

SYNCHRONOUSLY DEPLOYABLE TETRAHEDRAL TRUSS REFLECTOR

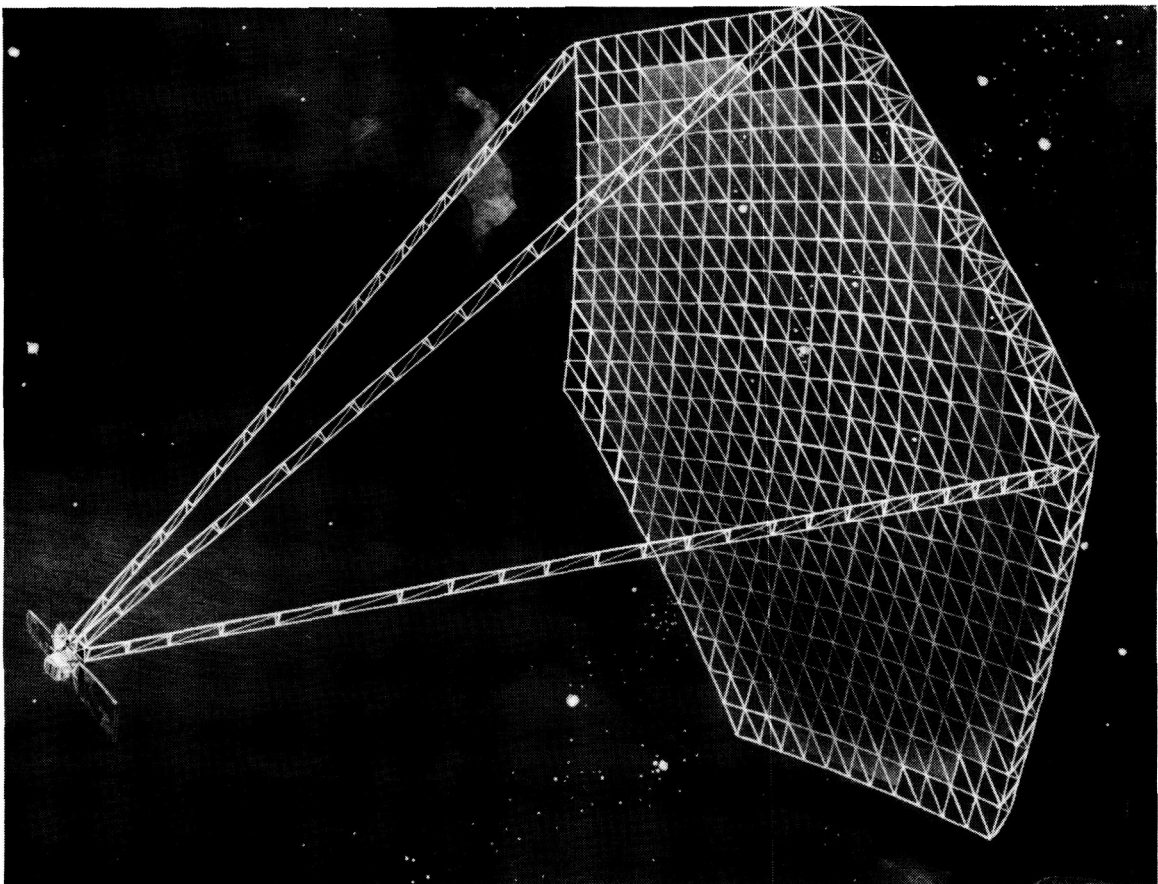
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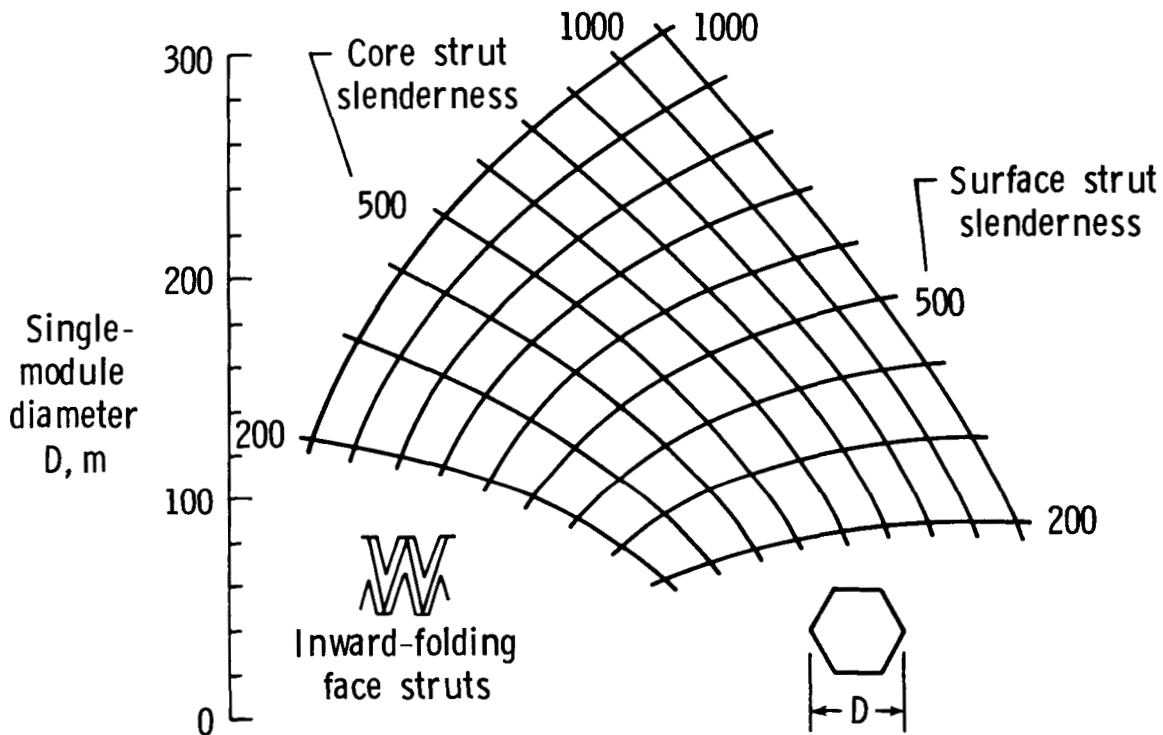
Various concepts have been examined for large antennas. Two examples of such concepts which have been extensively investigated are described in detail in references 1 and 2. Practical considerations limit these concepts to apertures of approximately 50 meters. For apertures above 50 meters, the high structural stiffness and compact packaging of the tetrahedral truss make this concept an attractive candidate for the reflector support structure. This paper will illustrate various features of a deployable, or foldable, doubly curved tetrahedral truss structure and the methods used to design the truss geometry and to synchronize deployment of the folding elements. An antenna with such a reflector structure is depicted in the figure which shows a side-mounted feed supported by a three-boom tripod. Particular application requirements will determine if a one- or three-boom feed support is required.



