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EFFICIENT STRUCTURES FOR GEOSYNCHRONOUS SPACECRAFT SOLAR ARRAYS

PHASE IV

by
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ARC-TN-1112

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Prepared for
Jet Propulsion Laboratory
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LIST OF TABLES AND FIGURES

LIST OF SYMBOLS

The following is a list of symbols used in this report:

SYMBOLS

ϕ	packaged diagonal angle
t	member thickness (m)
β	batten-diagonal angle
r	beam radius (m)
b	batten length (m)
ℓ	baylength (m)
d	diagonal length (m)
D	diagonal vector
H	hinge line vector
K	degrees Kelvin

SUBSCRIPTS

ℓh	longeron midhinge
1d	Vector 1 (centerline), deployed
1p	Vector 1, packaged
2d	Vector 2 (midhinge), deployed
2p	Vector 2, packaged

SECTION 1

INTRODUCTION

An investigation is being conducted by Astro Research Corporation (Astro) for Jet Propulsion Laboratory in which efficient structures for geosynchronous spacecraft solar arrays are being developed. Early phases of this study were concerned with selecting viable structural concepts for support of a solar array and comparing three of them on a parametric basis in order to recommend one for further study. These efforts have been documented in the Phase I, II, and III Final Report (ref. 1).

The STACBEAM (Stacking Triangular Articulated Compact Beam) concept is the result of these early phases. Its relative attractiveness can best be demonstrated by consideration of the solar-array system which is shown in Figure 1. The primary component, the solar-array blanket, is stored in a folded configuration and is deployed by controlled linear extension. Blanket stiffness is attained by axially tensioning the blanket and by providing periodic lateral ribs and standoffs which attach the blanket to the beam at several places along its length. The STACBEAM deploys sequentially (one bay at a time) using a deployer of sufficient rigidity so that beam stiffness is not degraded during deployment. The beam does not rotate during deployment, thus making blanket-beam attachment possible in the packaged condition. In addition to high bending stiffness, the STACBEAM possesses high torsional rigidity due to nonflexible diagonals. The concept is adaptable to various size and loading requirements by changing member diameter and baylength, thus affecting the ratio of packaged and deployed length.

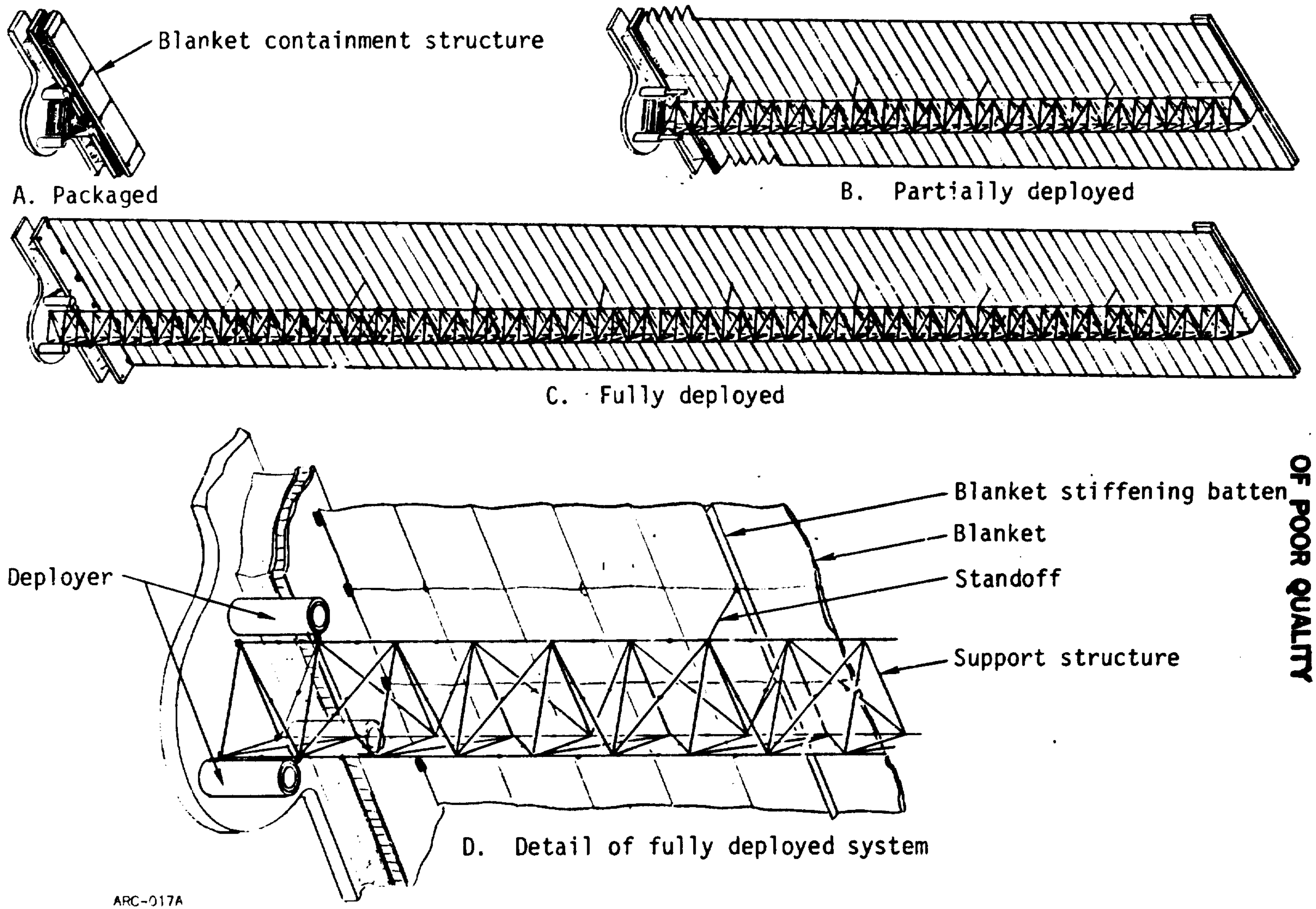

Figure 1. Solar-array system.

SECTION 2

STACBEAM DEVELOPMENT

The STACBEAM was developed in response to a need for a lightweight structure to deploy a solar-array blanket. In recent years, solar-cell efficiency has increased, and substrates have become thinner so that blanket power densities ranging from 200 to over 700 W/kg appear achievable in the near future. In addition, power requirements of geosynchronous satellites may exceed 20 kW. Such increases in blanket efficiency should be accompanied by improvements in structural efficiency.

Structural properties which are considered desirable are:

- Sequential deployment, whereby nearly all of the structure is either fully packaged or fully deployed, and only a small part is in transition
- Lightweight, including beam and deployment mechanism
- High torsional and bending stiffness
- Single-degree-of-freedom hinges
- Nonrotating deployment so that an extended payload can be attached

The STACBEAM, which satisfies each of these criteria, is shown conceptually in Figure 2. A unit of the STACBEAM consists of the following:

- A triangular batten frame, perpendicular to the beam axis
- A set of three longerons attached at the corners of the batten frame and directed parallel to the beam axis
- A set of three diagonals to provide shear and torsional stiffness

In the following analyses, notation is occasionally in triaxial space; that is, positions and vector orientations are given as sets of three terms indicating x, y, z position and i, j, k orientation, respectively.

2.1 GEOMETRY

In the ideal case, the ratio of batten length to baylength is $b/\ell = \sqrt{3}$, so that the relative diagonal length is $d/\ell = 2$, and the batten-diagonal angle is 30 degrees. These dimensions provide the geometry necessary for packaging,

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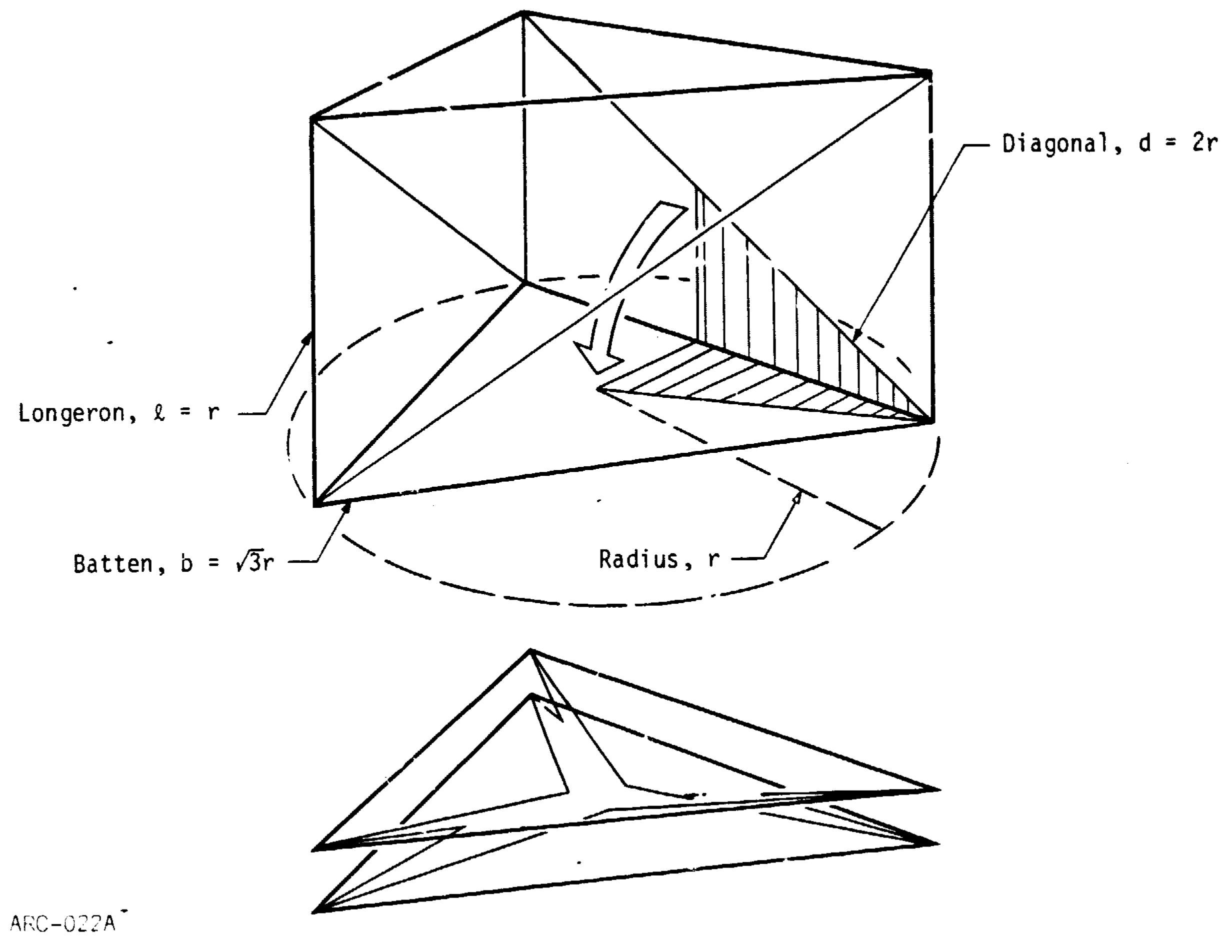

Figure 2. STACBEAM concept.

whereby the batten frames stack with a spacing of two member diameters. The diagonals fold midway along their lengths and package just above the batten plane with the midpoints grouped about the center. The packaged diagonal-batten angle is 30 degrees, unchanged from the deployed condition. The longerons also fold at midlength, toward the batten frame center, with the ends necessarily landing on top of each other.

2.1.1 Working Geometry

The geometry specified in Section 2.1 is ideal in that it assumes that the member diameters are constant, even at the joints. In the case of the STACBEAM, the joint at the middle of the longeron is wider than the member diameter which requires that the diagonal-batten angle be less than 30 degrees in order to package without interference. The required diagonal-batter angle is determined as follows.

