MOBILE WORK STATION CONCEPT FOR ASSEMBLY OF LARGE SPACE STRUCTURES (ZERO-GRAVITY SIMULATION TESTS)

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LARGE SPACE TRUSS STRUCTURE

Previous studies have identified truss structure such as illustrated in Fig. 1 as a prime candidate for low-mass, large-area spacecraft. Both deployable and erectable trusses have received considerable attention for this purpose, and both have their unique advantages and disadvantages. Deployable trusses which are intended to be preassembled on earth, packaged by folding for transportation to orbit in the Space Shuttle, and unfolded on-orbit can become structurally complex and are difficult to package efficiently. Erectable structures, on the other hand, which are intended to be assembled piece by piece on-orbit, are characterized by high packaging efficiency and relative structural simplicity. They, however, require development and demonstration of rapid on-orbit assembly methods employing quick-attachment joining techniques before advantage of such benefits can be realized. The Mobile Work Station concept presented herein is a Langley Research Center version that is intended to enhance astronaut assembly of truss structure that is either too large or complex to fold for efficient Shuttle delivery to orbit.

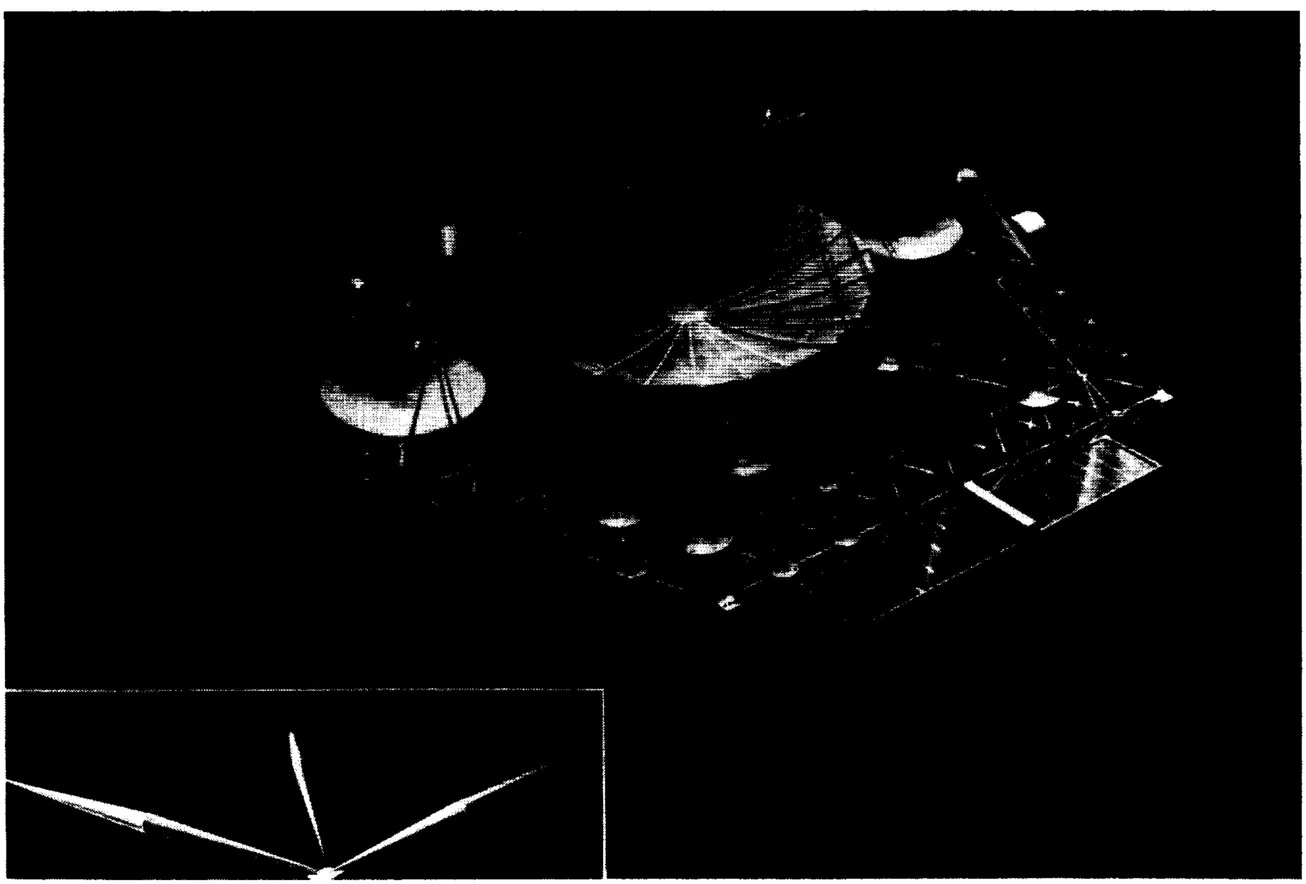

Figure 1

FEATURES OF ERECTABLE SPACE STRUCTURE

Two important features of erectable space structure (ref. 1) are presented in Fig. 2. The first is that minimum-mass erectable designs, based on stiffness requirements, are approximately equal in mass to deployable designs. Thus, mass-wise, there is no advantage of one concept over the other. However, it is also shown in reference 1 that erectable structures featuring nestable struts are superior to deployables from a packaging standpoint. This packaging advantage offers a potential economic payoff in terms of reduced Shuttle delivery flights provided efficient on-orbit methods of assembly for erectable structure are available.

