AUTOMATIC IN-ORBIT ASSEMBLY OF LARGE SPACE STRUCTURES

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INTRODUCTION

Large space platforms employing nested tapered graphite-epoxy columns reference 1 have been proposed for a number of applications such as communication satellites, multi-kilowatt power modules, large modularized antennas and geostationary platforms. Erection of these platforms which may be up to several square kilometers in size will require several Space Shuttle flights (about 10 per square kilometer) and will necessarily take place at space shuttle orbital altitude. Installation of platform payloads will also take place at this altitude and the completed unit will then be transferred to its final station by towing or under its own power.

The structural concept of these platforms is based on the triangulated tetrahedral space frame described in reference 2. Although this concept is relatively simple, its assembly presents a number of unusual problems because of the large size (20 m columns) and the great number of components which must be connected in a vacuum, zero gravity environment. This operation could be performed manually by astronauts in the course of an extra vehicular activity (EVA). However, the very large number of columns to be assembled (a full Space Shuttle load consists of about 3000 columns and 670 node joints) would require many hours of strenuous astronaut work in the restricted mobility of space suits. Therefore, it appears logical to consider mechanizing this process in order to lighten the astronauts work load. The automatic features of the assembly procedure should be such that only monitoring functions are required from the astronauts, with EVA's being required only in case of difficulties and to assist in loading and unloading supply cannisters.

More complete details of the concepts discussed herein are presented in reference 3.

SPACEFRAME CONFIGURATION

General Geometry

The space platform under consideration is based on the tetrahedral principle which makes use of tri-dimensional triangulation to achieve rigidity. The structure consisting of graphite epoxy columns connected by node joints is shown on Fig. 1. Each node has connections for 6 columns in one plane and 3 interplane columns. The planview configuration presents the appearance of two sets of hexagons offset with respect to each other (Fig. 1). Each column is 20 m (66 ft) long and a full Space Shuttle load corresponds to the assembly of a platform having approximate dimensions 1000 x 100 m (1/10 square kilometer). Since each node joint connects 9 columns and each column is connected to two node joints, the number of columns equals 4.5 times the number of node joints. For a given area, A, the required number of node joints is: $N_j = \frac{4}{\sqrt{3}} \frac{A}{\ell^2}$ where ℓ is the column length. Therefore one square kilometer requires 5774 node joints and 25981 columns, i.e. approximately 9 Space Shuttle loads.