2.1.1.1 DIAGONAL-BATTEN ANGLE - Inspection of Figure 3 shows that the deployed and packaged diagonal-batten angles must be equal. This angle β must be less than 30 degrees so that the diagonal clears the longeron center hinge. The diagonal centerline passes through the end hinge at

$$\frac{\sqrt{3}}{2}\,\frac{t}{\tan\beta}\ ,\quad -\frac{1}{2}\,\frac{t}{\tan\beta}\ ,\quad t$$

At an x coordinate of

$$\frac{\sqrt{3}}{2}\,r\,\tan\beta - \frac{t}{2}$$

it encounters the longeron midhinge. This hinge has a width $t_{\ell h}$. The batten diagonal angle β is given by

$$\beta = 30^{\circ} - \frac{\phi}{2}$$

where ϕ is the packaged subtended angle of the diagonal centerlines. At the longeron midhinge, these centerlines must be separated by $t_{\ell h}$ plus the member diameter t. Thus,

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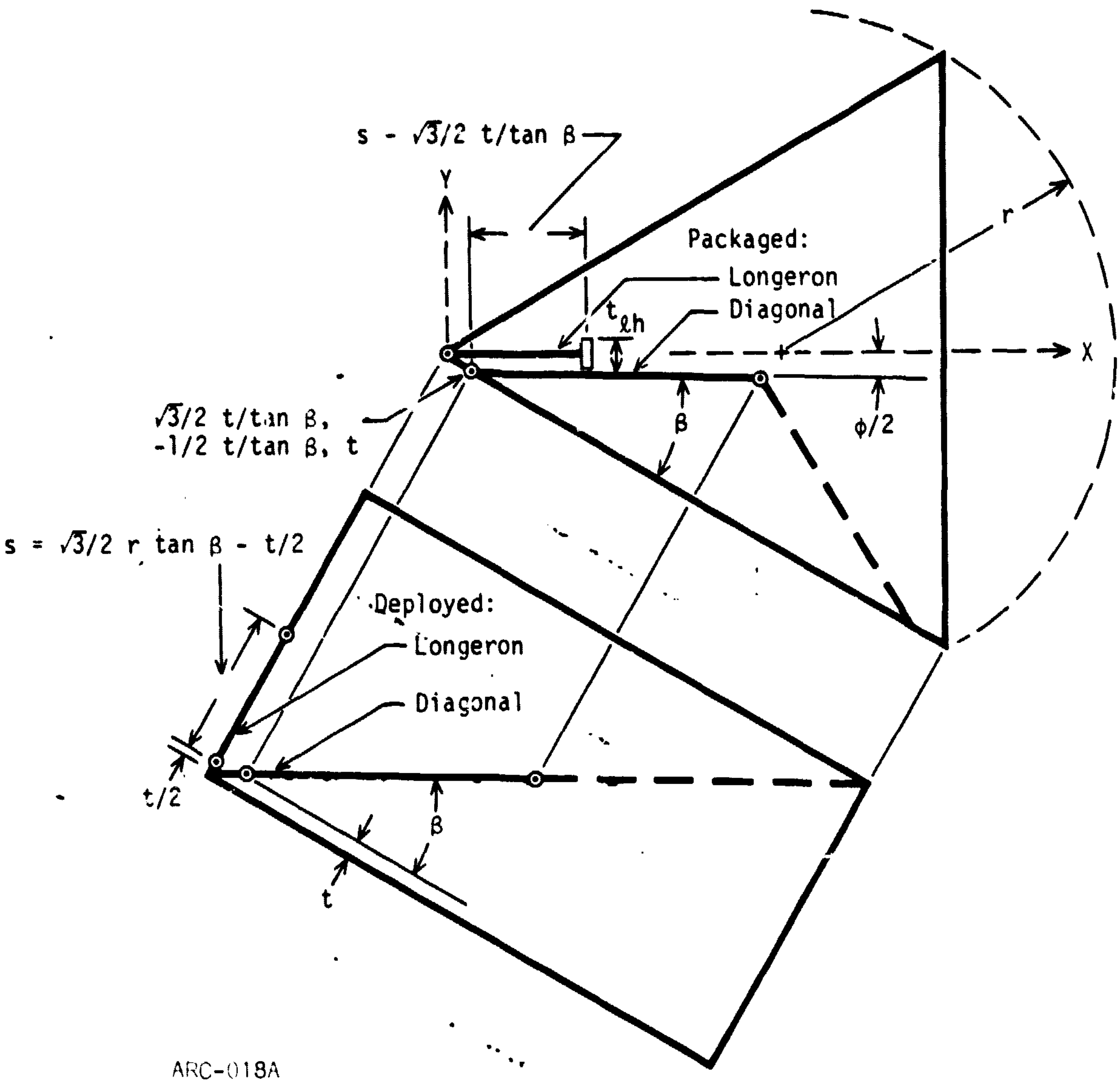

Figure 3. Bay length determination.

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$$\phi \approx \tan\phi = \frac{t_{\ell h} + t - \frac{t}{\tan\beta}}{\frac{\sqrt{3}}{2} r \tan\beta - \frac{t}{2} - \frac{\sqrt{3}}{2}\frac{t}{\tan\beta}}$$

The grazing angle, for $t_{\ell h}$ = 12.70 mm, t = 5.08 mm, and r = 0.45 m, is

$$\beta = 28.80 \text{ degrees}$$

2.1.1.2 MEMBER LENGTHS - In the deployed condition, there are center-of-action points through which all member centerlines pass. In the batten plane, these mark the corners of an equilateral triangle of side b, which is termed the batten length. In a direction parallel to the beam axis, the center-of-action points are spaced by the baylength ℓ.

The batten length is based on a beam radius of r = 0.45 m, so that

$$b = \sqrt{3}r = 0.779 \text{ m}$$

The baylength is

$$\ell = b \tan\beta = 0.428 \text{ m}$$

The diagonal length is

$$d = \sqrt{b^2 + \ell^2} = 0.889 \text{ m}$$

2.2 HINGE SPECIFICATION

Hinges required for packaging are located at the midpoint and ends of each longeron and diagonal. For rigidity in the deployed condition, locking hinges are provided at these midpoints.

2.2.1 Longeron Hinges

The arrangement of longeron hinges is shown in Figure 4. The longeron packages so that its centerline lies one-half member diameter above the batten plane with the midhinge oriented (0,1,0) in deployed and packaged conditions.

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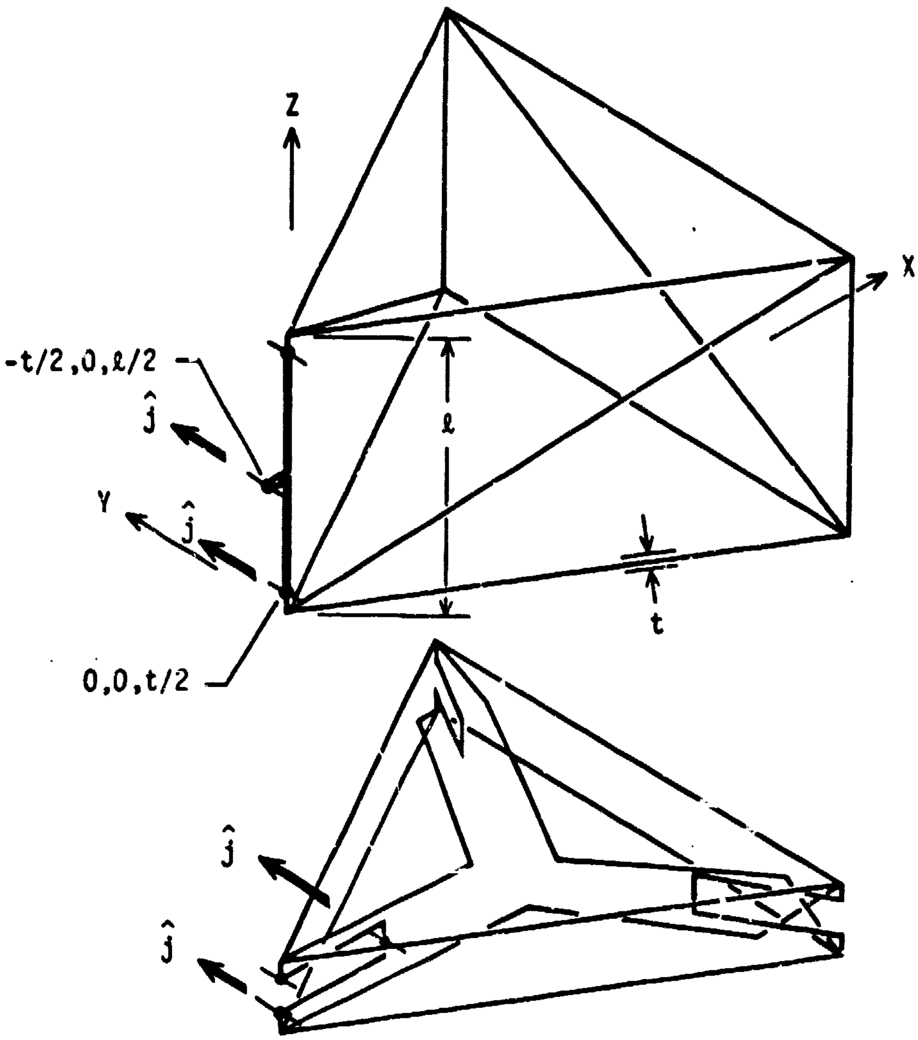

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Figure 4. Longeron hinge specification.

A point in the midhinge, deployed, is $(-t/2, 0, \ell/2)$, so that the longeron folds against itself in packaging. The required end hinge passes through $(0,0,t/2)$ and is aligned along $(0,1,0)$.

2.2.2 Diagonal Hinges

The hinge required for specified motion of a member is determined as follows from the motion of two lines in the member. For convenience, one line can be the member centerline, while the other can be any line whose motion does not describe a plane parallel to the plane of motion of the first. The direction of the required hinge is given by the cross product of the vector differences of each line as it moves from the packaged to the deployed position.

A coordinate system is established in Figure 5, with the origin on one of the center-of-action points, the x-y plane containing the battens at +30 degrees and -30 degrees from the x axis, and the longerons along the z axis. A diagonal extends, in the deployed condition, from the origin to

$$\frac{3}{2} r \ , \ -\frac{\sqrt{3}}{2} r \ , \ \ell$$

Member lengths given in Section 2.1.1.2 yield a deployed diagonal centerline unit vector of

$$\vec{D}_{1d} = 0.7589 \ \hat{i} - 0.4382 \ \hat{j} + 0.4818 \ \hat{k}$$

The packaged diagonal centerline has no z component and makes an angle of $-\phi/2$ with the x axis. Thus, the packaged diagonal centerline vector is

$$\vec{D}_{1p} = 0.9998 \ \hat{i} - 0.0209 \ \hat{j}$$

The second line in the diagonal member is its midhinge. Packaged, this line is directed along the beam axis; that is,

