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HOOP/COLUMN ANTENNA DEPLOYMENT MECHANISM OVERVIEW

B. B. Allen* and D. H. Butler**

ABSTRACT

The hoop/column antenna program is directed toward the development of a cost-effective, large-area, self-deploying reflector antenna system. Large-surface-area antenna systems (50-300 meters in diameter) are required in future space missions involving improved land communications, Earth resources observation, and the study of intergalactic energy sources. The hoop/column antenna is a concept where a large antenna system can be packaged within the Space Transportation System (Shuttle) payload bay, launched into Earth orbit where it is released either for deployment as an Earth observation or communications antenna, or boosted into deep space as an intergalactic energy probe. Currently, self-deployable antenna concepts are competing with astronaut-erectable concepts as the most efficient means of deploying large-surface-area antenna systems in space.

This paper describes various mechanisms and support structures that are required to deploy the hoop, which is used to support the antenna reflective surface, and the column that is used to position the antenna feeds and the reflector. It also describes a proof-of-concept model (15 meters in diameter) that is currently being ground-tested to determine the adequacy of the deployment mechanisms.

INTRODUCTION

Intergalactic energy probes, land mobile communications, Earth resources observation--these are mission scenarios projected by NASA and the scientific community of the year 2000 and beyond. Large-scale, self-deployable space antennas of diameters ranging from 50 to 300 meters will play an important role in these missions. Large reflectors will one day allow national land mobile communications with transmitter/receiver power levels comparable to today's citizens band radios. Large-aperture radiometers can be used for monitoring global hydrology on a weekly basis to aid agricultural and climate researchers.

The self-deployable hoop/column antenna concept has been under study for several years. The study program is at the proof-of-concept stage where scale-model hardware of the deployment mechanisms and support structure have been built and tested. This paper describes the deployment mechanisms and support structure necessary to launch and deploy an entire large-surface-antenna system with one Shuttle flight. It also describes the scale-model hardware that is currently being ground-tested to determine the deployment characteristics of the hoop/column concept.

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*Harris Corporation, Melbourne, Florida

**NASA Langley Research Center, Hampton, Virginia

HOOP/COLUMN DESIGN FEATURES

The elements of the antenna are labeled in Fig. 1-3. Primary structural elements of the hoop/column antenna concept are an extendable column, which deploys from a central hub, and a hoop made of articulating segments that is used as a frame for attaching the periphery of the reflector surface. The column consists of telescoping segments made of a triangular truss network of structural elements. Hoop position is controlled by a series of cables emanating from both the lower and upper column extremities and attached to each hoop joint. These cables serve to support and locate the hoop. The reflector surface, which is attached to both the hoop and lower hub section, is shaped by a series of catenary cord elements which support and contour the reflective mesh surface. The cord elements are high stiffness/low coefficient of thermal expansion quartz and graphite material which provide a very stable structure to which a gold-plated molybedenum reflective mesh is attached.

The remainder of the paper addresses major features of the 15-meter-diameter scale model of the hoop/column antenna. These features are the same as those of a 100-meter-diameter flight mode. The 15-meter-diameter size for the scale model was chosen so that the model could be tested in existing RF and thermal-vacuum ground test facilities and to minimize the effects of scaling on the deployment characteristics of the antenna.

ANTENNA DEPLOYMENT

Prior to deployment, the scale model antenna is stowed in a package 2.7 m long and 0.9 m in diameter as shown on Fig. 4. Approximately 30 minutes is required for deployment, with the time being divided between visual inspection and mechanism operation. Deployment is accomplished in three basic steps: column extension, hoop/surface deployment, and system preloading, which shapes the surface. Deployment begins with column extension (Fig. 5). The telescoping column is deployed by a cable-driven system that tensions the column during the final phase of deployment. This tensioning process is to allow the column cam lock latches to properly actuate. A feature of the column is the ability to deploy the telescoping sections sequentially, with the sequence being passively controlled by the latches themselves.

The next step is to deploy the hoop and surface (Figs. 6 and 7). The hoop consists of 24 tubular segments that contain double hinge joints at each end which permit rotation but do not allow torsional wrap-up. During deployment, the hoop segments simply rotate from vertical to horizontal orientation about an axis through the center of each member. Eight electrical motors, located at eight different hinge joints, drive worm gears that transmit torque through four bar mechanisms to passive joints. The surface is deployed with the hoop, but not shaped. Shaping of the surface is accomplished by the extension of the lower extremity of the column called the preload segment. Preloading consists of extending the column an additional 0.4 meter by means of a screw to properly pretension the structure and the surface (Fig. 8).

