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## DESIGN AND OPERATION OF A DEPLOYABLE TRUSS STRUCTURE

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## ABSTRACT

A new concept for the one-dimensional deployable truss structure is presented. The deployed configuration of the structure consists of the repetition of an octahedral truss module longitudinally, and thus it is exactly the so-called "geodesic beam" structure. The principal mechanical feature of the truss is that the lateral members comprising the lateral triangular truss are telescoping beams. Contracting of the lateral members results in the deployment of the truss structure. The geometric transformation of this truss of variable geometry is presented. It is shown that both simultaneous and sequential modes of transformation are possible. The validity of the transformation applied to the deployment is verified through design of a conceptual model. This concept of a deployable structure could be a potential candidate for future space applications.

## INTRODUCTION

At present, the only established concept for the deployable one-dimensional structure for space applications is the coilable longeron beam. However, a study (reference 1) has shown that the coilable longeron beam (Astromast) is limited to beam dimensions of less than 1 meter because of difficulties in packaging the stowed energy in the beam. For applications that require large beams, deployable beams with hinged longerons or erectable beams must be developed.

Recently, the Rockwell International Corporation and the Vought Corporation studied a number of existing structural concepts for fully deployable beams and platforms (references 2, 3). In spite of these efforts, a satisfactory structural concept which has an advantage over others in every respect has not yet been found. This situation is not changed even if a different set of criteria for selection is used. Under these circumstances, the derivation of new concepts through various possible approaches seems to be beneficial.

The present author has succeeded in devising a new concept for a one-dimensional deployable structure through a unique geometric approach.

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The concept was verified through a conceptual model. This paper describes briefly the theoretical foundation of the concept, the inherent mechanisms, and the mode of the deployment.

#### DEPLOYABLE TRUSS CONCEPT

The concept of the deployable truss, which the author proposes herein, is essentially a truss of variable geometry. Figure 1 illustrates a typical example of the proposed concept for the deployable truss structure. The fundamental module of the truss is an octahedral truss composed of a pair of lateral triangular trusses and six diagonal members. The two adjacent modules, which share the lateral truss, compose a repeating unit of the truss. Thus, the repetition of the unit in the longitudinal direction forms the whole structure of the deployable truss.

A part of Figure 1 is enlarged and shown in Figure 2, which illustrates the vicinity around a lateral triangular truss. The details of a lateral member are shown in Figure 3. This member, which is a telescoping beam whose length can vary, contains inside the tubular section an elastic tensile spring that is connected to both ends of the beam. In addition, a latch is installed in the beam to fix its length at the shortest state. Figures 4a and 4b illustrate the purely geometric configuration of the truss in the completely folded and deployed conditions, respectively. Figure 5 shows the almost folded state of the truss.

#### GEOMETRIC TRANSFORMATION OF THE TRUSS (SIMULTANEOUS MODE)

The outward appearance of the deployable truss shown in the preceding section is known elsewhere if it is a rigid static structure instead of a structure of variable geometry. For instance, in reference 4, that type of truss (geodesic or inverted batten beam) is studied to verify the theory of continuum analogy for large space structures. Actually, this truss is one of the most efficient light-weight structures using the minimum number of component members. In this section, the author shows the geometric transformation by which the truss can be transferred to a compact configuration. With mechanisms installed in the truss as described in the previous section, the truss becomes deployable.

The geometric transformation explained in this section is the mode where the folding/deploying is carried out simultaneously through the whole structure. Let it be called the simultaneous mode transformation.

