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SUMMARY

This paper describes the results of a test program to assess the potential of manned extravehicular activity (EVA) assembly of erectable space trusses. Seventeen tests were conducted in which six "space-weight" columns were assembled into a regular tetrahedral cell by a team of two "space"-suited test subjects. This cell represents the fundamental "element" of a tetrahedral truss structure. The tests were conducted under simulated zero-gravity conditions, achieved by neutral buoyancy in water. The cell was assembled on an "outrigger" assembly aid off the side of a mockup of the Shuttle Orbiter cargo bay. Both manual and simulated remote manipulator system (RMS) modes were evaluated. The simulated RMS was used only to transfer stowed hardware from the cargo bay to the work sites. Articulation limits of the pressure suit and zero gravity could be accommodated by work stations with foot restraints. The results of this study have confirmed that astronaut EVA assembly of large, erectable space structures is well within man's capabilities.

INTRODUCTION

Future NASA space missions, such as solar power generation and Earth observation, will require "large" truss-type structures, such as shown in figure 1, to support the necessary mission equipment. No experience exists on actual in-space construction of even a portion of a structure of this scale. The three major construction approaches (ref. 1) now under consideration are (1) erection of efficiently packaged components taken from the Shuttle cargo bay, (2) deployment of ground-assembled structure, and (3) fabrication of major structural elements from "raw" materials (shaping and joining flat stock) followed by assembly into major platforms. The erectable construction approach currently includes component (columns/joints) assembly by astronaut extravehicular activity (EVA), by astronaut-controlled operation of the Shuttle remote manipulation system (RMS), by programmed robotic manipulation, and by combinations of these methods. The effort described in this report focuses on determining the potential for EVA assembly of erectable structures by two astronauts with and without RMS support. The structure selected for assembly testing was a six-member tetrahedral cell, as shown in the upper left inset in figure 1, which is the basic "element" of the large space truss. A summary is provided in reference 2 of a series of assembly tests on two different sizes of structure, one using 5.4-m columns and the other using 9.1-m columns. The present paper provides a more comprehensive description and analysis of the assembly tests on the 5.4-m columns than is contained in reference 2.

The purpose of this 6-month study was to assess astronaut EVA capabilities in the assembly of large (5.4-m-long, 10-cm-maximum-diameter columns), "space-weight," erectable structures under simulated zero-gravity conditions. This assessment was based on determining the accomplishment, dexterity, and maneuverability of the space-suited test subjects, as well as observations of the effects of training, experience, and fatigue. Specific objectives were to

1. Evaluate and adapt preliminary space truss hardware and assembly aids to facilitate the assembly effort.

2. Develop procedures for a two-man EVA assembly of a six-member tetrahedral cell with and without support from the Shuttle remote manipulator system, RMS-assisted, and manual modes, respectively.

3. Determine representative time lines for the assembly of individual components and the complete tetrahedral cell for the two assembly modes.

A motion-picture film supplement has been prepared and is available on loan. A request form and a description of the film are found at the back of this paper.

APPARATUS AND TEST SETUP

The six-column tetrahedral cell is shown in the upper left inset in figure 1 and in the test setup in figure 2. The cell was assembled on an outrigger assembly aid by two space-suited test subjects. The test subjects removed the test hardware (columns, joints, unions, and simulated equipment module) from a stowed position in the cargo bay mockup and transferred it to the specific assembly sites. They translated to the work stations on the handrails mounted on the assembly aids, and worked from foot restraints in order to free their hands and to react their generated forces. The entire test setup was placed on the floor of the neutral-buoyancy water tank, shown in figure 3 (ref. 3). The columns, simulated equipment module, and suited test subjects were neutrally buoyed to simulate zero-gravity conditions; that is, flotation material or weights were added to prevent sinking, rising, or preferred orientation within the working depth. Details of the apparatus and test setup are described in the next two sections.

Test Hardware

The columns, end joints, and unions were designed for low-weight, high packaging efficiency, single-assembly space truss applications (see refs. 4 and 5). The simulated equipment module was included to provide an assessment of attaching an experiment package to a major structure.

The structural test column used in this test series is shown in figure 4 (ref. 4). These tapered columns are nestable to achieve high packing densities, and when assembled, are capable of supporting a 3.6-kN compressive axial load and at least that amount in tension.

The column end joints are shown in figure 5. Both joints use a circular wedge and mating slot as the load-carrying path. As the two halves are brought together (with a motion perpendicular to the column axis as shown) the circular wedges (barrel section) and corresponding slot on the opposite joint-half engage. Upon full insertion the joint is secured by the external latching tabs on the quick-assembly joint, or by the internal latch on the quick-assembly/disassembly joint. The quick-assembly/disassembly joint was used only on the column joints at the tetrahedral cell apex.

The unions, shown in figure 6, provided the structural interface for the assembly of the columns. As designed, this structure can accommodate nine columns to form a nodal point within a tetrahedral truss structure (fig. 1). For this test program, only three columns were assembled at each node, requiring only three preassembled joint-halves on each union. The unions were mounted on the outrigger to receive the columns during the assembly tests. The union mounting was accomplished by using an external latch joint in the pedestals on the outrigger at the node positons, as shown at station B in figure 2.

The simulated equipment module (SEM), shown in figure 2, was an 80- by 60- by 60-cm tubular frame, covered with wire mesh. Handrails outside this envelope allowed the module to be easily grasped and manipulated by the test subjects. The module was attached to the tetrahedral cell apex union with a 2.5-cm coarse screw thread. A conical guide on the female joint-half mounted on the apex union assisted the test subjects in inserting the screw thread on the module. The entire module was rotated to accomplish assembly.

Test Setup

The structure used to support the assembly tests included the test setup shown in figure 2. "Space" (pressure) suits were used by the "astronaut" test subjects.

The outrigger assembly aid, fabricated from aluminum channel (15.2 by 5.1 by 0.3 cm), was attached to the sill of the cargo bay mockup and was supported off the floor of the tank at the outboard corners. The apex assembly aid (AAA), an 11.43-cm-diameter aluminum pole, provided a structure to support the test subject and the union at the apex of the tetrahedral cell during assembly. The AAA had a hinged/swivel base to allow erection from an initial horizontal position in the cargo bay and swiveling on the axis of the pole to a final position against the sill of the cargo bay. The pole was secured at the lip of the cargo bay by a hinged strap, bolt, and knurled handnut. The base was secured against subsequent swiveling by a pin installed through the deck.

The foot restraints (ref. 3) were designed for Skylab to secure an astronaut's feet by sequentially inserting his boot toes into loops and rotating his heels from the center of the plate outward to capture a wedge on the heel in a slot on the plate. Since the astronaut cannot see his feet, this series of maneuvers is accomplished by "feel."

The pressure suit used in this test series (model A7L-B, ref. 3) was developed for the Skylab, and is shown in figure 7. This suit requires an umbilical supply for life support systems of air, cooling water, and a communication link. However, since the current suit is designed for independent, self-contained operation in space, dummy back and chest packs were mounted on the suit (see fig. 7) to simulate self-contained life support systems. The suits are made from fabric and fabric-reinforced rubber and are pressurized within a range of 10 to 24 kPa (1.5 to 3.5 psi) above ambient pressure.

The pressure suit physical motion limits are shown in figure 8. The joints and flexibility allow considerable articulation. However, "ballooning" of the suit under the pressures just described forces the relaxed test subject into an apelike posture (arms and legs extended) and creates appreciable resistance to motion, particularly at articulation limits. This resistance is partially offset by internal straps and elastic bands. To assist in articulation, suit fit was emphasized; the suits through the Skylab era were tailor-made for astronauts. The current suit design is made in three sizes with interchangeable components, such as gloves and boots, to allow greater adaptability. Arm and leg lengths, as well as glove fit at the palm, are adjustable with internal straps and laces.

TEST PROGRAM

A total of 17 tests were conducted in a 6-month time frame for assembling the tetrahedral cell shown in figure 2. The program was conducted in two phases: test setup and procedure development (first 11 tests), and determination of time lines (time to accomplish individual tasks and to complete assembly of the cell - final 6 tests). No design effort was made prior to the test series to optimize the test hardware (available columns, joints, and unions) or assembly aids and procedures to meet manned EVA requirements. The hardware aids and procedures were modified and adapted (within reasonable cost and time restraints) throughout the development phase of the test program to improve the performance of the test subjects.

The logic used for the initial test setup and assembly procedures was based on maintaining simplicity and minimizing motion and effort by the test subjects. The initial setup contained only two foot restraints (one at each end of the column rack), no apex assembly aid, and minimum handrails (on the outrigger and cargo bay sill). Test hardware, procedures, and assembly aid modifications proposed during the test series were incorporated only after a consensus of the test participants.

Two different modes of two-man assembly procedures were developed, a manual mode and an RMS-assisted mode. The manual-mode assembly procedure required the test subjects to install the three unions on the outrigger assembly aid, install the three base columns, erect the apex assembly aid, install the apex union and the three upper columns, and then install the simulated equipment module. For the RMS-assisted mode tests, the procedure was modified to include a simulated Shuttle remote manipulator system (RMS) to assist the two test subjects by transferring the columns and unions to the assembly sites. Also, the apex assembly aid was erected prior to the test. The RMS was simulated by scuba-equipped utility divers, supporting the columns at each end during translation. No attempt was made to simulate actual RMS operational characteristics.

Test subjects were required to pass a rigorous physical fitness examination and have both scuba and pressure suit training. In terms of pressure suit and neutral buoyancy test experience, the test subjects (a total of 11) that participated in this test program ranged in experience from novice to expert.

Test data were collected through a number of systems, including videotape (five cameras with different view angles) with voice recording on the tape, 16-mm motion-picture cameras, 35-mm still photographs, and post-test debriefings by all participants.

Component assembly time lines were collected throughout the test series. System level time lines were credible only during the final six tests in which no further variables were introduced.

RESULTS AND DISCUSSION

The test program results are presented in this section for the two major phases of test setup and procedure development and determination of assembly time lines. A film supplement on test subject motions and hardware dynamics is available on request.

Test Setup and Procedure Development

A number of modifications were made to develop the test setup (fig. 2) and procedures. These modifications fall under four headings: assembly aids, test hardware (columns, joints, unions, and simulated equipment module), assembly procedures, and test subject performance. The major modifications made during the development effort are outlined in table I.

Assembly aids.- The need for an apex assembly aid (AAA) was immediately recognized during initial walk-throughs, prior to any assembly testing. Furthermore, test-subject-induced deflections at the apex required a major redesign of the AAA. The pressure-suited test subjects could not confidently grasp the test column to translate themselves, nor could the unions withstand the reactive forces induced by a translating test subject. The initial AAA design, using a 5-cm-diameter pole, allowed 1.2-m deflections at the apex during normal assembly operations. The AAA was stiffened by using an 11.4-cm-diameter pole, which allowed a 0.3-m apex deflection. Further modifications were made to assist the test subjects in orienting and erecting the AAA. An alignment pin, installed by a test subject, through the swivel base into the deck prevented undesired rotation. The diameter of the knob used to clamp the AAA to the cargo bay sill was increased from 2.5 to 3.8 cm.