- **MINIMUM-MASS DESIGNS EQUAL IN MASS TO DEPLOYABLES**
- **ERECTABLE STRUCTURES SUPERIOR TO DEPLOYABLES FOR PACKAGING**

Figure 2

MODEL OF MOBILE WORK STATION

Fig. 3 is a photograph of a model of the Mobile Work Station that was used to study the problem. The Mobile Work Station consists of four pairs of major components: (1) work platforms, (2) elevator towers, (3) conveyor rails, and (4) trolley beds. These components are shown attached to the Shuttle cargo bay and supporting a tetrahedral truss beam which represents a large space structure being assembled. The Mobile Work Station concept requires two pressure-suited astronauts to make the structural connections. Each astronaut works from one of the moveable platforms located on each side of the structure being assembled. The astronauts are secured by foot restraints in the work platforms at all times during the assembly and are moved within a prescribed plane as required. The platforms can move up and down on the towers, and the towers can move left and right on the trolley beds. This allows the astronauts to concentrate on assembling the structure without expending great amounts of energy manually moving themselves and material. Upon completion of periodic stages of assembly, the truss is conveyed along the conveyor rails away from the work area to make room for additional structure to be assembled. For all tests a beam-like truss similar to that shown in Fig. 3 was assembled using 5.4-m-long nestable struts. Although the Mobile Work Station is shown attached to the Shuttle, it could also be attached to a Space Operations Center or it could even be a free flyer. This concept is simply a space version of an assembly line. Construction tasks are repetitive; many, if not all struts can be identical, and quick-attachment joints eliminate the need for tools.