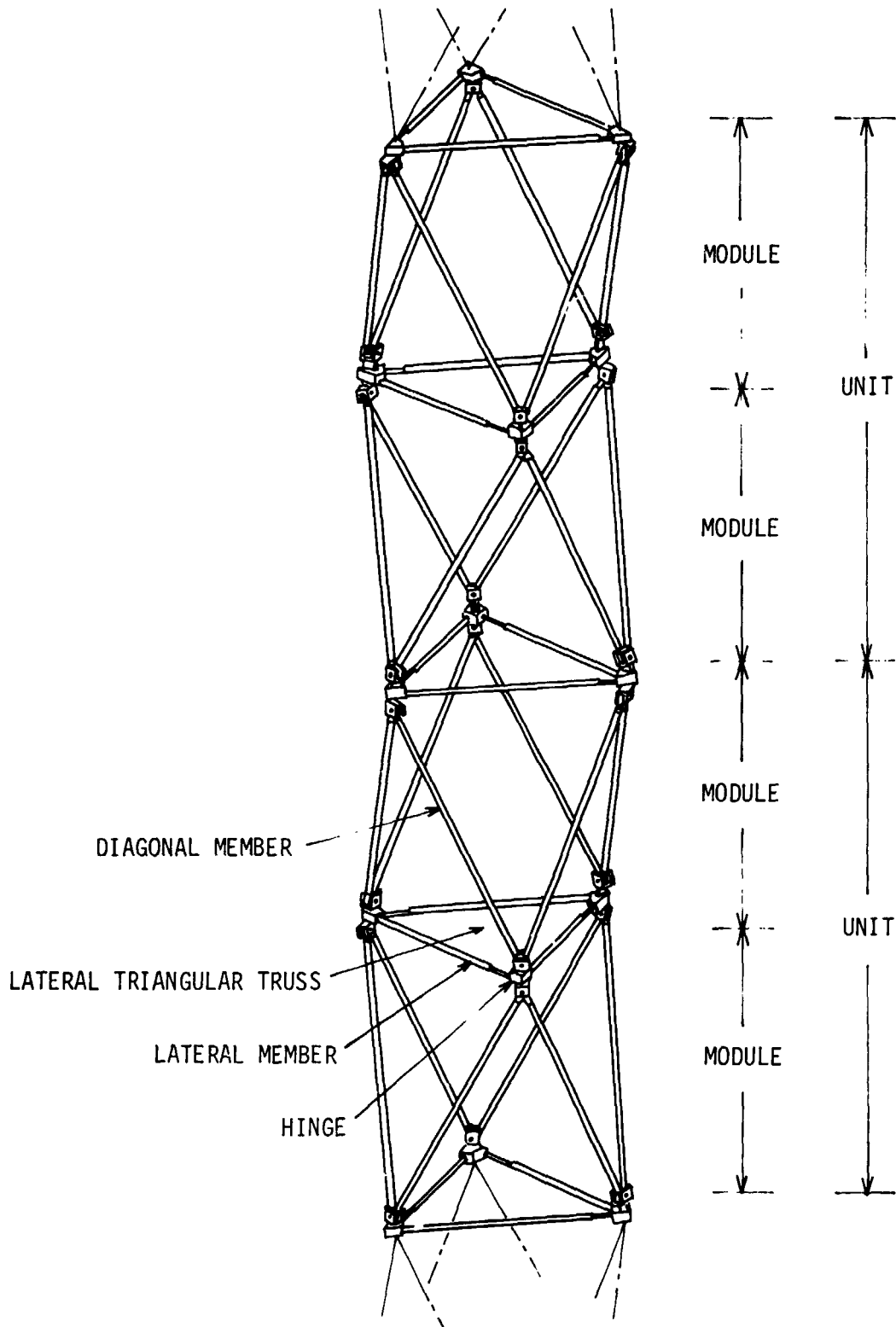


Figure 1. Proposed Concept of Deployable Truss Structure

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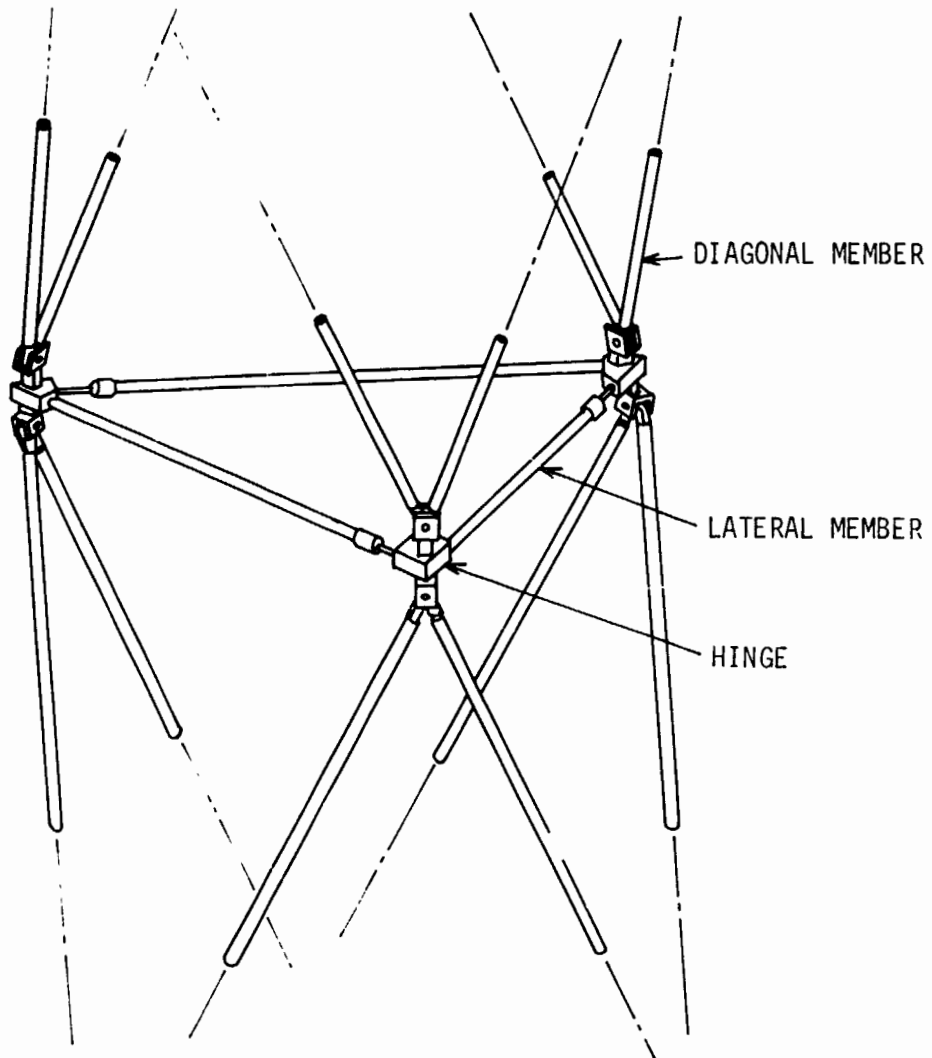


