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MARSHALL SPACE FLIGHT CENTER´S ROLE IN EASE/ACCESS MISSION MANAGEMENT

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ABSTRACT

The Marshall Space Flight Center (MSFC) Spacelab Payload Project Office has been responsible for the mission management and development of several successful payloads. Two recent space construction experiments, the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS), were combined into a payload managed by the center. EASE/ACCESS was flown aboard the Space Shuttle during a week-long mission from November 26 to December 2, 1985. The EASE/ACCESS experiments were the first structures assembled in space, and the method used to manage this successful effort will be useful for future space construction missions.

For the EASE/ACCESS mission as well as others, the MSFC mission management team ensures that the payload satisfies the needs of the investigators, is compatible with Shuttle resources, and operates safely during flight. The mission management team coordinates all activities that must be completed before launch, during payload operations, and after landing. During the mission, they are responsible for resolving any payload problems and aiding the crew and investigators in collecting data. The mission management team works closely with other NASA centers, especially the Johnson Space Center and the Kennedy Space Center.

This paper addresses the MSFC mission management responsibilities for the EASE/ACCESS mission and discusses how lessons learned from this mission can be applied to future space construction projects.

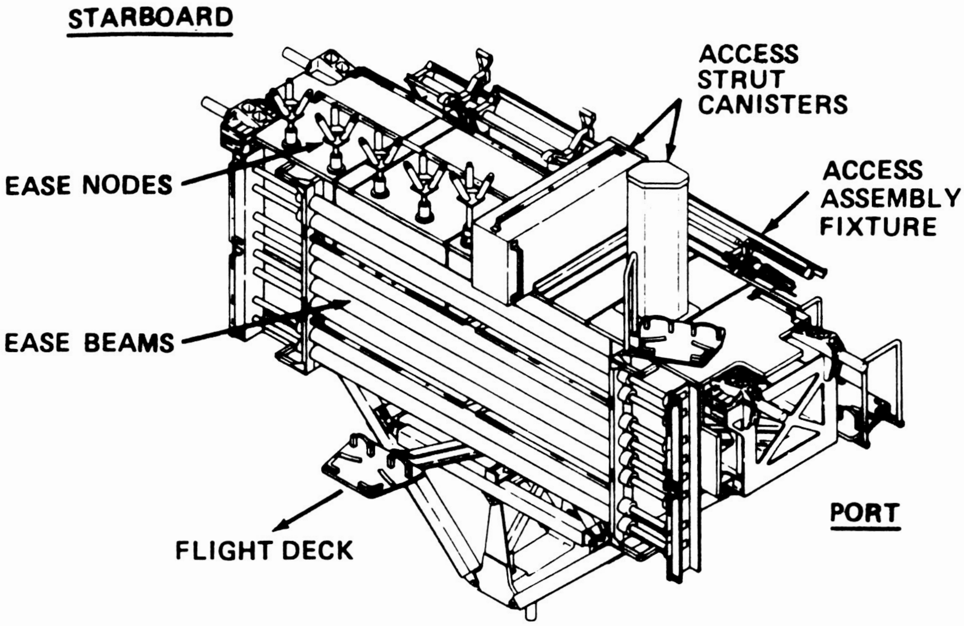
BACKGROUND

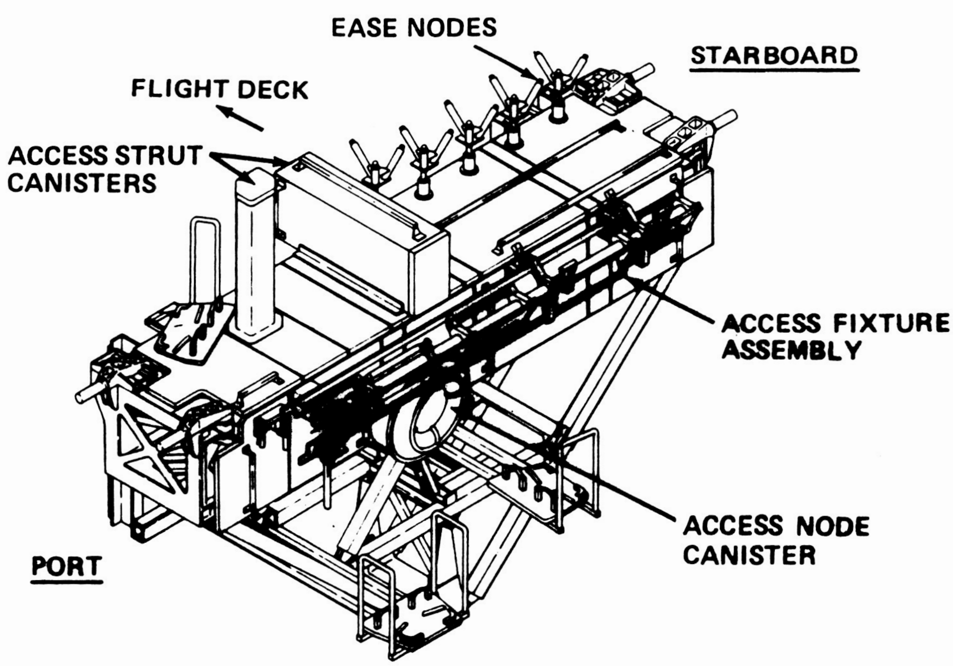
The payload mission manager at Marshall Space Flight Center (MSFC) must ensure experiments are integrated into a payload that can be flown successfully aboard the Space Transportation System (STS). This process begins when the National Aeronautics and Space Administration (NASA) Headquarters authorizes MSFC to integrate a set of experiments and requests that a payload be manifested on a Space Shuttle flight.

