N88-10872

EXPERIMENTAL ASSEMBLY OF STRUCTURES IN EVA: HARDWARE MORPHOLOGY AND DEVELOPMENT ISSUES

Robert S. Wolf
Mary L. Bowden

Space Systems Laboratory
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

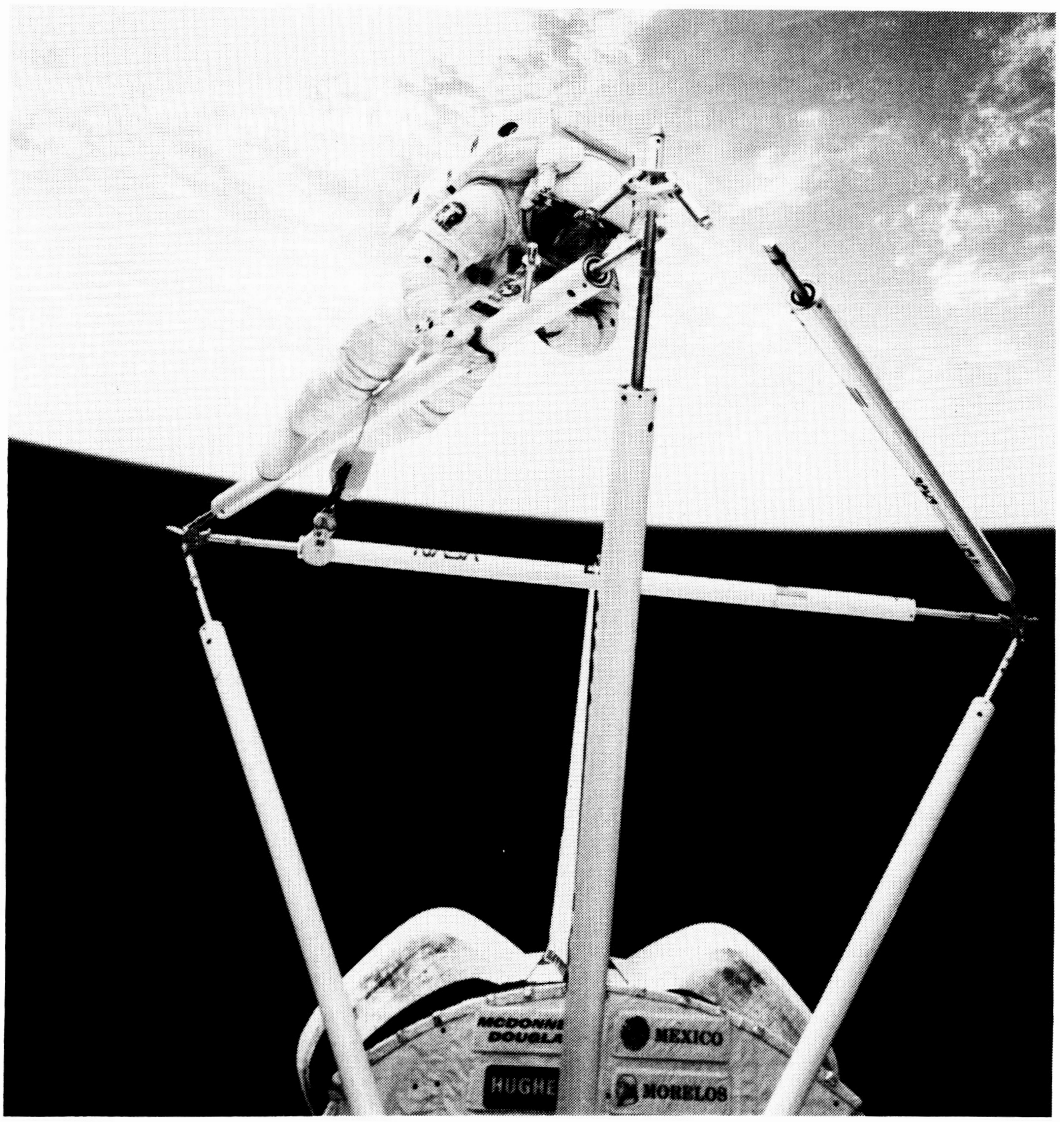
presented at the

Space Construction Conference
NASA Langley Research Center
6-7 August 1986

OVERVIEW

The MIT Space Systems Laboratory has been researching the human factors of space structural assembly since 1978. Previous systems studies of large space structures revealed that little was known about the productivity of humans in EVA structural assembly, despite its importance in overall systems optimization. A large body of data has been obtained by MIT during neutral buoyancy testing at the NASA Marshall Space Flight Center from 1980 to the present, and several conclusions were drawn. These efforts, and the most significant results therefrom, are summarized in this paper.