Figure 2. Details of Deployable Truss Structure

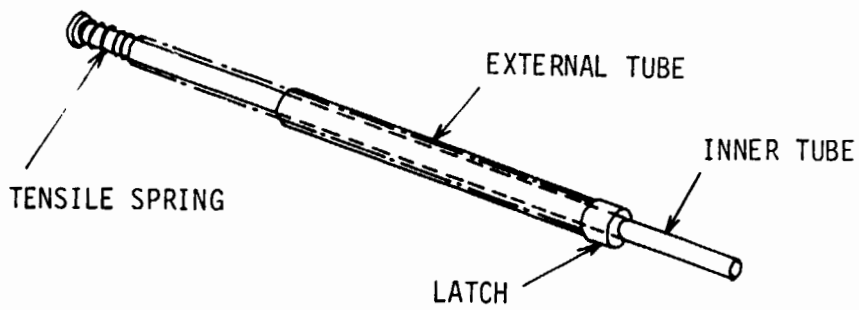
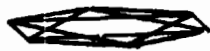
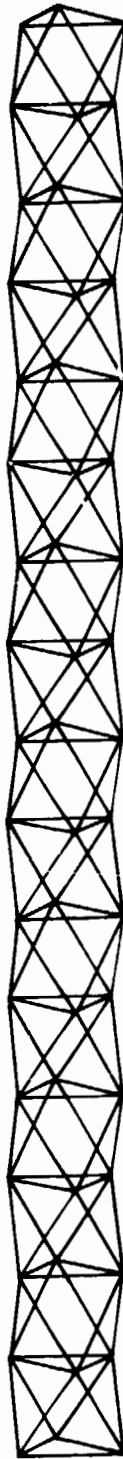


Figure 3. Details of Lateral Member

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(a) Folded



(b) Deployed

Figure 4. Geometric Configurations of Deployable Truss

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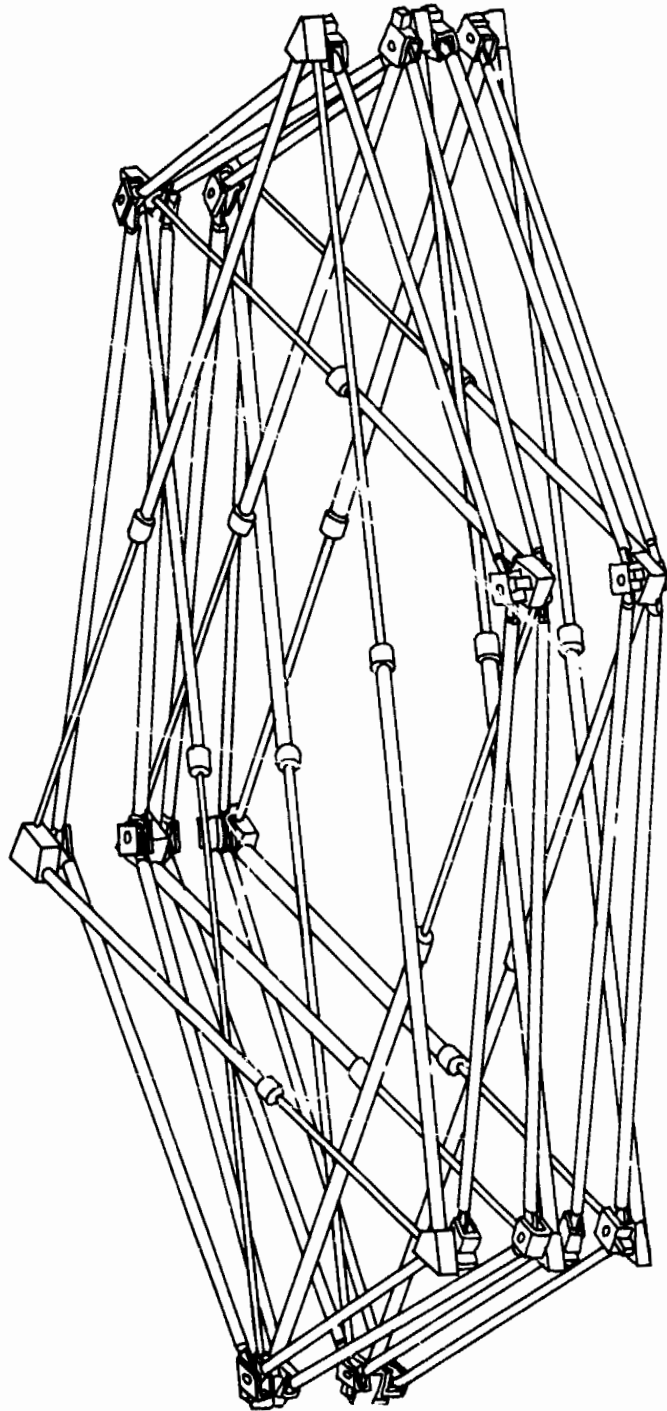