The MSFC Spacelab Payload Project Office (SPPO) has been responsible for managing several successful missions, including three Spacelab missions in which scientific laboratories occupied the entire Shuttle payload bay and partial payloads such as the early Shuttle science missions, OSTA-2 and OAST-1, and the Materials Science Laboratory missions. MSFC has developed a mission management technique to ensure that payloads satisfy the needs of the experimenters, utilize Shuttle resources efficiently, and operate safely during flight. The management team coordinates all activities that must be completed before launch, beginning with preliminary design and continuing through payload integration and checkout. During the mission, they continue to aid the crew and investigators in collecting data and resolving problems.

Recently, the MSFC Spacelab Payload Project Office managed and integrated a payload 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). EASE and ACCESS were successfully assembled and disassembled during two extravehicular activities (EVAs) on November 29 and December 1, 1985. Since EASE/ACCESS was the first planned space construction mission, the experiments were kept simple, with the main goal being to study human performance during on-orbit construction. The techniques and approaches used in managing these experiments will be useful as more complex missions are planned during the Space Station era.

EASE/ACCESS was a partial payload; it filled one-fourth of the Shuttle cargo bay. The remainder of the bay was occupied by three deployable satellites. Figure 1 shows two views of the EASE/ACCESS experiment hardware mounted on the Mission Peculiar Equipment Support Structure (MPESS), a carrier which fits inside the Space Shuttle cargo bay.

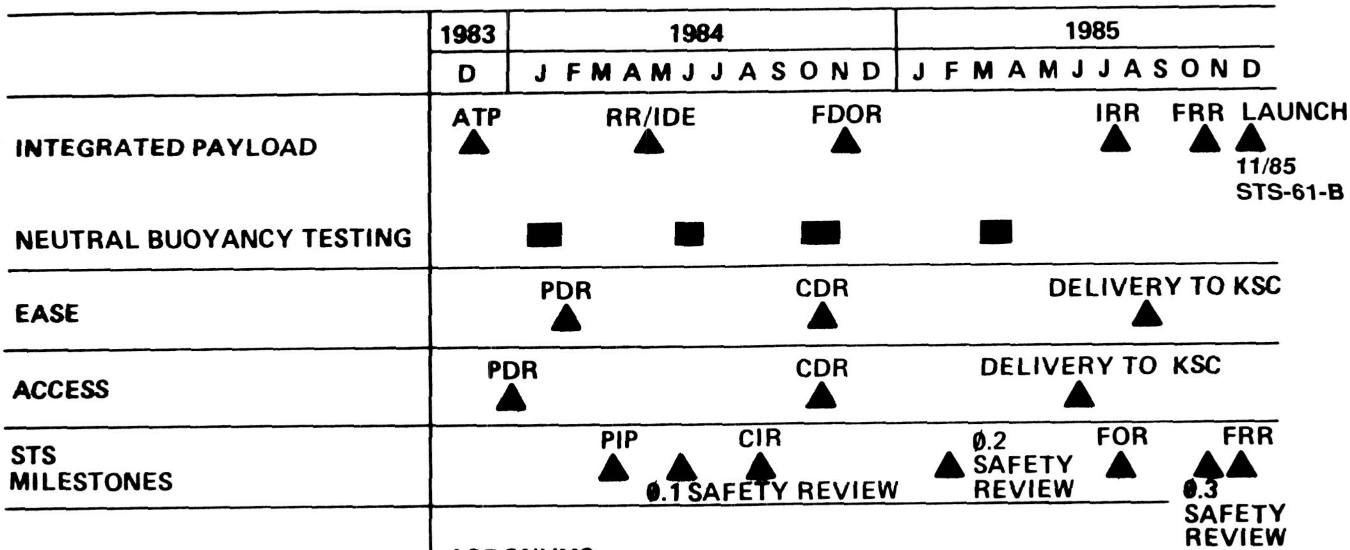




For the EASE/ACCESS mission, MSFC used an analytical integration process developed to manage partial payloads from payload definition through postflight activities. The steps of the process are similar for all partial payloads with emphasis on the payload's unique features. For example, EASE/ACCESS planning emphasized crew training and structural analysis, with minimal efforts for data processing. Other payloads such as the Materials Science Laboratory require little crew interaction, and therefore, planning efforts focus on other aspects of the mission.

