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A 60-METER ERECTABLE ASSEMBLY CONCEPT FOR A CONTROL OF FLEXIBLE STRUCTURES FLIGHT EXPERIMENT

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A 60-METER ERECTABLE ASSEMBLY CONCEPT FOR A CONTROL OF FLEXIBLE STRUCTURES FLIGHT EXPERIMENT

by
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Abstract

A flight experiment which proposes to use a 60-meter deployable/ retractable truss beam attached to the Space Shuttle to study dynamic characterization and control of flexible structures is being studied by NASA. The concept requires a relatively complex mechanism for deploying and retracting the truss on-orbit. Development of such a mechanism having a high degree of reliability will be expensive. This paper discusses an alternative method for constructing the truss that requires no new technology development or complex mechanisms and has already been demonstrated on-orbit. The alternative method proposes an erectable truss beam which can be assembled by two astronauts in EVA. The EVA crew would have to manually assemble the beam from 468 struts and 165 nodes, and install 7 instrumentation platforms with signal and power cabling. The predicted assembly time is 3 hours and 23 minutes. The structure would also have to be disassembled and restowed following testing, thus two EVA days would be required. To allow 25 hours for data collection (probably a bare minimum to accomplish meaningful tests), current Shuttle operations policy dictates a 9 day mission. The design, assembly procedure and issues associated with this alternative concept are discussed.

Introduction

The Control of Flexible Structures (COFS) program proposes a series of ground and flight activities to model and validate structural dynamic analysis and distributed control of large flexible structures (ref. 1-6). The overall program objective is to develop and validate a technology data base from which large low frequency spacecraft can be designed and controlled with confidence. The focus of the program is a generic in-space experiment (COFS I) to validate ground test technology and analysis tools. The COFS I flight experiment proposed to use a deployable truss beam, 60-meter length, which would be attached by a pallet to the Shuttle cargo bay. Actuators, instrumentation, and avionics necessary for excitation, measurement, and control of the structure would also be part of the system. In addition, a reliable deployer/retractor mechanism would have to be developed that would remotely deploy and retract the truss.

This paper presents an alternative method for constructing the truss that eliminates the need for the complex deployer/retractor mechanism. This alternative method proposes an erectable truss that is assembled piece-by- piece, on-orbit, by an EVA crew of two, similar to the method used in the ACCESS flight experiment (ref.7). Ground test assembly programs (ref. 8 - 10) performed in neutral buoyancy also support this method of space construction. The purpose of this paper is to present a proposed erectable truss concept for a COFS I flight experiment. The assembly/disassembly procedures, timelines, method for installing the instrumentation during assembly, data collection, and the issues involved with this concept are discussed.

COFS I Deployable Truss Concept

Truss design.- An artist sketch of a truss beam attached to the Space Shuttle proposed as the COFS I experiment is shown in figure 1. The truss is composed of longitudinal (longerons), diagonal (diagonals), and transverse (battens) members. The members are connected by joints at nodes to form a lattice beam 60 meters long with an equilateral triangle cross section. The truss is composed of 54 identical segments called bays (the nominal length of any bay is equal to the length of a longeron). Table 1 lists some of the design characterisics of the truss. More information on the structural characterisics of the truss can be found in reference 11.

Instrumentation.- To provide structural support for the required instrumentation, flat platforms are integrated into the truss battens. These platforms are located at the base and tip of the truss, and at the tops of bays 10, 20, 28, 38, and 46 as shown in figure 2. The platforms are designed to support the instrumentation in a volume dictated by the stowed configuration of the truss. Figure 3 shows some sketches of the layouts of the platforms and various critical dimensions for one deployable beam concept. In addition to the instrumentation shown, thermistors are attached to some strut members near the instrumentation platforms for use in determining temperature effects on the behavior of the truss. All the instrumentation is connected by electrical cables which are attached to the longerons along the entire length of the truss.

Procedure.- The deployable truss and instrumentation system must be assembled on Earth and stowed in a deployer/retractor mechanism for transport to orbit, and undergo numerous preflight checkout tests. On- orbit, the truss will be remotely deployed for testing at any even number of bays. At the end of each day the truss is retracted. In addition, a redundant, remote jettison capability must be provided for emergency situations where the structure can not be retracted below the cargo bay door hinge line.

Because the truss is deployable a scheduled EVA is not required to deploy the structure, however EVA training for the astronaut crew for contingency EVAs involving manual deployment or retraction of the structure would probably be required. Also since the truss can be deployed remotely from the Shuttle cabin without an EVA the truss could be deployed as early as flight day 2. This would allow for up to 5 days of testing for an 8 day flight (approximately 25 hours of data; see ref. 6).

Proposed Erectable Truss Concept

The proposed alternative method presented in this paper for construction of the COFS I truss is an erectable truss that is assembled piece-by-piece, on-orbit by two EVA astronauts. The concept is based on experience gained in an EVA assembly of an erectable truss provided by the ACCESS Shuttle flight experiment (November 1985) shown asssembled on-orbit in figure 4., and on current research on joint design for erectable Space Station structure. The ACCESS flight experiment consisted of a rotating assembly fixture, strut and node cannisters, fixed foot-restraints, and 93 struts and 33 nodal joints of truss structure. Two astronauts assembled the 45-foot truss beam on the assembly fixture, one bay at a time, rotating the assembly fixture as required to make all of the structural attachments from the fixed foot-restraints.

Erectable truss hardware.- A typical bay of the proposed erectable truss for COFS I is shown in figure 5a. Similarly to the deployable truss concept, the erectable truss would consist of 54 of these bays. The differences in the two concepts is in the strut dimensions and the joints (See Table 1). The battens and longerons are 44.25 inches long, the diagonals are 62.58 inches long and all struts are one inch in diameter. The length of the longerons was choosen to be the same length as the deployable truss longerons so the truss would have the same number of bays and the same length as the deployable structure. The length of the battens was set as the same length of the longerons for the convenience of only two different size struts for identification during assembly. The diameter of the struts for the proposed erectable truss was also based on the ACCESS hardware and does not vary in size for this study. Further research would be needed to determine strut diameter requirements that would meet the stiffness requirements of the truss. The nodal joints and strut end fittings are a scaled down version of the LaRC erectable joint hardware proposed for Space Station (see ref. 12), but reconfigured for a truss whose cross section is an equilateral triangle as shown in figures 5b and 5c. The three inch dimension shown in the sketch is the minimum necessary to allow clearance for the astronauts gloved hand during attachment of the struts. There are a total of 468 struts and 165 nodal joints required (21 batten struts can be replaced by instrumentation platforms). The struts would be fabricated from graphite-epoxy material and the nodes from titanium (the same as currently proposed for a deployable beam concept).