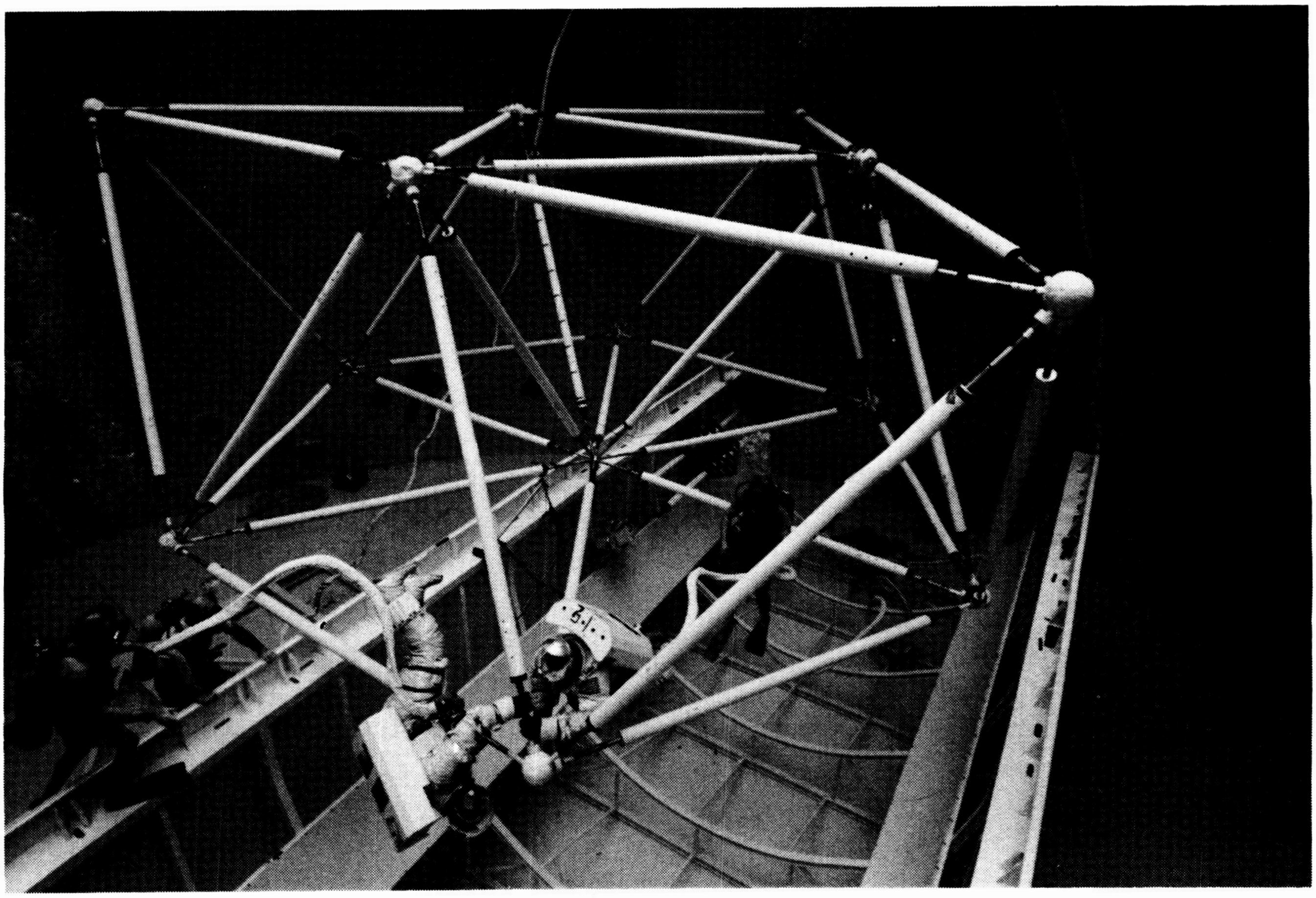
The EASE flight experiment was undertaken to validate these results on orbit, and to allow a quantitative comparison between orbital EVA and its neutral buoyancy simulation. Experiment hardware was designed and manufactured, and flown on STS 61-B in November 1985. This paper discusses the EASE experiment hardware, and illustrates how the experimental goals dictate its size, shape and operational characteristics.



COMPLEX 36-ELEMENT TETRAHEDRAL TRUSS

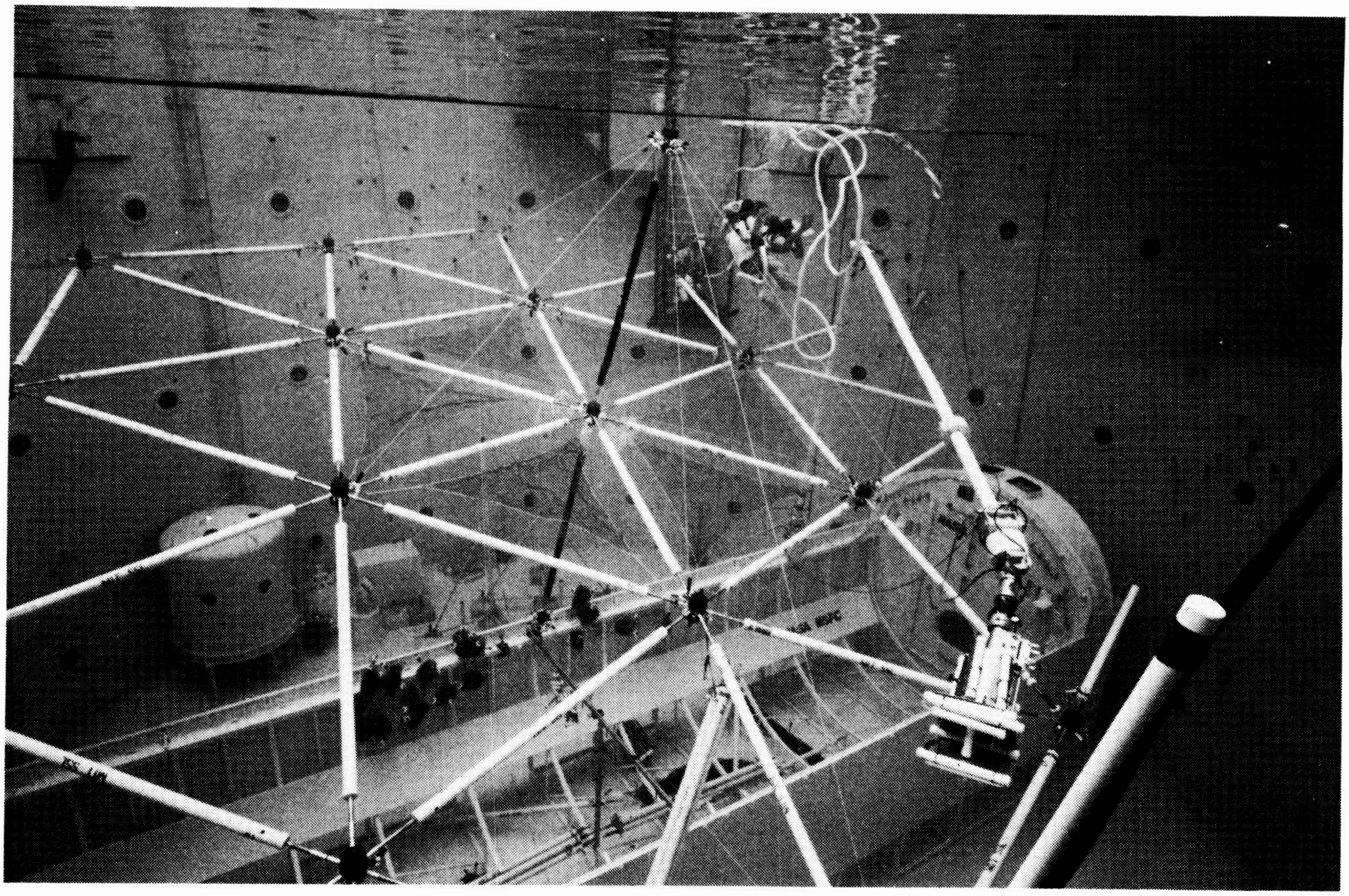
This structure consisted of 36 structural elements assembled to form a tetrahedral truss. This was used to obtain preliminary data on human productivity in weightlessness, on fatigue effects, and on teamwork for structural assembly. In addition, the worksite was set up so that the low man had foot restraints, while the high man performed his part of the assembly free-floating. The following results were obtained:

* People can be very productive in zero-g (approximately 600-700 kg/crewhour assembled).
* Fatigue could be a problem for extended EVA's.
* Teamwork should be kept flexible so that little time is spent waiting.
* While foot restraints are helpful, they are not essential for structural assembly.