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COLUMN DEPLOYMENT

The column is a sequentially deployed, cable-driven, telescoping, triangular truss unit with diagonals that resist compressive loads. The column, which is symmetrical about the center hub, extends in both directions from the hub. Longerons, circumferentials, and diagonals are all tubular members laminated from graphite epoxy material. A typical column segment is shown in Fig. 9. Diagonal direction is reversed from bay to bay to minimize column "wind-up" or a rotation relative to the hoop.

COLUMN DRIVE SYSTEM (CDS)

The following is a list of the major CDS requirements:

- Must be located at the stowed column center
- Must deploy and stow each column end simultaneously at a uniform rate
- Must be remotely controlled
- Must place column in tension during final phase of column deployment.

The column drive system (Figs. 10-13), located at the geometrical center of the column, is responsible for providing the forces necessary to deploy and stow the counterbalanced column system during testing. A tensile load is applied to the column by the CDS at the final stage of deployment to allow proper latching of the telescoping column sections. This tension is relieved upon completion of column deployment The CDS does not pretension the antenna. The structural design for the CDS consists of two large triangular plates separated by beam-column spacer brackets located directly in line with the column longerons.

Deployment of the column is accomplished by retrieving the deployment cables onto a drum (Fig. 11). There are six deployment cable which are threaded through each of the three longerons on each column half. The drum is threaded to ensure that the cables remain in a selected area. Longeron cables are routed from the drum to a single pulley on the spacer brackets which in turn directs the cable through the longerons. When the cable reaches the top of the longeron, a pulley in the striker housing turns the cable 180° and it proceeds (between the longerons) to the bottom of the second longeron. Then it is intercepted by another pulley located in the latch housing of the adjacent telescoping section and turns 180° to proceed up the inside of this longeron to the second striker housing. This path is repeated until the cable has been threaded though all four longerons.

The stow cables are attached to the latch actuation arms on the end telescoping section through a bridle unit. This cable is routed down along the column centerline and through the drum to a pulley attached to the opposite triangular plate. This pulley directs the cable to the beam spacer bracket containing dual pulleys, each turning the cable 90°. This brings the cables to the threaded drum and cam portion of the mechanism. Both stow cables have a small residual tensile load applied during the deployment and stow phases. Hi-lift cams (Fig. 12) relieve the residual tension loads in the stow cables, thereby allowing them to go slack. This feature is necessary for proper latching of the end sections because the stow cables are attached to the latch pawl (of the end telescoping sections) and latching can't occur while the cables are in tension. The cable drum is suspended between ball bearings attached to the triangular base plates (Fig. 13). Drum rotation is accomplished by a 28-VDC gear motor connected to a pinion and gear system. Drum back-driving is resisted by the gear motor. The motor and pinion assembly is mounted on the upper triangular plate.

The materials used for construction are primarily 6061-T6 aluminum, with 300 and 400 series stainless steel components and cables.

COLUMN LATCH

Primary latch requirements are

- o Latch the column sections into a rigid, predictable structure
- o Withstand a preload of 4000 N
- o Latch and unlatch the column sections remotely
- o Passively provide sequential deployment and stow
- o Provide adjustment capability.

The latch design provides positive latching, passively actuated sequential deployment, reasonably direct load path from longeron to longeron, and a high tolerance for error through adjustment capability. A depiction of the latch delineating the major components is shown in Fig. 14.

The latch is comprised of two assemblies located on the ends of the column longerons. The assembly loaded on the top of the longeron of each telescoping assembly is called the striker housing and contains the pawl striker plate. Active latching elements are contained in a latch housing located on the bottom of the telescoping column sections. The latch provides a continuous load path along the longerons without introducing excessive bending moments into the longerons. Both latch housings contain rollers that guide the deploying sections along the longerons of the previously latched telescoping section. When the column is in the stowed configuration, the latches are all positioned as shown in Fig. 15. When deployment is initiated, the motor, pinion, and gear arrangement rotates the CDS cable drum such that the deployment cable threaded through the longerons are collected on the drum. This in turn translates the inboard column segments upward (Fig. 16), thereby allowing the latching actuation gear to come into contact with the deployment trip roller. All telescoping sections deploy as a unit because the pawl cam does not allow the stowage rollers to advance. The pawl and lever arrangements are overcenter devices and are held in place by the spring/plunger assembly. Deployment continues unchanged until the latch actuation lever contacts the trip roller attached to the striker upward (Fig. 16), thereby allowing the latching actuation gear to come into contact with the deployment housing. The lever tip cannot traverse past the rollers, so the bottom of the pawl begins to move toward the striker housing. Binding is prevented because the spring/plunger assembly allows for length adjustments. Adjacent section release begins when the pawl cam rotates away from the stowage roller. It can be seen that the pawl has total control over the deployment sequence and, also, that no additional mechanisms are required to maintain that control.

