NASA Technical Memorandum 100661

Results of EVA/Mobile Transporter Space Station Truss Assembly Tests

J. J. Watson, W. L. Heard, Jr., H. G. Bush, M. S. Lake,
J. K. Jensen, R. E. Wallsom, and J. E. Phelps

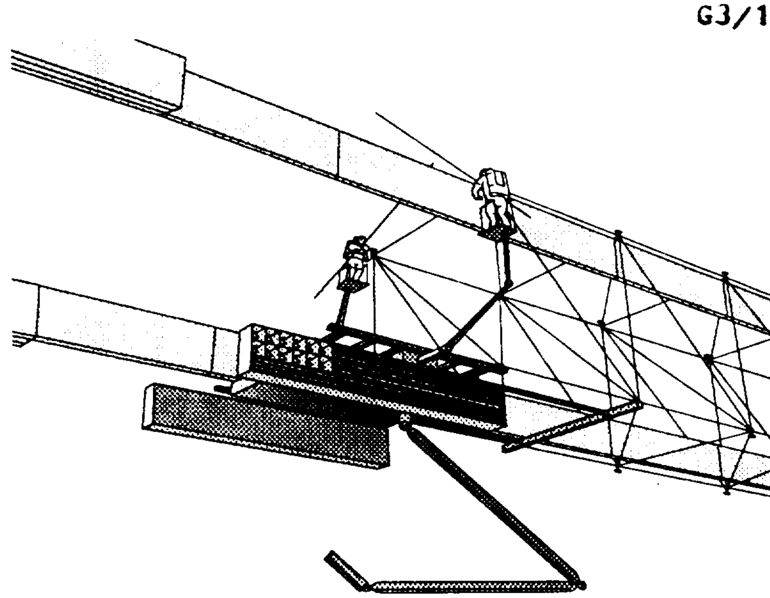
November 1988

(NASA-TM-100661) RESULTS OF EVA/MOBILE TRANSPORTER SPACE STATION TRUSS ASSEMBLY TESTS (NASA) 31 p CSCL 22B

N89-13483

Unclas

G3/18 0183250



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

RESULTS OF EVA/MOBILE TRANSPORTER SPACE STATION TRUSS ASSEMBLY TESTS

by

J. J. Watson, W. L. Heard Jr., H. G. Bush, M. S. Lake
J. K. Jensen, R. E. Wallsom, J. E. Phelps

INTRODUCTION

The Space Station Freedom (SSF) baseline configuration is shown in Figure 1. The primary structure is an erectable truss beam, 110 meters long, with a five-meter-square cross section. The current baseline proposal for on-orbit construction makes use of a Mobile Transporter (MT) attached to the top of an Assembly Work Platform (AWP) and two astronauts in extravehicular activity (EVA) as discussed in reference 1. The construction method uses the EVA astronauts to assemble the station from Astronaut Positioning Devices (APD's) on the AWP. The AWP, which is a partially deployable, partially erectable truss structure approaching 10 meters in length, remains attached directly to the Orbiter sills for all construction activities associated with the first two SSF buildup flights. The construction tasks include integrated installation of SSF system components as well as assembly of the primary truss structure. Currently, half of the truss beam with associated essential subsystems is to be completed during Flight 1 and the other half during Flight 2. However, this scenario is undergoing close scrutiny due to the complexity of the tasks involved and manifesting considerations.

The NASA Langley Research Center (LaRC) has an ongoing in-house research program to study a mobile transporter concept that could be used not only, as generally accepted, for maintenance, repair, and growth activities after SSF is operational, but also for construction during the first two SSF build up flights. This alternate construction scenario eliminates the AWP and the structural complexity and risk of moving the SSF truss system after each bay is completed. Instead, the SSF truss would be attached to the Orbiter sills through a transition truss, and the MT equipped with APD's (as originally conceived in references 2 and 3), would "walk" along the completed truss segment carrying the astronauts and building material as additional structure is being assembled. Although use of the MT in this manner requires the EVA crew and MT to move away from the cargo bay during the first two Station buildup flights, this is a requirement that is accepted for later flights.

This paper presents the results of a ground test program designed to study EVA assembly of near full scale SSF truss structure with integration of utility trays using the NASA LaRC alternate construction scenario. Test hardware, assembly procedures, and assembly times are presented for 1-g and neutral buoyancy tests.

MOBILE TRANSPORTER ASSEMBLY SCENARIO FOR SPACE STATION

A schematic of the Mobile Transporter (MT) as envisioned for the assembly of Space Station is shown in Figure 2. The MT would be folded in the Shuttle cargo bay and remotely deployed to an upright position when orbit is achieved. The Space Station truss consists of a series of segments called bays. Each bay is a five meter cube, and all bays are identical. Guide pins, attached to the truss nodal joints, form the interface between the MT guide rails and the truss structure. The truss is assembled one bay at a time above the MT platform by two EVA astronauts. The astronauts are secured in foot restraints attached to APD's. The APD's are not complex robotic arms, but relatively simple devices used to move the astronauts to various positions on their respective sides of the MT so that the required construction tasks can be accomplished. After the crew has assembled a bay, the MT drawbar extends (as shown in Fig. 2) pushing the MT one bay-length away from the completed structure along the truss longitudinal axis. The next contiguous bay is then assembled, after which the drawbar is retracted to grasp new nodal joint guide pins and extended to move the transporter into position for assembly of the next bay. In this way the MT steps along the truss as the truss is being assembled. The platform is used to transport Space Station operational equipment which requires integrated installation during the primary truss assembly. A Shuttle type remote manipulator arm attached to the MT is envisioned to support these tasks.

SCENARIO FOR INTEGRATED INSTALLATION OF UTILITY TRAYS

A major concern associated with SSF construction is installation of the utility system that is vital to the SSF operation. It is generally accepted that the electrical and fluid utility lines will be housed in protective trays that are attached to the inside of the primary truss structure. Although electrical and fluid line connections are beyond the scope of this investigation, a scenario for integrated installation of the utility trays during truss assembly was addressed. This scenario permits folded bay-length packages of tray segments to automatically deploy to their proper positions prior to assembly of the supporting bay of the truss. The deployed tray segments can then be attached directly to the truss nodes during truss assembly. This procedure, by minimizing astronaut handling, is designed to have a minimal impact on truss assembly.

A series of sketches representing the general procedure is shown in Figure 3. Sketch 1 represents a cross section of the Shuttle cargo bay with the MT deployed and ready for assembly to begin. Temporary utility tray supports are shown deployed on either side of the cargo bay. The utility trays are fan-folded into 5 m long packages. Critically damped springs are used at the hinge lines. The Shuttle Remote Manipulator System is used to unstow the packages and attach them to the supports before truss assembly is begun (sketch 2). The EVA astronauts release latches that allow the packages to unfold two bay lengths (sketches 3 and 4). The EVA crew then assembles the first bay of truss and attaches the utility trays (sketch 5). The MT then translates one bay-length, after which the EVA crew unlatches the utility tray package (allowing it to unfold another bay length) and assembles the next truss bay. The procedure is repeated until the desired truss configuration is achieved.

TEST HARDWARE

Mock-up and Operation of Mobile Transporter

Figure 4 is a schematic of the MT mock-up used in the Space Station truss EVA construction simulations conducted in 1-g at LaRC and in neutral buoyancy at the Marshall Space Flight Center's Neutral Buoyancy Simulator (NBS). The MT mock-up was supported on a tower and remained stationary during the tests. The truss structure was assembled one bay at a time under the transporter. When a bay was completed, it was moved out of the work area by the drawbar thus producing the relative motion between the truss and MT to simulate the MT "walking" along the completed truss structure. A remote manipulator arm was not required nor used for these tests. As indicated in the inset, the preferred position for the EVA astronauts is with their heads pointing away from the MT. This orientation provides the best visibility and least obstructed work area. However, for comfort and safety reasons, the test subjects were positioned with their heads pointing toward the MT during the 1-g and neutral buoyancy tests. To accomplish this, the lower segment of each astronaut positioning device (APD) was slaved to the motion of the rotating upper segment to remain vertical at all times. For the flight article the lower segment is envisioned to be independently rotated about and elbow joint. The APD's could also be moved one bay-length forward or aft as indicated by the arrows in the sketch. The two rectangular canisters shown attached to the top of the MT are for stowage of truss struts and nodes.

Strut and Node Stowage

All struts and nodes were stowed in two stowage canisters. The stowage arrangement is shown in Figure 5. Although the size of the NBS test facility limited the size of truss that could be assembled to only three bays, the canisters were sized to hold enough struts and nodes for assembly of 10 bays of truss (approximately half the size of the Space Station Revised Baseline Configuration) plus several spare components. The struts were supported at each end in the canisters by cups with internal spring-loaded pistons. Struts could be removed by the test subjects from any location along the canister by pushing the strut axially to depress the piston in one of the cups, thereby freeing the opposite end of the strut to enable removal (Fig. 5(a)).

The nodes were stowed in compartments. The compartments were sized to hold two nodes at a time, although only one node was stowed in a given compartment for the present tests. There were 12 node compartments (24 node capacity) located at one end of each canister. Each node was held in the compartment by two flanged guide rails which fit over the flange on the node guide pin (Fig. 5(b)).

Strut and Node Carriers

To minimize the required number of trips to the stowage canisters by the test subjects during truss assembly, provisions were made for temporary stowage of two struts and two nodes at each of the APD foot restraints. Figure 6(a) is a photograph of the foot restraint and truss component carriers. The handrails, used by the test subjects to ingress and egress the foot restraints (normally only at the beginning and end of each test), provided the structural support for the bracketry with which the struts and nodes were temporarily stowed. The test subjects manually locked the struts in the carrier brackets by 90 degree rotations of two latch handles (Fig. 6(b)). The nodes where stowed by placing the node guide pins over tapered cylindrical rods (Fig. 6(c)) which were mounted, one each, on either side of the foot restraints. A spring retainer clip was used to secure the node on the rod.

Control of Mobile Transporter Operations

The APD's, drawbar, and node latches on the drawbar (Fig. 7) were hydraulically powered. The controls were located at two remote consoles positioned on either side of the MT (at portholes outside the water tank for the neutral buoyancy tests). Each console was operated by one test engineer who could view the activity as shown in Figure 7 for the 1-g tests, or through a porthole for the neutral buoyancy tests. A photograph of a console and console operator during a 1-g test is shown in the inset.

Figure 8 shows a node latch on one end of the drawbar in both the unlocked and locked positions. The proper limits of motion for the drawbar and node latches were set prior to testing and required no vernier adjustments. The coarse movements of the test subjects to the strut/node canister and then to the vicinity of a work site was easily performed by the console operators following simple voice commands from the test subjects of "ready" when ready to move, or "stop" when appropriate. The rate of motion for the test subjects and drawbar was approximately one foot per second. If desired, vernier adjustments could be requested by the test subjects through additional voice commands until the test subject was satisfied with his working position. For the flight version of the MT, the APD's could be programed to move to appropriate work sites, and vernier adjustments made by the EVA astronauts from controls located at the foot restraints.

Truss Configuration and Hardware

An orthogonal tetrahedral truss (OTT) configuration (Fig. 9) was used for the tests discussed in the present paper primarily because of the operational benefits it exhibits over the currently baselined Warren type truss (ref. 4). The OTT geometry also simplifies the logistics of component stowage, the assembly procedures that must be followed by the test subjects, and the installation of utility trays. The truss tested in the present study had a 15-foot square cross section. In order to meet MT design and fabrication scheduling requirements, the cross-sectional dimensions had to be selected early, before NASA selected the 5-meter (16.4 ft) truss for the SSF baseline configuration.

The truss hardware was composed of struts (termed longerons, battens, and diagonals as indicated in Fig. 9) and nodes. The struts were two-inch-diameter aluminum tubes with a fitting at each end to permit side insertion into the mating node fitting during truss assembly. These fittings also were used to set all the strut lengths to within tolerance values prior to the tests. For the 1-g tests, the struts were fabricated from thin wall 7075 aluminum tubing to minimize their weight (approximately 8.8 lb. for each longeron and batten strut, and 11.9 lb. for a diagonal strut). The struts for the neutral buoyancy tests consisted of welded sections of 6061 aluminum tubing with a 1/8 inch wall thickness. The welded sections consisted of internal airtight chambers for positive buoyancy and flooded chambers to which lead shot could be added or removed for neutral buoyancy adjustment. Care was taken to set all strut lengths accurately, however, many of the struts fabricated for neutral buoyancy use did not meet the straightness requirements due to incorrect welding techniques and inadequate fixturing. In order to meet NBS scheduling, the as-fabricated struts were used in the tests, although the contractor fabricated some replacements that were used in later tests.

A typical truss nodal joint is shown in Figure 10. The nodes (top photograph) were modified spheres to which up to 26 fittings could be attached for accommodating strut (and payload) connections. (With this arrangement various truss configurations are possible and the potential for truss growth is provided). The joint used was designed at NASA LaRC to facilitate EVA assembly while retaining structural efficiency. An early version of the joint is presented in reference 5. A pattern was painted on the strut and node fittings to provide a highly visible lock position indicator. The photograph labeled INSERT shows the pattern when the strut locking collar is positioned for insertion into the mating node fitting. The photograph labeled CAPTURED shows the pattern when the strut is captured in the node fitting. With the locking collar in this position the strut-to-node joint is secure but will not provide the design structural stiffness. By manually rotating the locking collar 45 degrees, the locking pattern becomes a wide bar (photograph labeled LOCKED), and the joint is locked into its design preloaded condition. The nodes could not be made neutrally buoyant without adding external flotation. Thus, following assembly of a given bay, and before the truss was moved by the drawbar, flotation was attached by scuba divers to each of the lower nodes on each side of the truss to neutrally buoy it and the node directly above it. In this way the truss neutral buoyancy was maintained.

Utility Trays

The integrated utility tray installations were done only in neutral buoyancy tests. As shown in Figure 11, two neutrally buoyed tray systems were provided, one for each side of the three-bay truss. An individual tray was nominally a 3 X 15 X 0.5-foot aluminum box with a dry weight of approximately 150 lb. Three trays were linked together with simple hinges to form the utility tray system for one side of the truss. Four tubular members were attached to an edge of the unfolded tray system at intervals corresponding to truss node locations. These tubular members, which had end fittings identical to the strut end fittings, were used to attach the trays to the truss nodes during assembly.