TETRAHEDRAL TRUSS PACKAGING

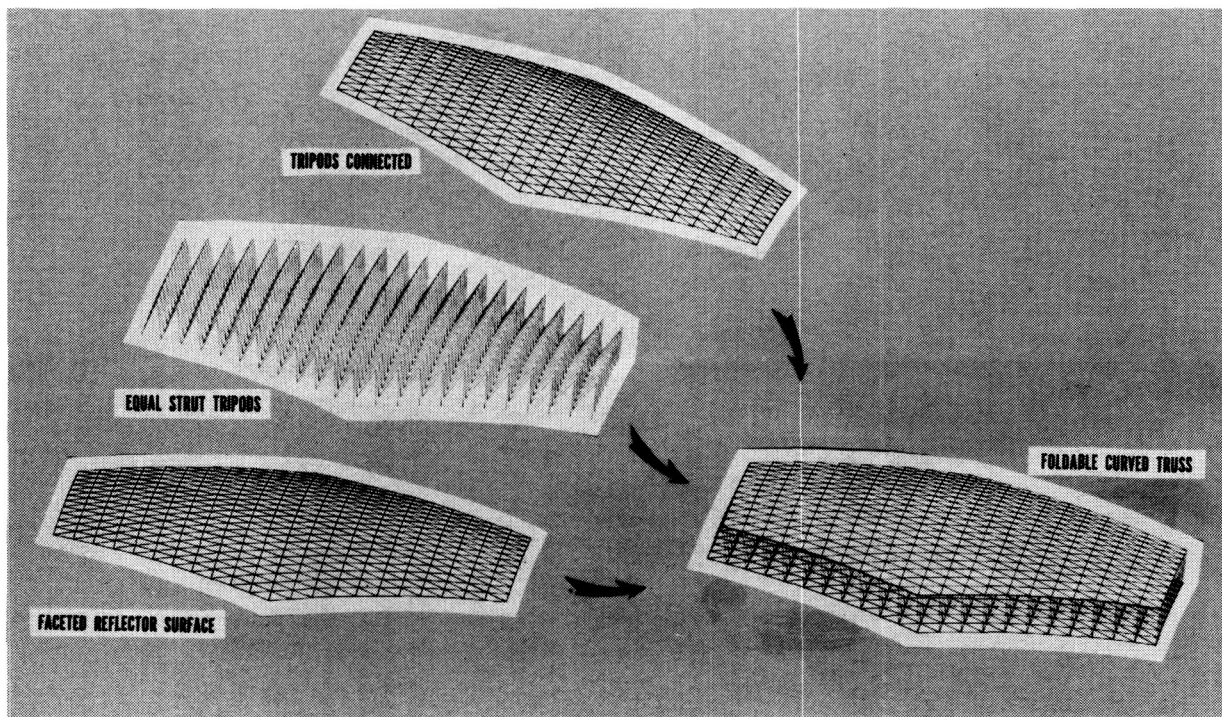
The tetrahedral truss considered herein uses inward-folding surface struts. The packaged geometry is illustrated in reference 3 and basic packaging equations are presented. The figure below presents the maximum diameter hexagonal planform tetrahedral truss that may be packaged within the diameter constraint of the Shuttle cargo bay. The deployed truss sizes are shown in the figure as a function of the surface and core strut slenderness ratios (i.e., length/radius of gyration). The figure shows that larger diameter deployed trusses require higher values of strut slenderness to package within the diameter of the cargo bay. Using struts with a slenderness of 1000 permits a 300-m-diameter truss to be packaged whereas a strut slenderness of 200 limits the maximum diameter truss module which can be transported via Shuttle to 60 m.

