N88-10880

RESULTS OF THE ACCESS EXPERIMENT

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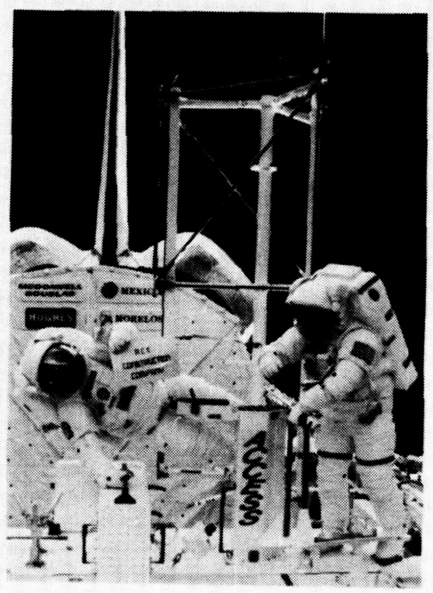
Space Construction Conference
NASA Langley Research Center
Hampton, Virginia

August 6 and 7, 1986

INTRODUCTION

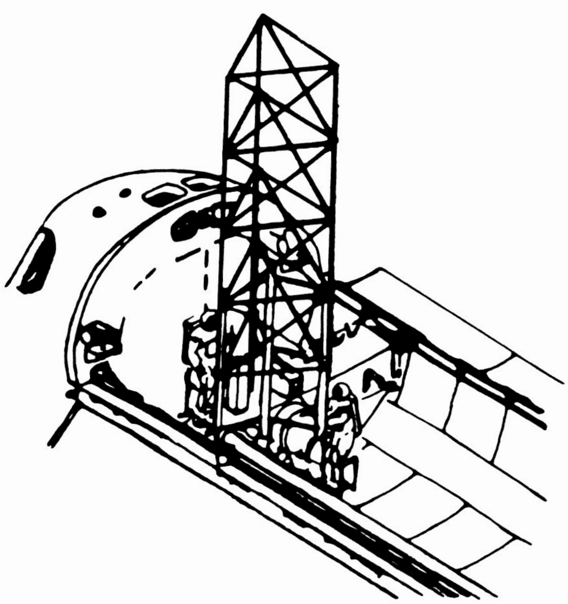
The ACCESS (Assembly Concept for Construction of Erectable Space Structure) experiment was conceived in June, 1983 to study manual assembly of a 45-foot long truss structure by two astronauts working in space suits in the Orbiter cargo bay. The experiment was launched 2 1/2 years later, November 26, 1985, on the Orbiter Atlantis, the 23rd voyage of the Shuttle program. From the outset, ACCESS was required to be flown as a payload of opportunity on a Shuttle mission with spare cargo capacity, and returned to Earth in the Shuttle following the experiment. In addition, ACCESS was to be flown with a companion payload of opportunity called EASE (Experimental Assembly of Structures in EVA) which would require sharing of the limited EVA time. Thus, to satisfy these requirements and to maintain manifesting flexibility, ACCESS was designed to be relatively simple to assemble and disassemble, compactly stowed, and lightweight. This paper describes the ACCESS experiment and procedures used by the astronauts, presents photographs of the construction tasks performed in underwater neutral buoyancy training tests as well as on-orbit, and compares on-orbit timelines with data from the neutral buoyancy tests.



OBJECTIVES AND GENERAL DESCRIPTION

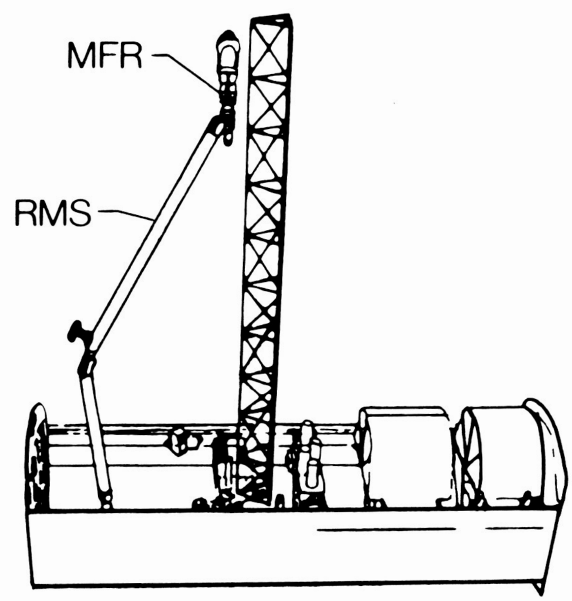
The primary objectives of ACCESS were to: (1) evaluate an assembly line technique for efficient use of astronauts as space construction workers, (2) provide on-orbit data for correlation of assembly rates and techniques developed in neutral buoyancy simulations, (3) gain on-orbit EVA (extravehicular activity) construction experience, and (4) evaluate assembly, handling, and maintenance of a large space structure in support of Space Station development. To meet these objectives ACCESS was divided into two parts, a baseline experiment, and an expanded experiment. As indicated in the figure, the baseline experiment involved two astronauts working from fixed foot-restraints, performing repetitive tasks in an assembly line fashion. The expanded experiment involved one astronaut working from a foot-restraint attached to the end of the Remote Manipulator System (RMS) robot arm to evaluate specific construction and maintenance tasks more suited to a mobile work station approach. These two ACCESS experiments were performed on separate EVA days of the mission. An EVA day is nominally six hours, and had to be shared with the EASE experiment.

