Swing-Arm Beam Erector (SABER) Concept for Single Astronaut Assembly of Space Structure

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NASA

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Summary

Results are presented of tests conducted to evaluate a mobile work station/assembly fixture concept that would mechanically assist an astronaut in the on-orbit manual assembly of erectable truss-beams. The concept, called the Swing-Arm Beam Erector (SABER), eliminates astronaut manual translation by use of a motorized work platform with foot restraints. The tests involved assembly of a tetrahedral truss-beam by a test subject in simulated zero gravity (neutral buoyancy in water). A three-bay truss-beam was assembled from 30 aluminum struts with quick attachment structural joints. When one bay of the truss-beam is assembled, the bay is mechanically advanced 1 bay length along its axis to clear the work site for assembly of a succeeding bay. This concept permits an assembly rate which depends on the length and maneuverability of the individual struts but not on the overall length of the truss-beam. The results show that average on-orbit assembly rates of 2.1 struts per minute can be expected for struts of the size employed in these tests. The equivalent of an 85-foot truss-beam was assembled in a 1 hour and 44 minute, simulated zero-gravity extravehicular activity period.

Introduction

To support future NASA space missions which will require large, low-mass space structures, the Langley Research Center is investigating concepts for efficient on-orbit manual assembly of erectable truss structure. In contrast to deployable trusses which are unfolded on-orbit, erectable trusses are assembled piece by piece. Shown in figure 1 is an artist's conception of a space station which makes extensive use of truss-beams. These trusses must be transported to orbit in a compact form and then either deployed or erected to their functional form. Both deployable and erectable construction methods have their applications, but erectable trusses feature more compact packaging (ref. 1) and relative structural simplicity. However, before erectables can be used effectively, efficient on-orbit assembly methods must be demonstrated.

Ground test programs (refs. 2 to 5) have been conducted to assess the potential of manned extravehicular activity (EVA) for orbital assembly of erectable trusses. Results of these programs show that astronaut EVA assembly is well within human capabilities. Assembly tasks have been broken down into basic steps to obtain average elemental times of performance which can be used to predict assembly times for larger and more complex structures. These task element times are useful, but totally manual assembly requires both astronaut and material translation and as the size of the structure increases, total translation time grows rapidly.

In 1981 an assembly experiment was performed by the Langley Research Center in the Neutral Buoyancy Simulator at the Marshall Space Flight Center. In this experiment two pressure-suited test subjects constructed a tetrahedral truss-beam with the aid of an assembly fixture and two mobile work stations (ref. 5). Two test subjects, secured to the mobile work stations by foot restraints, were mechanically transported within a defined work envelope while working cooperatively on opposite sides of the structure. When assembly of a structural segment (bay) of the beam was completed, the beam was advanced by conveyor 1 bay length along the assembly fixture to permit further assembly of the beam in the cleared work envelope.

The purpose of this report is to present another mobile work station concept which again combines the intellect, dexterity, and versatility of a human with the mechanical advantage of a machine to assemble truss-beams. This assembly concept, however, requires only one astronaut. An assembly fixture, incorporating a truss-advance mechanism, supports and manipulates the truss while a mobile work platform positions the astronaut. The concept is called the Swing-Arm Beam Erector (SABER). Using SABER, a multibay truss-beam is assembled one bay at a time. When a bay is completed, the fixture is advanced to clear the bay from the work area; the following bay is then assembled, and the fixture retracts to pick up the new bay and again advances to clear the work area. This procedure is repeated until a beam of the required number of bays is constructed.

This report describes the SABER hardware, truss hardware, and assembly tests performed in both $1g$ (Earth gravity in air) and simulated $0g$ (neutral buoyancy in water) environments. In addition, assembly rates obtained from these tests are presented and assembly times for on-orbit construction are estimated. A motion picture film of the tests in the simulated $0g$ environment is available on loan. A request form with a description of the film (L-1292) is available at the back of this report.

Apparatus

Truss Hardware

Struts. Thirty 1-inch diameter, tubular, aluminum struts, 20 of which are 5.3 feet long and 10 of which are 6.2 feet long, are assembled into a three-bay tetrahedral truss-beam of equilateral triangular cross section. The truss, sketched in figure 2, is 17.2 feet long. Typical struts are shown in figure 3(a). The struts are formed from two half-struts, each of which has an aluminum plug bonded into one end as shown in figure 3(b). Two half-struts are connected by an aluminum sleeve that is riveted to the plugs. (The struts are made

in two watertight halves to facilitate neutral buoyancy adjustment).

Aluminum end-joint fittings, as shown in figure 3(c), are bonded to one end of each half-strut, and a spring-loaded locking sleeve with a snap-ring retainer completes the assembly. The spring-loaded locking sleeve is designed to enable quick release as well as quick attachment of the joint by manual methods. The locking sleeve is fitted with a set-screw which travels along a groove in the end-joint fitting. The groove and set-screw arrangement allows for the sleeve to be retracted and held in the open position while the strut is being attached to the node. The fittings are designed to secure the joint by either automatic or manual closing of the locking sleeve. Figure 4 shows the sequence of attaching the strut to the node by using the automatic locking feature. Figure 4(a) shows the locking sleeve cocked and ready for attachment to a node. Figure 4(b) shows that as the strut end is brought laterally into the node, the locking sleeve is pushed in a longitudinal direction away from the node by the interlocking fingers of the joint. This action causes the set-screw in the sleeve to follow the helical groove in the strut, rotating the sleeve about the axis of the strut. After this rotation, the set-screw is aligned with the longitudinal groove in the strut; this allows the spring to propel the sleeve forward to secure the joint. Figure 4(c) shows the joint secured. The joint is released by retracting the sleeve. As shown in figure 4(d), the sleeve is locked in the fully retracted position for this operation so that the strut may be removed after both ends are released.

The watertight half-strut is buoyant in water; however, for the simulated 0g assembly tests the struts must be made neutrally buoyant. The hollow section of the joint end-fitting (labeled "ballast pocket" in fig. 5) is used for this purpose. Lead ballast is added to the strut end-joint fitting pocket to trim the half-strut to a neutrally buoyant condition in a vertically oriented position. A perforated stainless-steel disk and snap-ring retainer are used to contain the lead ballast. When two half-struts are joined, the full strut is neutrally buoyant in any orientation.

Nodes. A photograph of a typical node is shown in figure 6. Each node is required to serve as a junction for six struts. As can be seen in the photograph, fittings that interlock with the strut end fittings are bolted to the nodes. The nodes are made of formed aluminum sheet. A deep web with Teflon[1] pads was used to allow the node to slide in the assembly fixture guide rails. The web has a hook-shaped slot which serves as

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[1] Trademark of E. I. du Pont de Nemours & Co.

an attachment point for the advance mechanism of the assembly fixture.

SABER Hardware

A schematic of the SABER concept and hardware is shown in figure 7. A test subject is positioned in the work platform atop the telescoping mast, which is shown extended. The SABER consists of five major components: (1) a work platform, (2) a telescoping mast for the work platform (elevator), (3) a swing-arm for moving the work platform around the assembly fixture, (4) a strut stowage rack, and (5) an assembly fixture which features a truss-advance mechanism. This hardware is designed to fit on a pallet positioned inside the Shuttle cargo bay so that a beam of nearly any length can be assembled in the Shuttle $+z$-direction (yaw axis). A photograph of the SABER hardware is shown in figure 8. It should be pointed out that this is a laboratory prototype with weight (1800 lb) and configuration dictated by 1g assembly operations and by underwater operations. Assembly operation in space would permit a lighter, more compact system designed to meet the criteria of that environment. However, the basic configuration and operating principles would be similar.

In the SABER concept, one subject manually removes the struts from the stowage racks and makes the structural connections. At all times during the assembly, the test subject is secured by foot restraints on the work platform and is moved within a prescribed work envelope. The work platform, which is situated on the swing-arm, can be rotated to any position on a 270° arc about the axis of the assembly fixture mast and can also be raised or lowered on a telescoping mast. The completed segments (bays) of the truss are moved out of the work area by the advance mechanism. The SABER movable components are powered by three air motors (four in 1g to counteract the increased loads due to gravity) controlled by an operator at a remote console. The console and operator are shown in figure 9. The air motors and control system which are used to facilitate underwater operation are not representative of flight hardware. In space, motors and controls presumably would be electrical and the assembly procedure controlled by computer. Also, controls could be placed directly on the work platform for direct control by the working astronaut. For the present tests, the platform is moved at approximately 1.55 feet per second through the arc (5-foot radius) and 0.82 foot per second vertically. These speeds decrease somewhat in a 1g environment when test subject weight is more than approximately 150 pounds. In addition, deterioration of the lubricant as well as the hardware in the underwater environment also affects the operating speeds.

Tests

Test Setup

A series of 1g and simulated 0g assembly tests was performed. The 1g tests were performed at LaRC with the test subject in street clothes. As shown in figure 8, the SABER was located inside a building and attached to a concrete floor. The simulated 0g tests were performed underwater in the Neutral Buoyancy Simulator (NBS) at the Marshall Space Flight Center. Figure 10 shows a typical test nearing completion. The test subject is shown wearing a NASA A7L-B Skylab pressure suit. Several tests in the NBS were also performed with test subjects in scuba gear. These scuba tests were used for checkout of the equipment and test procedure. They were also used to obtain data for comparison with the 1g test results and the simulated 0g pressure suit test results. For the simulated 0g tests, SABER was attached to a mock-up of the European Space Agency (ESA) pallet. The ESA pallet was mounted inside a full-scale mock-up of the Shuttle cargo bay as shown in figure 10. The 30 struts used to assemble the beam were stored in racks located to the left- and right-hand sides of the test subject as shown in figure 11. The strut racks were mounted on the work station platform so that the stored struts were always within arm's reach of the test subject.

All simulated 0g tests were recorded by a roving videotape swim-camera. The videotapes include voice recordings of the test subjects during the assembly tests. In addition, 16-mm motion pictures and 35-mm still photographs were taken with portable underwater cameras. The 1g tests were recorded by still and motion photography.

Test Procedure

The assembly logistics for the 1g and 0g tests are identical. The work platform must visit six different positions to allow the astronaut to make the structural connections. These positions are designated by the double letters in the schematic shown in figure 7. The three guide rails are designated A, B, and C, respectively, with LA, LB, and LC being the lower work positions and HA, HB, and HC being the upper work positions. The tests are initiated with the test subject secured by the foot restraints on the work platform. The platform is located in the start position at guide rail A with the elevator in the fully retracted position as shown in figure 12. Struts are stored in the strut racks, and four nodes (three for the 1g tests) are stored at the lower end of each guide rail. There is two-way voice communication between the test subject and the console operator.