Figure 12 is a schematic showing the method used to install the trays during assembly of the truss. The view is looking downward on the mobile transporter (represented by the dashed lines). Since the MT support tower (also represented by dashed lines) would interfere with the initial, inward, unfolding of the utility tray packages, the packages were predeployed one bay-length. The two partially unfolded tray packages were then supported in place on the support tower. (This method simulated the temporary support system shown in Figure 13, envisioned for the Shuttle cargo bay, that holds the packages in place during assembly of the transition truss and first bay of SSF truss). The neutral buoyancy tests began with assembly of the initial truss bay and attachment of the first tray to two of the nodes. The pins used to secure the second and third trays in the folded configuration were then pulled and the trays unfolded with the aid of scuba divers (simulating springs) as the drawbar was extended to move the completed bay out of the work area.

TEST PROGRAM

Assembly tests were conducted both in 1-g and in neutral buoyancy. The 1-g tests were performed with the test subjects in street clothes. The neutral buoyancy tests were performed with the test subjects in scuba, and also with the test subjects in pressure suits (Extravehicular Mobility Units (EMU's)). These tests were conducted in an attempt to isolate the effects of water drag and pressure suit encumbrance on assembly times. Due to the effects of gravity the assembly procedures developed for the 1-g tests were necessarily somewhat different from those used for the 0-g tests. However, the 1-g assembly procedure, though not as efficient as the neutral buoyancy procedure, was duplicated in some of the scuba neutral buoyancy tests for comparison of assembly times. The size of the NBS test facility (75 feet in diameter and 40 feet deep) limited the size of truss that could be continuously assembled to only three bays. Complete or partial disassembly was accomplished by scuba divers between assemblies during a given test.

The assembly procedures used for the pressure suited neutral buoyancy tests were also duplicated in scuba tests. The difference in assembly times were assumed to be attributable to pressure suit encumbrance. The following three scenarios were used for the pressure suited assembly tests: (1) consecutive three-bay truss assemblies without integrated installation of utility trays (with associated scuba disassemblies of approximately 17 minute average durations), (2) consecutive three-bay truss assemblies with integrated installation of utility trays (with associated scuba disassemblies of approximately 26 minute average durations), and (3) an initial three-bay truss assembly with integrated utility trays followed by consecutive two-bay assemblies (with associated scuba disassemblies of two bays of approximately 10 minute average durations). During the scuba disassemblies, the test subjects were idle. The duration of a test was limited to approximately two hours by NBS safety rules which permitted only one decompression stop for the test subjects when being brought to the surface. The test scenarios were developed in order to build as much truss structure as possible in the limited time available for a given test. Tethering of the hardware was not addressed in these tests.

1-g Tests

Figure 14 shows a 1-g test in progress. Figure 14(a) shows the first bay being assembled. The truss support frame, shown at the lower right, was used in the 1-g tests to carry the weight of the truss after assembly. Figure 14(b) shows the entire three-bay truss. To facilitate handling by the test subjects,it was necessary to develop unique assembly procedures for the 1-g tests because of gravity effects. The short bracket shown attached to the tower in Figure 14(a) was used as a prop to help support the upper truss struts as they were being passed from the test subject on the far side of the truss to the test subject on the near side. When a lower truss member was being passed across the truss, an engineer on the floor assisted by manually supporting the free end of the strut.

Numerous truss assemblies were performed in 1-g by a number of different subjects including two NASA astronauts in order to check out the hardware, develop efficient procedures,and train test subjects and console operators. Following these preliminary tests, four timed tests were performed in which well trained engineers were used as test subjects and expert console operators, exclusively. A three-bay truss was assembled for each of these tests.

Neutral Buoyancy Tests

Figure 15 is a schematic showing the assembly sequence used for the neutral buoyancy tests. After the first batten frame is assembled, all remaining bays are assembled identically following a very simple and easily memorized routine. Test subject 1 always moves in a counterclockwise direction, while the test subject 2 always moves in a clockwise direction. Struts and nodes are removed from the stowage canister and temporarily stowed on the APD foot restraint handrails when the test subjects pass the canisters so that no long distance translations are required for material resupply.

Figure 16, 17, and 18 show neutral buoyancy tests in progress. Figure 16 shows a scuba assembly, and Figures. 17 and 18 show pressure suit assemblies both with and without integrated installation of utility trays. As with the 1-g tests, numerous assemblies for hardware checkout, procedural development, and personnel familiarity were performed in scuba. Several additional pressure suit tests were also performed to verify the test setup. Two different pairs of test subjects were used in these tests as well as two pairs of console operators. Eight timed assembly tests were performed during which a total of 49 bays of truss were assembled by a single pair each of trained, engineer test subjects and expert console operators, respectively. In the last five of these tests 34 bays of truss were assembled with integrated installation of utility trays. Two additional tests were performed by a pair of NASA astronauts to provide them with some hands-on experience with the assembly procedures and hardware, and to solicit their comments for consideration.

TEST RESULTS

Pressure Suited Neutral Buoyancy Tests

The assembly times using trained engineers as test subjects for the first batten frame and succeeding general bays of the truss are presented in Figure 19 as a function of build number. The build number applies to a three-bay assembly, with the exception of builds 16 and 17 which were two-bay assemblies performed during Test 8 . As can be seen, the assembly times generally decreased as the test subjects and the console operators became more experienced. The few spikes in the data reflect minor difficulties encountered while making some of the strut-to-node connections (attributed to strut crookedness). However, all connections were accomplished by the test subjects without scuba diver assistance. It is interesting to note that as the test subjects became more experienced, and developed their techniques, the assembly times which included integrated installation of utility trays became faster than the assembly times without utility trays. These assembly times are considerably faster than the 13.5-14 minutes per bay (with no utility trays) reported in reference 6 for neutral buoyancy assembly tests of competing Space Station truss concepts. The tests reported in reference 6, however, used several different AWP hardware configurations, as well as different assembly procedures than those used in the tests reported herein. The fidelity of the test fixtures used in the ref. 6 tests and the assembly procedures were compromised significantly by the small size of the Weightless Environment Training Facility (WETF) in which they were performed, and by the use of many pairs of astronaut test subjects performing only one or two tests each, so that they could not become thoroughly trained or highly experienced with the various AWP hardware designs and assembly concepts. Such "quick-look" tests should not be considered verifications of a concept.

The assembly times by a pair of astronaut test subjects for the first batten frame and succeeding general bays of the truss in the present tests are presented in Figure 20 as a function of build number. One of these astronauts had no previous experience with the Mobile Transporter or the truss hardware, and relatively few hours of neutral buoyancy experience in the pressure suit. The other astronaut had performed several 1-g assemblies with the MT using the same truss hardware, but different assembly procedures. However, this astronaut had many hours of neutral buoyancy pressure suit experience plus approximately 12 hours of actual on-orbit EVA structural assembly experience with the ACCESS Shuttle flight experiment (ref. 5). A comparison of Figs. 19 and 20 shows that the astronaut assembly times were somewhat greater than those from the first few tests of the experienced test subjects, and significantly greater than the times realized in the latter builds. Except for the two spikes that are indicative of additional time taken to install crooked struts, the astronaut times also show a generally downward trend as experience is gained. These results demonstrate the importance of using only well trained test subjects to verify assembly times and evaluate hardware or concepts.

Comparison of 1-g, Scuba, and Pressure Suit Three-bay Assemblies

In order to provide data that may be useful for more accurate estimations of on-orbit assembly times from data obtained in 1-g and neutral buoyancy assembly tests, an attempt was made to isolate the effects of water drag and pressure suit encumbrance. Figure 21 shows a comparison of three-bay truss assemblies performed in 1-g with the test subjects in street clothes, and in neutral buoyancy with the test subjects in either scuba or pressure suits. All of these results were obtained with the same pair of trained, engineer test subjects and the same pair of trained console operators. The neutral buoyancy tests included integrated installation of utility trays, whereas utility tray installation was not possible with the 1-g test setup. The average assembly time for the three-bay truss without utility trays was approximately 14.82 minutes in 1-g and 15.73 minutes in scuba. Because these assembly times are so close and the effects of gravity were significant deviations from the scuba tests, it is unlikely that any realistic conclusions on the effects of water drag can be drawn.

However, the results from the scuba and pressure suit neutral buoyancy tests can be used to estimate the effects of pressure suit encumbrance because these tests were essentially identical except for the test subjects' attire. The average assembly time for a three-bay truss was approximately four minutes longer in pressure suits than in scuba. These results suggest that, with the particular assembly concept studied, a five to six seconds per strut penalty in assembly time is directly attributable to the current pressure suit (Extravehicular Mobility Unit (EMU)) design, and primarily the glove design. It was necessary to use the series 1000 gloves in these tests because the series 3000 gloves were not available. However the astronauts commented that use of series 3000 gloves with low torque wrist bearings would improve performance considerably.

Concluding Remarks

Eight timed neutral buoyancy tests were conducted to evaluate the use of a Mobile Transporter concept in conjunction with EVA astronauts to construct Space Station truss structure. A three-bay orthogonal tetrahedral truss configuration (consisting of 44 two-inch-diameter aluminum struts) with a 15-foot square cross section was repeatedly assembled by a single pair of trained pressure suited test subjects working from the Mobile Transporter astronaut positioning devices (mobile foot restraints). The test subjects were translated to various work sites at the approximate rate of one foot per second. A total of 48 bays of truss were assembled, 34 of which included integrated installation of utility trays. The unit assembly time averaged from the last four assemblies of the three-bay truss (44 struts) was 27.6 s/strut, or 6 min/bay, which includes integrated installation of utility trays. Tethering of the hardware was not addressed in these tests.

The Mobile Transporter mock-up was designed to closely simulate the outward appearance and functions of a flight version. However, one of the more important variations, dictated by test subject safety and comfort considerations in ground tests, was the orientation of the test subjects. For these tests, the test subjects were oriented in a heads-up position. Thus their heads were always pointing towards the Mobile Transporter body. The preferred orientation would be with their heads pointing away from the Mobile Transporter, which provides better visibility and a less obstructed work site by surrounding structure. The inverted orientation was somewhat restricting and required several vernier motions of the test subjects at the work sites, especially at the Mobile Transporter guide rails, to make the structural connections. However, after several tests, the test subjects and console operators learned the most optimum positions for doing specific tasks, and fast assembly times were realized. Use of temporary strut and node carriers on the foot restraint handrails permitted the strut and node stowage canisters to be located on the platform area of the Mobile Transporter instead of on the astronaut positioning devices, and proved to be effective in maintaining unobstructed work sites for the test subjects.

The relatively highly developed joint, designed at the NASA Langley Research Center, was used for all structural connections. In several instances difficulties in making joint connections were encountered which were likely caused by use of crooked struts that were excessively out of tolerance. However, trained test subjects were able to make all of the structural connections without assistance from utility divers. The rapid assembly times achieved demonstrate the compatibility of the joint design with EVA assembly. The pattern painted on each joint was highly visible from long distances and easily interpreted by the test subjects and console operators as to the locked or unlocked condition of the joint and the direction of rotation of the locking collar necessary to achieve either of these conditions.

The results of these tests indicate that EVA assembly of Space Station size structure can be significantly enhanced when using a Mobile Transporter equipped with astronaut positioning devices. Rapid assembly times can be expected and are dependent primarily on the rate of translation permissible for on-orbit operations. The concept used to demonstrate integrated installation of utility trays requires minimal EVA handling and consequentially, as the results show, has little impact on overall assembly times.

References

1. Adkisson,R. W.:"The Role of a Mobile Transporter in Large Space Structures Assembly and Maintenance." Engineering, Construction, and Operations in Space, August 1988, pp. 787-796.

2. Mikulas, Martin M., Jr.; Bush, Harold G.; Wallsom, Richard E.; Dorsey, John T.; and Rhodes, Marvin D.: A Manned-Machine Space Station Construction Concept. NASA TM 85762, February 1984.

3. Bush, Harold G.; Mikulas, Martin M., Jr.; Wallsom, Richard E.; and Jensen, J. Kermit: Conceptual Design of a Mobile Remote Manipulator System. NASA TM 86262, July 1984.

4. Sutter, Thomas R. and Bush, Harold G.: A Comparison of Two Trusses for the Space Station Structure. NASA TM 4093, 1989.

5. Heard, Walter L., Jr.; Bush, Harold G.,; Watson, Judith J.; Spring, Sherwood C.; and Ross, Jerry L.: Astronaut/EVA Construction of Space Station. AIAA Paper No. 88-2454. Presented at the AIAA SDM Issues of International Space Station Conference, Williamsburg, Va., April 21-22 1988.

6. Lichwala, B. E.: Selection of an Assembly Truss Member Arrangement for the NASA Space Station. Presented at the AIAA SDM Issues of International Space Station Conference, Williamsburg, Va., April 21-22 1988.

ORIGINAL PAGE IS
OF POOR QUALITY

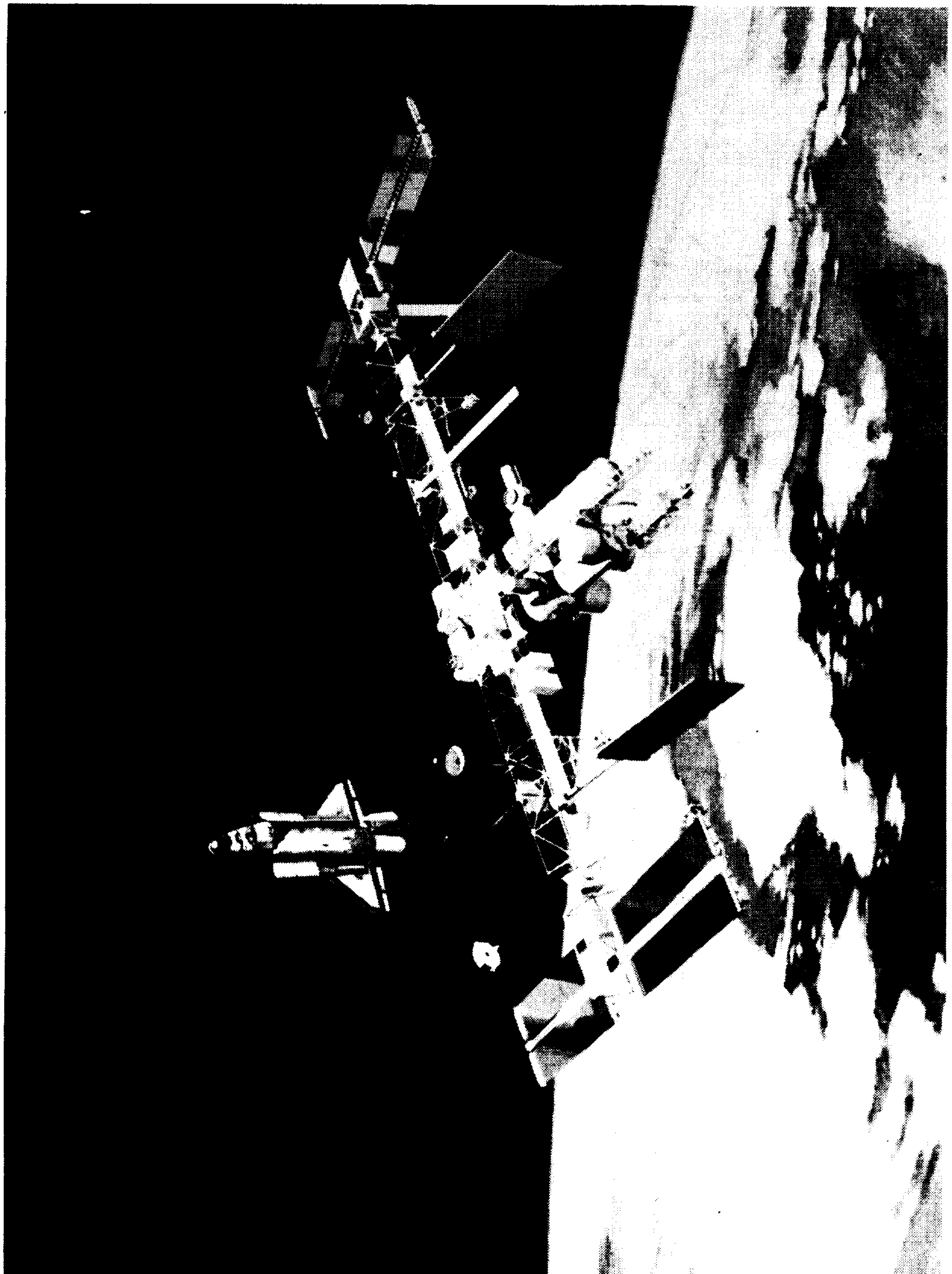


Figure 1. - Space Station Freedom revised baseline configuration.