Foot restraints were added and reoriented throughout the development effort. All the assembly aids proved to be flexible, which caused considerable difficulty in locating and aligning the unions to receive the columns. Consequently, the test subjects had to force the columns and unions into relative alignment, reacting these forces against the foot restraints.

Test hardware.- The space-weight columns and unions were easily manipulated and transferred, but considerable difficulty was encountered in joint assembly and verification of assembly.

The test subjects initially attempted to carry the unions (fig. 6) in a nylon "dive bag" for translation to the work sites. Although the unions could be easily grasped, their shape allowed snagging during withdrawal from the bag. This situation led to the elimination of the bag and the use of wrist tether attachments of the unions for translation.

Assembly of the column joints (fig. 5) was difficult, due to the close-tolerance design and the flexibility of the assembly aids. Installing the union pedestal joint (fig. 6), as shown in figure 9, presented little difficulty; the test subject could easily manipulate and align the pedestal to allow full seating and latch engagement. However, since the outrigger and apex assembly aid were not stiffened to prevent moving or twisting, the unions were neither properly located nor aligned relative to each other. Misalignment was reduced by pretest alignment of union pedestals, using the tetrahedral cell as an alignment fixture. Joint assembly difficulty was further reduced by allowing the column end joints to rotate and coordinating test subjects movements (see fig. 10) to assure that both ends were correctly located prior to assembly.

Verification of joint assembly (fully inserted and latched) presented a second difficulty. The four external latching tabs of each joint required only small deflections to open and latch, but could not be easily viewed or recognized by touch by the test subjects. Rotating and tugging the joint risked damage to the external latches if the joint had not been fully latched.

The external-latch joint could not be used in attaching the simulated equipment module to the cell apex union. The test subject had to reach under the SEM to grasp the joint with one hand, while attempting to align the joint by manipulating the SEM with the other hand. This maneuver, as well as an attempt to grasp, with both hands, the joint-half mounted on the SEM, was virtually impossible due to the interference of the test subject's helmet and the suit resistance to his accomplishing the necessary reach. Therefore, a threaded joint was substituted which allowed the test subject to grasp the SEM at its extremities, as shown in figure 11, and to install the SEM by rotation.

Assembly procedures.- The finalized assembly procedures for the manual and RMS-assisted modes are shown in tables II and III, respectively. Improvements in test subject performance were achieved by recognition through testing: establishing the best translation routes, establishing which subject of the two-subject team accomplished a particular function most effectively, and determining the best hardware location. For example, one change was in a maneuver which required a test subject to translate from station C to station A (see fig. 2) to initiate the erection of the apex assembly aid, which was stowed toward station A. This maneuver was changed to stow the apex assembly aid toward station B to allow the test subject already at station B to initiate the erection, while the subject at station C was translating through station A to the base of the apex assembly aid. Also, installing the apex union on column 4 prior to the start of the test (see table II) and installing that column as the first apex column (opposite the AAA), not only reduced the installation effort, but stiffened and stabilized the apex assembly aid.

The RMS-assisted mode assembly procedure (table III) capitalized on having erected the apex assembly aid prior to the assembly test, as well as using a simulated RMS to transfer the hardware to the work sites. Translation reductions were achieved in the initial transfer of unions from subject 1 to subject 2, in erecting the apex assembly aid, and in transferring the simulated equipment module.

Test subject performance.- Several general results on test subject performance were obtained from observation and test subject comments.

Although neutrally buoyed, test subjects' grasping and manipulating capabilities were affected by their gravity-influenced position in the suit. On reorienting themselves the test subjects "fell" inside the suit, due to the large interior volume. This falling repositioned the test subjects and prevented them from fully inserting their arms and hands into the limits of the ballooned suit and, consequently, reduced their ability to grasp objects. Grasping, manipulating, and passing the columns presented little difficulty, since minimal hand dexterity was required. The columns were grasped at one end with either two hands, as shown in figure 12, or with one hand after inserting the column in the armpit of the same arm. The test subjects were able to confidently slide the column through their hands, holding it against their shoulder and helmet, to allow the column to be grasped at any position along its length. The erection of the apex assembly aid (fig. 13) was a manageable task in spite of the fact that it was not neutrally buoyed; one test subject lifted the pole at approximately its midpoint and passed it to the other test subject at the pole's base. Installation of the pin in the base of the apex assembly aid was easily accomplished by a test subject in a prone position, as shown in figure 14. However, the assembly of the AAA latches at the cargo bay sill and the apex proved to be difficult in grasping and rotating the knurled knobs; the test subjects experienced appreciable fatigue in accomplishing the approximately 12 turns of the knob to seat each latch. Furthermore, at the apex of the AAA (fig. 15) the test subject was forced to reach to his limits, due to interference with his chest pack and pressure control unit.

Test subject view angles were limited by suit protuberances and stiffness. The subjects had difficulty in looking downward and in stooping and bending to achieve better view angles. In order to fully view an object, the test subjects routinely maneuvered their entire bodies (as in zero gravity) with their hands and arms, while maintaining a straight posture.

The degree of difficulty of body maneuvers to accomplish beneficial work ranged widely in this test program. All test subjects were comfortable and confident during hand-over-hand translations. (See fig. 16.) The most difficult work site (prior to incorporating foot restraints) was at station C (fig. 2). An extremely agile, experienced test subject could cling to the outrigger with his legs, toes, or arms and still be productive. The addition of a leg loop, as shown in figure 17, afforded little support; the subjects still needed an additional hand, foot, or arm for security. In fact, the test subjects had considerable difficulty in orienting their bodies and entering the leg loops, due to the bulkiness and protuberances on the suit. The use of foot restraints provided an adequate method of freeing the test subjects' hands and reacting forces, but required the test subjects to accomplish a blind maneuver (fig. 18) in positioning, orienting, and sequentially inserting their boots. These maneuvers were influenced by the surrounding structure from which the test subjects could grasp and apply moments and forces to accomplish entry. Once in the restraints, the test subjects' maneuvers and reach envelope were limited by the suit resistance. Furthermore, the location of the foot restraints, relative to the hardware to be manipulated (even at an ideal chest-high location), often did not provide an ideal mechanical advantage for the test subjects to apply forces, and thereby increased their expended effort.

Time Lines

Assembly time lines and time-line assessments are described in this section. Improvements in test subject performance are described in terms of total assembly times (fig. 19) for the tetrahedral cell and test setup modifications (table I).

The problems encountered in test 1 were caused by more than simple lack of experience. The 5-cm-diameter apex assembly aid allowed excessive deflections at the apex. These large deflections compounded the difficulty of completing the assembly of the apex structure. The test was terminated after the test subject, while attempting to climb on the test structure (during the installation of the simulated equipment module) fractured two columns.

In tests 2 to 4, the performance improved sharply over the initial run as the support hardware was modified. The apex assembly aid was stiffened, and foot restraints and handrails were installed. The simulated equipment module was moved to a more advantageous location at the base of the apex assembly aid.

The large reduction in assembly time for test 5 can be attributed to the experience and skill of the two test subjects. These subjects had many hours of previous experience in zero-gravity simulation tests, had nearly perfect fits in their pressure suits, and were entirely comfortable and confident in this test condition. Consequently, they were able to manipulate themselves and the hardware better than any other subjects in the test series.

In tests 6 to 8, the significant improvement over tests 2 to 4 can be attributed to providing foot restraints at station C (fig. 2).

In tests 9 to 12, a totally inexperienced test subject went through an impressive learning cycle. This test subject received his introduction to both the pressure suit and the test method simultaneously. Hardware improvements included outrigger alignment, allowing the column joints to rotate, and installing union D on column 4 (see sketch in table II) prior to the test before assembly of the cell.

The six final tests that were run to determine performance reproducibility yielded the following results: 29.3 minutes average with a spread of 0.24 minute for the manual mode and 15.4 average with a spread of 2.05 minutes for the RMS-assisted mode assembly. Since erecting the apex assembly aid was not included in the RMS-assisted mode, a more accurate comparison of assembly times between the two modes should include an additonal 3 minutes (fig. 19). On a per-column basis (for assembly of the tetrahedral cell and simulated equipment module) the manual mode required approximately 5 minutes per column, and the RMS-assisted mode required approximately 3 minutes per column.

The time lines for the assembly of individual components are shown in table IV as averaged values of data collected throughout the test program. These data were difficult to compile, since the starting and stopping times of each task could not be sharply defined. Furthermore, 11 different test subjects, numerous changes in test configuration, and an insufficient number of runs precluded the establishment of statistical inferences.

The greatest amount of total time consumed for assembly tasks (due to frequency) was in transferring the columns and assembling and verifying the integrity of the column end joints (103 seconds per column, items 7.5, 8.2, and 9.2), followed by the test subjects positioning themselves and ingressing the foot restraints (29 to 36 seconds, items 3.1, 4.1, and 4.2). Test subject translation times were significant in that all activity had to stop to allow both subjects to be in place at their work stations before work could continue. More difficult tasks, such as closing and verifying the clamps to secure the apex assembly aid pole (items 8.7 and 9.3) and apex union to the pole (items 8.8 and 9.4) required predictably longer times, 86 and 90 seconds. The single longest task (127 seconds) was to remove and install the simulated equipment module (items 1.5, 8.4, and 8.6).

No appreciable change in the time to accomplish individual tasks was observed as the test program progressed. That is, task element times from earlier tests were nearly equal to those obtained from later tests in which the assembly times were much shorter. This apparent incongruity can be explained by analyzing the nonassembly activities. Much of the nonassembly activities resulting in lost time were associated with resting, requesting instructions, making suggestions, and indecision. In fact, a 15-percent additional time factor was apparent, even among trained subjects.

CONCLUDING REMARKS

To assess manned extravehicular activity (EVA) assembly of a large orbiting space structure, 17 assembly tests were conducted on a regular six-column tetrahedral cell. This cell represents the fundamental "element" of a large tetrahedral truss structure. A simulated equipment module was installed at the cell apex to complete the system representation. The 5.4-m long, space-weight columns and joints were assembled by a team of two test subjects, wearing pressurized space suits, in both manual and simulated remote-manipulator-assisted modes. The cell was assembled on a Shuttle cargo bay mockup under simulated zero gravity (neutral buoyancy in water). The test setup (assembly aids and tetrahedral cell components) and procedures were modified during the test program to enhance test subjects' performance.

Assembly aids were the greatest contributor to assembly performance by the test subjects. These aids provided a fixture on which the cell was assembled, and a structure on which the test subjects translated and worked. Foot restraints at each work station freed the test subjects' hands and allowed them to react their generated forces.

The operational activities of test subjects are appreciably restricted by the pressurized space suits. Test subjects must learn to accommodate the limits of vision, articulation, and feel. The suit bulk and surface projections limit maneuvers and can make apparently simple tasks difficult, such as inserting a leg into a loop. Furthermore, relatively simple motions of hand-grasping and rotating hardware, such as screws, quickly cause fatigue. The columns were easily manipulated and passed by the test subjects, but once the joints were assembled, verification was difficult. The most difficult maneuver required for the test subjects in the final test setup was positioning and orienting themselves and entering the foot restraints. Once in the foot restraints, the test subjects often had to accomplish the work with poor mechanical advantages.