ANTENNA STRUCTURE

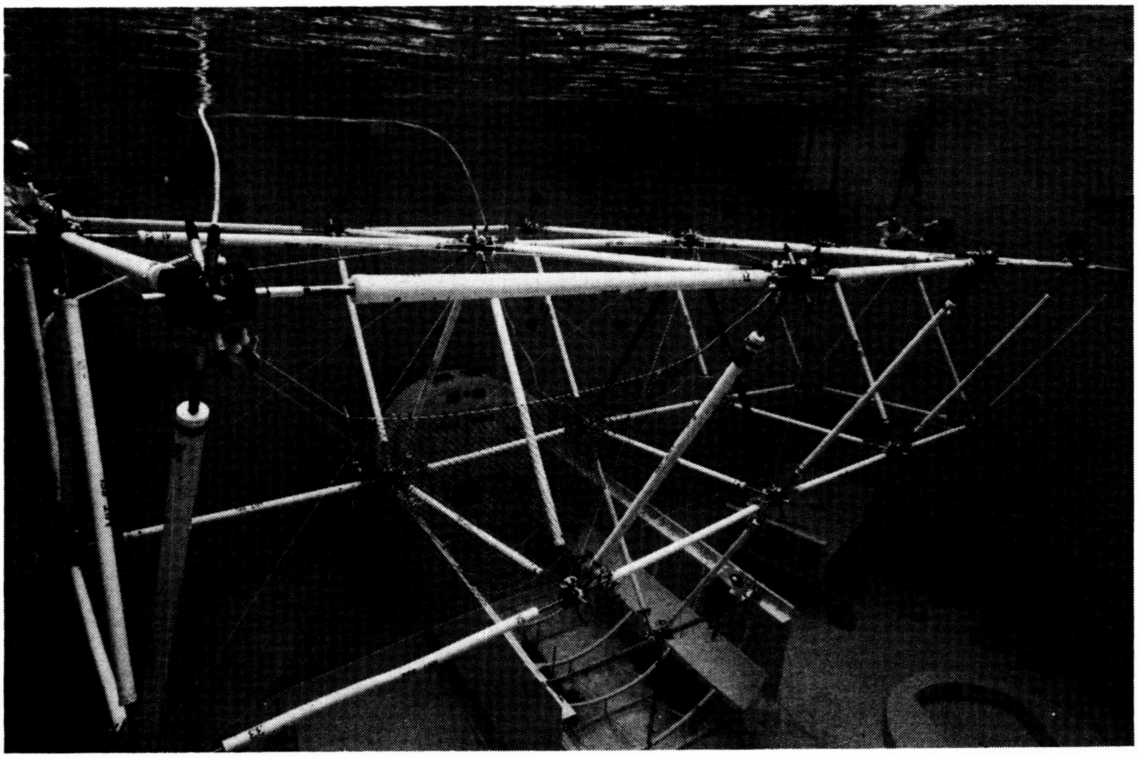
This structure consisted of 44 structural elements arranged in a planar configuration to simulate an antenna-type structure. The real challenge of this construction was the installation of stiffening cables at all of the nodes of the structure. It was found that pressure suited subjects are perfectly capable of installing such cables, but it is time consuming and the cable cartridge mechanisms must be carefully designed for ease of operation.