$$\vec{D}_{2p} = \hat{k}$$

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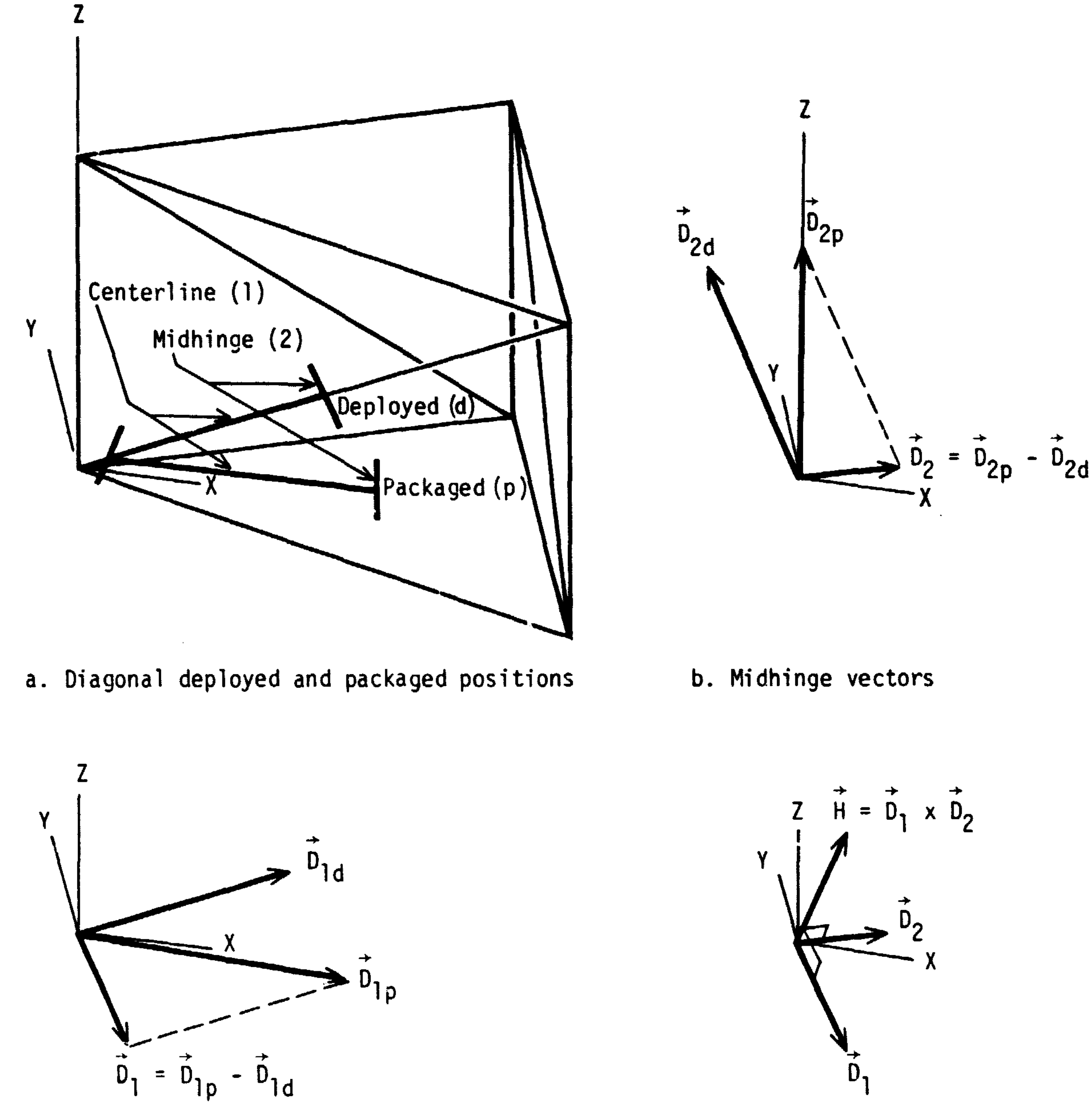

a. Diagonal deployed and packaged positions

b. Midhinge vectors

c. Centerline vectors

d. Required hinge vector

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Figure 5. Diagonal hinge specification.

Deployed, this hinge line has a z component of cos β and an x-y component of sin β, shared according to $-\sqrt{3}/2$ sin β, 1/2 sin β. The deployed midhinge vector is thus

$$\vec{D}_{2d} = -0.4172\ \hat{i} + 0.2409\ \hat{j} + 0.8763\ \hat{k}$$

The vector differences are

$$\vec{D}_1 = \vec{D}_{1p} - \vec{D}_{1d}$$

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and

$$\vec{D}_2 = \vec{D}_{2p} - \vec{D}_{2d}$$

so that the required hinge is $D_1 \times D_2$, or

$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0.2409 & 0.4173 & -0.4818 \\ 0.4172 & -0.2409 & 0.1237 \end{vmatrix}$$

$$= -0.0645\ \hat{i} - 0.2308\ \hat{j} - 0.2321\ \hat{k}$$

and the unit vector is

$$\hat{H} = 0.1932\ \hat{i} + 0.6919\ \hat{j} + 0.6957\ \hat{k}$$

The required hinge position, from Section 2.1.1.1, is $(\sqrt{3}/2$ t/tan β, - 1/2 t/tan β, t) which for t = 5.08 mm is (8.00 mm, -4.62mm, 5.08 mm).

2.2.3 <u>Locking Hinges</u>

Locking hinges are required for those members which fold in the middle so that the member simulates a continuous rod in the deployed condition. A hinge which has been developed to do this, shown conceptually in Figure 6, relies on the lever action of several linking parts to magnify a spring force in the fully deployed position.

2.2.3.1 LONGERON LOCKING HINGE - Photographs of the longeron locking hinges are shown in Figure 7. These hinges are designed so that the packaged longeron lies folded against itself with 180 degrees of rotation about the hinge from deployed to packaged positions. The packaged height of the hinge pair is two member diameters so that efficient packaging is realized. The hinge width is approximately two and one-half member diameters, thus providing stability. A torsion spring is placed where the links are joined, in an orientation such that it tends to decrease the link-link angle.

2.2.3.2 DIAGONAL LOCKING HINGE - Photographs of the diagonal locking hinge are shown in Figure 8. This hinge differs from the longeron locking hinge in two respects: The main hinge pin is on the centerline of the member, rather than the edge, and the locking links are on the inside (toward the fold) rather than the outside. The width of this hinge is precisely two member diameters, which is the maximum value considering packaging requirements. Torsion springs are placed where needed, in an orientation such that they tend to increase the link-link angle.

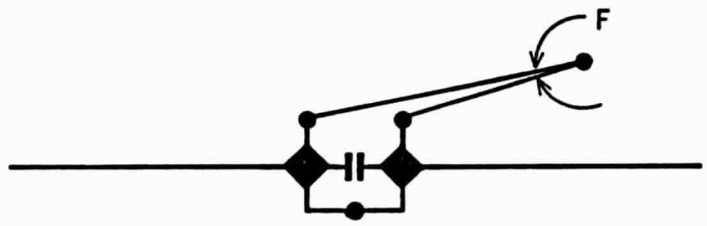
2.3 MATERIAL SELECTION

Items for which material selection was required were as follows: rods, hinges, bonding material, hinge pins, and springs.

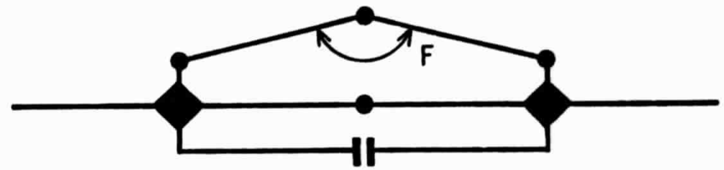
2.3.1 Rods

Rod material was specified early in the contract to be graphite/epoxy pultrusion which has a very high modulus (approximately 120 GPa) and low density (1520 kg/m^3). Its thermal expansion coefficient is small (-0.9×10^{-6} K^{-1}).

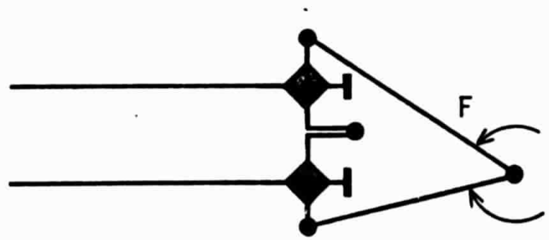
Various companies were contacted to supply this material of 3.1-mm diameter, 0.82-m length, and a straightness within 1/10-diameter over its length. A relatively small quantity, by most suppliers' standards, was requested (62 m); this limited the number who could supply at a reasonable



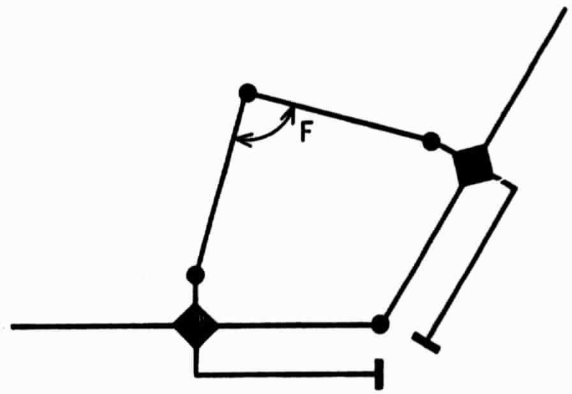
a. Deployed longeron locking hinge



c. Deployed diagonal locking hinge



b. Packaged longeron locking hinge



d. Packaged diagonal locking hinge

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Figure 6. Locking hinge concept (spring force F causes high deployed preload due to near linearity of three link hinge pins).

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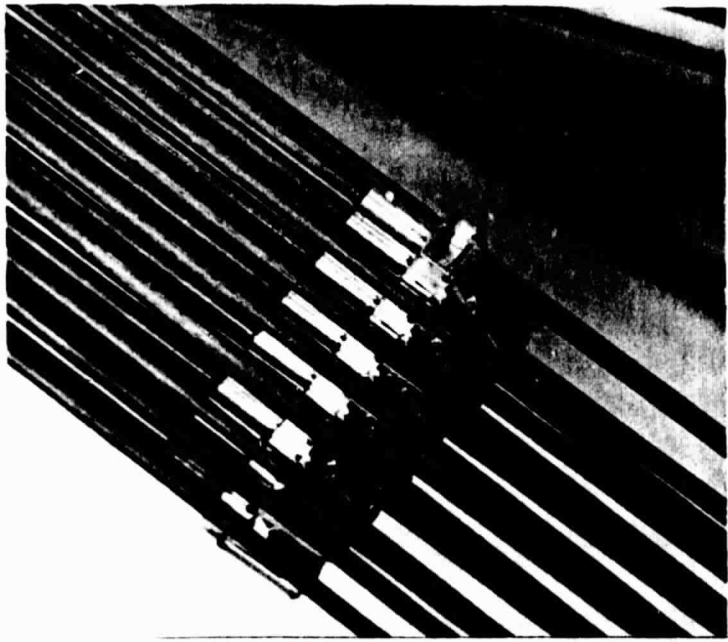