A unique feature of the pawl is the cam profile (Fig. 17a) on the surface that contacts the striker plate. This feature allows the pawl to seat itself against the striker plate so that the normal force vector at the point of contact results in an opening moment, preventing binding. The cam profile also compensates for possible errors in the striker plate location (Fig. 17b). This design incorporates shims under the striker plate so that the deployed pawl angle can be adjusted prior to final column assembly. The cam feature allows the pawl to be prestressed to reduce the joint nonlinear motion. Prestressing is accomplished by applying a large tensile force to the deployment cables located inside each longeron (Fig. 17c). The cable tension strains the latch housing and the pawl pivot to increase the distance between the latch/striker housing interface and the pawl pivot. Pawl rotation will continue because the spring/plunger assembly pushes it clockwise. When the cable tension is relieved, friction prevents pawl release (counterclockwise rotation).

Latch housings are plaster mold A355 aluminum castings and the latching components are 17-4 PH stainless steel.

The column latch has demonstrated conformance to the requirements through component and system-level testing.

PRELOAD SEGMENT

Preload segment design requirements are

- Extend against a load of 3560 N
- Deploy against rigid stops
- Be remotely controlled
- Have a redundant stop mechanism

The preload segment (Figs. 18 and 19) attaches to the lower end of the column (Fig. 8). The purpose of the preload segment is to extend the column to its design length in order to pretension the hoop and surface control cords. The preload segment travels approximately 0.4 m from its stowed to deployed state.

An axial, motor-driven screw was selected to drive the preload segment from the stowed to the deployed position. Screw loads are carried to the longeron through a triple beam arrangement. The beam brackets are bonded to the inside of the longerons as shown in Fig. 18. This bracket design is not the most desirable, but the outer portions of the longerons were reserved for rollers and guides located on other deployable sections (Fig. 14). Power to drive the screw is provided by a 28-VDC gear motor. Motor torque is transferred to the column nodes through a thin flex plate. The plate is essentially rigid in torsion, but can allow axial displacement to account for manufacturing errors. The screw is 16-mm steel with acme threads. Ball screws were considered and rejected because the coefficient of friction is not adequate to prevent back driving under load without a brake. Preload segment extension is terminated by limited switches and redundant current sensors.

The preload segment is manufactured from the same structural materials as the column.

HOOP DEPLOYMENT

The primary hoop requirements are to deploy under its own power and against the following loads:

- One-g catenary load of the mesh
- A 1500-N compressive load
- A 20-N-M deployment moment
- Forces developed by the hoop support and surface control cords.
- Internal friction
- Counterbalance system unbalances

The hoop (Fig. 20), when deployed, forms a rigid ring around the column. It is precisely located at each of its 24 joints by the hoop support cords (Fig. 2) and forms a rigid boundary to which the RF reflective surface attaches.

In order to ensure a smooth and symmetrical deployment, each of the 24 joints is kinematically linked to another (Fig. 21). Synchronization rods working in concert with the gears at each of the joints provide the hoop with its kinematic synchronization. Deployment energy for the hoop is supplied by eight 28-VDC gear motors located 45° apart. (A space-deployed antenna would use four motors at 90°.) The gear motor is directly coupled to a worm which drives mutually interfaced worm gears (Fig. 22). This configuration provides a mechanical advantage of 35 to 1. During deployment the synchronization rods, which are tension members only, maintain the platforms parallel to one another. Passive gears (Fig. 23) transmit the moment necessary to deploy the hoop into the passive segments and synchronization rods. The gear motors are electrically connected in parallel to synchronize hoop deployment. Hoop deployment is terminated by limit switches.

Primary materials for the hoop are 6061-T6 aluminum alloy, graphite epoxy, and 416 stainless steel gears.

GROUND TESTING

Ground-based testing that simulates the zero-g space environment presents a great challenge for the 15-meter hoop/column antenna and, for that matter, any other large, deployable, structural system. This is because large, deployable structures are usually not self-supporting in the Earth's gravity field during deployment. Neutralizing the gravity field cannot be accomplished on all elements, such as the reflector surface for example. The 15-meter antenna is self-supporting after deployment, but the structural deformations associated with the 1-g effect require that the surface be designed to include these deformations. This surface would not have the same shape in space.