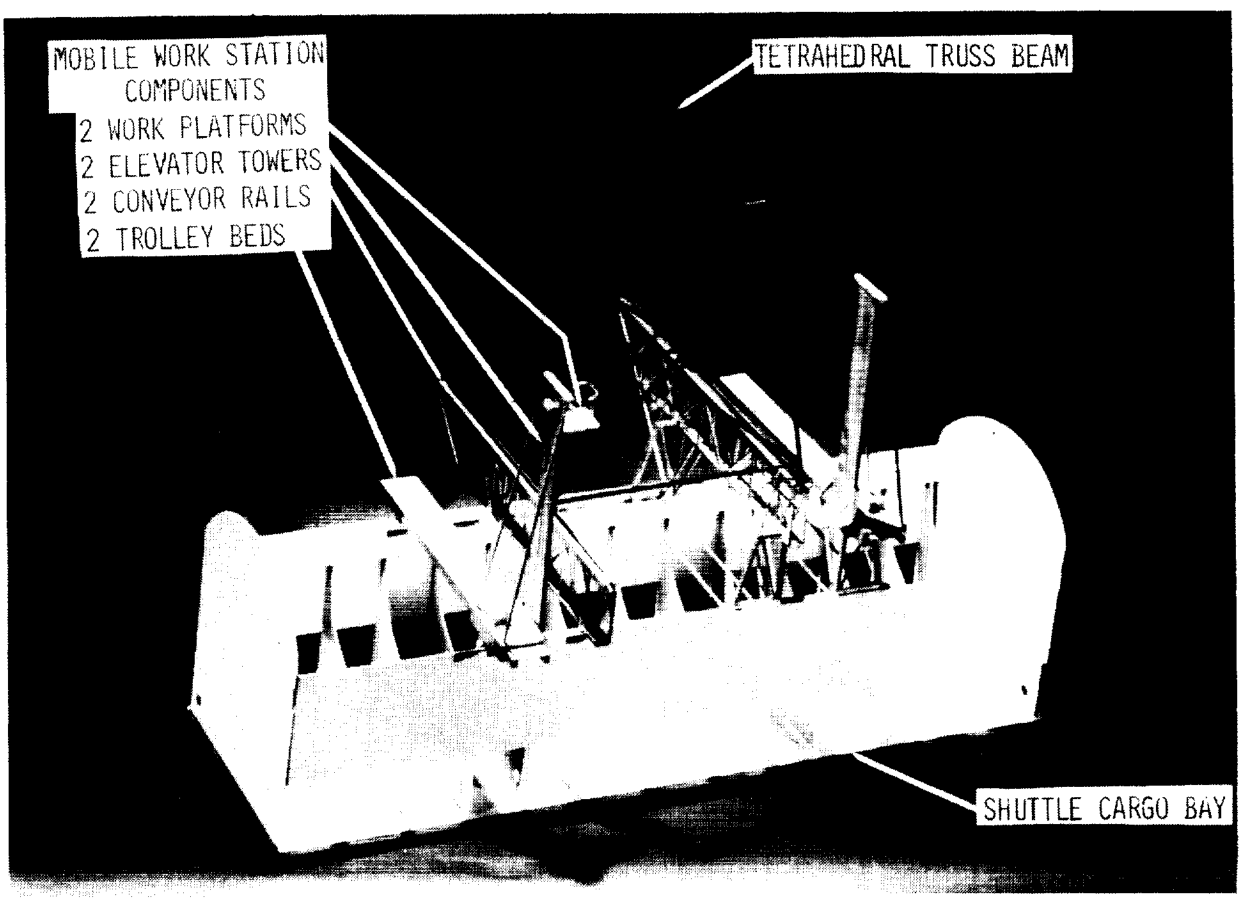

Figure 3

MOBILE WORK STATION

Fig. 4 is a photograph of the Mobile Work Station actual hardware. It weighs about 1360 kg. Much of this weight and volume of structure was required to support the two test subjects in an upright position while performing the 1-g assembly operations and to meet the requirements of underwater operation. A space version of the concept would have an entirely different configuration than the one shown in Fig. 4 because it would not have these restrictions and would be made lighter and less voluminous.