The results of this study have confirmed that astronaut EVA assembly of large space structures is well within man's physical capabilities in spite of the limitations of the pressure suit. The time to complete the assembly of the tetrahedral cell, 29 minutes or 5 minutes per column, may be significantly improved by using machines, such as a remote manipulator, to reduce the number of EVA tasks to yield a 3 minute per column assembly rate.

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TABLE I.- SUMMARY OF ASSEMBLY TIMES AND HARDWARE AND PROCEDURE MODIFICATIONS

Manual EVA mode

Test	Date	Assembly time, min	Hardware and procedure modifications affecting next test
1	3/22/79	87.0	AAA redesigned - diameter enlarged, foot restraint replaced leg loop restraints Column rack redesigned to hold columns in two rows of three columns each Relocated AAA to more vertical position Dive bag for tethering of unions discarded for wire loop tether on wrist Redesigned SEM attachment mechanism from snap joint to threaded configuration Relocated SEM stowage area from near station B to near base of AAA
2	4/16/79	54.37	Handrails installed at ends of column rack Relocated AAA foot restraint Indexed AAA base clamp Added leg loop restraint at station C
3	4/17/79	56.95	Loosened union mounting pedestals on outrigger
4	4/17/79	58.80	Enlarged knobs on AAA base clamp Added foot restraint at station A
5	4/18/79	33.33	Added alignment pins at base of AAA Modified AAA deployment procedure Added foot restraint at station C
6	4/19/79	45.75	Added handrails on diagonal braces of outrigger Reoriented AAA in stowed position
7	9/10/79	42.37	Repositioned AAA foot restraint
8	9/10/79	40.52	Modified procedure to install column 4 in union D as first apex column Repositioned foot restraints at station A, B, and C
9	9/11/79	54.58	Realigned outrigger, pedestals, etc.
10	9/11/79	40.18	Rotated joints on cell base to allow column installation with a downward motion, rather than upward
11	9/12/79	26.80	Placed apex (union D) on column 4 prior to start of test

TABLE I.- Concluded

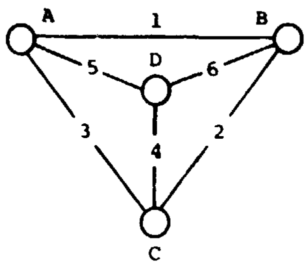
Manual EVA mode
to
determine cell assembly times (no modifications)

Test	Date	Assembly time, min
12	9/12/79	29.18
13	9/12/79	29.42
14	9/12/79	29.32

RMS-assisted EVA mode
to
determine cell assembly times (no modifications)

Test	Date	Assembly time, min
15	9/14/79	16.55
16	9/14/79	14.50
17	9/14/79	15.08

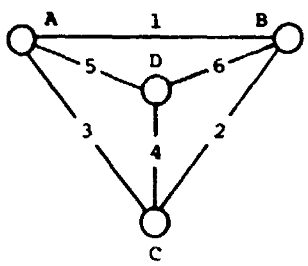
TABLE II.- MANUAL EVA ASSEMBLY PROCEDURE



Initial conditions: (1) Subjects 1 and 2 at station B
(2) AAA stowed down, toward station A
(3) Unions A, B, and C are in locker
(4) Union D is mounted on column 4

Step	Subject 1	Subject 2
1	Remove unions A and C Transfer unions to subject 2	Receive unions A and C Install C then A on wrist tether
2	Remove union B Install union B	Translate to station A Install union A
3	Maneuver column 1 toward station A Install column 1	Install column 1
4	Maneuver column 2 toward station C Install column 2	Translate to station C Install union C Install column 2
5	Translate to station A Maneuver column 3 toward station C Install column 3	Install column 3
6	Erect AAA Install position pin in AAA base	Translate to AAA base Secure clamp on AAA
7	Translate to station B Maneuver column 4 toward station D	Translate to station D Maneuver column 4 toward station C
8	Translate to station C Install column 4	Install union D in clamp
9	Translate to station A Maneuver column 5 toward station D Install column 5	Install column 5
10	Translate to station B Maneuver column 6 toward station D Install column 6	Install column 6
11	Translate to SEM Tether SEM Transfer SEM to station D	Install SEM

TABLE III.- RMS-ASSISTED EVA ASSEMBLY PROCEDURE



Initial conditions:
(1) AAA erected
(2) Subject 1 at station B, subject 2 at station A
(3) Subject 1 has union B tethered, subject 2 has unions C then A tethered
(4) Union D is mounted on column 4

Step	Subject 1	Subject 2
1	Install union B	Install union A
2	(RMS transfers column 1) Install column 1	Install column 1
3	(RMS transfers column 2)	Translate to station C Install union C
4	Install column 2	Install column 2
5	Translate to station A Install column 3	(RMS transfers column 3) Install column 3
6	Translate to station D Install union D in clamp	(RMS transfers column 4) Install column 4
7	(RMS transfers column 5) Install column 5	Translate to station A Install column 5
8	(RMS transfers column 6) Install column 6	Translate to station B Install column 6
9	(RMS transfers SEM) Install SEM	

TABLE IV.- ASSEMBLY TASK ELEMENT TIMES

Item	Task Element	Time, sec
1.0	Remove	
1.1	Union from box	7
1.2	Column from rack	8
1.3	Union from wrist tether	18
1.4	Waist tether from handrail	10
1.5	SEM from stowage	20
2.0	Translate	
2.1	Along sill 3 m	24
2.2	Along sill 6 m	43
2.3	Over edge of sill from outrigger	18
2.4	Over sill from cargo bay	10
2.5	Up AAA 4.5 m	33
2.6	Down AAA 4.5 m	22
2.7	Up AAA with SEM	44
3.0	Position body	
3.1	To ingress foot restraint	16
3.2	To ingress leg restraint	29
3.3	To receive column without leg restraint	13
4.0	Ingress	
4.1	Foot restraint (1 handrail)	20
4.2	Foot restraint (2 handrails)	13
4.3	Leg restraint (1 handrail)	37
5.0	Egress	
5.1	Foot restraint (1 handrail)	7
5.2	Foot restraint (2 handrails)	5
5.3	Leg restraint (1 handrail)	14
6.0	Attach	
6.1	Waist tether to handrail with restraint	16
6.2	Waist tether to handrail without restraint	21
6.3	Union to own wrist tether	17
7.0	Transfer	
7.1	AAA to vertical position	33
7.2	AAA to locked position	26
7.3	Column - 10° angular swing in horizontal plane, using foot restraint	12
7.4	Column - 60° swing, using foot restraint	44
7.5	Column - 60° swing without foot restraint	44
8.0	Mate	
8.1	Union to pedestal	28
8.2	Column to union (manual mode)	23
8.3	Column to union (RMS mode)	9
8.4	SEM to union (manual mode)	95
8.5	SEM to union (RMS mode)	34
8.6	Tighten SEM to union	12
8.7	AAA clamp to pole	56
8.8	Union to AAA pole clamp	55
9.0	Verify	
9.1	Union mated	20
9.2	Column end mated	36
9.3	AAA clamp secure	30
9.4	AAA union clamp secure	35

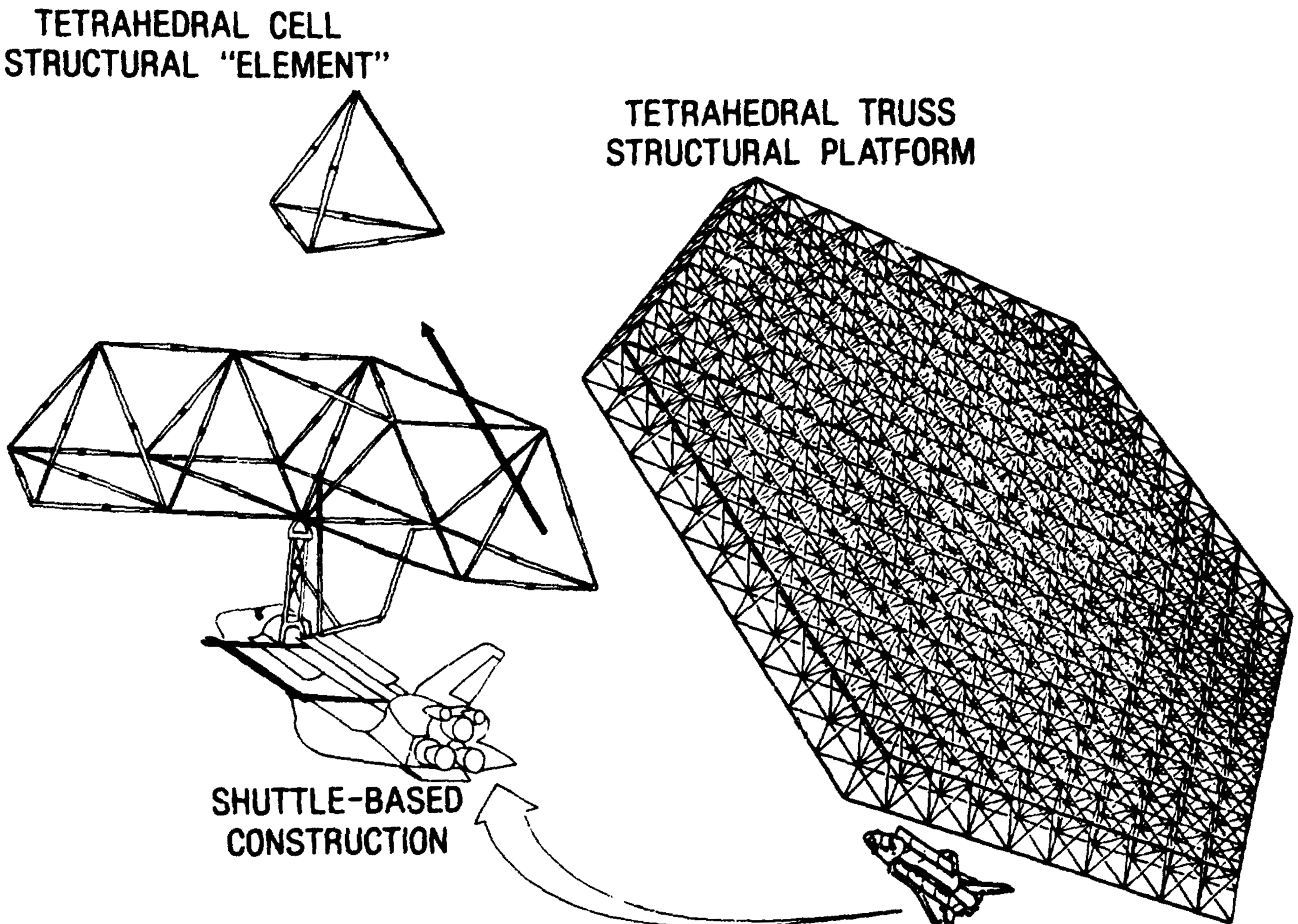


Figure 1.- Large space structure concept.