REFLECTOR DIAMETER VERSUS STRUT SLENDERNESS



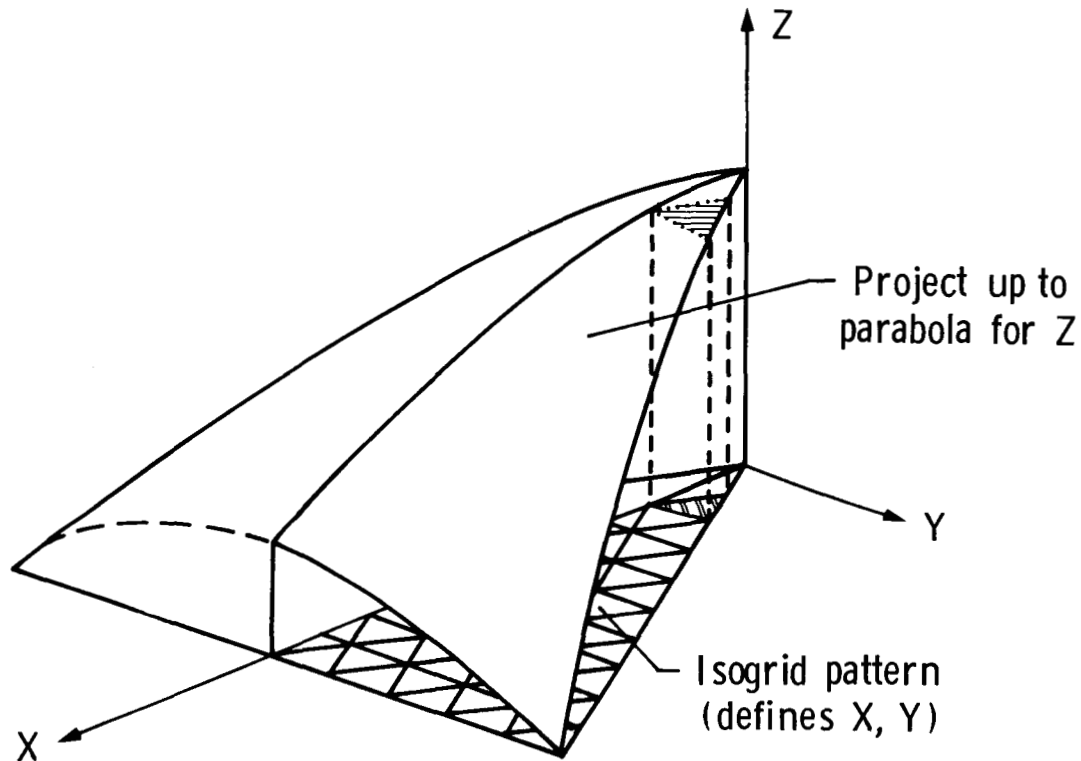
ANTENNA REFLECTOR TRUSS CONSTRUCTION

The geometric technique for defining a foldable truss concept is illustrated in the figure below. The desired doubly curved reflector surface is divided appropriately into a triangular pattern of points which are connected by struts. Equal length strut tripods are erected from the strut nodes on the convex side of the reflector surface. The tripod apices are connected with a triangular strut arrangement. The resulting configuration can be designed to fold into a compact package in which all the nodes within a surface lie in a plane. This feature permits "banding" the nodes solidly together to survive the vibrating environment resulting from the Shuttle being boosted into orbit. Use of inward-folding face struts (instead of outward folding) results in a package which is minimum length. This feature is important because a premium is placed on the cargo bay length occupied by a payload. In addition, inward-folding face struts are considered to pose fewer interference problems with any mesh reflector surface which is attached to the truss.