EVA-1: Nov. 29, 1985



Baseline experiment
fixed foot-restraints

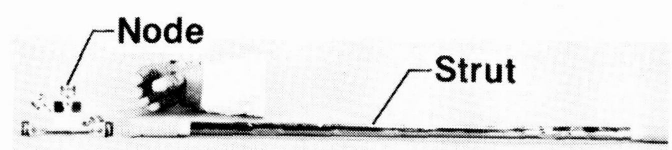
EVA-2: Dec. 1, 1985

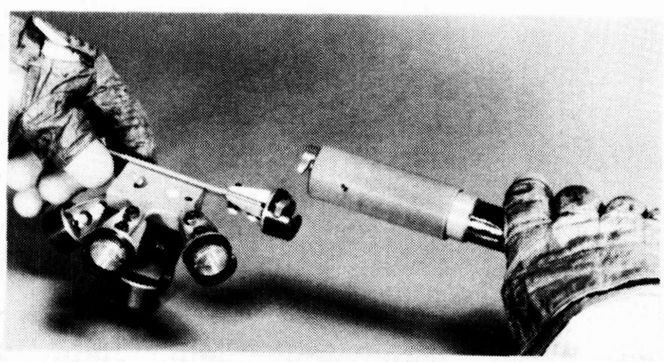


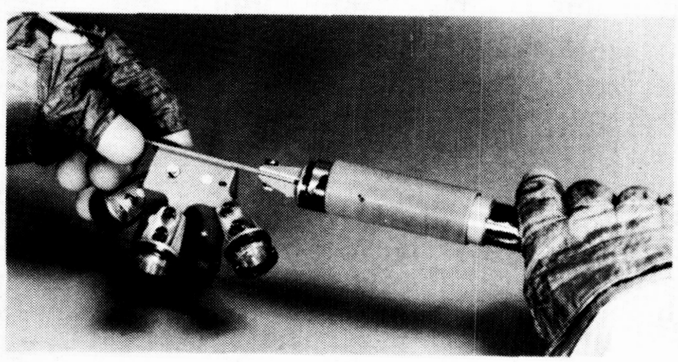
Expanded experiment
mobile foot-restraint

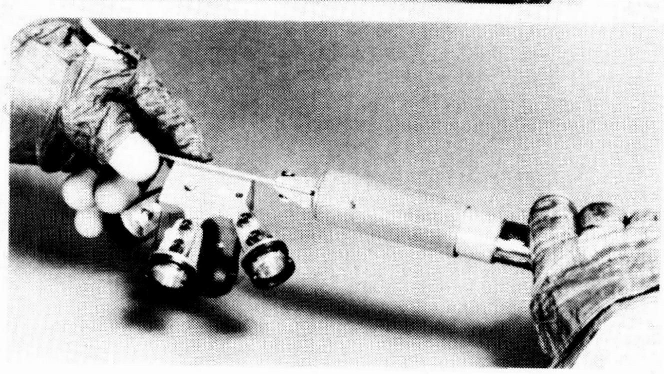
TRUSS HARDWARE

The truss was made up of: (1) 30 longerons (main vertical struts), (2) 30 diagonals (bracing struts), (3) 33 battens (horizontal struts that maintain the triangular cross section of the truss), and (4) 33 nodes (strut connectors). The battens and longerons were 3.95-feet long, the diagonals were 5.81-feet long, and all struts were one inch in diameter. The fully assembled truss consisted of ten identical bays, each with 4.5-foot square sides (measured between node centerlines). Each strut was thermally insulated with a thin gold-colored plastic film (Kapton) for dimensional stability. Each node had six strut attachment points. The joints were designed to permit one-handed engagement. A spring-loaded locking sleeve on the strut end could be placed in an intermediate position so that as the strut and node were mated, the locking sleeve would automatically close to secure the joint. The red-colored node half of the joint was covered by the locking sleeve when the joint was secure, thus giving the astronaut a visual means to verify a proper connection. The locking sleeve could also be locked in a fully open position to permit disassembly of the truss for restowage and return from orbit. None of the ACCESS hardware was tethered for handling on-orbit. All nodes, short struts, and long struts were interchangeable with like parts. All major parts were fabricated from aluminum. A node, batten/longeron strut, and diagonal strut weighed 1.0 lb, 1.55 lb, and 1.94 lb, respectively. The truss weighed 188.8 lb. The moments of inertia of mass about the center of gravity of the truss were Ixx = Iyy = 12896 in-lb-s^2 and Izz = 352.8 in-lb-s^2.