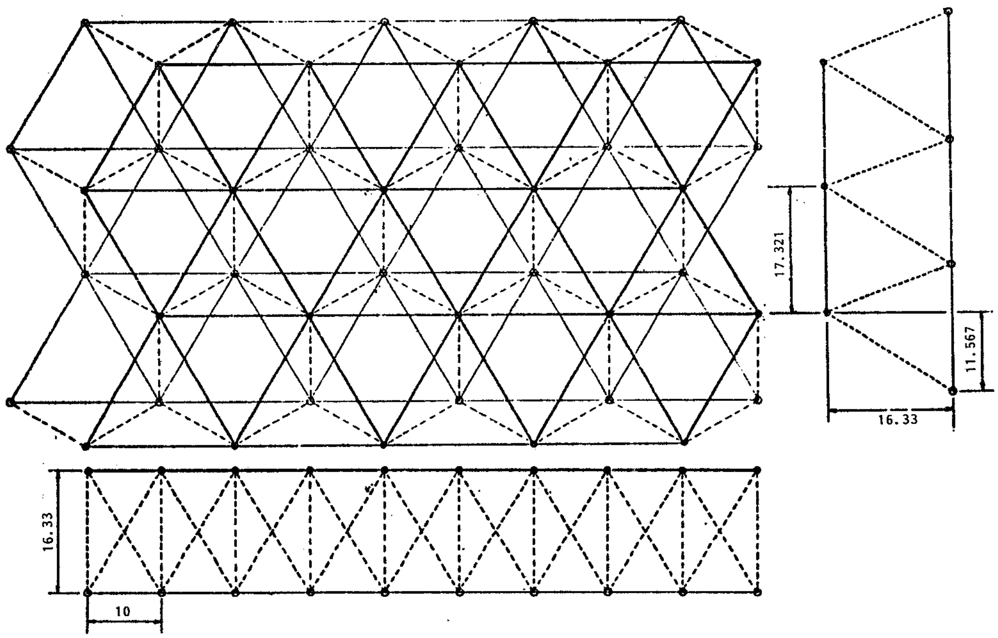

Fig. 1

Columns

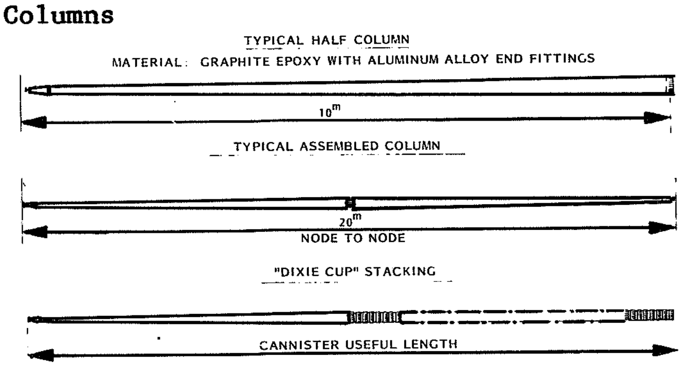

Fig. 2

The design of the columns is conditioned by the Space Shuttle Stowage requirements. In order to attain the desired loading density, column stacking is a necessity; therefore, each column is made of two narrow conical halves with a connector in the middle. The cones are thin graphite epoxy shells, which allows nesting, or stacking in the fashion of plastic cups. The number of half columns which may be nested in one stack within the length of the Space Shuttle cargo bay is of the order of 50. Figure 2 presents some details of the columns and the stacking mode. An alternate concept makes use of full columns hinged at the center thus allowing column erection by simple deployment about the spring loaded hinge line without altering the stacking capabilities of the system. This type of column is equipped with a locking mechanism which is a part of its deployment system.

NODE JOINTS

The node joints must provide adequate rigidity to the assembly as well as ease of column insertion. One such design which meets these requirements is shown on Fig. 3. This node connector is self-locking and provides good rigidity about all axes. It can be disconnected manually without effort, even by an astronauts wearing gloves, a feature which allows easy repairs and modifications to the space structure in EVA.

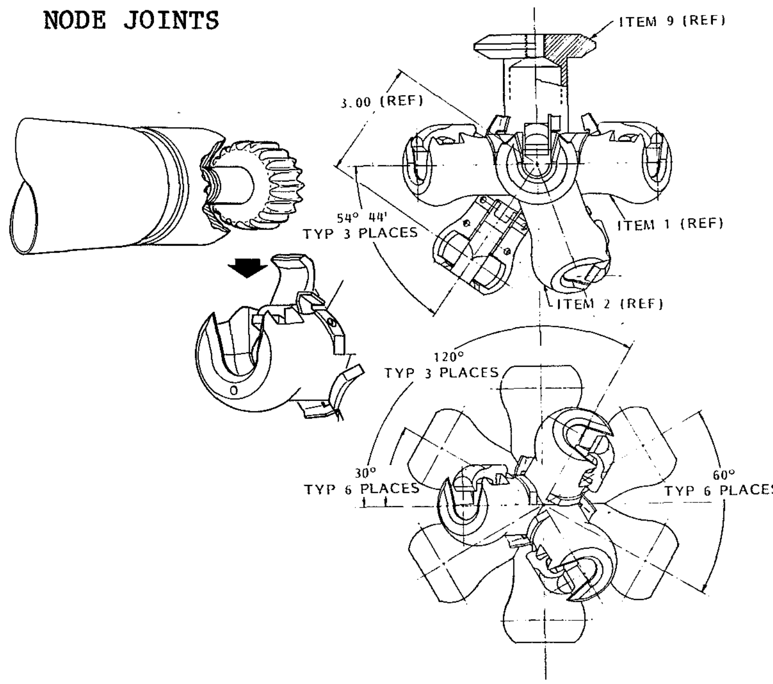

Fig. 3

ASSEMBLERS

General Criteria

In view of the complexity and repetitive nature of the task involved in the assembly of these large space structures, it is desirable to mechanize the process as much as possible and control it through a computer by means of appropriate software. The major criteria which must be satisfied by these machines are as follows:

o Provide adequate jigging of the node joints for accurate column insertion

o Column insertion performed by specialized robotic devices using appropriate end effectors.

o Automatic capture of node joints from supply cannisters, automatic release after installation.

o Automatic capture of columns from supply cannisters, controlled release after insertion is secured.

o Capability to operate during "day" and "night" periods.

o EVA backup mode for emergency operation.