The counterbalance system shown in Fig. 24 was used to offset the 1-g effects of the structural elements during deployment. The system consists of eight towers supporting a 24-segment, 16-m-diameter ring. Twenty-four radial cables attach the ring segment intersections to a central hub. Trolleys containing a small cable attached to the hoop, and a hoop counterbalance weight, traverse the radial cables during deployment. The counterbalance system central hub is raised or lowered to attempt to cancel the drag induced by friction in the hoop joint worm gears and counterbalance system cable sag. The drag increased near full deployment, requiring full capacity off our four 28-VDC electrical motors. Radial cable tracks were used because of installation/removal requirements for the counterbalance system in various facilities.

The mechanisms utilizing electric gear motors were controlled by a remote console during ground testing. The console contained current sensors that terminated deployment approximately one second after a system current level exceeded predetermined values. This remote console would be replaced with a on-board computer system for a flight antenna.

Test observations were conducted during and after deployment. Gear motor current levels and hoop synchronization sensors were monitored during deployment. After pretensioning, structural element positions and loads were measured and correlated with required values. The antenna mechanisms performed as designed, but the couterbalance system drag on the hoop require' the addition of four active joints (for a total of eight) so that hoop deployment can be implemented when the surface is installed. There was a 3 second delay between deployment termination of the first hoop active joint and the final active joint. This time delay did not appear to affect the hoop geometry.

The geometry of the structural system was within the error budget except for the hoop radial component. The allowable radial deviationwas 1.27 mm rms as compared to the measured value of 4 mm rms. Adjustments will be implemented to attempt to obtain the error budget when the surface is installed.

TEST CONCLUSIONS

All mechanisms performed as designed. The hoop drive system needs to be reevaluated with respect to the friction associated with worm gears in the hoop joints. Ground-test results indicate structural elements of a 15-meter hoop/column antenna can be fabricated and adjusted so that when the reflector is installed a 1.75 mm rms deviation from a true parabola, when referenced to surface nodes, can be expected. Precision measurements of all structural components are needed before assembly to assure compliance with error budgets.

The structural deployment program is considered to have been successful. This leads to the conclusion that large, deployable antennas can be fabricated, ground-tested, and placed in orbit with the expectation of success.

If future programs require a high-quality zero-gravity simulation, design and development of such a facility would be comparable to the antenna or structural system itself.