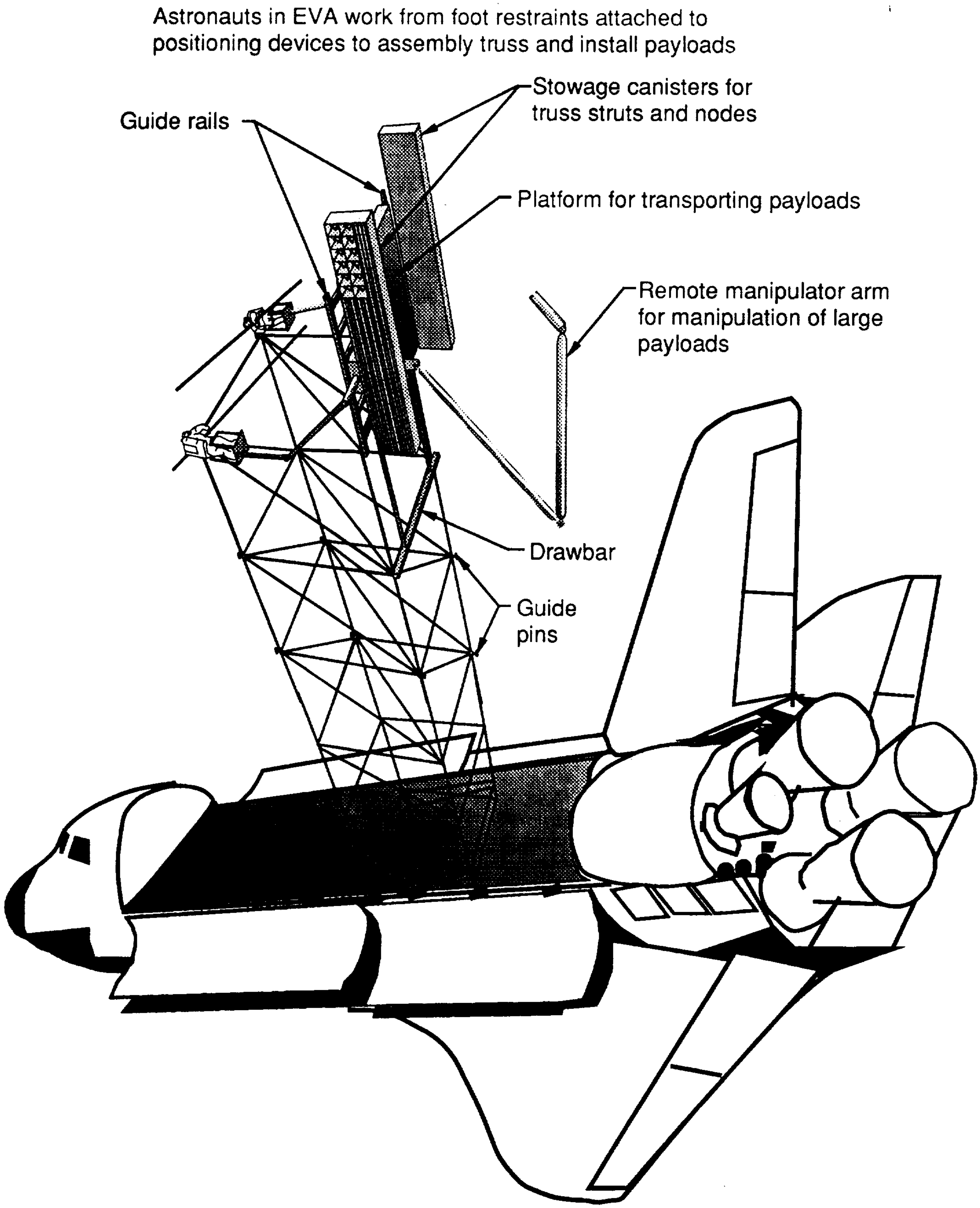


Figure 2.-EVA/Mobile Transporter concept for assembly of Space Station.

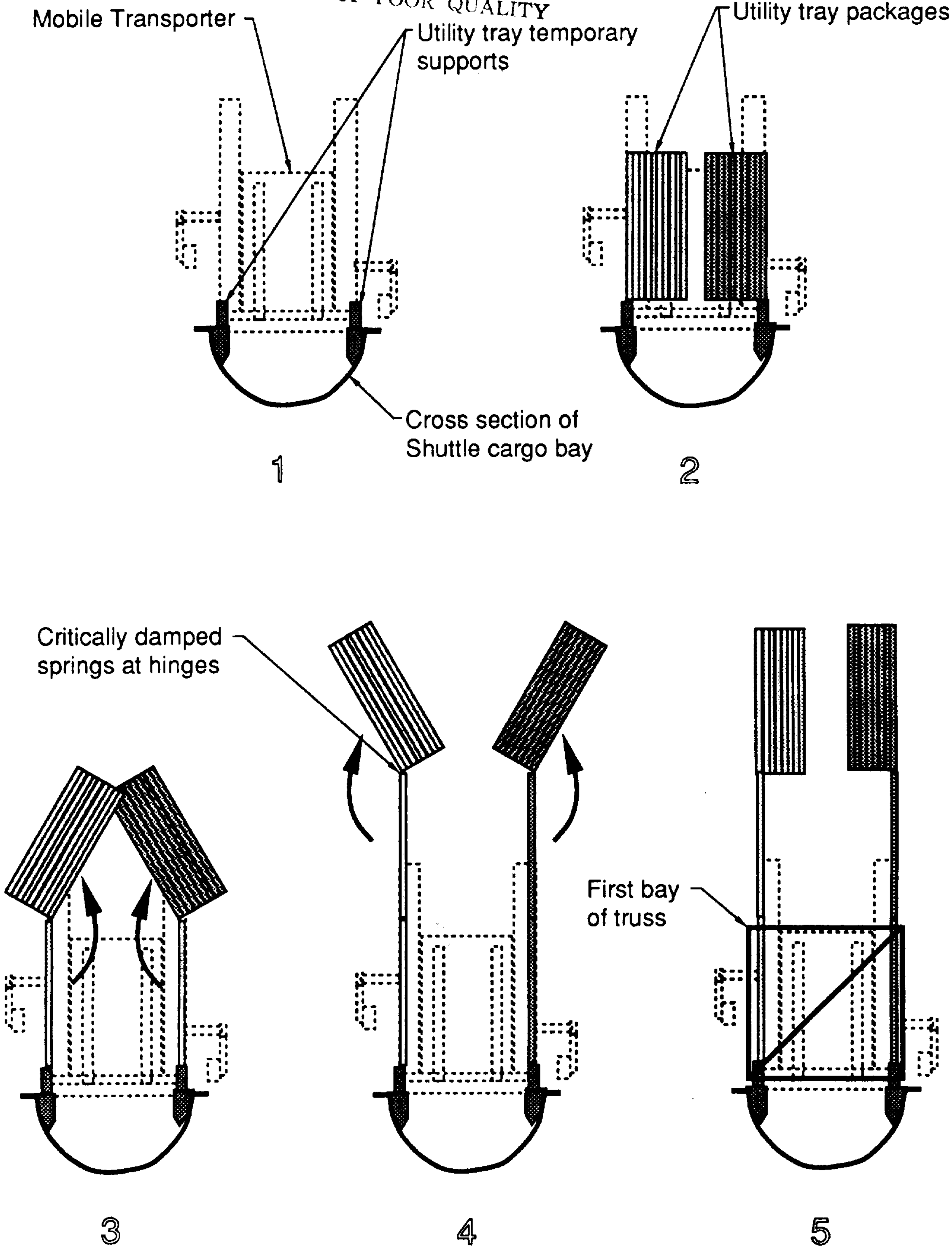


Figure 3.-Concept for utility tray deployment.

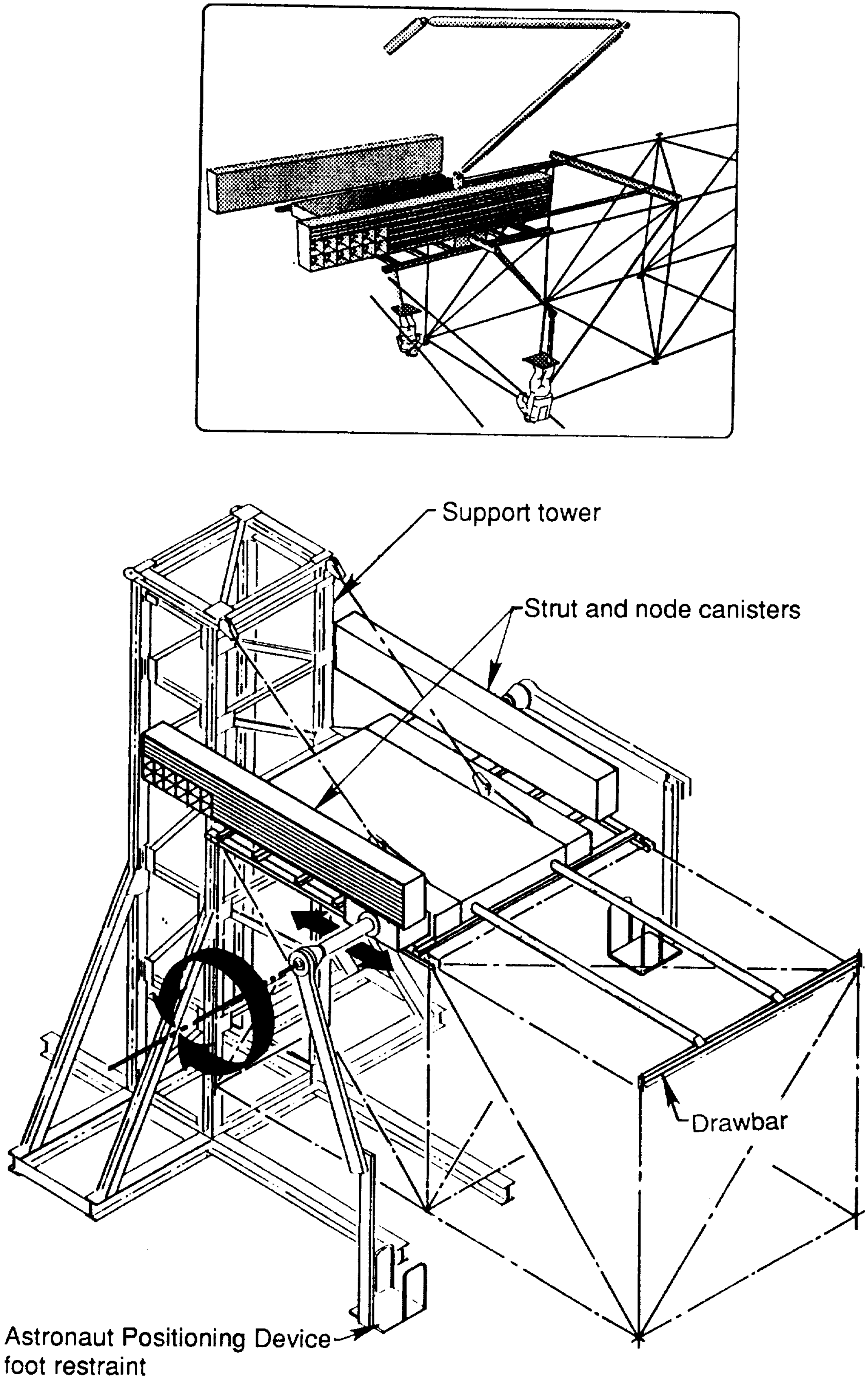
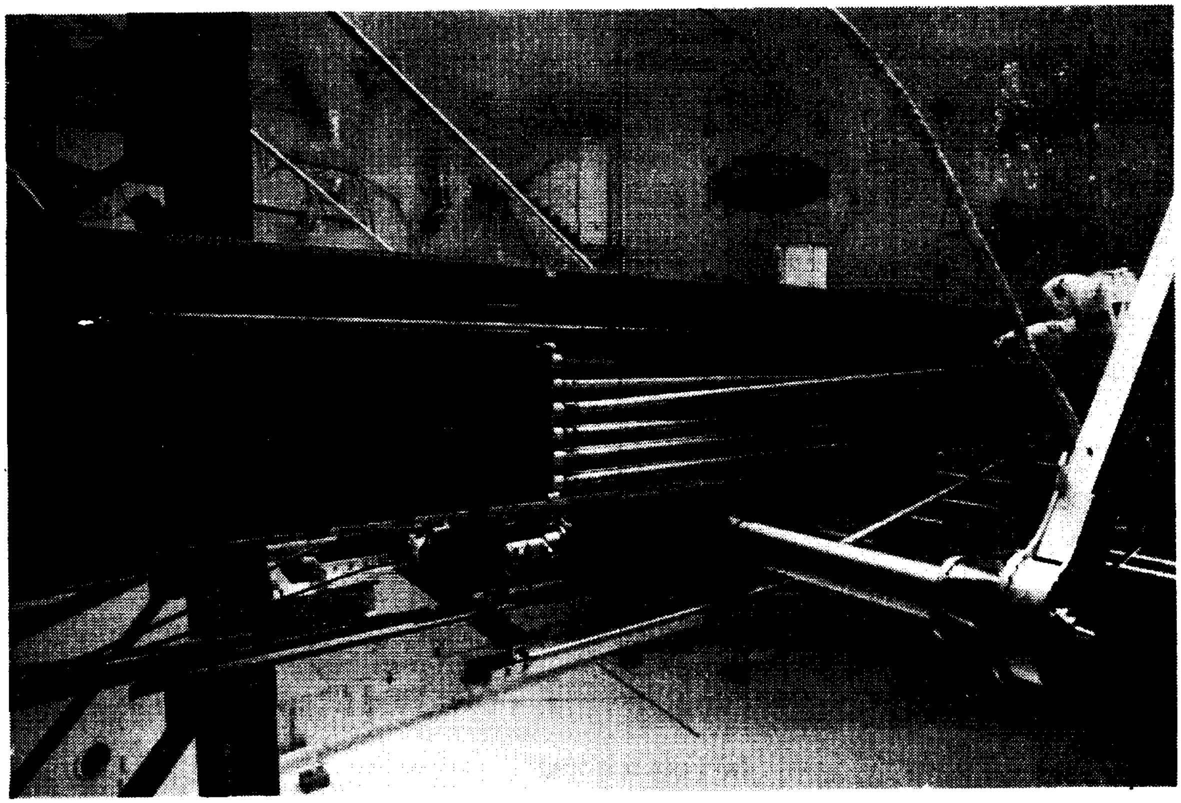


Figure 4. - Schematic of Mobile Transporter mock-up.