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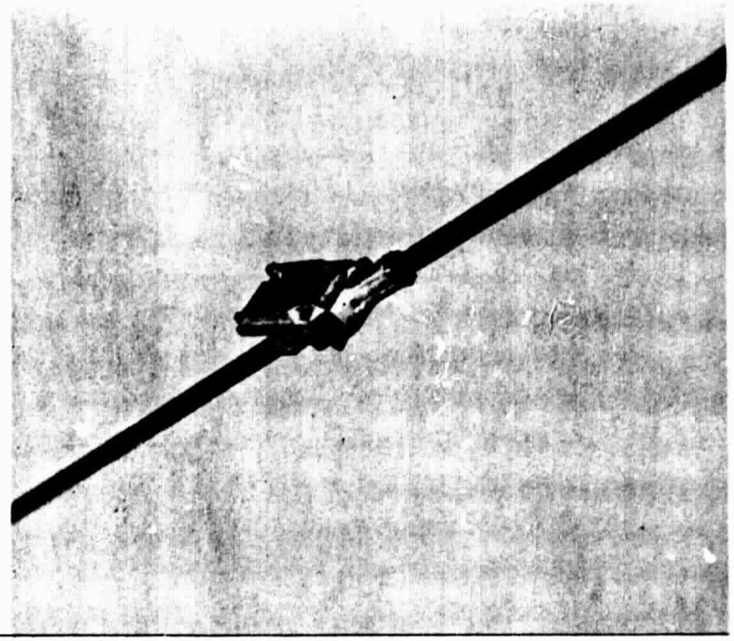
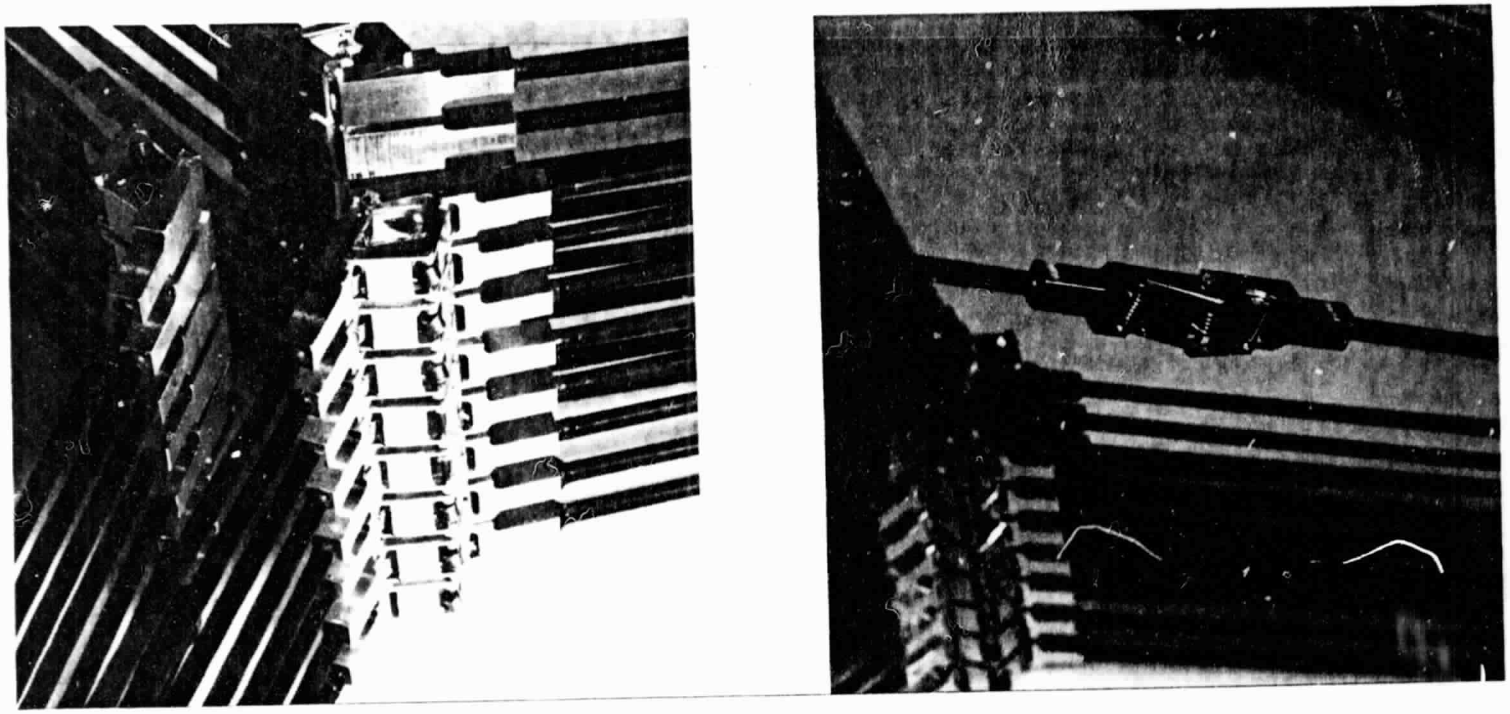
a. Packaged



b. Deployed

Figure 7. Longeron locking hinge.



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a. Packaged

b. Deployed

Figure 8. Diagonal locking hinge.

price per length. Stevens Products of New Jersey was selected to pultrude Hercules graphite filaments, in an epoxy binder, at a cost of approximately $14/meter.

The rods, as delivered, were of constant but slightly too large diameter (3.4 mm). Centerless grinding, a simple and inexpensive procedure, was successful in reducing the diameter to a constant 3.1 mm. A more important problem was rod straightness. Bowing of the rods, over the 0.82-m length, was randomly distributed in the range from less than a one-tenth member diameter to a half-diameter. Approximately 15 percent of the rods were in the former category, and these were used to fabricate the longerons, since they are loaded column-wise. Next, in order of straightness requirements, are the diagonals followed by the battens, and rods were selected accordingly.

2.3.2 Hinges

For spacecraft applications, materials such as stainless steel or titanium are commonly selected for applications requiring high strength, hardness, and low thermal expansion. Hinges certainly are in this category. However, for demonstration purposes, the alternate criteria of machinability, cost, and availability were used, and aluminum alloy 2024-T351 was selected. A significant, but misleading, weight reduction results from this selection, and hinge masses must be adjusted according to material density (aluminum sp. gr. = 2.70, stainless steel sp. gr. = 7.83, titanium sp. gr. = 4.46).

2.3.3 Bonding Material

For bonding the graphite/epoxy rods to the aluminum hinges, two types of epoxy adhesive have been used. Devcon, a convenient two-part, 5-minute-setting adhesive, has been used in some joints. The cured adhesive has the advantageous property of flowing at high temperature so that bond alignments can be adjusted or parts can be changed. Hysol EA 934 has been used to bond the Astromast and the Seasat ESS (Extendible Support Structure) and was used on some joints of this STACBEAM model.

2.3.4 Hinge Pins

Hinge pins are composed of 0.040-inch-diameter drill rod of various lengths to span the various hinges. Drill rod is fairly easily machined and can be held in place by slight deforming of one or both of its ends.

2.3.5 Springs

Springs are used in the longeron and diagonal locking hinges. They are torsionally acting and consist of wound music wire. The longeron locking springs are 0.025-inch-diameter wire, wound 10 times around a 1/16-inch mandrel. Two types of diagonal locking springs are used: a six-turn spring of 0.025-diameter, and a four-turn spring of 0.029-diameter wire, each wound about a 1/16-inch mandrel.

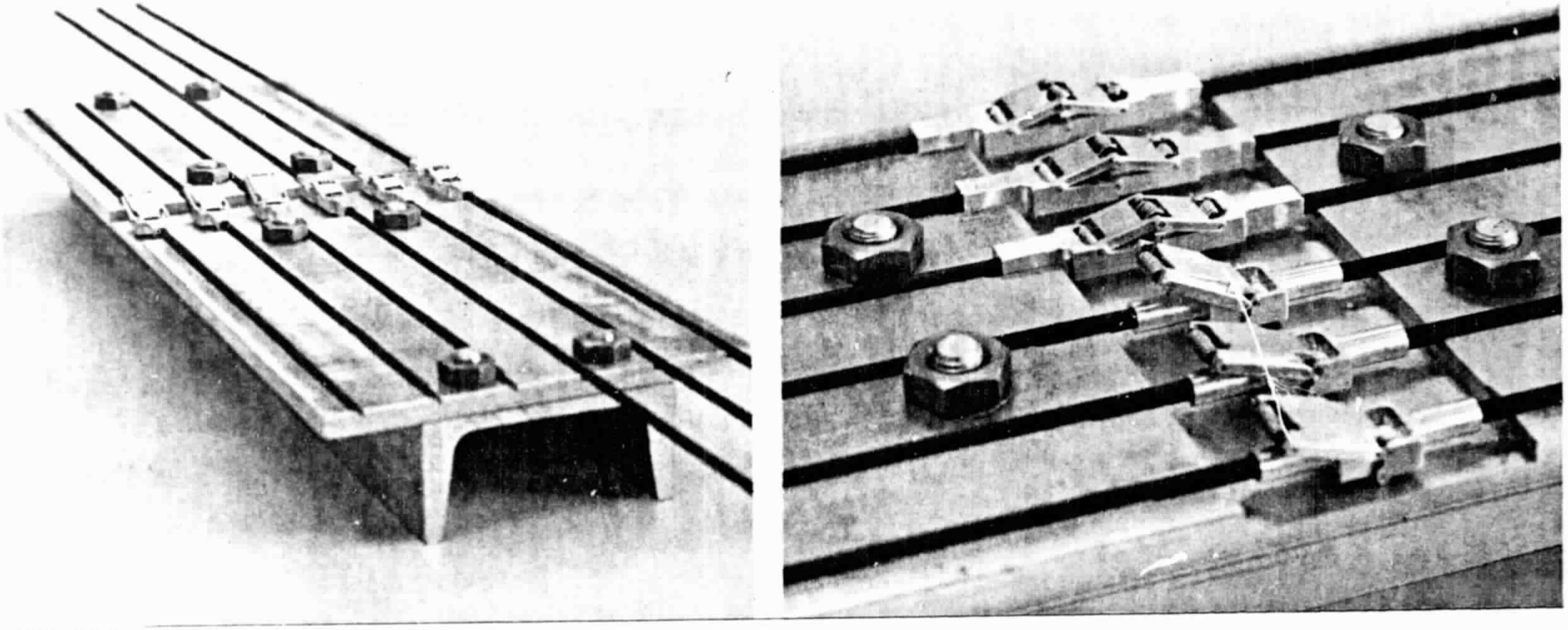
2.4 BONDING PROCEDURES

In bonding the rods to hinges, the major concern has been hinge line placement and orientation so that deployed rod alignment is correct. Bonding fixtures have thus been used. For primary alignment of knee joints, the fixture shown in Figure 9 was used. All subsequent bonding was done on a large steel plate shown in Figure 10.

It is important that members which fold along their length for packaging are straight (continuous centerline) when deployed so that Euler column loadings can be achieved. Thus these members are assembled in the following order:

- The midhinge, a locking assembly, is put together complete with springs and is worked until its deployed configuration is set.
- Rods are inserted into both ends of the midhinge with bonding material and placed in the alignment fixture shown in Figure 9 for cure.
- End hinges are bonded to the rods using methods discussed below.

Holes are set in the large plate (Figure 10a) for positioning of the batten corner fittings during bonding of the batten frames. The longerons are bonded separately (Figure 10b) using holes in the fixture to orient the end hinges correctly relative to the midhinge. The end hinges of the diagonals are thus held in place (Figure 10c), and the diagonal midhinges are held with long hinge pins in their packaged positions near the center of the fixture (Figure 10d) for bonding of the diagonals.



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a. Rod alignment fixture

b. Foreground: Longeron locking hinge
Background: Diagonal locking hinge

Figure 9. Rod alignment fixture.

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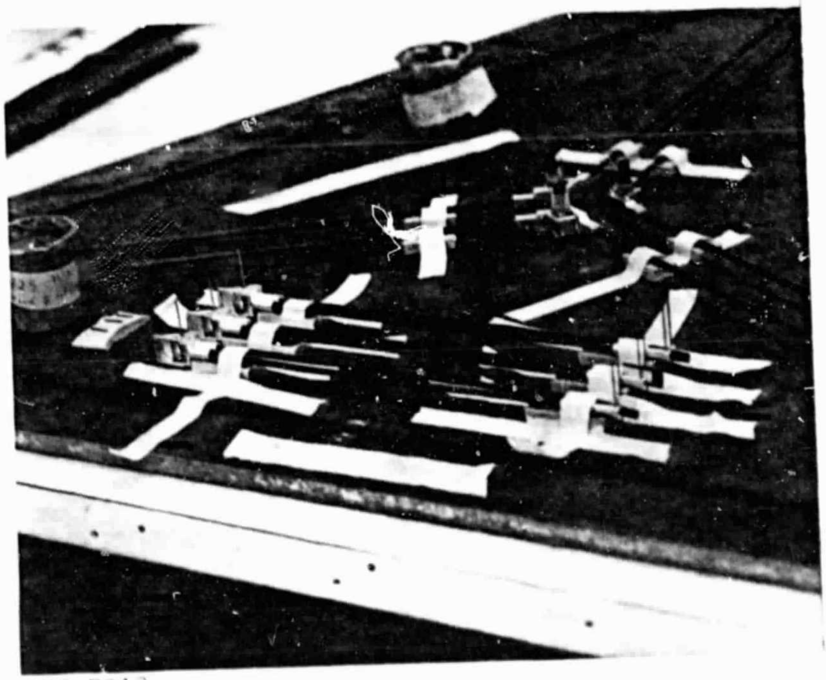
a. Overall view