Assembly fixture.- The proposed EVA assembly concept for the erectable truss is shown in figure 6. Most of the assembly tasks are performed at a fixed plane above the cargo bay with the astronauts standing in fixed foot restraints. The struts for the COFS I beam are short enough to be installed without having to move the assembly fixture or the astronauts. Thus, the concept consists of a stationary assembly fixture with fixed (non-moving) foot restraints. The assembly fixture has two guide rails that are long enough to support three bays of the truss at one time which insures that the truss is always attached to the fixture by at least four points. The instrumentation package housing, which is attached near the aft end of the pallet, is part of the assembly fixture. The guide rails are attached by hinges to the top of the instrumentation package housing and are stowed for launch and reentry in a horizontal position. They are rotated to the upright position by the EVA astronauts before assembly of the beam is begun. The two fixed foot-restraints are attached, one each, on the port and starboard sides. The canisters containing the nodal joints are fixed to the rails in a stowed position prior to launch and are automatically rotated with the guide rails into position for easy access by the astronauts. Two strut canisters are attached near the forward end of the pallet. Each canister is supported by a fixture that can be manually rotated so that all struts are accessible from the fixed foot-restraints. The canister heights can be adjusted in the support fixtures as needed by the EVA astronauts. All of the equipment can be stored on a standard Shuttle pallet. However, for launch and reentry, the assembly fixture guide rails would require additional structure for support in the folded position. This may or may not require an additional pallet and cargo bay space than allotted for a deployable design.

Instrumentation.- The instrumentation package for the erectable truss concept is based on a proposed deployable truss instrumentation package for COFS I. It would contain seven instrumentation platforms that must be integrated into the structure as it is being assembled. These platforms, shown in figure 7, have a usable cross-sectional area of 700 square inches per side and have the same triangular shape as the cross-section of the truss. (The deployable truss platforms have a cross-sectional area of only 190 square inches per side). With the larger area available, the instrumentation components could all be attached to one face of the platform. (Both faces must be used in the deployable beam design). Nodal joints are preattached to each of the three corners of the platforms. The platforms are stacked in the appropriate order and inserted into a triangular shaped canister that has three guide rails. During assembly of the truss, the platforms can be fed either automatically or manually into position for attachment to the longerons and diagonals of the appropriate bays, thus taking the place of a batten frame. To attach the instrumentation platforms it may be necessary for the astronauts to egress the foot-restraints and move to the lower plane of the bay being assembled. This task is only occasionally required, however, and probably could be accomplished using strategically placed hand holds. The electrical cables are integrated with the platforms and are deployed and connected to the longerons as each bay is assembled.

Assembly Procedures and Time Lines

Assembly procedure.- The sequence of the assembly procedure for the truss is illustrated in figure 8. Figure 8a shows the hardware stowed for launch and reentry. Figure 8b shows the assembly fixture guide rails and the strut cannisters deployed. After the assembly fixture is deployed, the first instrumentation package (which also includes a tip mass) is raised, either manually or automatically, into position on the guide rails. This first package is larger than the other instrumentation platforms and is supported by four nodes in the assembly fixture guide rails. The crew begins assembling the truss by attaching three longerons and three diagonals to the nodes at the bottom of the instrumentation package. The free ends of the struts point towards the cargo bay. This configuration is then automatically moved up the guide rails one bay length. Three nodal joints are removed from the canisters and attached to the free ends of the longerons and diagonals, and three battens are taken from the canisters and installed to close out the bay. Longerons and diagonals are installed for the next bay and then the truss is moved up the guide rails one bay length so the assembly of the next bay can be completed. The installation of the struts and nodes is repeated for each contiguous bay of truss. At bays 10, 20, 28, 38, and 46 and at the base of the truss instrumentation platforms are attached to the free end of the struts in place of the battens (see figure 8d). When assembly is complete, the guide rails are disconnected from the truss nodal joints and folded down (figure 8e) so as not to interfere with testing.

Time lines.- An estimated time line for the assembly is given in table 2. The times are based on results from the ACCESS flight experiment (ref. 7) and previous neutral buoyancy tests of similar structures. Using the ACCESS assembly rate of 2.5 minutes/bay the erectable concept takes one hour and 18 minutes (138 minutes) to assemble the truss, however, the total time, which includes deploying the assembly fixture and canisters, assembling the truss, installing the instrumentation platforms, and preparing the structure for testing is three hours and 23 minutes. This does not allow for any rest periods, contingency operations or astronaut preparation for leaving the pressurized Shuttle cabin for EVA. The total time for the crew to disassemble and stow the hardware after the testing is two hours and 47 minutes.

Testing and Data Collection

Current NASA policy permits two scheduled EVA days per Shuttle flight. Flight rules dictate that the first EVA cannot begin until flight day 4 (an EVA on flight day 3 is possible under certain conditions as allowed by the flight rules), and the final EVA must be completed at least one day before reentry (see reference 13). Thus the truss must be assembled during the first EVA and disassembled and stowed during the second EVA. Testing must be accomplished between these EVAs. Figure 9 shows that the time available between EVAs for testing and data collection depends upon the number of flight days in the mission. There are 7 hours per day of testing and data collection available with 2 hours possible during an EVA day depending upon scheduled crew activities. This available test time is based on a proposed test schedule for the COFS I experiment given in reference 6. To allow 25 hours for testing and data collection a nine day mission would be necessary for the erectable truss concept.

Issues

The erectable truss concept is a straightforward approach that has already been demonstrated on-orbit and is well understood by the astronauts. It also eliminates the need for a complex deployer/retractor mechanism. However, there are some issues that must be addressed:

1. No known structural design exists for one inch diameter erectable joints (ACCESS used a 1-1/2 inch joint that was functional for "proof of concept" but did not have adequate stiffness for COFS I). Hardware would have to be designed, developed, and tested to meet the stiffness requirements of the COFS I experiment and to be compatible with astronaut handling. In addition, special machining techniques may be required for the small titanium joint fittings (titanium being the proposed material for the joints).

2. Because the assembly fixture and truss extend beyond the cargo bay door hinge line of the Shuttle so the doors can not be closed during assembly and testing, a redundant emergency jettison system must be provided. This system must also have the capability to be remotely controlled from the Shuttle cabin.

3. The hardware design would require additional support structure during the stowed configuration. This may or may not require an additional pallet and cargo bay space than allotted for the deployable design.

4. There is a concern that the 25 hours available for testing (assuming a nine day mission is feasible) may be insufficient to collect data for adequate characterization of the truss .

5. The truss must be designed to withstand the inertial loads associated with firings of the Shuttle primary reaction control system (PRCS). Although the Shuttle attitude would normally be controlled by the vernier reaction control system (VRCS) during truss tests, in event of VRCS failure, the PRCS would have to be used.

The first three issues can probably be resolved with good, sound engineering design involving no new technology development. The fourth issue depends on testing strategy--whether, or not, a procedure can be worked out for the time available that provides enough test time for meaningful results. Shuttle missions in excess of ten days are not an option. The fifth issue may be critical to the erectable truss concept. If the truss were designed to withstand the PRCS inertial loads, its stiffness may exceed that required for the dynamics and controls portion of the experiment. The flight rules could specify that no PRCS firings are allowed for the duration of the tests, however, this would mean that the risk of VRCS failure and, consequently, emergency jettison of the hardware would have to be accepted. Another option that may have merit would be to develop a control law as part of the controls portion of the experiment. The control law would be operational between the test sessions in case of a PRCS firing. (This control law would not be operational during testing as two control systems can not be operational simultaneously.)