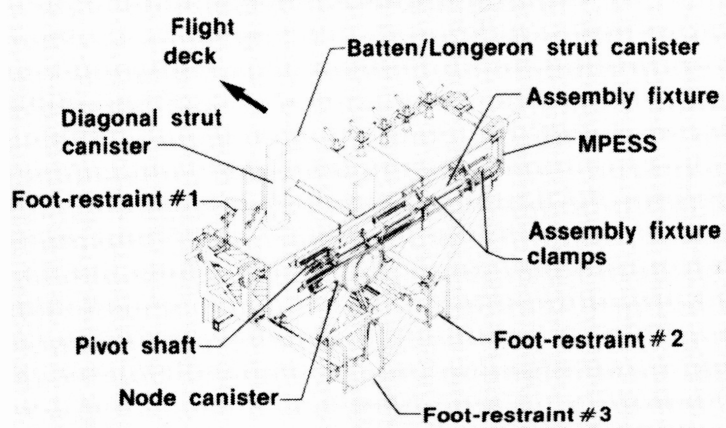


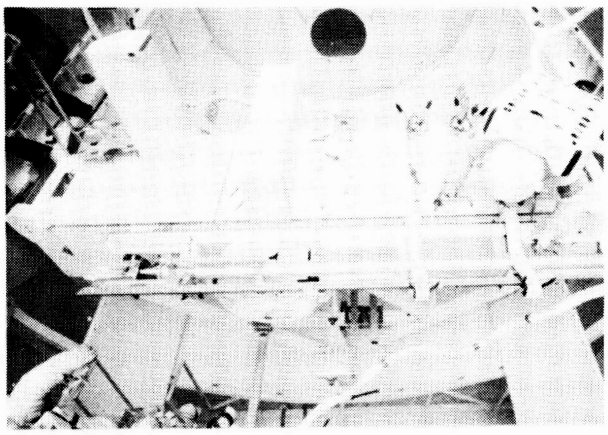


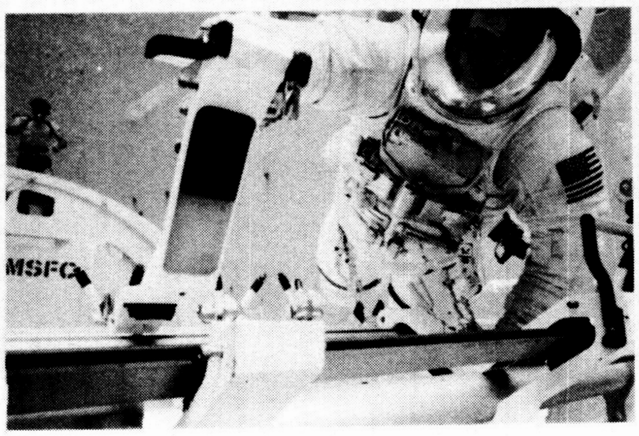
HARDWARE STOWAGE CONFIGURATION

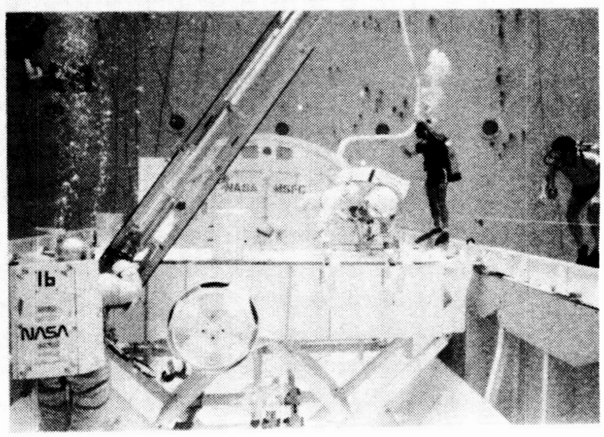
The ACCESS hardware is shown in the figure in its stowed configuration. In addition to the truss hardware, it consisted of three fixed foot-restraints, two strut canisters, a node canister, and an assembly fixture. These components were attached to a pallet called a Mission Peculiar Equipment Support Structure (MPESS), a standard Shuttle pallet which has been used on several other flights. ACCESS was confined to the top left and aft faces of the MPESS. EASE used the rest of the MPESS area. The assembly fixture, which consisted of a central tubular mast with three guide rails (shown folded along the mast), was attached to the aft face of the MPESS by a pivot shaft and two clamps. The pivot shaft was located toward the port side of the MPESS with the shaft axis perpendicular to the aft face. Before assembly of the truss could begin, the astronauts had to release the two clamps, pivot the assembly fixture to an upright position, and deploy the three guide rails. Photographs of some of these activities performed in neutral buoyancy tests are shown in the figure. Foot-restraint three was used only for raising/lowering the assembly fixture. Foot-restraints one and two were used to deploy/fold the guide rails, open/close the strut and node canisters, and assemble/disassemble the truss.

STOWED CONFIGURATION



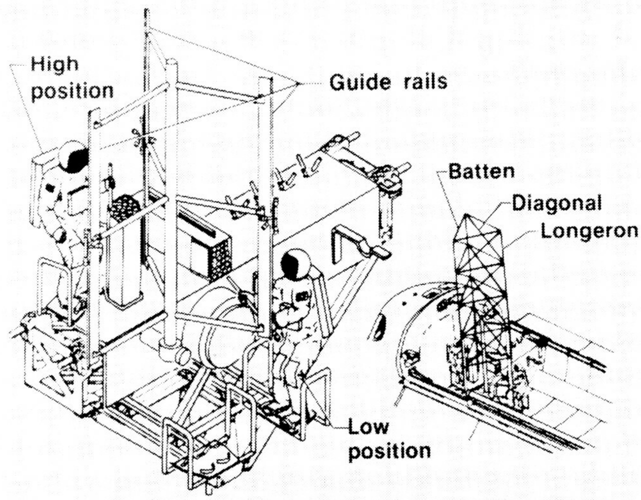


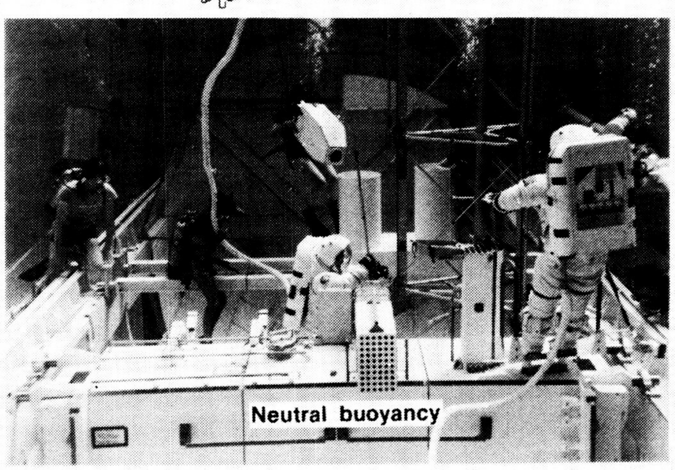




BASELINE EXPERIMENT ASSEMBLY PROCEDURE

The baseline experiment involved an assembly line method of construction which enabled the astronauts to work in foot-restraints at a fixed station. The struts and nodes were made readily accessible so that the astronauts were not required to leave the station during the assembly. The truss was assembled one bay at a time on the lower half of the assembly fixture guide rails which were two bays long. The assembly fixture could be manually rotated about the longitudinal axis of the truss being assembled. Thus, one astronaut, stationed in a "high position" foot-restraint, could make all the joint connections at the top edge of the bay being assembled (approximately 30 % of the work), and the other astronaut, in a "low position" foot-restraint, could install the nodes on the guide rails and make all the connections at the bottom edge of the bay (approximately 70 % of the work). When the bay was complete, the astronauts were required to release a latch and push the bay up the guide rails to the upper half of the assembly fixture where the latch reengaged automatically. The lower half of the assembly fixture was then clear for assembly of the next bay. The process was repeated until the entire 10-bay truss was assembled. The photograph shows the baseline experiment being practiced in the Neutral Buoyancy Simulator at the Marshall Space Flight Center.





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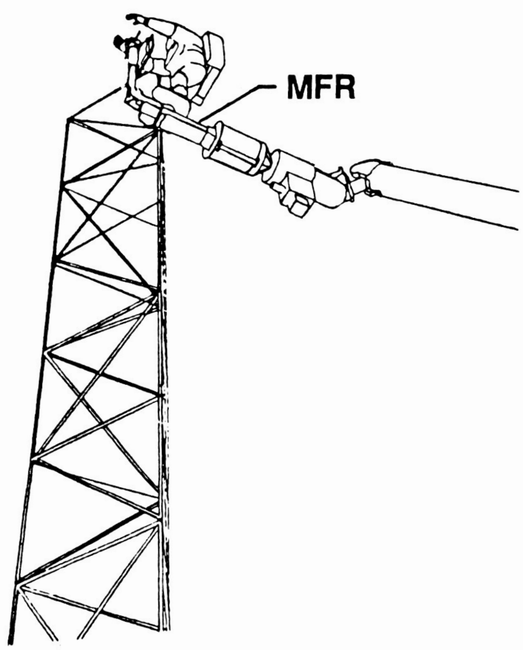
EXPANDED EXPERIMENT TASKS

The expanded experiment used the Shuttle Remote Manipulator System (RMS) and the Manipulator Foot Restraint (MFR) as a mobile work station to assist an astronaut in performing selected construction tasks. The baseline method was used initially to build nine bays of the truss. Then one astronaut ingressed the MFR, loaded nine struts and three nodes onto the MFR Component Carrier, and was moved to the top of the truss to begin the expanded experiment tasks. These tasks included: (1) assembly and disassembly of the topmost bay, (2) installation of simulated electrical cable, (3) replacement of a strut and a node in an interior bay to simulate truss repair, and (4) detachment of the truss from the assembly fixture, manual manipulation of the truss, and reattachment to the assembly fixture. Each astronaut performed some of these tasks. Following the expanded experiment, the astronauts disassembled and stowed the truss and assembly fixture by the baseline method.



