPESS used for EASE/ACCESS had been sent to Marshall for major modifications, the MPE saddle and plates were also installed at Marshall. An additional MPE modification, flagged by the design agency, was the first piece of flight hardware to be installed at KSC. This modification consisted of a stiffener bracket which reinforced the carrier. As is the case when an unplanned change to flight hardware must be made, Marshall generated an engineering order and sent it along with the hardware and drawings as part of a mod kit. An engineering order authorizes a change to flight hardware and is always generated by the design center. KSC then wrote a test preparation sheet to perform the modification. Next, KSC installed the MPE foot restraint support structure using a test and assembly procedure. This was a planned part of MPE installation.

The remaining MPE hardware had to be installed later in the flow, because of late deliveries and because of interference with experiment installation. This MPE included four handrails for the EASE end racks, the foot restraints, the handrail assemblies for the foot restraints, and velcro for the MPESS top closure plates. The handrail assemblies for the foot restraints were installed during the week following initial EASE integration. The foot restraints, which were late delivery items from Johnson, arrived at KSC just prior to crew training operations. Three of the four foot restraints were installed for the crew training operations. The fourth foot restraint was installed afterwards, due to interference with ground scaffolding needed to reach the experiments for crew training. The foot restraint MPE and the foot restraints were installed per a test and assembly procedure.

The actual time it takes for hardware installation is usually longer than the amount predicted by the designers. This is because problems or new modifications (requested by the designer) often arise. KSC tries to prepare for this by ensuring that time estimates are conservative. Because of this, KSC was able to incorporate the many modifications to the EASE/ACCESS payload without impacting the launch date.

One modification occurred just prior to installation of the foot restraints. A mod kit was received from Marshall to increase the elevation of the foot restraint on the forward side (the EASE side) of the MPESS. The MPE interface between the MPESS and the foot restraint was changed. This modification was incorporated using a test preparation sheet.

A problem was then encountered with the orientation of the foot restraint on the forward side of the MPESS. The foot restraint was to be installed so that it directly faced the forward side of the MPESS. Based on the current MPE and foot restraint configuration, this could not be accomplished. A problem report was written to document this problem, and the appropriate personnel at Marshall and Johnson were consulted. After considering several complicated solutions, a relatively simple one was reached. This solution involved a simple reconfiguration of the foot restraint assembly. A field engineering change, which authorizes a change to the flight configuration, was written prior to hardware reconfiguration, and approval was obtained from Johnson. The foot restraint platform was reoriented with respect to the gimbal joint/probe assembly at a four bolt attachment location, and then the entire foot restraint assembly was reoriented with respect to the MPE interface clamp. This situation did not occur until very late in the flow, just several weeks prior to payload installation into the canister. Timely delivery of all hardware can help avoid such hardware problems late in the payload flow. This problem report was closed just one and a half weeks prior to the payload leaving the O&C building.

Two more MPE mod kits were also incorporated into the payload. The first modification called for the installation of two MPE handrails onto each of the two EASE end racks. The second modification added four velcro pads to the MPESS top closure plates to provide a storage location for the EASE cluster assembly pip pins.

EXPERIMENT INSTALLATION

After the ACCESS experiment was turned over to KSC, the bolts, nuts, washers, and other loose hardware were organized into kits, as part of the preparation for experiment installation. ACCESS was the first experiment to be installed. Because of the size and weight of the experiment canisters, the low bay crane was used, making these operations hazardous. After each component was attached to the crane hook, the area was cleared of non-essential personnel, the safety office was contacted, and the lift began.

The first item of ACCESS hardware to be installed was the node canister. A problem was encountered at the start when it was discovered that a small hole for an ACCESS alignment pin was missing from an MPE plate. NASA/Boeing personnel drilled the hole per the specifications in the drawing and proceeded with node canister installation. Afterwards KSC installed the two mast clamps and the assembly fixture. The assembly fixture was the first item to require use of the crane.

The diagonal strut canister was installed next. Another problem was encountered when the canister would not fit in the MPE plate cutout. As a result, KSC had to enlarge the cutout by filing five slots in the plate; this modification meant that the plate would no longer be "per drawing". Since it would take too long to have the design agency generate an engineering order to change the drawing and then forward the order to KSC as part of a mod kit, KSC chose to generate a field engineering change. Both a field engineering change and an engineering order can be used to authorize flight hardware modifications. The difference is that the engineering order is generated by the design agency and permanently accompanies the official drawing for that piece of hardware. The field engineering change, on the other hand, is generated by KSC and can be used to make hardware changes realtime. If a field engineering change is written, then the mission management team accepts the responsibility for amending the applicable drawing at a future date. The field engineering change generated for the MPE plate was quickly signed by the appropriate KSC personnel and by the design agency representative. NASA/Boeing then filed the needed slots and proceeded with the diagonal strut canister installation on the following day. The use of an field engineering change allowed the operation to proceed smoothly after all applicable parties had approved the change, without causing a significant delay.

The batten/longeron strut canister was the next item to be installed. When the door stop for the canister was installed and tested, it was discovered that shims had been sent to be used as needed, and several were in fact required. None of these spacers, however, where listed in the integration drawing. NASA opened a problem report since the door stop could not be properly installed without spacers. Next, NASA generated a field engineering change to add the shims to the integration drawing. Finally, NASA/Boeing installed the needed shims. The last item of the ACCESS experiment to be installed was the tool stowage assembly. No problems were encountered.

The EASE experiment arrived at KSC approximately one month after the arrival of the MPESS. Receiving and inspection, hardware turnover to KSC, and hardware kitting for installation were performed upon arrival. The majority of EASE installation was completed in two days. Since the EASE beams could be comfortably handled by several people, the facility crane was not required.

One problem encountered during the initial integration of EASE concerned the stiffness of the upper latch on the starboard restraint cradle. The problem was solved promptly by cleaning and lubricating the latch. Two weeks later, upon arrival of the pip pins and tethers, the four EASE clusters were installed. The base cluster and redundant jettison fitting were installed six weeks after initial integration.