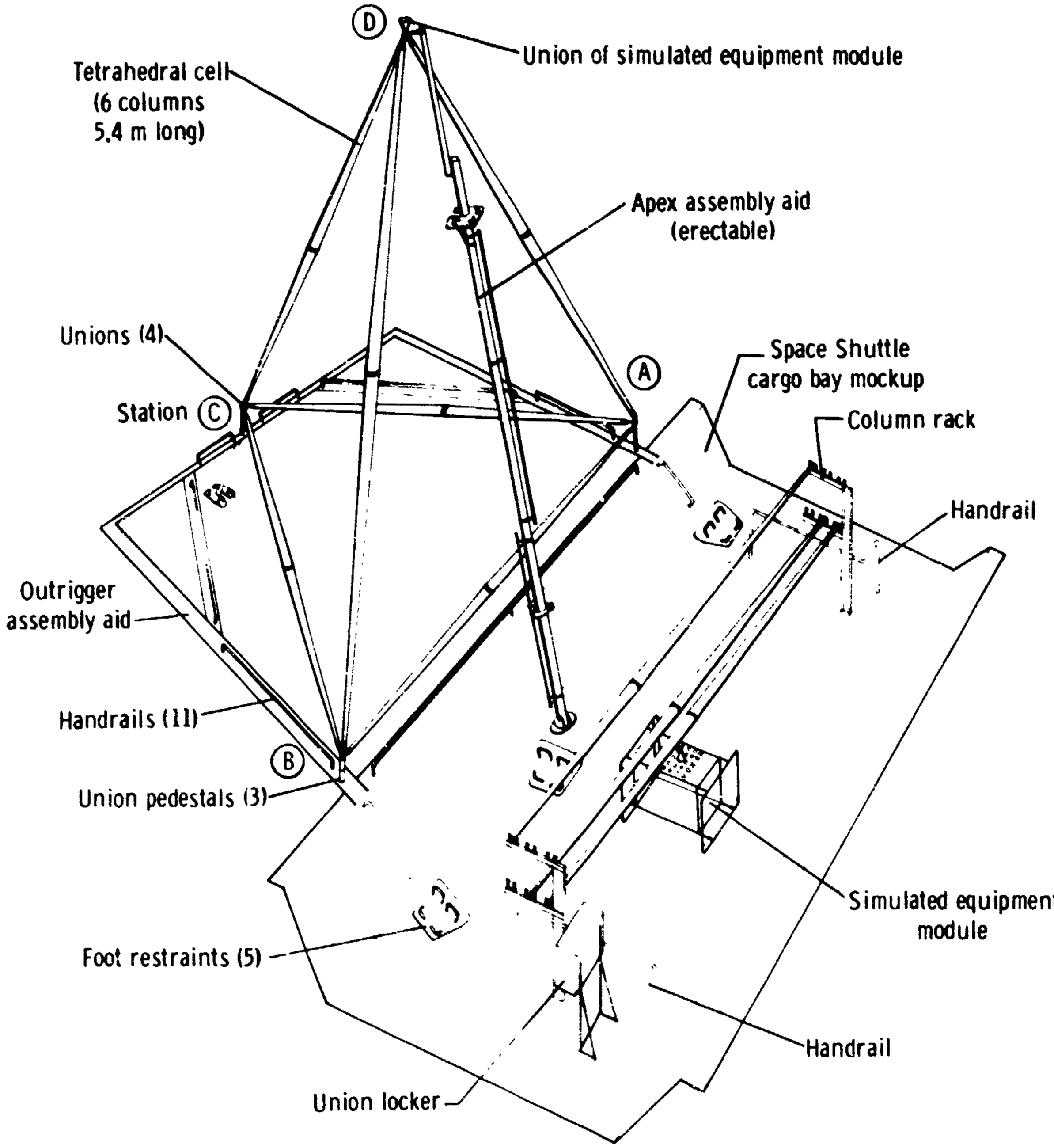
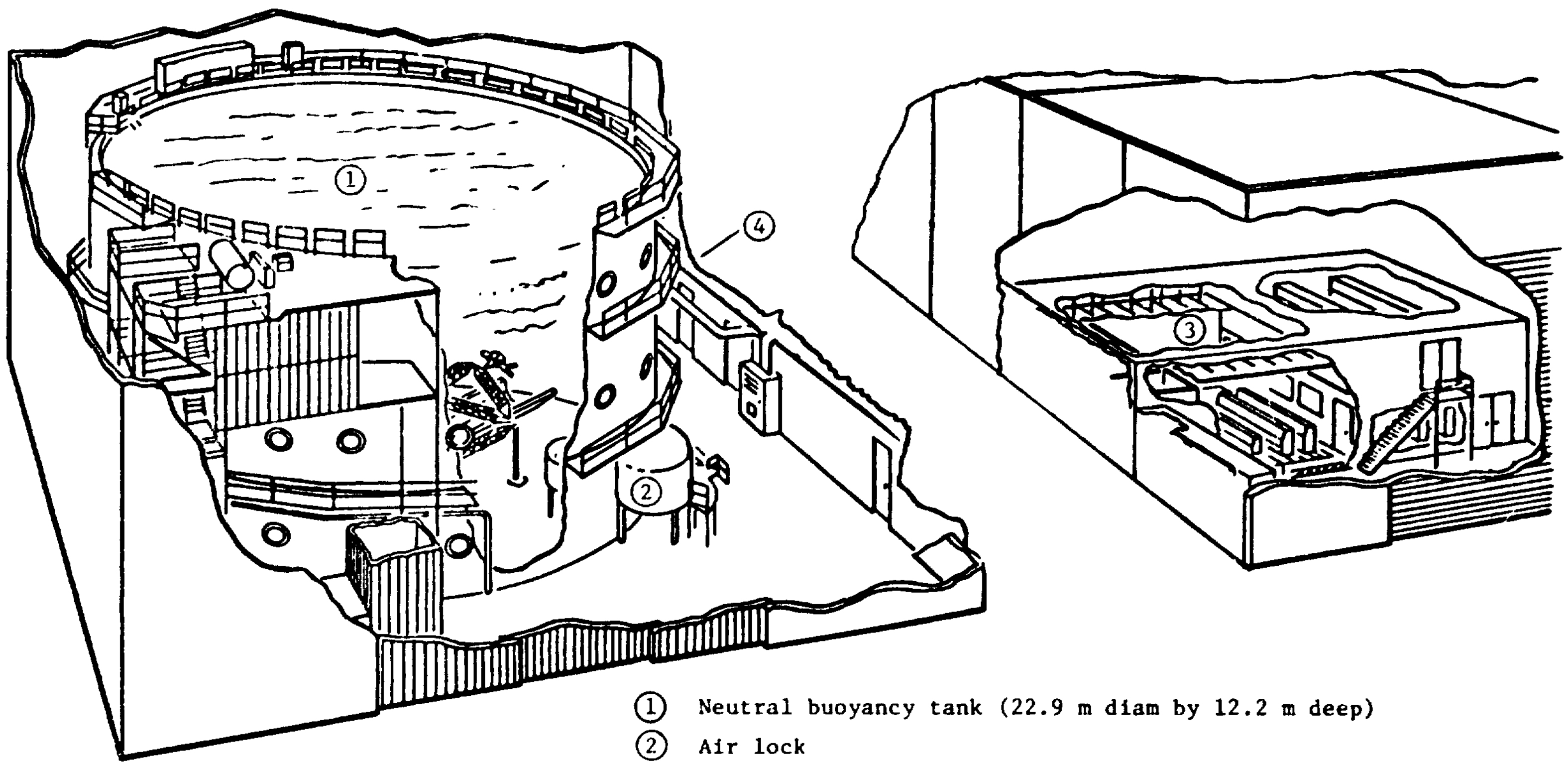


Figure 2.- Test setup for simulated zero-gravity assembly of space structure element.



① Neutral buoyancy tank (22.9 m diam by 12.2 m deep)
② Air lock
③ Control room
④ Suit-up room (not shown)

Figure 3.- Neutral-buoyancy, zero-gravity simulation facility.

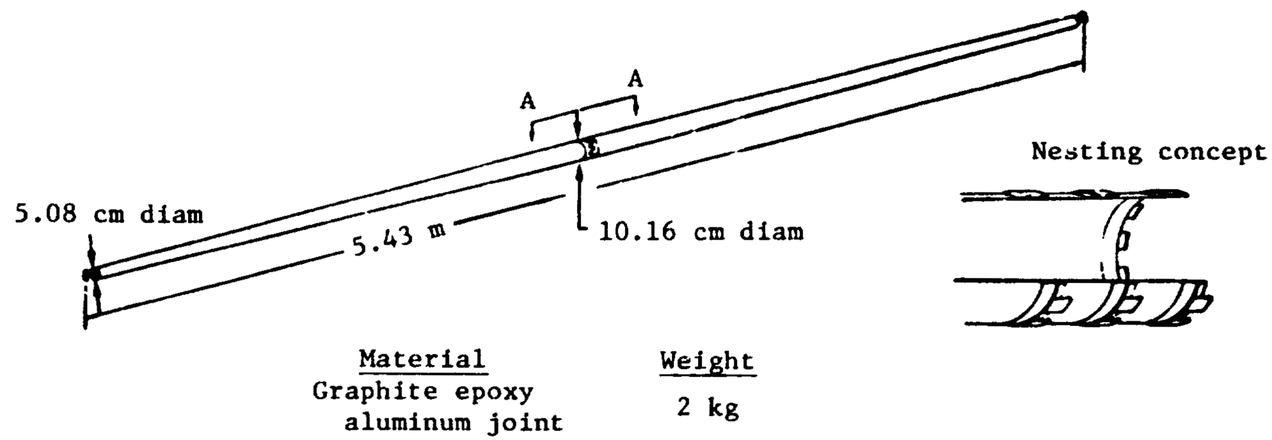
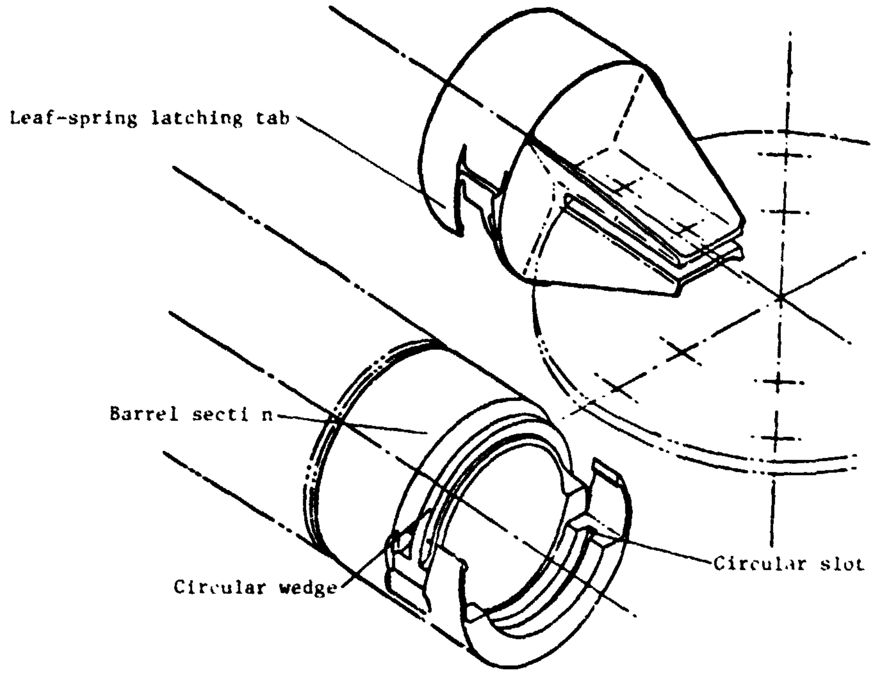
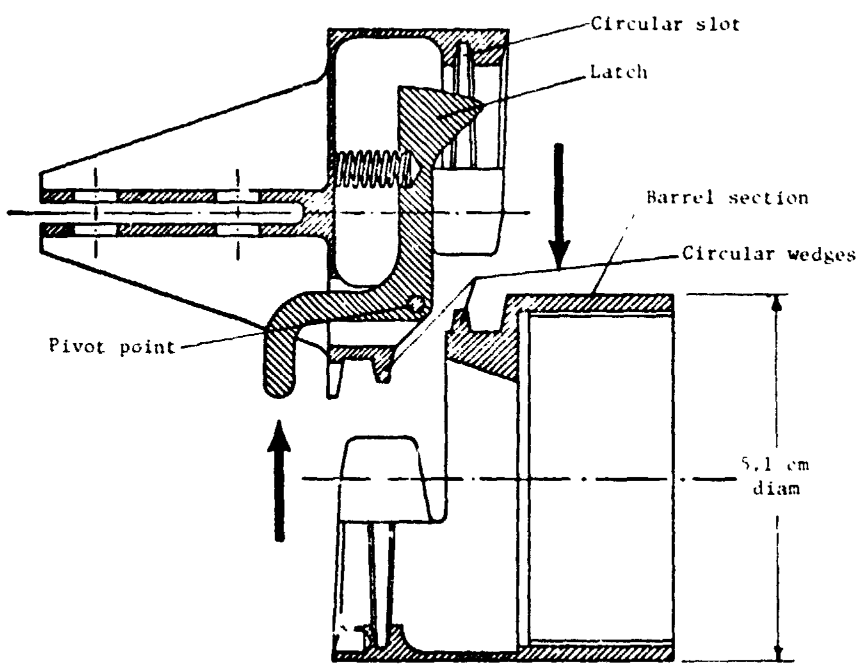