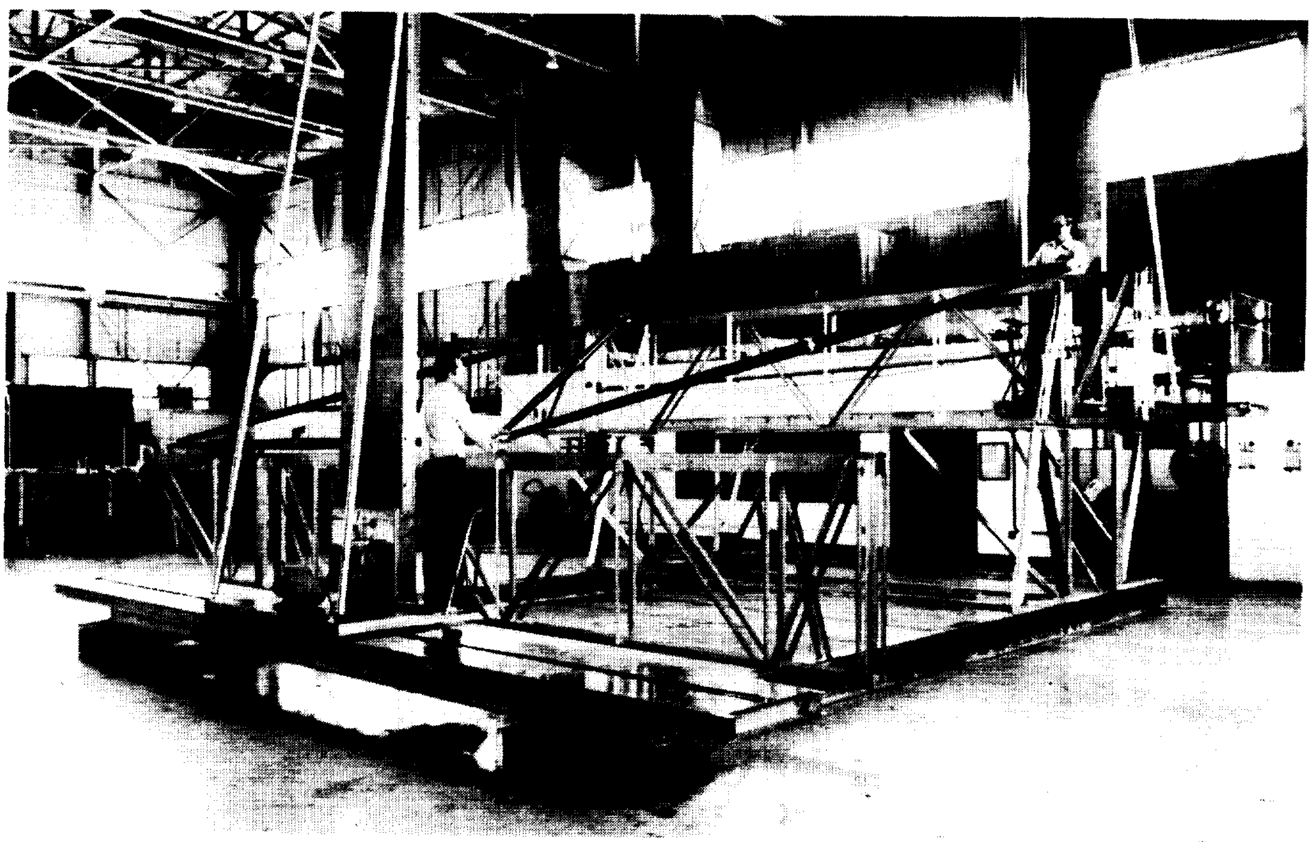

Figure 4

MOBILE WORK STATION 1-G ASSEMBLY TEST

Fig. 5 shows the Mobile Work Station 1-g assembly test in progress. The two test subjects are installing a transverse strut. The movement of the platforms as well as the conveyor is powered by air motors which are operated by a third subject at a console using "joy stick" controllers. The air motors and control console are not representative of flight hardware, but were used for economy reasons and to facilitate underwater operation in the neutral buoyancy tests. All of the hoses shown in the figure are air lines and would not be present in an actual flight version.