In the 1g tests, three different subjects manned the work platform, and two different console operators were used. During the simulated 0g tests, two different subjects manned the work platform while only one console operator was used. Table I presents a summary of the participation of the test subjects and the console operators for all tests.

The basic task of the test subject is to locate the nodes (fig. 13) and then to install the struts by attaching the ends to the correct node fittings, as indicated in figure 14. A strut being attached to a node at station LB is shown in figure 15. When this step is completed, the swing-arm moves the test subject to his right to station LA. The test subject then picks up the top node from storage, slides it up the guide rail and attaches it to the free ends of the struts shown in the upper right in figure 15. The console operator has responsibility for moving the subject to the various work stations and keeping the subject informed of the appropriate steps in the assembly procedure. The fully assembled truss in the simulated 0g environment is shown in figure 10.

A number of 1g tests were performed to develop the assembly procedure, which is presented in the appendix. Once this procedure was developed, several 1g tests were timed to establish assembly rates. A comparison of figure 8 showing a 1g test and figure 11 showing a 0g test reveals that the strut stowage racks were mounted on the work platform in different orientations. In the 0g tests, a change in the strut stowage rack locations was required to accommodate the pressure-suited test subject because test subject movement was found to be restricted by interference between the pressure control unit (used solely for life support for underwater operation) and the strut stowage rack. Data taken from subsequent 1g tests with the strut stowage racks reoriented showed that this change had no effect on 1g test assembly rates. After this minor design change, 31 simulated 0g tests (16 with test subjects in pressure suits and 15 in scuba gear) were conducted and timed. For these tests a given test subject always had the same console operator. In all but the scuba tests, the console operator controlled the tests by following the assembly procedure so that the correct instructions could be relayed over the two-way voice communication system. Since the assembly procedure consisted of simple repetitive steps, it was quickly memorized by the test subject; therefore, the scuba tests could be conducted with no voice communications. Only simple hand signals by the test subject were required to notify the console operator that a particular task was completed.

Results and Discussion

A 5-minute film supplement of the simulated 0g tests is available upon request. A request form for this supplement appears at the back of this report.

Assembly Logistics

A systematic assembly procedure developed for these tests is presented in the appendix. The procedure consists of a series of assembly tasks which the test subject must perform to construct one bay of the truss. The series of assembly tasks is then repeated for each successive bay assembly. Because of the repetitiveness of the steps, the test subject and console operator quickly learned the procedure during the first several $1g$ tests. Little voice communication was needed for subsequent tests. Each test subject learned to anticipate the next set of instructions and the console operator learned to move the test subject and advance the truss while giving instructions; thus, periods of idleness were eliminated. An untimed $1g$ assembly was also performed by each of two NASA astronauts who were unfamiliar with SABER and the assembly procedure. After receiving a short briefing and watching a partial assembly by an experienced test subject, the astronauts easily performed a successful assembly test.

Although tethering of the crew and truss hardware may be a requirement for space operation, no tethers were used in the SABER tests. A crew tether was not used because the test subject was not required to leave the foot restraints during the assembly tests. Also, despite the absence of strut and node tethers, no loss of hardware occurred in either $1g$ or simulated $0g$ tests. Since climbing on the structure was not required, a strut secured at only one end remained in place while the test subject was moved to the next work position to secure the opposite end.

An important feature of the SABER concept is that it enables astronaut construction of large truss-beams in space with state-of-the-art techniques. SABER relieves the astronaut of the difficult and fatiguing tasks of manual translation of himself and hardware to advantageous work positions.

Assembly Times

Average assembly times and corresponding assembly rates of the three-bay truss-beam using SABER are shown in table II for three ground test conditions. Also shown is an estimated assembly rate for space operation of SABER. Because of laboratory space restrictions, only two bays of the truss-beam could be assembled in the $1g$ environment. Assuming the third-bay assembly time identical to that measured for the second bay resulted in an average assembly time of 9.0 minutes for three full bays of structure assembled in $1g$ with test subjects in street clothes. This translates into an assembly rate of 3.3 struts per minute. The simulated $0g$ assembly in scuba gear also took an average of 9.0 minutes for three bays for an identical assembly rate. The similarity of the data from these two tests

shows that the effect of water drag on the assembly times was insignificant for the relatively small struts being assembled. The simulated $0g$ assembly with pressure suits required 14.5 minutes for three bays for an assembly rate of 2.1 struts per minute.

The assembly time for the $1g$ tests is shown in figure 16 plotted as a function of test number for each test subject. The solid symbols are the measured times for assembly of two bays. Also shown by the open symbols are the projected three-bay assembly times, assuming the third bay is assembled at the same rate as the second bay. These projected assembly times are presented for comparison with the data taken during the simulated $0g$ tests where three bays were assembled. The simulated $0g$ data are presented in figure 17. The solid symbols represent times for scuba assemblies and the open symbols represent times for pressure suit assemblies.

A comparison of figures 16 and 17 shows that times for $1g$ street clothes and $0g$ scuba gear assembly become asymptotic to an assembly time of about 9.0 minutes, indicating essentially no effect of water drag or gravity on assembly times. Hence, the assembly times from pressure suit tests should be a good approximation of space assembly times.

Five consecutive assemblies of a three-bay beam performed by one pressure suited test subject in one simulated EVA test provided an indication of how SABER minimizes the effect of astronaut fatigue on assembly rate. The simulated EVA lasted 1 hour and 44 minutes including four 10-minute rest periods. The total amount of structure assembled was equivalent to an 85-foot, 15-bay beam consisting of 150 struts and 48 nodes. The four rest periods were not requested by the test subject but were required in the test procedure for disassembly of the beam by utility divers. Reduction in productivity due to astronaut fatigue was not a factor within the limits of the data taken, as can be seen by the general decreasing trend for assembly rates in figures 16 and 17. An extrapolation of an assembly rate of 2.1 struts per minute including the 10-minute rest periods every three bays can be seen in figure 18. Current Shuttle EVA time limits (6 hours) would allow for the assembly of 47 bays (or approximately 270 feet) of truss-beam including the 10-minute rests.

Concluding Remarks

Tests were conducted to evaluate a mobile work station/assembly fixture concept that would mechanically assist astronaut manual assembly of truss-beams on-orbit. The concept, called the Swing-Arm Beam Erector (SABER), uses a work platform to which a single astronaut is secured in foot restraints. The work platform can be moved to strategic work positions within a prescribed work envelope; thus, astro-

naut manual translation tasks are·eliminated. A tetrahedral truss-beam was assembled by a single test subject with and without pressure (space) suits, both in Earth gravity and in simulated zero gravity (neutral buoyancy in water). A three-bay truss-beam was assembled by the test subject from 30 struts, 5.3 and 6.2 feet in length, and 9 nodal joints. The joining process was accomplished manually by using struts with fittings and nodes designed for quick attachment. The truss was assembled one bay at a time. An advance mechanism was used to move the truss along the assembly fixture axis 1 bay length to clear the work site for assembly of a succeeding bay. The assembled truss was approximately 17.2 feet long with an equilateral triangular cross section of side length 5.04 feet.

It was found that assembly of erectable beam-like trusses by a single astronaut with the aid of SABER is an effective and feasible concept. Using SABER to transport the astronaut and the building material to the required work positions eliminates the primary source of astronaut fatigue in extravehicular activity (EVA); thus, astronaut productivity is greatly enhanced. The equivalent of an 85-foot beam-like truss was assembled in a 1 hour and 44 minute, simulated $0g$ EVA. All the assembly procedure tasks were performed effectively by the test subjects in Skylab space suits. The repetitive tasks of the assembly procedure are quickly learned and are amenable to general truss structure.

The data show that average in-space assembly rates of approximately 2.1 struts per minute can be expected when assembling struts comparable in size to those used in these tests. The SABER concept assembly rate depends on the length and maneuverability of individual struts but not on the length of the truss being assembled.

Appendix

Truss-Beam Assembly Procedure

Crew Procedures

Nomenclature

HA	high nodal joint: station A
HB	high nodal joint: station B
HC	high nodal joint: station C
LA	low nodal joint: station A
LB	low nodal joint: station B
LC	low nodal joint: station C
short	attach short strut
long	attach long strut
attach	attach free-end struts to node
( )	optional voice commands

Initial positions

- Nodal joints are in storage positions at end of guide rails
- Beam elements are in storage positions on racks on either side of work platform
- Console operator is at console
- Console adjusted to correct air pressure settings
- Suited subject is on work platform below location LA

Procedure

1	move subject and node up (HA)
2	short down
3	long right—down
4	short left—down
5	move subject left and down (LB)
6	move subject and node up (HB)
7	(1 attach)
8	short down
9	long right—down
10	short left—down
11	move subject left and down (LC)
12	move subject and node up (LC)
13	(2 attach)
14	short down
15	long right—down
16	short left—down
17	move subject down (LC)
18	(move node up to LC)
19	(1 attach)
20	long left—up
21	short right—up
22	move subject right—up (LB)
23	(move node up to LB)
24	(3 attach)
25	short right—up
26	move subject right—up (LA)
27	(move node up to LA)
28	(5 attach)
29	move subject up (HA)
*30	move Feed/Bay up
31	(check node position)
32	short down
33	move subject left—down (HB)
34	(check node position)
35	short down
36	long right—down
37	move subject left and down (HC)
38	(check node position)
39	short down
40	long right—down
41	short left—down
42	move subject down (LC)
43	(move node up)
44	(1 attach)
45	long left—up
46	short right—up
47	move subject right and up (LB)
48	(move node up)
49	(3 attach)
50	short right—up
51	move subject right and up (LA)
52	move node up
53	(5 attach)
54	move subject up (HA)

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* Repeat steps 30 through 54 until beam is completed.