ORIGINAL PAGE IS
OF POOR QUALITY

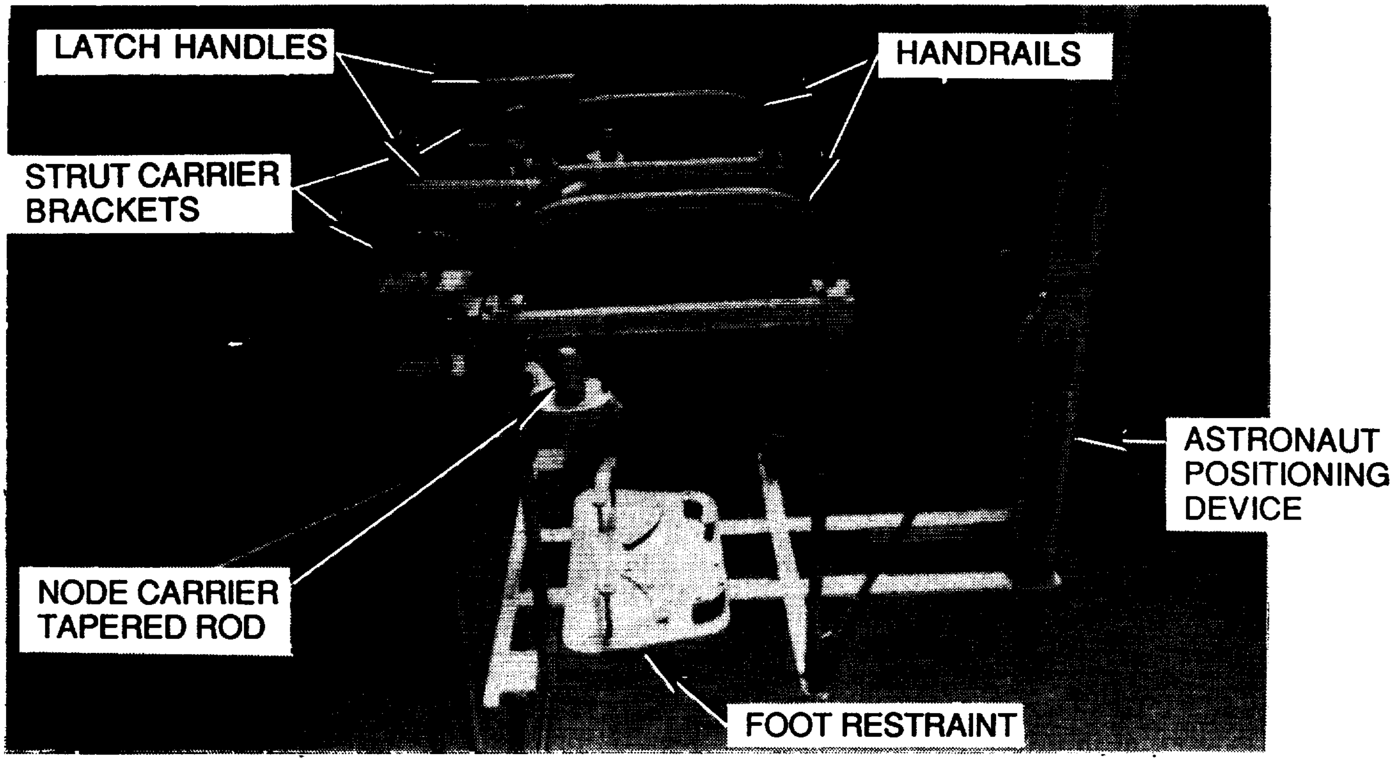


(a) Strut stowage and removal

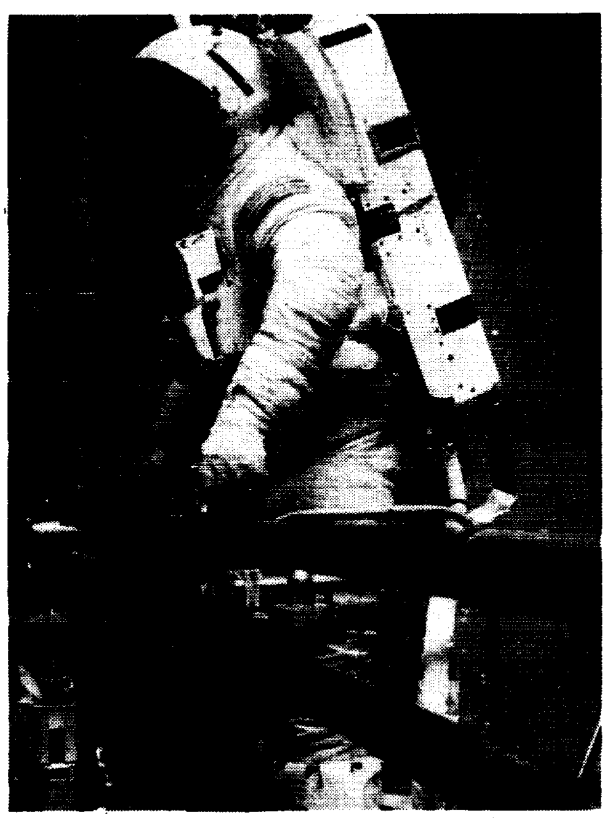
(b) Node stowage compartments

Figure 5. - Strut and node stowage canister.

ORIGINAL PAGE IS
OF POOR QUALITY



(a) Foot restraint



(b) Locking struts in carriers

(c) Placing node on carrier

Figure 6. - Foot restraint with strut and node carriers.

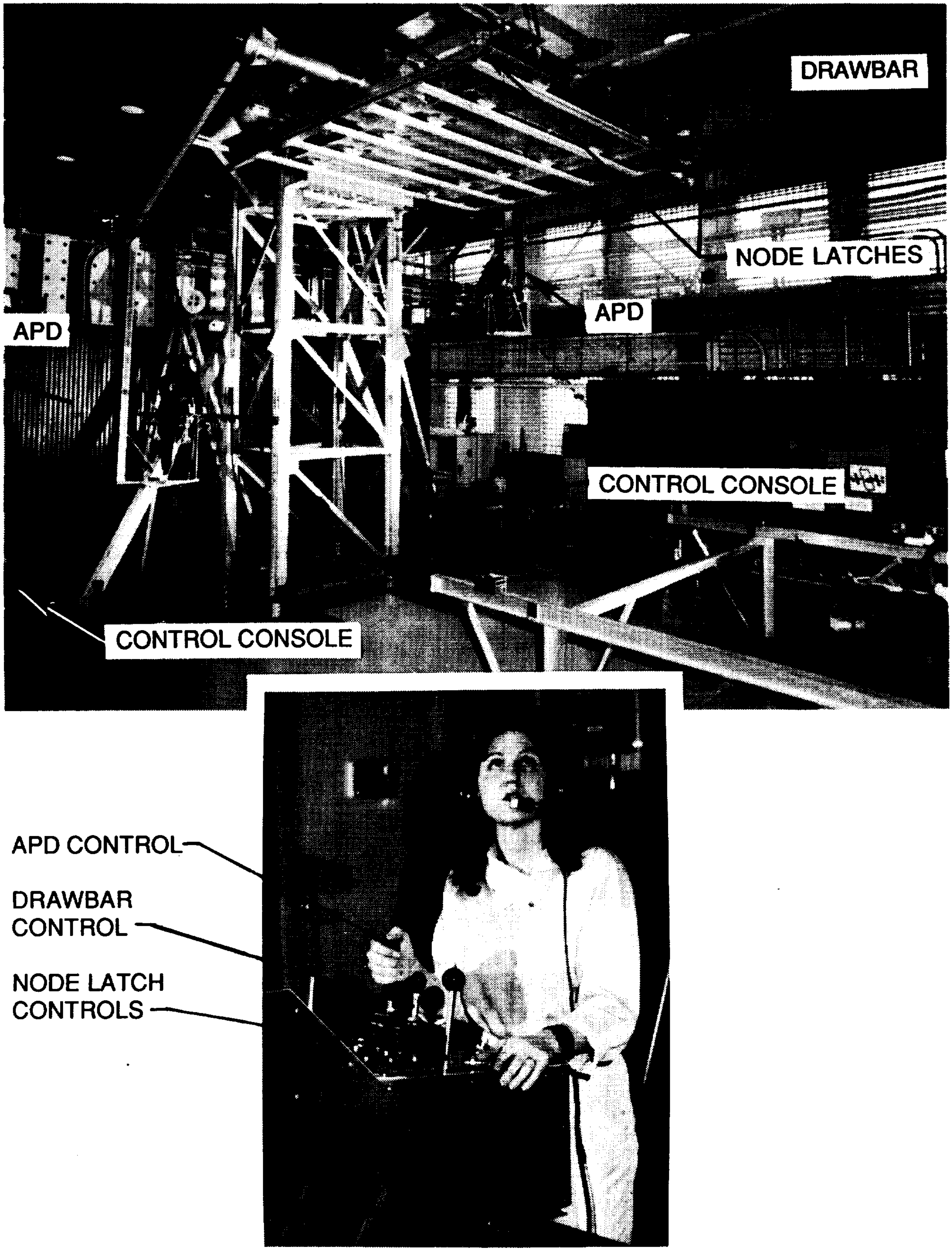
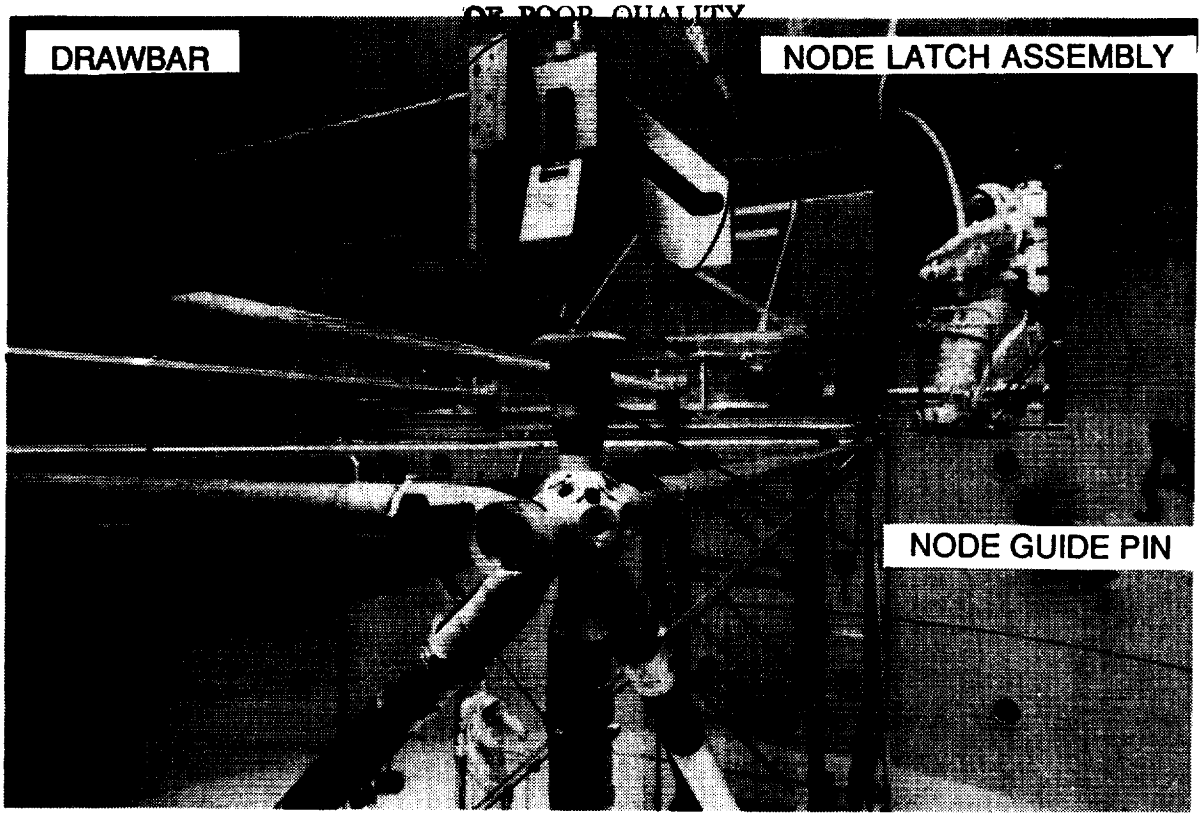
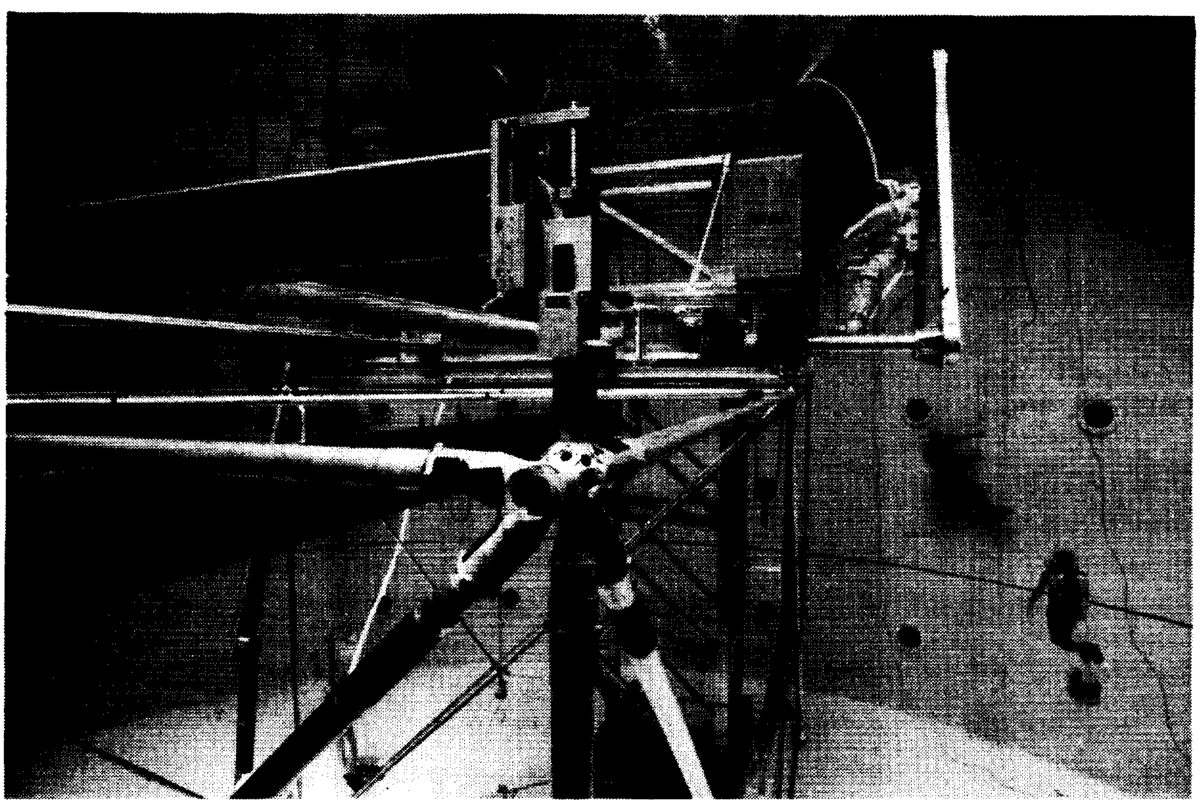