- Compact stowage of the machine in the Space Shuttle Cargo Bay and simple on-orbit assembly without need for special tooling.

Based on these criteria, two assembler designs have been conceptually developed. They are presented below.

Assembler No. 1

The general configuration of Assembler No. 1 is shown on Fig 4. It consists of a main frame which supports a crew and computer compartment on one side and six movable arms on the other side. These arms carry cannisters containing the supply of node joints and columns. Typical concepts of supply mechanisms are presented on Fig. 5. Column insertion is performed by means of special mechanisms or robotic manipulator devices as shown on Fig. 6. These devices will be designed for each column insertion point and will perform simple tasks in a rapid repetive manner.

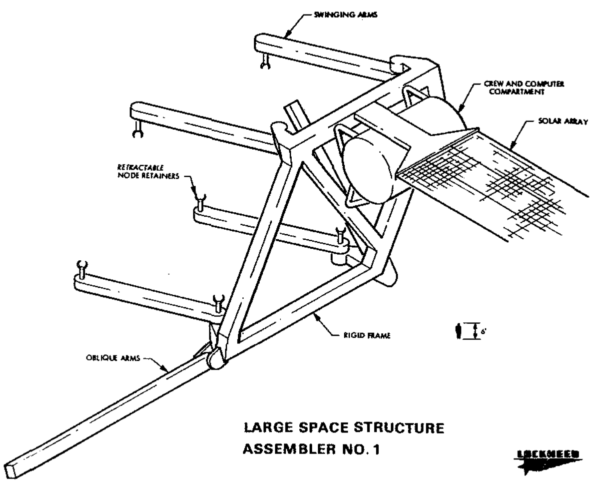

Fig. 4

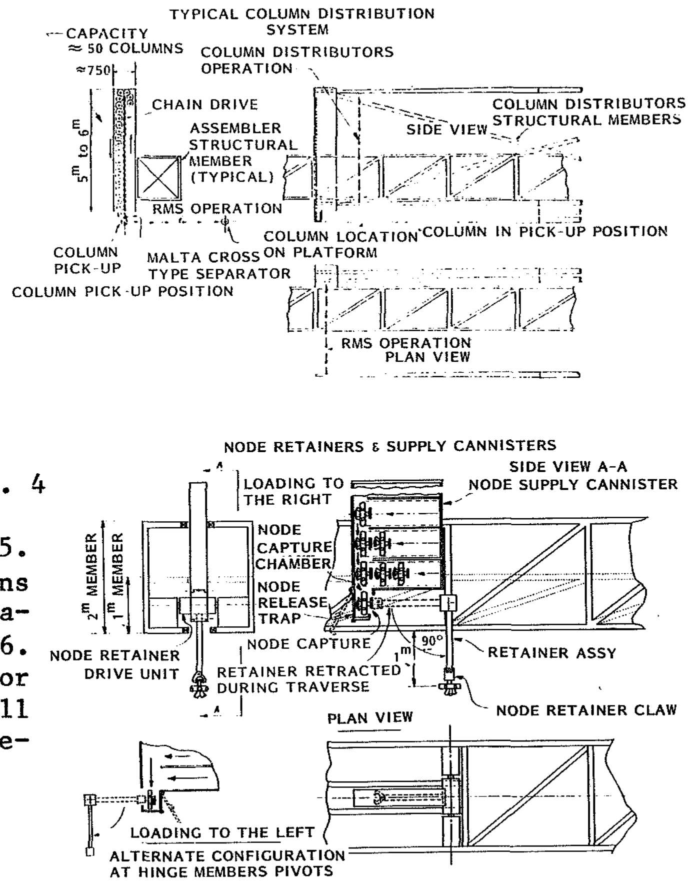

Fig. 5

Traverse Motion

In operation, this assembler progresses along the edge of the space platform, building it as it goes. Its sideways motion (traverse) is somewhat similar to that of a crab as the swinging arms are rotated to walk from node to node on the platform. New nodes are captured from the