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TABLE I. DUTIES OF TEST SUBJECTS DURING ASSEMBLY TESTS

1g tests

Subject[a] (c)	Assembly	Test	Operator[b] (c)
(1)	1	1	(3)
(1)	2	4	(3)
(1)	3	4	(2)
(1)	4	6	(3)
(1)	5	6	(3)
(1)	6	6	(3)
(1)	7	6	(3)
(1)	8	6	(3)
(2)	1	1	(3)
(2)	2	1	(3)
(2)	3	1	(3)
(2)	4	4	(3)
(2)	5	4	(3)
(2)	6	5	(3)
(2)	7	6	(3)
(2)	8	6	(3)
(2)	9	6	(3)
(3)	1	1	(2)
(3)	2	2	(2)
(3)	3	2	(2)
(3)	4	3	(2)
(3)	5	3	(2)
(3)	6	5	(2)
(3)	7	5	(2)
(3)	8	5	(2)

Simulated 0g scuba tests

Subject[a] (c)	Assembly	Test	Operator[b] (c)
(1)	1	1	(3)
(1)	2	1	(3)
(1)	3	1	(3)
(1)	4	5	(3)
(1)	5	5	(3)
(2)	1	3	(3)
(2)	2	3	(3)
(2)	3	3	(3)
(2)	4	5	(3)
(2)	5	5	(3)
(3)	1	2	(2)
(3)	2	2	(2)
(3)	3	4	(2)
(3)	4	4	(2)
(3)	5	4	(2)

Simulated 0g EVA tests

Subject[a] (c)	Assembly	Test	Operator[b] (c)
(1)	1	2	(3)
(1)	2	2	(3)
(1)	3	2	(3)
(1)	4	2	(3)
(1)	5	3	(3)
(1)	6	3	(3)
(1)	7	3	(3)
(1)	8	3	(3)
(1)	9	3	(3)
(2)	1	1	(3)
(2)	2	1	(3)
(2)	3	4	(3)
(2)	4	4	(3)
(2)	5	4	(3)
(2)	6	4	(3)
(2)	7	5	(3)

[a]Work station subject.
[b]Console operator.
[c](1)—subject 1; (2)—subject 2; (3)—subject 3.

TABLE II. TIMES AND RATES FROM SABER ASSEMBLY TESTS

Test conditions	Time, min, for—						Rate, Struts/min
	Bay 1	Bay advance	Bay 2	Bay advance	Bay 3	Total three bays	
Experimental:							
1g; street clothes; air	3.5	0.17	2.5	0.33	*2.5	9.0	3.3
0g; scuba gear; water	3.8		2.5		2.5	9.0	3.3
0g; pressure suit; water	6.0		4.0		4.0	14.5	2.1
Estimated:							
0g; pressure suit; space	6.00		4.0		4.0	14.5	2.1

*Estimated.
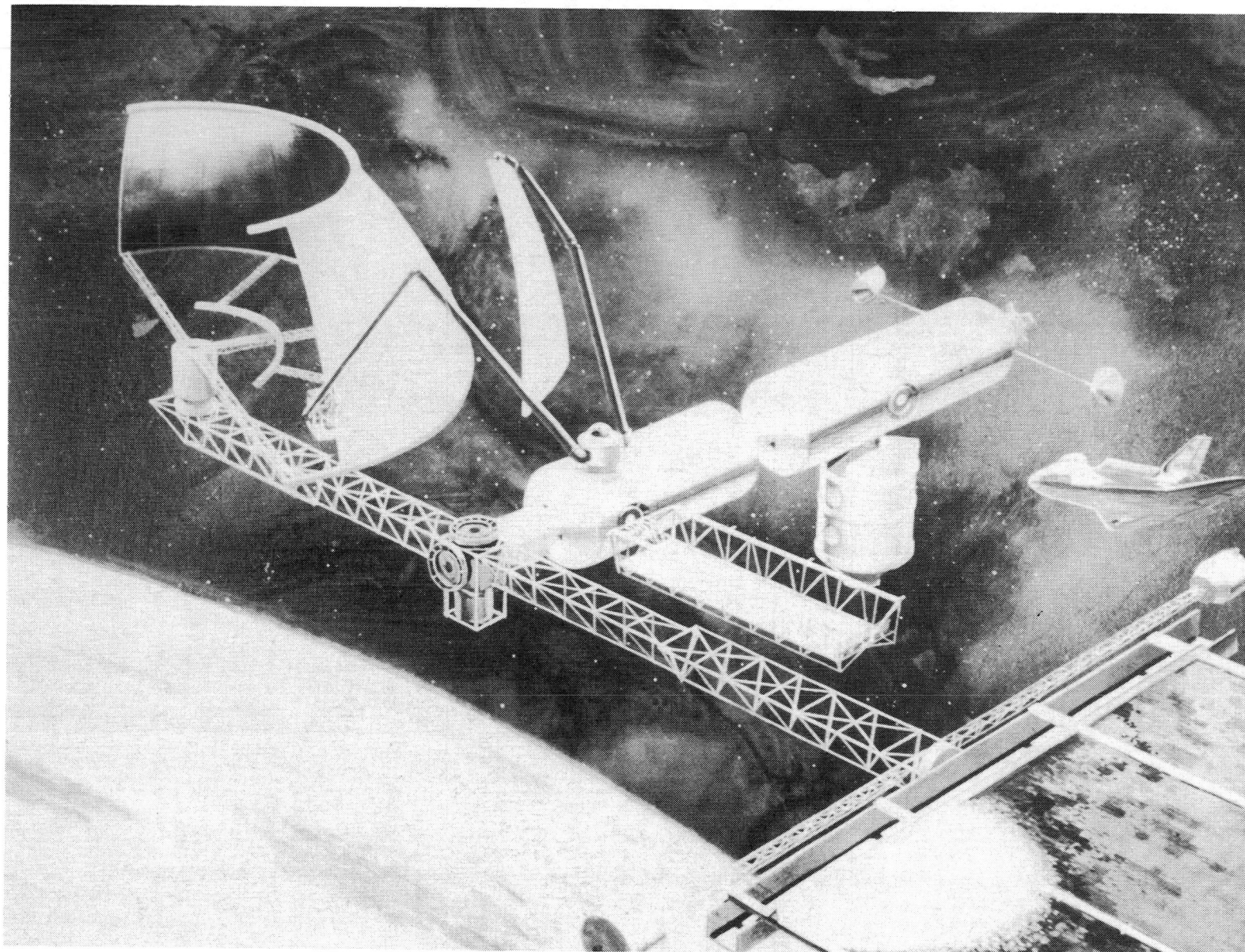
L-82-10,145

Figure 1. Space Station concept with truss-beams.

17.2 ft

SIDE VIEW

5.04 ft
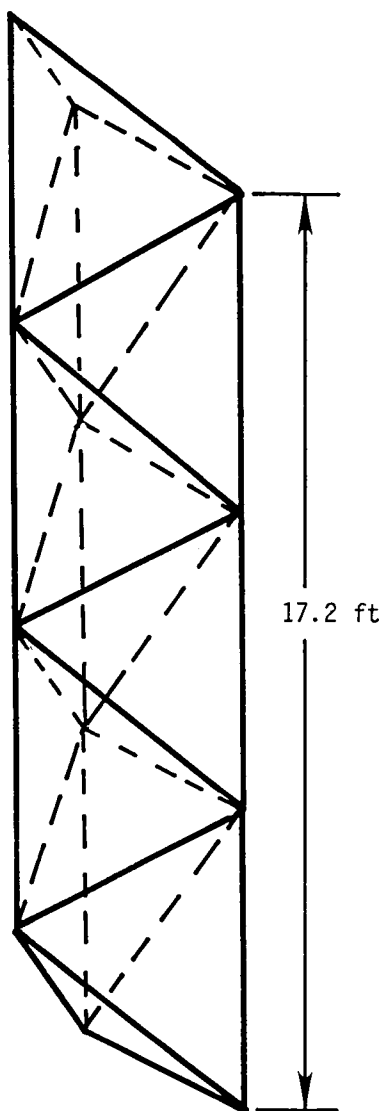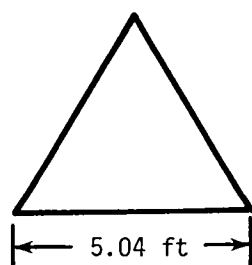
CROSS-SECTIONAL VIEW

Figure 2. Geometry of tetrahedral truss-beam assembled with the SABER concept.
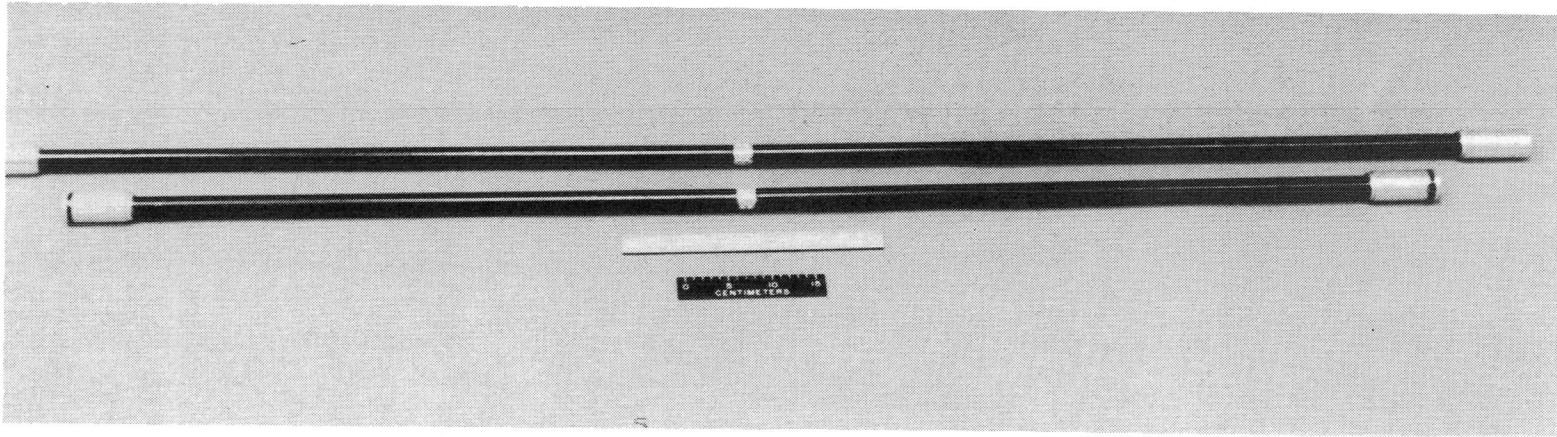
(a) Typical struts.
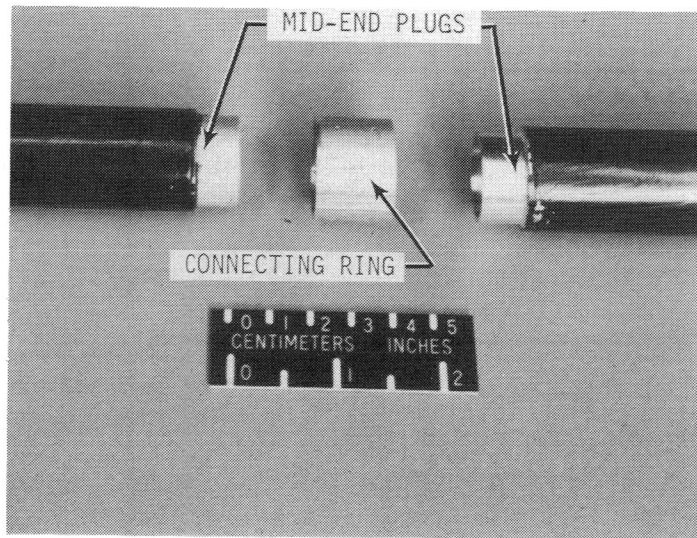
(b) Strut mid-section connection.
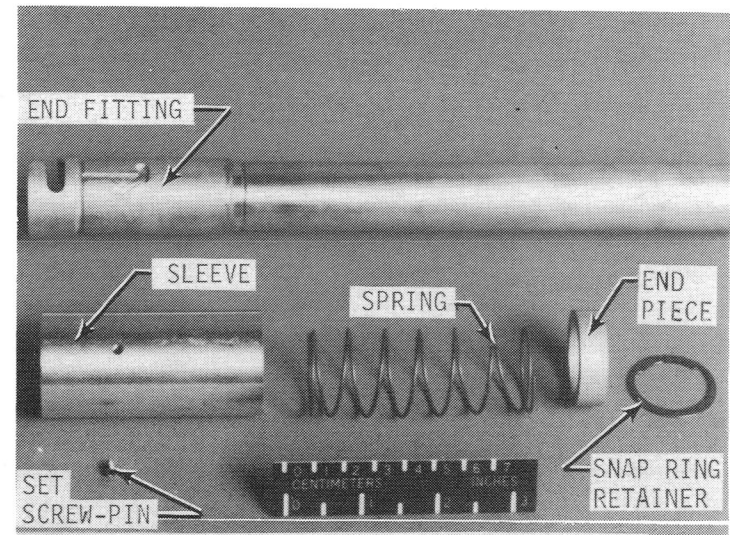
(c) Strut end-joint, exploded view.

