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## A NESTABLE TAPERED COLUMN CONCEPT FOR LARGE SPACE STRUCTURES

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July 1976



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16. Abstract

This report describes a structural element concept which permits achievement of weight critical payloads for Space Shuttle. These columns are highly efficient structural members which could be the basic building elements for very large, space truss structures. Parametric results are presented which show that untapered cylindrical columns result in volume limited payloads on the Space Shuttle and that nestable, tapered columns easily eliminate this problem. It is recognized that the tapered column concept belongs to a class of structures which must be assembled in orbit. However, analytical results are presented which indicate that the gain in the amount of structure placed in orbit per launch, is great enough that such a concept should be considered in future systems studies of very large (kilometer-size) space structures.

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## INTRODUCTION

The introduction of the Space Shuttle Transportation System in the 1980's provides new opportunities for man's exploitation of space. The capability to economically place large payloads in orbit offers the chance to perform missions that previously were impractical. Projects for consideration include such items as extremely large antenna for communications or earth surveillance, space based manufacturing facilities, and/or solar power stations which convert and transmit collected solar energy to earth. These missions are characterized by structures which have huge areas even by earth standards. The prospect of orbiting such structures provides unparalleled challenges to the design community to develop extremely efficient structural concepts. The feasibility of these missions will also depend on the success of the structural designer in identifying and developing new and unique ways to fabricate and assemble large structures.

Although Space Shuttle represents an improvement in orbital payload capability, it is not without restrictions. The Space Shuttle's 65000 lbm payload and 15 ft diameter x 60 ft long cargo bay represent severe constraints which must be considered. Realistically, any mission in space involving large structures, or technology development for such a mission prior to the year 2000, will be accomplished via Space Shuttle. Therefore, it is advantageous to develop efficient structural concepts to minimize the total mass which must be orbited. This development will permit weight critical payloads for Space Shuttle to be achieved and thereby minimize the total number of flights required.

While definition of exact structural details awaits identification of a particular mission, certain types of generic structures can be developed now and adapted to a particular mission later. One attractive space structure concept is a three-dimensional truss network which is very large (eg, kilometer size) in two dimensions. Such a structural grid system would be an assemblage of highly efficient compression members such as cylinders or truss columns. An important feature of this compression member is that it must also be compatible with shuttle packing constraints. The purpose of this paper is to present an efficient tapered circular compression column concept which has a high packing density and permits weight critical payloads with Space Shuttle to be achieved. All studies in this paper consider the columns to be made of graphite/epoxy material because of its low thermal expansion characteristics and its low density.

## TAPERED COLUMN CONCEPT

A concept for a compression element which has a high structural efficiency and a high packing density is illustrated in figure 1. The concept consists of tapered half-column elements which, when assembled by joining the large ends of two elements, form a column as shown in figure 1a. The half-column elements nest together as shown in figure 1b in the same manner as the packaging of paper cups.

### Structural Efficiency

Although the prime motivation for developing the tapered column concept was improved packing density, it also has an improved structural efficiency when compared with a cylindrical column. In figure 2 the Euler buckling load ratio ($P_{\text{tapered column}}/P_{\text{cylinder}}$) is plotted as a function of the taper ratio $r_1/r_2$. For the curve in figure 2 the tapered columns have a mean radius equal to the cylindrical radius and all thicknesses are equal so that all the columns are of equal weight. It can be seen that the tapered columns carry more load than an equivalent cylinder except for highly tapered columns where $r_1/r_2$ is less than about .15. The values for the curve in figure 2 were taken directly from reference 1 for $r_1/r_2 > .464$ and were generated numerically on a computer for $r_1/r_2 < .464$. An optimum is shown to exist at a taper ratio of $r_1/r_2 \approx .41$, where a tapered column carries approximately 30% more load than an untapered column of the same weight.

## Packing Efficiency

The payload capability of Space Shuttle (65000 lbm) and cargo bay volume (15'D x 60'L) pose severe packing constraints for accomplishing missions in space which require a large structural mass. The problem of achieving weight critical payloads is accentuated when efficient structural concepts are considered. It is enlightening to examine the amount of mass that may be packed into one Space Shuttle cargo bay, using various efficient structural elements.