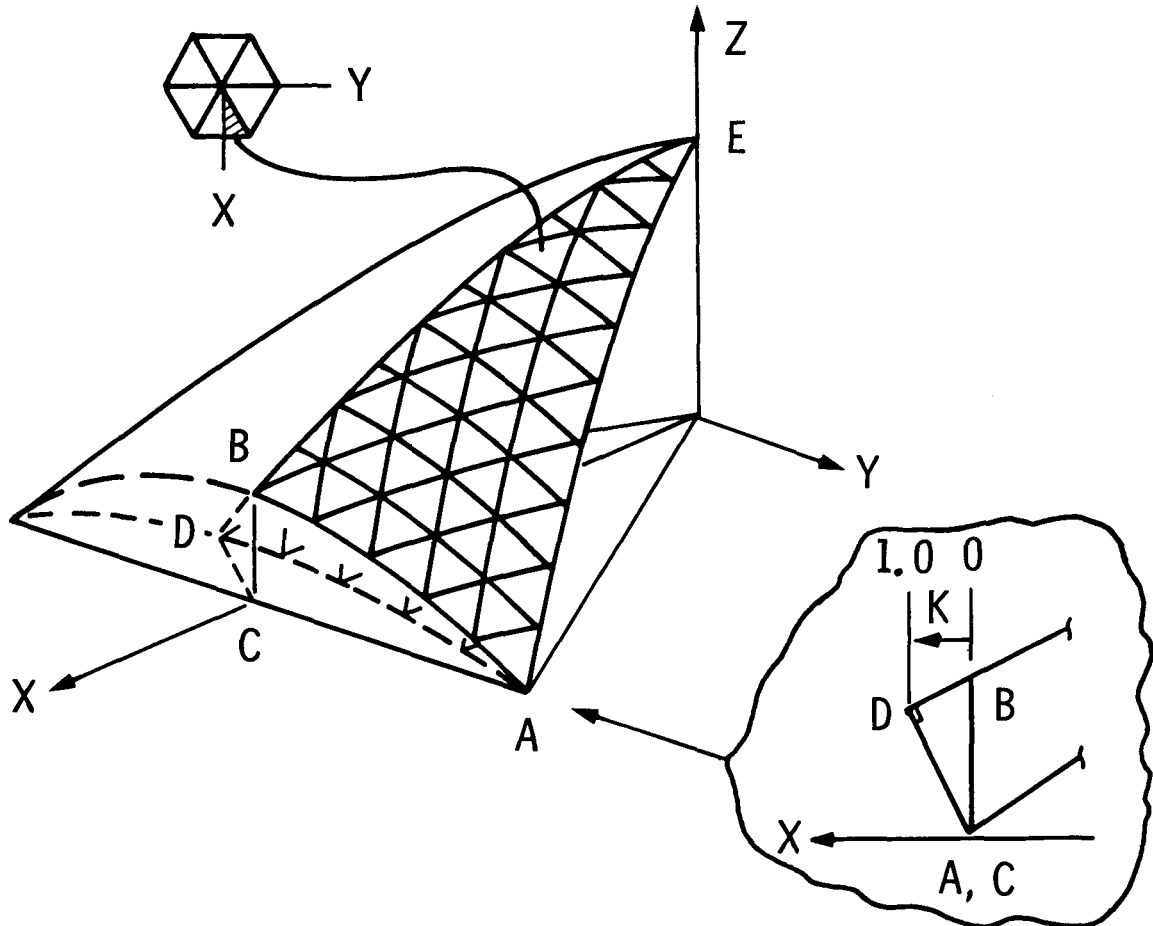
NODAL DISTRIBUTION BY NORMAL PROJECTION

The method most commonly used to define the triangular nodal point pattern of a tetrahedral truss face on a parabolic reflector is known as normal projection. The method consists of forming an equilateral triangle pattern in a plane (i.e., the x-y plane) to determine the x and y coordinates to be used to fix node locations. The z coordinate is then calculated from the parabolic surface equation using the known x and y coordinates. This method corresponds to projecting each point of the planar equilateral triangle arrangement parallel to the z axis onto the parabolic surface, as shown in the figure, hence the term normal projection. Due to curvature of the parabolic surface, the triangular pattern thus formed exhibits a wide variation in strut length and in the local geometry of each node. These features have an adverse effect on design, fabrication, and, ultimately, cost of the reflector truss structure.