Figure 7. - Mobile Transporter controls.



(a) Drawbar node latch not engaged



(b) Drawbar node latch engaged and locked

Figure 8. - Drawbar node latch.

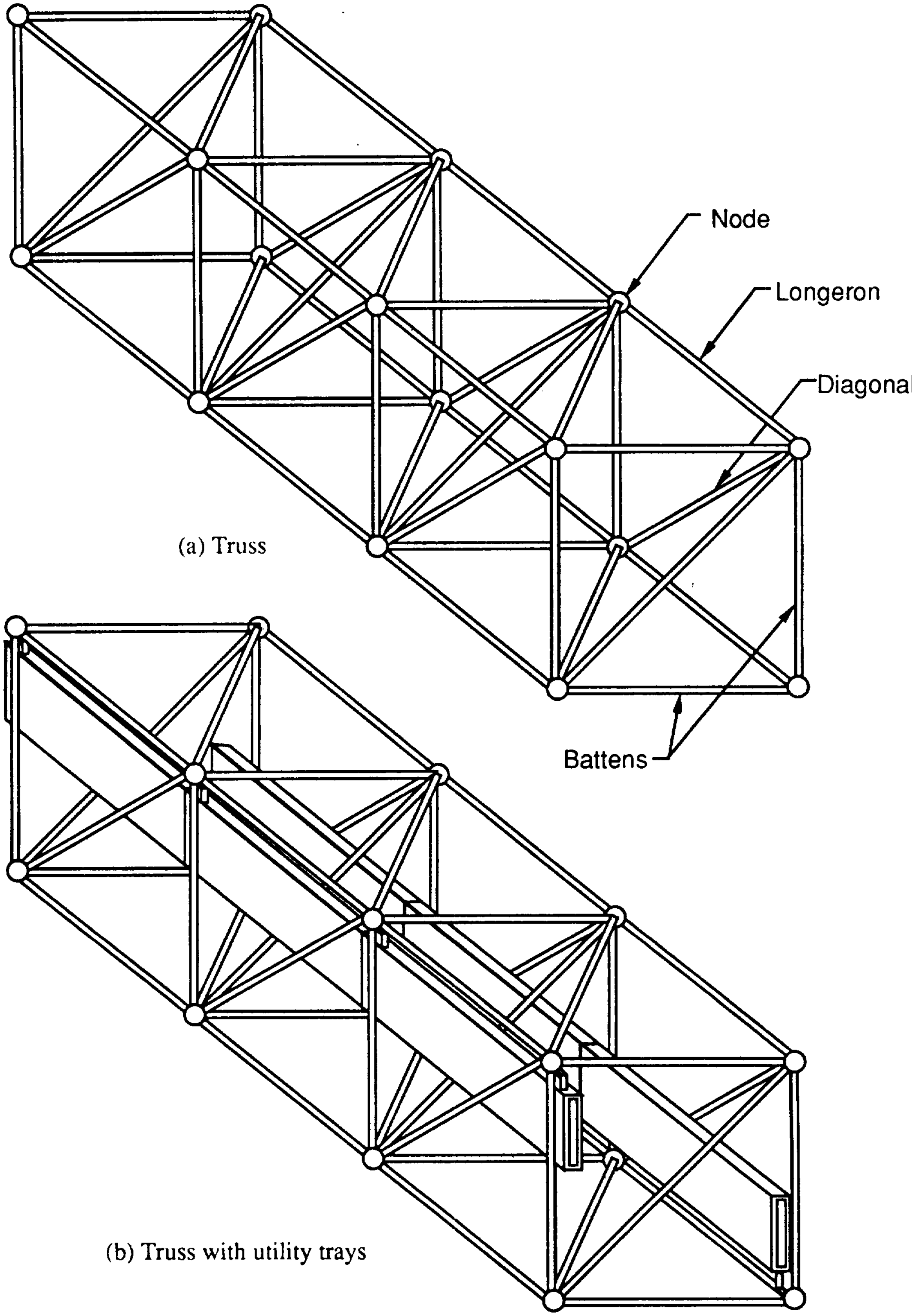


Figure 9.- Orthogonal tetrahedral truss (OTT) configuration.

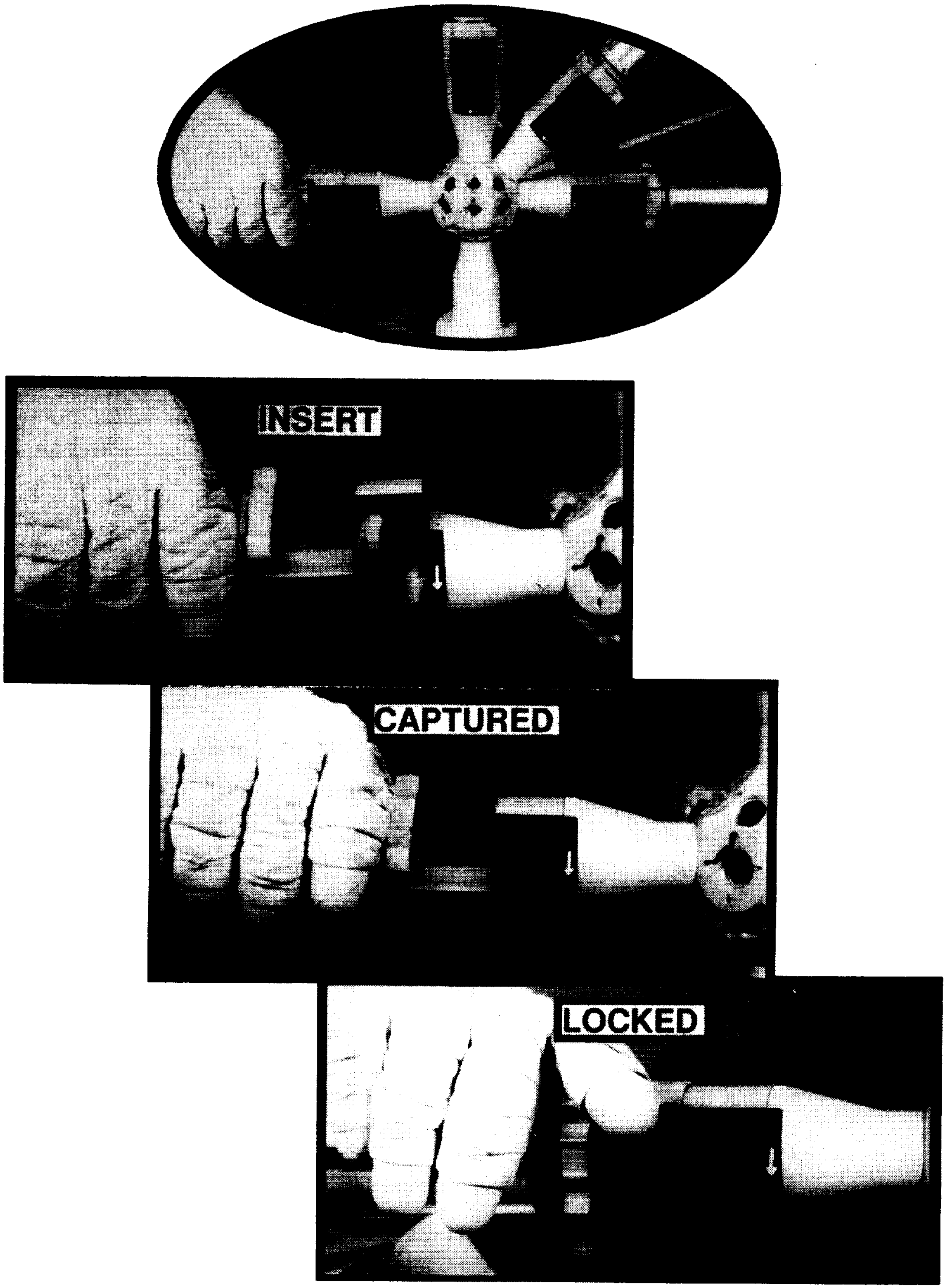


Figure 10. - Attachment of strut to node.

ORIGINAL PAGE IS
OF POOR QUALITY

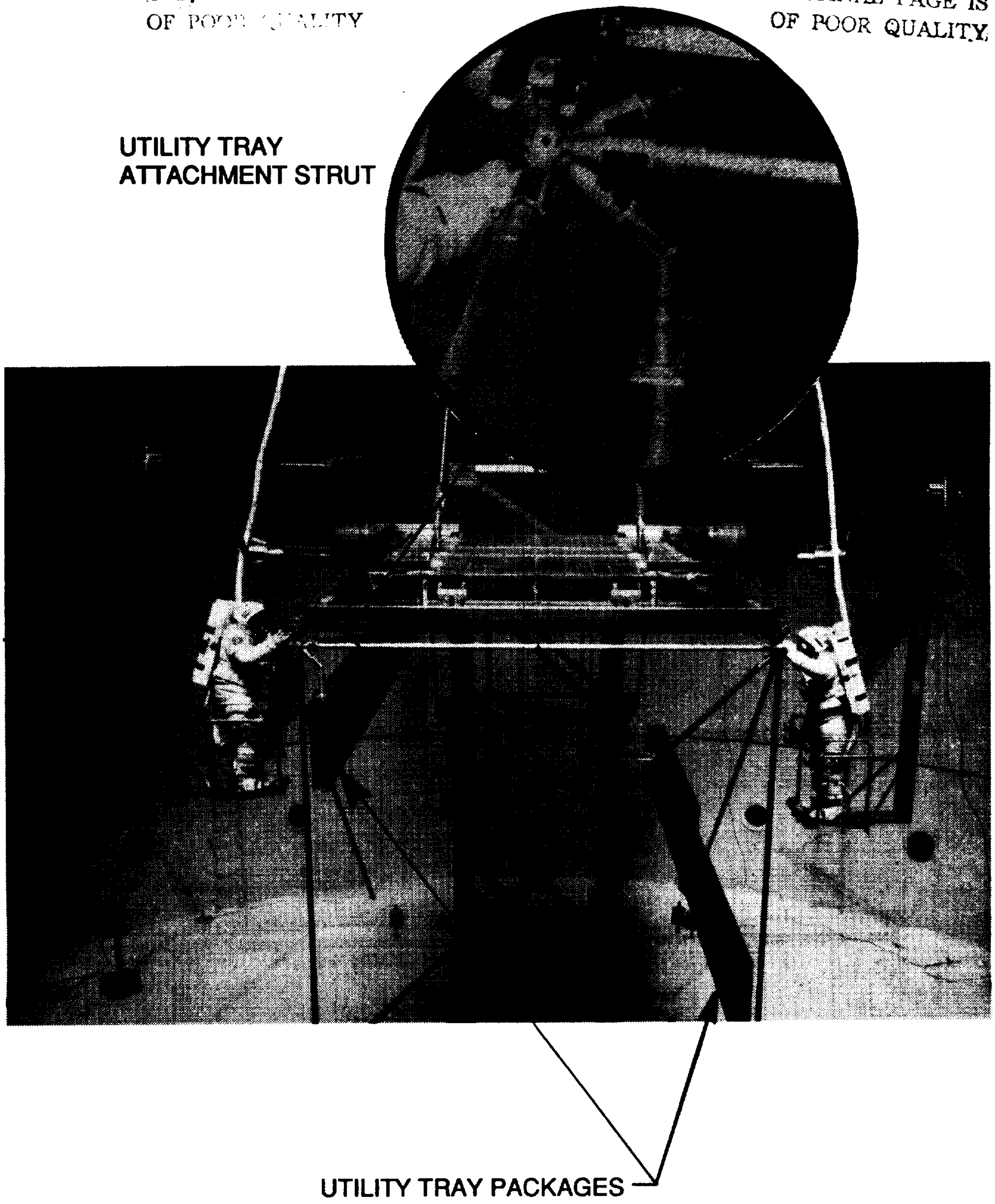


Figure 11. - Utility tray packages used in neutral buoyancy assembly tests.