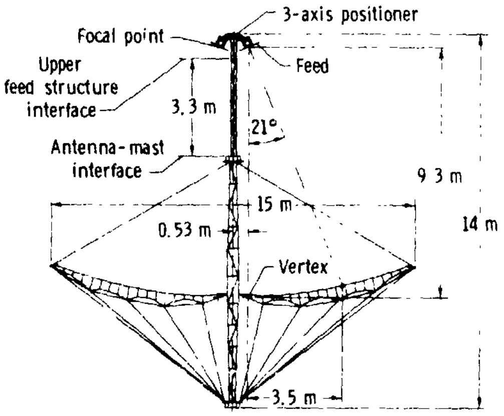


Figure 1. 15-Meter Hoop/Column Antenna

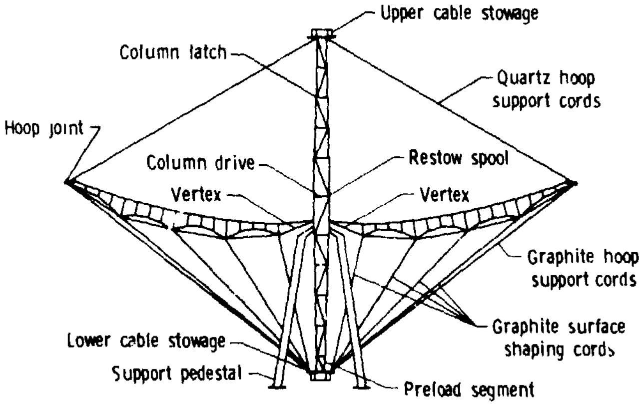


Figure 2. 15-Meter Antenna Structure

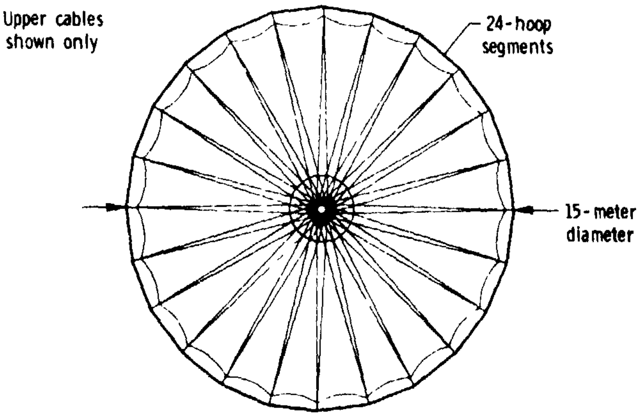


Figure 3. 15-Meter Antenna — Top View

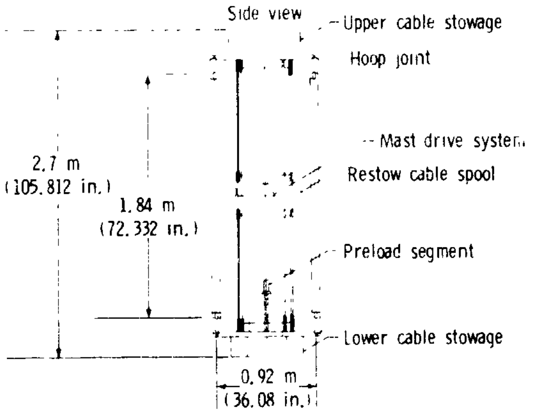
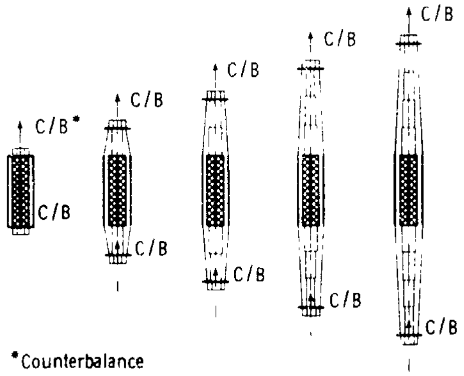
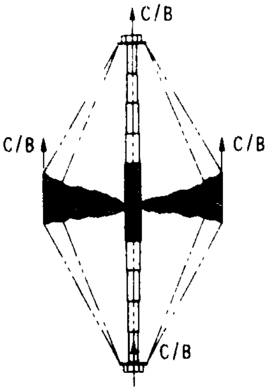


Figure 4. 15 - Meter Antenna — Stowed



*Counterbalance

Figure 5. Column Deployment



T ~ 8.5 minutes

Figure 6. Partial Hoop Deployment

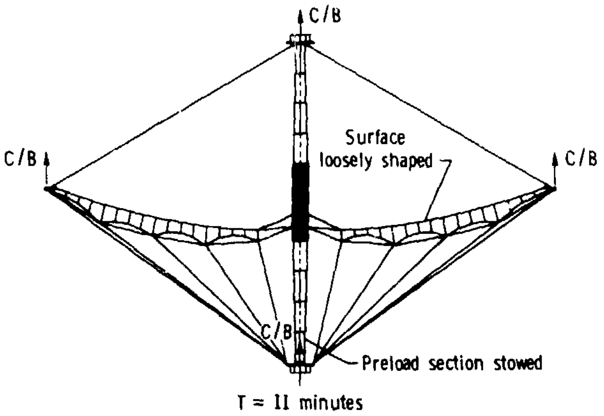


Figure 7. Hoop and Column Deployed

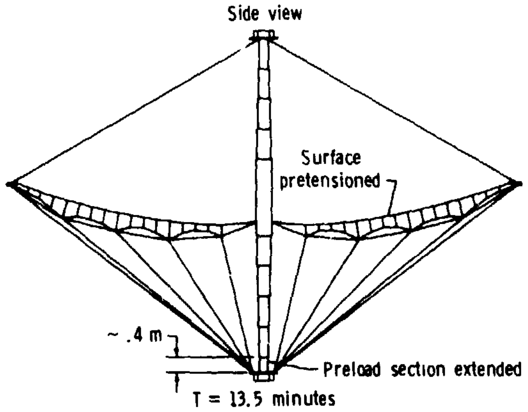


Figure 8. Antenna Fully Deployed

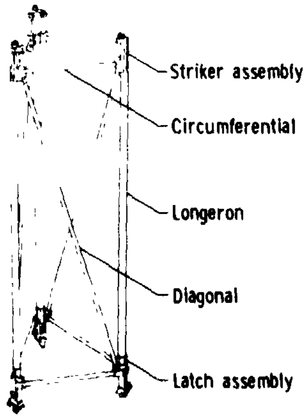


Figure 9. Typical Column Segment

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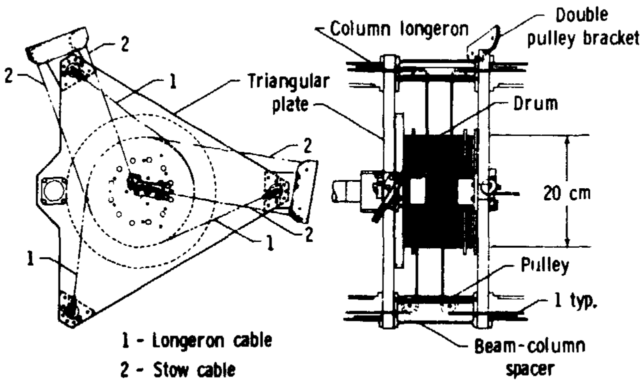