Figure 5. Deployable Truss in Almost Folded State

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Let us consider a single unit that is composed of a pair of octahedral trusses as shown in Figure 6. It is assumed that the lateral triangular truss is regular, the length of a diagonal member is  $a$ , and the length of the side of the lateral triangle is  $b$ . Then the geometry of the octahedral truss is completely defined by the magnitude of  $a$  and  $b$ . If  $a$  is equal to  $b$ , the truss becomes a regular octahedral truss. We shall start with this case and study how the truss is transformed, depending on the relative magnitude of  $b$  to  $a$ .

As shown in Figure 6a, the face angle between a pair of triangles which compose a concave diamond pattern is taken as  $2\theta$ . Then we have

$$\theta = \cos^{-1} ( b/2\sqrt{3} \sqrt{a^2 - b^2/4} ). \quad (1)$$

For the configuration of Figure 6a,  $a$  equals  $b$ , and therefore

$$\theta = \cos^{-1} (1/3) = 70.53 \text{ (deg.)}.$$

We are immediately aware that Equation 1 has a nontrivial solution for  $\theta$  equal to zero. This is the fundamental fact on which the present concept of deployable truss depends. That is

$$\theta = 0, \quad \text{if } b = \sqrt{3} a. \quad (2)$$

The vanishing of the face angle  $\theta$  means that the height of each octahedral module vanishes, too. In other words, the complete truss is transformed to a flat configuration as shown in Figure 6b.

The proposed concept of deployable truss uses this fact. If we are able to design the lateral member with variable length (i.e., a telescoping beam), we are close to the solution. Let the length of the lateral member vary as follows:

$$a \leq b \leq \sqrt{3} a, \quad (3)$$

then, the height of a module  $h$  varies between the limits:

$$\sqrt{a^2 - b^2/3} \geq h \geq 0. \quad (4)$$

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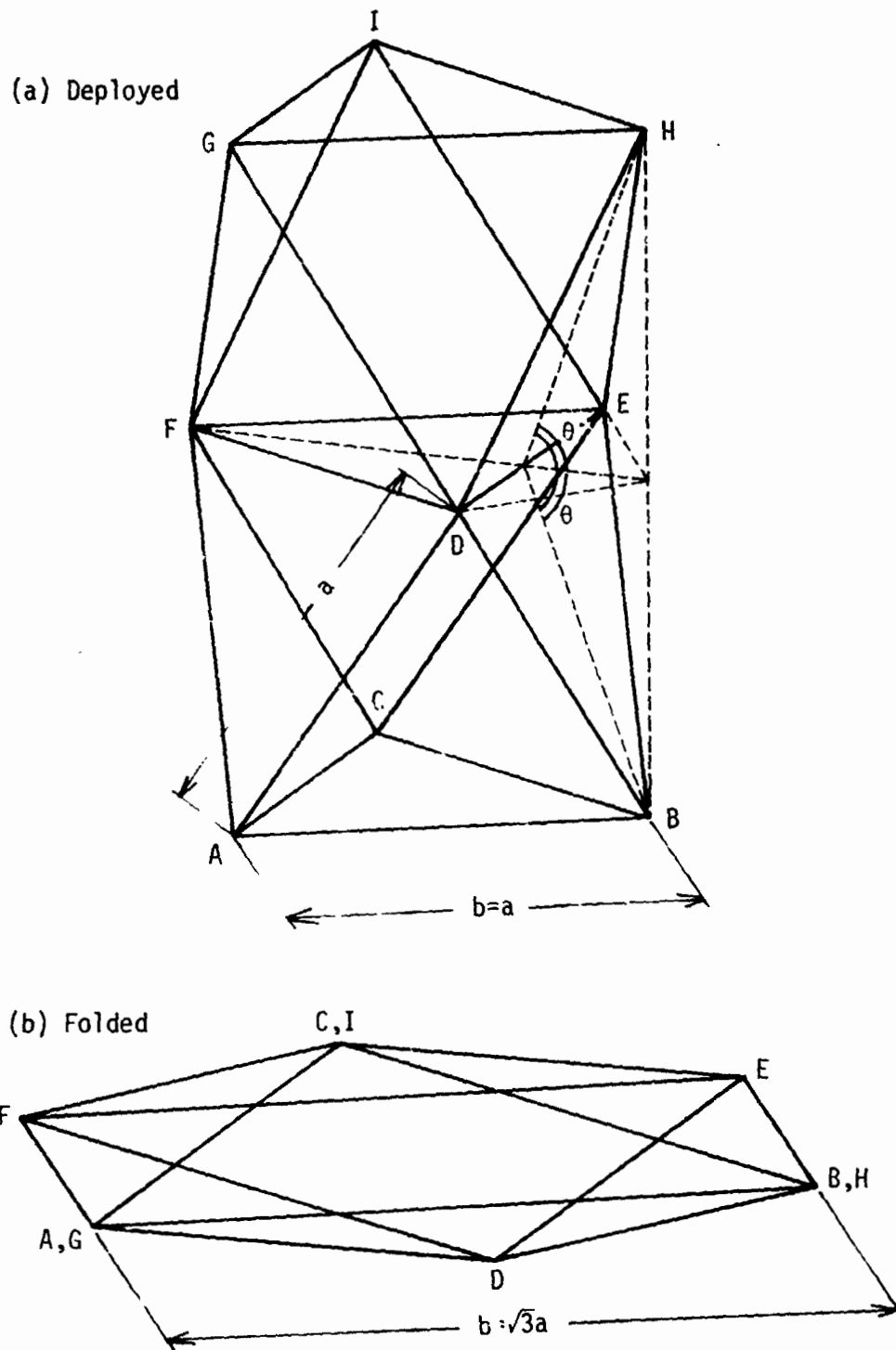