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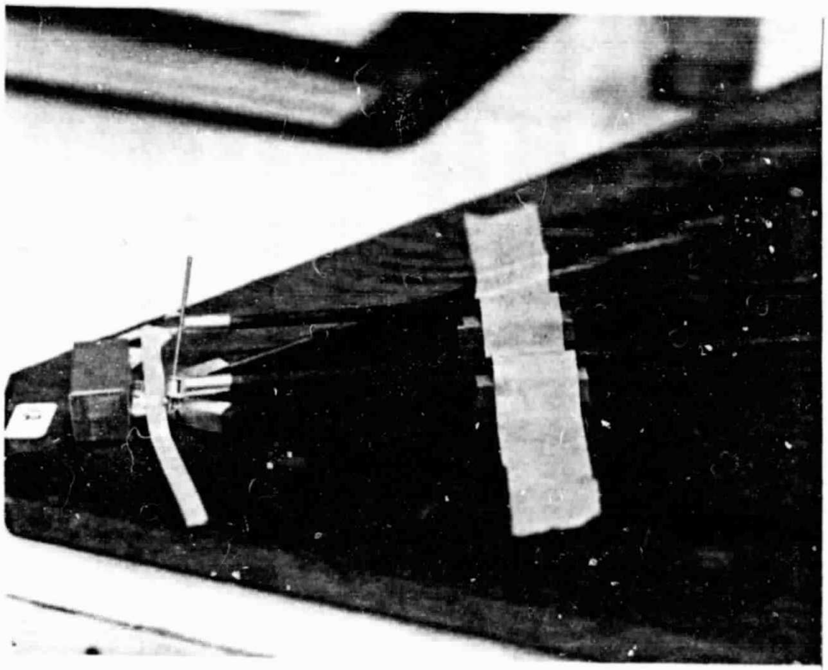
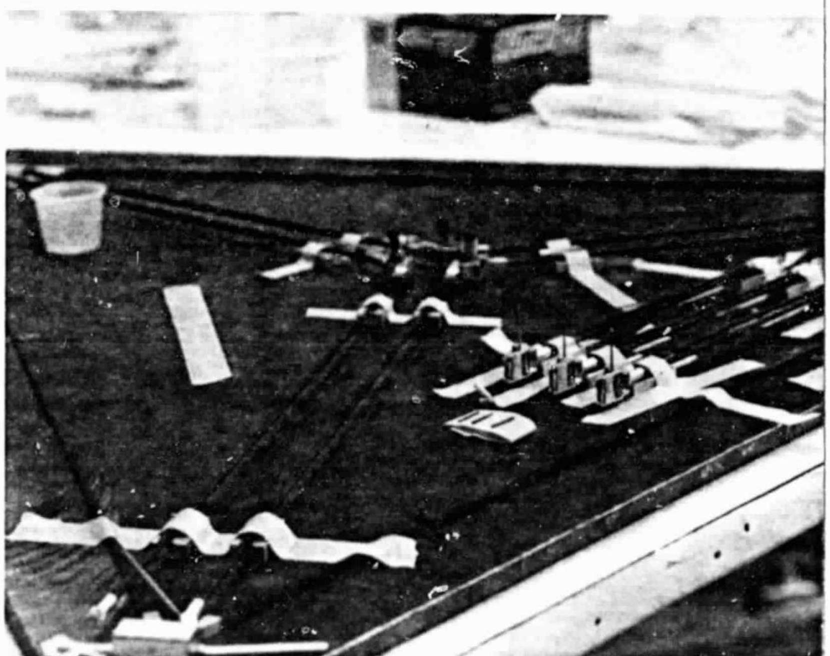
b. Bonding of longeron ends

Figure 10. Large bonding fixture.



c. Detail of Figure 10d



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d. Bonding of diagonal ends

Figure 10. (concluded).

2.5 ASSEMBLY PROCEDURES

Component parts of the eight-bay STACBEAM consisted of:

- Nine batten frames, each a triangular array of three batten rods and three hinge bodies which hold the longeron and diagonal ends
- Twenty-four (24) longerons, each having a locking midhinge, two rods, and two end hinges (all bonded in position prior to assembly)
- Twenty-four (24) diagonals, each having a locking midhinge, two rods, and two end hinges (all bonded in position prior to assembly)
- Ninety-six (96) hinge pins for the ends of the longerons and diagonals

Before any bonding took place, hinge parts were fitted together in clusters each consisting of a hinge body, two longeron ends, and two diagonal ends. These clusters were worked until parts moved easily, then each was numbered. Upon assembly of the bonded longerons, diagonals, and batten frames, these original clusters were brought back together to ensure free movement.

SECTION 3

PRELIMINARY DEPLOYER DEVELOPMENT

The STACBEAM is an efficient, low-mass, sequentially deployable structure. In that regard, it is essential that an efficient, low-mass deployer be developed to complement the STACBEAM.

3.1 CONCEPT

In design of the preliminary deployer, the intent has been to incorporate the major features of the conceptual prototype deployer. These features are shown in Figure 11 and included the following:

- Starwheels for batten frame detention passively hold a deploying frame against any forces except those exerted by the corner catches
- Corner catches act positively to separate a batten frame away from starwheel detention.
- A shuttle moves the starwheels and corner catches relative to each other so that they are alternately at the same level, for separation from detention, and moved apart a distance of one bay length for pulling the next batten frame into detention.

3.2 DESIGN

The preliminary deployer has been designed to follow the concept outlined in Section 3.1. Little attempt has been made to make it a low-mass structure. As assembled, without the packaged beam, the deployer shown in Figure 12 weighs 8.6 kg, which compares favorably with the target weight of the deployer (6.4 kg).

3.2.1 Starwheels and Corner Catches

The starwheels serve the following functions:

- Passively hold a batten frame in a closely controlled position
- Release it in the event that the corner catches exert sufficient force
- Capture and hold a new batten frame which is brought in by action of the shuttle

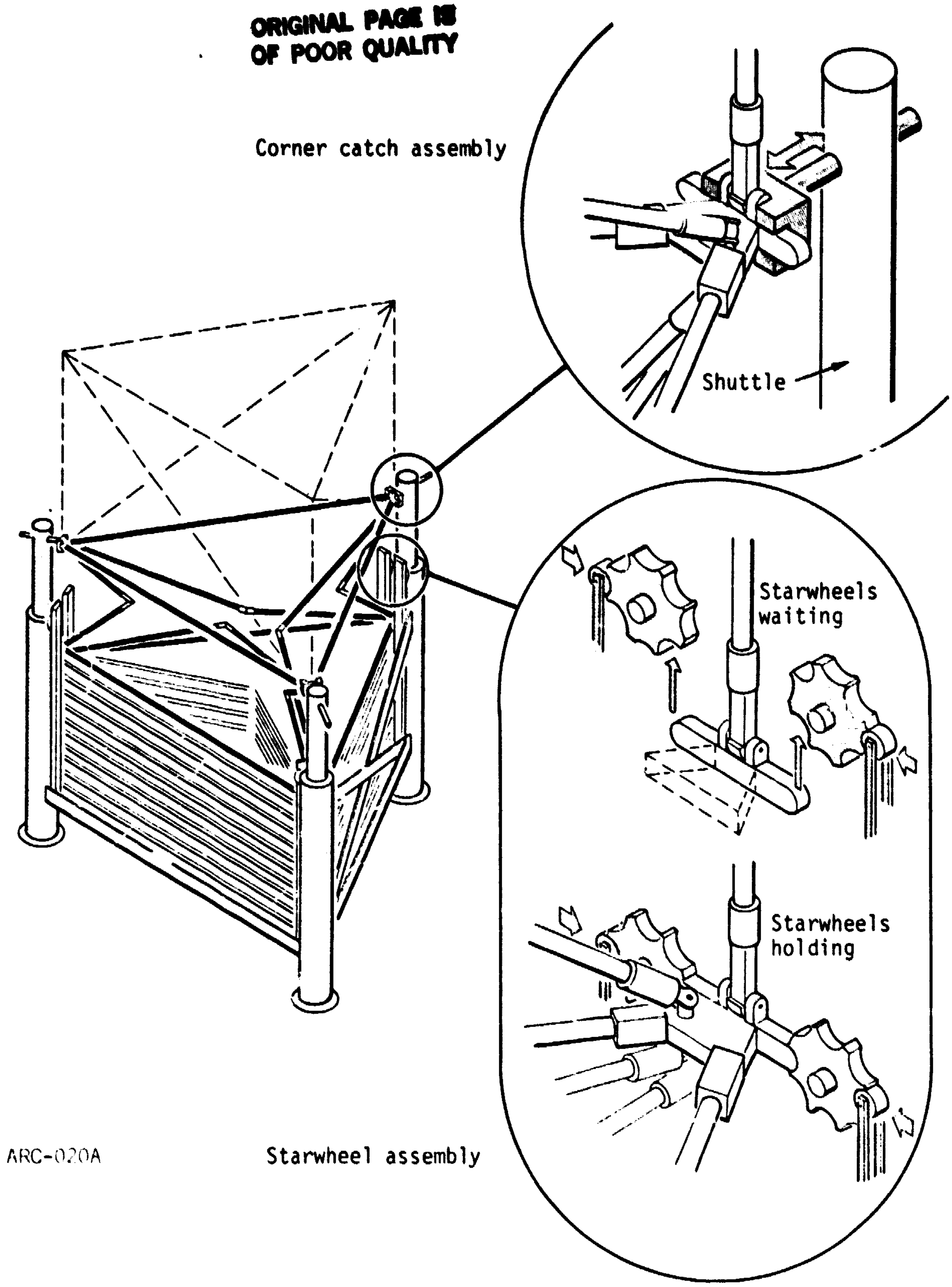

Figure 11. Deployer concept.

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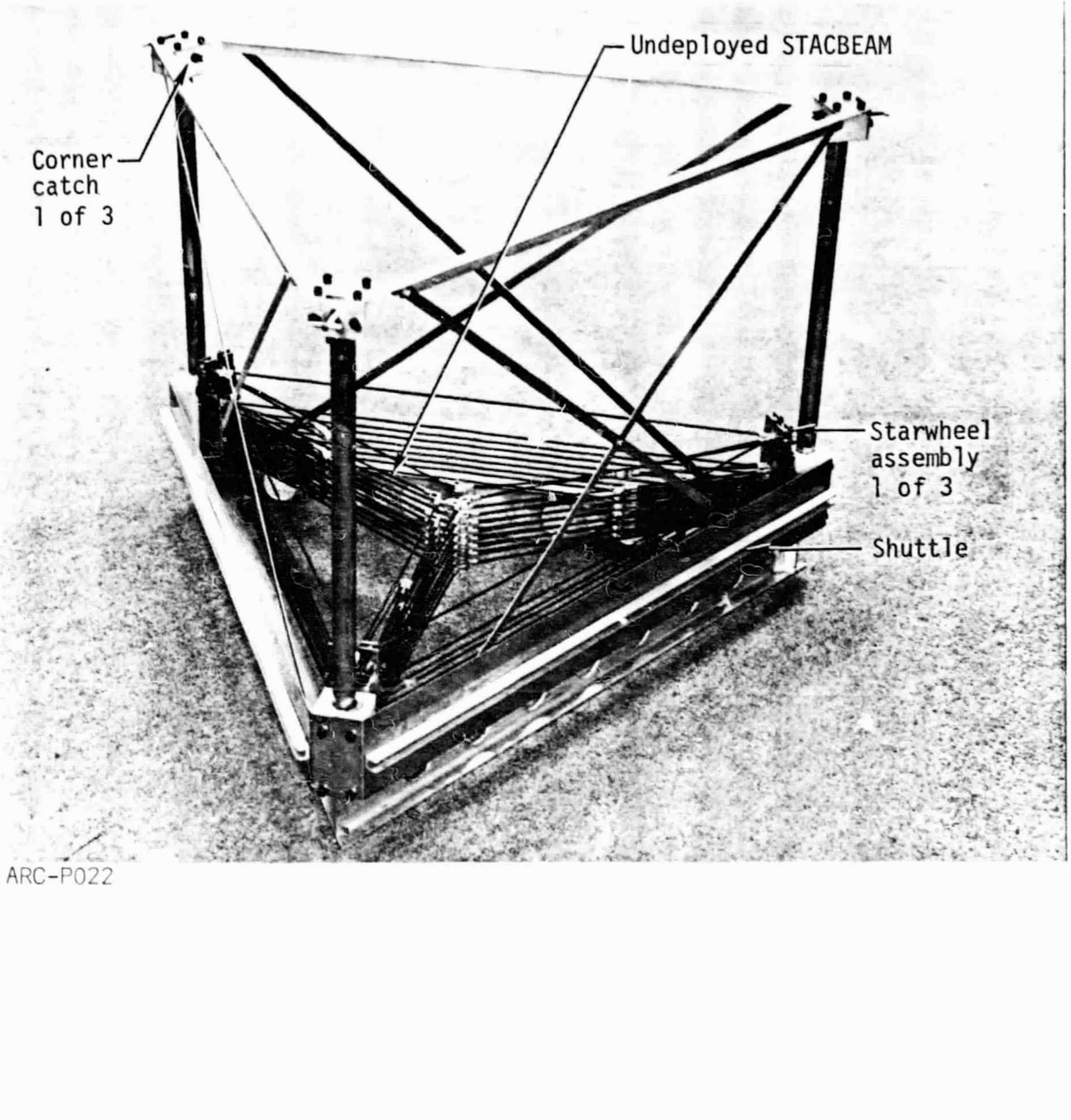

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Figure 12. STACBEAM preliminary deployer.