Figure 10. Column Drive System

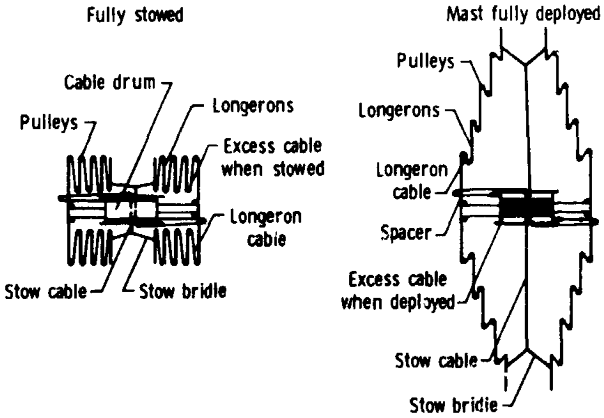

Figure 11. Column Drive System Principle

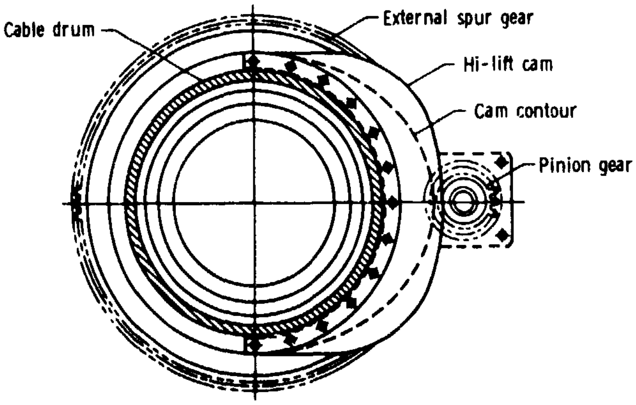

Figure 12. CDS Hi-Lift Cam

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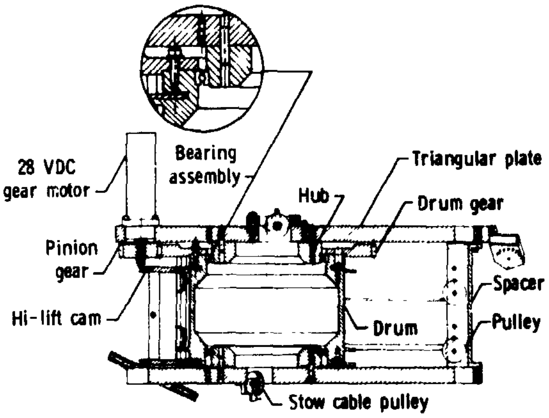