Cylindrical Columns:- In order to examine the problem parametrically, it is assumed that a square stacking array is used. The number of cylindrical columns that may be packed into one cargo bay is given by

$$N_{cyl} = \left(\frac{720''}{L}\right) \left(\frac{\pi D^2}{4}\right) \left(\frac{1}{d^2}\right) \tag{1}$$

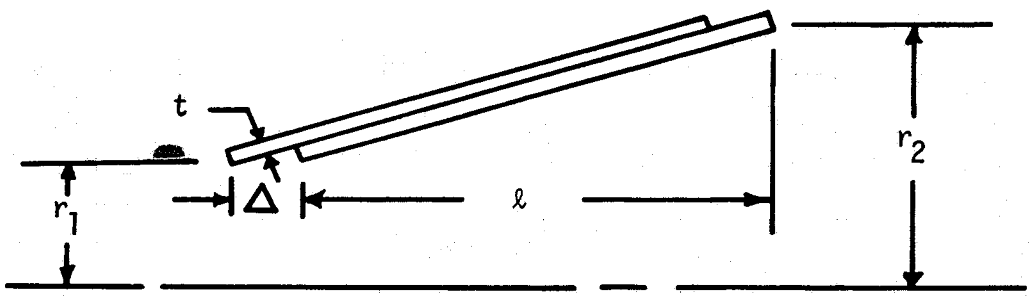
Where L = column length (integer increment of 720")
d = column diameter
D = cargo bay diameter (180")

The weight of one cargo bay full of cylindrical columns is given by

$$W_{cyl} = N_{cyl} \, (\pi d t) \, (720'') \, (\rho) \tag{2}$$

Where t = cylinder wall thickness
ρ = cylinder material density

Tapered Columns:- Considering sketch a, the stacking increment ($\Delta$) required per tapered, half column element




Sketch a.- Tube nesting details

may be determined to be

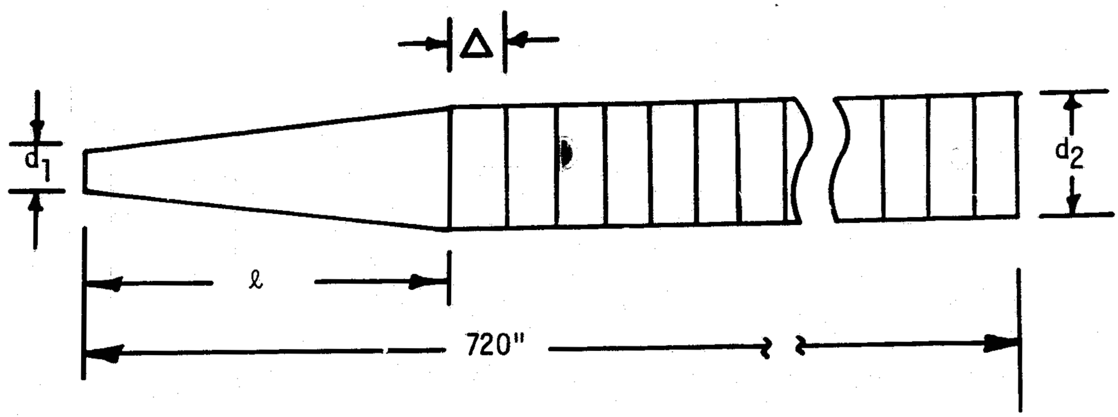
$$\Delta \approx \left(\frac{t}{h}\right)\ell \tag{3}$$

where $\ell = \frac{L}{2}$

$h = r_2 - r_1$

and

$r_1, r_2$ = min. and max. tube radii, respectively.




Sketch b.- One stack of nested half-column elements

Considering sketch b, the number of half-column elements (n) that may be packed into one stack which is the length of the cargo bay is given by

$$n = \frac{720 - \ell}{\Delta} + 1 \tag{4}$$

Assuming a square packing array (determined by $d_2$) the weight of one cargo bay full of half-tube elements is given by

$$W_{taper} = n \frac{\pi D^2}{4 d_2^2} \pi \bar{d} t \rho \ell \tag{5}$$

where $\bar{d} = \dfrac{d_1 + d_2}{2}$

<u>Comparison of Cylindrical and Tapered Columns</u>:- The difficulty in achieving weight critical payloads with efficient structure is illustrated in figure 3.

This figure shows the total weight of one cargo bay volume of graphite/epoxy cylinders as a function of cylinder diameter. The solid lines are for constant diameter cylinders 60' long and were calculated from equation (2). These curves show that weight critical payloads are only achievable for very small diameters (eg, 1 to 1.5 in.) and that for larger diameters the payload fraction is very small. In order to illustrate efficient column designs, two points are provided. Point 1 shows that a 60' long column (.028" thick) designed to carry 1000 lbf, would have a diameter of 6.7" and that only a 13,500 lbm payload can be achieved. Point 2 shows that a similar design for a 30' length has a diameter of 4.3" and results in only a 21,000 lbm payload. It is noted that automatically deployable truss structures, built from similar elements, would be even more severely volume constrained since these structures cannot be packaged as efficiently as individual elements.

The dashed curves on the figure, calculated from equation 5, show the packaging potential of the tapered column concept whereby tapered half-column elements are nested (eg, like paper cups), one inside another. These half-column elements are mechanically joined at the largest diameter to form complete columns. Design points 1 and 2 on the dashed curves are for 30' and 60' long tapered graphite/epoxy columns which have the same weight, respectively, as points 1 and 2 on the solid curves. For these designs, the tapered column concept far exceeds the maximum shuttle weight payload. Thus, volume critical payloads can easily be avoided using the tapered column concept.