Concluding Remarks

An erectable truss and EVA assembly method have been presented as alternatives to the deployable truss with its complex deployer/retractor mechanism for the COFS I Shuttle flight experiment. EVA assembly of an erectable truss eliminates the expense of developing a truss deployer/retractor mechanism and is a straightforward construction method that requires no new technology development. The EVA method of assembly has already been demonstated on-orbit, thus it is well understood by the astronauts. A procedure has been presented in which the entire 60-meter long truss including all instrumentation can be assembled during a three hour and 23 minute EVA. Following testing, the truss can be disassembled and all hardware restowed for reentry in a second EVA of two hours and 47 minutes. Under current NASA policy for Shuttle operations, a nine day mission would be necessary to allow 25 hours of testing between EVA's, and no tests could be performed on short configurations of the truss as proposed for the deployable truss concept. A critical issue associated with the erectable truss concept is how to control the Shuttle attitude with the truss fully erected should the vernier reaction control system become inoperative. Use of the primary reaction control system as a backup would probably induce excessive loads in the structure. The development of a control law as part of the controls portion of the COFS I experiment is possible, however, an in-depth study that goes beyond the scope of the paper would be needed.

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TABLE 1. - COFS GEOMETRY AND MASS PROPERTIES

	BASELINE DEPLOYABLE DESIGN (Z-BEAM)	ALTERNATE ERECTABLE DESIGN	DELTA
Number of Bays	54	54	0
Bay Length	44.25 in.	44.25 in.	0
Total Length	2,389.5 in.	2,389.5 in.	0
Longeron Length	44.25 in.	44.25 in.	0
Diagonal Length	65.0889 in.	62.58 in.	2.51 in.
Batten Length	47.7337 in.	44.25 in.	3.48 in.
Tube Diameters			
Longeron	0.90 in.	1.00 in.	0.1 in.
Diagonal	0.945 in.	1.00 in.	.055 in.
Batten A	0.625 in.	1.00 in.	.375 in.
Batten B*	0.50 in.		
Total Beam Mass**	556.7 lb.	597.5 lb.	40.8 lb..
Mass Moment of Inertia**	856 lb-in-sec^2	1010 lb-in-sec^2	154 lb-in-sec^2

* Deployable design only

** Erectable design weights and inertia derived from deployable beam (ref.11) and ACCESS joint hardware

TABLE 2. - EVA ASSEMBLY TIME LINE

TASK	TIME (min)
EVA 1	
1. Deploy assembly fixture*	5
2. Build truss *	138
3. Cable and instrument pallet management (6 pallets)	30
4. Release and tie down truss	30
	203 (3 hr 23 min)
EVA 2	
1. Release and replace truss to fixture	30
2. Cable and instrument pallet management	30
3. Diassembly of truss *	102
4. Stow assembly fixture*	5
	167 (2 hr 47 min)

*based on ACCESS flight data (2.5 bays/min)

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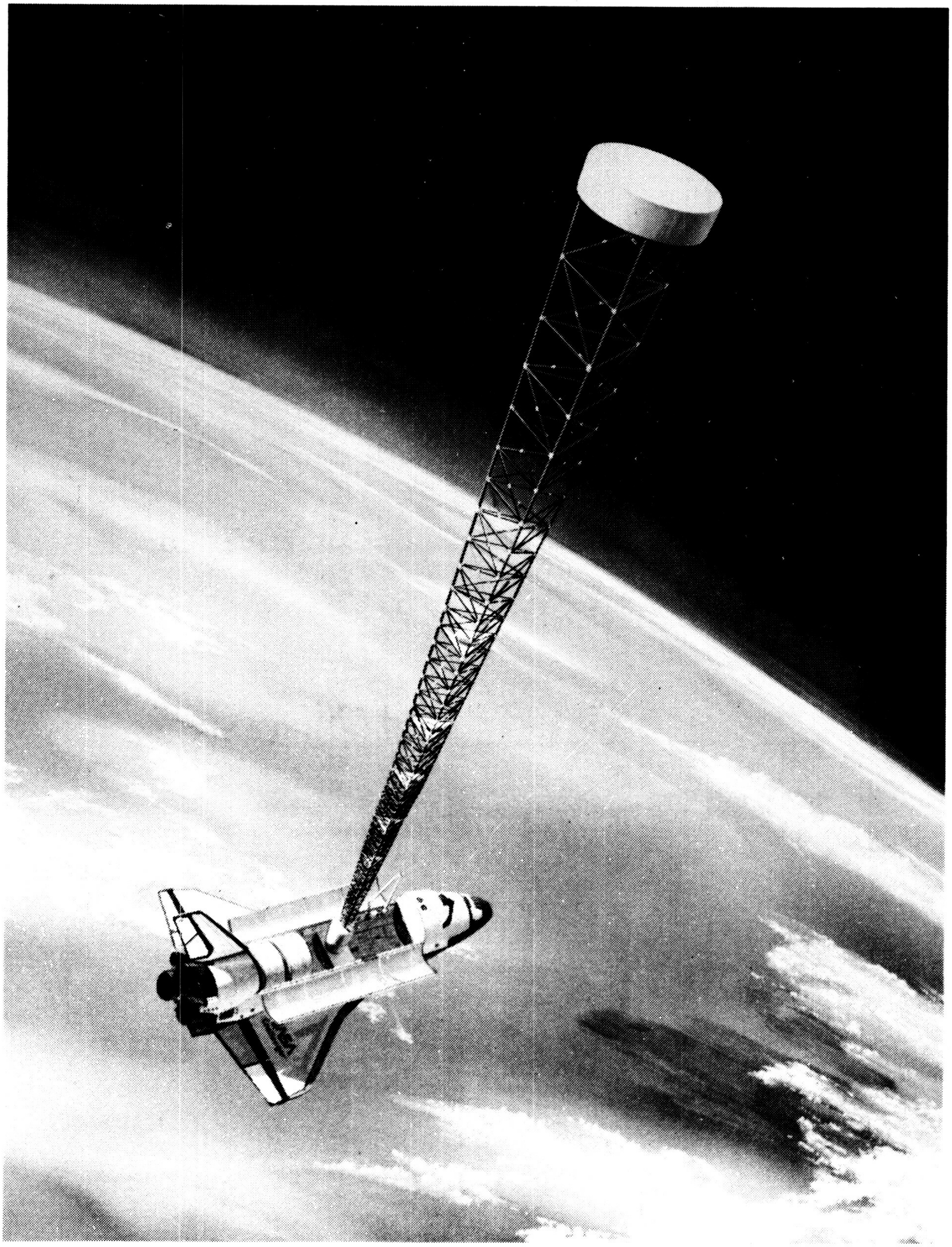

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Figure 1. COFS I flight experiment