Figure 6. Repeating Unit of Truss



This means that, by extending the lateral members by a factor of  $\sqrt{3}$ , the height of the truss should vanish.

See Figure 3 for an example of the lateral telescoping member. This member consists of an external tube, an inner tube, a tensile elastic spring inside the tube, and a latch mechanism that is actuated when the member is shortened to a defined length. The diagonal members are fixed length members. Although the hinge mechanism is not shown in detail, it is designed to follow the movement of the truss. Figure 5 shows the shape of the truss at almost fully folded state. This rather strange roiding mechanism may be somewhat beyond one's insight. It is easier for one to understand the mechanism through a three-dimensional kinetic model.

#### GEOMETRIC TRANSFORMATION OF THE TRUSS (SEQUENTIAL MODE)

Theoretically speaking, a geometric transformation in a sequential mode is possible in which each module is deployed successively and other modules remain fixed. Because the sequential mode is important from the point of view of deployment control, we will study that mode in this section.

Figure 7 shows the zone of the truss where the sequential deployment is underway. For clarity of explanation, it is better to divide the whole truss into the following three zones: the deployed zone, the transient zone, and the folded zone. It is assumed that the truss comprises  $n$  lateral triangular trusses and  $n-1$  modules. The previously mentioned three zones are explained as follows:

	<u>Deployed Zone</u>	<u>Transient Zone</u>	<u>Folded Zone</u>
Lateral truss	1,2,3,..... i-1	i	i+1,.....
Module	1,2,3,.....i-2	i-1, i	i,i+1,...

The important fact is that there exists a geometric transformation which allows the contraction of the  $i$ -th lateral triangular truss and the following deployment of the  $(i-1)$ -th and  $i$ -th modules without interfering with other zones of the truss.

The sequence of motions of the truss, which constitutes the contraction of the  $i$ -th lateral truss, is explained as follows: When the  $i$ -th triangular truss starts contracting, it is raised from the base and the  $i$ -th module starts to deploy. Before that, the  $(i-1)$ -th module is partially deployed,