## Example Truss

It was shown that use of the tapered column compression element permits achieving weight critical payloads for Space Shuttle with very efficient lightweight, structural components. Another critical feature of any structural concept is the number of flights required to orbit a structure with a specified planform area.

Although structural requirements will vary between missions, it is enlightening to study the problem generically to determine the structural mass fractions associated with various truss concepts. For economy, any proposed truss concept should have as many identical elements as possible.

The tetrahedral truss concept (as an example) may be constructed with all identical elements.

The mass requirements of this type of structure, using either cylindrical or tapered columns as the basic elements, are presented in figure 4. The ordinate is the number of shuttle flights (assuming 65,000 lbm per flight) required to orbit enough mass to construct various areas of structure as dictated by the tetrahedral truss requirements. Parametric results are presented, assuming cylindrical elements of various lengths (dashed lines), which show that increasing column length requires more shuttle flights to orbit a given area of structure. Also shown on the figure is a currently considered concept which uses deployable tetrahedral truss modules (reference 2) which are constructed of 10' cylindrical column elements. This type of structure is highly volume constrained and requires approximately 3.5 times as many flights to orbit a given area of structure as is required using erectable 10' cylindrical elements.

Parametric results for the tapered column concept are presented (solid lines) which show that increasing column length requires fewer shuttle flights. Also it is shown that using 100' long tapered columns results in approximately a factor of 10 reduction in the number of flights over that required using the deployable truss modules. It is recognized that the tapered column concept requires in-orbit assembly, with all of the attendant logistic problems; however, the potential efficiencies of such an approach suggest that man's capability for erecting nestable, tapered columns should be determined.

## Tapered Column Design Features

The use of tapered-half-column elements as compression members in the manner described herein, requires in orbit assembly of the column and subsequently the entire truss-type structure. In order to efficiently assemble the columns, a preliminary design has been developed for a symmetric center joint which requires only axial motion and approximately 50 lb. axial force to lock. A photograph of this joint is shown in figure 5 in both the unassembled and assembled positions. The joint shown has a tapered hub for integral bonding to the tube wall. It is anticipated that truss elements would also be subjected to tensile as well as compressive loads. A test article of the joint shown has been tested in tension to 1200 lbf without failure. The graphite/epoxy column shown was designed for approximately a 1000 lbf compressive load. The column diameter is 4 inches at the center and 2 inches at the ends. It is 17 ft. long and weighs 3 lbm including aluminum fittings.

## Structural Assembly Site

Orbital assembly of large structures will be an arduous task, requiring that every effort be made to minimize construction difficulties. In order to achieve maximum efficiency, establishment of a structural assembly site will be required. This assembly site would probably be established in low earth orbit to minimize logistic and resupply requirements. A generic concept for such a site is shown in figure 6. The site would be multi-functional: (1) providing the necessary quarters and life support equipment for assembly technicians, (2) serving as a docking and storage facility for Space Shuttle to offload cargos of men and/or material and (3) providing an assembly line for fabricating structural modules. The large canopy could serve as a solar shield (and possible power source) to protect men and equipment from the solar environment. Interior floodlights (and radiant heat sources if required) would be used to provide through-shadow lighting for continuous operation.

The assembly line would use automated equipment where possible for material handling and to assist or accomplish the various assembly tasks. Workers and equipment could be tethered along the assembly line, while magnetic or mechanical clamps could be used to hold truss components in place for joining operations.

Fabricated modules would be incorporated into larger structural assemblies nearby as shown, or "stacked" for transfer to higher orbit. The subassemblies would be positioned for joining to the larger structure using a stabilized platform with a teleoperator.

## SUMMARY

A nestable tapered column concept has been described which permits achievement of weight critical payloads for Space Shuttle. These columns are highly efficient structural members which could be the basic building elements for very large space truss structures. It is shown that untapered cylindrical columns result in volume limited payloads on the Space Shuttle and that nestable tapered columns easily eliminate this problem. It is recognized that nestable tapered columns belong to a class of structural concepts which must be assembled in orbit. However, the gain in the amount of structure placed in orbit per launch is great enough that such a concept should be considered in future systems studies of very large (kilometer-size) space structures.