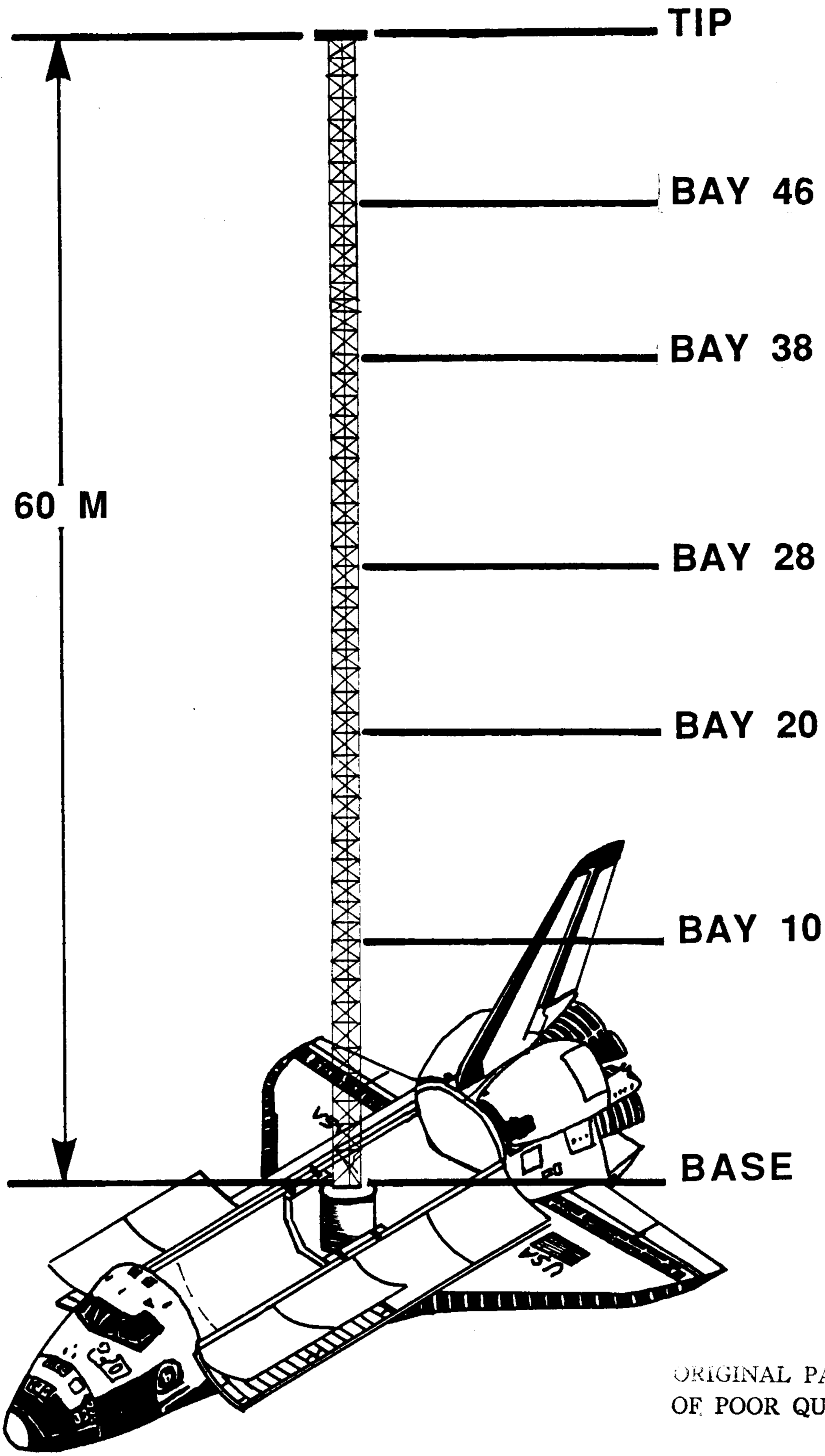

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Figure 2. Instrumentation platform locations