Setup
Build 9 bays
(BASELINE)

Assemble 10th bay
Install/remove cable
Manipulate truss
Astronaut #1

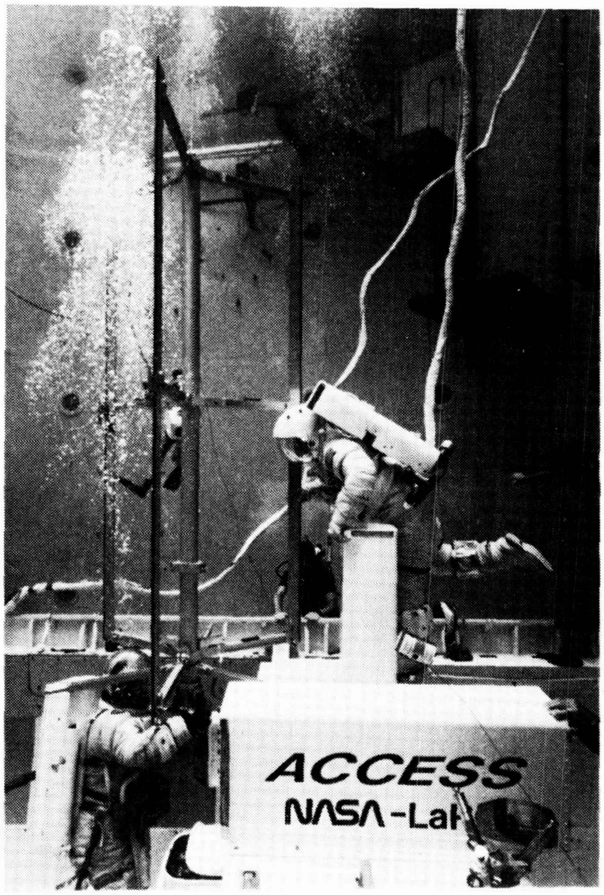
Change MFR astronaut

Disassemble 10th bay
Structural repair
Assemble 10th bay
Manipulate truss
Astronaut #2

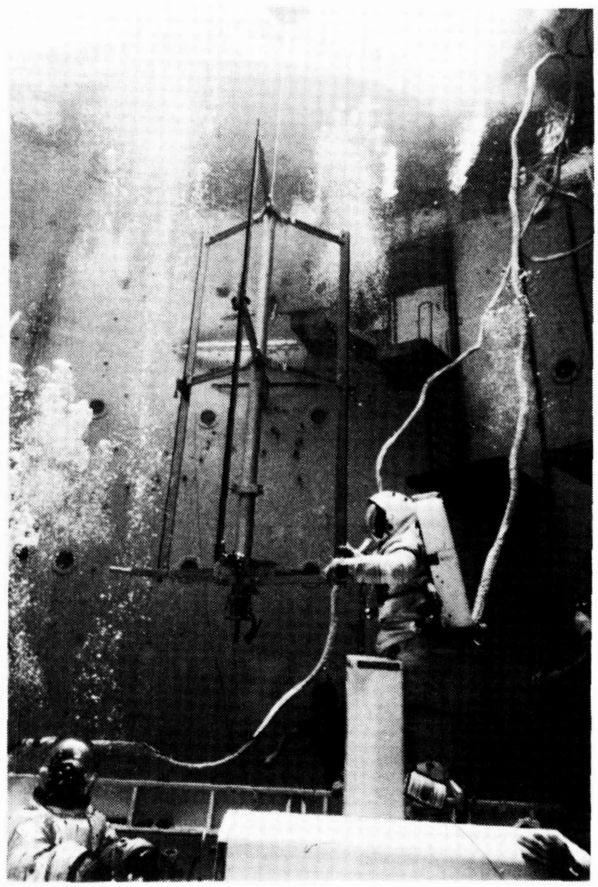
Stow & close up (BASELINE)

SAFETY CONSIDERATIONS

Safety considerations heavily influenced the design and fabrication of the hardware. Because ACCESS was a hand intensive experiment (the EVA astronauts were required to handle virtually every piece of the hardware several times), not only did the standard practice of eliminating all sharp edges and snags apply, but glove wear showed up in neutral buoyancy tests and required attention. For this experiment a wear-resistant protective coating (silicone coated Nomex fabric) was designed and substituted for the usual Teflon T-62 cloth used in the palms of the flight gloves of the Shuttle space suit (Extravehicular Mobility Unit (EMU)). In addition, because the ACCESS structure protruded out of the cargo bay, it was necessary to provide redundant means to jettison the hardware in case an emergency situation required immediate closing of the cargo bay doors to return the Shuttle to the reentry configuration. The primary jettison procedure, which involved release of a marman band clamp followed by retraction of a retainer pin, is shown in the figure and could be accomplished in neutral buoyancy in less than 10 seconds. A secondary method involved the removal of four captured bolts and the one inch nut holding the assembly fixture on the pivot shaft. The assembly fixture could then be pulled off the pivot shaft and jettisoned. Both methods were practiced in neutral buoyancy.