## REFERENCES


1. Timoshenko, S. P.; and Gere, J. M.: Theory of Elastic Stability. 2nd Edition, McGraw Hill Book Company, 1961.

2. Barclay, D. L.; Brogren, E. W.; and Straayer, J. W.: Evaluate the Influence of Operational and System Imposed Requirements on the Structural Design of Large Flexible Spacecraft. Final Report (Draft) of Task I, Contract NAS1-13967, with Boeing Aerospace Co., 1975.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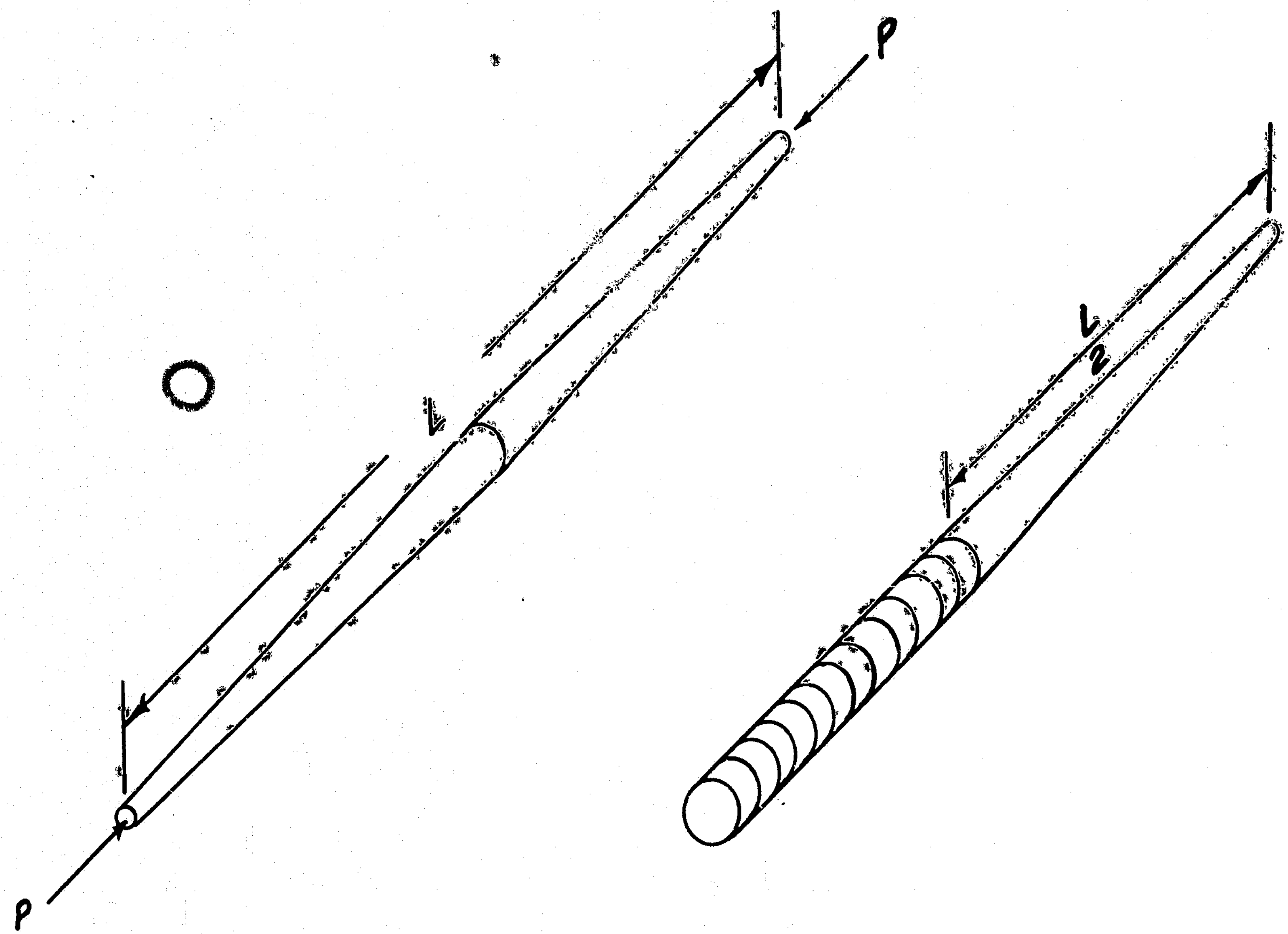