Figure 3. Typical strut configuration.

L-84-12,912
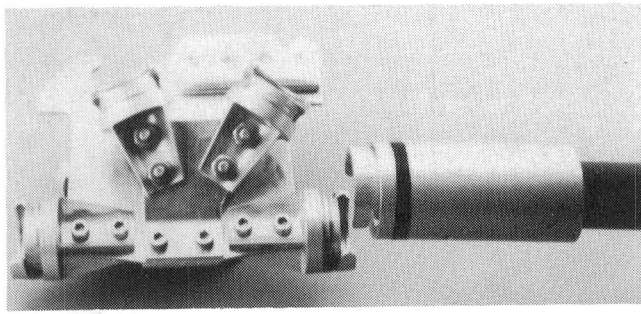
(a) Locking sleeve, cocked and ready for attachment.
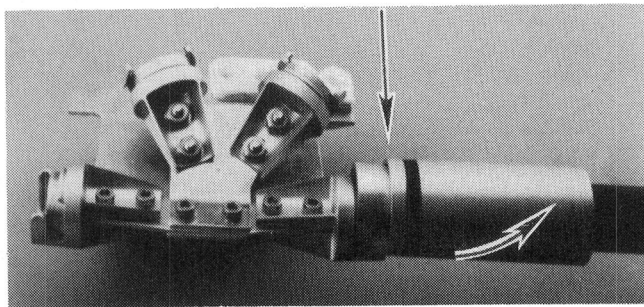
(b) Initial motion of locking sleeve during attachment.
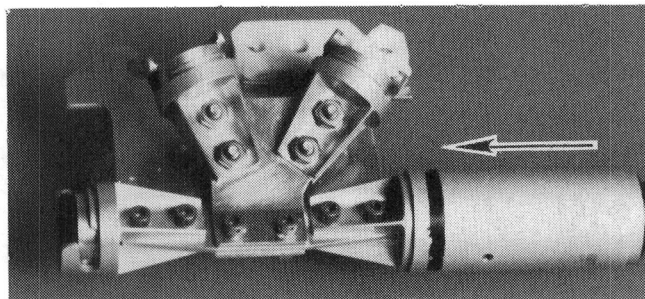
(c) Final motion of locking sleeve to secure the joint.
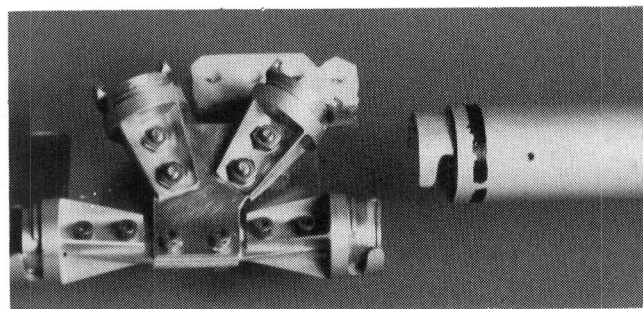
(d) Sleeve locked in open position for strut removal.

L-84-7950

Figure 4. Strut attachment to node.
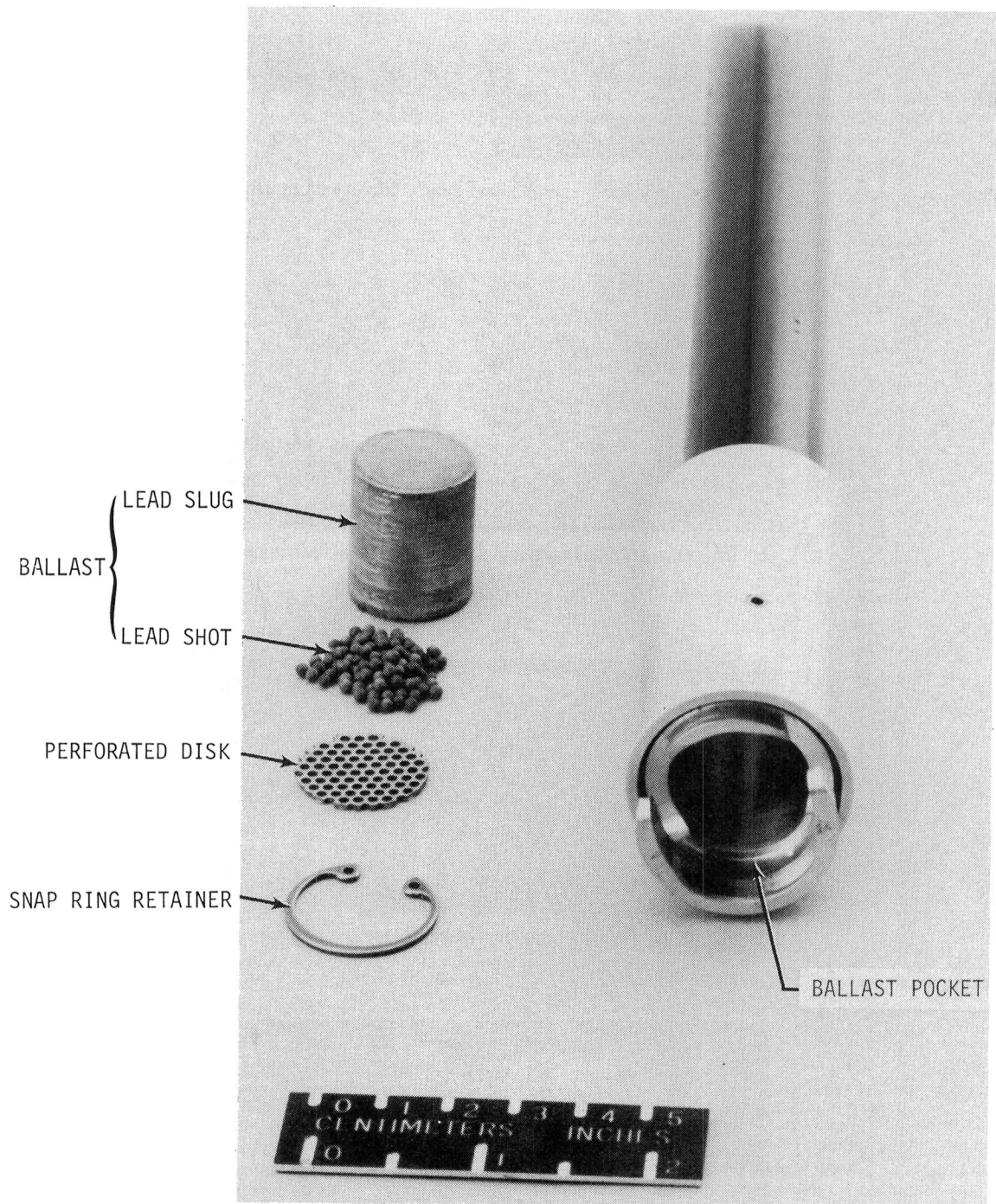
Figure 5. Typical neutral buoyancy ballast for struts.