Release of assembly fixture

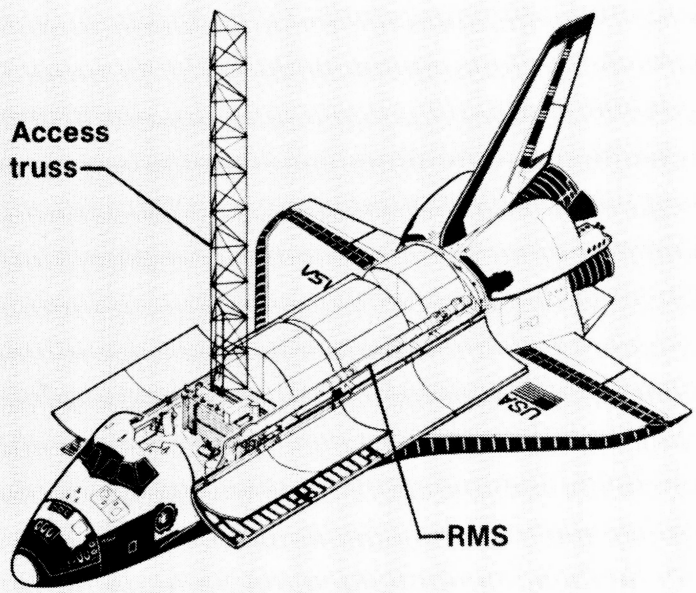


Assembly fixture jettisoned

CREW AND CARGO BAY CONFIGURATION

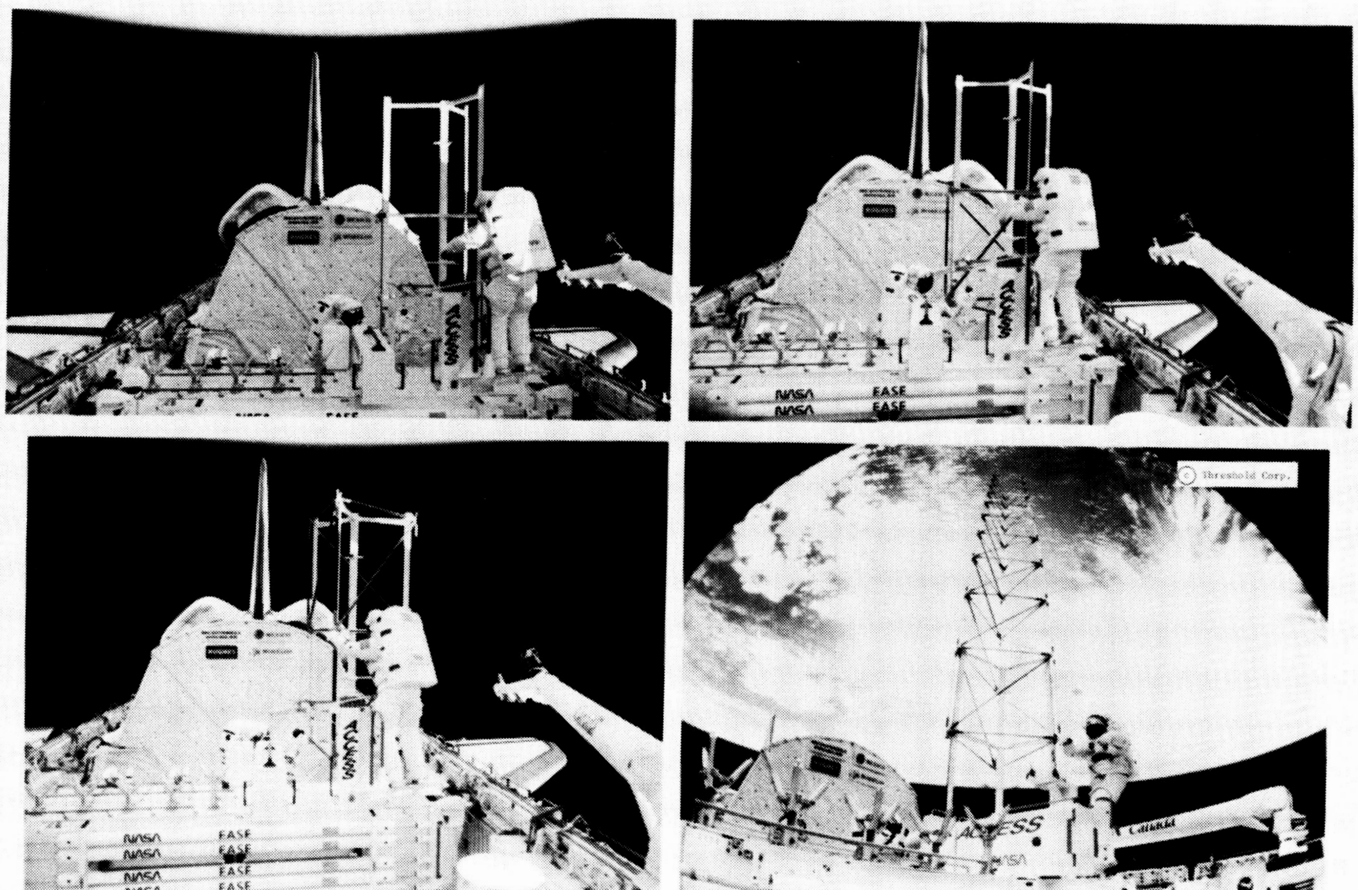
The five crew members responsible for the ACCESS experiment are shown in the photograph. They are Commander Brewster Shaw, Pilot Bryan O'Connor, and Mission Specialists Jerry Ross, Sherwood Spring, and Mary Cleave. In addition to performing their normal Shuttle mission activities, Shaw, O'Connor, and Cleave were responsible for monitoring the highly active EVAs, continuous video and photographic coverage of the experiment tasks, maintaining EVA procedures and timelines, and insuring crew safety. Ross and Spring performed the EVAs; Cleave operated the RMS during the expanded experiment activities. The figure shows the cargo bay configuration and the extreme forward location of the ACCESS payload.

O'Connor, Ross, Cleave, Spring, Shaw



BASELINE EXPERIMENT ASSEMBLY

These photographs show the truss being assembled on-orbit by the baseline method. Top left shows the assembly fixture deployed, the strut canister doors open, and the astronauts in the foot-restraints ready to begin assembly. Top right shows the first bay of the truss assembled and ready to be moved to the upper half of the assembly fixture. Bottom left shows the completed bay in the upper position on the assembly fixture, with construction of the second bay having begun. This photograph was taken while the assembly fixture was being rotated (from left-to-right) following attachment of the bottom end of a longeron and the right end of a batten by the lower astronaut. Following the 120 degree rotation, he will connect the left end of the batten to the node on the next guide rail. The upper astronaut is attaching the top end of the longeron with his left hand during the rotation. Bottom right shows the entire 10-bay truss assembled and moved up the guide rails so that six nodes of the bottom bay attach the truss to the top half of the assembly fixture.