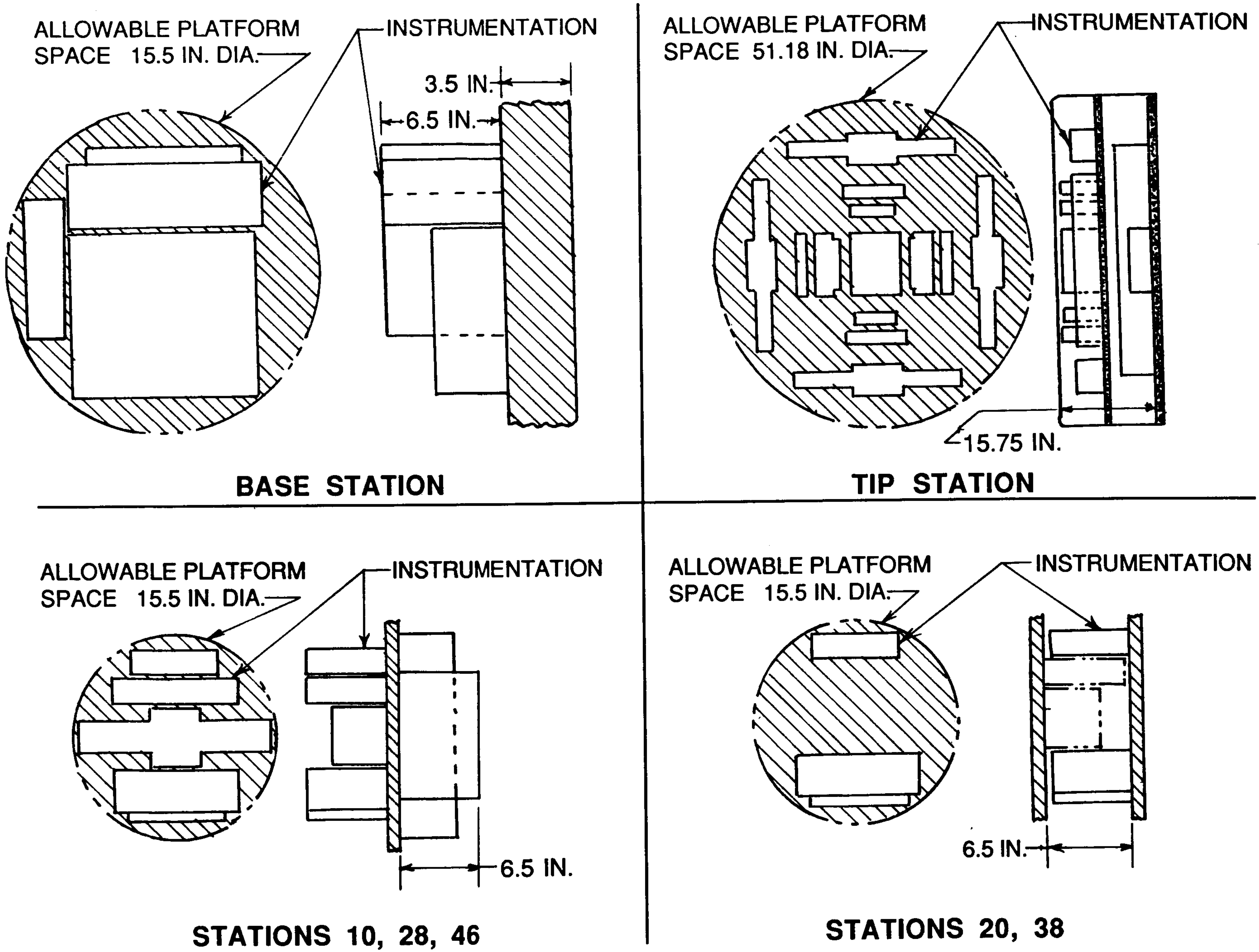

Figure 3. Instrumentation platforms for deployable COFS structure

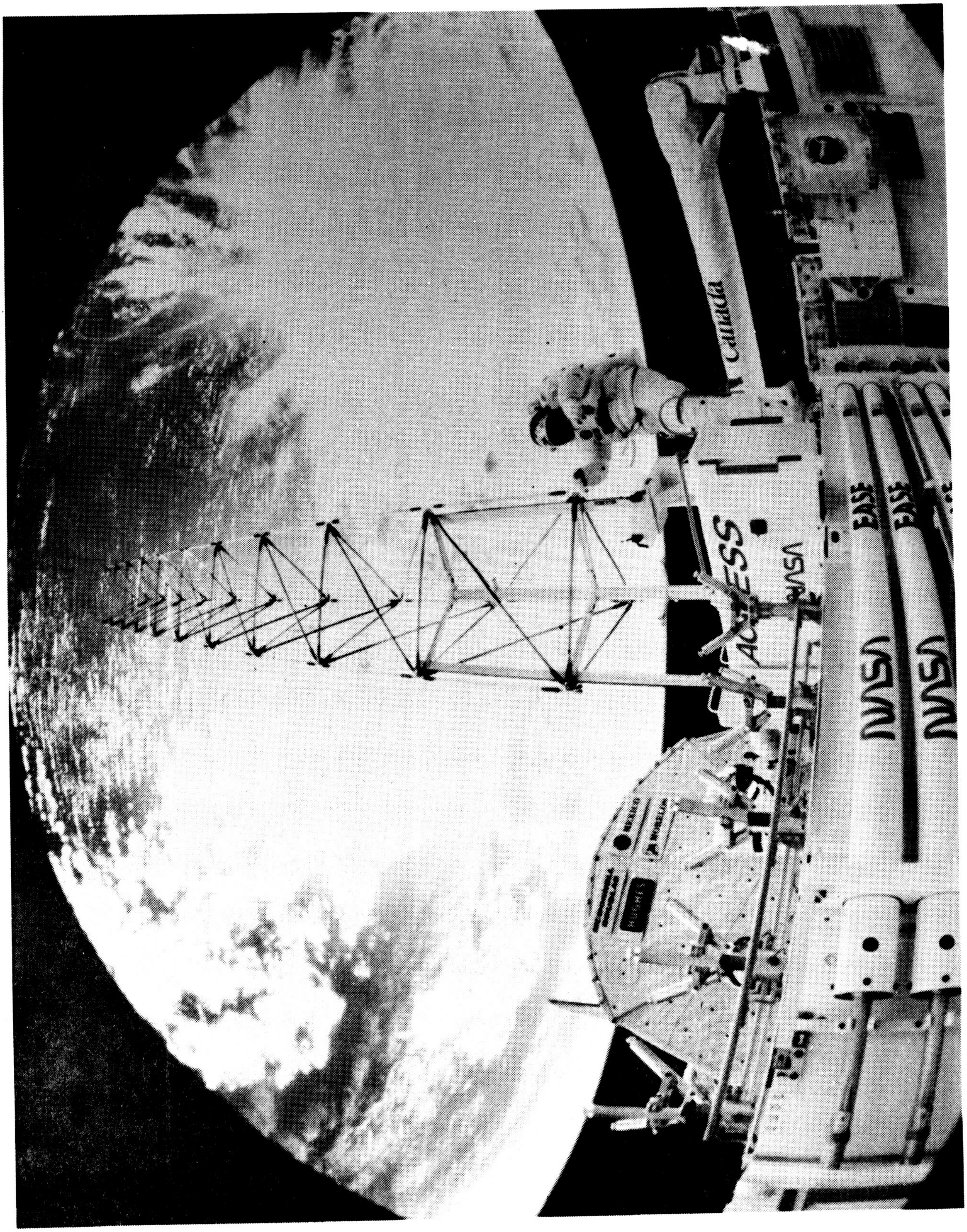

Figure 4. ACCESS flight experiment

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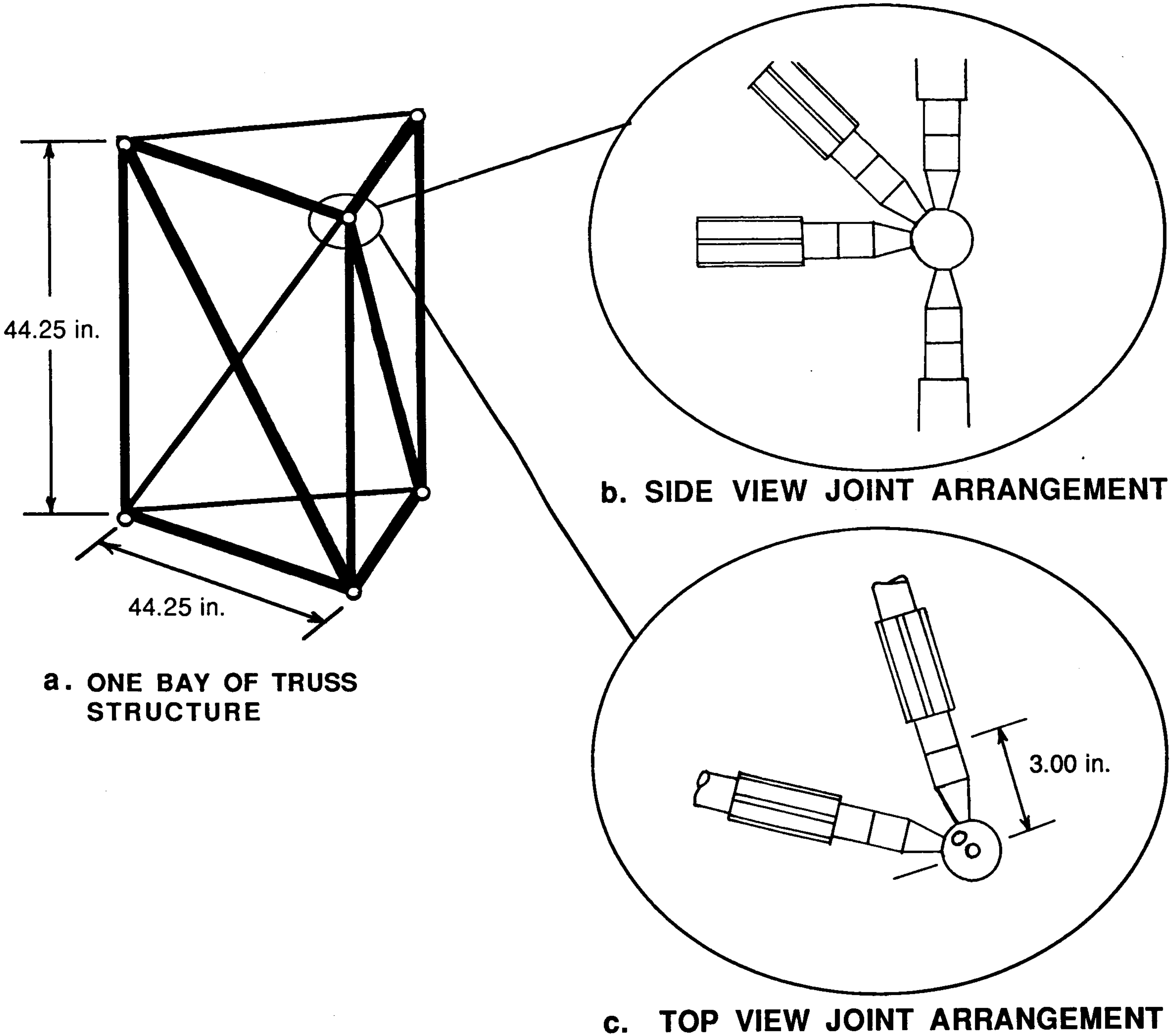