L-84-12,913

WEB

TEFLON PAD
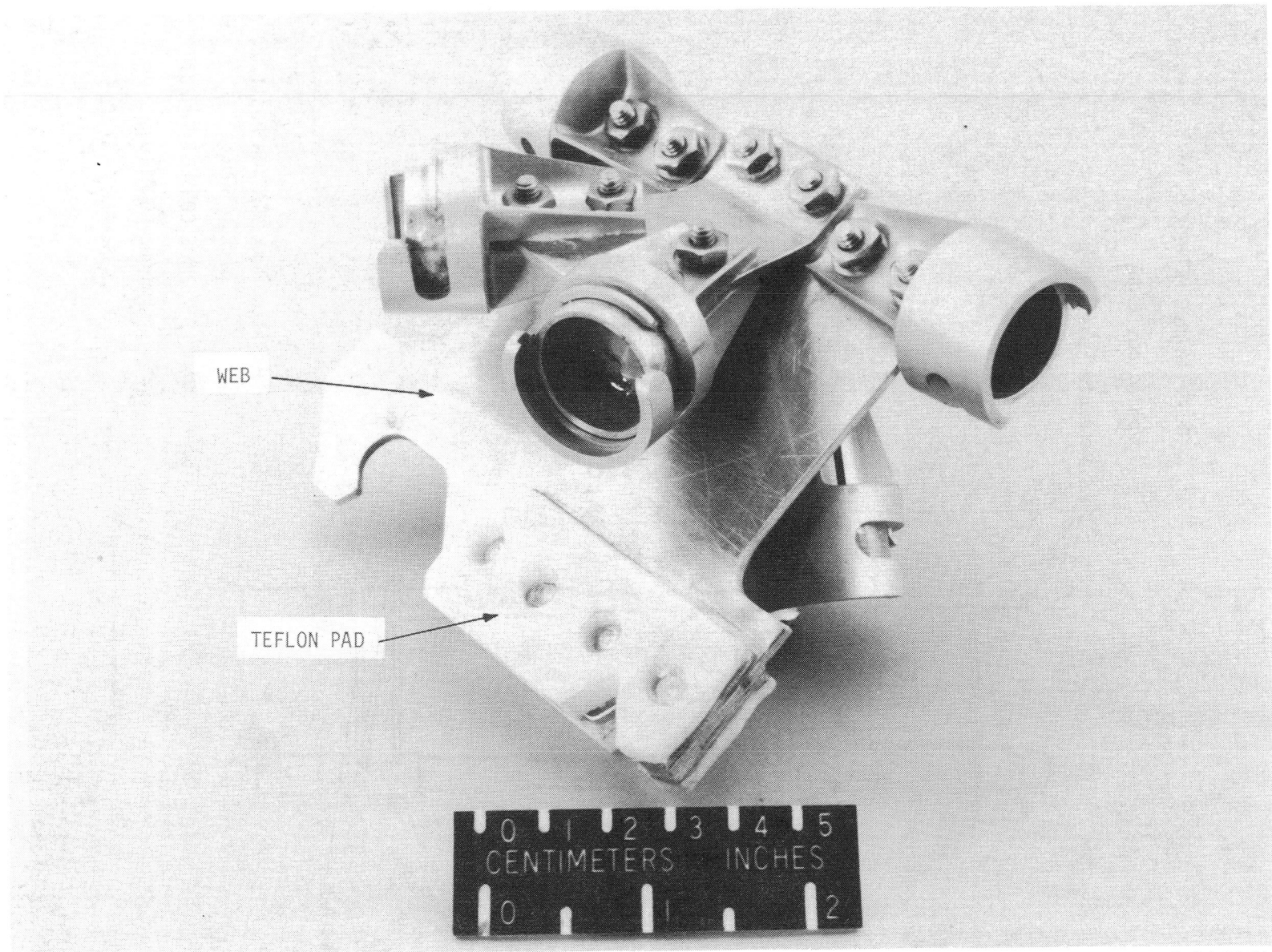
L-84-12,914

Figure 6. Typical node.

TRUSS ADVANCE MECHANISM

(Advanced position)

(Retracted position)

TEST SUBJECT

STRUT STOWAGE RACK

WORK PLATFORM

TYPICAL GUIDE RAIL

ASSEMBLY FIXTURE

TELESCOPING MAST (ELEVATOR)

SWING-ARM

AIR MOTORS

HA, etc. WORK STATION POSITIONS
△ STORED NODES
● NODE CONNECTION POINTS
○ NODE LOCATIONS
− − − ASSEMBLED STRUTS

HA HB HC LA LB LC
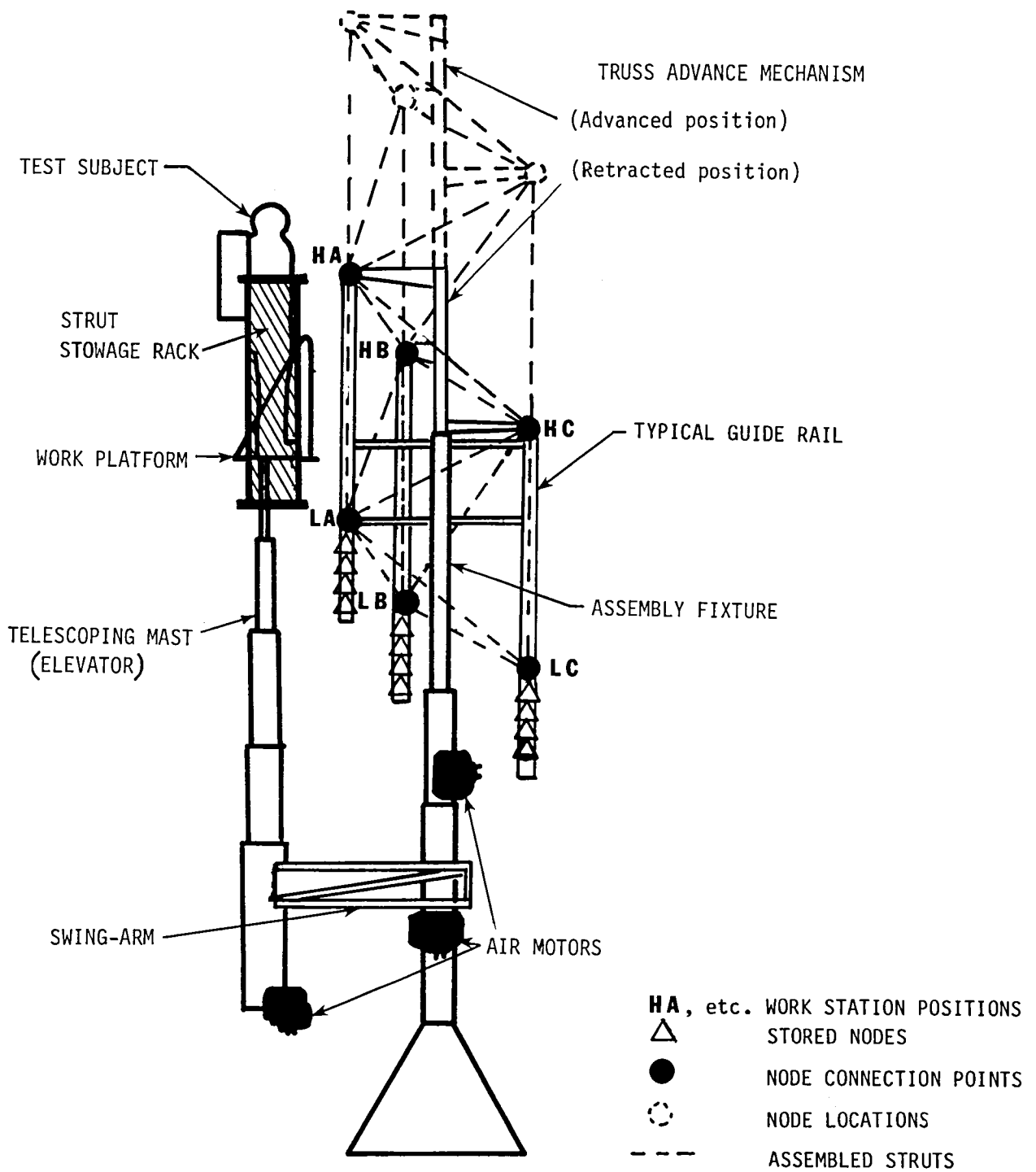
Figure 7. Schematic of SABER.

TEST SUBJECT

TRUSS ADVANCE MECHANISM

WORK PLATFORM

TELESCOPING MAST
(ELEVATOR)

ASSEMBLY FIXTURE

NASA
LaRC

SWING-ARM
COUNTER-BALANCE

SWING-ARM
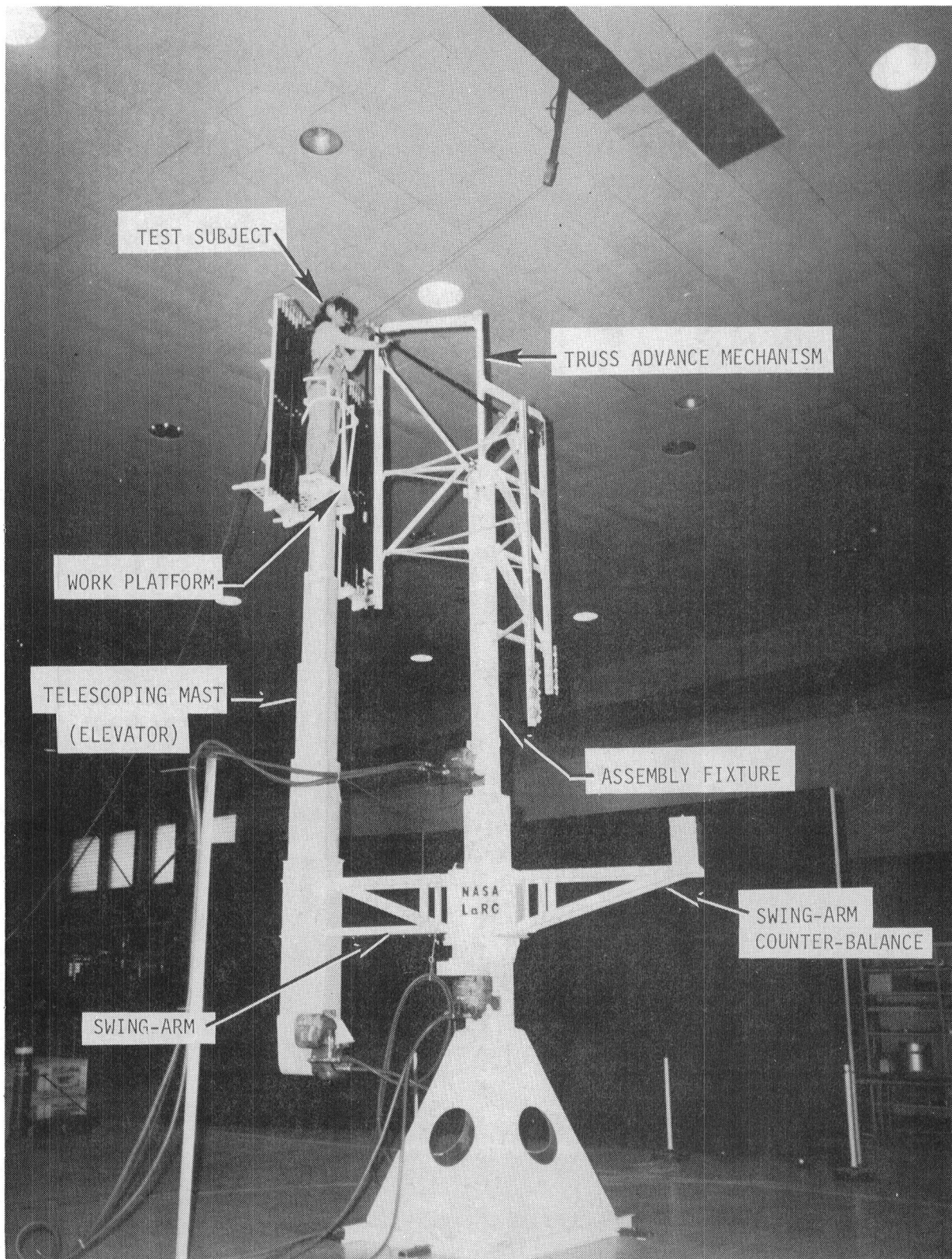
L-84-12,915

Figure 8. SABER hardware in 1*g* laboratory.

Figure 9. Operator's console for SABER.