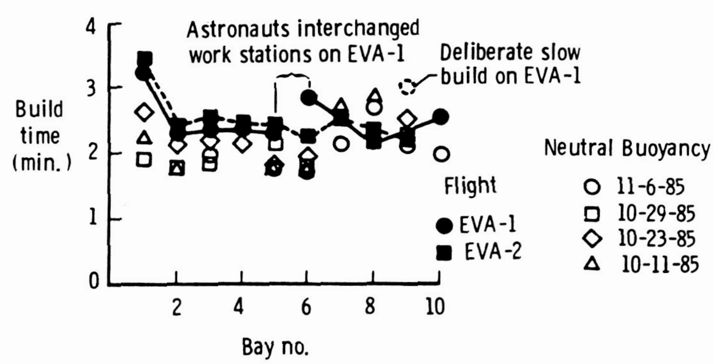
BASELINE EXPERIMENT TASK TIMES

The average task times are given in the Table. The first column of numbers gives average times from tests conducted in the Neutral Buoyancy Simulator (NBS) located at the Marshall Space Flight Center. These tests include some development tests in which the test subjects were not yet fully trained, the assembly procedure not fully developed, nor the hardware finalized. The second column lists the average task times from tests performed by Ross and Spring in the Weightless Environment Training Facility (WETF) located at the Johnson Space Center, after they were fully trained. The final column gives the flight data. The truss was assembled in 25 1/2 minutes on-orbit for an assembly rate of 3.6 struts/min. This was not quite as fast as the astronauts best times in the WETF. However, this result was attributed by both astronauts to having to work with new and, therefore, tighter tolerance hardware on-orbit, whereas the training hardware had become well-worn from the many neutral buoyancy tests. Both astronauts reported that the work effort was about the same as in neutral buoyancy. The plot shows the times taken to build each bay on-orbit (solid symbols) compared with times obtained in neutral buoyancy training (open symbols). The flight data are fairly uniform at about 2.4 min./bay except for the first and sixth bays on EVA-1 and the first bay on EVA-2, which took longer. This phenomenon is probably not a result of learning (both astronauts were already well trained), but more of establishing the "rhythm" of the assembly procedure. Bay six was the first bay constructed on EVA-1 after the astronauts exchanged foot-restraint positions (which also involved exchanging assembly procedures).

Baseline experiment average task times

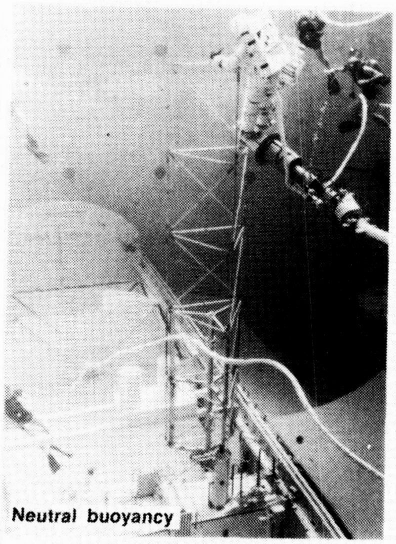
Task	Time (min.)		
	NBS*	WETF**	FLIGHT
Setup	4.0	3.1	3.5
Assemble 10 bays	30.2	21.7	25.5
Disassemble 10 bays	18.7	15.7	18.9
Stow & close up	5.4	4.5	4.2
	58.3	45.0	52.1

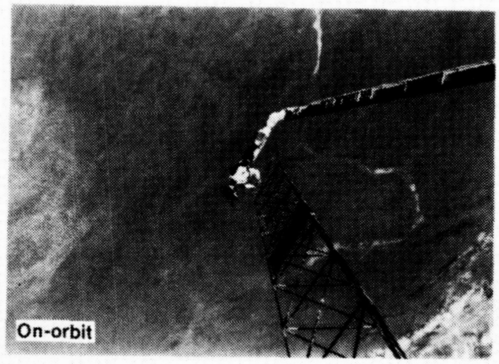
*Includes development tests with untrained test subjects at the Marshall Space Center's Neutral Buoyancy Simulator (NBS).
**Highly trained astronaut test subjects Ross and Spring at the Johnson Space Center's Weightless Environment Training Facility (WETF).

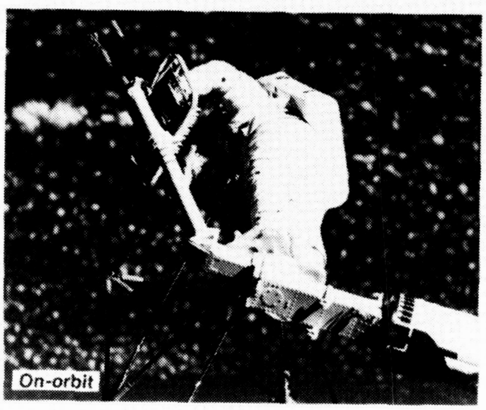


EXPANDED EXPERIMENT RMS-MFR ASSEMBLY

The top photographs show the astronaut at the top of the truss and in the process of assembling the top bay both in neutral buoyancy (left) and on-orbit (right). Bottom left shows the astronaut removing a strut from the MFR component carrier on-orbit. This figure also shows how the nodes were stowed on the struts for transport to the top of the truss. Bottom right shows an on-orbit closeup view of the bay assembly. The RMS operator was required to move the astronaut to six different node positions around the truss, and place him close enough to the node to make the structural connections without touching the truss with the RMS. These delicate maneuvers were complicated by the operator's limited view through the aft flight deck windows and having to operate the RMS at the edge of its operational envelope due to the extreme forward location of ACCESS in the cargo bay and its 45-foot length. The moving Earth background complicated the relative motion perception of the RMS operator, and the marginal lighting conditions at the top of the truss further restricted the RMS operator's view during night passes. Increased rates of motion for the RMS were approved for this mission. The maximum rate of rotation was increased from 1.49 deg./s to 2.79 deg./s, and the maximum rate of translation from 0.44 ft./s to 0.77 ft./s.