Figure 5. Erectable truss elements

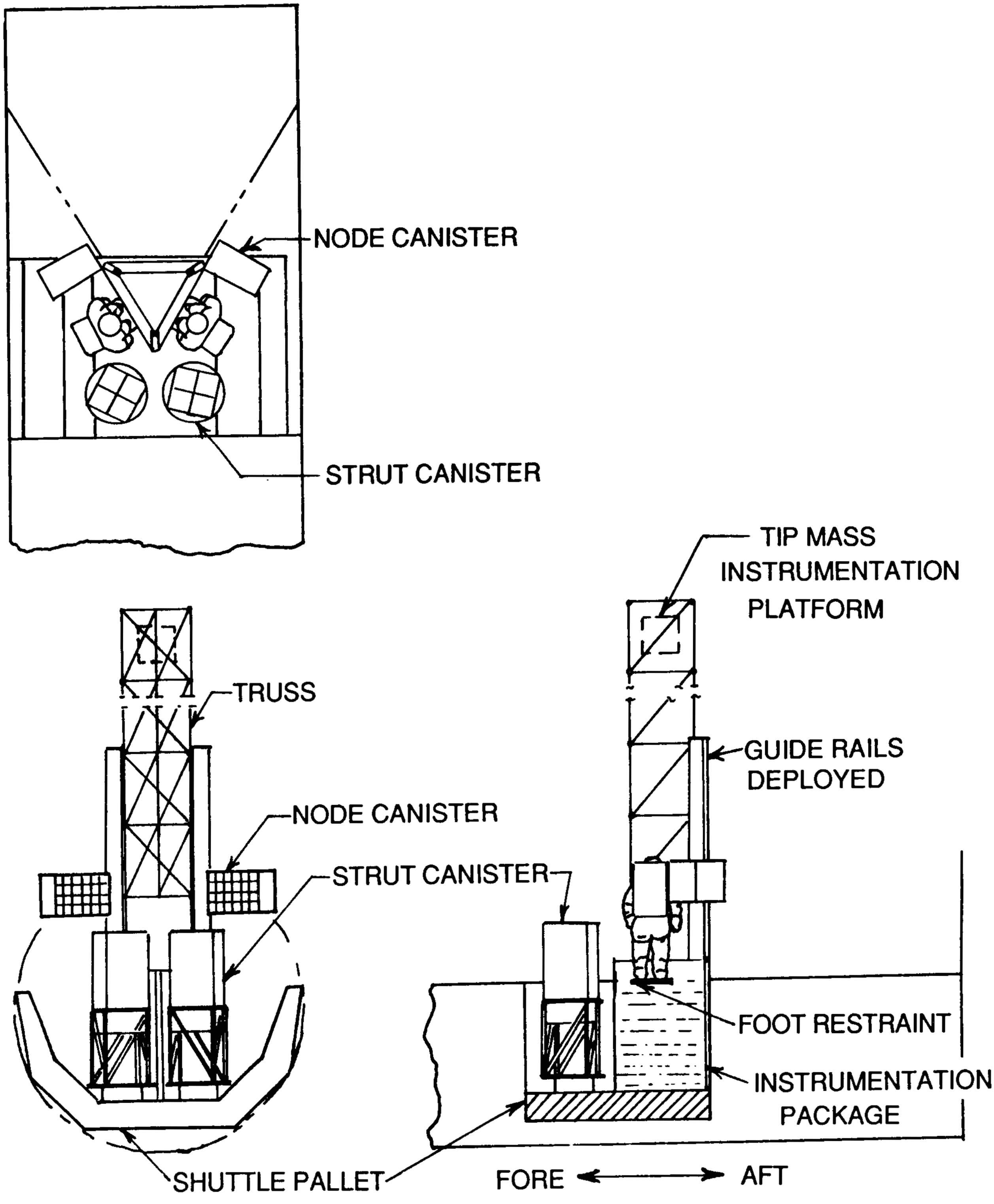


Figure 6. Sketch of erectable assembly concept for COFS

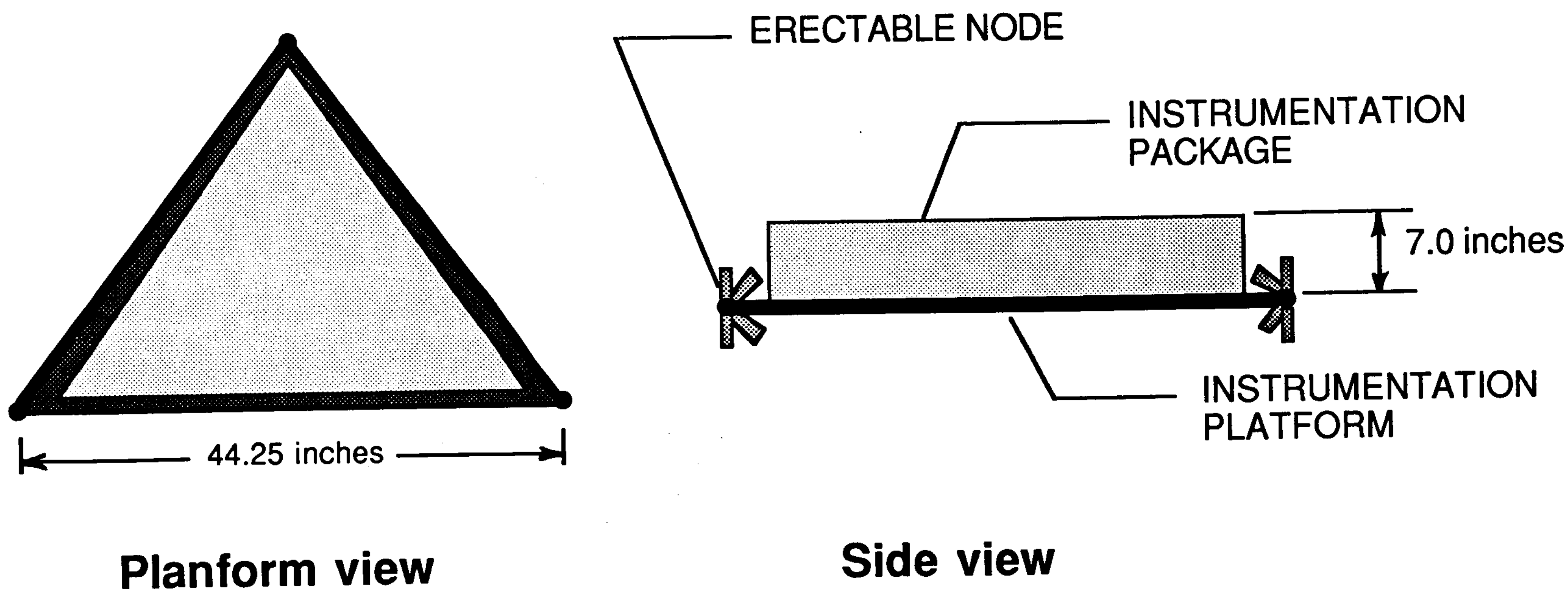