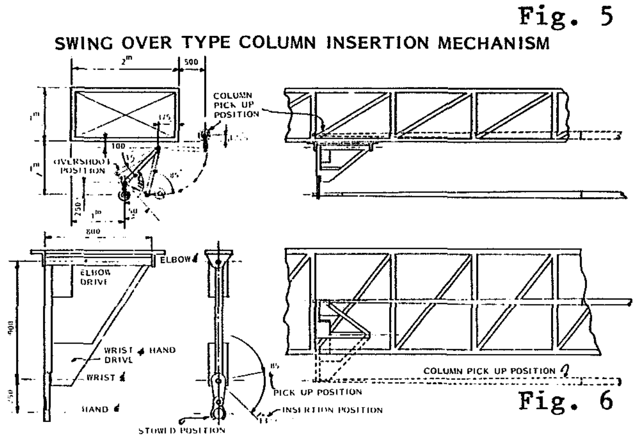

Fig. 6

cannisters, set in place and interconnected with columns. The design can be operated to traverse either to the right or to the left. Also it can be controlled to perform a change of row at the end of a traverse or to go around the corner of a triangle. All these maneuvers can be made computer software dependent, needing only astronaut supervision either by direct observation through the windows of the crew compartment or via spotlights and TV cameras during the night periods.

Specialized Remote Manipulator System (RMS) - Column Insertion

On this assembler, the column cannisters are mounted on the sides of the machine structural members, in close proximity to the final position of the columns. Column insertion is performed over generally short distances and along simple paths. Multi-degree of freedom robotic devices (similar to the Space Shuttle Payload RMS) have been considered to perform this operation because the same system can be used at all column insertion points, thereby simplifying the maintenance and spare parts problem. Such an approach is not very efficient from an operational standpoint since some degrees of freedom will be redundant at some locations. As an alternate, simplified assembly devices have been considered. In this case, the appropriate mechanism differs for each insertion since it must be adapted to meet local requirements. One such typical device is shown on Fig. 7. It consists only of the forearm and wrist with each hinge having only one degree of freedom. This mechanism follows a simple trajectory from the column cannister to the node joint and the wrist motion could be controlled by purely mechanical means (e.g. a cam system). The end effector, however would still have to be powered and controlled separately.

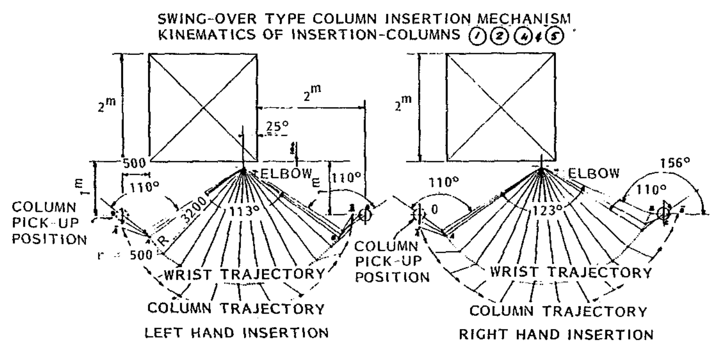

Fig. 7

Column Cannisters

In this application, it is assumed that the half columns would be assembled by a separate machine parked in the vicinity. This machine would receive the Space Shuttle load of cannisters, connect the half-columns together and insert them into the assembly machine cannisters. The astronauts, would then transport these cannisters to install them on the platform assembly machine. The design concept of these cannisters has not been detailed at this time but it is thought of as a mechanically driven system consisting of electrically or mechanically operated holding devices to move the columns and release them one by one upon demand. Each cannister must be approximately 21 m long (70 ft) and requires drive mechanisms at each end. Figure 5 presents the general configuration of these cannisters.

Node Joint Cannisters

The general principle of a node joint cannister is shown on Fig. 8. The node joints are held in position in appropriate compartments and moved forward by a mechanism somewhat similar to that of the column cannisters. Upon reaching the front wall, the node joints are caught by another mechanical transport mechanism which directs them one by one to the capture chamber where the assembly machine node joint retainer can grasp and swing them into place for column insertion.