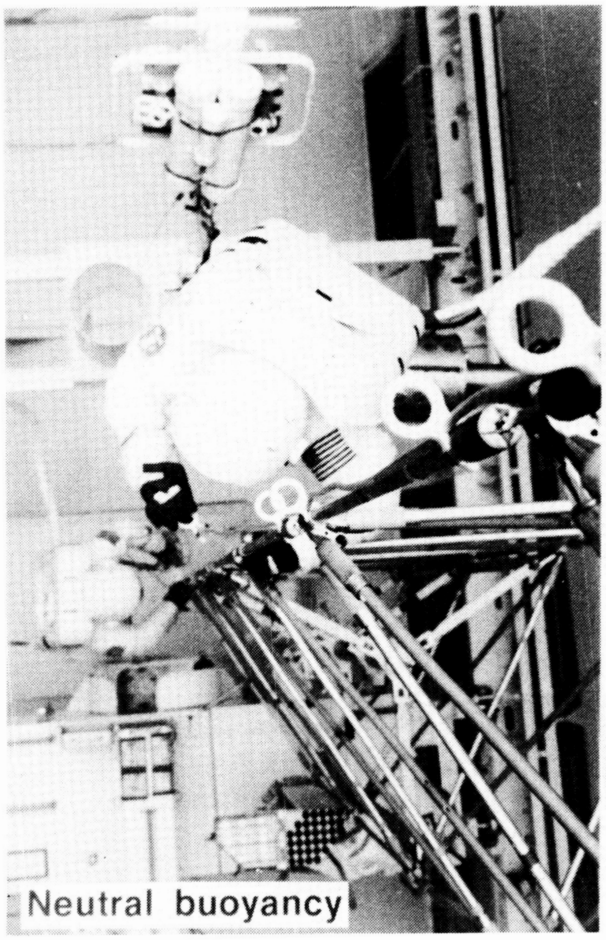




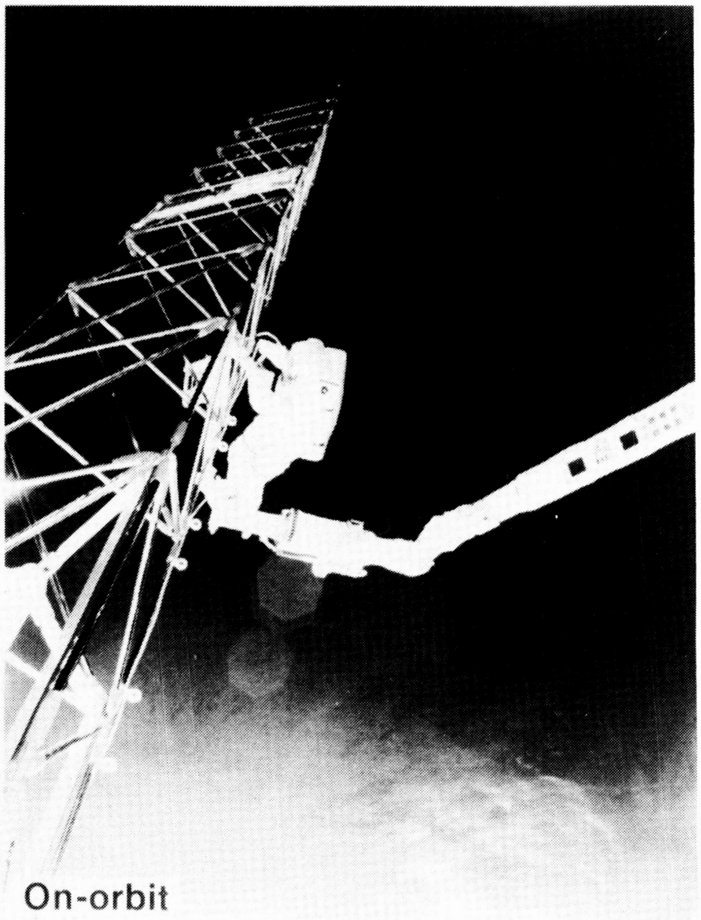


EXPANDED EXPERIMENT CABLE INSTALLATION

These photographs show the simulated cable installation in neutral buoyancy (left) and on-orbit (right). The Shuttle standard rope reel was used for this demonstration. A 5/8-inch diameter rope was unwound from the reel by the astronaut in the MFR and attached to the longeron struts with plastic clips placed on either side of each node. The clips were supplied from a stowage area on the MFR component carrier. Following installation, the rope was removed from the structure, rewound on the rope reel, and the clips were restowed on the MFR. Normal RMS-MFR operations are to move the astronaut into position and apply the RMS brakes before any work on the structure is begun. However, astronaut Cleave reported that during the cable run it became apparent that the cable could be strung without using the brakes.



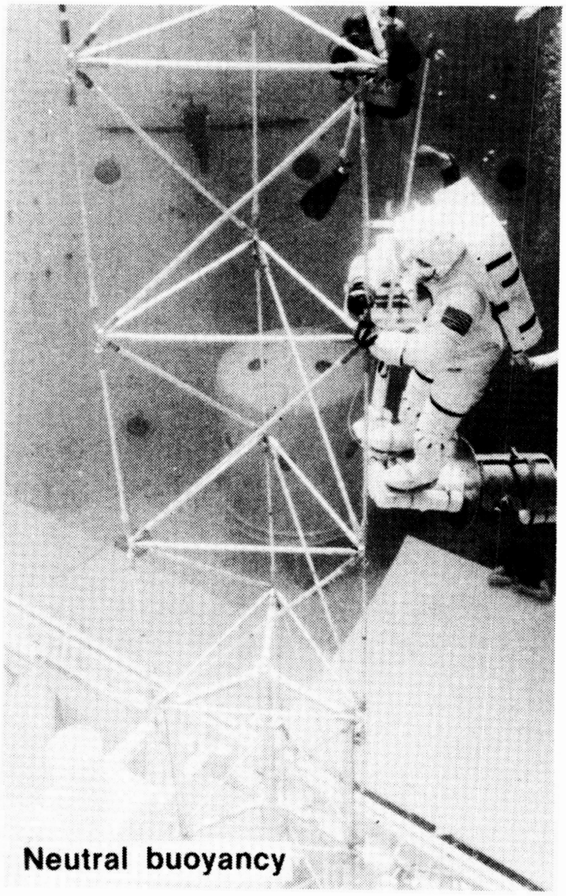
Neutral buoyancy



On-orbit

EXPANDED EXPERIMENT TRUSS REPAIR

These photographs show the truss repair activity in neutral buoyancy (left) and on-orbit (right). In neutral buoyancy, a longeron, diagonal, and node were removed. On-orbit a longeron and node were removed from the seventh bay. (To remove one node, six struts had to be disconnected in this statically determinant truss). The strut and node were then replaced. The truss remained stable in the weightless environment with the struts disconnected and appeared to be unaffected by firings of the Orbiter attitude control system vernier thrusters. (Although likely, it has not yet been determined from the flight records if the vernier thrusters actually fired during this activity. However, the astronauts reported they never noticed vernier firings during either EVA days.)