Figure 13a shows the starwheel assembly in the first function. The semi-circular sides of the batten corner body fit snugly into recesses in the starwheels which are locked against rotation by spring-loaded detent arms. Note that the batten frame is in close proximity of a corner catch. Figure 13b shows the corner catch having engaged the corner body. In Figure 13c, the starwheels no longer have control of the corner body which has been moved by the corner catch (second function). The starwheels are in a "waiting" configuration, whereby they are held in a light detent position which provides clearance for the next corner body. Deployment of a single bay is accomplished by separating the corner catches from the starwheels by the baylength ℓ. This is shown just before full deployment in Figure 14a, where the starwheels are ready for capture of the next batten frame corner body (third function). In Figure 14b, the starwheels have captured the next batten frame.

3.2.2 Shuttle

The shuttle is shown in Figure 12. In the demonstration model of the deployer the corner catches are part of the stationary structure, while the shuttle acts to move the three starwheel assemblies and the undeployed STACBEAM relative to these corner catches. This motion is equivalent to that of the conceptual deployer in which the corner catches move, and the starwheel assemblies and undeployed STACBEAM are stationary.

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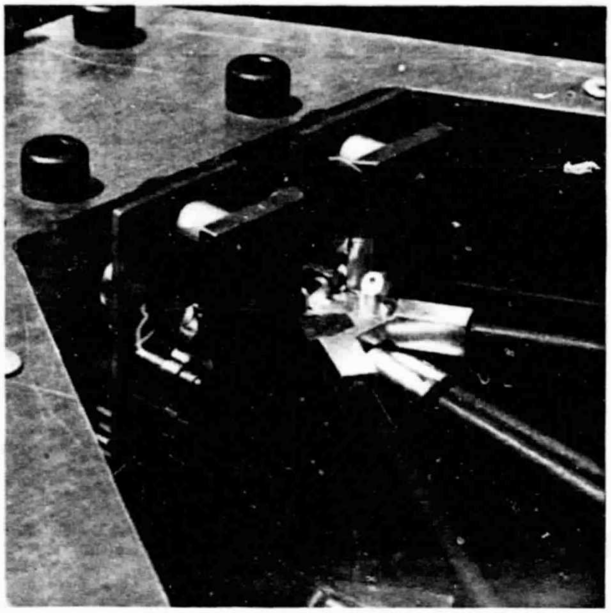
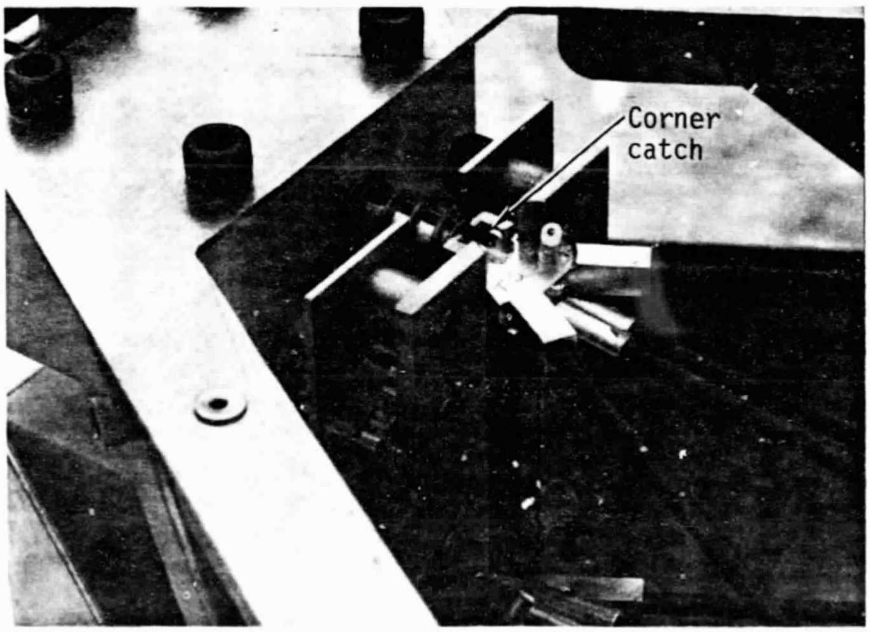
a. Corner body in starwheels, near corner catch



b. Corner catch engages corner body in starwheels



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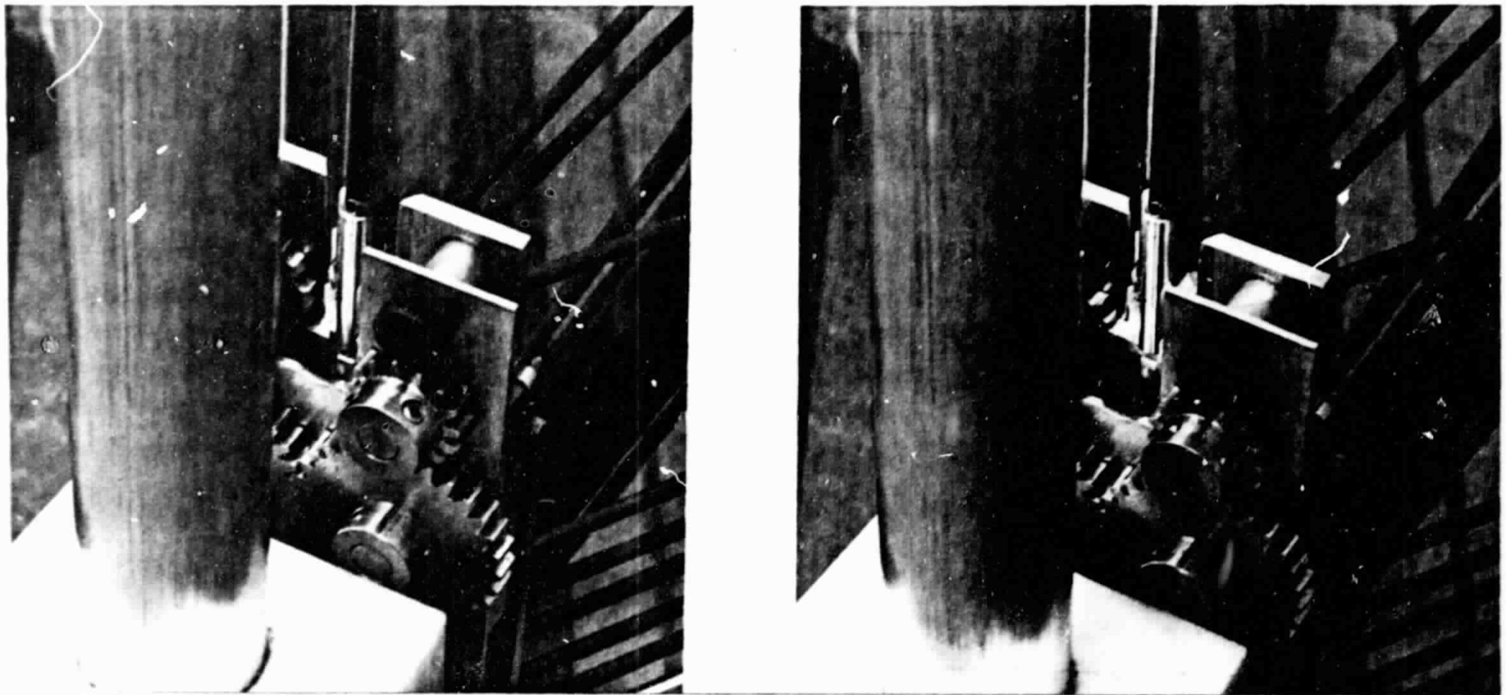
c. Corner body and corner catch separated from starwheels

Figure 13. Corner catch assuming control of batten frame.



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a. Batten frame below starwheels

b. Corner body held in starwheel assembly

Figure 14. Starwheels capturing batten frame.

SECTION 4

TESTS

Testing of the STACBEAM and the preliminary deployer consisted of:

- Operational tests to verify deploying action of STACBEAM
- Operational tests to demonstrate deployer
- Cantilever test on deployed STACBEAM
- Detailed inspection of STACBEAM

4.1 STACBEAM GEOMETRY VERIFICATION

Figures 15 through 20 show the STACBEAM in various views and stages of deployment. A high degree of symmetry is evident in both packaged and deployed conditions.

4.2 DEPLOYER OPERATION

Figures 13 and 14, discussed in Section 3, show the deployer in its various stages of operation. The deployer was designed to make minor adjustments possible so that its geometry can be finely tuned to that of the STACBEAM. With proper adjustments having been made, operational tests were performed.

Results of these tests can be summarized as follows.

4.2.1 Starwheel Operation

The starwheels operated successfully in all their functions (Section 3.2.1), with the the following significant problems:

- A tendency is seen for the starwheels to flywheel past the waiting position when a batten frame is pulled out too vigorously. Perhaps an escapement mechanism is necessary.
- The beam does not retract conveniently, thus making testing difficult. Beam retraction is feasible by design modification, but because of the intended use at the low load levels of geosynchronous orbit, retractability was not a contract requirement.