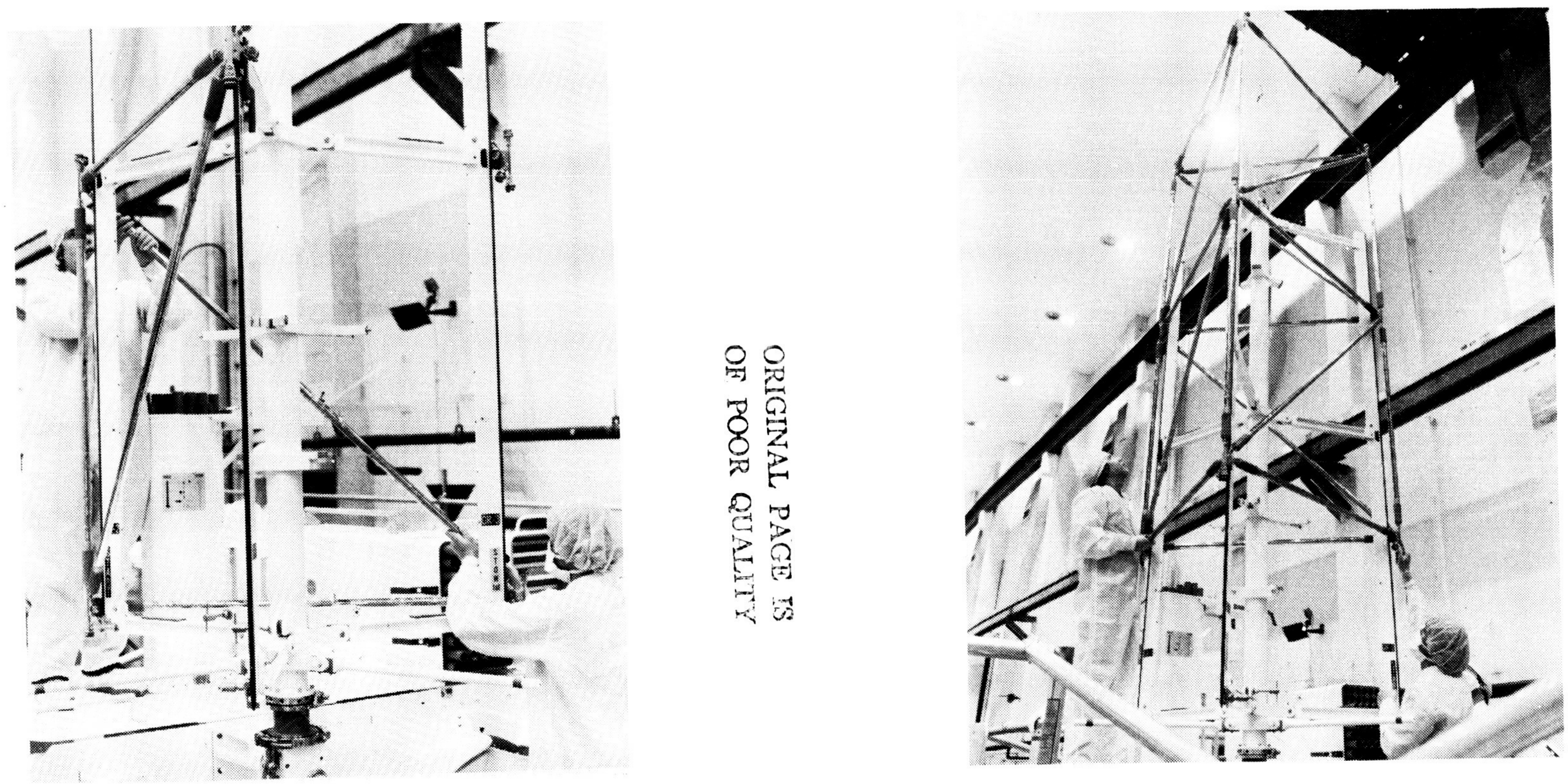
One requirement listed in the GIRD stated that KSC must verify the ability of the payload retention device to hold EASE cradles in the closed position. To perform this, KSC requested a payload retention device from the Johnson crew equipment office. The verification was performed as part of the EASE installation procedure.

NASA/Boeing generally perform any necessary hardware modifications once a payload has been turned over to KSC. A modification to the EASE hardware was requested by Marshall after installation was complete. This requirement was given to KSC in the form of a mod kit. The modification entailed the installation of threaded inserts into the joint cluster assemblies. The five cluster assemblies at KSC (four installed, one spare) were disassembled, modified, and reassembled. Much later in the payload flow, just prior to the crew training exercise, KSC received an additional mod kit for the changeout of hardware used to secure the ACCESS node canister. The ACCESS investigator travelled to KSC to observe the modification and was able to verify acceptable rotation of the canister.

EXPERIMENT TESTING

After experiment installation is complete, the experiments are functionally tested. For the EASE/ACCESS payload, ACCESS was tested in order to verify that all components worked together properly, but no functional testing of EASE was required at KSC. Although experiment interfaces are normally verified at KSC during functional testing, this was not possible with the EASE experiment. EASE was designed to be assembled only in zero-gravity, and any ground assembly had to be done in a water tank. In addition, no new interfaces were made at KSC that required testing. Therefore, it was agreed to by all concerned that no test of EASE would be performed at KSC. Since raising the ACCESS assembly fixture required the use of the crane, this procedure was hazardous. The ACCESS experiment, on the other hand, required a thorough checkout. Testing began by raising the fixture and verifying that it could be properly secured in the vertical position. The node canister, the diagonal strut canister, and the batten/longeron strut canister were checked next. Each strut was examined and the tools in the contingency tool kit were fit-checked. The contingency jettison hardware was operated to verify that it would work properly in flight. Every pip pin, latch, joint, and lever was cycled to verify smooth and proper movement. Finally, two bays were assembled and then stowed as shown in Figure 12. At the end of the functional test, the non-flight lifting hardware was removed from the ACCESS experiment.

As is normally the case, all operations are performed by NASA/Boeing personnel. The investigators are asked to be present to verify operations and



12.1 — ASSEMBLY OF FIRST BAY

12.2 — COMPLETION OF TWO BAY ASSEMBLY

FIGURE 12 — ACCESS FUNCTIONAL TESTING

to provide trouble-shooting recommendations if a problem occurs. Because of the subjective "feel" criteria involved in assembling a space construction experiment, the ACCESS experimenter had provided an approximate range of pounds of force required to operate each item as a part of the procedure input. In several instances, NASA/Boeing questioned the feel of an item and the experimenter was asked to cycle the hardware and to make an evaluation. For each case, an interim problem report was opened as soon as a question arose. This type of report differs from a problem report in that the first identifies a potential problem or a problem that cannot yet be attributed to a specific item of hardware. The situation is evaluated during troubleshooting and all steps taken are documented on the interim problem report. If a specific problem is identified, then the interim report is upgraded to a problem report at which point the problem is fixed. If it is discovered that no problem exists and that the experiment does operate nominally, then the interim problem report is closed. For example, if the ACCESS experimenter indicated that no problem existed, as was the case with the latching of the first bay, then the report was immediately closed. If, however, the experimenter was not satisfied with the operation, as was the case with the force required to rotate the node canister, the interim problem report was upgraded to a problem report. The typical steps followed during problem identification and resolution are outlined in Figure 13. In the case of the node canister, several washers were removed and a lock mechanism was adjusted until the experimenter stated that the required force for rotation was acceptable.