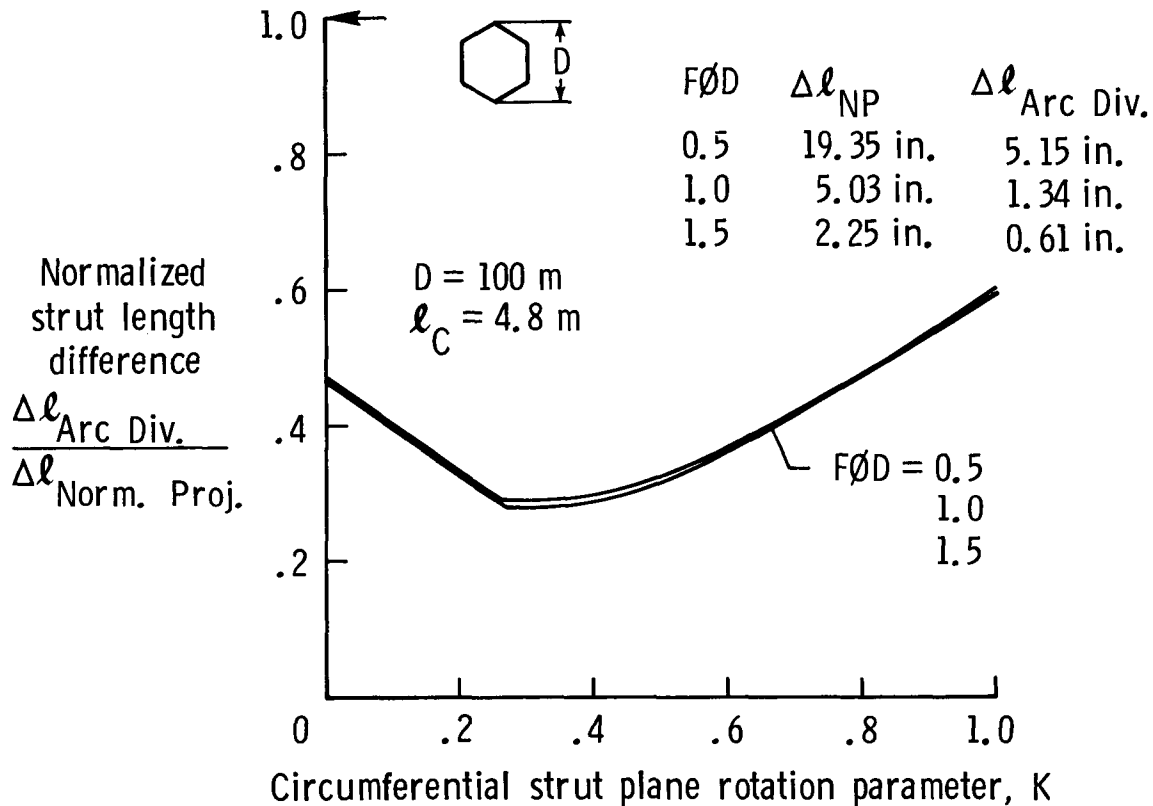
NODAL DISTRIBUTION BY ARC DIVISION

Theoretically, it is possible to have an equilateral triangle (isogrid) strut arrangement only in a flat surface. It is not possible to achieve this in a doubly curved surface, such as a parabolic antenna reflector. However, the variation of geometric properties between nodes can be reduced if a nearly equilateral surface distribution of nodal points can be found. The figure below illustrates one such method. Considering first the shaded sector of a parabolic surface, bounded on the outside edge by arc AB, the meridional and circumferential boundaries of the sector are divided into the appropriate number of equal length arcs. Interior points are located by dividing each interior circumferential arc parallel to AB into the appropriate number of equal length arcs. A triangular truss thus formed exhibits a more nearly equal variation of strut lengths than does the normal projection technique. Further improvement is possible if the edge plane ABC (which was originally vertical as shown in the inset) is rotated outward about the line AC as shown in the figure (see ADC). Interior circumferential arcs are rotated in a similar manner and divided into equal length arcs. The rotation parameter k , shown in the inset, has a zero value when the plane containing each circumferential arc (similar to AB) is vertical, and has the value 1.0 when each plane is perpendicular to the meridian DE.



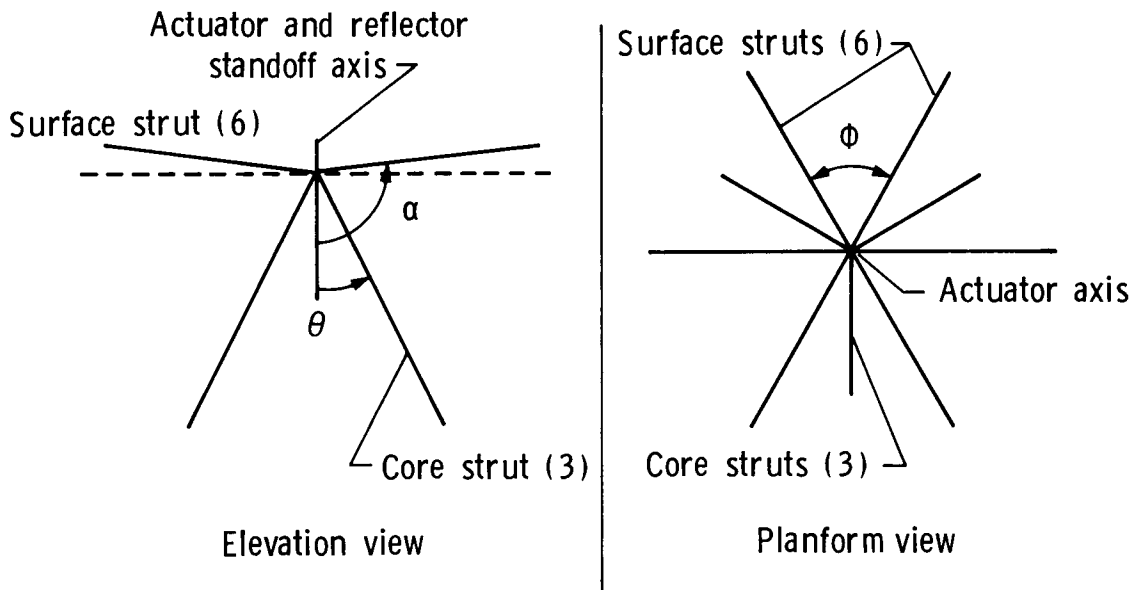
STRUT LENGTH DIFFERENCE MINIMIZATION

The objective of redistributing nodal points by the arc division technique was to minimize differences in the strut lengths to aid in arriving at a common node design for each of the two truss surfaces. The figure shows the strut length error occurring for a 100-m-diameter parabolic truss with nodal point location determined by arc division (normalized with respect to similar values from normal projection). The strut length difference is shown for three values of truss curvature ($F\phi D = .5, 1.0$ and 1.5). The normalized variation of strut length difference is shown to be essentially equal for all three values of $F\phi D$, and exhibits a "minimum" at a value of the geometric parameter k equal to 0.27. Similar reductions in differences of the geometric angles α , θ , and ϕ also occur. While it is not possible to have geometrically identical nodes (within each truss surface), it appears that differences can be reduced to acceptable values such that a common node design for each surface appears feasible.