(a) Assembled Column

(b) Nested Half-Column Elements

Figure 1.- Tapered Column Concept

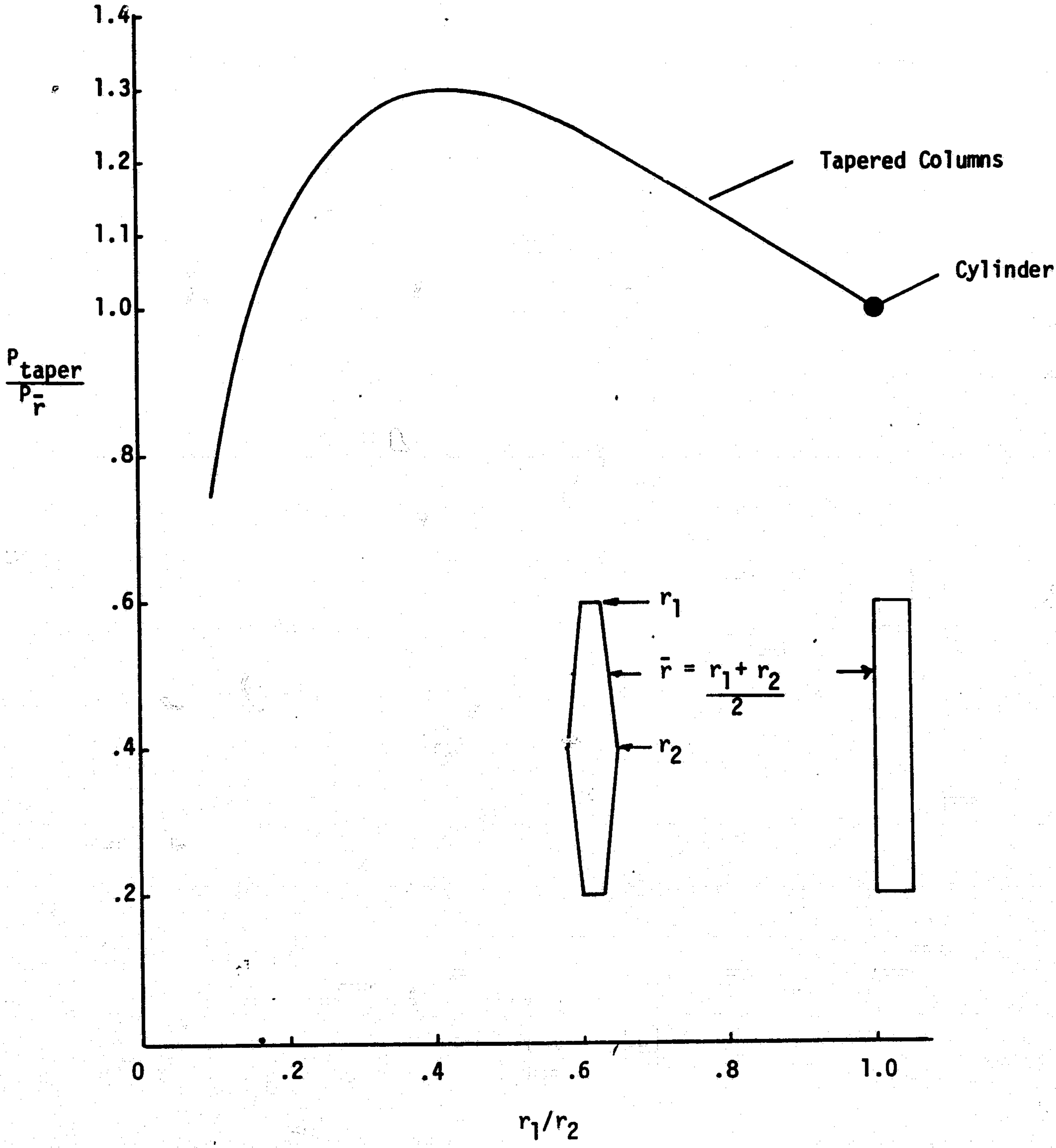



Figure 2.- Euler buckling load comparison of equal weight tapered and untapered columns.