L-84-1495

TRUSS

SABER

SHUTTLE CARGO BAY
MOCK-UP

ESA PALLET
MOCK-UP
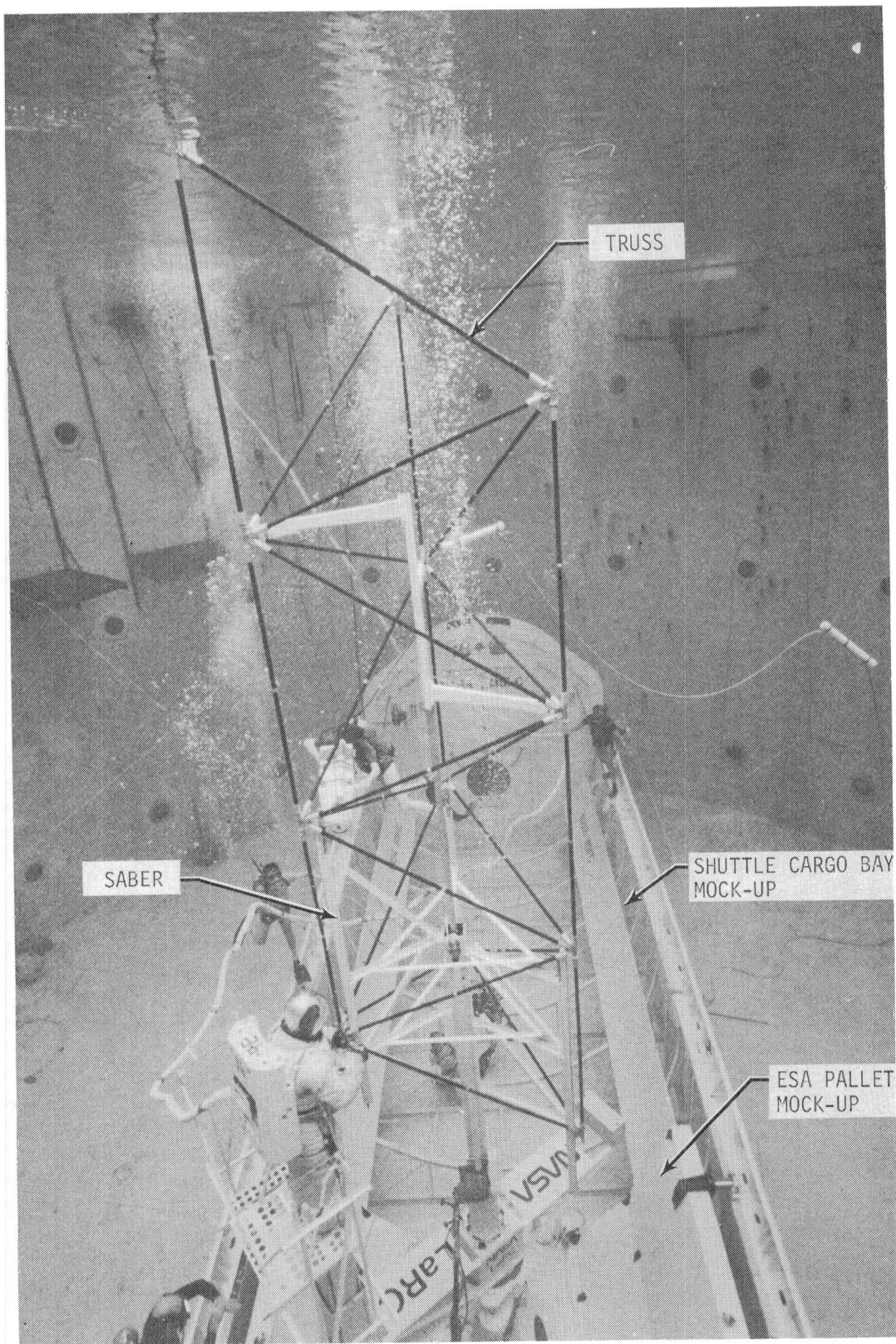
L-84-12,916

Figure 10. SABER and assembled truss in Neutral Buoyancy Simulator.

STRUT STOWAGE RACKS

TEST SUBJECT
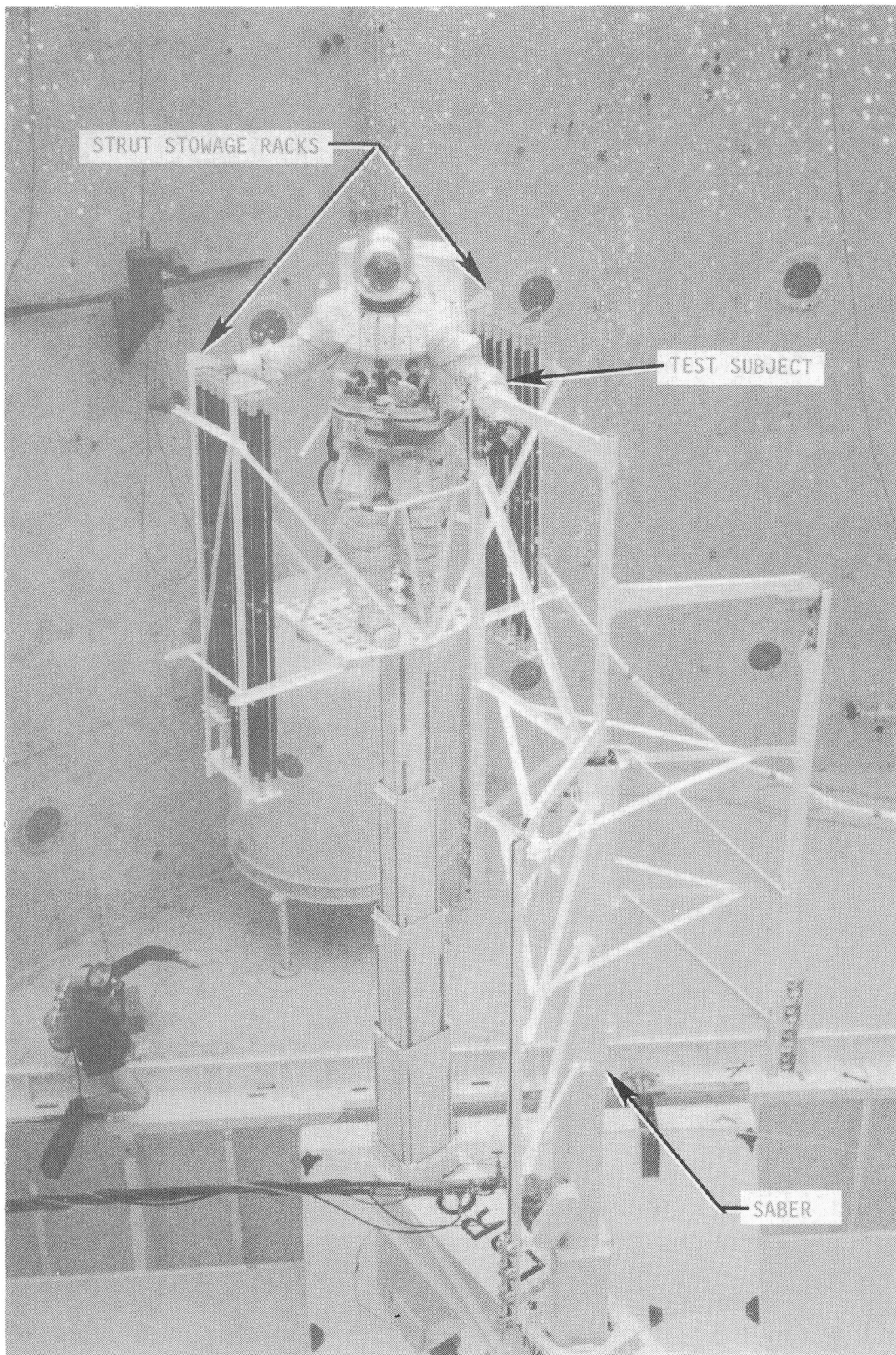
SABER

L-84-12,917

Figure 11. SABER in Neutral Buoyancy Simulator.

GUIDE RAIL A

STORED NODES

STRUT STOWAGE RACK
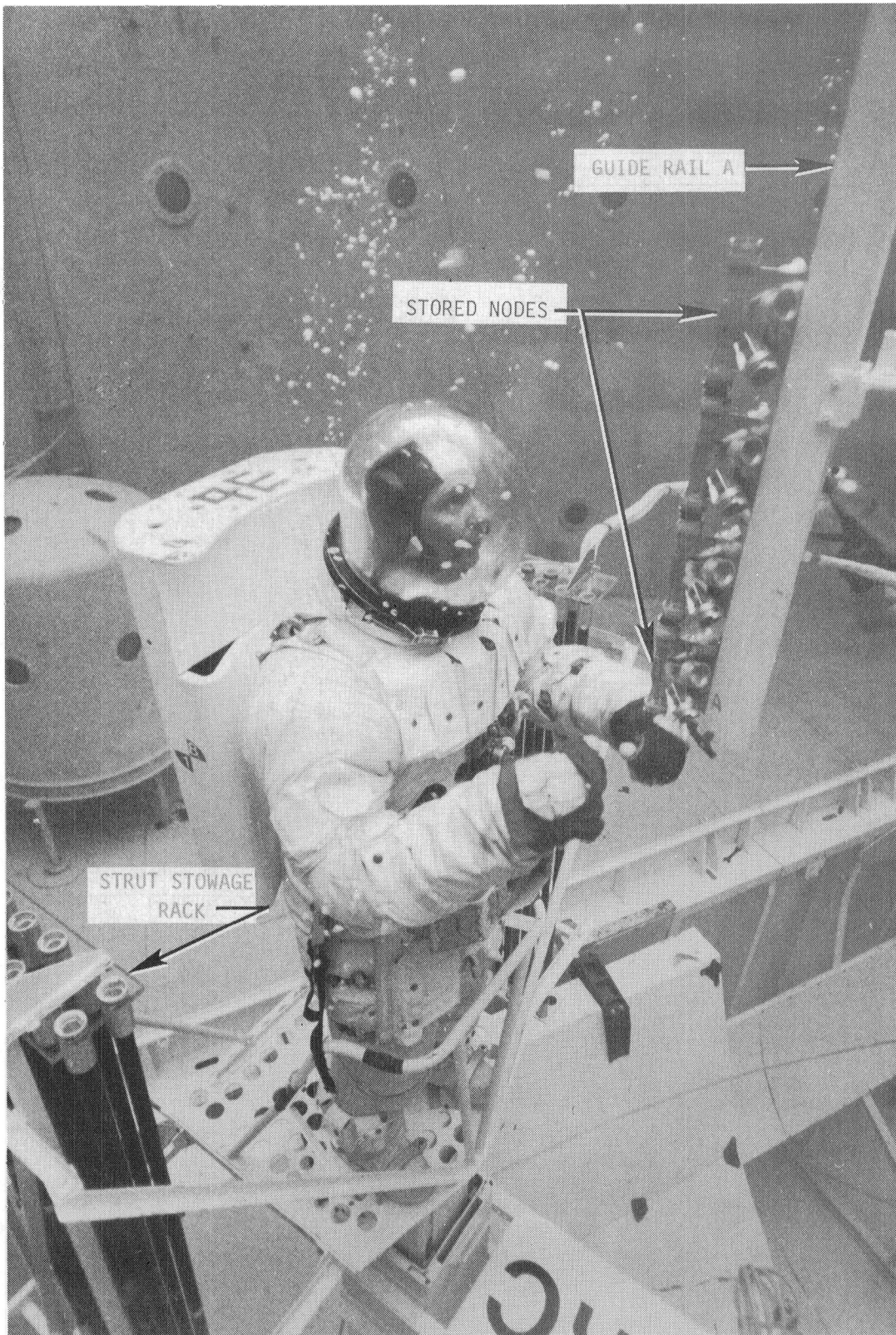
L-84-12,918

Figure 12. Start position of work platform for simulated 0g assembly test.