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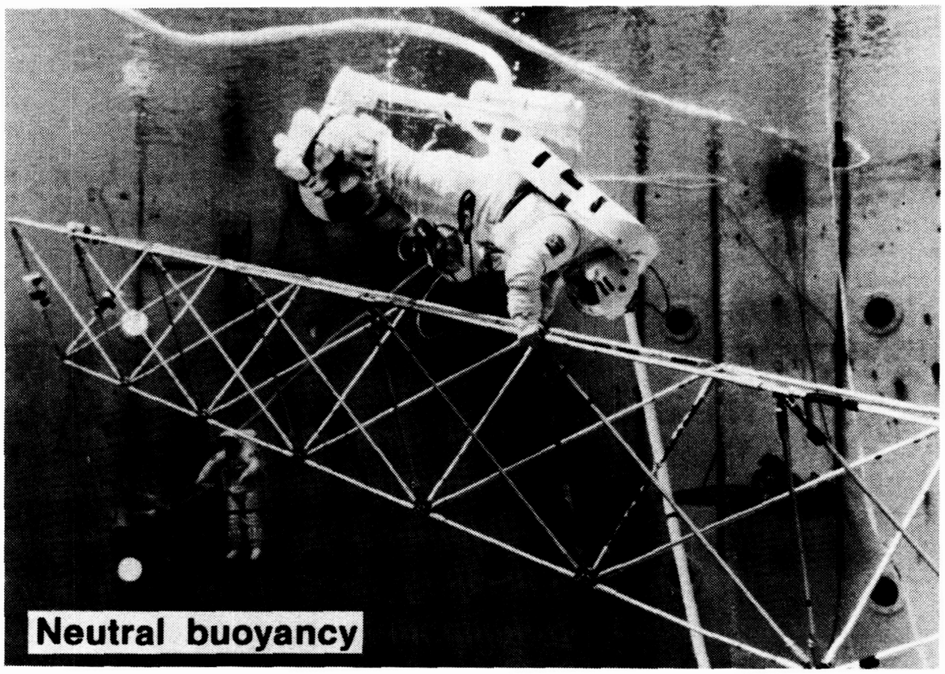
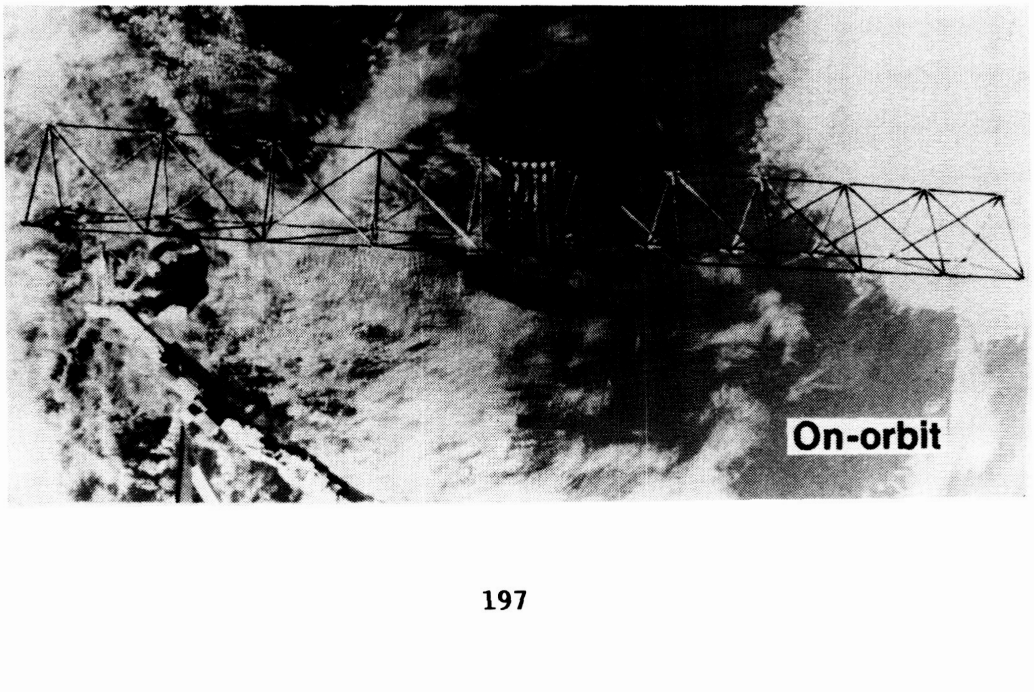
EXPANDED EXPERIMENT TRUSS MANIPULATION

The photographs show the truss being manipulated in neutral buoyancy (top) and on-orbit (bottom). This activity began with the bottom two bays attached to the assembly fixture guide rails. The truss was unlatched from the assembly fixture by the astronaut not in the MFR. It was then slid off the guide rails, rotated, and translated by the astronaut in the MFR. Following the manipulation, it was slid back onto the guide rails until two bays were supported. The truss was maneuvered both from the middle and from the end, and both astronauts reported ACCESS easier to maneuver on-orbit than in neutral buoyancy. Angular accelerations are difficult to determine from the video tapes, but it is estimated that the torque applied to one end of the truss by the astronaut to start or stop the truss rotation was between 25 and 50 foot-pounds. Translational accelerations given the truss along its longitudinal axis probably never required an applied force of more than 10 pounds.





CONCLUDING REMARKS

All basic EVA space construction tasks included in the experiment were accomplished on-orbit successfully, and the construction task times show good correlation with neutral buoyancy data. However, the flight assembly times were slightly longer than the best times obtained in the water tank. This result was attributed by the EVA astronauts to the new, tighter tolerance truss hardware used on-orbit as opposed to the well-worn training hardware used in neutral buoyancy and was, thus, not a space related phenomenon. The baseline experiment demonstrated that erectable structure can be assembled effectively by astronauts in EVA. The average assembly time for the 45-foot truss was 25.5 minutes. The assembly rate was about 3.6 struts per minute. The baseline experiment was judged by the astronauts to be very hand-intensive, especially for the man working in the low position because he had to do about 70% of the work with no periods of rest. Numbness of the fingers occurred which was attributed to pressure points in the gloves. (Gloves are currently being modified and tested in the WETF at JSC using ACCESS training hardware). The work effort level was reported to be essentially the same as that experienced in neutral buoyancy. Over 500 untethered pieces of hardware ranging in weight from one pound nodal joints to the entire 188.8 pound truss were handled without mishap. The astronauts reported that tethering probably would have doubled the assembly time and tripled the hand fatigue. Although the Orbiter was on automatic attitude control during the EVAs, neither astronaut could detect any vernier firings. The truss manipulation was found to be easier than in neutral buoyancy, and both astronauts said a much larger mass could be handled easily if the rates were kept low enough. The increased rates of motion approved for the RMS for this mission were nearly double the rates used on previous flights, and were reported to be comfortable for the astronaut in the manipulator foot restraint, even when the RMS was extended to the top of the 45-foot truss. The success of ACCESS confirmed the feasibility of EVA space assembly of erectable trusses and played a role in the decision to baseline Space Station as a 5-meter erectable structure.