Figure 13. CDS Cross Section

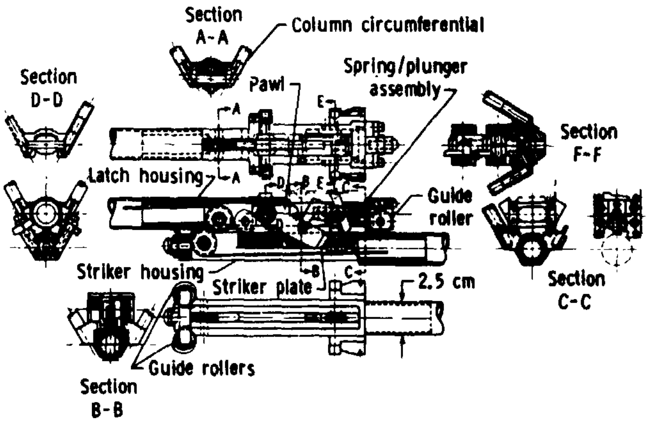

Figure 14. Column Latch Assembly

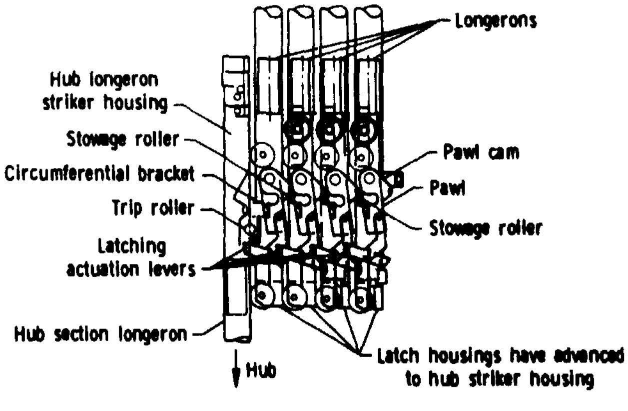

Figure 15. Stowed Column Latches

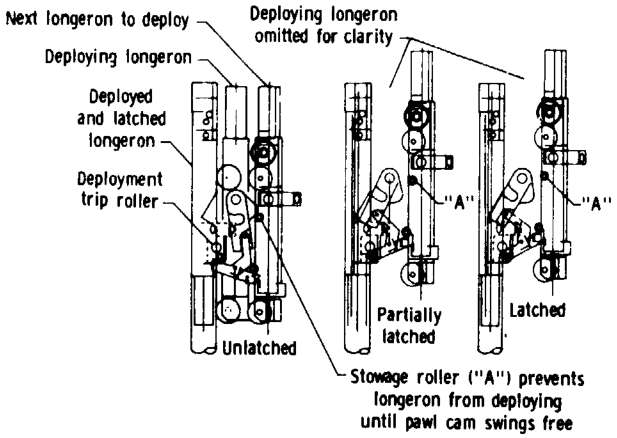

Figure 16. Column Latch Actuation Sequence

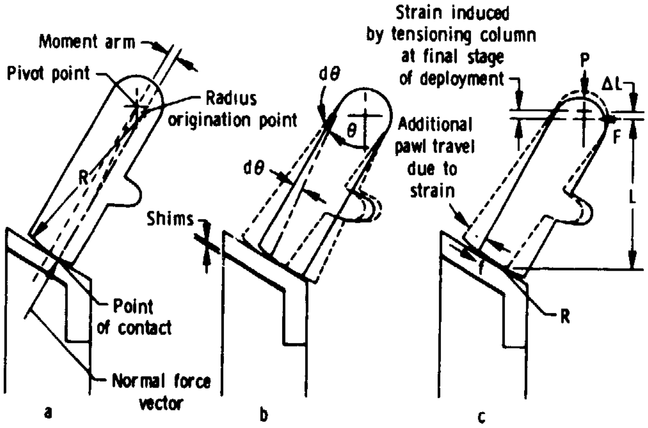

Figure 17. Column Latch Unique Features

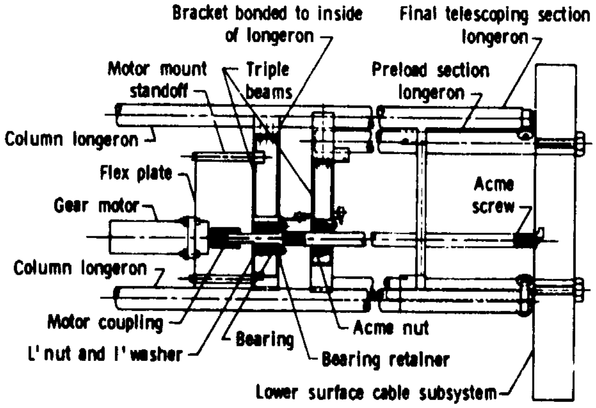

Figure 18. Column Preload Segment

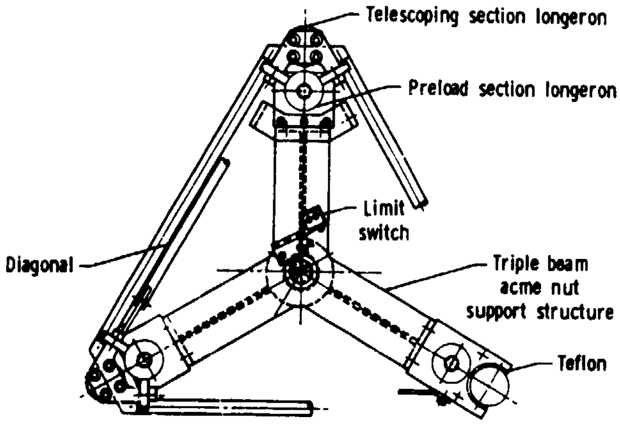