As is shown in Figure 2, the integration activity began in December 1983 and ended with experiment operations aboard STS 61-B. As the integration schedule in Figure 2 shows, the completion of each phase of the program was marked with a design review. These reviews served to assure compatible development of all aspects of the integrated payload.

EASE/ACCESS INTEGRATION SCHEDULE



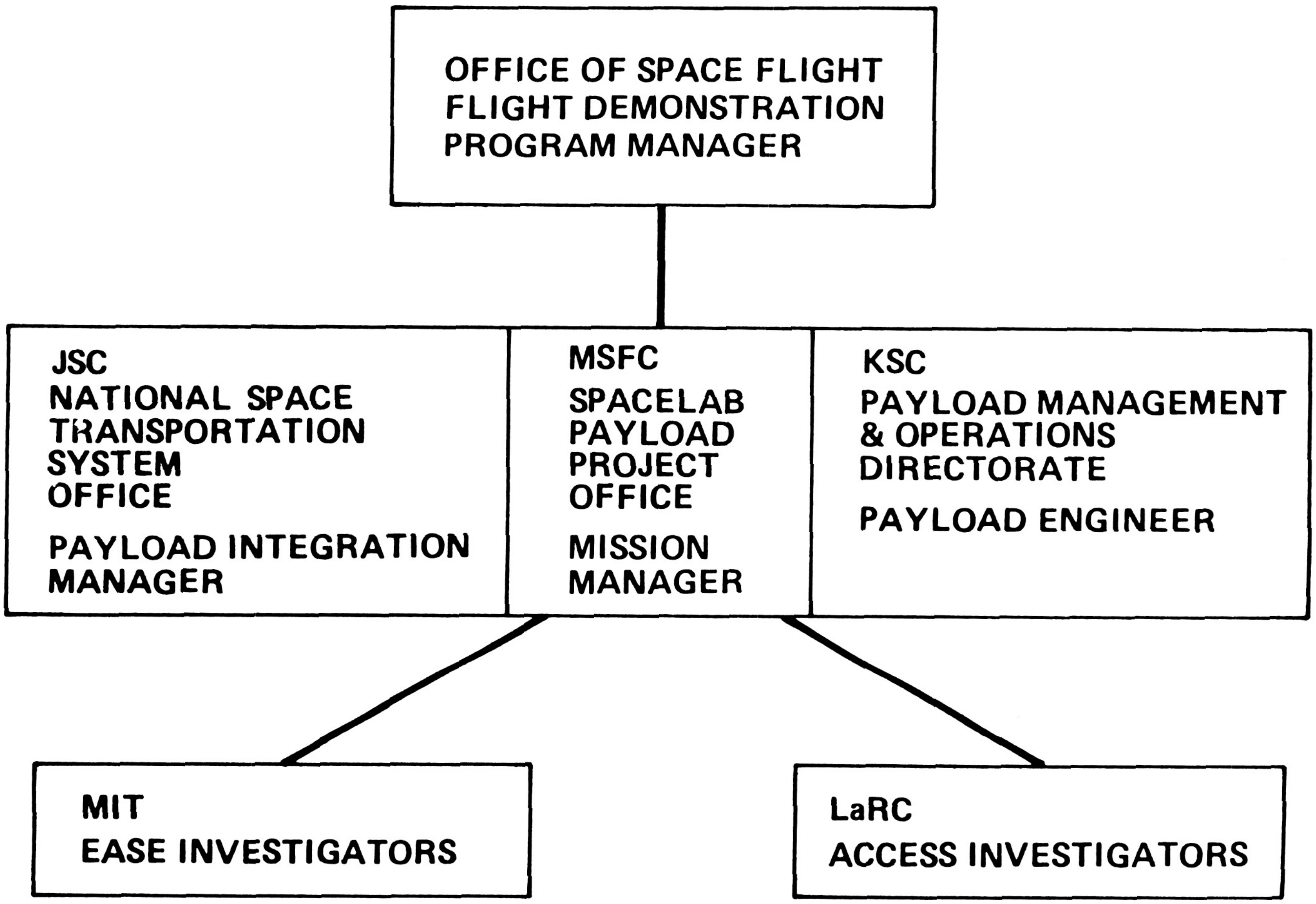
ACRONYMS

ATP	AUTHORITY TO PROCEED
RR	REQUIREMENTS REVIEW
IDE	INTERMEDIATE DESIGN EVALUATION
FDOR	FINAL DESIGN & OPERATIONS REVIEW
IRR	INTEGRATION READINESS REVIEW
FRR	FLIGHT READINESS REVIEW
PDR	PRELIMINARY DESIGN REVIEW
CDR	CRITICAL DESIGN REVIEW
PIP	PAYLOAD INTEGRATION PLAN
CIR	CARGO INTEGRATION REVIEW
FOR	FLIGHT OPERATIONS REVIEW