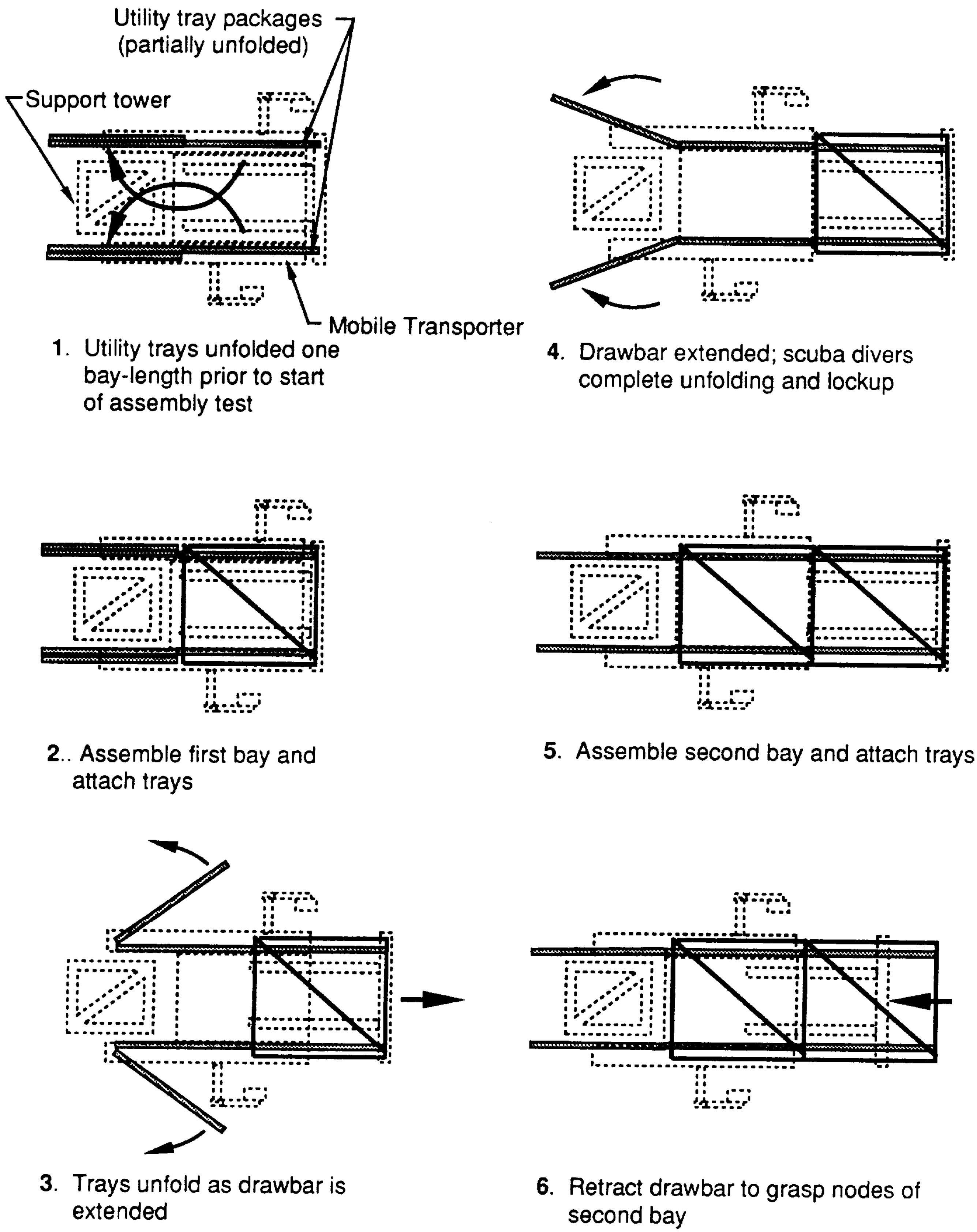


Figure 12- Schematic of utility tray deployment for neutral buoyancy tests.

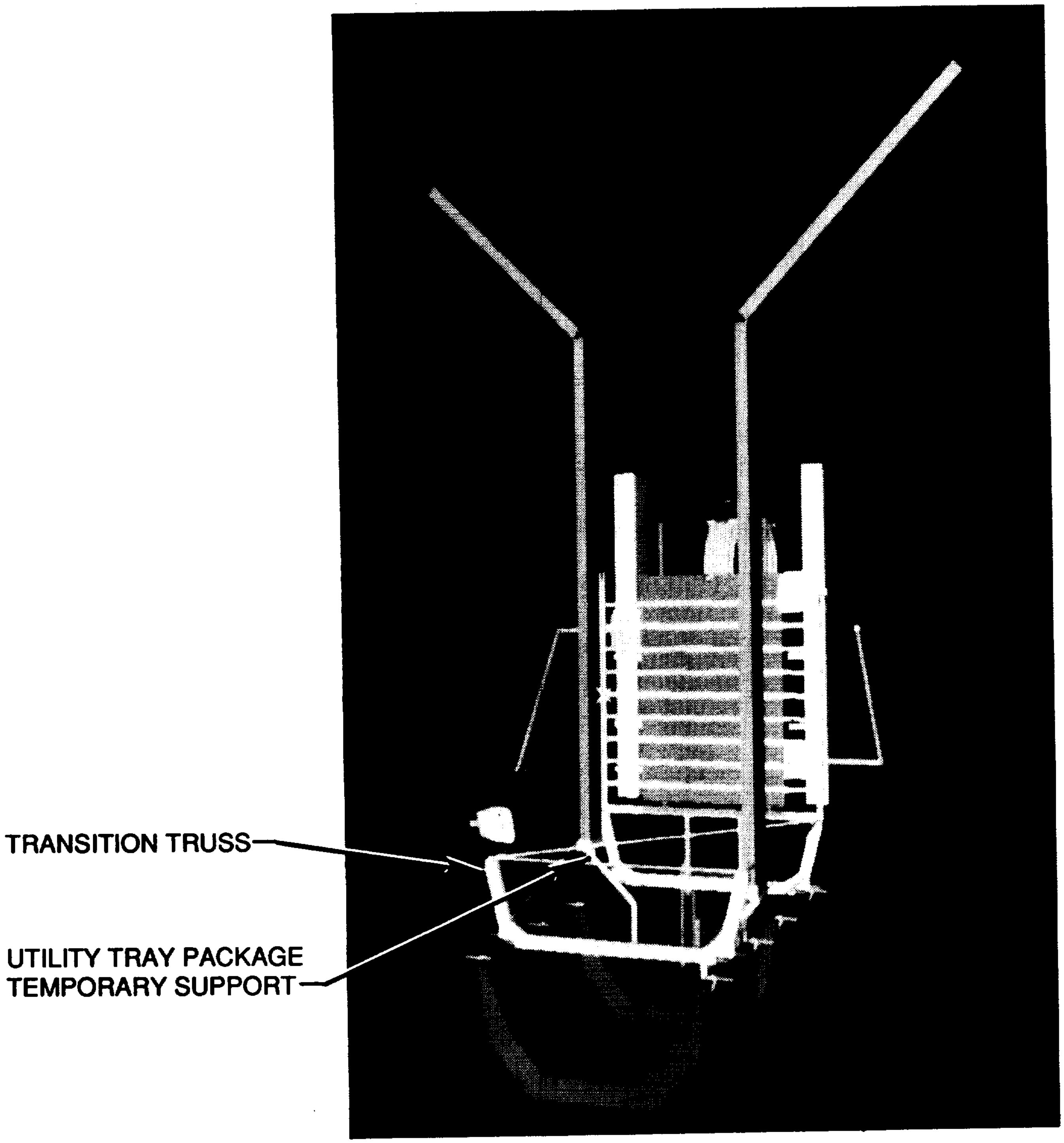
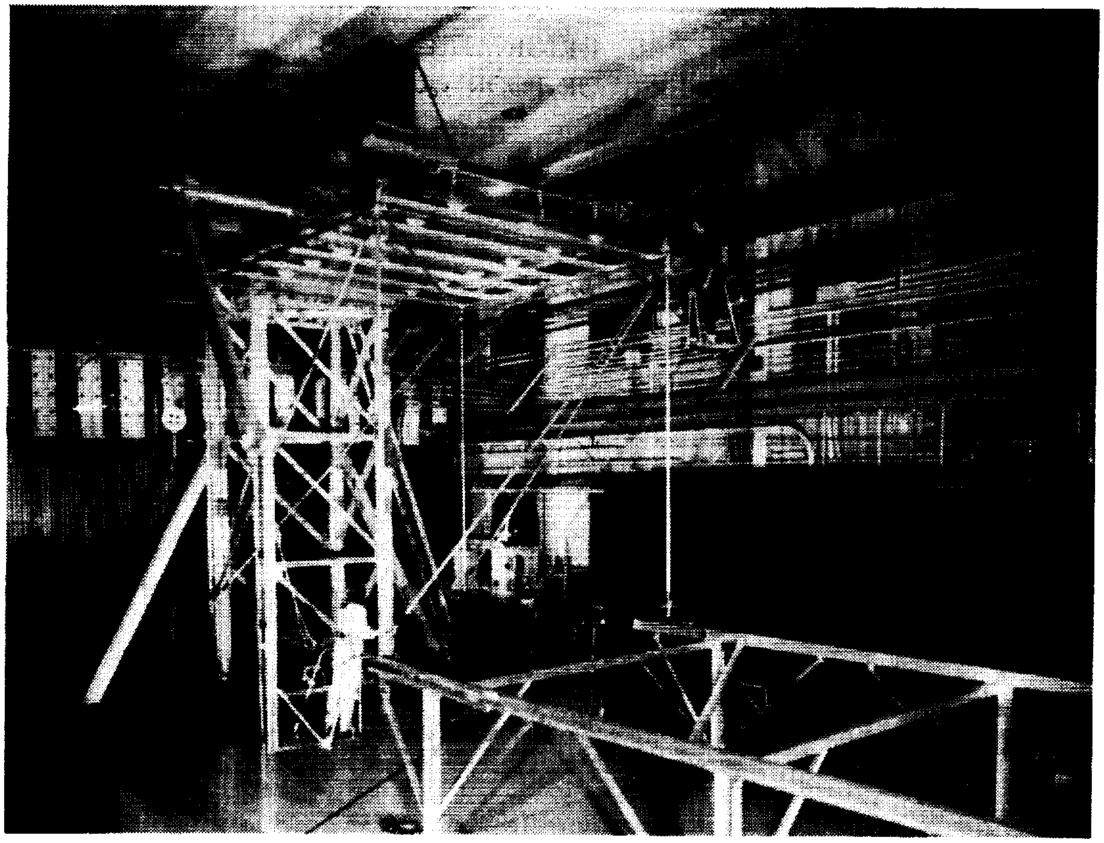
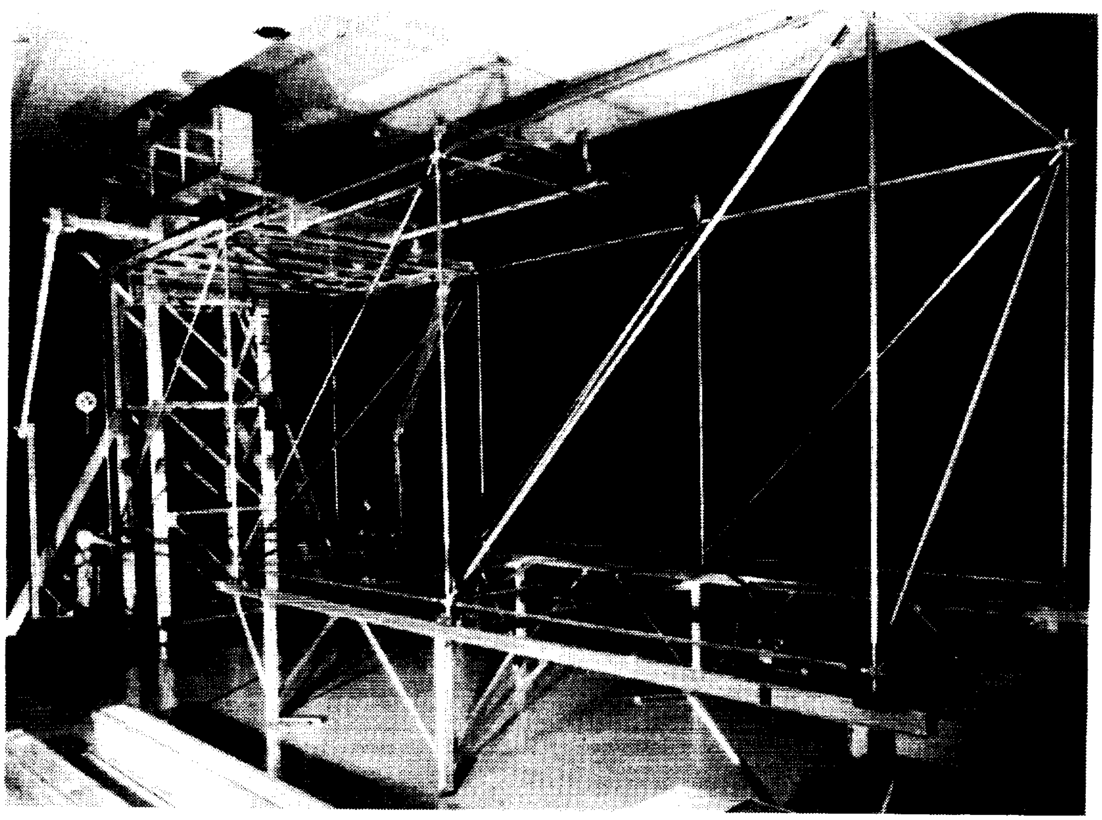


Figure 13. - Computer drawing of predeployment of three-bay utility tray system.

ORIGINAL PAGE IS
OF POOR QUALITY



(a) Assembly of first bay.



(b) Three-bay truss completed.

Figure 14. - Three-bay Space Station truss assembly in 1-g with Mobile Transporter.