Figure 19. Preload Segment — Top View

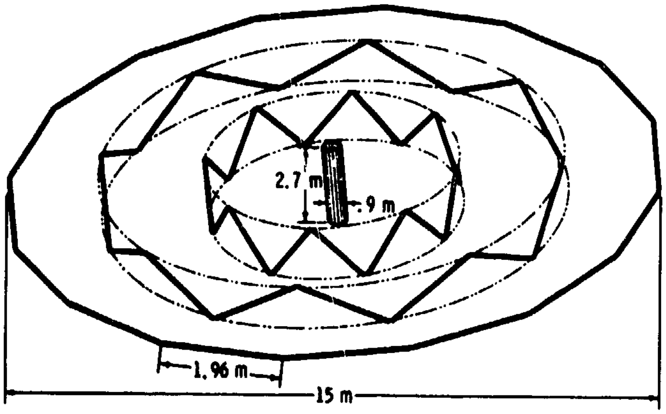

Figure 20. Hoop Deployment Sequence

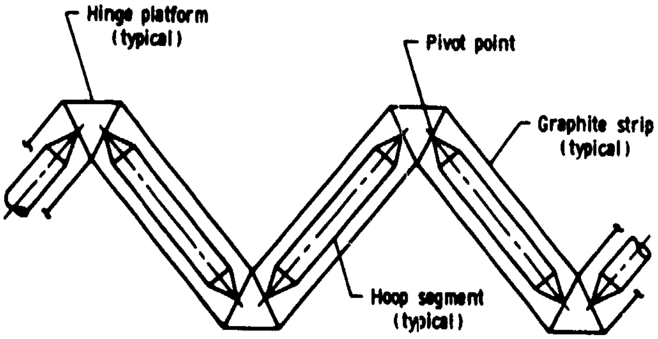

Figure 21. Hoop Synchronization Approach

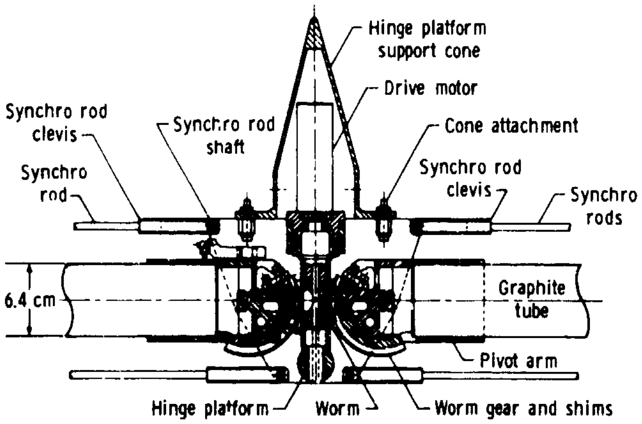

Figure 22. Active Hoop Hinge

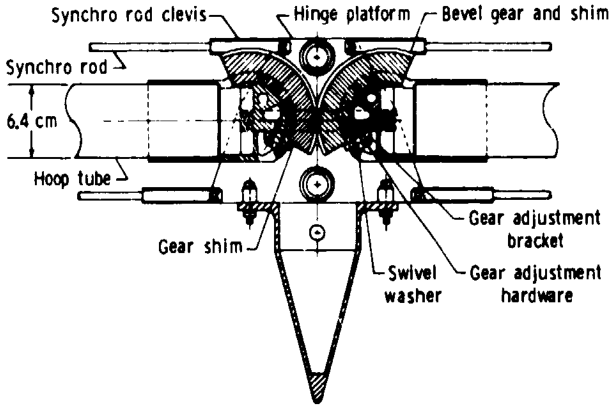

Figure 23. Passive Hoop Hinge

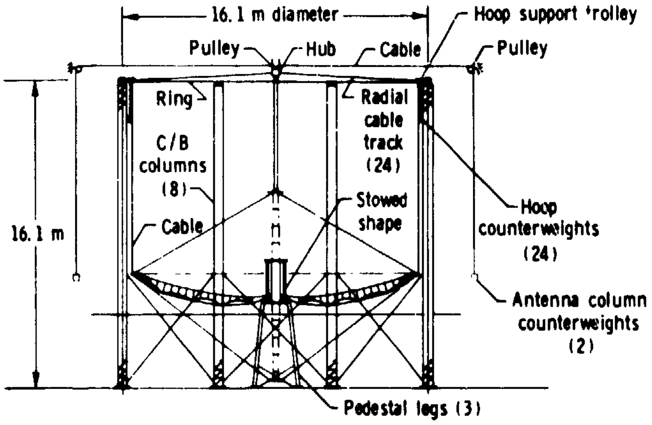

Figure 24. Antenna Counterbalance System