Figure 7. Proposed instrumentation Platform

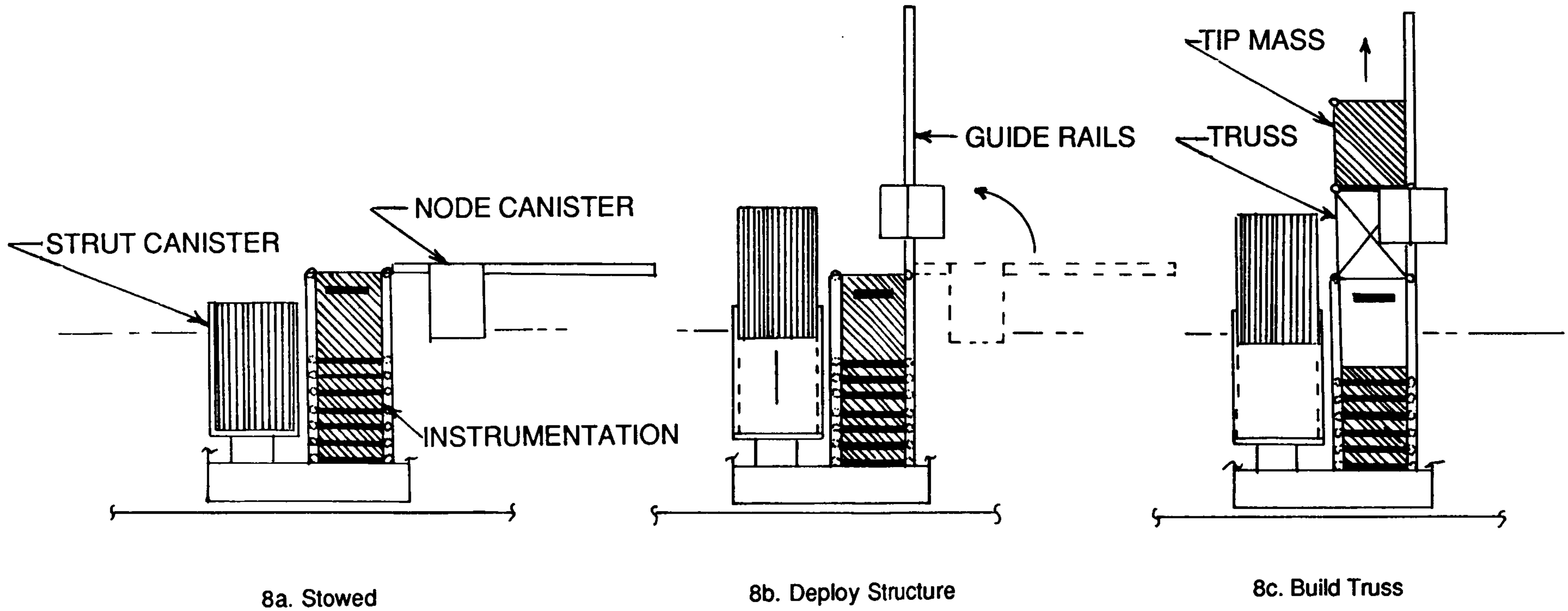
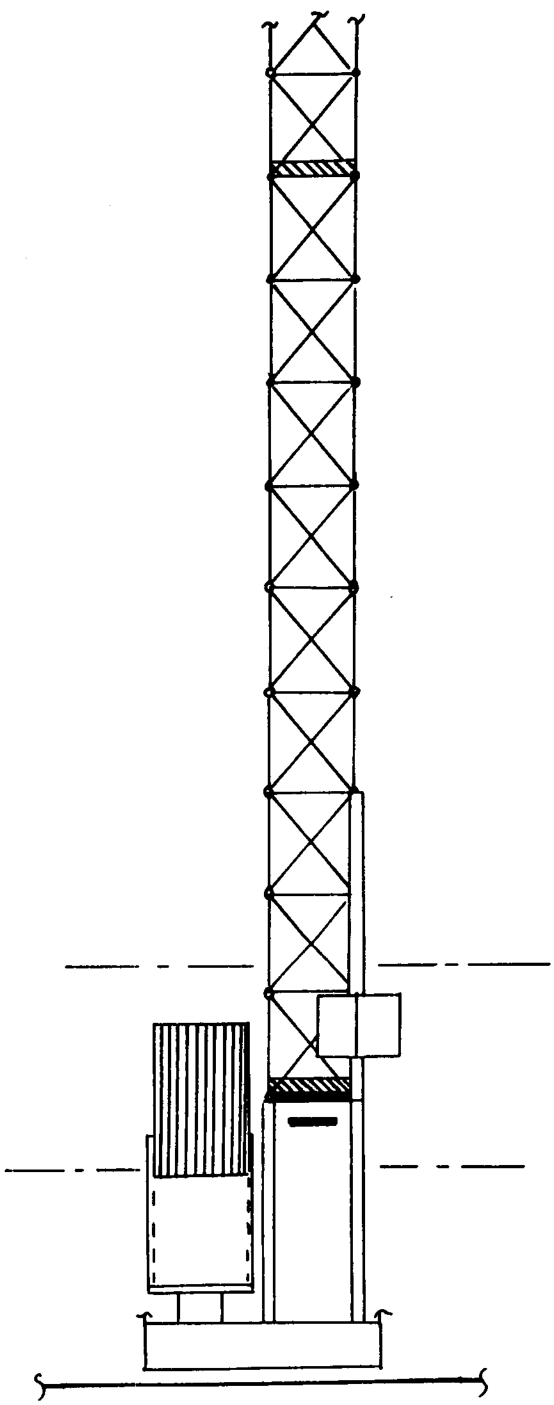
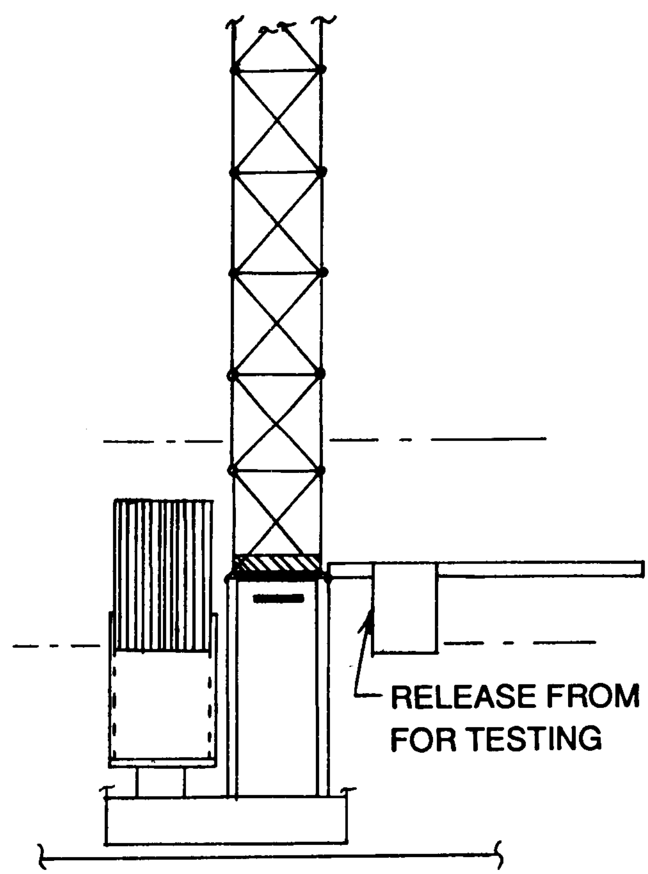