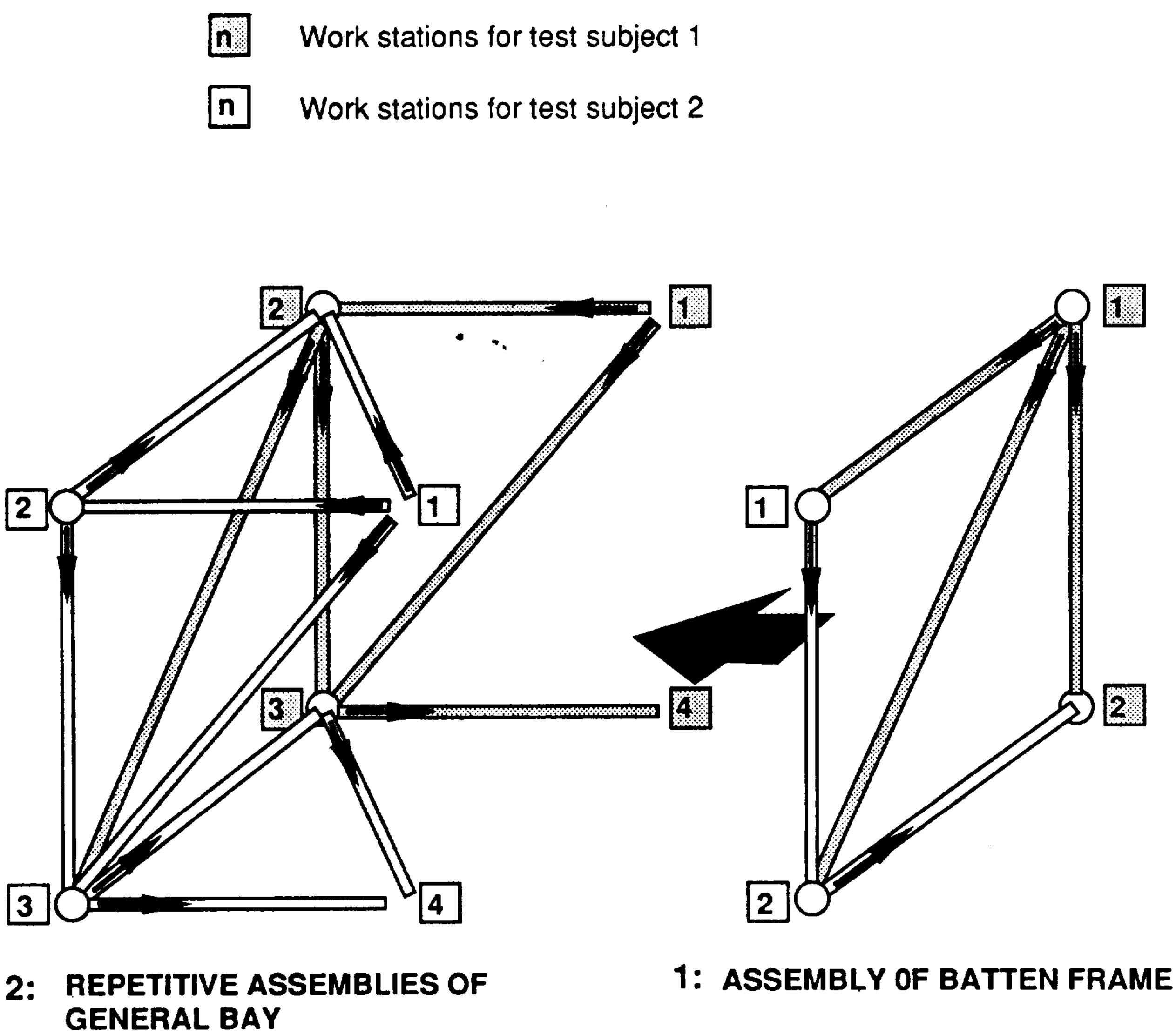
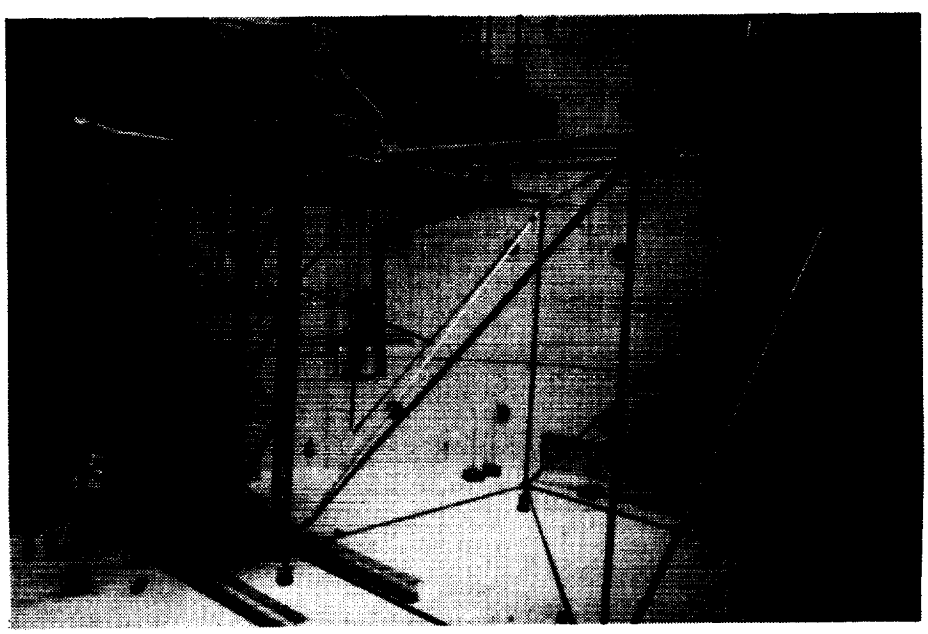


Figure 15.- Assembly procedure for neutral buoyancy tests.

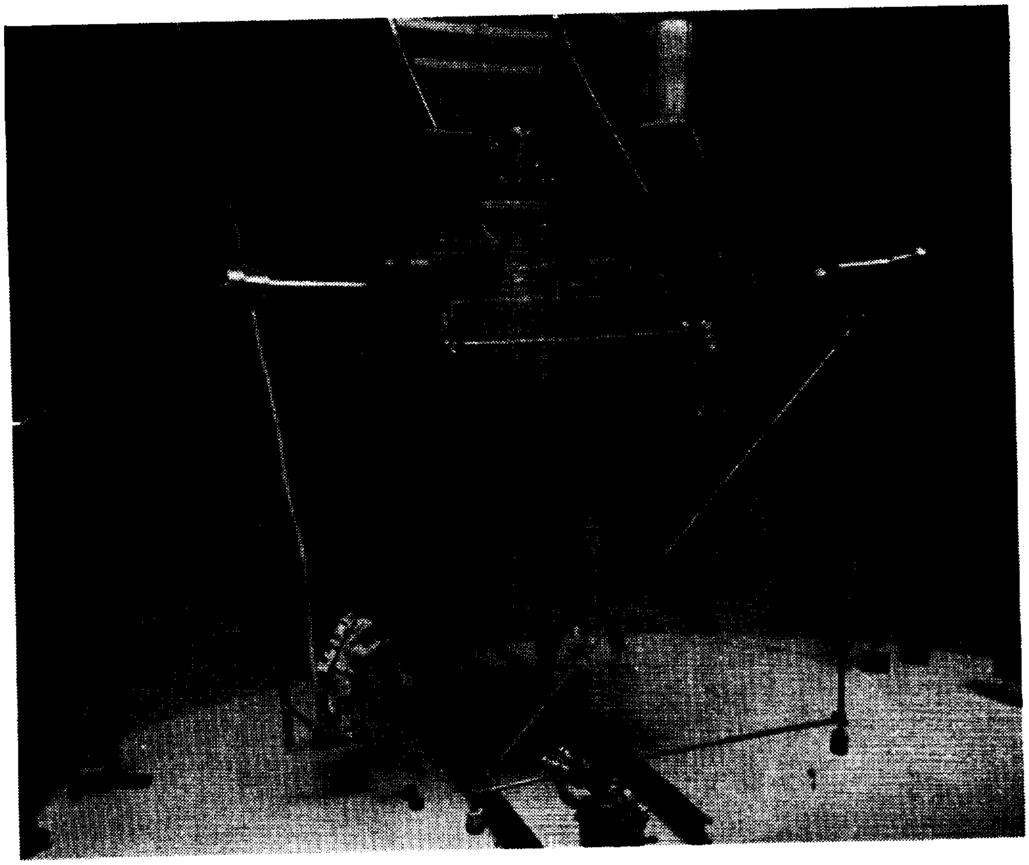
ORIGINAL PAGE IS
OF POOR QUALITY

(a) Test subjects in APD foot restraints ready to begin test.

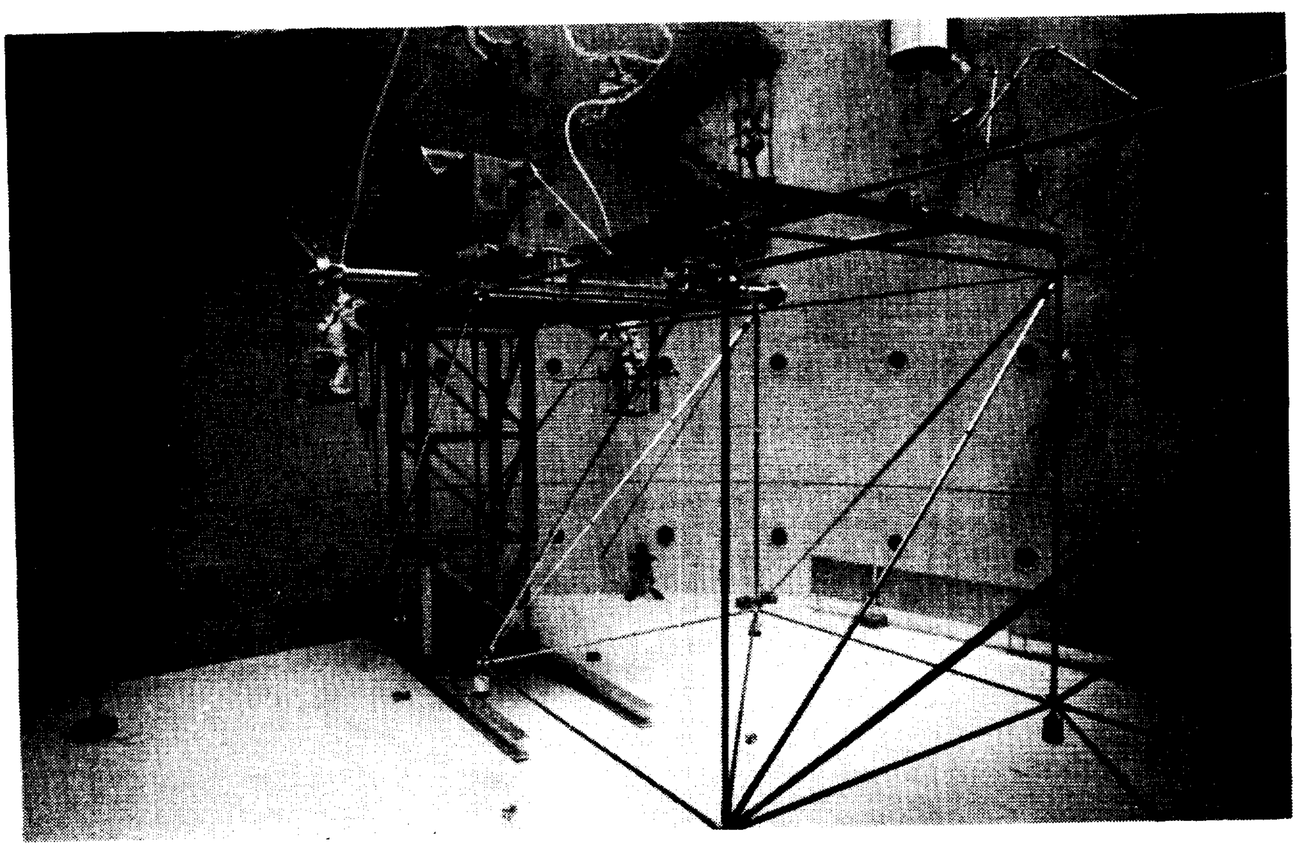


(b) Assembly of second bay

Figure 16. - Scuba assembly test in neutral buoyancy.