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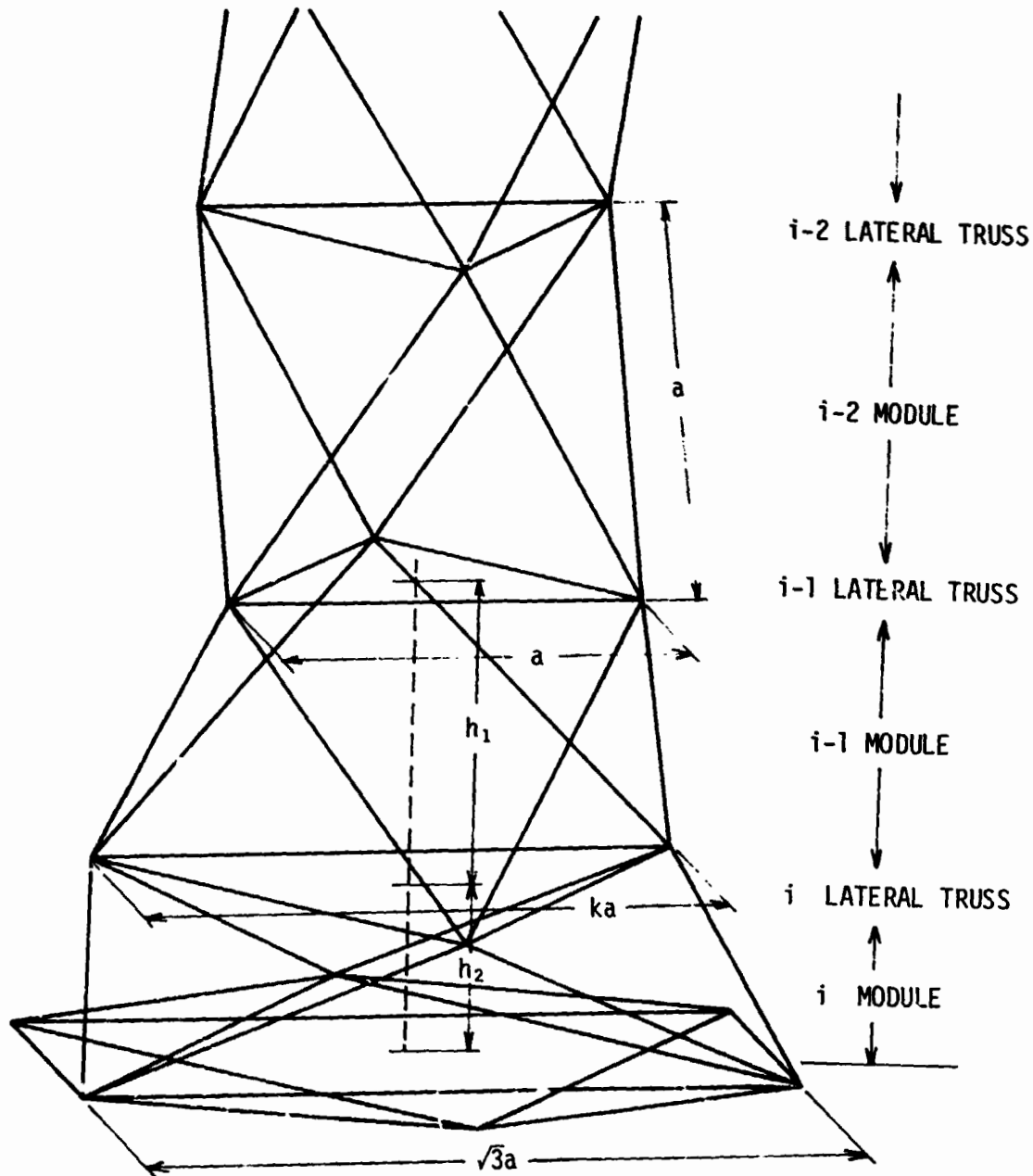


Figure 7. Sequential Mode Deployment

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and is continuing to deploy. When the  $i$ -th lateral truss finishes its contraction and is latched, the  $(i-1)$ -th module completes the deployment. The sequence of this process is illustrated in the series of figures in Figure 8.

The relation between the length of the diagonal member  $a$ , the length of the lateral member  $b$ , and the height of the module  $h$  is obtained easily by using Figure 7. If  $a$  and  $b$  are connected with the variable parameter  $k$ ,

$$b = k \cdot a, \quad \text{where} \quad \sqrt{3} \geq k \geq 1, \quad (5)$$

then, the heights of the modules are

$$h_1 = \sqrt{(2 + k - k^2) / 3} \cdot a, \quad ( (i-1)\text{-th module} ) \quad (6)$$

$$h_2 = \sqrt{k/\sqrt{3} - k^2/3} \cdot a. \quad ( i\text{-th module} ) \quad (7)$$

From a practical standpoint, the sequential mode transformation possesses a great advantage over the simultaneous one. This is because in the former case the deploying/folding takes place near the base and thus design of the mechanism is simpler. The outer truss is then always extending from the base as a rigid structure.

#### CONCEPTUAL MODEL

Although there is no doubt of the validity of the geometric transformations, a model has been constructed to demonstrate the concept. This model, made of acrylic glass tubes and aluminum hinges, is shown in Figure 9. The deployment of the model in a sequential mode is shown in the series of photos in Figure 10. The model works as expected and demonstrates the validity of the geometric transformation.

#### CONCLUDING REMARKS

A new concept for the one-dimensional deployable truss structure is presented. The deployed configuration of the structure consists of the repetition of an octahedral truss module longitudinally, and thus is exactly the so-called "geodesic beam" structure. The principal mechanical feature