L-84-12,919

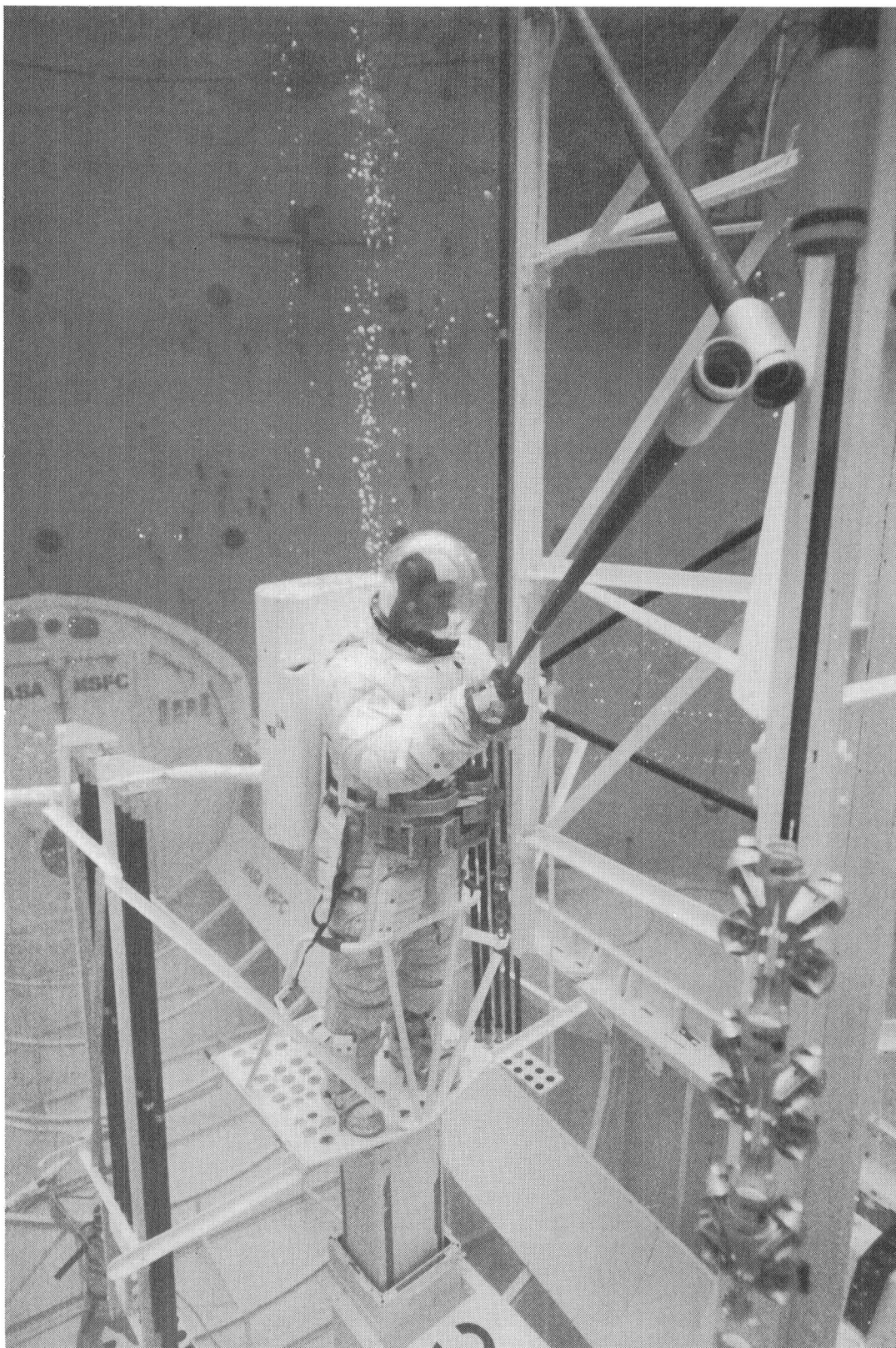Figure 13. Typical installation of node.
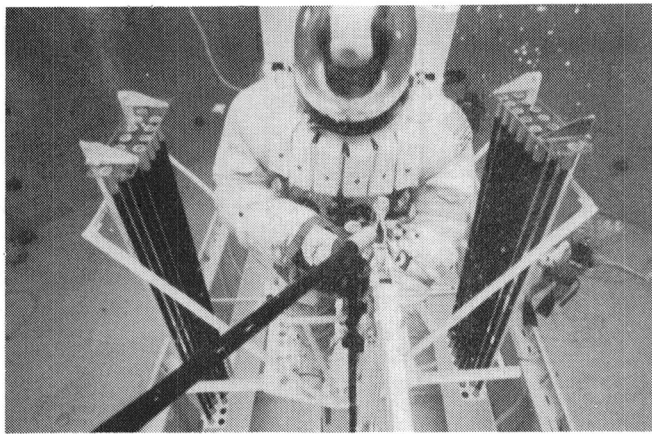
(a) Short strut down.
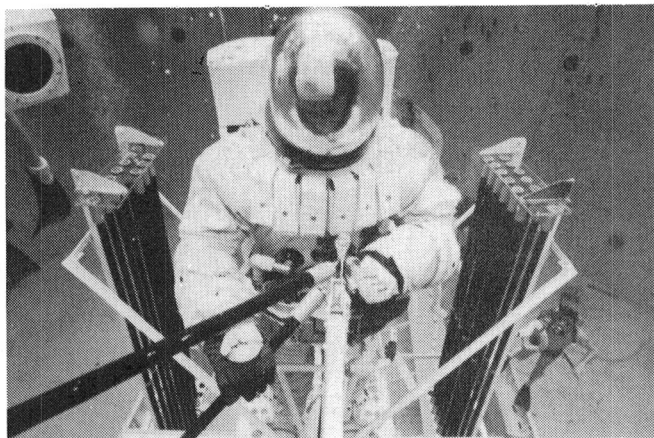
(b) Long strut right and down.
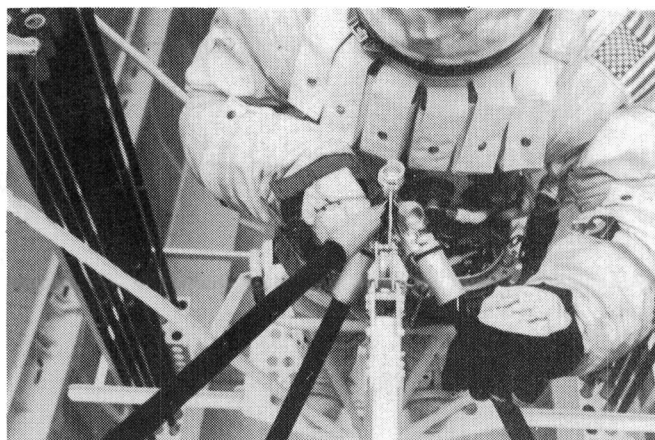
L-84-7949

(c) Short strut left and down.

Figure 14. Typical strut attachment sequence.

L-84-12,920

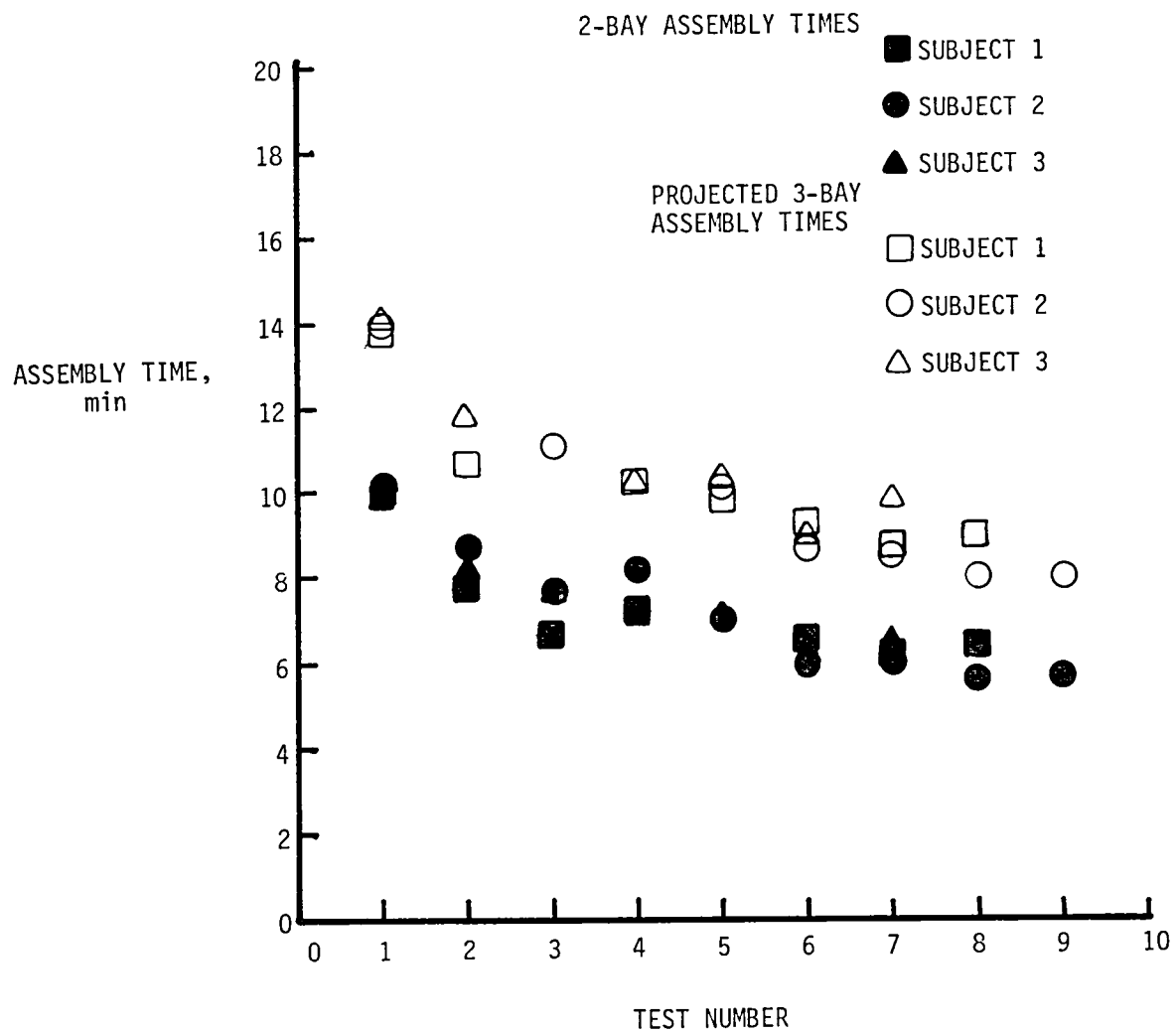Figure 15. Typical strut attachment showing unattached ends.