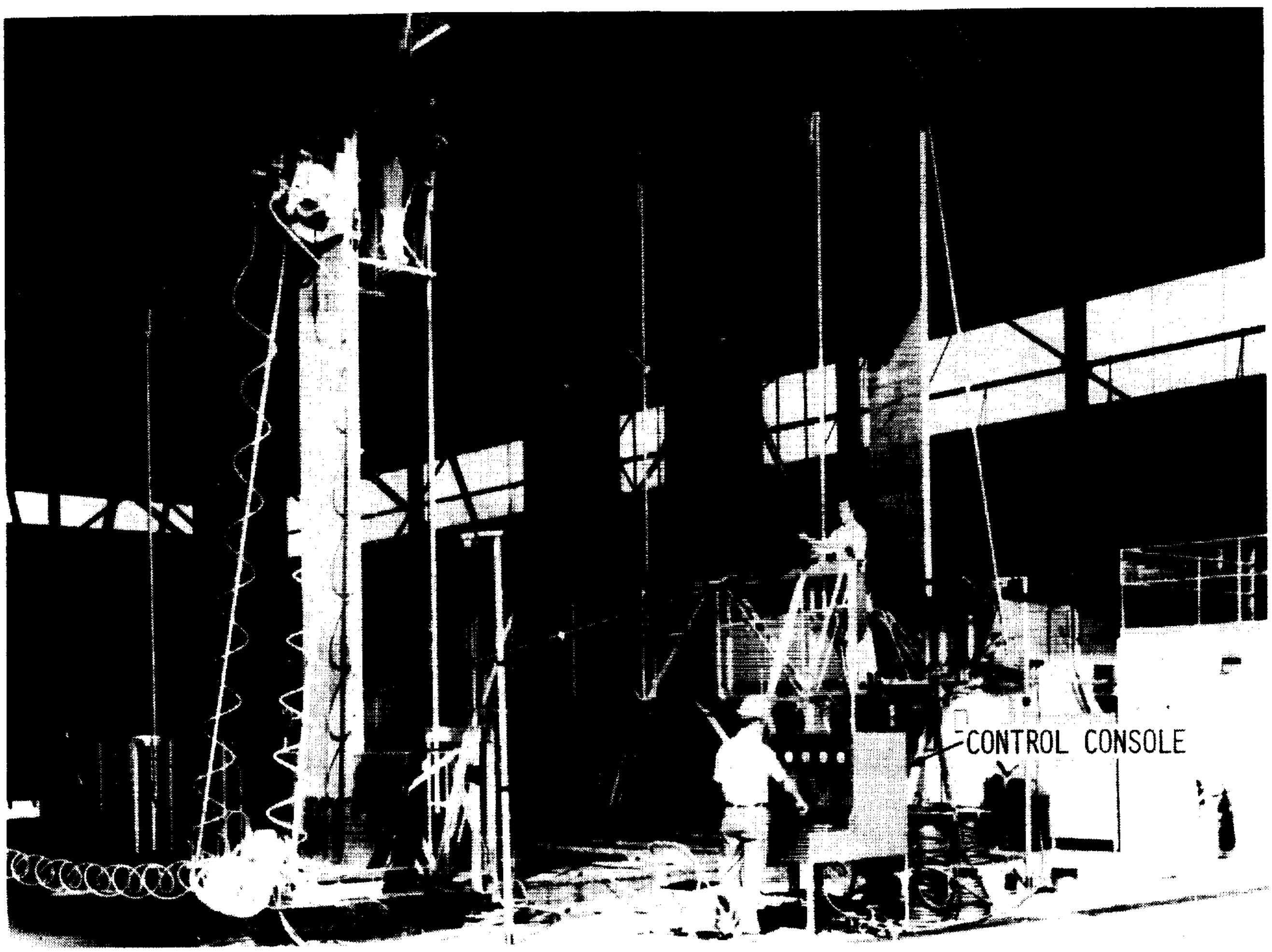

Figure 5

MOBILE WORK STATION 0-G TEST SETUP

Fig. 6 shows the Mobile Work Station simulated 0-g test setup in Marshall Space Flight Center's Neutral Buoyancy Facility. The struts were stored in racks on each side of the test subjects. Each subject had 19 struts within reach, all of of which were neutrally buoyant as were both test subjects.