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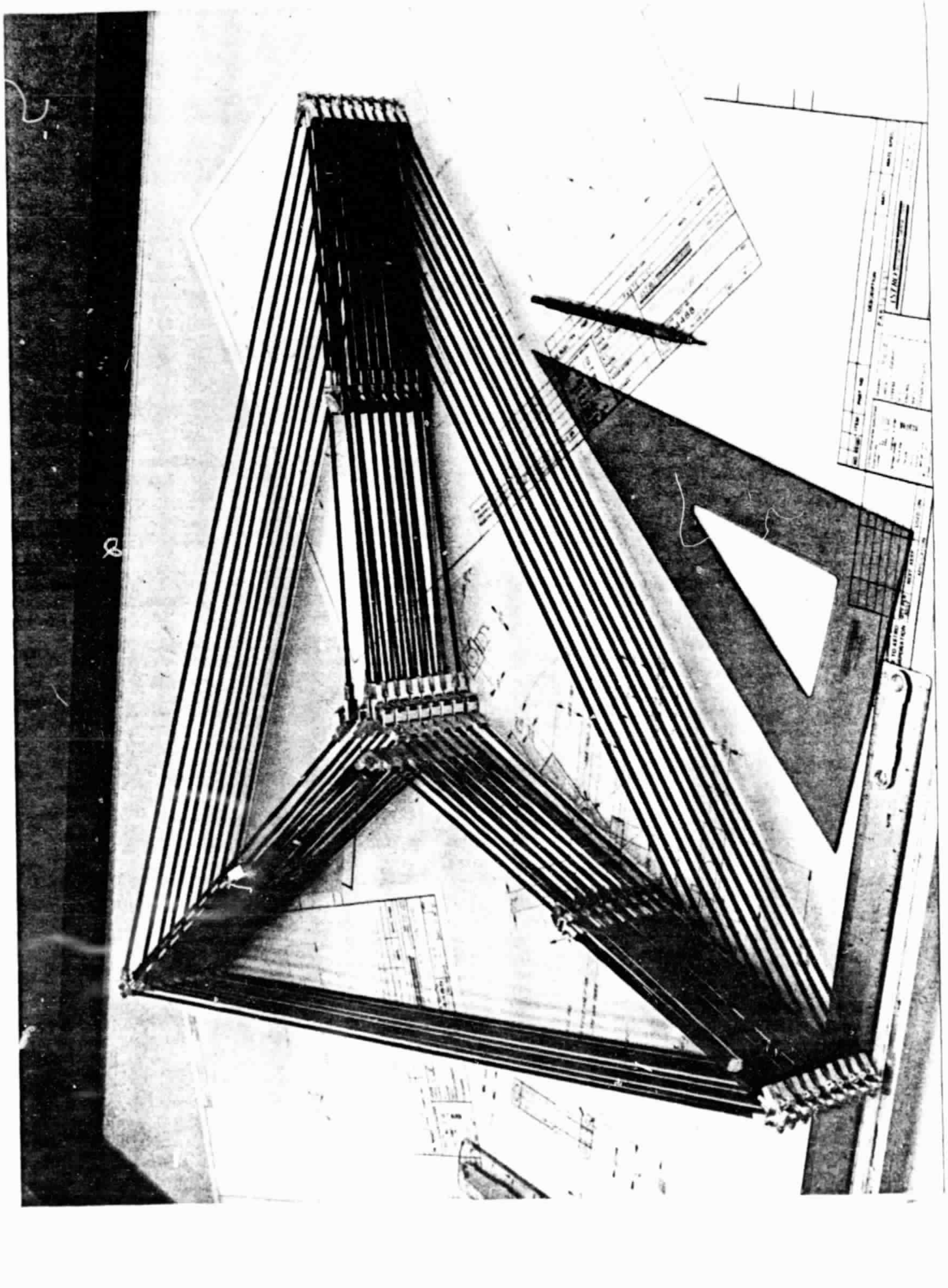

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Figure 15. STACBEAM design.

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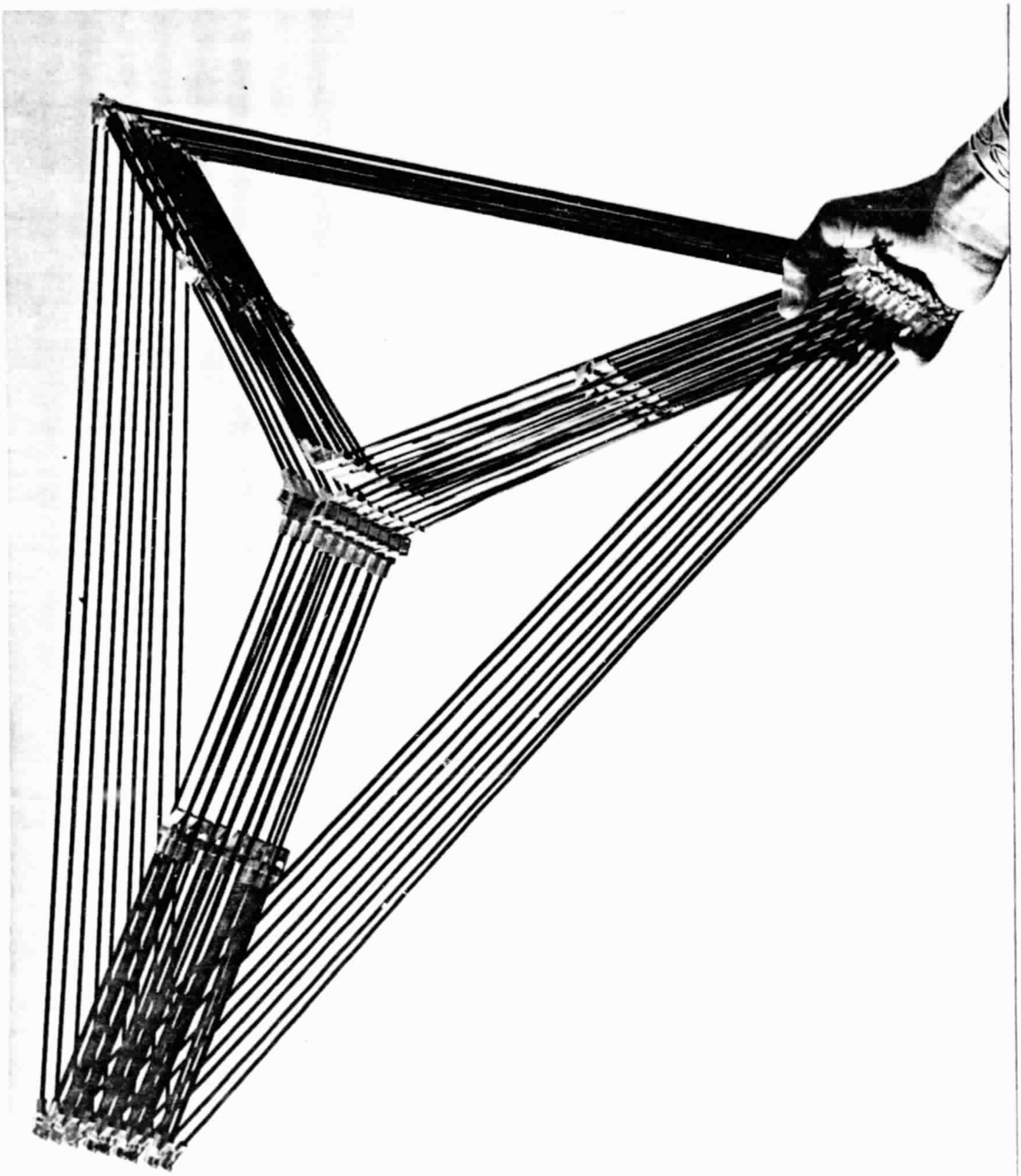

Figure 16. Packaged STACBEAM.

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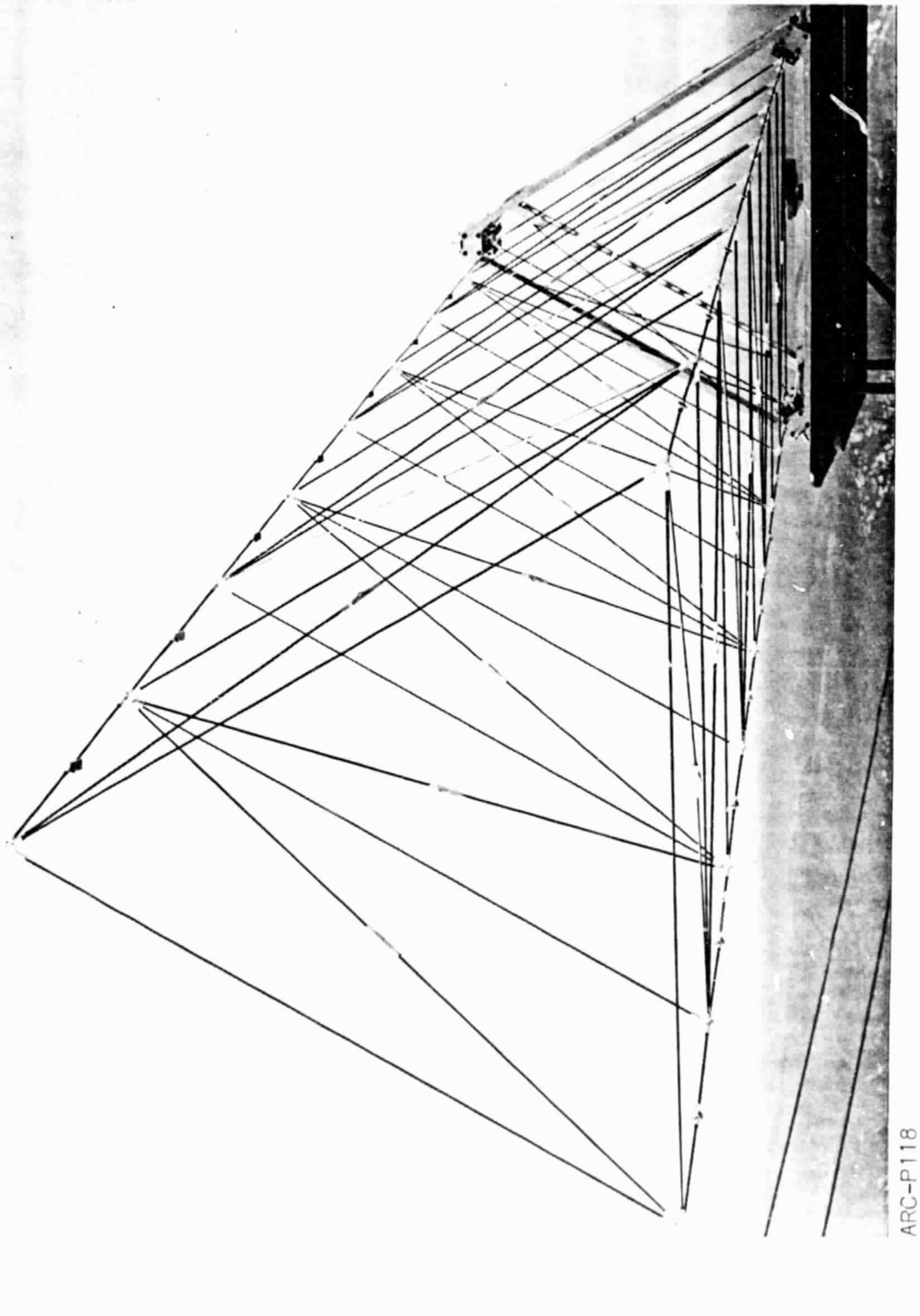

Figure 17. Deployed STACBEAM.