Figure 4.- Graphite epoxy nestable column.



(a) Quick-assembly, external latch joint.



(b) Quick-assembly/disassembly, internal latch joint.

Figure 5.- Column end joints.

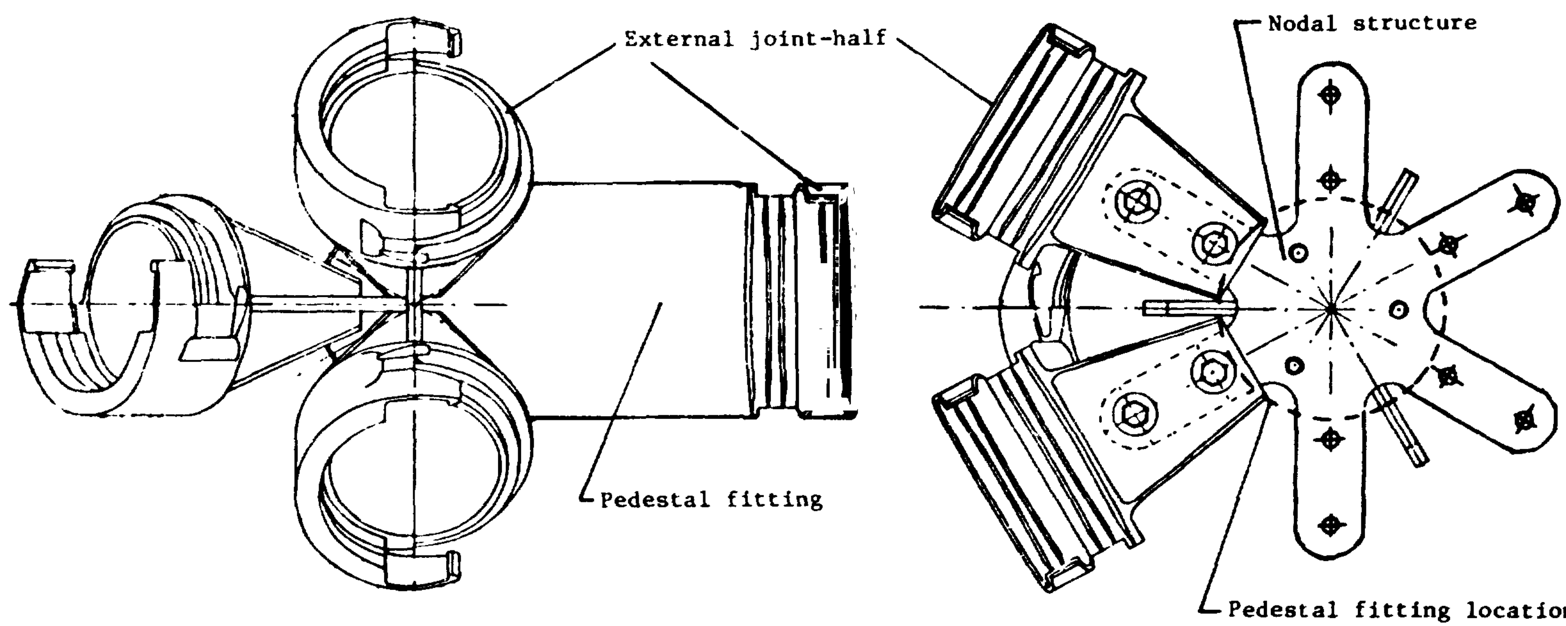


Figure 6.- Union for tetrahedral cell nodal structure, using external latch joint.

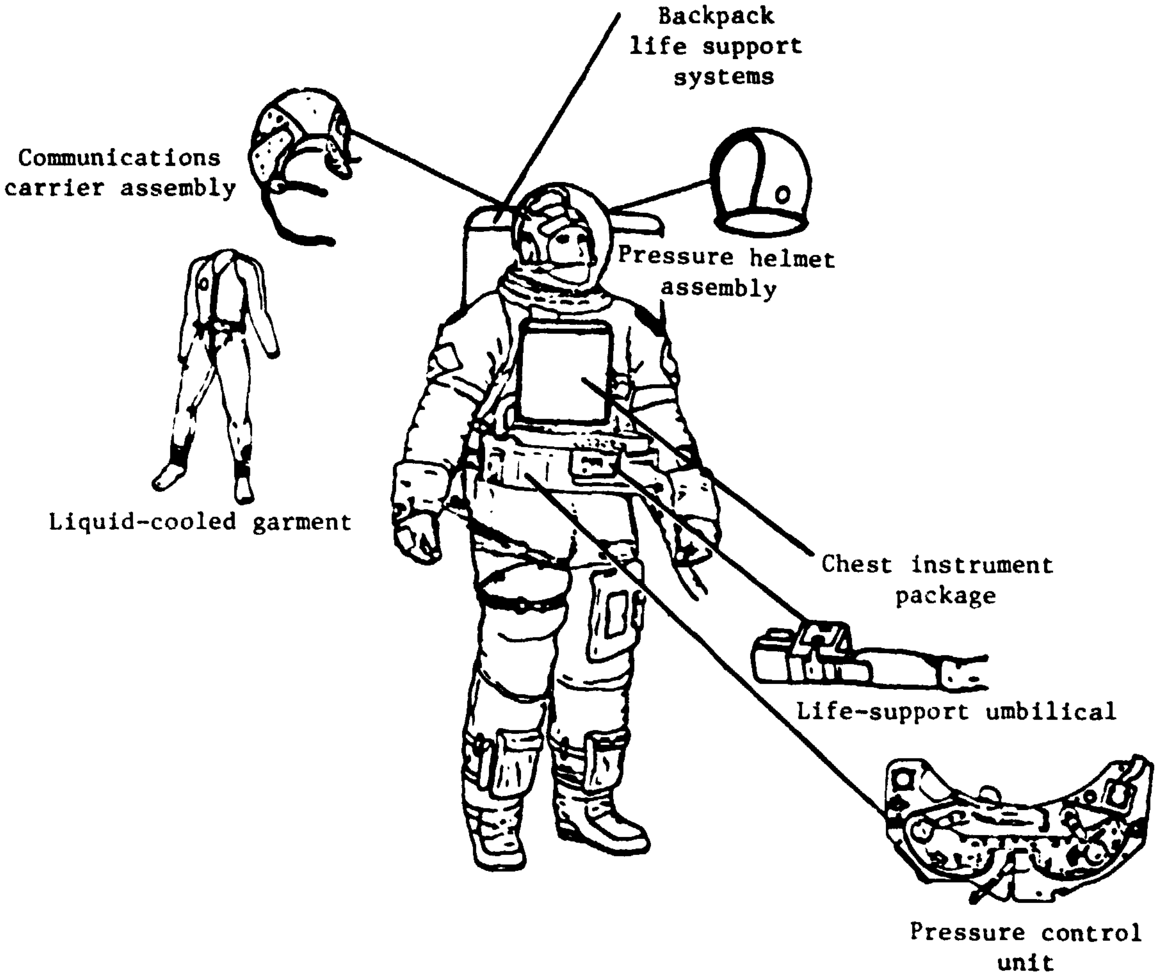


Figure 7.- EVA pressure suit.