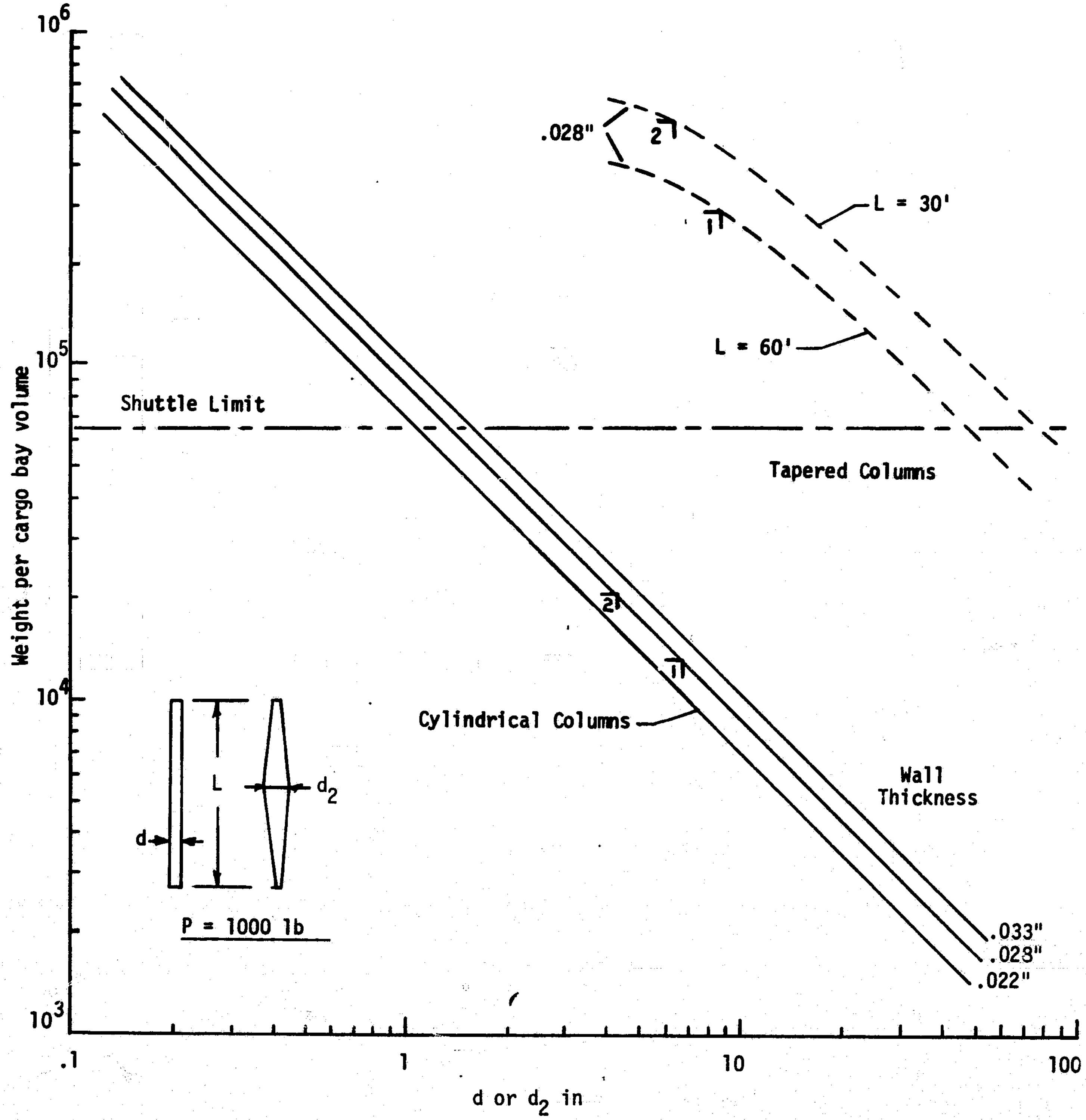



Figure 3.- Packing characteristics of tapered and untapered columns.