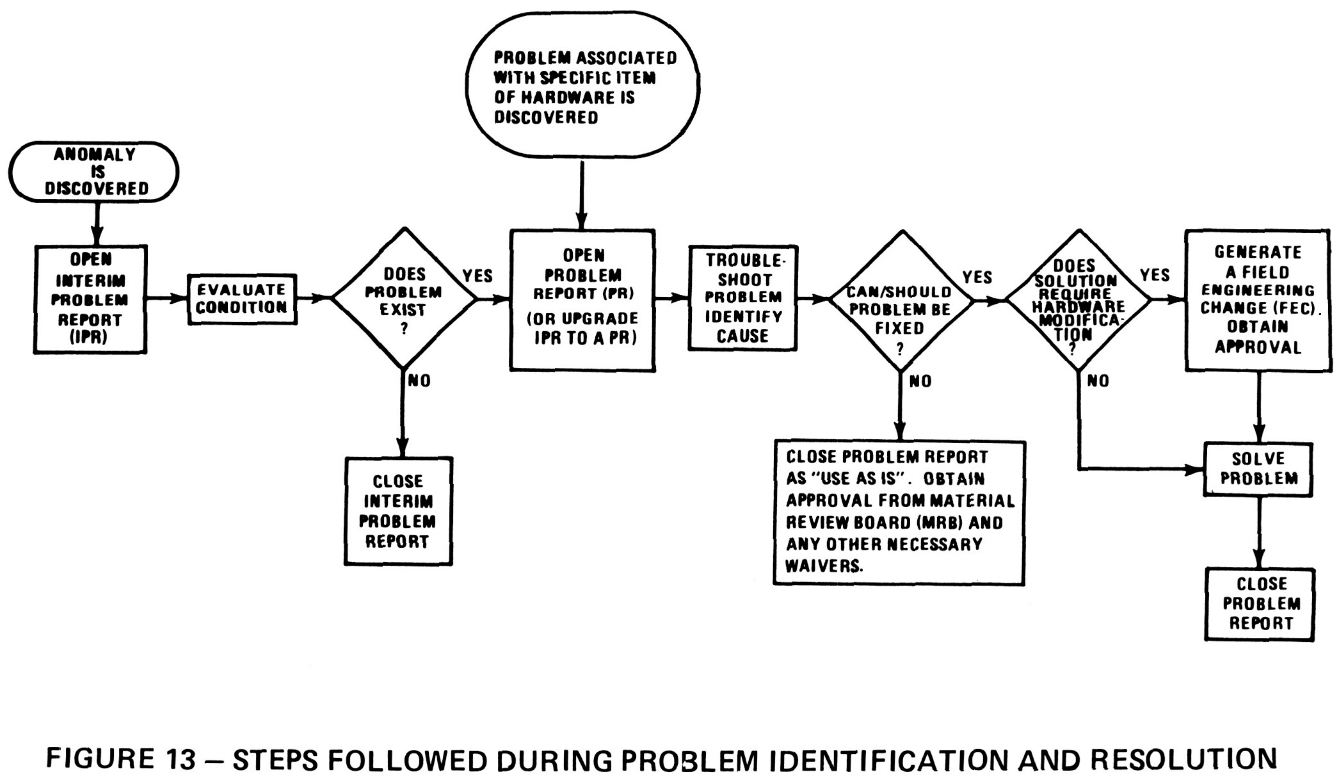


FIGURE 13 – STEPS FOLLOWED DURING PROBLEM IDENTIFICATION AND RESOLUTION

Normally, after all experiments complete their individual functional tests, the payload is operated together in an integrated test. This test is usually comprised of portions taken from the planned mission timeline. The specific time slices are chosen to represent the most active and demanding periods of the mission. If, for example, the experiments use electrical power to transmit data to the ground, then times where power use and data transmittal are at a peak are chosen. If the experiments involve manual operations by the crew, then a time which places maximum demand on the crew is chosen. With the EASE/ACCESS payload, each experiment was to be operated at a different time and neither experiment required the use of shared resources. Therefore, an integrated test was not required.

Crew involvement during payload processing enables the crew to gain experience with a payload's operation. Crew members are welcome at KSC for participation in regularly scheduled payload testing. This includes powered-up testing for those payloads with electrical interfaces. For most missions involving horizontal payloads, the crew participates in all integrated tests and in some functional tests. Unless a separate item is placed in the GIRD requesting an additional crew training session or an inflight maintenance procedure walkdown, no time for such a test is built into the KSC processing schedule. As for all experiments, the crew was welcome to participate in the ACCESS functional test. Unfortunately, they did not attend this test. Later in the payload flow, after the ACCESS experiment closeout had already been performed, a special test was requested by the mission manager. With many payloads being processed in parallel, and KSC resources (including personnel) being shared by all payloads, the schedule usually does not allow for such arrangements.

Fortunately, after coordinating resources scheduled by other payloads, a crew training session was worked into the processing flow. This test enabled the crew to check out the EASE and ACCESS experiments and the MPE. A test preparation sheet was written for the crew training exercise. In order to perform the crew training operations, several ACCESS flight screws had to be removed and the non-flight lifting hardware for the assembly fixture had to be reinstalled. During training with the EASE experiment, the mission specialists removed and replaced each beam, one at a time, and verified the operation of the beams/clusters. The ACCESS portion of the training was hazardous since the facility crane was used. The mission specialists assembled two bays of the ACCESS experiment and also fit-checked the contingency tools. Additional equipment had to be shipped to KSC to support the crew training operations. This equipment consisted of the EASE harpoons and special connector, and the ACCESS tool boards. During crew training, the mission specialists verified the interfaces between this equipment and the experiments. Also, the foot restraint locations and heights were visually checked. The crew members then performed a sharp edge inspection of the payload. Upon completion of the crew operations, the ACCESS experiment closeout was reperformed.

During the crew training exercise, the crew members discovered several hardware changes that they wanted incorporated. These changes were documented as crew squawks, problem reports specifically requested by a crew member. In addition to the usual signatures required for closure, a crew squawk must be signed by a flight crew representative before the problem report can be closed. Three major crew squawks concerned the forward foot restraint orientation, the ACCESS node canister rotation, and the EASE base cluster top pip pin operation. Two minor crew squawks included requests for markings on the wrenches in the ACCESS contingency tool kit and for numbers on the node canister buckets.

The problem with the foot restraint orientation was fixed with hardware reconfiguration, as discussed previously. Difficulty in rotating the node canister was again flagged. Extensive troubleshooting was performed on the node canister hardware in order to obtain smoother rotation. The solution was reached by reducing the torque on the twenty bolts attaching the shroud to the MPESS, and by lubricating the rollers on the node canister caps. The reduction in torque required a field engineering change for approval, since it altered the hardware configuration from that indicated on the integration drawing. The problem report on the EASE base cluster addressed stiff operation of the top pip pin. To correct this problem, the pip pin hole was enlarged to drawing specification. At the same time, the bottom pip pin hole was also enlarged. Smooth operation was obtained for both pip pins at the base cluster/jettison fitting. The markings requested on the wrenches and the numbers requested on the node canister buckets were made using a special pen with approved flight ink. Field engineering changes also had to be generated for these last two problems.

PAYLOAD CLOSEOUT

After all experiment installation and testing is complete, the payload is ready to be prepared for transfer to the orbiter. Payload closeout operations begin prior to leaving the O&C building and include sharp edge inspections, payload envelope clearance checks, weight and center of gravity measurements, cleaning, inspection, and closeout photographs.

Payload sharp edge inspection is particularly important for Shuttle missions that have a planned EVA (Extravehicular Activity). The ACCESS experiment and associated MPE were checked for sharp edges immediately following its functional test. Two sharp edges were found on the MPE and were rounded. ACCESS was then closed out for flight. As stated previously, the ACCESS closeout had to be reperformed after the crew training session. A sharp edge inspection of the entire payload was performed during crew training operations. No additional sharp edges were found on the payload. Although it is not required, KSC encourages the flight crew to perform their own payload walkdown and sharp edge inspection during the scheduled closeout.

Just prior to EASE/ACCESS closeout operations, a last minute modification was received from Marshall to install thirty-two logos onto the payload. A few logos could not be installed due to hardware interference.

Another closeout operation that is normally scheduled is payload envelope clearance checks. A computerized optical alignment system is used to determine if the payload is within the orbiter payload bay dynamic envelope, and to ensure that the payload will not interfere with the orbiter and/or with other payloads. During envelope checks for EASE/ACCESS, the outboard handrail for the top foot restraint was found to be outside the payload envelope by four inches. A problem report was written and was referred to the mission management team for resolution. The MPE handrail had to be removed from the carrier the day before payload transfer to the canister after weight and center of gravity measurements had been performed.

Payload cleaning occurs just before final closeout inspection. During this final inspection the payload is verified to be clean, to have all non-flight hardware removed (unless the hardware is scheduled to be removed later in the flow), and to have no obvious anomalies. Closeout photographs, such as the one in Figure 14, are also taken to document the payload configuration.

The final closeout operation performed prior to payload installation into the canister is normally the payload weight and center of gravity measurements. This is a hazardous operation, due to the use of the facility crane. The entire payload is lifted with the crane and is set down so that each trunnion rests on a load cell. These load cells are installed on an adjacent trunnion support fixture. The payload weight and center of gravity (x and y axes only) are then calculated by KSC. The EASE/ACCESS payload weighed 4364.5 pounds and the center of gravity was at x=788.49 and y=-5.85 in orbiter coordinates. These numbers take into account the handrail that was removed.