ORIGINAL PAGE IS
OF POOR QUALITY

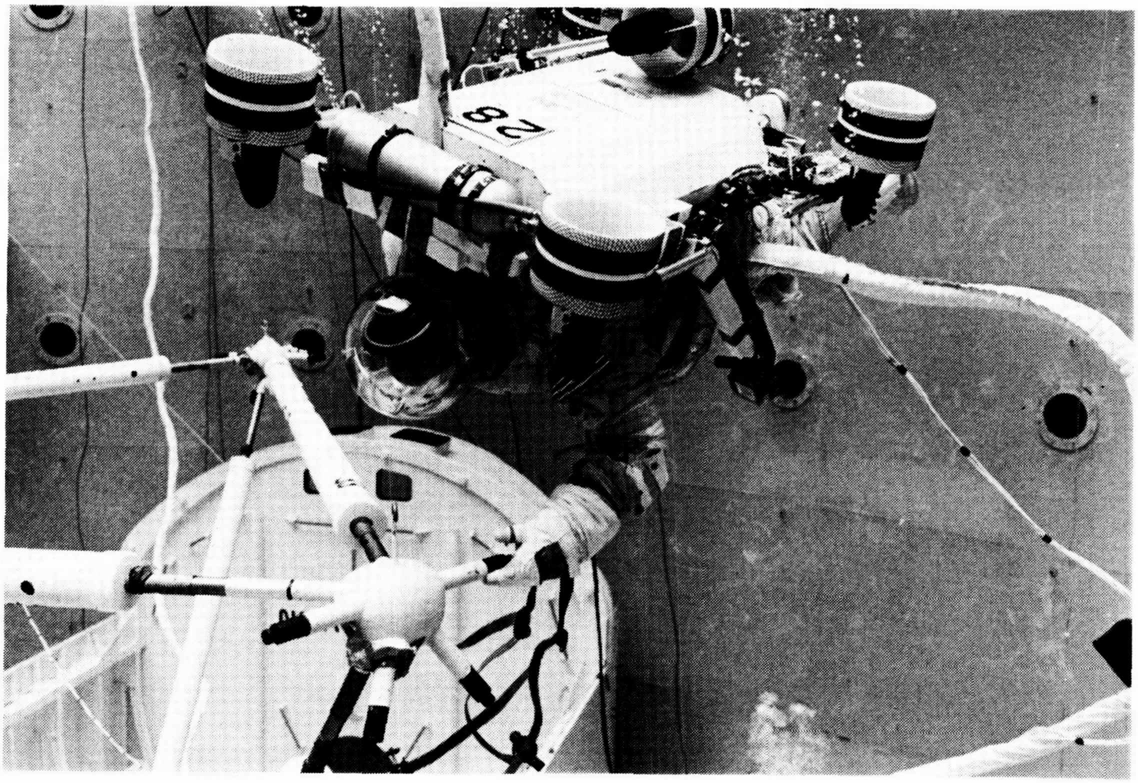
TRAPEZOIDAL TRUSS PLATFORM

This structure, consisting of 57 structural elements, was also used to test the ability of pressure-suited subjects to install cables as part of the assembly process. In addition, net sheets were installed on the structure to simulate reflective material that might be necessary on some space structures. Large equipment packages were also manipulated and mounted in this construction process in order to simulate activities that would be required to make a platform operational. All of these activities were found to be feasible, but the difficulty was very strongly dependent on the details of the particular simulation hardware.



PERSONAL UNDERWATER MANEUVERING APPARATUS

The Personal Underwater Maneuvering Apparatus (PUMA) was designed by the MIT Space Systems Lab to simulate the NASA Manned Maneuvering Unit (MMU) during neutral buoyancy tests. The PUMA was controlled by the subject using 2 hand controllers, one on each arm of the unit. One of the most important results was that for use during hardware manipulation (such as structural assembly), it was very helpful to have all controls located on the same side, so that the other hand could be free for carrying hardware. Overall, the PUMA was found to be very helpful for construction operations, primarily because it allowed maneuvers that otherwise would have been impossible if the subject were obliged to hold on to the structure at all times. However, it is not clear whether productivity is enhanced.



<u>SUMMARY OF EARLY NEUTRAL BUOYANCY RESULTS</u>

The list of results shown below is a summary of neutral buoyancy results obtained by the MIT Space Systems Lab prior to the start of the EASE program.

Summary of Space Systems Laboratory Neutral Buoyancy Results

- **Learning rates are higher in simulated weightlessness (60-70% vs 80% typical in similar 1-G tasks)**

- **Productivities average 600-700 kg assembled/crew hr in truss structure assembly**

- **Subjects manifest instinctive adaptations to the weightless environment given sufficient time (>15-20 hours) without foot restraints**

- **Questions unanswered by neutral buoyancy simulation:**

  - **How does crew performance in zero-G compare to that in neutral buoyancy?**
  - **Does underwater adaptation carry over to actual zero-G?**
  - **What physical workload is required to perform a strenuous task in EVA?**
  - **How do zero-G dynamics affect crew operations?**
  - **Are neutral buoyancy timelines accurate indicators of time for the same task in EVA?**
  - **Can a mathematical formulation of environmental dynamics be used to increase the fidelity of neutral buoyancy simulations?**
  - **What are the benefits and liabilities of restraint systems?**

EXPERIMENT METHODOLOGY

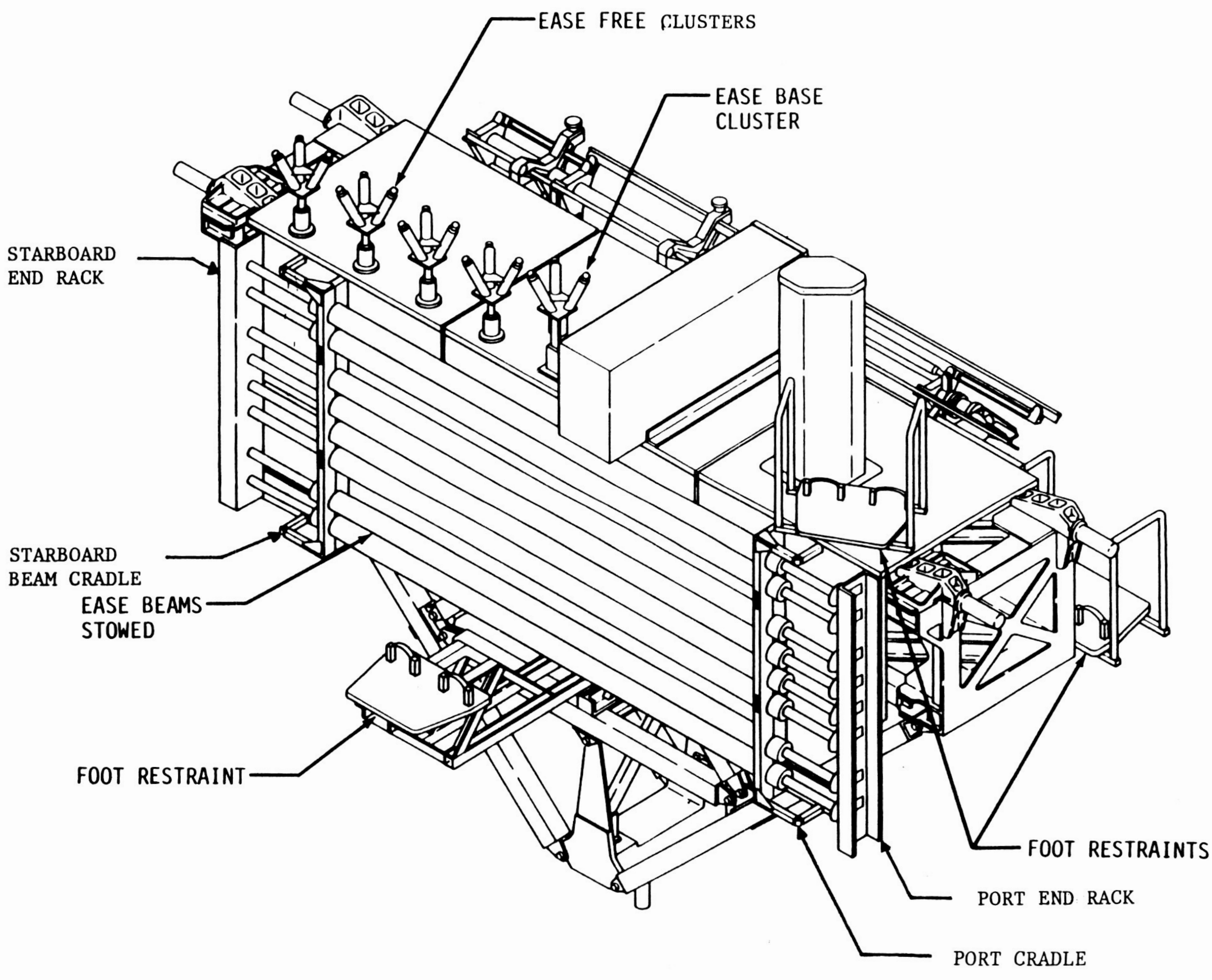
The design of the flight and training hardware was heavily influenced by the experiment methodology. The hardware was made as generic as possible so that the research results would be applicable to a wide class of space structures. Flight hardware was designed to have identical mass properties to the training hardware (since the flight hardware duplicated that used in previous neutral buoyancy research, flight hardware was designed to match their neutral buoyancy counterparts rather than vice versa). In order to minimize the required cargo bay volume, multiple repetitions of assembling a six-beam structure were accomplished rather than a single assembly of a larger structure. Data collection was limited to photographic sources, thus eliminating power and cooling requirements for the experiment hardware. Finally, a high degree of student involvement in hardware design and production was desired. This final requirement affected producibility of the hardware to the extent that moderate precision production methods were employed wherever high precision was not absolutely required. As an example, beams were assembled by match drilling parts in a jig, rather than manufacturing a full flight set of interchangeable beam components.