NASA CENTER RESPONSIBILITIES

Three NASA centers were primarily responsible for integrating the EASE/ACCESS payload: Marshall Space Flight Center, Johnson Space Center (JSC), and Kennedy Space Center (KSC). All three centers worked closely together throughout the development and flight of the payload. Figure 3 shows the organizational relationships between the three mission integration centers, NASA headquarters, and the experiment developers.

MISSION INTEGRATION MANAGEMENT RELATIONSHIPS



The MSFC mission management team was responsible for analytically planning the EASE/ACCESS mission and providing Mission Peculiar Equipment (MPE), additional equipment needed to support the payload. The analytical integration process was directed by a payload mission manager who was ultimately responsible for integrated payload definition and design, verification of STS compatibility and safety compliance, and coordination of requirements with managers of supporting organizations. To fulfill these obligations, the mission manager relied on a team of integration engineers. The mission management team served as the liaison with the investigators. The EASE experiment was developed by the Massachusetts Institute of Technology (MIT) under contract to MSFC. The ACCESS experiment was developed by the NASA Langley Research Center.

The Johnson Space Center was responsible for gathering data on all the payloads assigned to the mission, defining the cargo, designing an integration plan for the entire cargo, certifying that the Shuttle and all payloads on board were safe, and planning on-orbit operations. MSFC provided the EASE/ACCESS payload requirements, and the JSC integration team used them to integrate EASE/ACCESS with the Shuttle and the rest of the payloads assigned to the mission.

The Kennedy Space Center was responsible for physically integrating the experiments into a payload, installing them in the Space Shuttle, and providing launch and landing support. The MSFC mission management team provided KSC with the specifications for checkout and integration of the experiments and Mission Peculiar Equipment.

PAYLOAD DEFINITION

Following the assignment of mission management responsibility to MSFC, several meetings are held with the experiment developers. At this point, usually the concept for each experiment is well defined, but experiment requirements have not been specified and hardware has not been designed. The mission management team and the investigators determine the requirements for each experiment and decide how the Space Transportation System and available support hardware can meet these needs.

ACCESS, a 12-meter (40-foot) high tower constructed with 93 struts and 33 nodes, and EASE, a tetrahedron-shaped structure made of 6 large beams and 4 connector clusters, had many of the same requirements. Both the EASE and ACCESS experiments called for the structures to be positioned forward in the payload bay for clear line of sight photography from the aft flight deck; for adequate clearance for suited EVA astronauts in the payload bay; and for a carrier for experiment hardware. With these demands in mind, MSFC engineers selected the Mission Peculiar Equipment Support Structure (MPESS) to serve as the carrier for the EASE/ACCESS payload. (Figure 1 shows the MPESS launch configuration.) The MPESS was selected because it was available, takes up a minimum of cargo bay space, provides adequate clearance for EVA astronauts, and requires a minimum of Mission Peculiar Equipment. Other available carriers were rejected because they failed to satisfy the requirements of the mission as efficiently. For instance, a Spacelab pallet was ruled out because it was heavier, took up more space than the MPESS, and required more Mission Peculiar Equipment. The MPESS bridged the Shuttle payload bay, serving as a work platform for the astronauts as well as an equipment carrier.

During the early stages of payload development, other standard STS equipment is identified for use by the experimenters. Using this equipment reduces experiment costs and enhances reliability. EASE/ACCESS made use of 16- and 70-mm film cameras, video cameras and recorders, foot restraints, and tethers from the STS inventory. However, an EASE experiment requirement to record time on two synchronized 16-mm film cameras required the modification of the standard cameras. With this modification, the two 16-mm cameras recorded stereoscopic images of the EVA astronauts at work.

As the experiment requirements are defined, the mission manager works with the experiment developers and JSC to determine if and how requirements can be met. Both EASE and ACCESS required locations in front of the other payloads. The experiments had to be forward enough in the payload bay to allow accurate photography from the aft flight deck but back far enough to leave room for the EVA astronauts to assemble the structures.