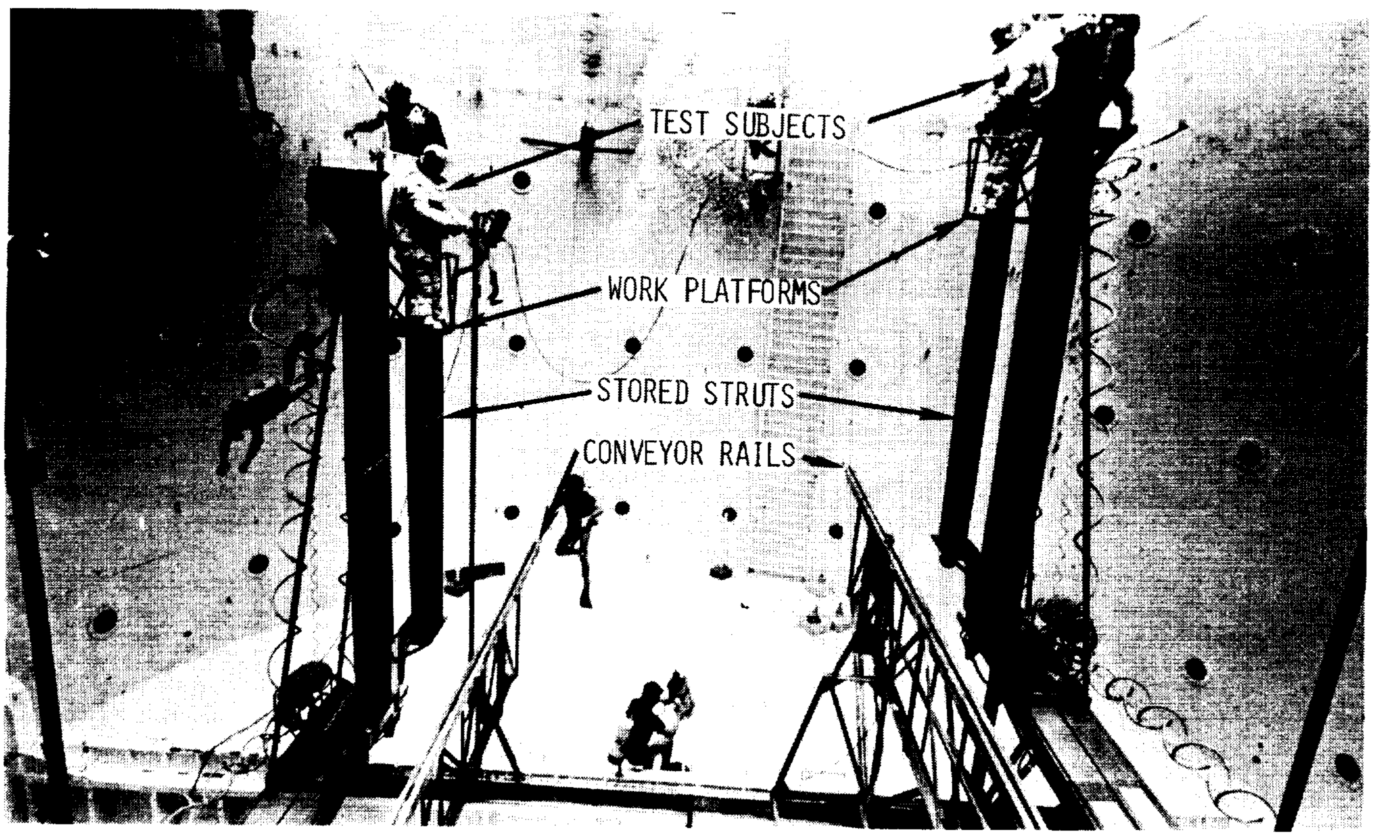

Figure 6

38-STRUT TRUSS ASSEMBLY IN MOBILE WORK STATION

Fig. 7 shows the truss completely assembled. The final structure was approximately 16.5 m in length and 4.5 m each side. It consisted of 38 struts. The assembly procedure was predetermined and was followed precisely through use of a third test subject located at a control console outside the tank. This third subject was in voice contact with the test subjects and controlled the location of the work platforms with the aid of video monitors. Only the struts spanning the truss width could be installed by both subjects simultaneously as shown in Fig. 7. The horizontal and diagonal struts on each side of the truss required installation by one test subject alone. This task was not difficult in the neutral buoyancy environment. Weightlessness allowed the test subject to connect only one end of the strut at a time, and since no climbing on the structure was required, the strut remained in place while the test subject was translated to connect the opposite end. Preset precision lengths of the interchangeable struts permitted this redundant structure to go together with relative ease.