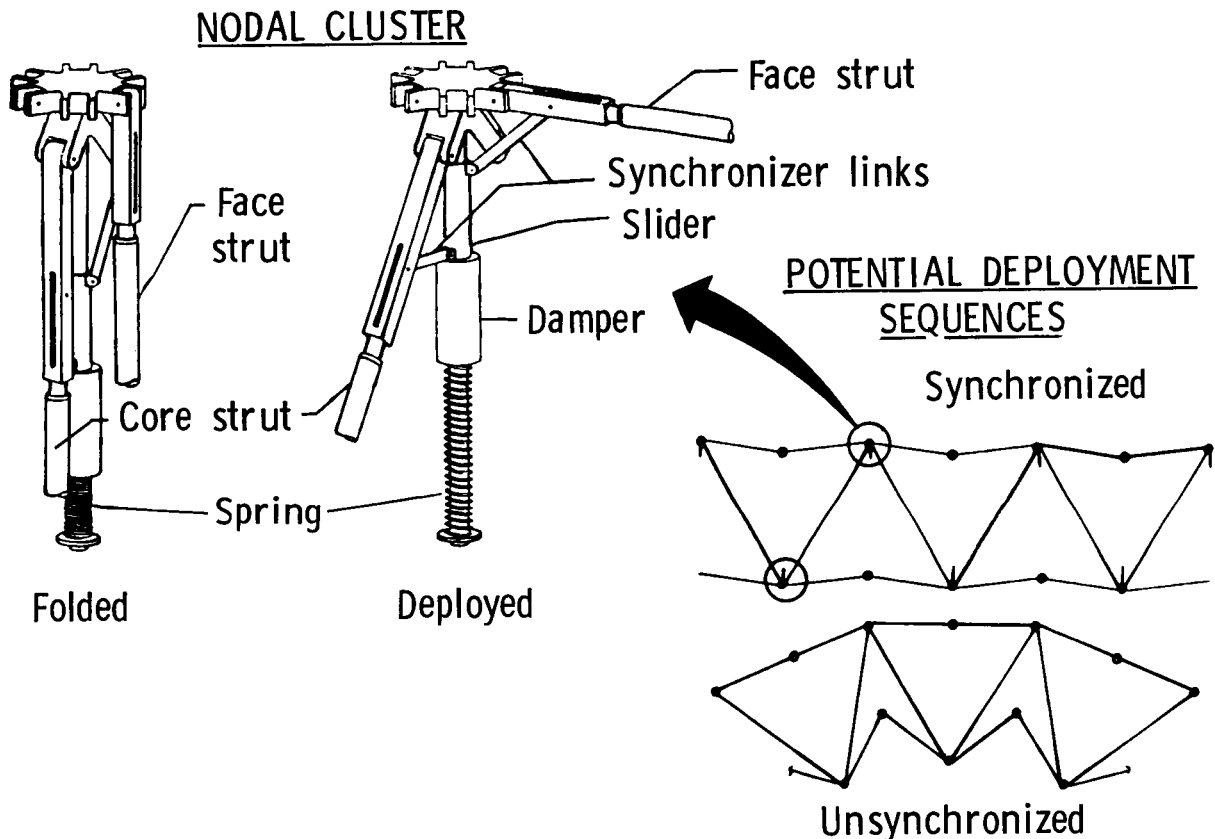
NODAL GEOMETRY DEFINITION

The geometric layout of a tetrahedral node including the location of a local actuator axis is shown in the figure. The actuator axis is constructed perpendicular to the core strut tripod base and passes through the tripod apex. At each node, the three equal length core struts, by definition, each form an angle θ with respect to the actuator axis. The angle θ varies from node to node. Each face strut is shown to form an angle α with respect to the actuator axis. The angle α varies from strut to strut as well as node to node. The surface struts are shown in the planform view to form a projected angle ϕ with respect to adjacent surface struts. The angle ϕ varies from strut to strut as well as node to node. The objective of the arc division method of nodal distribution is to minimize the difference between surface strut lengths and additionally to minimize variations in the angles α , θ , and ϕ . Reduction of variations in the local geometric features of each node to a small enough magnitude will permit the use of a single-node design each for the convex and concave surfaces of the truss structure. This feature is a practical necessity for large deployable trusses.