During payload definition, the MSFC team also provides experiment developers with design criteria for using the Space Shuttle. This includes environmental and safety design criteria as well as lists of available services and equipment such as the Remote Manipulator System (RMS). With this knowledge, the investigators define requirements placed on the Space Transportation System in a formal document, the Experiment Requirements Document (ERD), which is submitted to the MSFC mission manager. The ERD describes the experiment's requirements in the following areas: experiment operation and configuration, electrical, thermal, and command and data handling controls, physical integration plans, and ground operations support plans. The ERD is updated as the experiment evolves.

The MSFC mission manager uses the ERD and other information from the investigators to formalize payload requirements with JSC in the Payload Integration Plan (PIP), the master plan used to allocate STS resources for a specific payload. MSFC personnel helped prepare annexes to the PIP that identified details pertinent to EASE and ACCESS. Since the structures were constructed during EVAs, the assembly and disassembly process had to be identified in step by step procedures. Other annexes addressed various aspects of the mission: flight operations support by personnel working on the ground; crew training; command and data handling; equipment placement and stowage; launch site support; payload safety verification; and EVA activities and equipment.

After the basic payload is defined, the experiment developers begin preliminary design. For EASE and ACCESS, a great deal of conceptual work had already been accomplished before the experiments were assigned to a Shuttle flight. Investigators from Langley and MIT had already done research and neutral buoyancy testing with various large space structures. This experience helped them determine the appropriate structure size, configuration, and assembly procedure. ACCESS used an assembly line technique with the crew remaining at designated work stations and moving the tower along an assembly fixture as they assembled it bay by bay. EASE used an assembly technique with crew members working both in restraints and unrestrained. Neutral buoyancy mockups of the two structures were fabricated, and investigators refined the hardware design and assembly techniques.

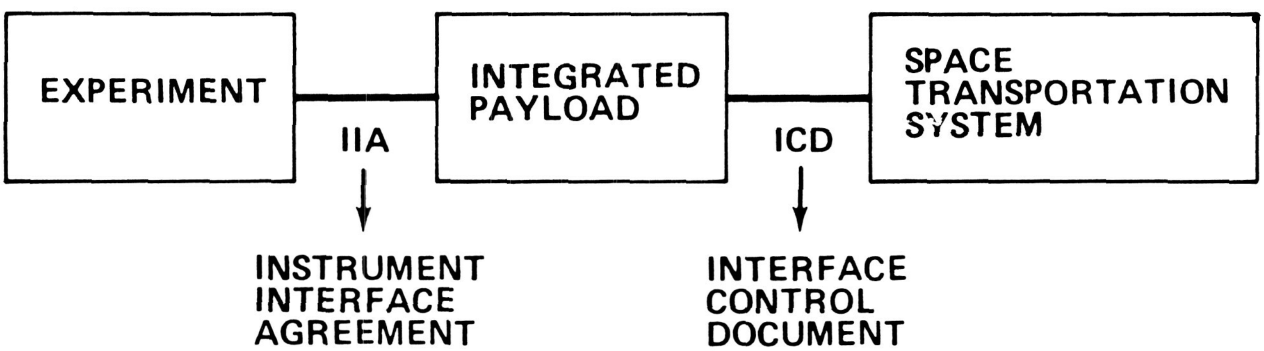
Throughout the hardware design and integration process, a series of formal design reviews play an important role in coordinating efforts. Figure 2 shows a schedule for reviews of the EASE/ACCESS payload. Each review occurs at a natural transition point in payload development. For example, the purpose of the Integrated Payload Preliminary Design Review is to finalize mission requirements, the baseline payload interfaces, the safety verification methods and begin planning for physical integration and flight support. The last review before delivery of hardware to KSC is the Integrated Payload Integration Readiness Review in which the payload is reviewed against the established requirements to verify payload safety and compatibility with the orbiter and other payload elements.

INTERFACE DEFINITION

Interfaces are defined between each experiment and the integrated payload and between the integrated payload and the STS. As shown in Figure 4, the experiment to payload interfaces are defined in the Instrument Interface Agreement (IIA), and the payload to STS interfaces are defined in the unique Interface Control Document (ICD). As all the payloads assigned to the mission and the individual experiments evolve, it is often necessary to reconsider the interface definitions. Changes are defined in the IIA which is used to obtain the agreement of the effected design groups.

Interfaces have to be defined for each subsystem of a payload including all the electrical, mechanical, and thermal connections between the experiment hardware and the carrier. An envelope drawing indicating maximum experiment size, limits of motion, and connector locations and mounting is documented. As the first space construction payload, EASE/ACCESS had simple interfaces, consisting mainly of structural and mechanical interfaces where the experiments, the MPESS, and support hardware were connected or attached; there were no requirements for electrical or power systems or microprocessor commands and data.