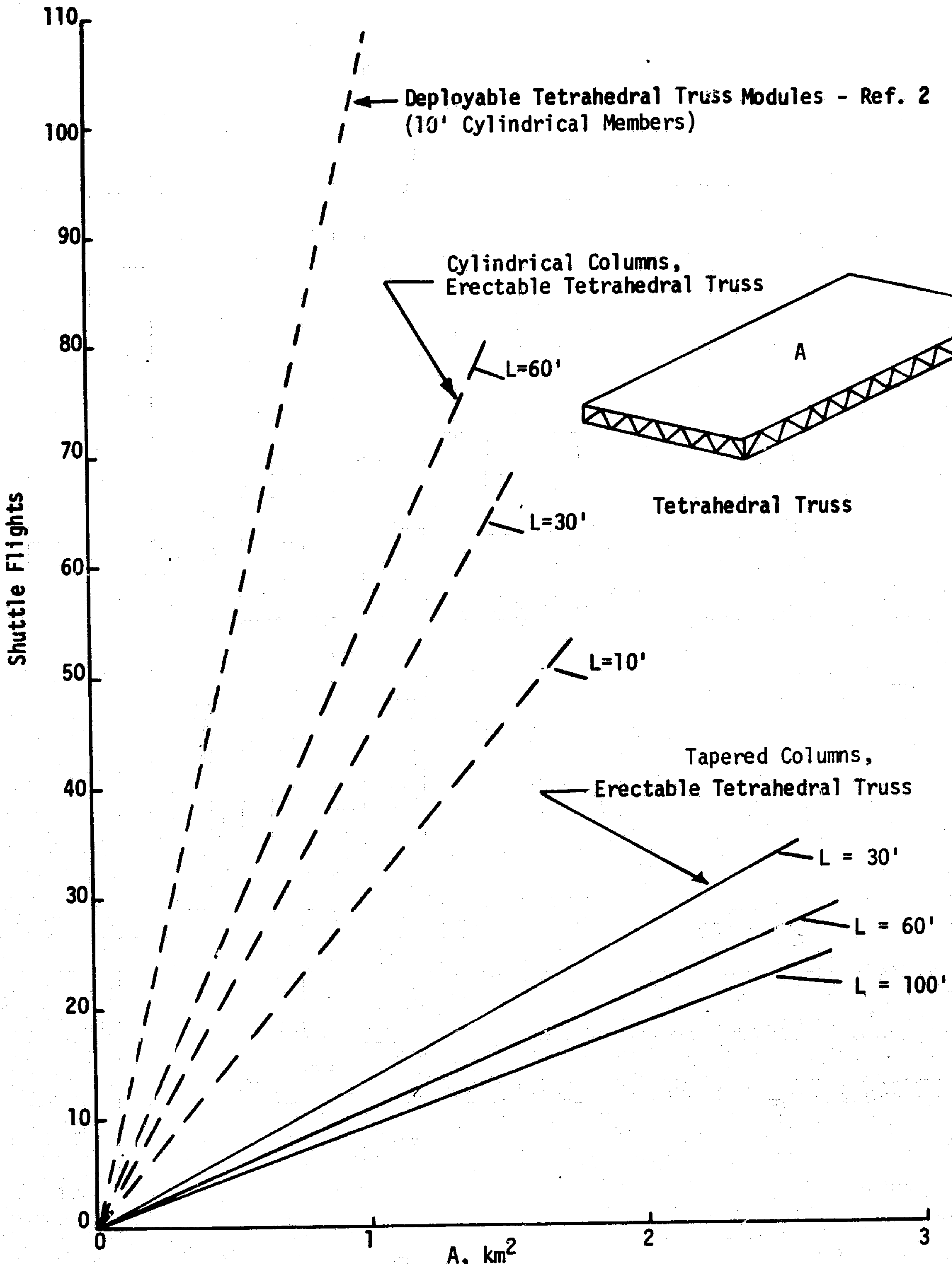
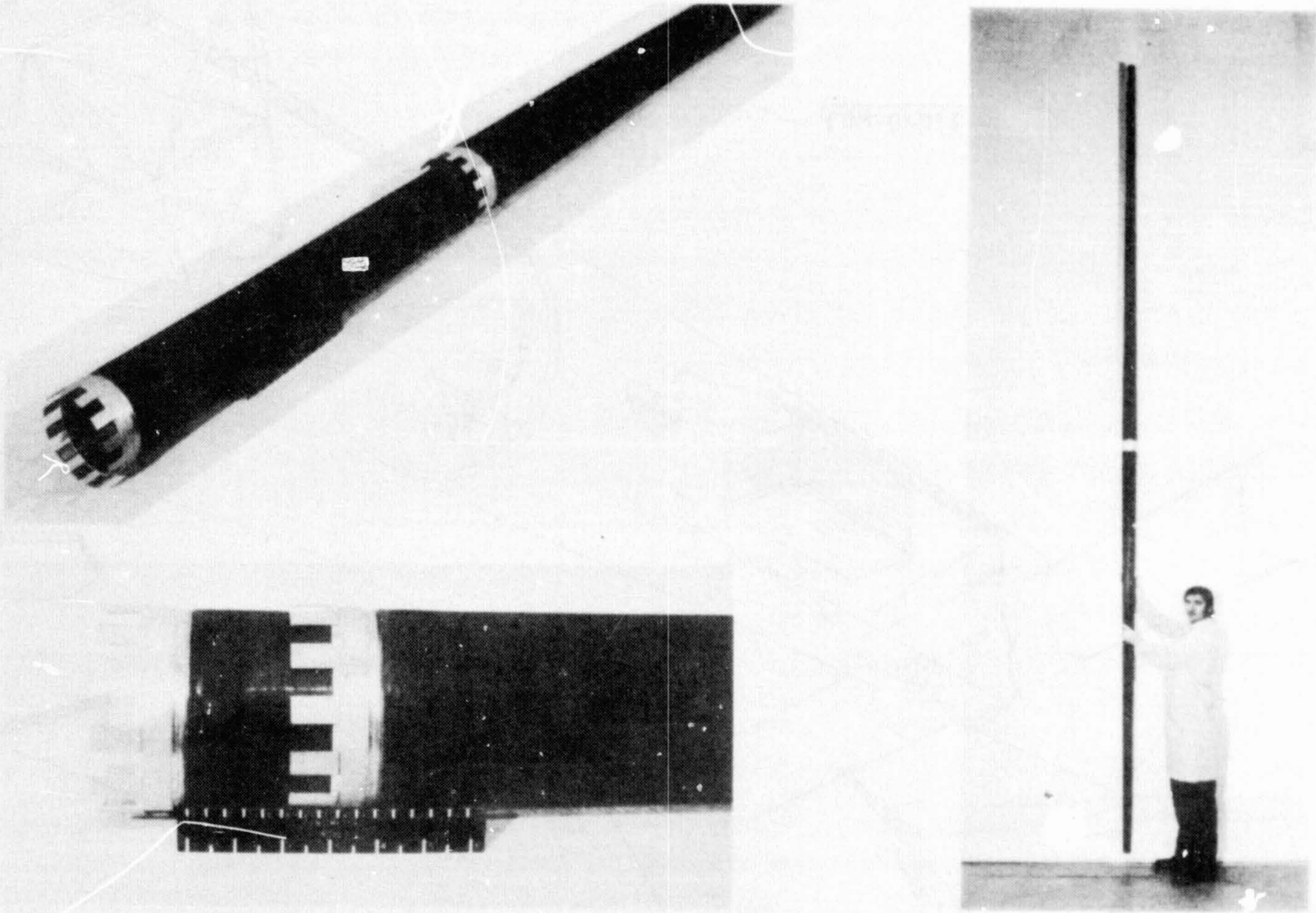



Figure 4.- Number of shuttle flights required for placing a tetrahedral truss structure in orbit.