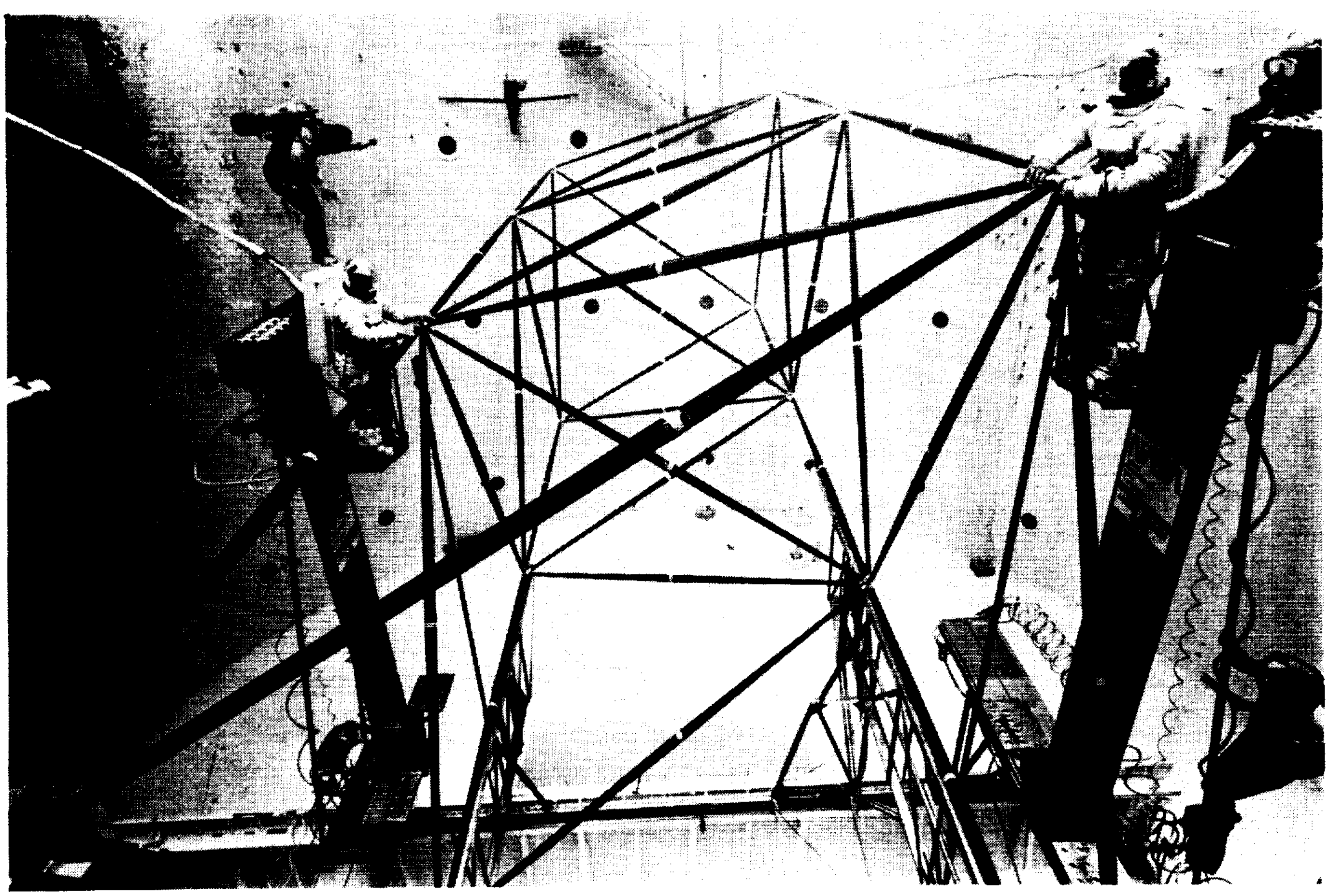

Figure 7

ASSEMBLY RATES

Assembly rates using the Mobile Work Station in three ground test environments are shown in Fig. 8. Also shown is a projected assembly rate that represents an estimate for space operation of the Mobile Work Station. The 1-g assembly in street clothes and air took an average of 24 seonds per strut. Maneuvering the struts in air is more realistic of space operation than in water based on drag effects; however, the test subjects were not impeded by pressure suits for these tests. The effects of gravity were of little consequence because the struts were so light--only about 1.6 kg apiece. The assembly performed in neutral buoyancy in SCUBA averaged 39 seconds per strut. Thus, water drag added about 15 seconds per strut to the assembly rate in air. Finally, the neutral buoyancy and pressure suit test yielded an average of 53 seconds per strut. Thus, the pressure suit encumberance added another 14 seconds per strut to the neutral buoyancy assembly rate obtained in SCUBA. An assembly rate for space operation can be approximated by either subtracting the 15 seconds per strut which is apparently the result of water drag from the 53 seconds per strut assembly rate, or by adding the 14 seconds per strut which is apparently the result of pressure-suit restrictions to the 24 seconds per strut assembly rate. In either case, the projected space assembly rate appears to be about 38 seconds per strut.

	TEST ENVIRONMENT	ASSEMBLY RATE SEC/STRUT
TEST	1-G, STREET CLOTHES, AIR	24
	0-G, SCUBA, WATER	39
	0-G, PRESSURE SUIT, WATER	53
PROJECTED	0-G, PRESSURE SUIT, SPACE	38

Figure 8

COMPARISON OF ON-ORBIT ASSEMBLY METHODS

A comparison of other on-orbit assembly methods with the Mobile Work Station data is given in Fig. 9. The on-orbit assembly time in days is plotted against assembly rate in struts per day for various size, hexagonal, tetrahedral truss platforms of maximum span D. Curves are plotted for D of 200, 400, 600, and 800 meters. Also shown by the dashed line is the present, five-day, on-orbit operational limit of the Space Shuttle. The shaded vertical bars represent assembly rates assuming 8-hour days for: (1) all manual, EVA assembly based on data obtained from neutral buoyancy assembly tests of a six strut tetrahedral truss structure (ref.2), (2) the Mobile Work Station data presented herein, and (3) automatic machine assembly rates derived from theoretical timelines assuming 24-hour-per-day operation (ref. 3). It is shown in Fig. 9 that the Mobile Work Station assembly rate is approximately a factor of five faster than manual assembly and approaches predictions for automatic assembly. It should be noted, however, that manual assembly requires manual translation which increases as the size of the structure increases. With the Mobile Work Station, astronaut translation requirements depend only on the length of the struts and not the size of the structure. Thus, long translation times are eliminated and extravehicular time is devoted primarily to structural assembly.