Figure 8. Assembly sequence



8d. Completed Build



8e. Test Configuration

Figure 8. continued

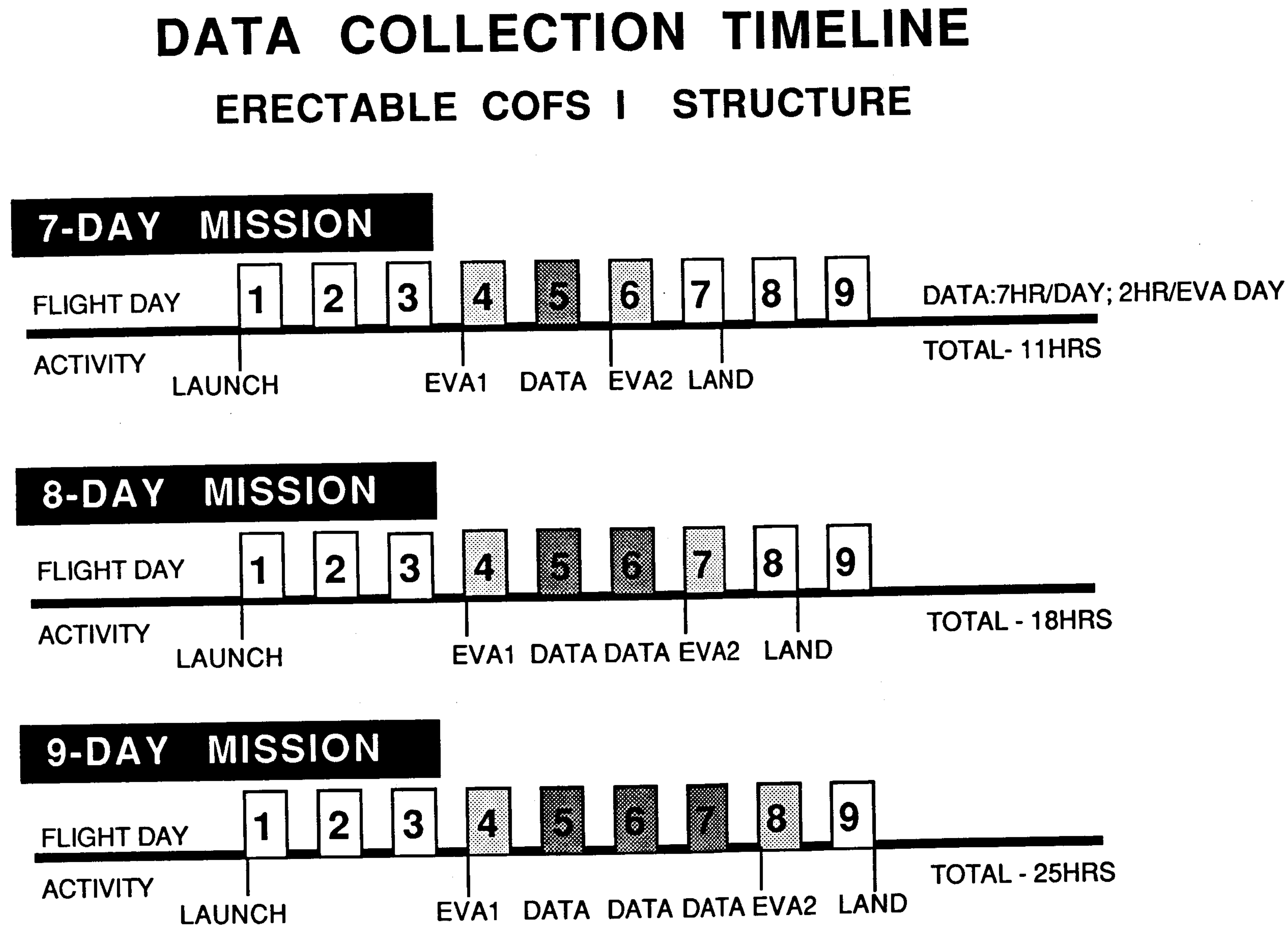


Figure 9. Available time for Data Collection

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15. Supplementary Notes

16. Abstract

A flight experiment which proposes to use a 60-meter deployable/retractable truss beam attached to the Space Shuttle to study dynamic characterization and control of flexible structures is being studied by NASA. The concept requires a relatively complex mechanism for deploying and retracting the truss on-orbit. Development of such a mechanism having a high degree of reliability will be expensive. This paper discusses an alternative method for constructing the truss that requires no new technology development or complex mechanisms and has already been demonstrated on-orbit. The alternative method proposes an erectable truss beam which can be assembled by two astronauts in EVA. The EVA crew would have to manually assemble the beam from 468 struts and 165 nodes, and install 7 instrumentation platforms with signal and power cabling. The predicted assembly time is 3 hours and 23 minutes. The structure would also have to be disassembled and restowed following testing, thus 2 EVA days would be required. To allow 25 hours for data collection (proably a bare minimum to accomplish meaningful tests), current Shuttle operations policy dictates a 9-day mission. The design, assembly procedure and issues associated with this alternative concept are discussed.

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