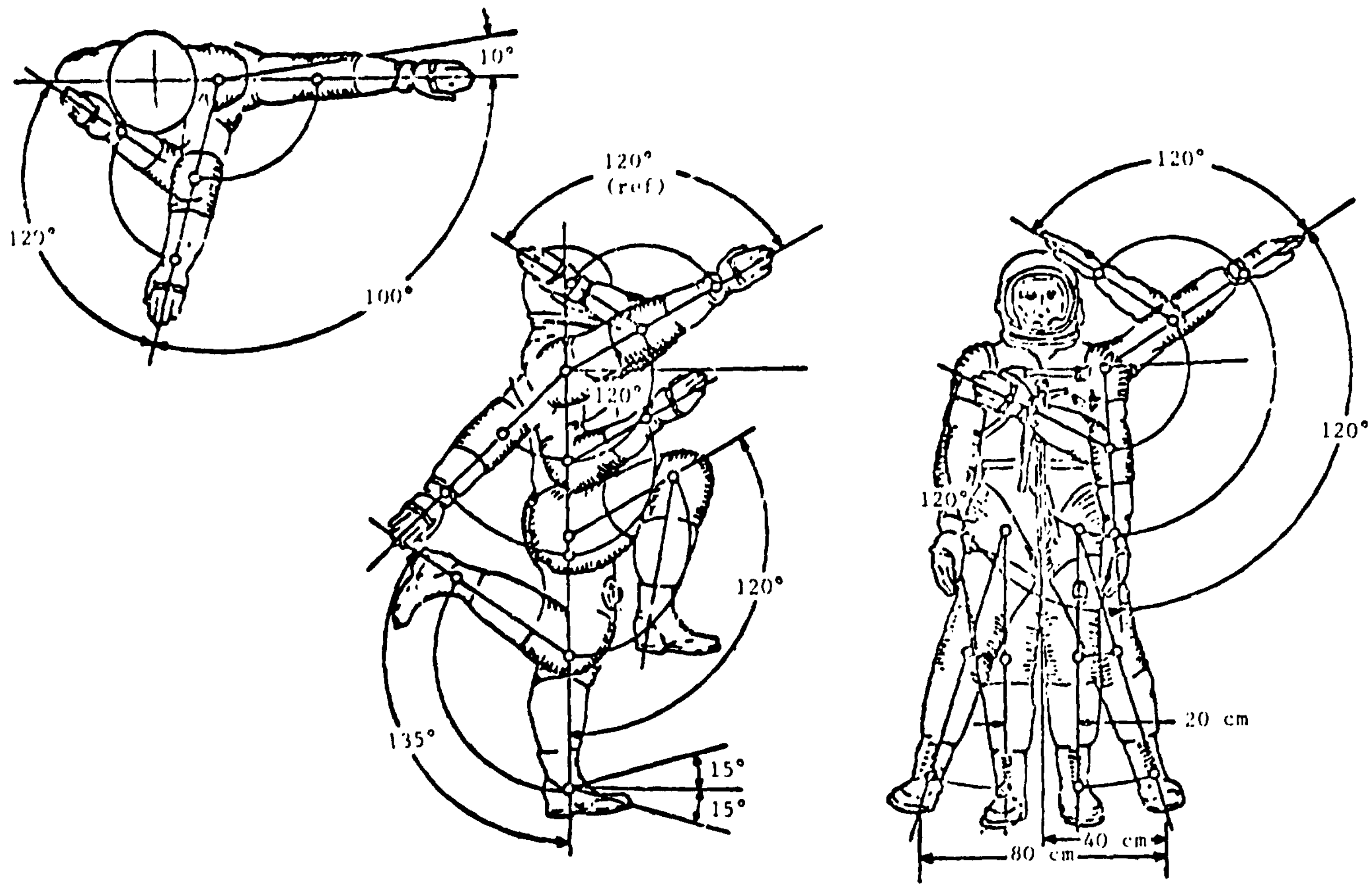


Figure 8.- Pressure-suit physical motion limits at 24 kPa (3.5 psig) pressure in suit.

L-81-141

Figure 9.- Union pedestal installation.

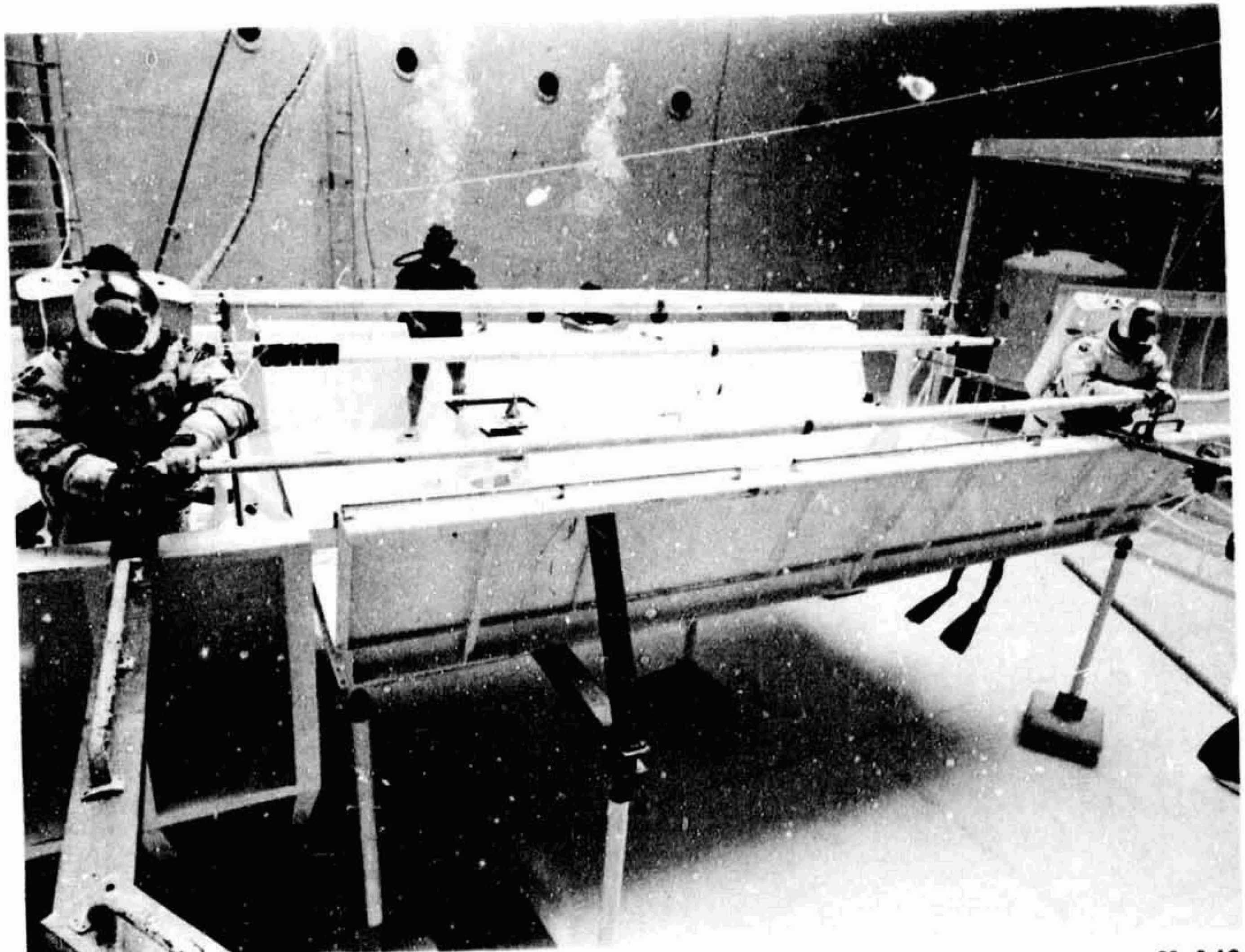


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Figure 10.- Column installation.

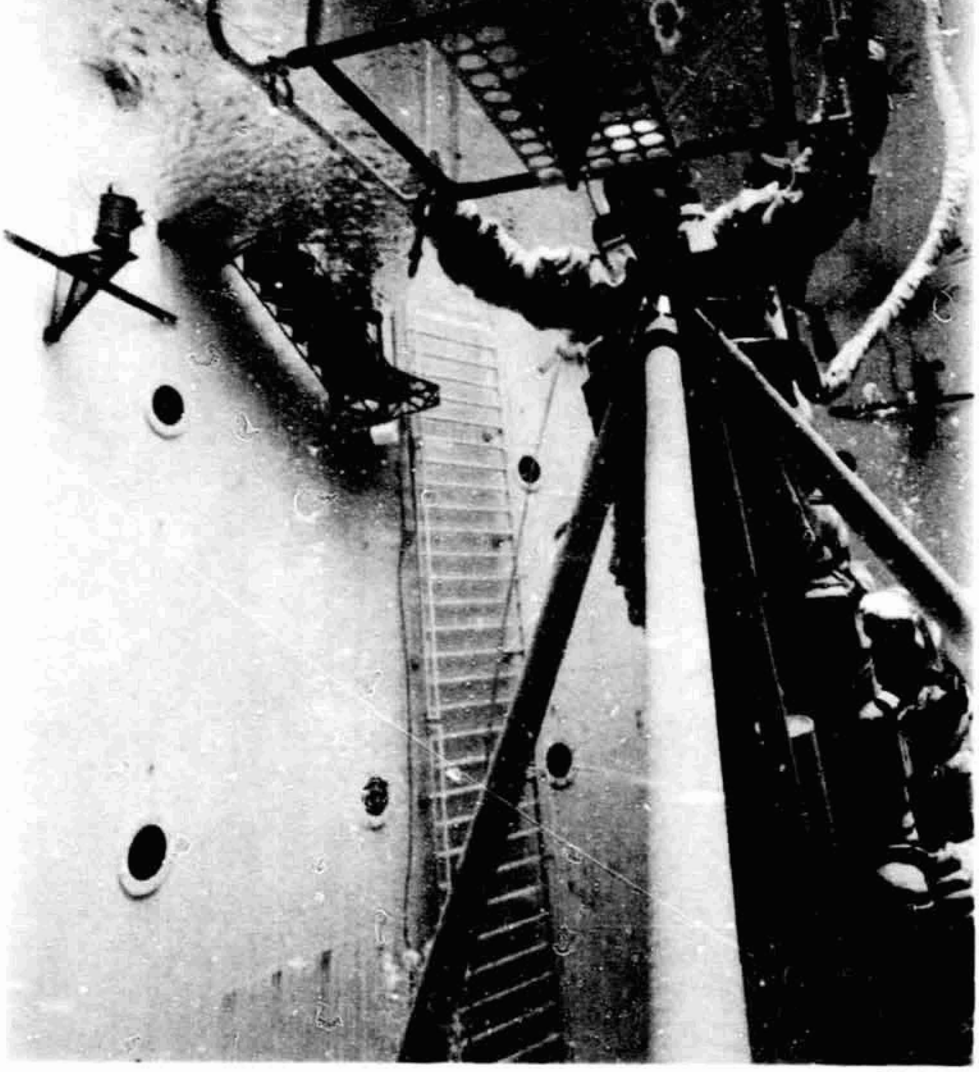

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Figure 11.- Installation of simulated equipment module.

L-81-144

Figure 12.- Column manipulation to installation site.