EXPERIMENTAL METHODOLOGY

- **Use generic structural hardware rather than mission-peculiar hardware**
- **Design flight hardware to have the same mass and moment of inertia as neutral buoyancy hardware**
- **Obtain data base by repetition of single cell assembly/disassembly, rather than flying multiple cell hardware**
- **Obtain body dynamics data by stereo imaging of worksite from aft flight deck windows**
- **Obtain task/timeline data by tracking EV subjects with shuttle CCTV system**

RESTRAINT HARDWARE

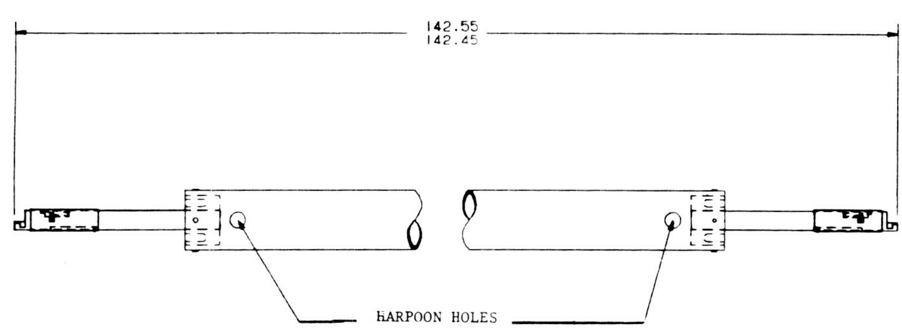
The EASE experiment hardware was mounted in the orbiter payload bay on the front surface of a Mission Peculiar Equipment Support Structure. This MPESS pallet, built by Teledyne Brown Engineering and supplied by NASA/MSFC, provided mounting points for experiment hardware to withstand launch and entry loads, and established the work stations for EVA operations. All experiment hardware had to be mounted to the MPESS pallet securely enough to withstand all design loading conditions, yet remain easily removable by the EVA crew for experimental activities. The beams were held in place for launch and landing by beam cradles and end racks. The cradles provided restraint in the orbiter X and Z directions, while the starboard end rack provided restraint in the Y direction. The port end rack was used to provide containment of loose beams, both as a redundant unit for launch and entry, and as the primary unit when the cradles were open during the experiment.



EASE/ACCESS FRONT VIEW CONFIGURATION

BEAMS

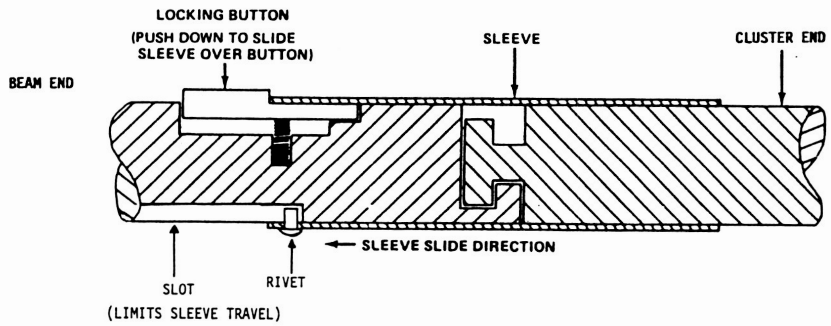
The beams used in the early MIT tests at MSFC consisted of ten-foot lengths of four-inch diameter PVC (polyvinyl chloride plastic) tubes filled with water. A smaller air-filled aluminum tube ran down the centerline of the beam to provide flotation. Joints were attached to the ends of the internal aluminum tube, resulting in overall beam lengths of 142.5 inches. The mass of each beam, including the trapped water inside the PVC tube, was approximately 63 pounds. Two new sets of beams were designed and built for the EASE experiment. One set was used for neutral buoyancy training, and the other set reserved for use in flight. Both sets of beams were 142.5 inches long (joint to joint), 4.25 inches in diameter, and weighed 63 pounds each. Each beam consisted of a hollow 6061-T6 aluminum tube 118 inches long with a wall thickness of .375 inches. The wall thickness was chosen to duplicate the mass distribution of the precursor PVC/water/aluminum beams. A structural adapter connected the large diameter tube to smaller diameter end rods. The end rods, with a sleeve and locking button, formed the female end of the MIT connector. A pair of holes was drilled in the tube at each end to accommodate the MIT temporary tethering device (the "harpoon"). The training beams were very similar to the flight beams, except that the underwater beams were sealed with a pressure bulkhead just inboard of the harpoon holes to provide flotation. The structural adapters of the flight beams were slightly thicker to account for the missing mass of the bulkhead and the small volume of trapped water. In all other respects the two sets of beams were identical.