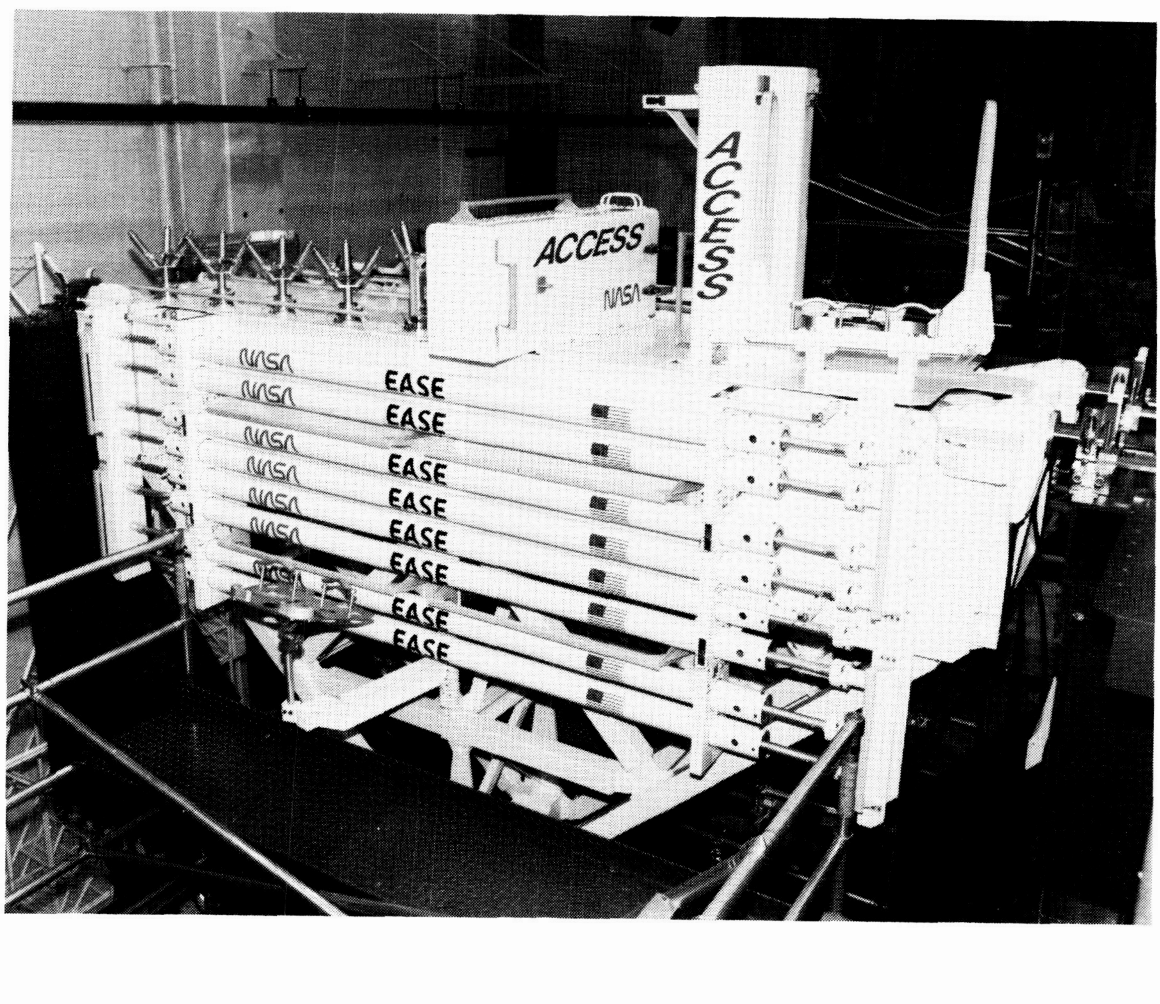


FIGURE 14 – EASE/ACCESS LEVEL IV CLOSEOUT

ORBITER OPERATIONS

After the completion of payload closeout, the carrier is prepared for Level I integration. Level I includes all payload operations that involve the orbiter or orbiter simulators. The first Level I operation occurs in the CITE stand in the O&C building. The CITE stand simulates orbiter interfaces, and interface verification testing is usually performed when the payload is at this stand. The payload is again secured and then transferred to the orbiter at either the Orbiter Processing Facility (OPF) or the pad. If any experiment to orbiter interfaces need to be verified, then another payload interface verification test is performed, this time using the actual orbiter. For example, if a space construction experiment has sensors that will be transmitting data to the ground during the flight, then the data stream is sent through the actual communications loop and verified. Such a test may involve sending the data from the experiment through the orbiter (either at the pad or the OPF) to the tracking data relay satellite, to White Sands Test Facility, to Goddard Space Flight Center, to Johnson Space Center and back to Kennedy Space Center. In this way, the entire loop is verified. Since EASE/ACCESS required no interface verification testing and had no electrical interfaces with the orbiter that needed verification, the payload was transferred directly to the orbiter after Level IV closeout.

At the same time that the payload is being processed in the O&C building, the Space Shuttle is being prepared for flight in the OPF. After the orbiter is ready and any payloads that must be installed horizontally are in place, the vehicle is rolled out to the Vehicle Assembly Building (VAB). In this facility, the two solid rocket boosters are mated to the external tank. When the orbiter arrives, a special handling fixture is attached to it, and the orbiter is rotated from the horizontal to the vertical position, as shown in Figure 15. The vehicle is then mated to the external tank. The entire Space Shuttle is then rolled out to the pad aboard the mobile launcher platform. Once the Shuttle arrives at the pad, it is ready to receive any remaining payloads.

Payloads are transported from the O&C building to the orbiter in the environmentally controlled payload canister. Most horizontal payloads are installed into the orbiter in the OPF. The OPF is the facility where orbiter refurbishments and flight preparations occur. Some horizontal payloads and all vertical payloads are installed into the orbiter at the launch pad. Reference Figure 7 for the complete horizontal payload processing flow.

The EASE/ACCESS horizontal payload was installed at the pad. EASE/ACCESS was first installed into the canister in the O&C building, with the canister in a horizontal position, as shown in Figure 16. The facility crane was used for this hazardous operation. The canister then traveled to the VAB and was rotated to the vertical position, as shown in Figure 17.1. In this vertical position, the canister traveled to the Vertical Processing Facility (VPF) in order to pick up the three satellites that were flown on the same mission. In Figure 17.2 the mission 61-B payloads are shown in the canister at the VPF. The VPF is similar to the O&C building in that both are the sites of Shuttle payload processing. The VPF, however, only accomodates vertical payloads; whereas, the O&C low bay only accommodates horizontal payloads. Following transfer of the three satellites from the VPF into the canister, the canister traveled to the pad.

Once at the pad, the payloads were transferred from the canister into the payload changeout room using a special handling mechanism. Payload canister