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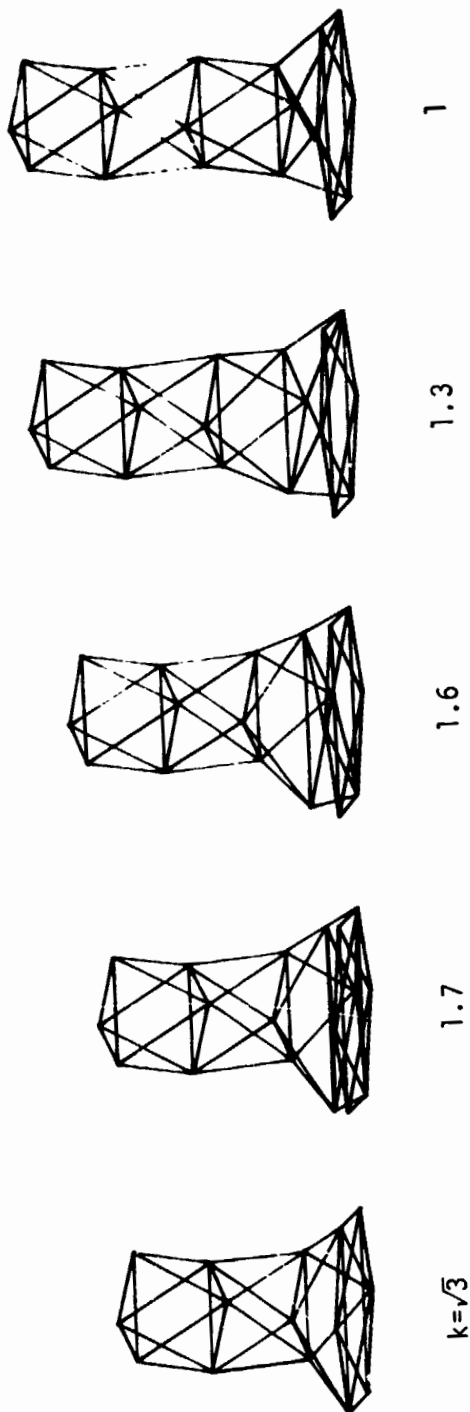


Figure 8. Contracting of Lateral Member and Birth of a Module

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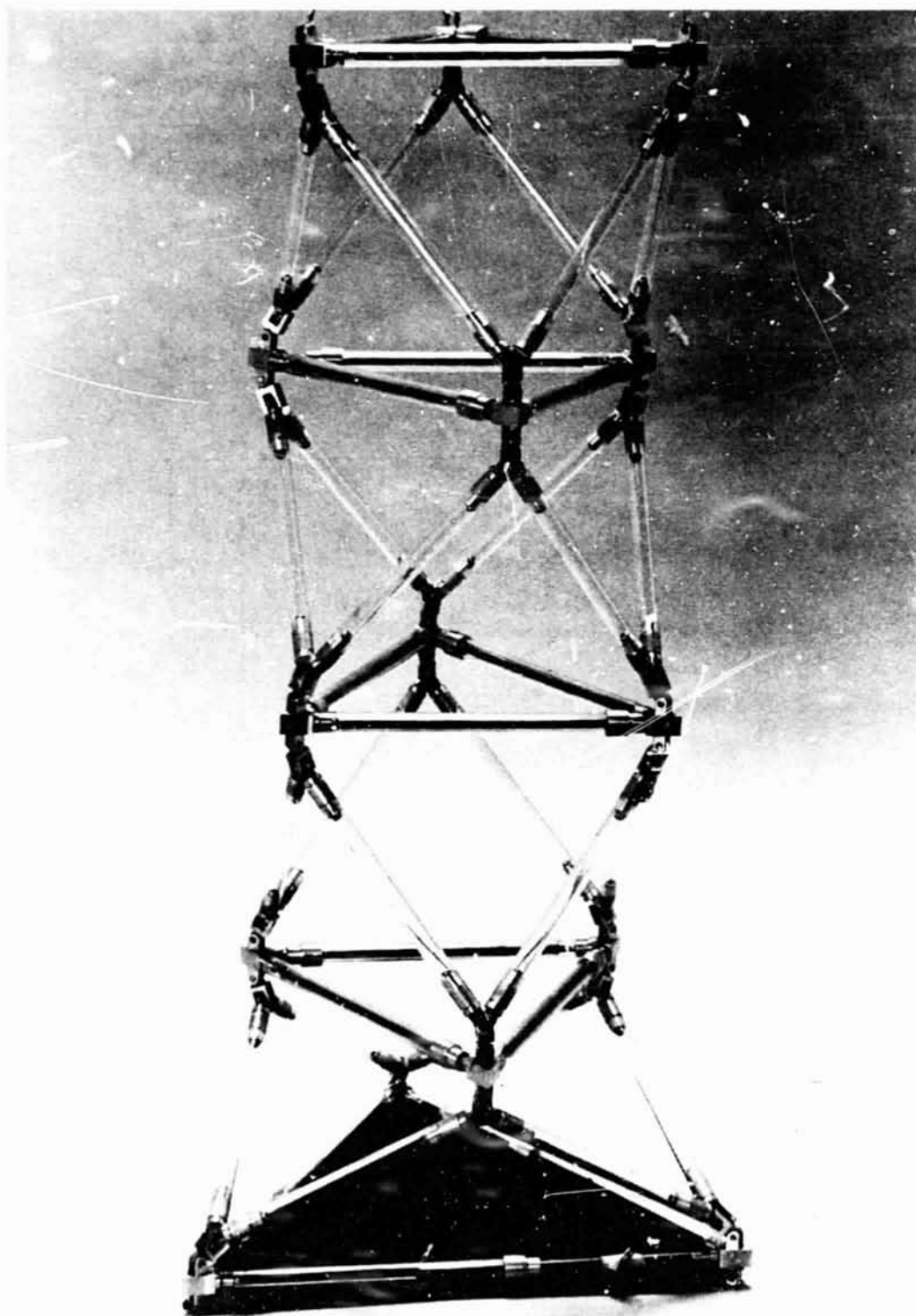