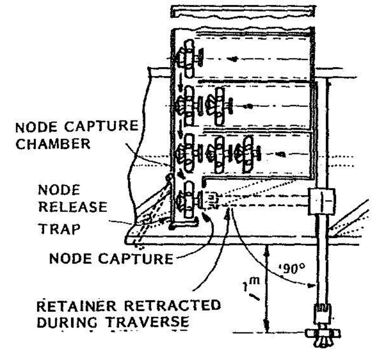

Fig. 8

ASSEMBLER NO. 2

General Principle and Configuration

An alternate concept for assembly of tetrahedral structures is presented on Fig. 9. In this system, the frame work is rigid and serves as the jigging reference. A set of four tracks simultaneously provides the traverse translational facilities and the node joint supply mechanism. The column cannisters are installed at only two locations on the main frame and the transport and insertion of the columns is performed by four identical robotic arms similar in concept to the Space Shuttle RMS, but scaled down and designed to meet these specialized requirements. Here again, it is anticipated that the half column assembly would be performed separately. However, in the case where folded self-deploying columns would be used, it is possible to perform this operation on the machine itself thereby greatly simplifying the whole assembly procedure.

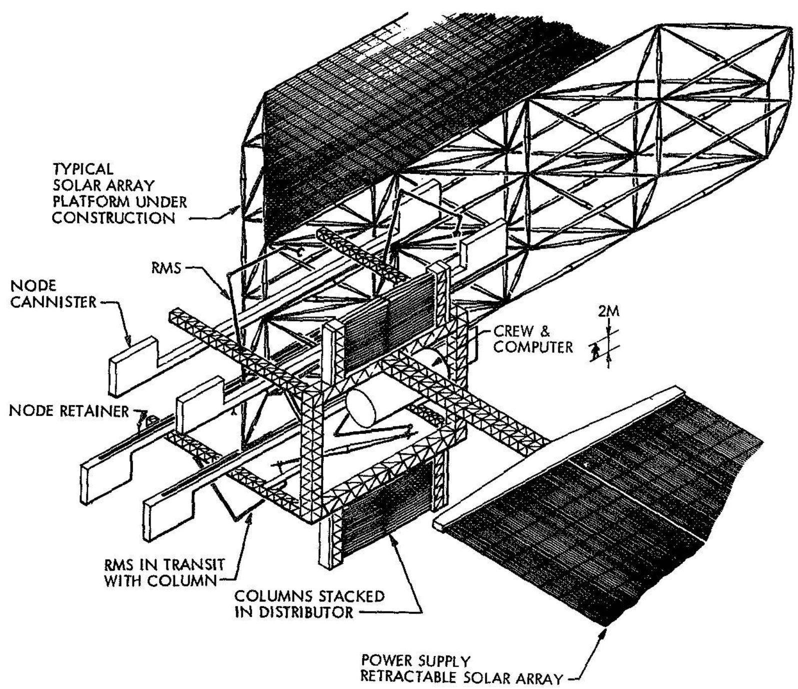

Fig. 9

Traverse Mechanism - Row Change

The traverse mechanism is based on a track system which carries a set of carriages driven by an endless chain, Fig. 10. The node joint retainers are retractable and may be given precision positioning capabilities. The carriages can be located with precision by a track notch locking system capable of providing repeatable positions within specified tolerances.

The traverse motion is obtained similarly to that of a tracked vehicle with the node joint retainers getting hold of the node joint heads in a hand-over-hand fashion, under computer control.

In order to change row, the machine must disconnect itself from the platform under construction and reposition it with respect to the track system. This is accomplished by using the four robotic arms to perform the required manipulations.