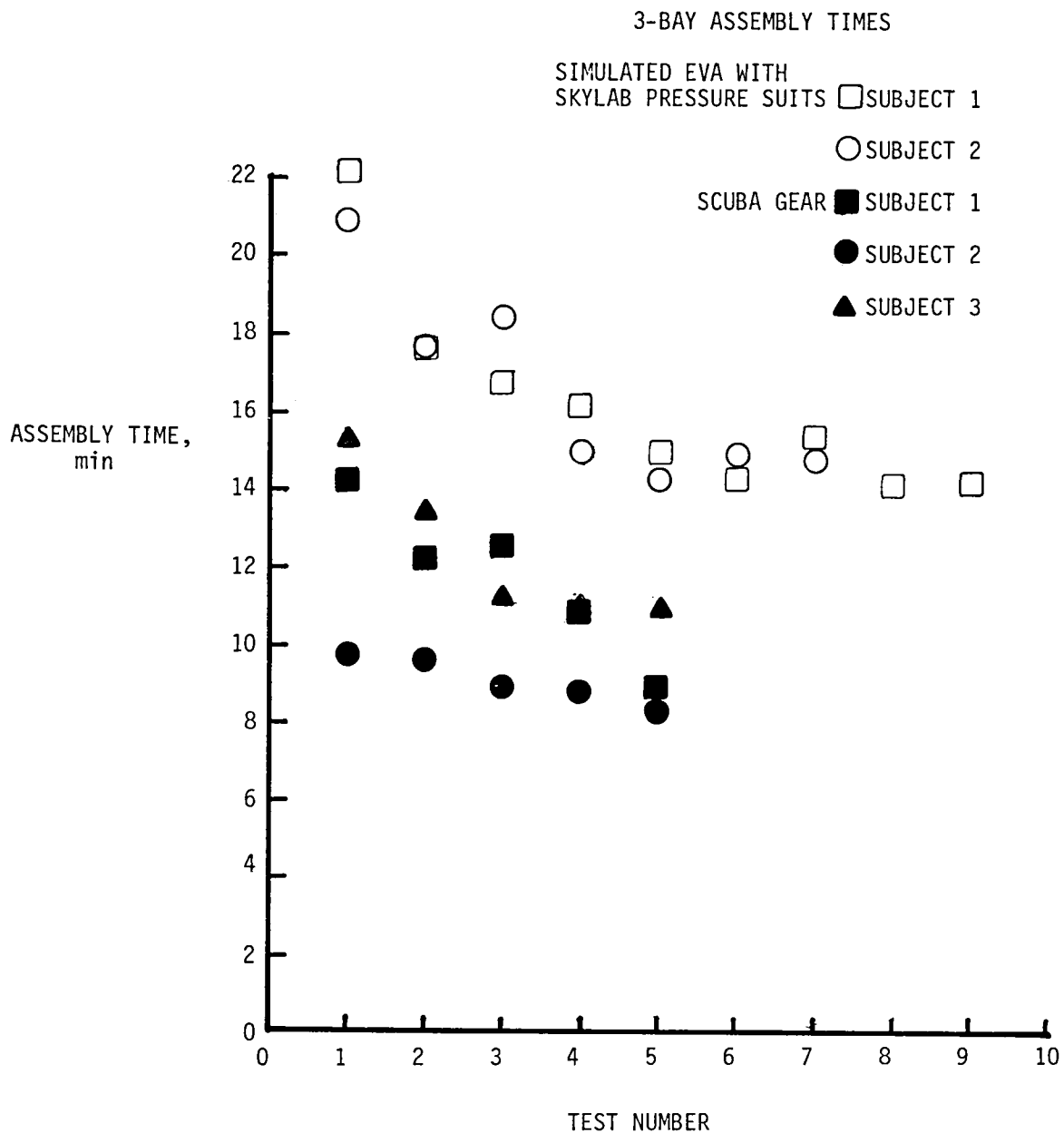Figure 16. Assembly time as function of test number from $1g$ assembly tests.

Figure 17. Assembly time as function of test number from simulated $0g$ assembly tests.
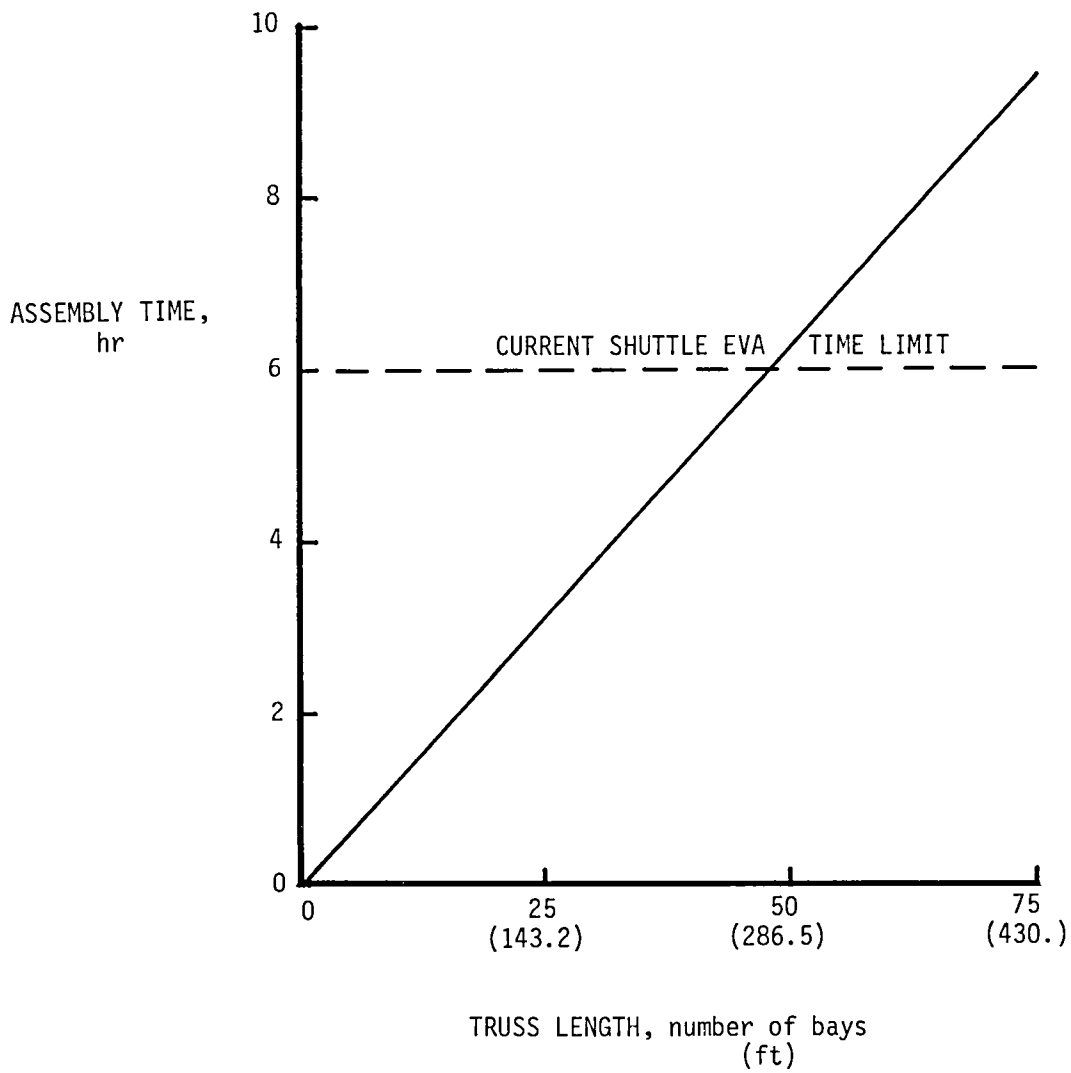
Figure 18. Projected on-orbit assembly times, including 10-minute rest after every third bay.

Motion-picture film supplement L-1292 is available on loan. Requests will be filled in the order received.

The film (16 mm, 5 min, color, silent) shows selected segments of the assembly of a truss-beam by a space-suited test subject using SABER during a simulated EVA (neutral buoyancy in water).

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1. Report No. NASA TP-2379	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Swing-Arm Beam Erector (SABER) Concept for Single Astronaut Assembly of Space Structure		5. Report Date March 1985
		6. Performing Organization Code 506-53-43-01
7. Author(s) Judith J. Watson, Walter L. Heard, Jr., and J. Kermit Jensen		8. Performing Organization Report No. L-15886
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Paper
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Results are presented of tests conducted to evaluate a mobile work station/assembly fixture concept that would mechanically assist an astronaut in the on-orbit manual assembly of erectable truss-beams. The concept eliminates astronaut manual translation by use of a motorized work platform with foot restraints. The tests involved assembly of a tetrahedral truss-beam by a test subject in simulated zero gravity (neutral buoyancy in water). A three-bay truss-beam was assembled from 30 aluminum struts with quick-attachment structural joints. The results show that average on-orbit assembly rates of 2.1 struts per minute can be expected for struts of the size employed in these tests.

17. Key Words (Suggested by Authors(s)) Space assembly EVA assembly Space truss structure Zero-gravity simulation	18. Distribution Statement Unclassified—Unlimited Subject Category 18

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 31	22. Price A03

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