INTERFACE DEFINITION



The principal interfaces vary with each payload. For EASE/ACCESS, crew interaction with the structures was a primary concern. It was critical that the experiments be compatible with the crew. The astronauts participated in experiment development tests and helped define details such as the location and number of foot restraints and handholds and the location and assembly instructions provided on decals placed on the flight hardware. The hardware materials met crew touch temperature limit standards. The hardware had to be easy to handle by a suited astronaut; this requirement resulted in the development of a harpoon, a pip pin with a tether, designed by the MIT experiment developers to restrain the large EASE beams during handling. It also resulted in the waiver of some requirements. The flight rule that all hardware handled during an EVA must be tethered was waived because tests verified that the small ACCESS struts could be manipulated safely and easily without tethers.

Interface definition continues to change and evolve until flight. Design solutions for changes are identified in formal documents and all effected groups are notified of changes. For instance, if it is determined that an extra handhold is needed on experiment hardware, investigators are informed of the requirement and given instructions to modify hardware to accommodate the change. In some cases, the investigators will request a modification. For instance, the Langley experiment developers added insulation to the ACCESS structural members to prevent thermal gradients from causing the hardware to bind.

SAFETY AND VERIFICATION PROCESS

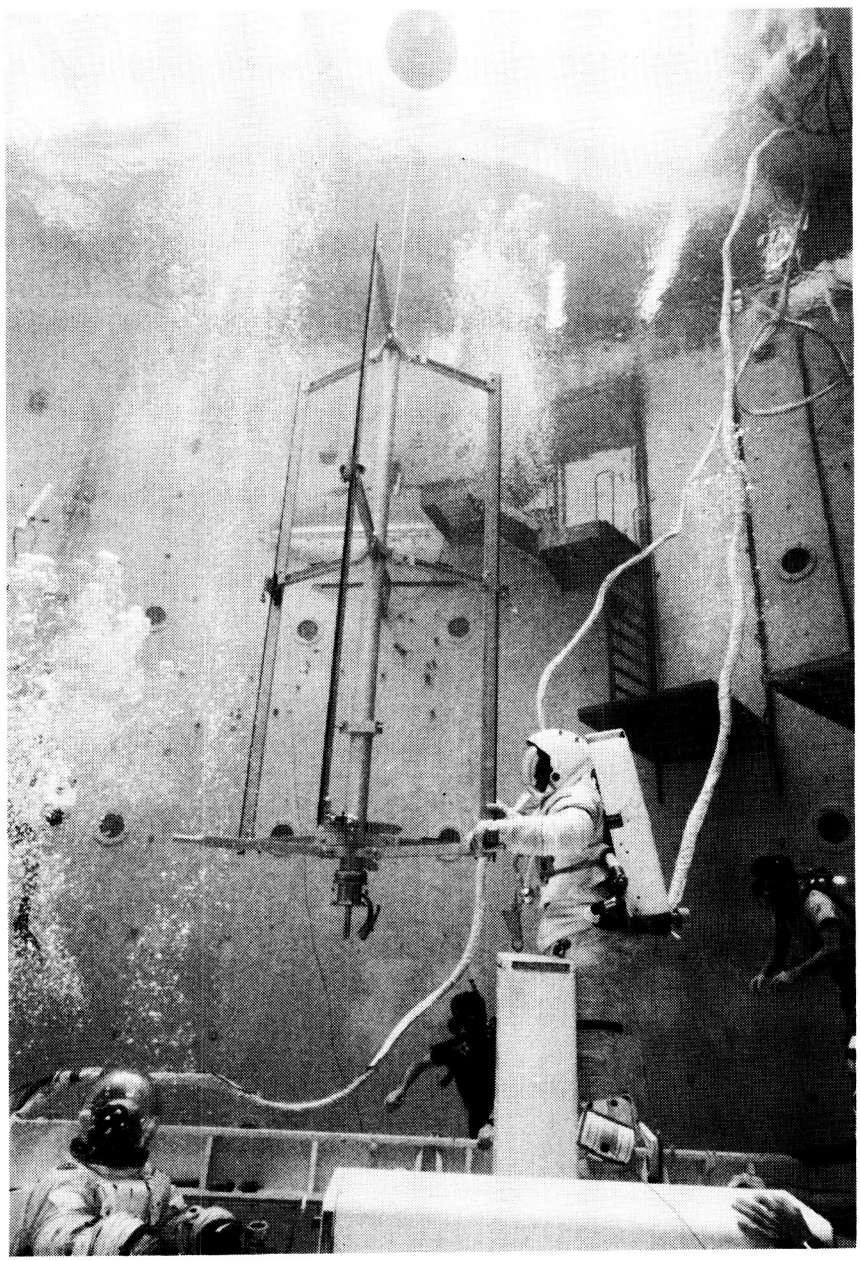
Safety is considered throughout the experiment development and integration process. Tests and analyses are used to verify that all hardware is safe for flight. The experiment developers provide data to the mission manager for their hardware. The mission manager compiles this data with data for the integration hardware into an integrated payload safety analysis which is presented to the STS safety panel for approval.