BEAM

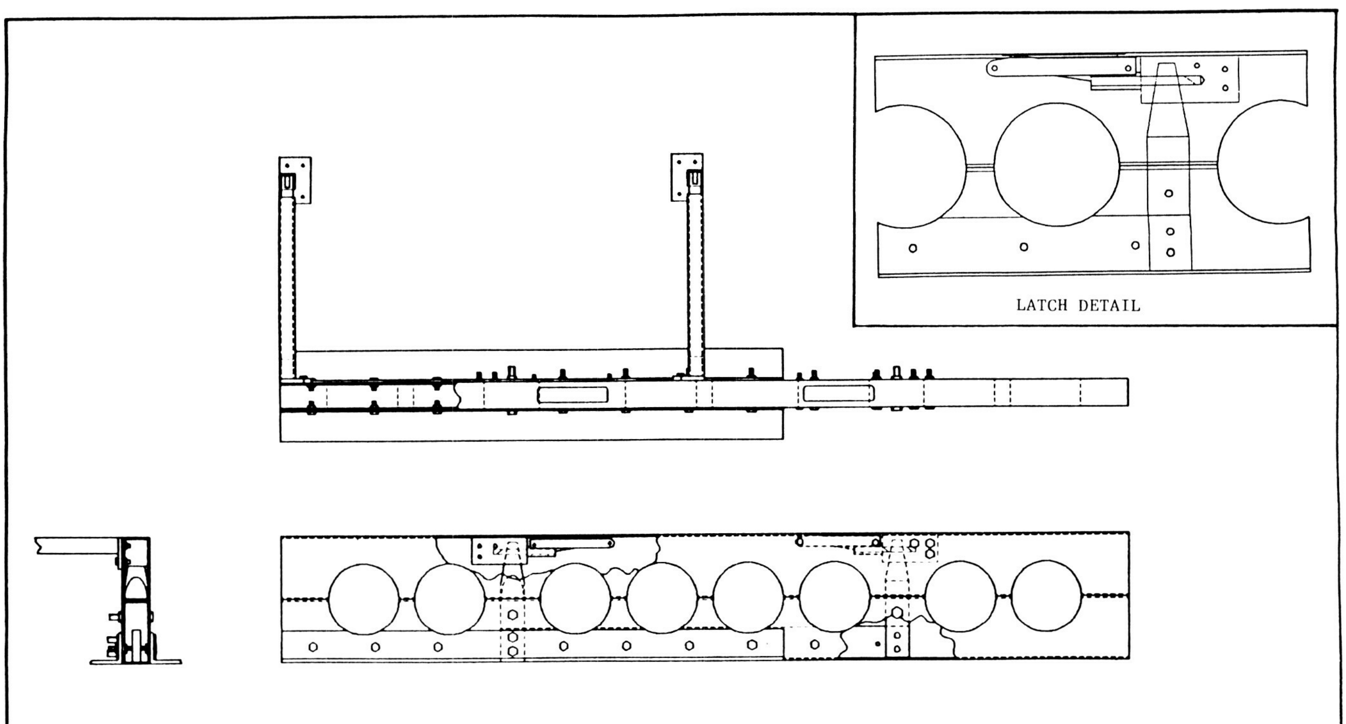
<u>MIT STRUCTURAL CONNECTOR</u>

The EASE joint configuration was chosen from among many designs during the early structural assembly tests performed at MIT. It is operated by placing the "mushroom" end in the matching receptacle and sliding the sleeve until the locking button pops up. Disassembly is effected by depressing the locking button, then sliding the sleeve over the button to expose the mushroom. It has several unique features which make it ideal for human factors research in space construction, though not necessarily suitable for future space structures. Foremost among these is the precise angular alignment required to slide the sleeve. Second is the unmistakable indication of a positive lock. Third is the side-entry configuration, which eliminates the requirement to deform the structure to insert the last beam. Fourth is the ease of disassembly. Last (but very important nonetheless) is its ease of construction from standard sized metal stock by students.



BEAM RESTRAINT CRADLES

The beam cradles were constructed from rectangular aluminum extrusion. Each cradle assembly consisted of two such pieces, attached edge to edge. One piece, called the fixed cradle, was bolted to flanges which were in turn bolted to the front face of the MPESS pallet. The other piece, called the restraint cradle, was mounted to a swing-arm assembly; this allowed the restraint cradle to be rotated outboard, out of the way for unobstructed access to the beams during assembly operations on-orbit. Each fixed cradle had two pylons, which mated to receptacles on the restraint cradles. The restraint cradles were equipped with flush-mounted shear pin latches to hold the cradles together during launch and entry.

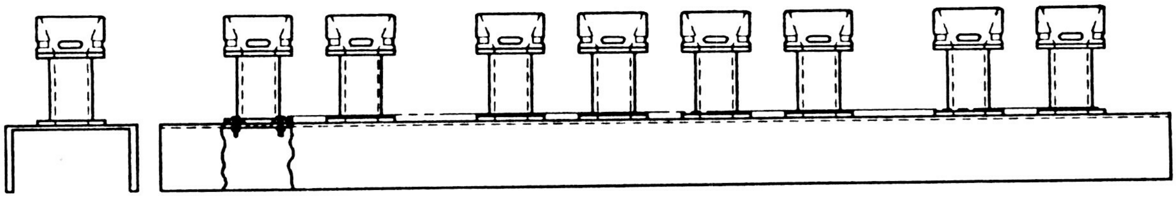


BEAM CRADLE (PORT SHOWN, STARBOARD OPPOSITE)

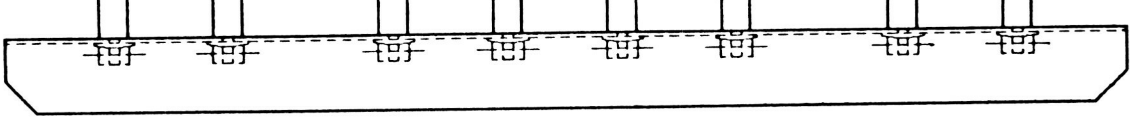
END RACKS

The end racks were constructed from aluminum channel stock. The starboard end rack was equipped with beam attach fittings, to which the beams were connected during launch and entry. The beam attach fitting was designed around the male end of the MIT connector, allowing the matching end of the beam to be used to secure the beam against Y-axis launch loads. The beam attach fittings were designed to float in the X and Z directions, while providing rigid restraint in the Y direction. This free play was an essential feature which served two purposes: decoupling end rack vibration from beam/cradle vibration, and providing tolerance for misalignment between the end racks and cradles. The port endrack was equipped with "beam cups," which were funnel-shaped fittings into which a beam end could be inserted with up to 20° of misalignment. The purpose of the cups was to restrain the port end of the beams when the cradles were open.