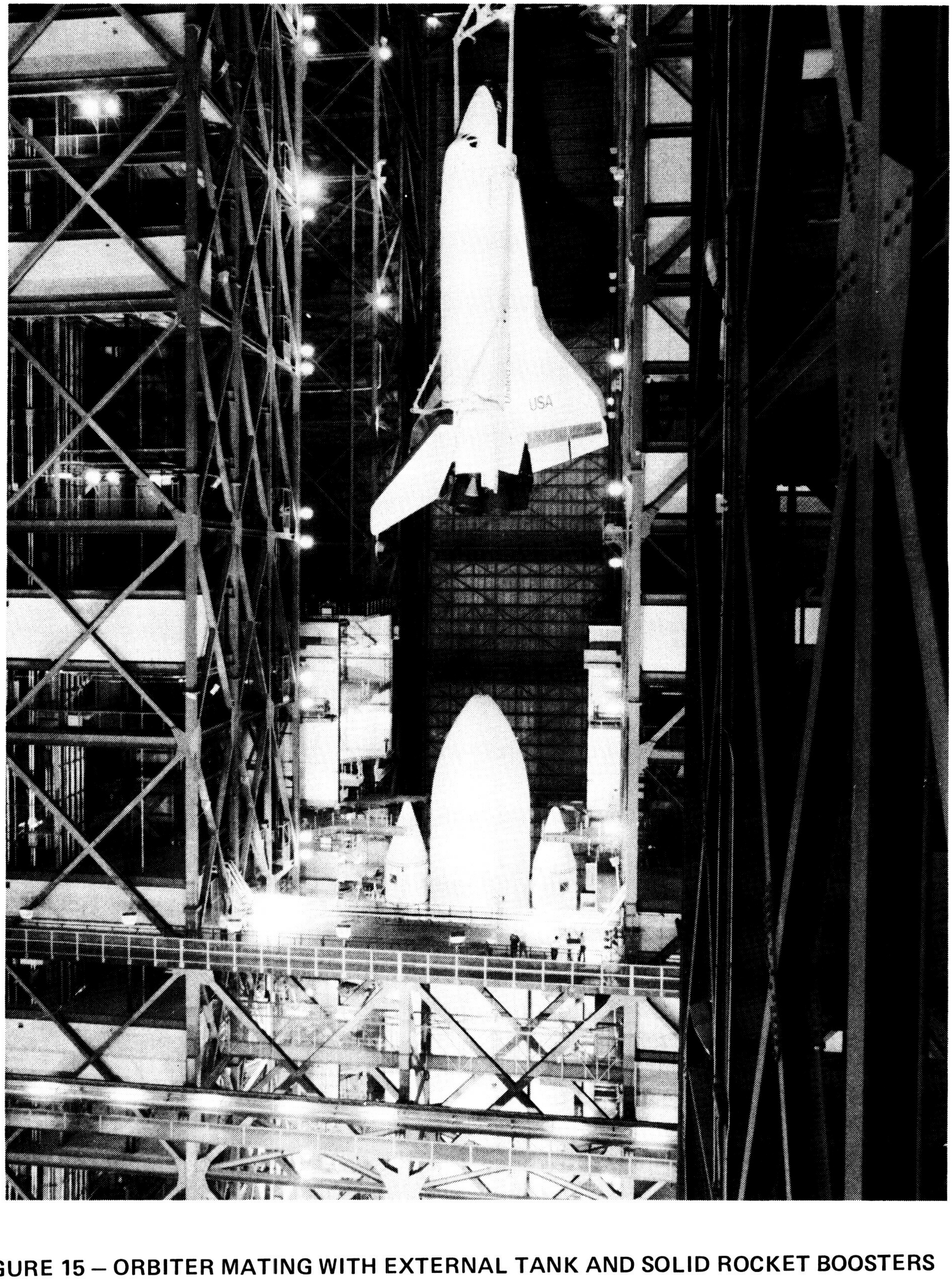


FIGURE 15 – ORBITER MATING WITH EXTERNAL TANK AND SOLID ROCKET BOOSTERS

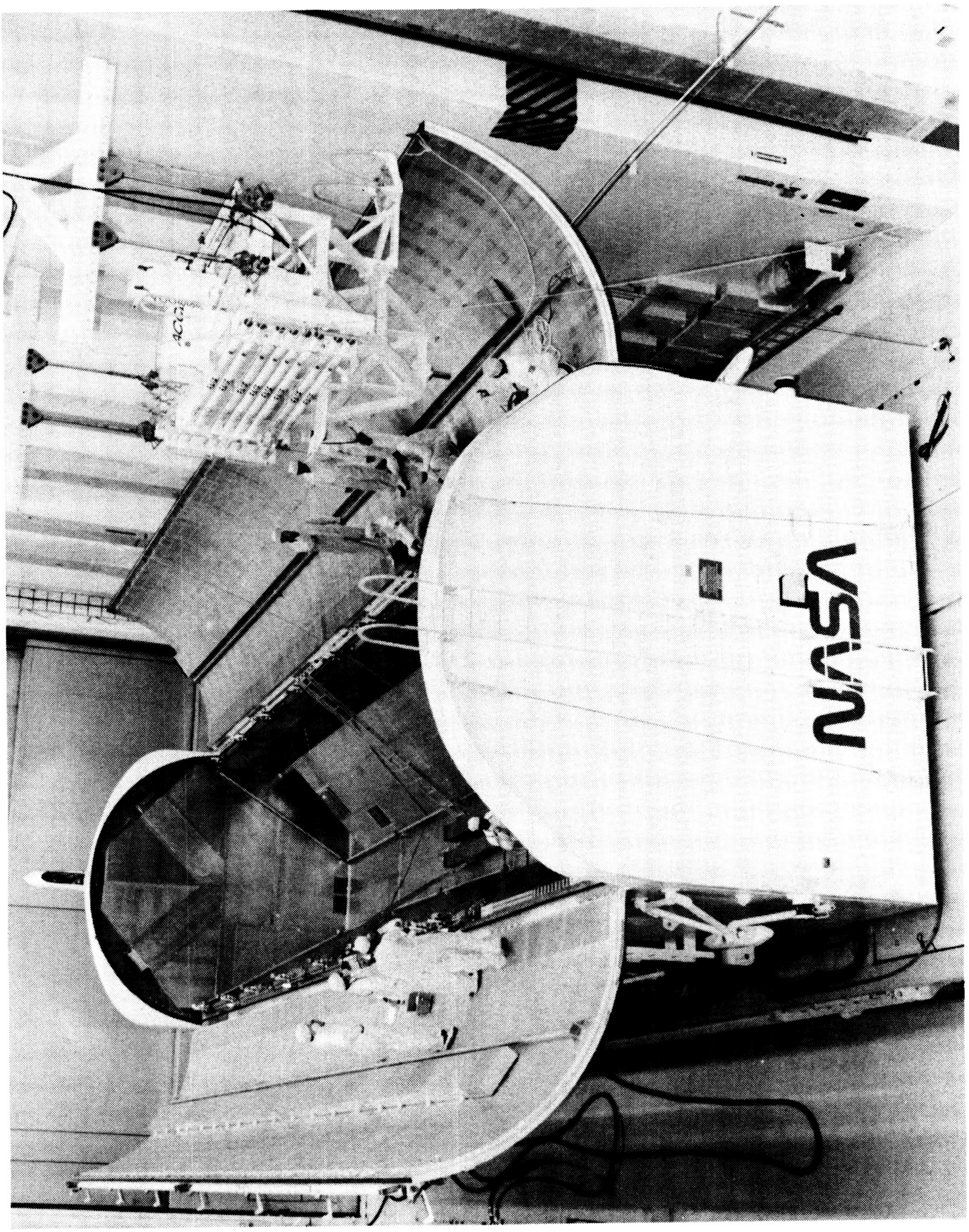
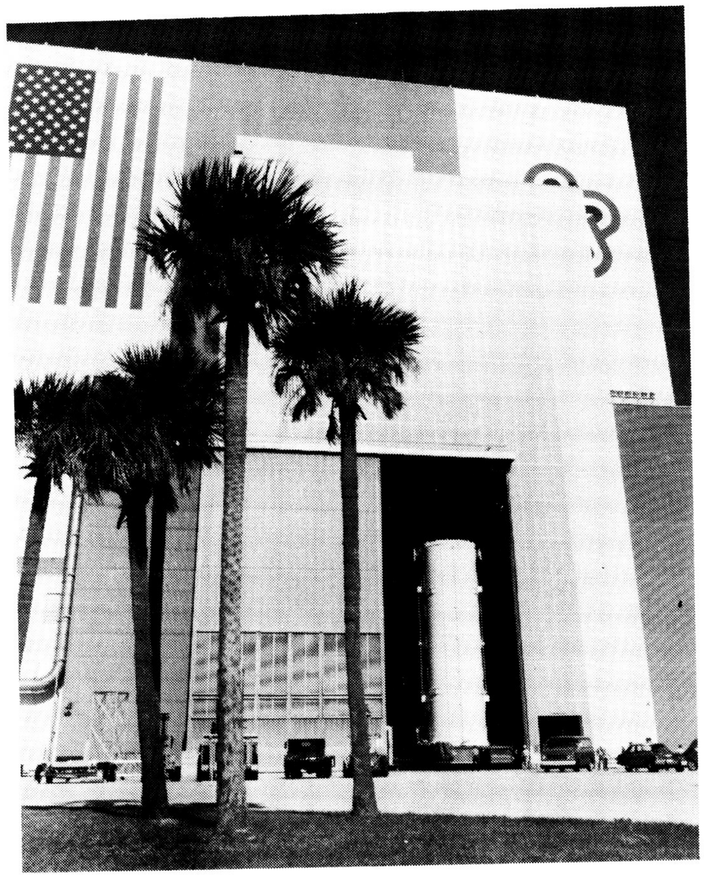
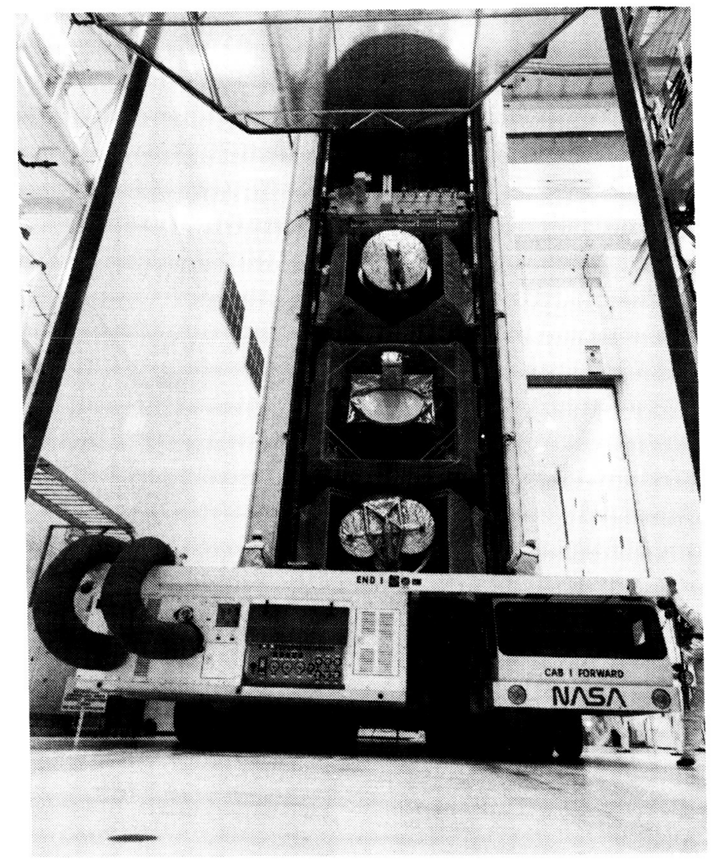