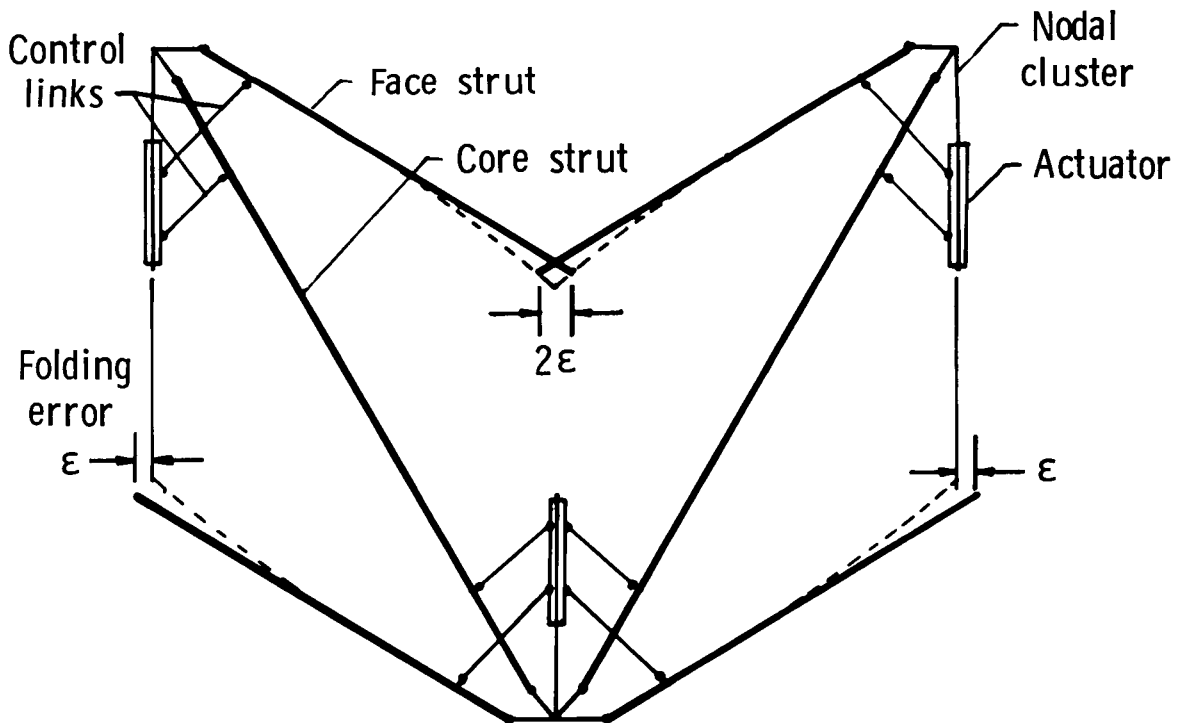
STRUT SYNCHRONIZER DESIGN FEATURES

The method chosen to affect and regulate the deployment of the tetrahedral truss reflector is illustrated in the figure. The nodal cluster shown has a single-face and single-core strut attached for clarity. In actuality, up to six face struts and three core struts will be connected at a single node. Face and core struts are actuated and synchronized by mechanical links which are attached to a common slider. This slider is powered by a passive spring which is released at a rate determined by either (1) distributed local passive dampers as shown in the figure or (2) a global restraint (tether) system. The slider-crank synchronizer geometry is designed to preclude interference between deploying face and core members. Each node deploys independently in a manner that is compatible (free of interference) with adjacent nodes. Kinematic loops are formed between the truss surfaces which are connected by the core struts. These kinematic loops synchronize deployment of the truss surfaces.



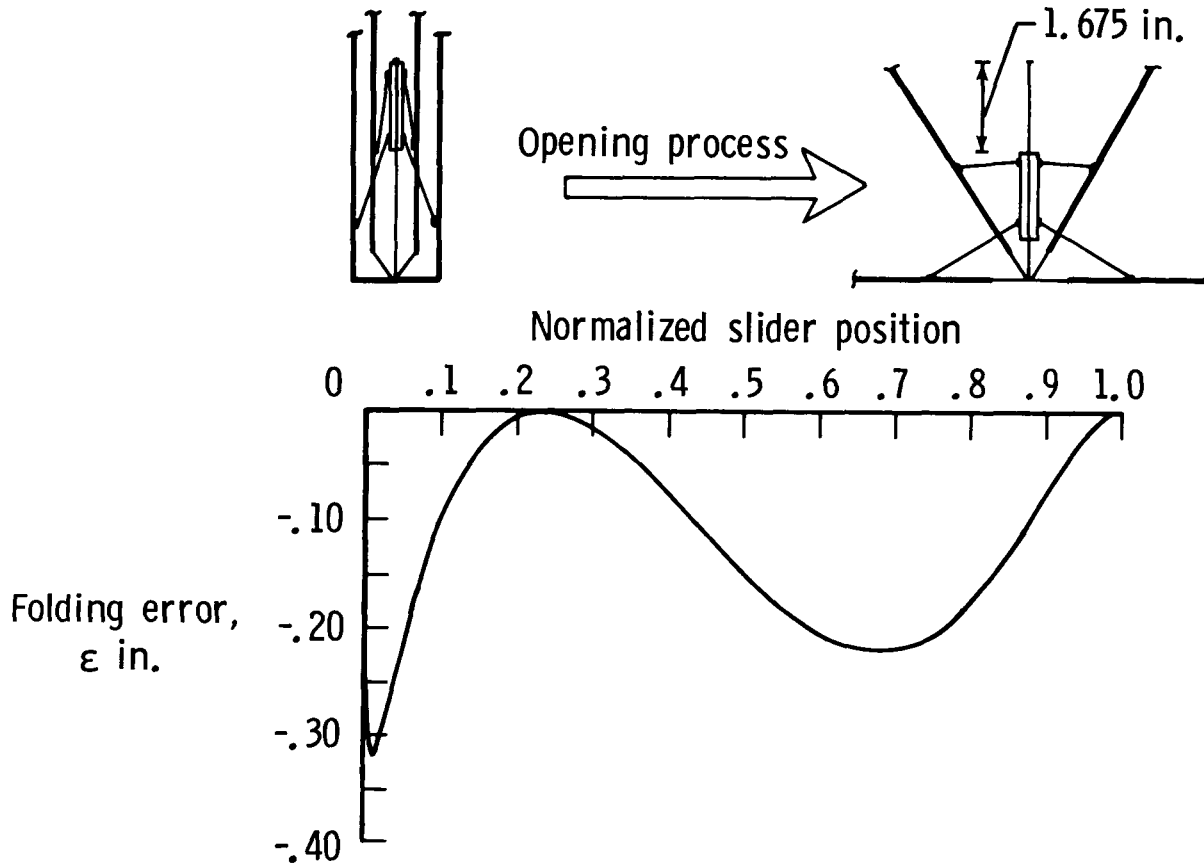
STRUT SYNCHRONIZATION ANALYTICAL MODEL

The figure illustrates the geometry of the analytical model used to determine the synchronizer design which resulted in minimizing the folding error parameter, ϵ , as shown. Pivot locations were iterated until the maximum value of ϵ was minimized over the entire actuator and strut movement range--from fully folded to complete deployment. In the design approach illustrated by the figure, both the face and core struts are attached to a common actuator (slider). While ϵ cannot be reduced to zero, it can be reduced to a small value which has negligible consequences on the kinematic deployment of a folded truss. Since the error ϵ cannot be completely eliminated, it must be accommodated by bending of the struts using the design approach illustrated. An alternative approach, not illustrated or discussed, is to provide a two-piece actuator slide--spring connected--which will accommodate the kinematic error without strut bending.