The beam restraint system also included a row of delrin clips near the starboard end rack. These clips were similar in size, shape, and function to broom clips found in household closets. The clips were used to restrain the starboard end of the beams when the cradles were open. The beam clips were easier to use for temporary beam restraint during EASE operations than the beam attach fittings, which were intended to be cycled only once during the course of the EASE experiment. The combination of the beam cups and the delrin clips allowed easy access and stowage of the beams from any position along the forward face of the MPESS pallet. The clips provided a retention force of approximately 20 pounds in room temperature ground-based tests. This retention force was sufficient to preclude equipment loss while not impeding access to the hardware.



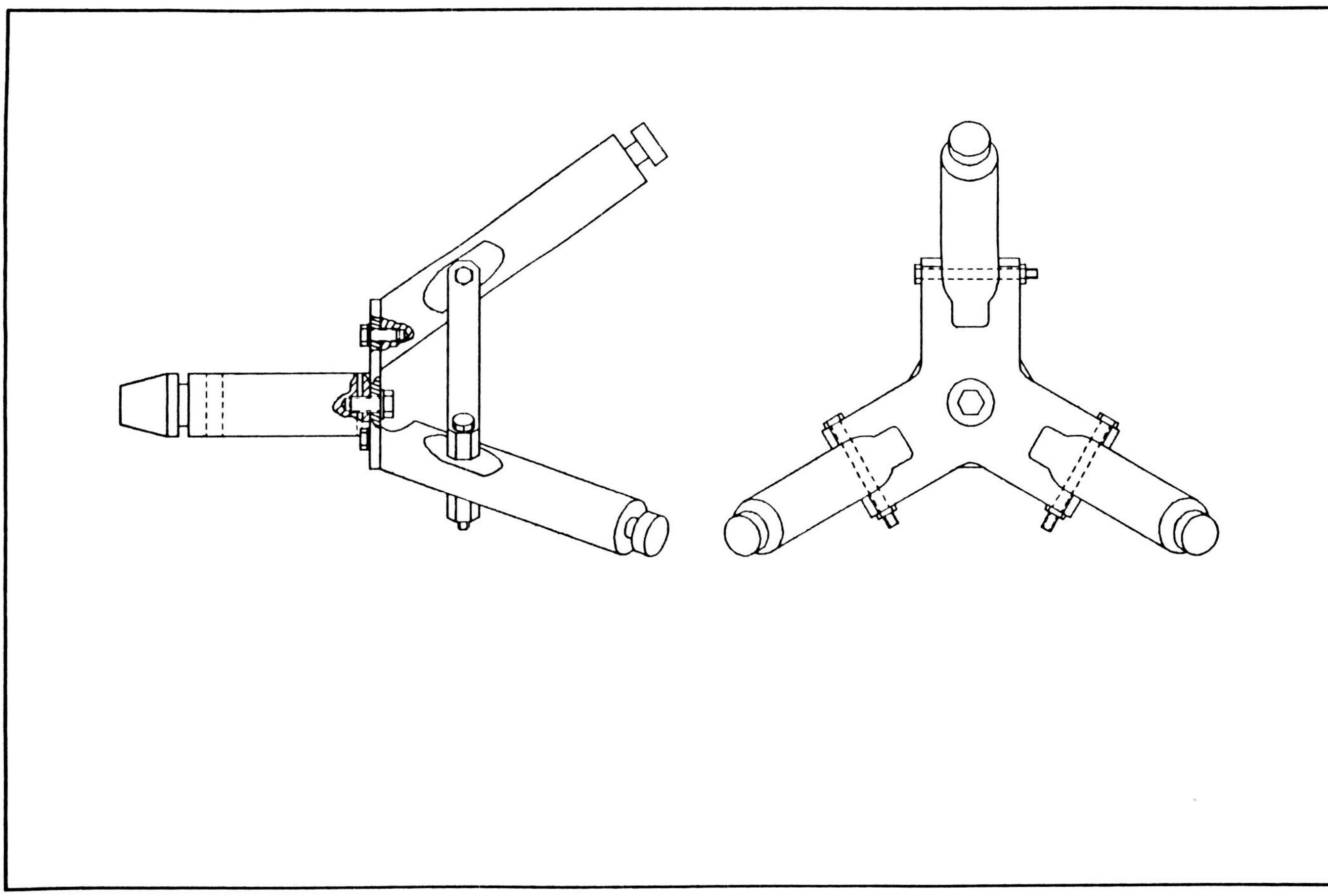
STARBOARD END RACK



PORT END RACK

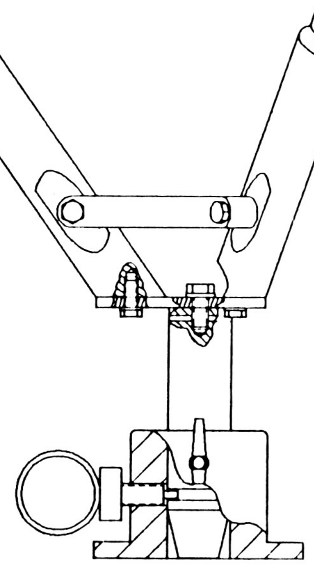
JOINT CLUSTERS

Each joint cluster contained three joint ends, held rigidly at the proper angles for attachment into the tetrahedron. The flight and neutral buoyancy clusters differed only by the use of flotation foam to make the underwater clusters neutrally buoyant. The EASE structure was built in the shape of an inverted tetrahedron, mounted to the flight support structure only at the single lower vertex. This "base" cluster was made to be kept fixed; the three "free" clusters were designed to be removed from their restraints to be mounted into the upper vertices of the structure.