FIGURE 16 – EASE/ACCESS INSTALLATION INTO PAYLOAD CANISTER



17.1 — CANISTER LEAVING THE VEHICLE ASSEMBLY BUILDING (VAB) AFTER ROTATION TO VERTICAL



17.2 — MISSION 61—B PAYLOADS IN CANISTER AT VERTICAL PROCESSING FACILITY (VPF)

FIGURE 17 — PAYLOAD CANISTER OPERATIONS

installation at the pad is shown in Figure 18. After the payloads were transferred into the changeout room, the EASE/ACCESS MPESS required light cleaning. The rotating service structure, which houses the changeout room, was then rotated to the orbiter, and the payloads were installed into the payload bay. Lockheed fulfilled the one payload-generated orbiter requirement by verifying the electrical bonding between the MPESS and the orbiter. Just prior to the closing of the payload bay doors, EASE/ACCESS was inspected for

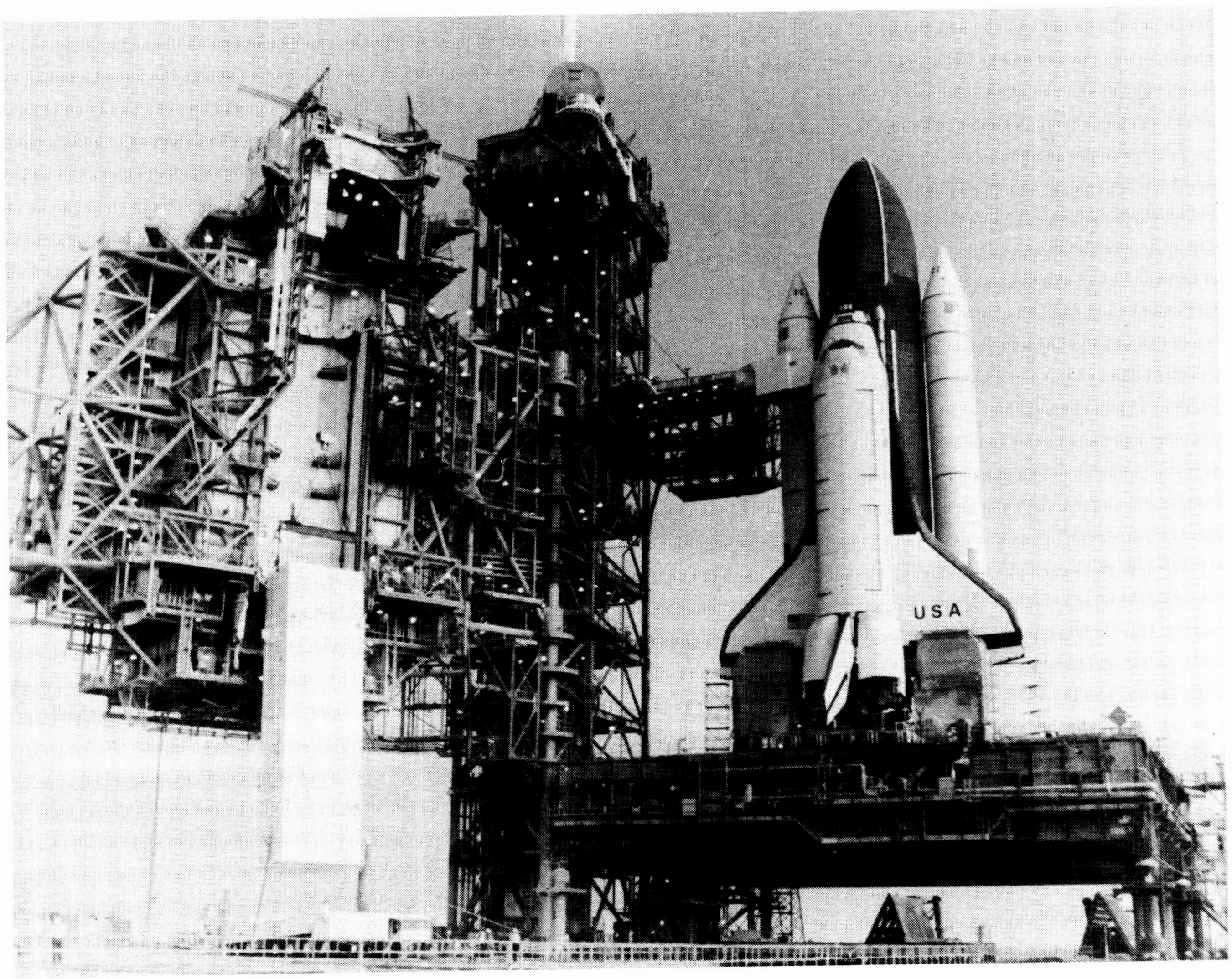


FIGURE 18 – PAYLOAD CANISTER INSTALLATION AT THE PAD

anomalies and final pad closeout photos were taken. Figure 19 is one of the pad closeout photos.