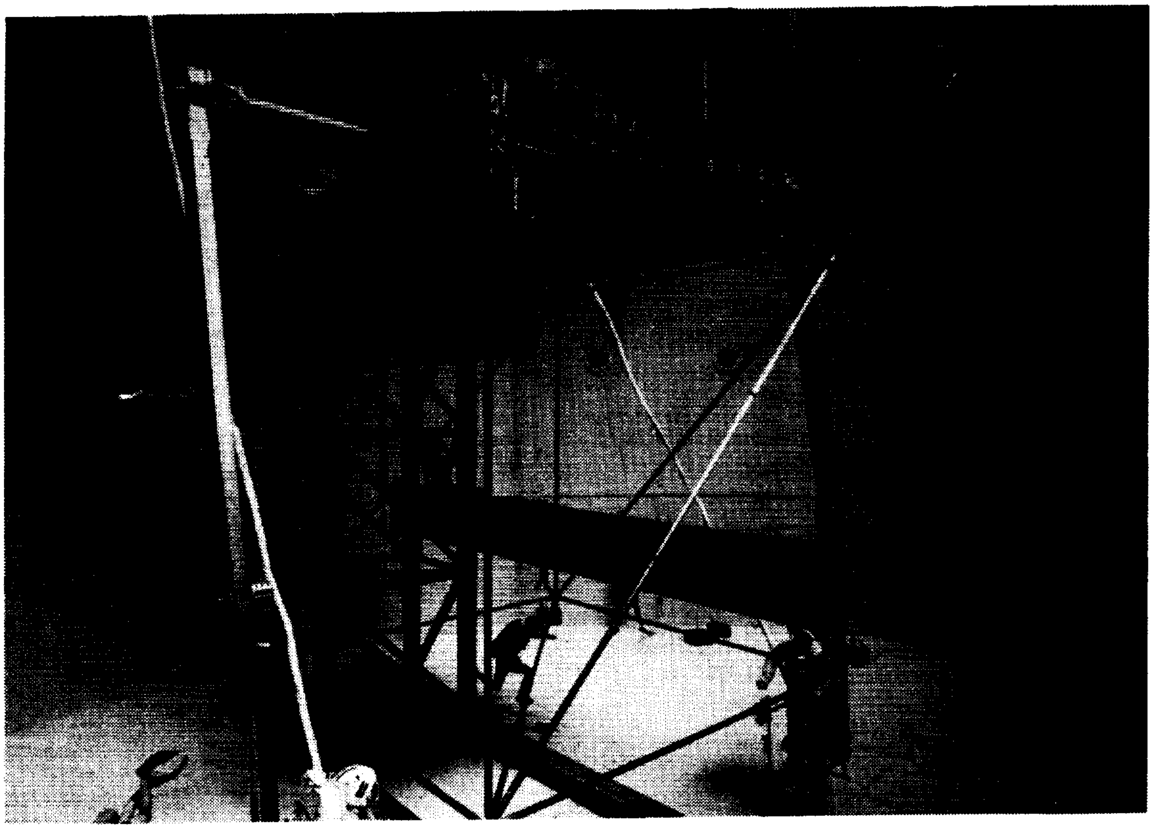


(a) Assembly of first bay

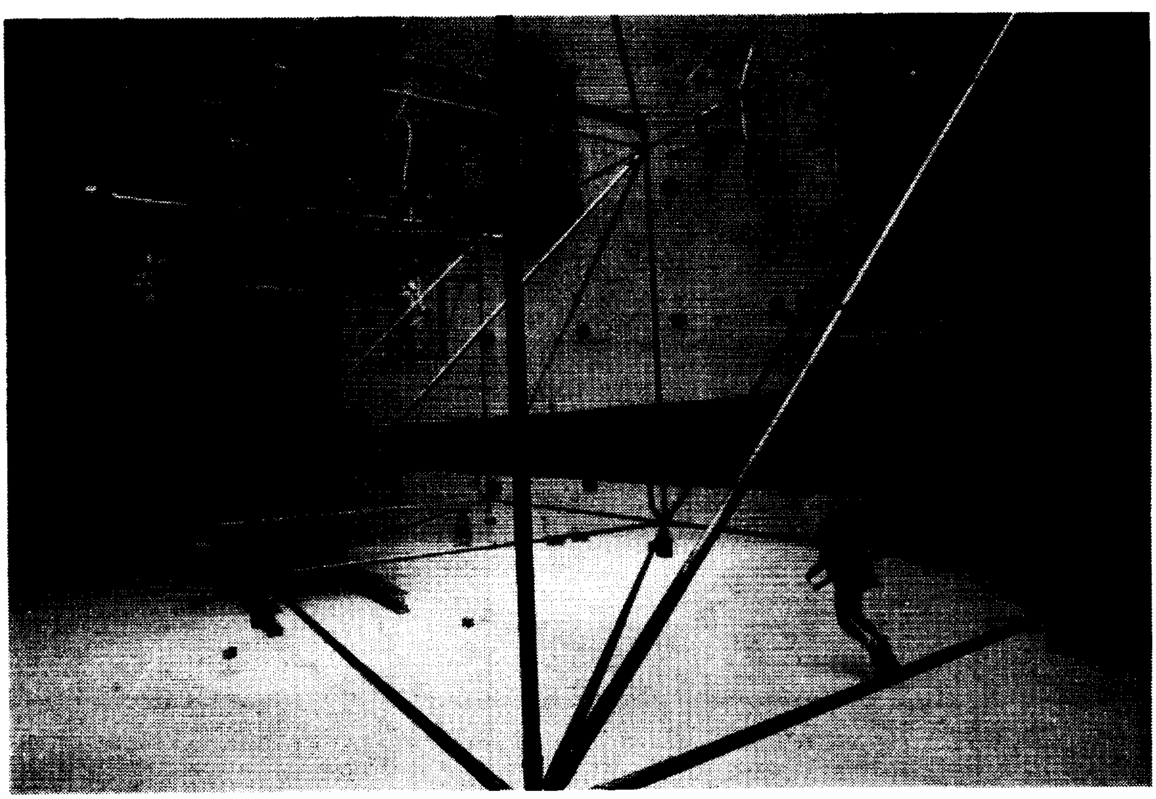


(b) Assembly of third bay

Figure 17. - Neutral Buoyancy truss assembly by test subjects in pressure suits.



(a) Assembly of first bay



(b) Assembly of third bay

Figure 18. - Neutral buoyancy truss assembly and integration of utility trays by test subjects in pressure suits.

Test No.	Three-Bay Build No.
1	1
2	2, 3
3	4, 5
4	6, 7
5	8, 9
6	10, 11
7	12, 13, 14
8	15, 16*, 17*

* Two-bay build

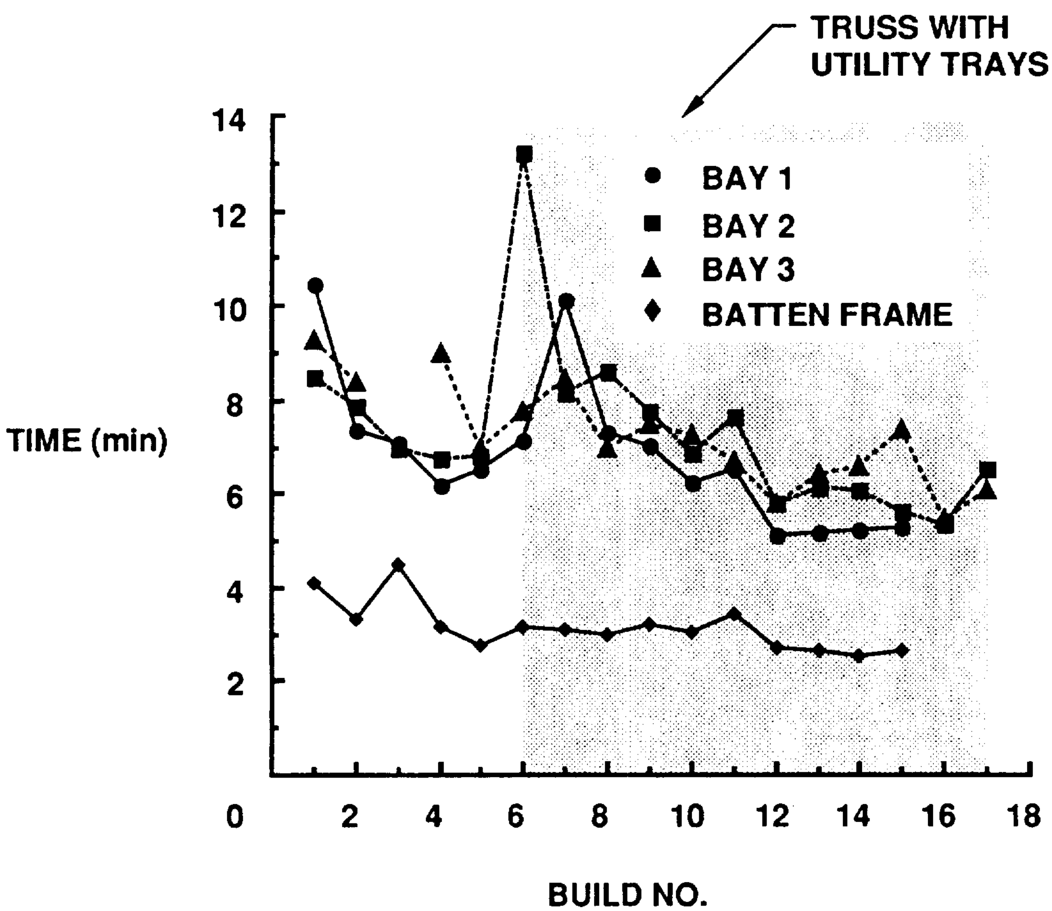


Figure 19.- Neutral buoyancy assembly times per bay by trained test subjects in pressure suits.

Test No.	Three-Bay Build No.
1	1, 2
2	3,4*

*Two-bay build

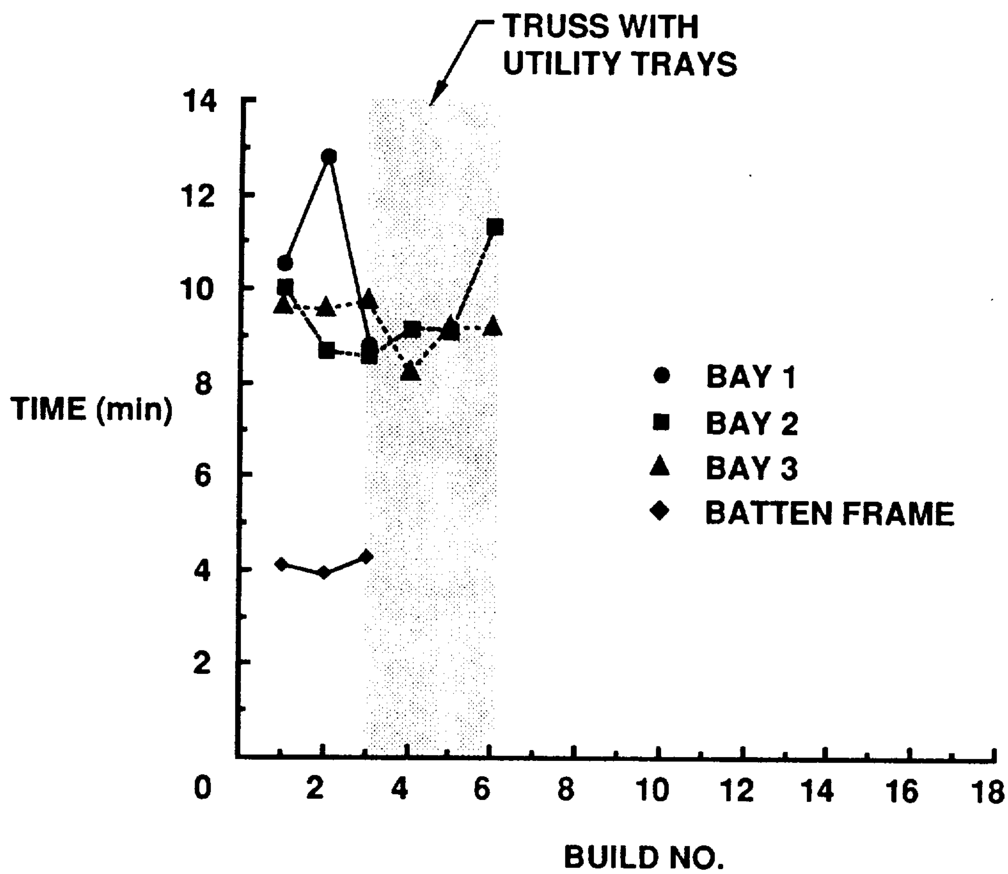


Figure 20.- Neutral buoyancy assembly times per bay by astronaut test subjects in pressure suits.

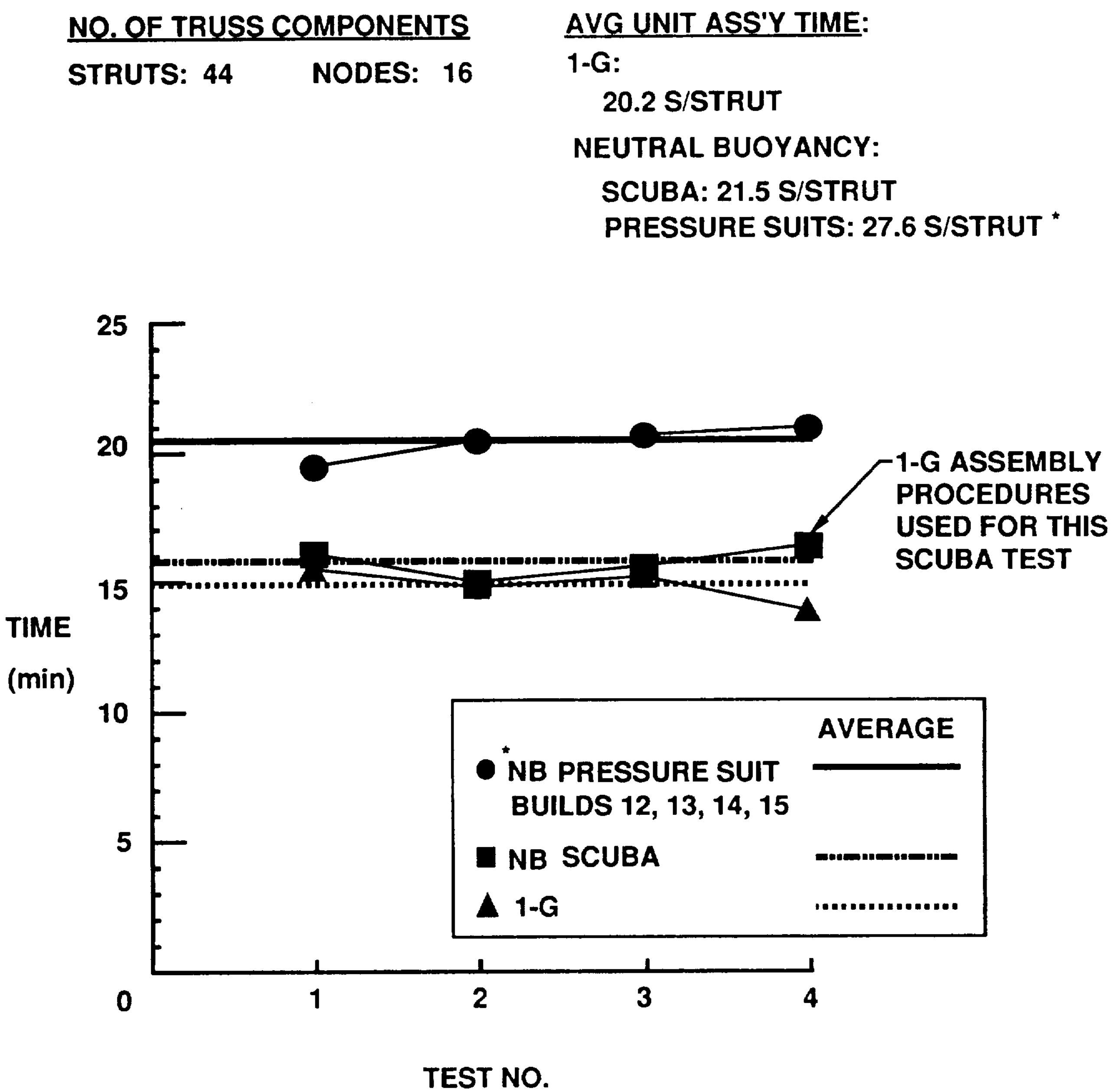


Figure 21 .- Comparison of three-bay truss assembly times.

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100661		

4. Title and Subtitle	5. Report Date
Results of EVA/Mobile Transporter Space Station Truss Assembly Tests	November 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J. J. Watson, W. L. Heard, Jr., H. G. Bush, M. S. Lake, J. K. Jensen, R. E. Wallsom, and J. E. Phelps	
	10. Work Unit No. 506-43-41-02
9. Performing Organization Name and Address	11. Contract or Grant No.
Langley Research Center Hampton, VA 23665-5225	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

J. K. Jensen, R. E. Wallsom, and J. E. Phelps: PRC/Kentron, Inc., Hampton, VA.
J. J. Watson, W. L. Heard, Jr., H. G. Bush, and M. S. Lake: Langley Research Center, Hampton, VA.

16. Abstract

Underwater neutral buoyancy tests were conducted to evaluate the use of a Mobile Transporter concept in conjunction with EVA astronauts to construct the Space Station Freedom truss structure. A three-bay orthogonal tetrahedral truss configuration with a 15-foot-square cross section was repeatedly assembled by a single pair of pressure suited test subjects working from the Mobile Transporter astronaut positioning devices (mobile foot restraints). The average unit assembly time (which included integrated installation of utility trays) was 27.6 s/strut, or 6 min/bay. The results of these tests indicate that EVA assembly of space station size structure can be significantly enhanced when using a Mobile Transporter equipped with astronaut positioning devices. Rapid assembly time can be expected and are dependent primarily on the rate of translation permissible for on-orbit operations. The concept used to demonstrate integrated installation of utility trays requires minimal EVA handling and consequentially, as the results show, has little impact on overall assembly times.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space Station Assembly EVA Assembly Truss Structures Erectable Structures Mobile Transporter Large Space Structures	Unclassified - Unlimited Subject Category - 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	30	A03

NASA FORM 1626 OCT 86