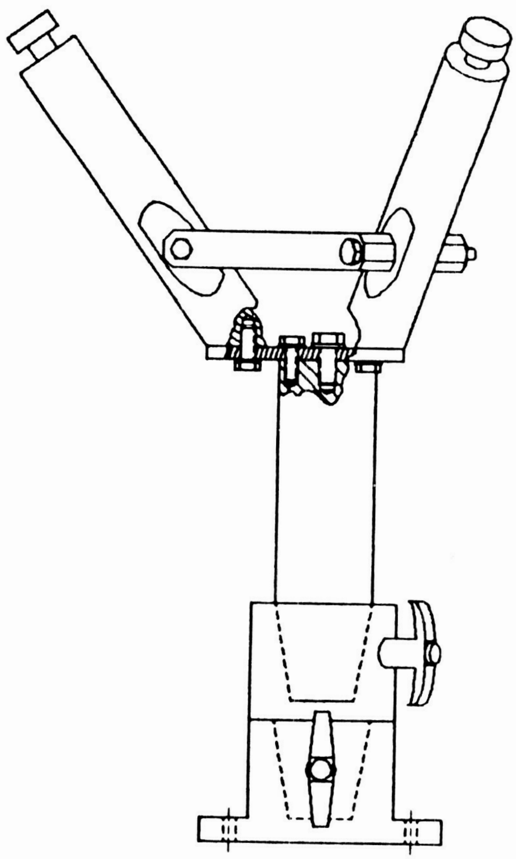
FREE CLUSTER STOWAGE

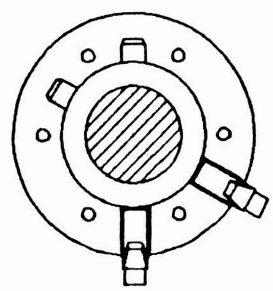
The launch restraint system for the free clusters consisted of a flanged receptacle with a pip pin, and a spring-loaded plunger. The pip pin, a locking pin controlled by a push-button on the end of the T-handled shaft, provided positive restraint for launch and reentry, and was removed during the experiment operation. The spring-loaded plunger, actuated with a 1.5 inch pull ring, was used to hold the cluster while the experiment was in progress. The cluster could be inserted into the receptacle with one hand; the plunger retracted as the tapered cluster handle was pushed past, then extended into an annular slot around the circumference of the handle as the cluster seated in the receptacle. Removing the cluster required two hands; one to pull the plunger back, and the other to pull out the cluster. This design was chosen to permit easy one-handed stowage, while precluding inadvertent release by kicking the cluster or snagging it with a tether.



BASE CLUSTER WITH JETTISON CAPABILITY

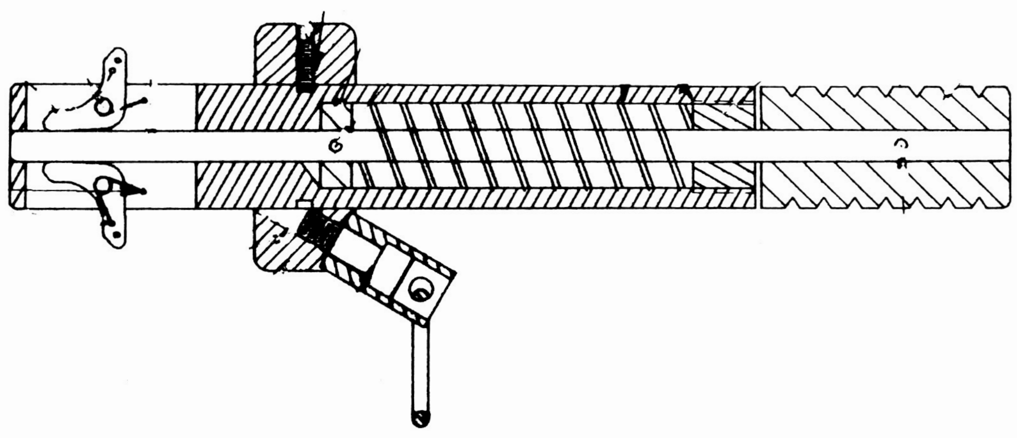
The base cluster was similar to the free clusters, except for its attachment to the MPESS pallet. Certain failure scenarios required the rapid jettison of a fully or partially assembled tetrahedron. Therefore, a design was chosen which incorporated a single-pin manual jettison capability. This jettison capability was duplicated to provide redundancy. Since the assembly loads were transmitted to the orbiter through the base cluster handle, a larger handle was used than those on the free clusters. For assembly loads, the junction between the base cluster and its handle was strengthened with a collar.





HARPOONS

An easy-actuating tethering device called a "harpoon" was used to facilitate tethering beams and clusters. The harpoon was originally developed in 1980 by MIT students for tethering hardware in neutral buoyancy, since the standard EVA tether hooks were too cumbersome for extended and repeated use. Two spring-loaded pins on one end of the cylindrical barrel were designed to pivot backwards, allowing the insertion of the pins through a 1.125 inch hole. Once inside, the pins return to their extended position, securing the piece of hardware. By grasping and pulling the handle of the harpoon, the pins are released to rotate forward, releasing the harpoon from the hole. The barrel of the harpoon incorporated a 1.5 inch ring for use with the EVA tethers. Originally made from plastic, the harpoons were redesigned for flight use by the substitution of aluminum for plastic, and the strengthening of the tether attach point. Four of the harpoons flown were intended to be used by the EVA crew, attached to standard wrist tethers. The fifth was permanently attached to a 35 ft wire cable with spring return, identical to those used on the port and starboard slide wires for crew restraint. This assembly, tethered to an fixture next to the base cluster, was used to keep the large beams under positive restraint while not attached to the structure or inserted in the beam cradles.



SPECIAL CONNECTOR

In support of Space Station Office objectives, there was a requirement to connect two EASE beams together in a straight line. It was felt that this configuration, 4.25 inches in diameter by 25 feet long and 125 pounds mass, was representative of heat pipes planned for incorporation into the space station thermal management system. To allow the EVA crew to manipulate such an assembly, a linear beam interconnect, known as the "EASE special connector", was designed and delivered. This simple device, machined from a single piece of aluminum, provided two male connector ends with a recessed hole for tethering purposes. The special connector and the five flight harpoons were launched in the provisional stowage assembly, and thus required no special launch restraint mechanisms.