In addition to payload hands-on operations, several readiness reviews are conducted at KSC prior to launch. The first of these is the Payload Readiness Review. The purpose of this review is to verify the readiness of the payloads for integration with the orbiter and to verify the readiness of the orbiter for payload installation. For the STS-61B mission, the Payload Readiness Review was conducted the day before the payload was installed into the canister. The next scheduled review is the Launch Readiness Review. This review verifies the readiness of the Shuttle, the payload, and all launch and landing support systems. All test anomalies and unsolved problems are

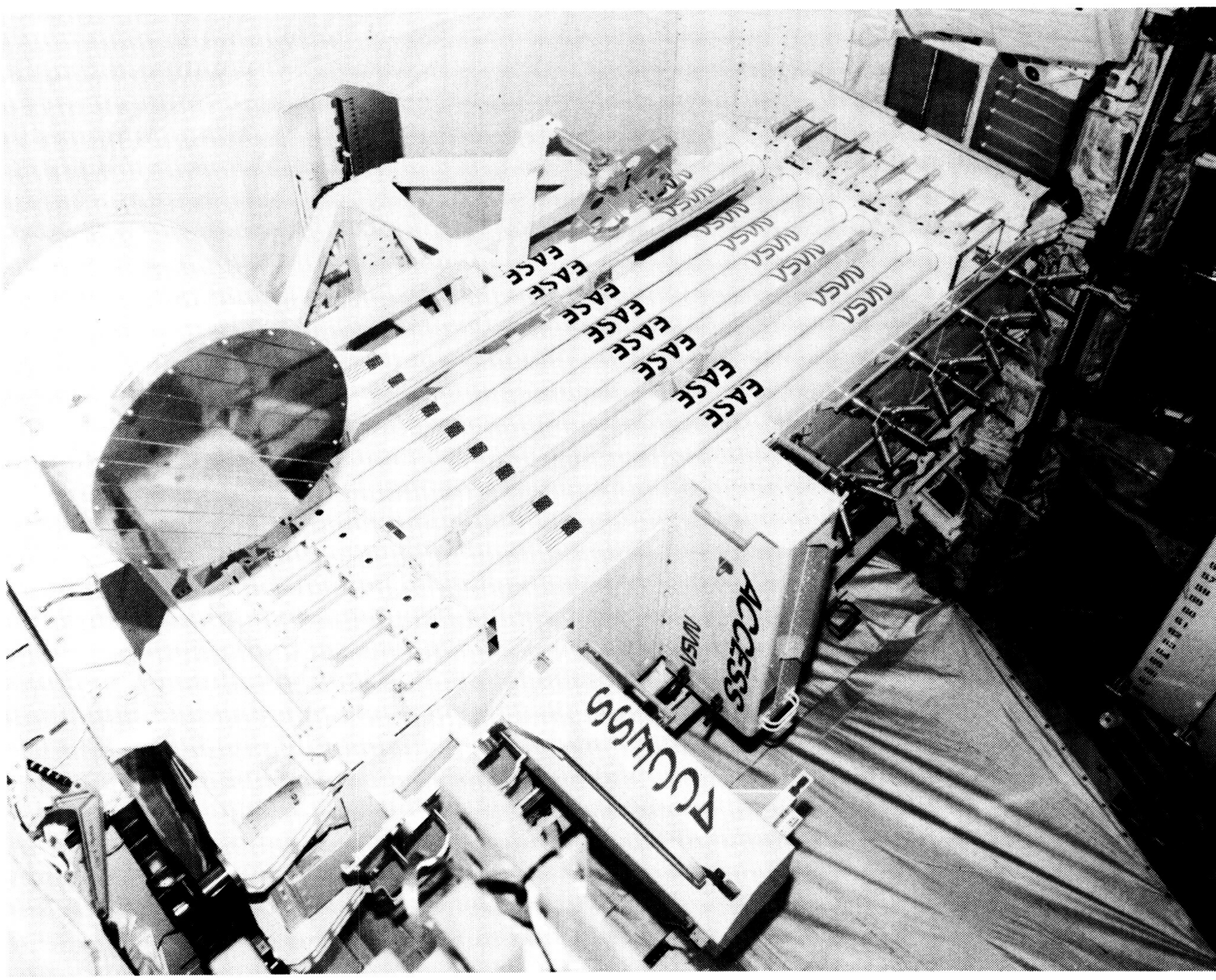


FIGURE 19 – EASE/ACCESS PAD CLOSEOUT

discussed at this meeting. The final review is the Flight Readiness Review, which verifies the readiness of the entire STS system and all operational plans and procedures. Mission 61-B launch, which was a night launch, is shown in Figure 20.

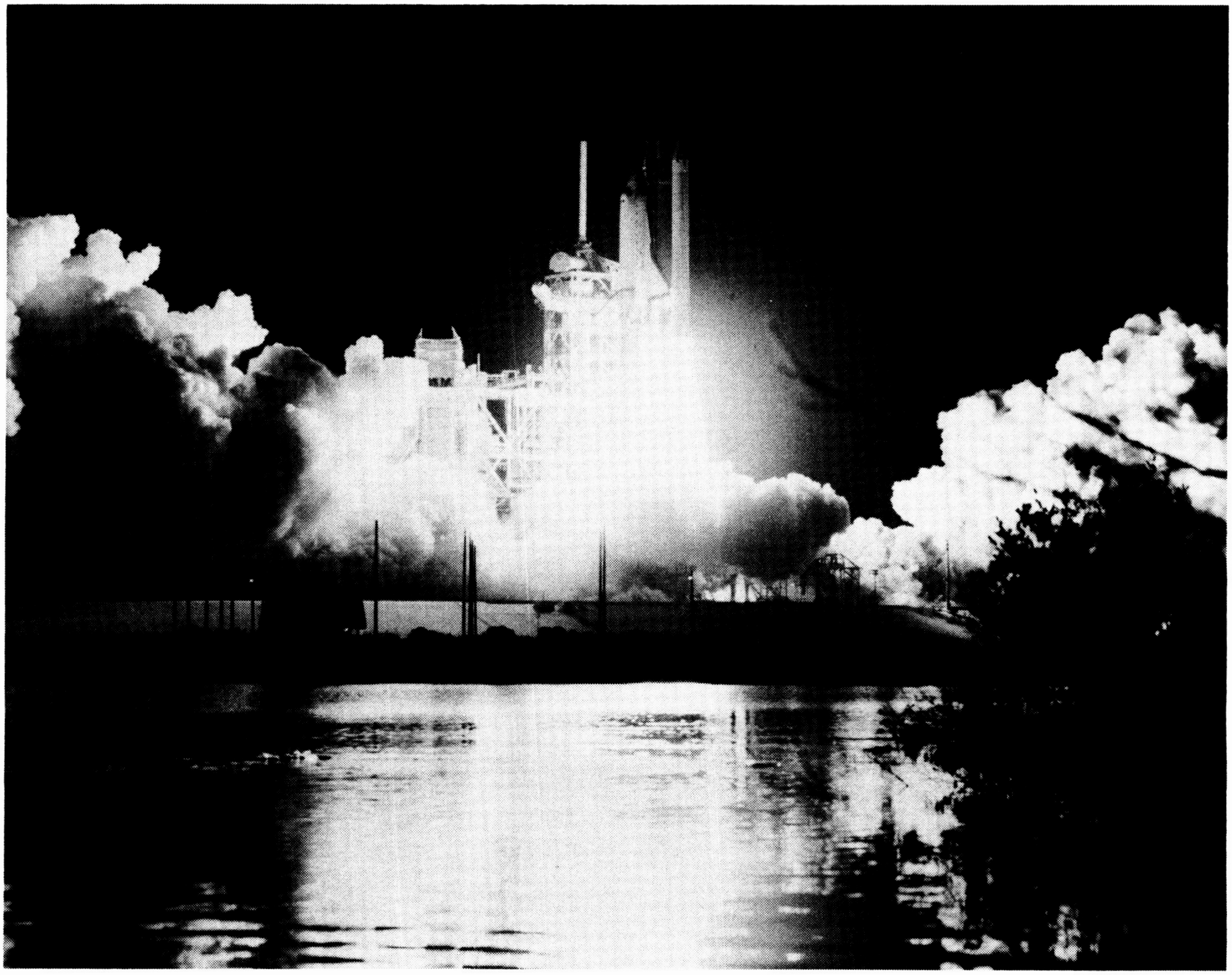


FIGURE 20 – MISSION 61–B LAUNCH

POSTFLIGHT

After the mission, the orbiter lands at either KSC or Dryden Flight Research Facility. Mission 61B landed at Dryden. Normally, there is no access to the payload bay while the orbiter is at Dryden. If during initial formulation of the GIRD and LSSP, however, it is agreed upon that hardware inside the payload bay is time-critical and must be removed at Dryden, then special arrangements can be made for NASA/Boeing personnel to enter the payload bay at Dryden and remove the time-critical items. All plans must be made well in advance and must be agreed to by KSC. Since the payload bay doors cannot be opened at Dryden, this activity requires KSC personnel to enter through the crew compartment and traverse out the airlock into the bay. Special ladders and platforms need to be fabricated and installed for this activity. Non-flight lights and air cooling hoses also need to be routed into the payload bay. Because of the complexity involved and the short time it takes the orbiter to return to KSC aboard the Shuttle carrier aircraft (approximately 1 week), hardware removal at Dryden is avoided whenever possible. In any case, whether at Dryden or at KSC, experiment hardware is always removed by KSC personnel. The orbiter is shown landing at KSC in Figure 21 and is being ferried back to KSC in Figure 22.