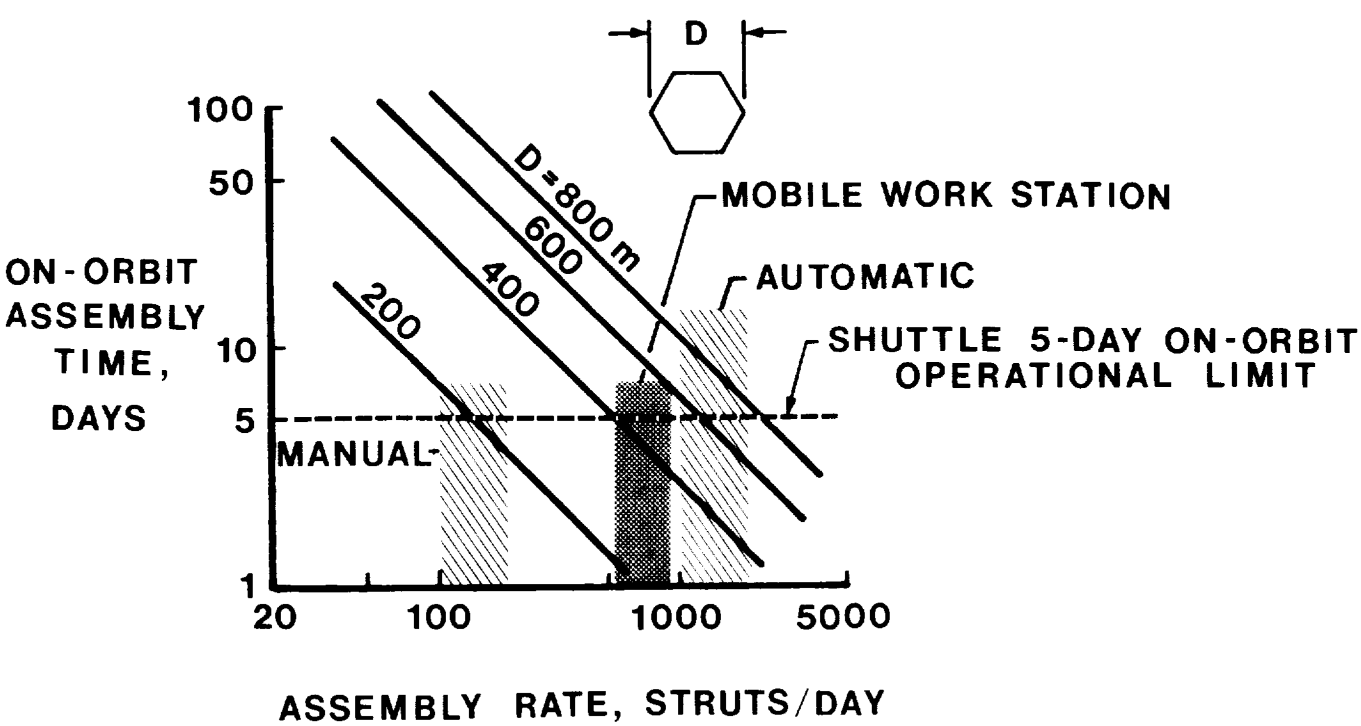

Figure 9

CONCLUDING REMARKS

The potential of augmented astronaut assembly can be illustrated by applying the result of this test program to a "barebones" assembly of the truss structure shown in Fig. 1. If this structure were assembled from the same nestable struts that were used in the Mobile Work Station assembly tests, the spacecraft would be 55 meters in diameter and consist of about 500 struts. The struts could be packaged in less than 1/2 % of the Shuttle cargo-bay volume and would take up approximately 3 % of the mass lift capability. They could be assembled in approximately four hours. Thus it appears that this rather simple but rapid on-orbit assembly concept for erectable structures is not only feasible, but could be used to significant economic advantage by permitting the superior packaging feature of erectable structures to be exploited and thereby reduce expensive Shuttle delivery flights.

REFERENCES

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