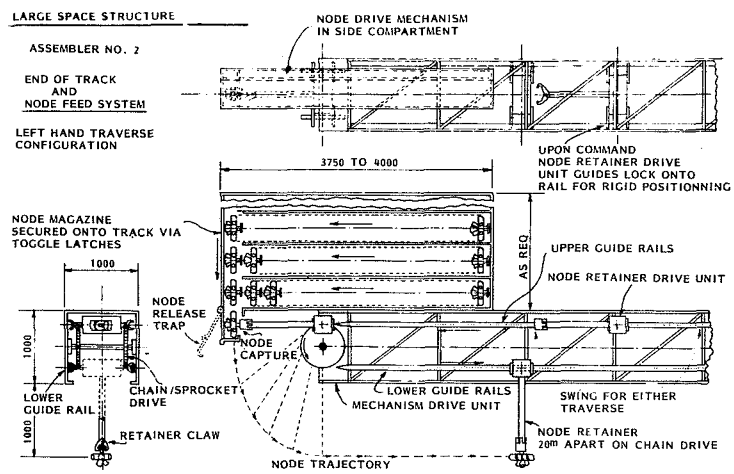

Fig. 10

Specialized Robotic Assembly Devices - Column Insertion

In this system, the columns must be picked up from the cannisters and maneuvered past a number of obstructions to be inserted into the node joints. This manipulation can be performed by robotic arms designed for this purpose. The robotic manipulations required for this application can be designed to move small masses (a few kilograms) but must have the capability to operate at relatively high speeds. The procedure by which this can be achieved consists of defining the coordinates of the trajectories of each end of the columns. A computer program directs the manipulator to follow these trajectories at specified velocities varying with position. Thus accelerations can be controlled throughout the motion and allowances can be made for minimizing the effect of structural flexibility.

Since for this assembler there are only four identical robotic manipulators located in very accessible positions, the problems of interchangeability and replacement are minimized.

Column Cannisters

Except for larger capacity, the design and mechanisms of the column cannisters would follow the principles outlined for those of Assembler No 1. The larger capacity is desirable to reduce the number of loadings and unloadings and to minimize the number of assembly interruptions. The location of these cannisters was selected for its ease of access and the freedom it affords in setting the maximum practical capacity. It is shown on Fig. 11.

Node Joint Cannisters

The storage method and mode of transit of the node joints in their cannisters is similar to that described for Assembler No 1. The size and shape of the cannisters is somewhat different to accommodate the particular conditions at the end of the tracks. Eight cannisters are required in each Space Shuttle load to carry the complement of node joint corresponding to the number of columns.

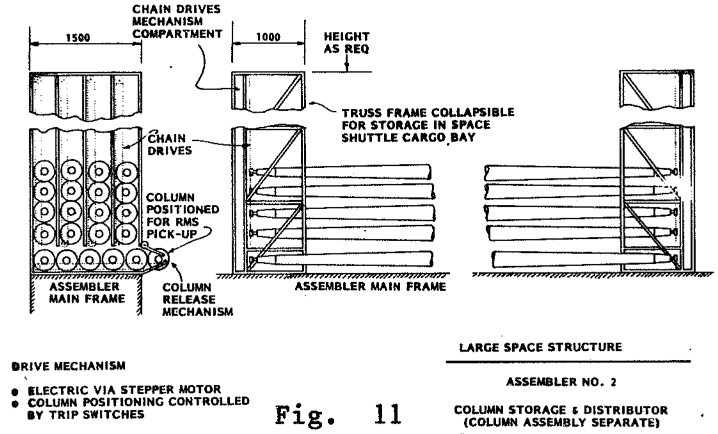

Fig. 11

STRUCTURAL DETAILS OF ASSEMBLERS FRAMES

The structural concept considered for the basic frame of either assemblers is the Warren Truss made from graphite epoxy or aluminum members. These structures are of collapsible type which is self-erectable under the power of spring loaded four-bar linkages. Thus, structural components can be built up on the the ground, deployed in orbit and connected together to form the basic frame. The collapsed elements can be stowed under minimum volume into the cargo bay of the Space Shuttle. Erection of the assembler is therefore considered as an EVA operation.

CONCLUSION

In view of the very large number of components required for the on-orbit erection of large tetrahedral space platforms, their automated assembly is a necessity if the work is to be carried out in a reasonably short time and without undue strain for the astronauts.

The assembly machine is a huge jig in which a multitude of mechanisms must operate continuously in the thermo vacuum environment of space and under the control of computers programmed to command every step of each motion.

The concepts presented in this paper must be refined to determine the most reliable solution. Continuous operation of mechanisms in space presents many unresolved problems, particularly with regard to lubrication of unprotected devices, such as chain drives, which must maintain reasonable positioning tolerances.

ACKNOWLEDGEMENT

This study was sponsored by the NASA Langley Research Center under contract NAS 1-15240, "Development of Assembly and Joint Concepts for Erectable Space Structures".

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