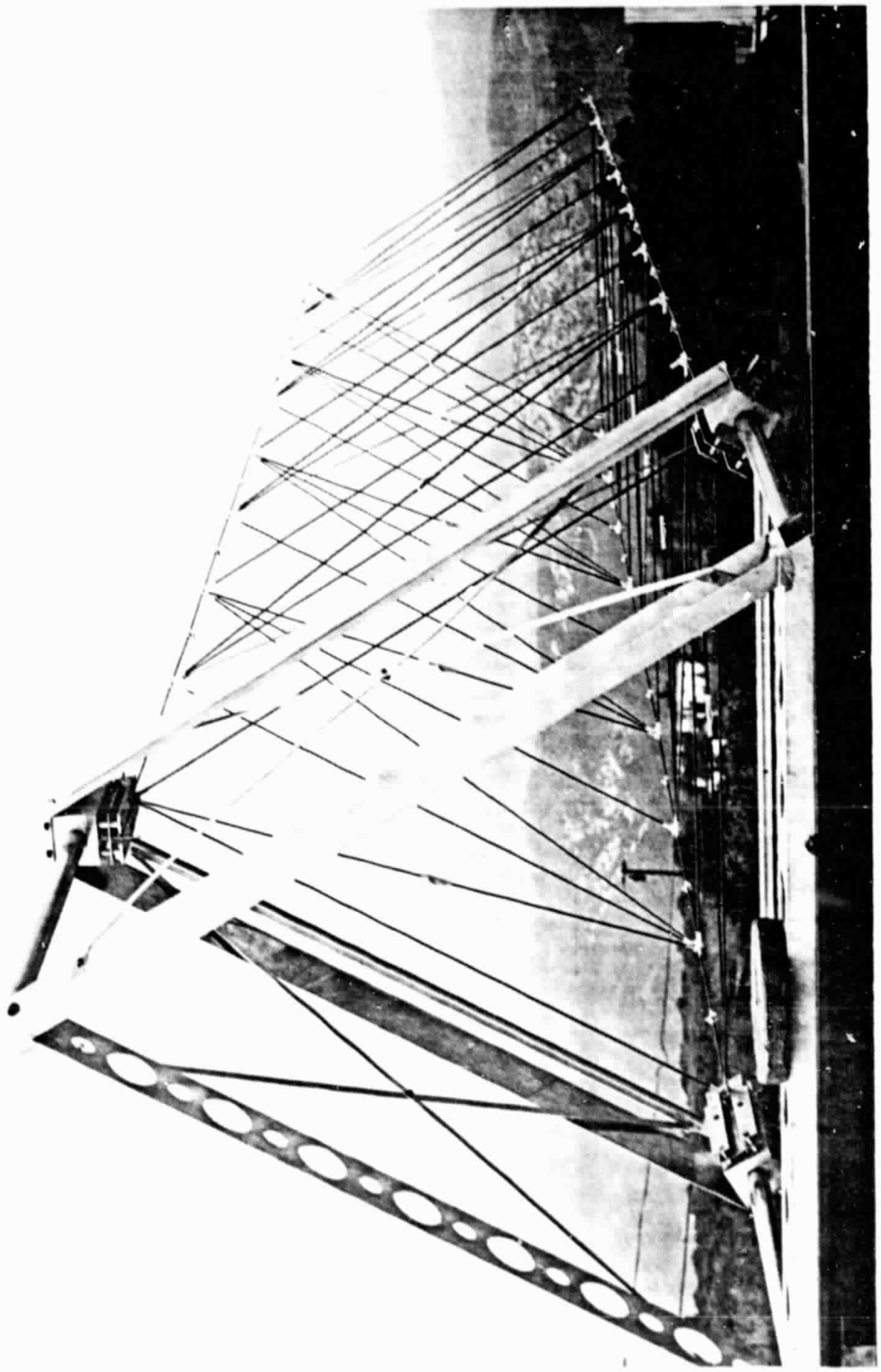

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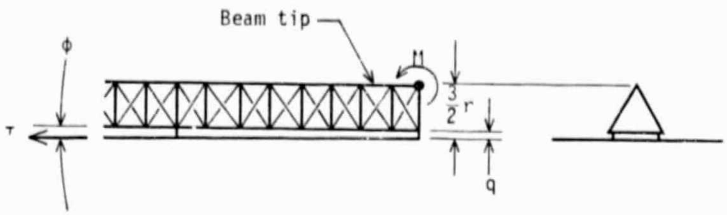
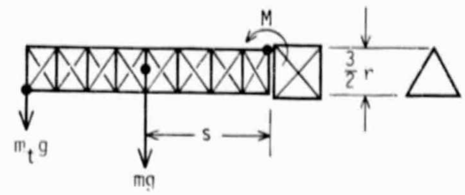
Figure 18. STACBEAM: cantilevered from deployer.

c = longeron compressive load

$r = 0.45$ m	$m = 0.862$ kg
$q = 15$ mm	$g = 9.78$ m/s^2
$T = 24$ N	$s = 1.72$ m
$\phi = 0.0138$ rad	$m_t = 0.5$ kg





$$M = -T\left(\frac{3}{2} r + q\right) + 2c\left(\frac{3}{2} r\right) = 0$$

$$c = \left(\frac{1}{2} + \frac{1}{3}\frac{q}{r}\right) T$$

$$= 12.3 \text{ N}$$

$$V = T\phi$$

$$= 0.33 \text{ N}$$

$$M = mgs - 2c\left(\frac{3}{2} r\right) + 2m_t gs = 0$$

$$c = \frac{(m + 2m_t)gs}{3r}$$

$$= 23.2 \text{ N}$$

$$V = (m + m_t)g$$

$$= 13.32 \text{ N}$$

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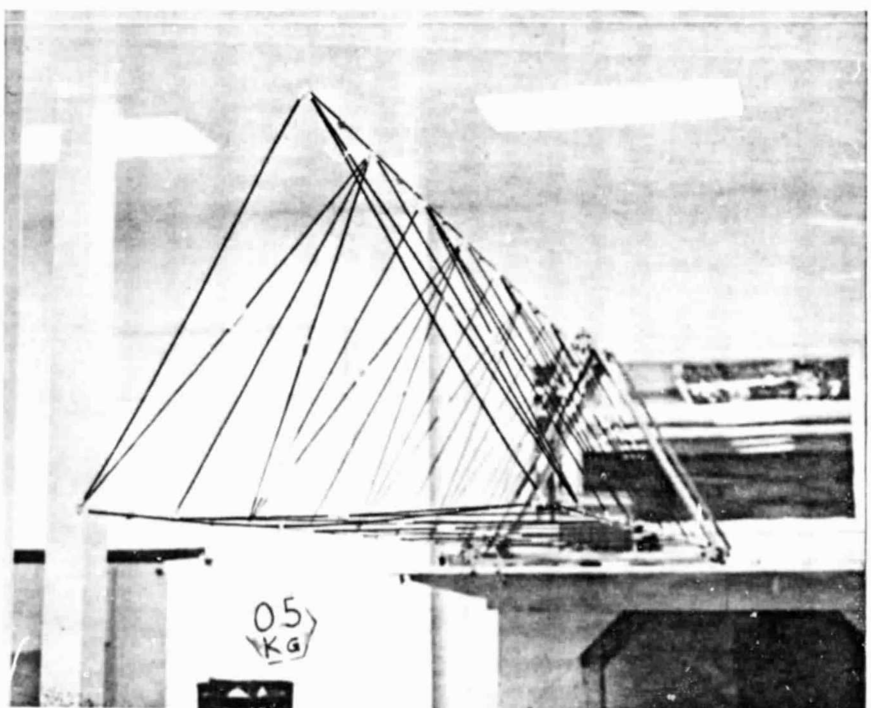

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Figure 19. STACBEAM cantilever test.

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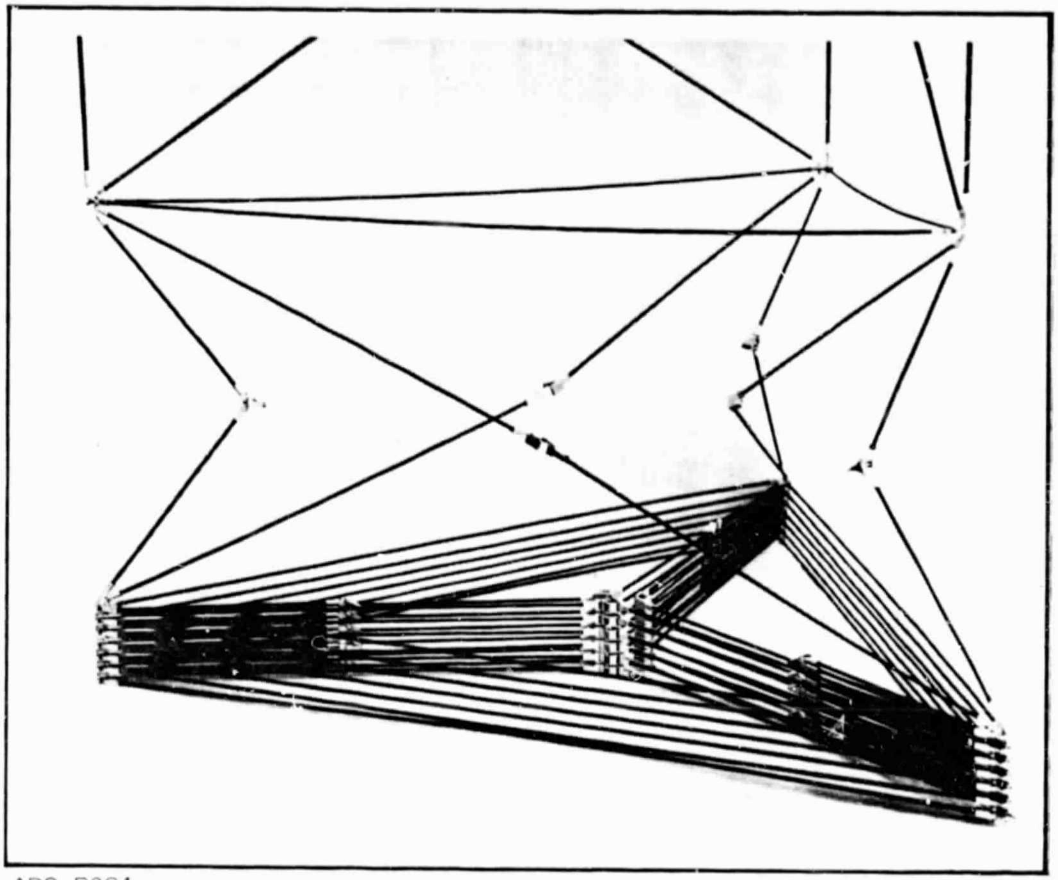

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Figure 20. Partially deployed bay of STACBEAM.

4.2.2 Corner Catch Operation

No difficulties were observed in corner catch operation.

4.2.3 Shuttle Operation

The shuttle operated satisfactorily in its basic function which is to deploy a single bay.

4.3 STACBEAM CANTILEVER TEST

A cantilever suspension test of the STACBEAM is instructive because the root moment approximates the tip moment of the operational STACBEAM arising from the blanket tension. In Figure 19, the moment at the tip of the beam due to blanket tension is reacted by two longerons in compression (12.3 N) and one in tension. The cantilever test results in the same load configuration. Adding a 0.5-kg tip mass, which was done in the test shown in Figure 19, boosted the root moment to almost twice the operational tip moment. This loaded the root longerons to their Euler buckling design limit without failure.

4.4 DETAILED INSPECTION

A description of the model is listed in Table 1. General observation of the STACBEAM model reveals that the packaged and deployed configurations are as conceived. The deployed member centerlines pass through common points so that no net torque is applied to a corner body. Folding members package efficiently and are straight and comparatively rigid when open.

Because of the preliminary nature of the hinges, in terms of the material and design, measurement of the stiffness of the STACBEAM was postponed. Areas of concern in regard to hinges are discussed in the following sections.

4.4.1 Locking Hinges

The locking hinges may be evaluated as follows:

- Some redesign effort is required for the diagonal locking hinges because the deployed preload force is too small.
- The longeron locking hinges have sufficient preload.

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TABLE 1. STACBEAM MODEL DESCRIPTION

PARAMETER	TARGET	ACTUAL
Materials		
Rods	Graphite/epoxy	Graphite/epoxy
Hinges	TBD	AL 2024-T351
Adhesive	Epoxy	Hysol EA 934 & Devcon
Rod diameter, mm (in.)	3.1	3.175 (0.125)
Effective diameter, mm	5.08	5.08
Beam diameter (circumscribed), m	0.900	0.900
Bay length, m	0.450	0.428
Number of bays	8	8
Deployed length, m	3.60	3.43
Packaged length,	0.0813	0.0805
Ratio	0.0226	0.0235
Hinge mass, kg	0.545	0.265 (titanium 0.439)
Beam mass, kg	1.089	0.862 (titanium 1.036)
Stiffness (EI), Nm^2	2.9×10^5	TBD

- Because of the use of aluminum hinges instead of a harder material such as stainless steel or titanium, some of the locking hinges are loose and/or have drifted away from the deployed angle of 180 degrees.

4.4.2 Hinge Pins

The hinge pins have a tendency to work out of their holes, due partially to wear in the aluminum and also to a need for a positive means for holding the pins in.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

There were two major objectives of this phase of the study: to fabricate a working prototype model of the STACBEAM, and to fabricate a working demonstration model of the deployer. Both of these objectives were met.

The following recommendations are made:

- A prototype model of the deployer be designed and built
- A preliminary design of the solar-array system be performed in order that no subsystem is inadvertently impacted by the deployer design
- Reasonable changes be made in the STACBEAM model to correct problems discussed in Section 4.4
- A retraction concept be developed to provide additional flexibility for structure applications

REFERENCES

1. Adams, Louis R.; and Hedgepeth, John M.: Efficient Structures for Geosynchronous Spacecraft Solar Arrays, Phase I, II, and III Final Report. Astro Research Corporation, ARC-TN-1096, 14 September 1980.