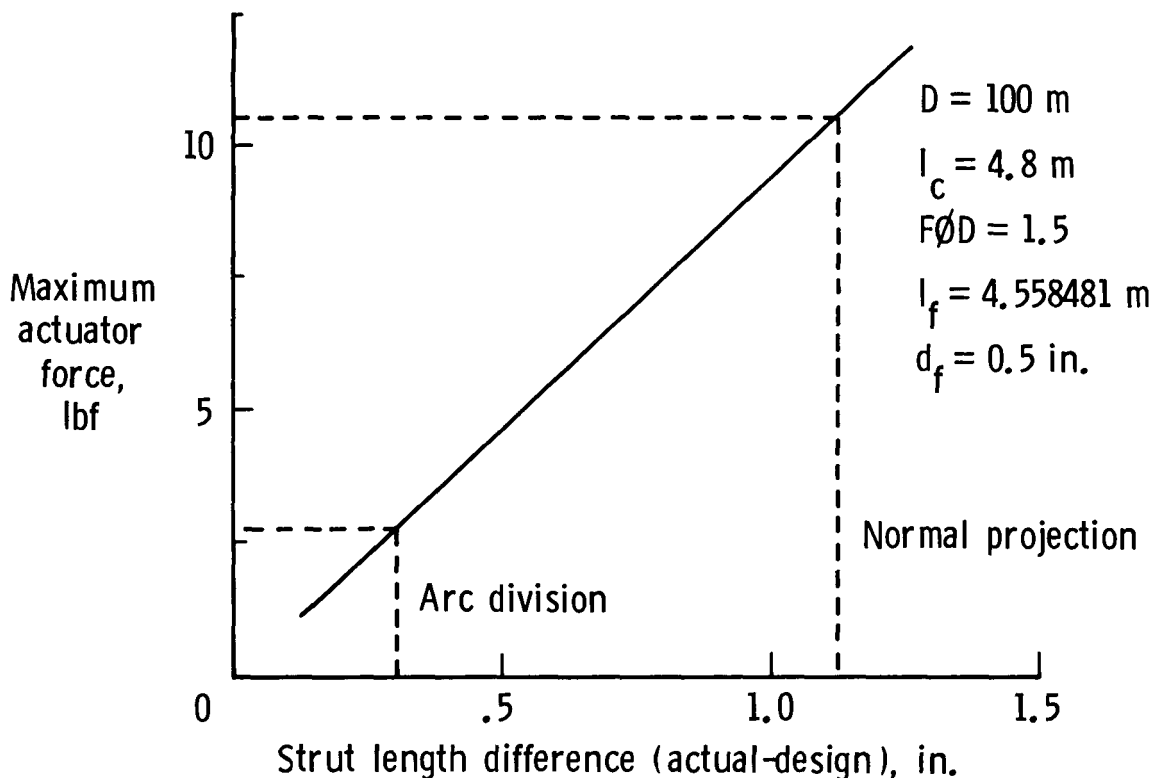
FOLDING ERROR

The folding error ϵ , defined previously, was calculated for a 100-m-diameter parabolic reflector structure ($F/D = 1.5$). The analytical results are shown in the figure as a function of slider position. The kinematic linkage was designed for mean values of the design parameters, computed by the arc division method. The folding error ϵ for this case is shown in the figure. The maximum magnitude of error is shown to be approximately .32 inches and occurs near the start of the deployment process. A second peak in folding error ($\sim .22$ inches) occurs approximately 70% through the deployment operation. These values of error represent "hard" spots in the deployment process which must be overcome by the local actuator spring force.



ACTUATOR FORCE REQUIREMENTS

A combined kinematics and force analysis was performed using the analytical model configuration discussed previously. A rigid-body kinematics code, ADAMS, was modified to permit strut bending during deployment. Using this approximate analysis, and neglecting friction, parametric studies were performed to determine the actuator force required to insure deployment of the truss configurations under investigation. The figure shows that the force required to overcome strut-bending deformations was found to be essentially linear with respect to surface strut length difference. The kinematic linkage was designed (i.e., ϵ was minimized) for median values of the nodal geometric parameters--including surface strut length. The force requirements were examined using this linkage design and different values of strut length. Plotted on the figure are the maximum strut length differences resulting from the arc division and normal projection techniques. Neglecting friction, the arc division method is shown to require an actuator force of approximately 3 lbf whereas the normal projection method requires approximately 11 lbf.



CONCLUDING REMARKS

An arc division method for distributing truss nodal locations over a doubly curved reflector surface has been presented. This method has been shown to decrease differences in surface strut lengths and to increase the geometric similarity of all node configurations in each truss surface. These features enhance the design of a single node and strut synchronizer mechanism for each surface of the deployable tetrahedral truss examined. The folding error resulting from using this design approach was found to be minimal. Nodal actuator spring forces were calculated from an approximate analysis and found to be on the order of three pounds (neglecting friction) for the 100-m-diameter baseline reflector being considered.

Investigative efforts to date indicate the feasibility of using an arc division technique in conjunction with a strut synchronization approach for constructing and regulating operation of a deployable tetrahedral truss reflector.

- Slender struts required to achieve large-diameter single-module reflector surfaces
- Arc division method decreases strut length differences
- Use of single-node/synchronizer design appears feasible for each surface

REFERENCES

1. Woods, A. A., Jr.; and Garcia, N. F.: Offset Wrap Rib Antenna Concept Development. NASA CP-2215, November 1981, pp. 439-469.
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3. Heard, W. L., Jr.; Bush, H. G.; Walz, J. E.; and Rehder, J. J.: Structural Sizing Considerations for Large Space Platforms. Journal of Spacecraft and Rockets, Vol. 18, No. 6, November-December 1981, p. 556.