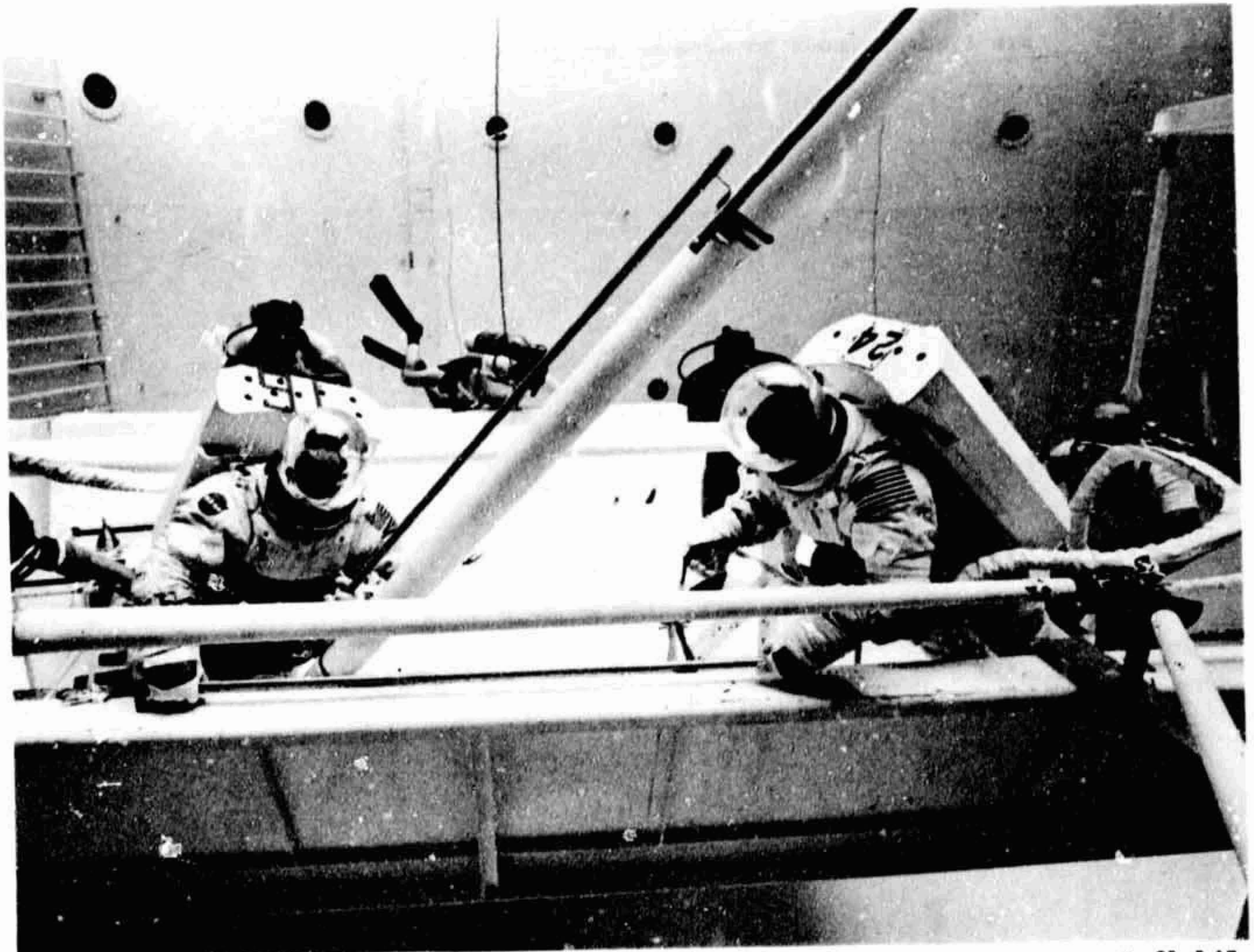

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Figure 13.- Apex assembly aid erection and latching.

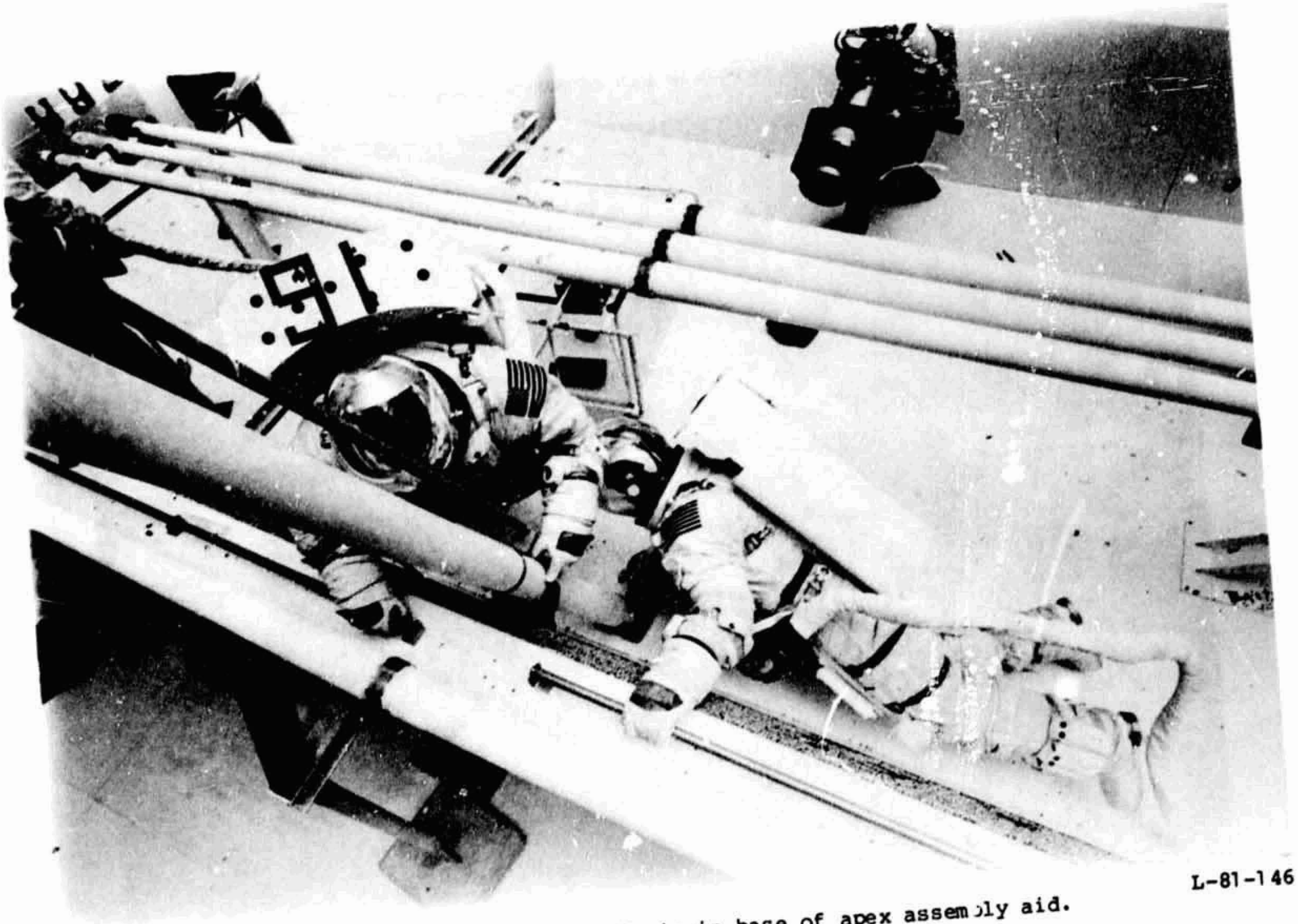

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Figure 14.- Installation of pin in base of apex assembly aid.

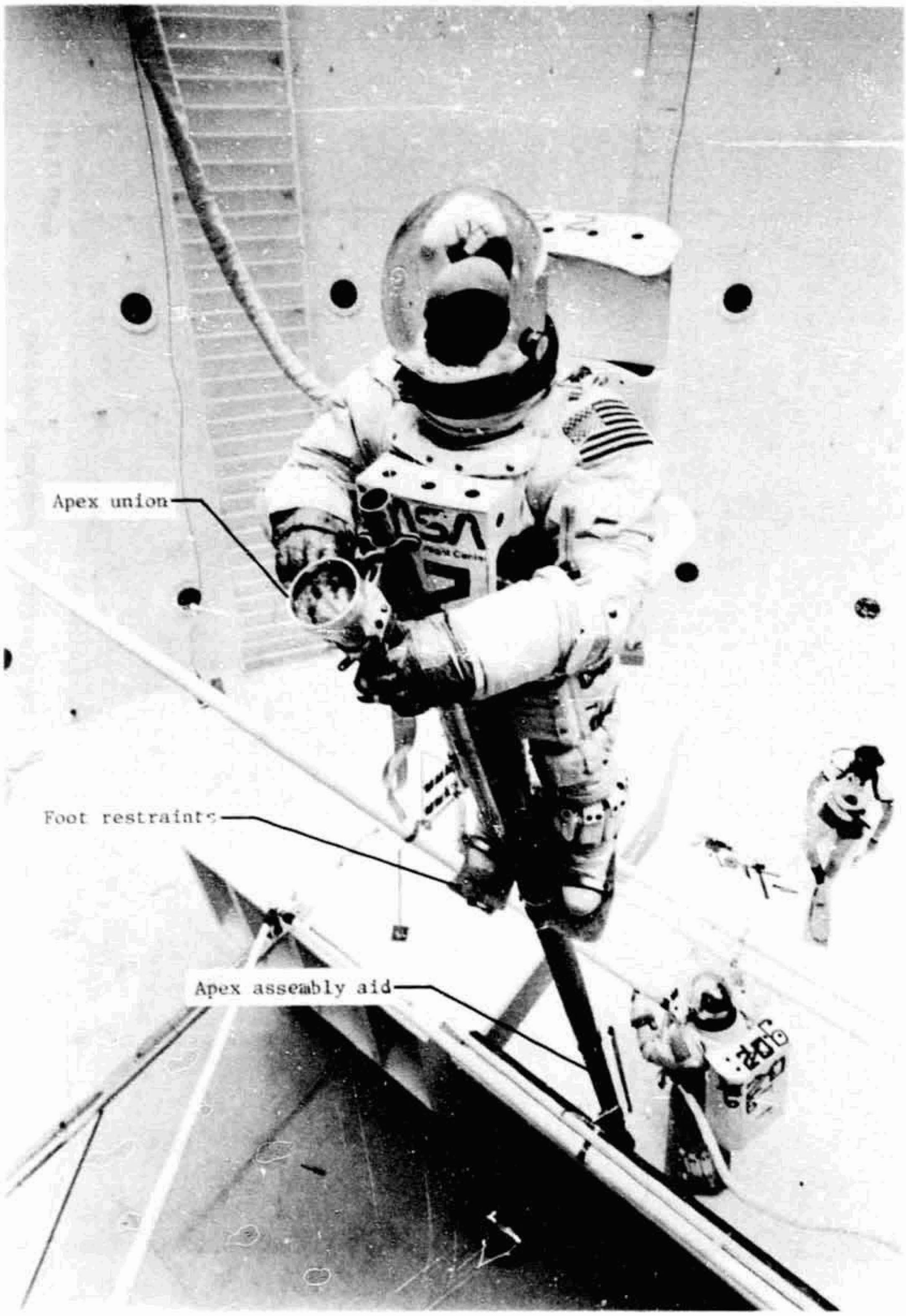

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Figure 15.- Test subject on apex assembly aid.

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Figure 16.- Test subject translating to another station.