Figure 9. Conceptual Model

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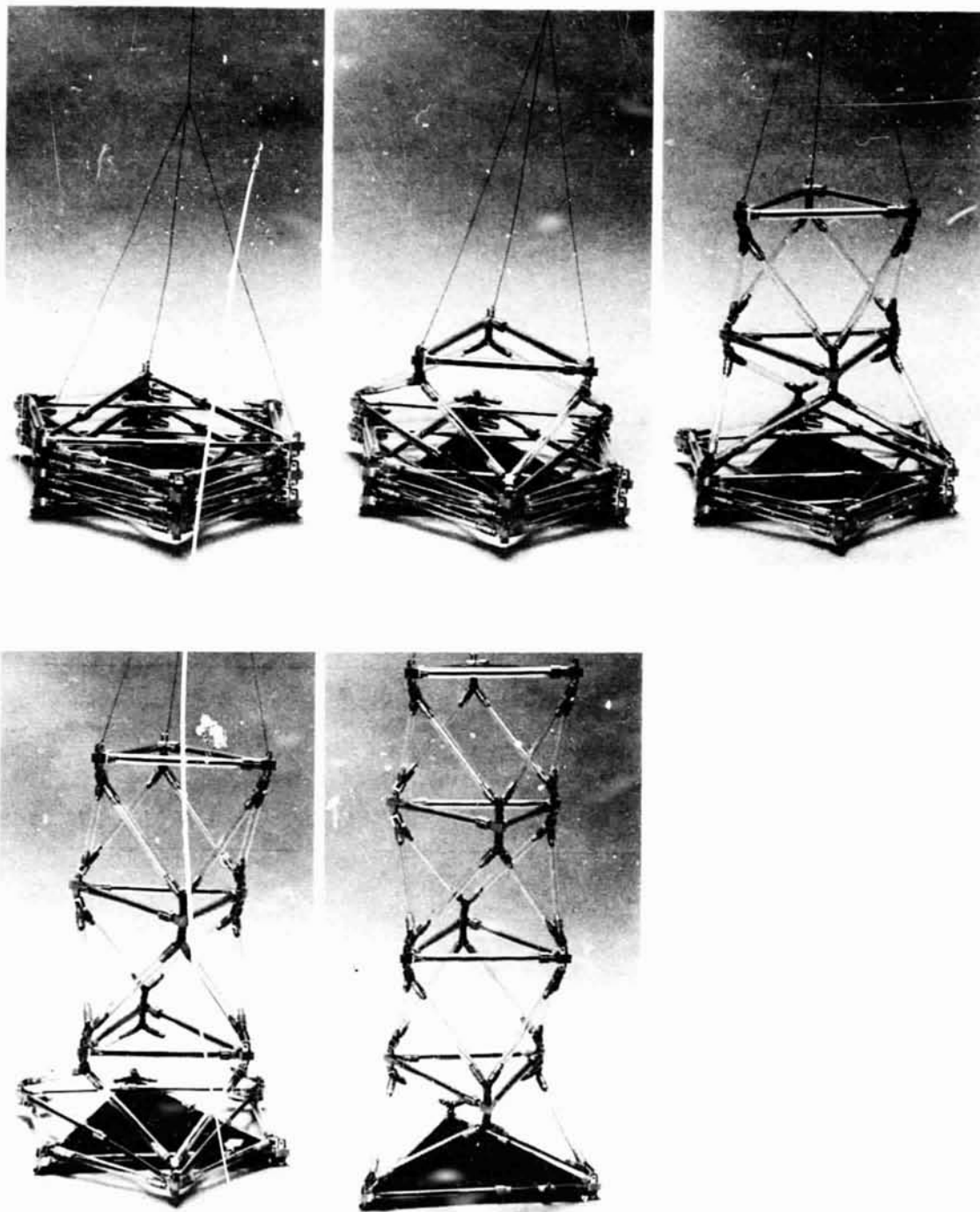


Figure 10. Deployment of Model in a Sequential Mode

of the truss is that the lateral members comprising the lateral triangular truss are telescoping beams. Contraction of the lateral members results in deployment of the truss. The geometric transformation of this truss of variable geometry is presented. It is shown that both simultaneous and sequential modes of deployment are possible. The validity of the concept is verified by means of a conceptual model. Though the study is in its initial phase, this concept for the deployable truss structure seems to have qualities suitable for space applications.

#### ACKNOWLEDGMENT

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