The safety process consists of analyzing each potential hazard and devising a solution to assure that the hazard cannot occur. Figure 5 identifies the steps of the safety process.

SAFETY PROCESS

- **PHASE 0 – IDENTIFY POTENTIAL HAZARDS**
- **PHASE 1 – IDENTIFY APPROACHES TO ELIMINATE OR CONTROL HAZARDS**
- **PHASE 2 – VERIFY DESIGN, IMPLEMENT CONTROLS**
- **PHASE 3 – VERIFY HARDWARE AS BUILT, CERTIFY SAFETY COMPLIANCE**

Each system that is potentially hazardous must be safe after any two failures. Some of the potential hazards analyzed for the EASE/ACCESS mission concerned structural failures caused by loads or stress corrosion; damage to the EVA suits by sharp edges; and electrical interference caused by static electricity. However, the most significant hazard addressed was the potential failure to disassemble the EASE or ACCESS structures which would prevent closing the payload bay doors. To preclude this hazard, two independent systems were designed to separate the assembled structures from the orbiter. Neutral buoyancy tests were performed to verify the operation of these contingency systems and to train the crew in their use. Figure 6 shows the crew exercising one of the ACCESS separation systems in the MSFC Neutral Buoyancy Simulator (NBS).



An important element of the safety process is to verify that the payload is compatible with the Shuttle and the space environment. Early in the program, tests, analyses, and inspections are identified and scheduled to ensure safe and compatible interfaces. A verification plan is designed for each experiment and for Mission Peculiar Equipment.

The structural loads analysis is a critical part of the verification process. During the mission definition phase, each instrument developer is given design loads based on the past experience of similar hardware. After the hardware designs are completed, each developer provides a math model of their experiment to the mission manager for integration with other experiment math models. This math model for the integrated payload is supplied to JSC for simulation of launch and landing load conditions. Results of this simulation are compared with the design loads to verify adequate margins of safety.

A similar simulation was performed to determine loads imposed by the orbiter control system on the deployed EASE and ACCESS structures. This was required because the control system could excite resonant frequencies of the deployed structures with the possibility of causing structural failures. The results of this simulation imposed operating constraints on the orbiter during some of the experiment operations. The constraints prohibited the use of orbit controls during assembly and disassembly of the EASE experiment and during one part of the ACCESS experiment.

Some parts of the verification plan can be simplified if safety is not compromised. For example, the EASE/ACCESS payload was designed with flight approved materials and did not dissipate any energy as heat; therefore, a major integrated thermal analysis was not necessary. For most payloads, a thermal analysis using models of all of the payloads and the orbiter is performed to define the thermal environment for each payload and experiment.

The MSFC mission manager also performs safety analyses to ensure that the payload can be safely integrated and disassembled at KSC and that handling and testing equipment can be used safely. The results of these analyses are incorporated in the design of the flight hardware and ground support equipment and into the testing and handling procedures.

All payloads must comply with several established rules identified in the "Safety Policy and Requirements for Payloads Using the Space Transportation System", and the "STS Payload Ground Safety Handbook." Four safety reviews are held for flight safety and three are held for ground safety operations. The MSFC mission manager integrates the safety data provided by the instrument developers with the integrated payload analysis and presents it to the STS safety panel for final flight and ground safety certification. The payload must receive safety certification before it is delivered and integrated at KSC.

GROUND PAYLOAD PROCESSING

Ground payload processing occurs at the Kennedy Space Center were the payload elements are integrated on the carrier, checked out, and installed in the orbiter. The MSFC mission management team is responsible for developing the requirements and specifications which define payload processing at KSC. These requirements are documented in the Ground Integration Requirements Document. Typical requirements include off-line laboratory space and equipment for post-shipment tests by experimenters, procedures for attaching the experiments to the carrier, integrated checkout and verification tests, and envelope clearance tests for experiments. Requirements for interface tests, servicing, calibration, or special handling are specified.

The KSC integration team is in charge of payload processing; however, the MSFC mission management team and the experiment developers support these activities. After the payload is mechanically integrated, MSFC personnel and experimenters may participate in functional testing. For example, the integrated ACCESS structure was partially assembled to verify that the interfaces fit together properly. Other testing included inspections for sharp edges that might damage EVA suits and measurements to ensure proper clearance.

A Crew Equipment Interface Test (CEIT) was performed by the EVA crew to familiarize them with the flight hardware. For this test the astronauts remove each piece of hardware, examine it for fit and function, and return it to its launch configuration. A CEIT is required for payloads with extensive crew interfaces.