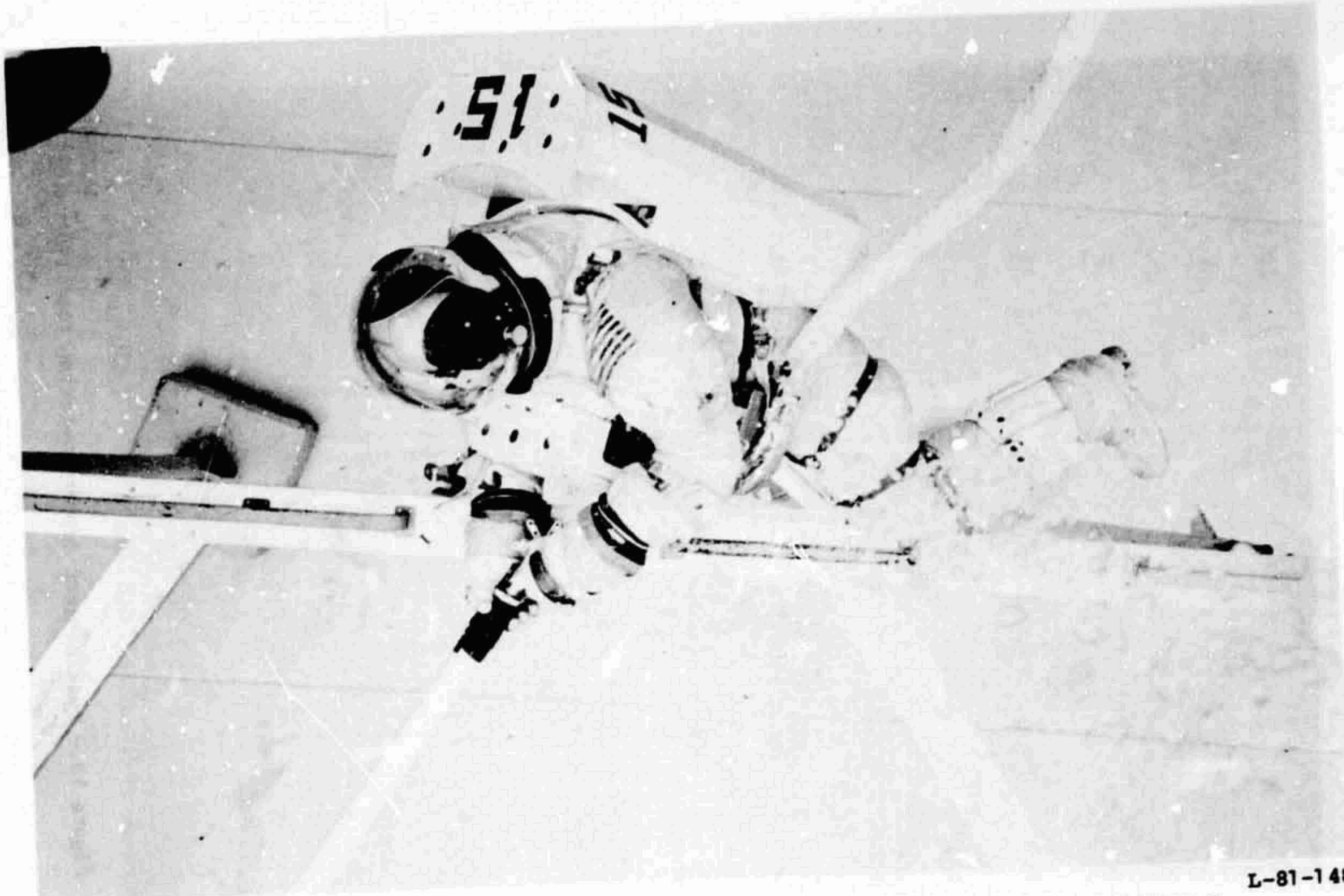

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Figure 17.- Test subject clinging to structure in leg loop restraint at station C.

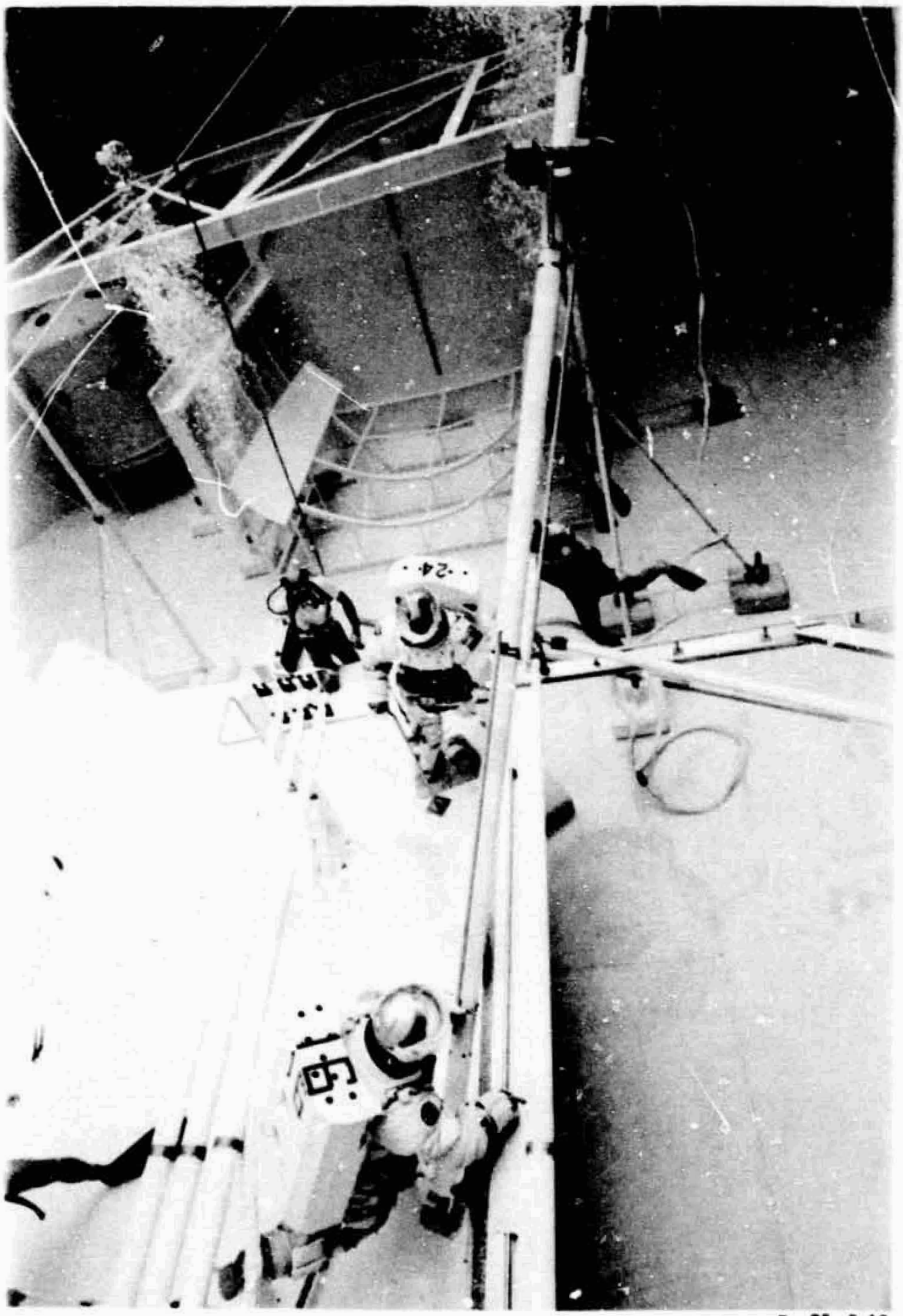

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Figure 18.- Test subject (upper) entering foot restraints.

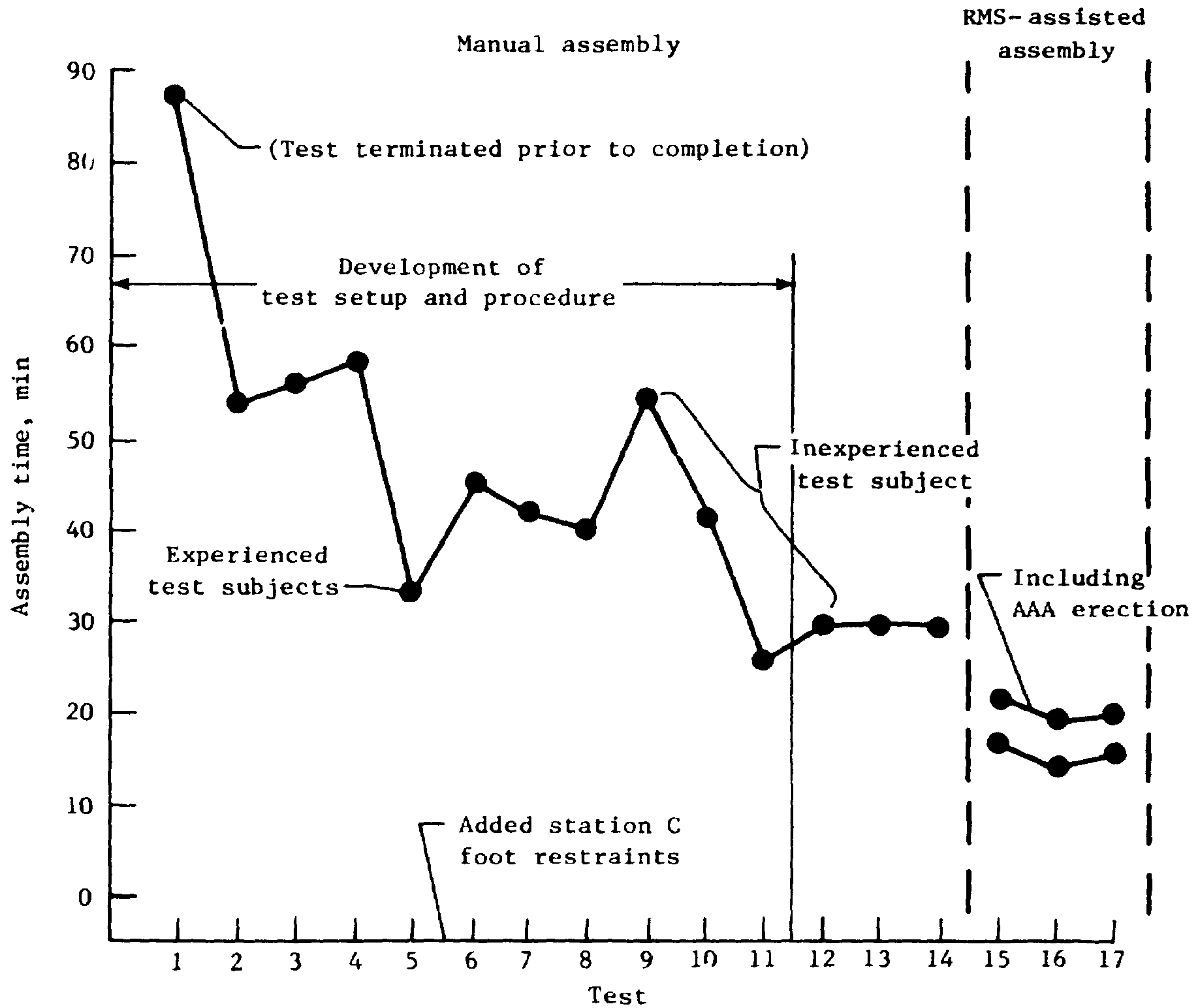

Figure 19.- Completion times of EVA assembly tests.