If the orbiter lands at KSC, none of the above operations are required. Entry into the payload bay is available within 48 hours after landing. For payloads that are not time-critical, such as EASE/ACCESS, the entire carrier is removed from the payload bay after the orbiter is returned to the OPF. The carrier is placed in the payload canister and transported to the O&C building where it is installed in a Level IV stand. The individual experiments are then deintegrated from the MPESS and returned to the payload mission manager. If time-critical items need to be removed in the OPF before the MPESS is returned to the O&C, access is available. All special requirements, however, such as for early removal of experiment hardware, must be stated in the GIRD and must be agreed to in the LSSP.

Deintegration of the EASE and ACCESS experiments was accomplished in three days. All hardware removal was performed per test preparation sheet. Deintegration of all MPE hardware (including the foot restraints) took approximately one week. After the experiments were removed by NASA/Boeing personnel, the items were officially turned over to the mission manager and then shipped from KSC to the experimenters. After the MPE hardware was deintegrated, it was turned over to the mission manager. The foot restraints were then shipped to Johnson and the remaining MPE hardware was shipped to Marshall. After all payload hardware had been removed, the MPESS was moved to an offline lab in the O&C building.

At this point in the flow, the carrier is inspected and all nonconformance items are corrected. For the EASE/ACCESS mission carrier, paint had chipped off in certain areas of the MPESS and excess epoxy residue, used for securing bolts, remained after the experiment and MPE hardware had been removed. A problem report was written, the residue was removed, the paint was touched-up, and the MPESS was brought back to flight configuration. The MPESS now remains in the offline lab until the next payload is ready to be installed onto it. At that time, the MPESS is moved to the Level IV stand, and the integration process begins again with the installation of the MPE and experiment hardware.

FIGURE 21 – SHUTTLE ORBITER LANDS AT KSC

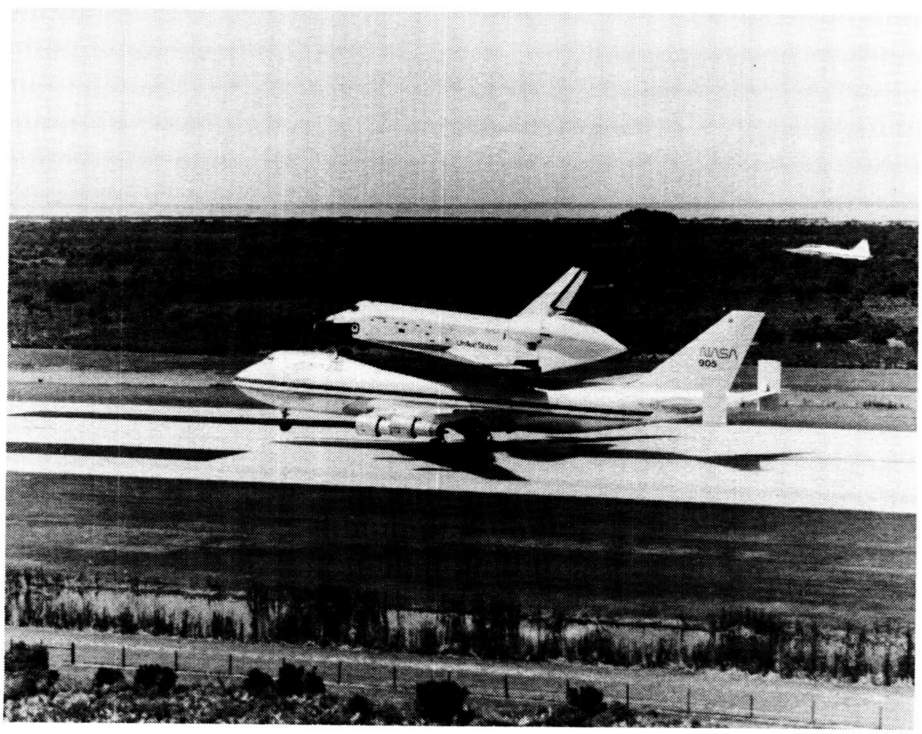


FIGURE 22 – SHUTTLE ORBITER IS FERRIED BACK TO KSC FROM DRYDEN

CONCLUSION

The processing of EASE/ACCESS can serve as a good example for future space construction experiments. Ground processing and installation into the orbiter for all such payloads are performed at KSC. The experiments arrive separately and are integrated onto the carrier and into the Shuttle. All interfaces are verified at the launch site. The processing flow is standardized, yet flexible enough to accommodate individual payload requirements, as was demonstrated by EASE/ACCESS integration. Minor problems can arise, however, during integration. Recommendations for investigators are detailed in Figure 23. Investigators can decrease the likelihood that common problems occur by ensuring that all processing requirements are clearly documented in the GIRD, by verifying that their experiments are completely built and thoroughly tested prior to shipment, by carefully reviewing all integration drawings and checking to see that every item to be installed is included, by submitting detailed procedure inputs to KSC for every planned operation, by supporting any scheduled operation on an as-needed basis, by delivering the hardware on schedule, and by fully informing KSC about the exact status of the hardware at delivery. With the opportunities for working in space increasing, many more types of payloads will be flown aboard the Space Shuttle. By planning ahead and working together with KSC personnel, payload preparation for flight can be a smooth and valuable step to reaching orbit and ensuring mission success.

- STATE (IN GIRD) ALL EXPERIMENT REQUIREMENTS (E.G., INSTALLATION, TESTING, MAINTENANCE, CALIBRATION).
- STATE (IN GIRD) ALL KSC RESOURCES REQUIRED (E.G., OFFLINE LAB, SPECIAL HANDLING DEVICES, FLUIDS, GASES, POWER).
- COMPLETE EXPERIMENT FABRICATION, THOROUGHLY TEST EXPERIMENT, AND OBTAIN ALL BASELINE DATA PRIOR TO SHIPMENT.
- PROVIDE WRITTEN PROCEDURES TO KSC ENGINEERS.
- STATE IN THE DELIVERABLE ITEMS LIST ALL ITEMS TO BE SHIPPED TO KSC.
- DELIVER ALL EXPERIMENT HARDWARE ACCORDING TO THE AGREED-UPON SCHEDULE.
- PROVIDE COMPLETE DATA PACKAGE TO KSC AT TIME OF HARDWARE DELIVERY.
- CAREFULLY REVIEW INTEGRATION DRAWINGS AND KSC PROCEDURES.
- ADDRESS ANY DISCREPANCIES RESULTING FROM PAYLOAD REVIEWS.
- PARTICIPATE IN PAYLOAD MEETINGS.
- SUPPORT KSC OPERATIONS AS REQUIRED.
- ENSURE THAT ALL EXPERIMENT HANDLING EQUIPMENT IS PROOFLOADED TO KSC SPECIFICATIONS AND THAT ALL OTHER SAFETY REQUIREMENTS HAVE BEEN MET PRIOR TO HARDWARE ARRIVAL AT KSC.
- DURING EXPERIMENT DESIGN PHASE, CONSIDER ONE-G ACTIVITIES TO BE PERFORMED AT KSC, AS WELL AS ZERO-G ACTIVITIES IN FLIGHT.

FIGURE 23 – RECOMMENDATIONS FOR INVESTIGATORS