If a problem arises during integration, KSC issues a report describing the situation. Upon receiving the report, the MSFC management team meets with any involved parties to assess the problem. For example, during EASE/ACCESS integration, Kennedy personnel found a handrail that extended beyond the envelope for RMS clearance. The handrail had been added during experiment development to make it easier for the astronauts to get in and out of foot restraints. Since the handrail problem was discovered near launch time, MSFC, the experimenters, and JSC decided to remove the handrail rather than modify the hardware.

As the payload is processed, MSFC and KSC personnel may hold formal meetings to discuss any outstanding situations that need resolution. Crew training and experiment procedures are usually underway simultaneously with payload processing. The management team may decide to modify the integration plan as a result of a discovery during crew training. For example, during EASE/ACCESS neutral buoyancy tests, it became apparent that a foot restraint needed to be moved for easier handling of equipment. To make these kinds of modifications, MSFC prepares a modification kit to be installed by KSC personnel.

FLIGHT PLANNING

The MSFC mission management responsibility also includes developing plans for inflight activities that support payload operations. For partial payloads, JSC is responsible for creating a plan that outlines all flight activities. This plan is based on inputs from MSFC and other organizations with payloads assigned to the flight.

Some of this information is available in the Experiment Requirements Document input by the investigators. Other data are identified during development testing like that done for EASE/ACCESS in the MSFC Neutral Buoyancy Simulator. For EASE/ACCESS, MSFC provided JSC with information such as the number of EVAs required for assembly, the number of assemblies and disassemblies of each structure required to gather data on human performance during space construction, the approximate time needed for each assembly, the number of EVA crew members required for each task, and the length of each EVA.

The mission management team provided JSC with step-by-step descriptions of crew tasks. For EASE/ACCESS, MSFC provided input into the EVA annex describing all operations during the two six-hour EVAs and payload flight data files with procedures for assembly and disassembly of the structures as well as data collection. Procedures to solve possible contingencies were also outlined. Working with the experimenters, MSFC decides which tasks have the highest priority in case an EVA or the mission ends early. Using all this data, JSC can write flight rules, develop a detailed Crew Activity Plan for the entire mission, and decide which tasks have priority. Before the mission, flight rules are written for potential malfunctions so that decisions can be made expediently on-orbit.

The MSFC management team also carefully plans flight payload operations support activities that take place on the ground. Before the mission, key personnel and their responsibilities are defined. The EASE/ACCESS team worked in the Customer Support Room (CSR) at JSC and in the Huntsville Operations Support Center (HOSC) at MSFC.

There must be a mutual understanding between the STS flight operations staff and the teams supporting various payloads. For EASE/ACCESS, JSC personnel communicated directly with the crew, and the MSFC mission manager communicated with the Johnson EVA officer via a voice loop. Other key personnel such as EASE/ACCESS experimenters and MSFC engineers who wrote assembly procedures or designed hardware served as technical advisors during the mission.

Two to three months before a mission, planning for inflight and ground operations culminate in joint integrated mission simulations in which crucial segments of the mission are rehearsed. These serve to train both the astronauts and the flight operations support crew and to identify any unresolved problems. For EASE/ACCESS, EVA activities were practiced with the astronauts assembling and disassembling the structures in the JSC Weightless Environment Training Facility while JSC and MSFC personnel performed their roles from the JSC Mission Control Center (MCC) and CSR and the MSFC HOSC.

The result of these flight planning activities was smooth on-orbit operations during the EASE/ACCESS experiments. Both experiment teams gathered data beyond their mission objectives. After the mission, the MSFC mission management team continued to support postflight activities, such as crew debriefings. The EASE/ACCESS hardware was deintegrated at KSC and returned to the appropriate organizations.

SUMMARY

The mission management and integration activities were carried out successfully for the EASE/ACCESS mission. This means that the payload was compatible with the orbiter interfaces; the payload operated safely; and the experiment requirements were fully satisfied. These efforts were accomplished within the cost and schedule originally established for the project.

Costs were minimized by using available hardware and an established mission integration process. The structural carrier used for EASE/ACCESS was the Mission Peculiar Equipment Support Structure (MPESS), which was available in the existing hardware inventory. In addition, standard STS hardware such as the CCTV, movie and still film cameras, and video recorders was used for data collection.

With the exception of designing the crew interfaces for extravehicular activities (EVAs), the mission management and integration of EASE/ACCESS was accomplished using methods developed for previous missions. Missions such as OSTA-2 and OAST-1 were simple payloads which utilized the MPESS in a manner similar to EASE/ACCESS. However, the extensive crew involvement in EVAs and the tests in the MSFC Neutral Buoyancy Facility were unique aspects of the mission. It is the purpose of this paper to make others aware of the experience gained on this mission in hope that it will be of benefit in planning future space construction missions involving EVA.