NESTED HALF-COLUMN ELEMENTS

ASSEMBLED COLUMN

Figure 5.- Photographs of tapered column and joints.

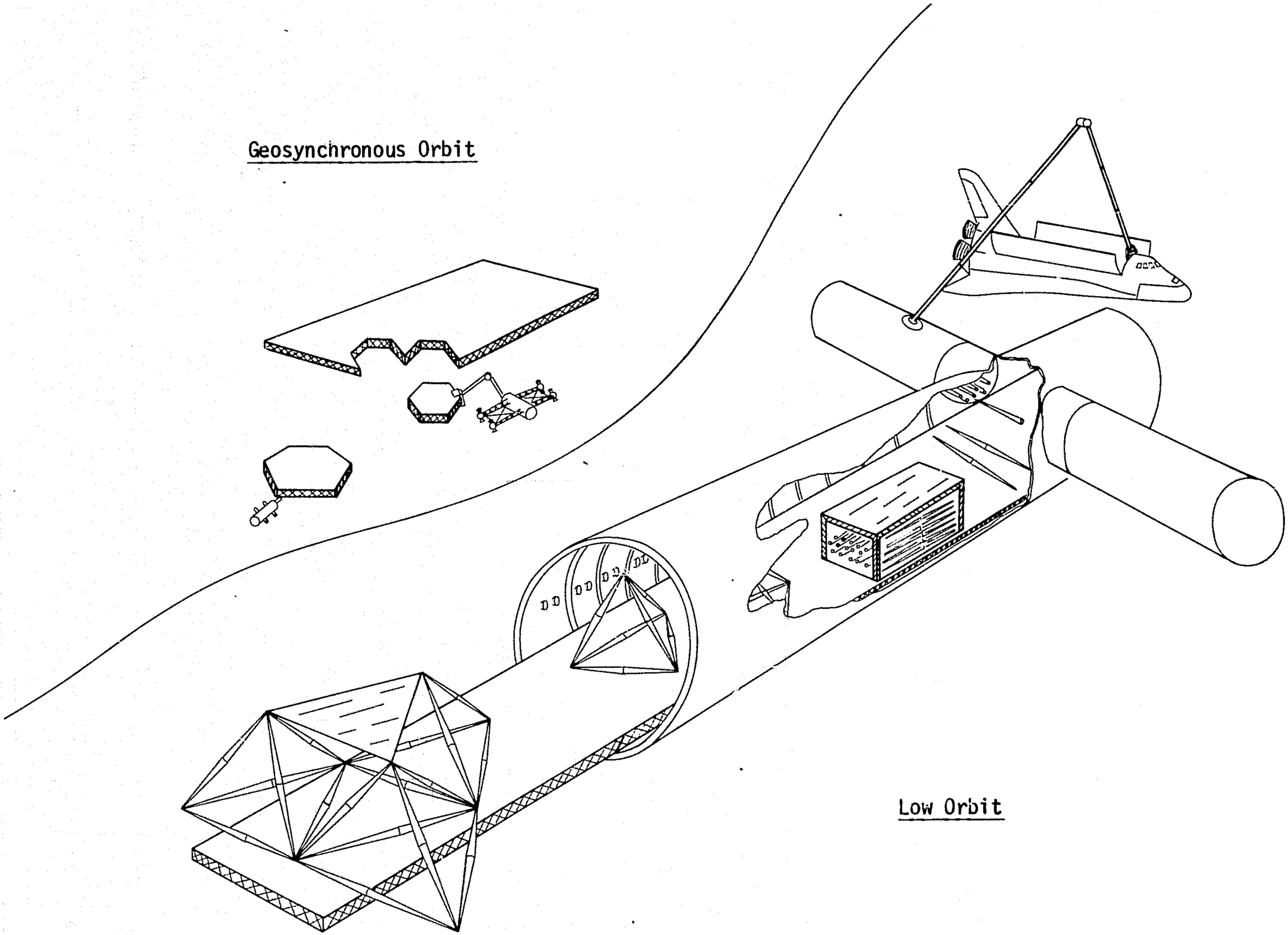



Figure 6.- Structural Assembly Site