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RADIOMETER-DEPLOYMENT SUBSYSTEM

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ABSTRACT

A radiometer-deployment subsystem for the Nimbus E spacecraft has been designed, developed, and qualified for space use. The dimensions of the radiometer are 0.9 meter square by 0.1 meter, and it weighs 32 kilograms. Rigidly secured to the spacecraft during launch, the radiometer is deployed when the spacecraft reaches orbit. Deployment is achieved without permitting any portion of the radiometer to intersect the field of view of the infrared horizon scanner. This accomplishment necessitated a nonlinear deployment profile, which was accomplished by using a four-bar linkage composed of arms, cams, pivots, and steel tapes.

INTRODUCTION

The electrically scanning microwave radiometer (ESMR) deployment subsystem is designed to support the ESMR during spacecraft launch and to deploy or to retract the ESMR upon command. This subsystem is a portion of the Nimbus E weather satellite scheduled for launch later this year (fig. 1). During spacecraft launch, the radiometer is held securely in a vertical position with pyrotechnically activated bolts. The earthward side of the radiometer (waveguide surface) is held against the structure in such a way as not to damage the radiometer. The radiometer bolts are released in orbit, and the radiometer is deployed to a near-horizontal position. A major requirement of this subsystem is that of never allowing the radiometer or any of the supporting equipment to enter the field of view of the attitude control system horizon scanner. This requirement led to a design using cams and tapes, which would cause the radiometer to counterrotate about the deployment arms as the arms were driven to the deployed or retracted positions. Essentially, the principle involved is that of a four-bar linkage mechanism.

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DESIGN CRITERIA

The ESMR deployment subsystem was designed to meet the following requirements.

1. Deploy and retract radiometer upon command

2. Deploy/retract time: 4 to 6 minutes

3. Deploy/retract in such a way as not to interfere with infrared scanner field of view or the volume swept by solar paddles

4. Mechanism weight: 15.9 kilograms maximum

5. Spacecraft power not required to keep radiometer deployed or retracted

6. Deploy to a position accuracy of $\pm 1^\circ$

7. Required motor power: 12 watts maximum

8. Natural frequency stowed (locked) shall be greater than 65 hertz

9. Natural frequency deployed shall be greater than 1.3 hertz

DESCRIPTION

General

The ESMR deployment subsystem consists of a rigid support structure that houses the drive mechanism, drive shaft, lower cams, tape-adjustment device, positive stops (for the deployment arms), retract limit switches, and associated telemetry thermistors and cabling. The drive mechanism contains a two-phase ac servomotor and gearhead, a magnetic hysteresis brake, a ball-detent clutch, a torque-out device (soft coupling), the associated cabling, a position potentiometer, and the deploy limit switches. Attached to each end of the drive shaft is a deployment arm. At the radiometer end of each arm is the upper pivot assembly, consisting of a torsion spring, the upper cam, a position potentiometer, and the radiometer-attachment fittings.

As the deployment arms are driven from a position of 10° off spacecraft vertical to a position of 120° off spacecraft vertical, the tapes bear against the upper and lower cams, causing the tapes to pull the radiometer in a counterrotating fashion to the desired deployment profile. As the tapes unwind from the upper cams, they wind on the lower cams. When the arms reach the 120° position, they bear against positive stops, causing the soft coupling to wind to a predetermined torque level and to trip the deploy limit switch that removes power from the motor. The magnetic hysteresis brake prevents the radiometer from leaving the fully deployed position. The radiometer is shown in the retracted, the partially deployed, and the deployed positions in figures 2, 3, and 4. The large yokelike structure is part of the counterbalance.

Drive Assembly

The drive assembly consists of an aluminum housing that contains the motor/gearhead, clutch, and soft coupling (fig. 5). The overall housing dimensions are 10.1 centimeters by 10.8 centimeters by 12.7 centimeters.

Motor/Gearhead

The motor/gearhead unit utilizes a size 11, two-phase servomotor capable of delivering 2.83×10^4 dyne-centimeters (0.4 ounce-inch) of torque (with brake attached) at stall when energized with 27-volt root mean square, 400-hertz square wave. Power dissipation under this condition is less than 6 watts per phase. The motor bearings are class ABEC 7 with balls and races of 440C stainless steel. The bearing retainers are made of bleached cotton-based phenolic and are vacuum impregnated with SF-50 silicone fluid.

Attached to the motor is a 8203:1 gearhead composed of six stages of spur gearing and a planetary output system. The gear material is 17-4 PH stainless steel with Micro-X nitriding to increase surface hardness. All bearings containing metallic retainers or full complement bearings are packed with G300 SC silicone grease to 25 percent of the available volume. The gearhead bearings all have balls and races of 440C stainless steel. The gear lubricant is also G300 SC silicone grease.

Attached to the opposite end of the motor is a magnetic hysteresis brake, which develops a constant drag equivalent to 0.7×10^4 to 1.0×10^4 dyne-centimeters (0.1 to 0.14 ounce-inch) of torque. The brake consists of a permanent magnet rotating inside a cobalt ring to maintain the soft coupling-locking torque by preventing backdriving of the geartrain.

The motor/gearhead is capable of continuously driving a load of 56.5×10^6 dyne-centimeters (800 ounce-inches) at a base-plate temperature of 298.15° K (25° C). The static load rating is 106×10^6 dyne-centimeters (1500 ounce-inches). This device has an output speed of 160° to 200°/min at a load of 13.5×10^6 dyne-centimeters (192 ounce-inches). The motor/gearhead pinion joins a beryllium copper gear lubricated with dry-film metallic-bonded molybdenum disulfide. Six clutch-housing retainer mounts are an integral part of this gear. Each mount contains a compression spring, a plunger, and a clutch ball. Dyflon bushings are pressed into each end of the gear. Through the bushings, the gear is supported on a 0.635-centimeter 440C stainless-steel intermediate shaft.

The intermediate shaft is an integral machined part with the clutch plate. The shaft contains 30 equally spaced conical detents on one side and reaction pins for three soft coupling springs on the other side. The shaft is supported on both ends by Dyflon bushings (asbestos-filled Teflon). The output pinion is made of Society of Automotive Engineers (SAE) 4340 with a hardness of Rc 50 and is isolated from the shaft with Dyflon bushings. This gear is an integral machined part with three leaf-spring mounts and a spring preload arm. The total gear is covered with a black oxide coating to retard corrosion. This output pinion is coupled to a beryllium-copper segment gear, which transmits the torques to the main output torque tube. This stainless-steel tube transmits the torques to the center of the output shaft, which, in turn, is coupled to both arms.

Clutch

The simple ball-detent-type clutch uses 440C stainless-steel-ball actuators, 0.476-centimeter standard hardened 440C stainless balls, and 302 stainless-steel-coil compression springs packaged in an aluminum case. The actuators and the balls are dry lubricated with a phenolic resin-bonded molybdenum-disulfide coating to prevent cold welding. Each clutch-housing assembly is calibrated to 5.45 kilograms by use of laminated shims. In an engaged position, the coil springs are operating at 50 percent of the allowable stress level; in the slip condition, they operate at 75 percent of the allowable stress level. Maximum compressive stresses occur during clutch slip when the spherical ball is pressed against the hardened flat clutch plate, at which time 60 percent of the maximum-allowable Hertzian stresses are achieved. The clutch is calibrated for 113×10^6 dyne-centimeters (100 inch-pounds) of torque, and the main purpose of the clutch is to protect the gearhead during ground handling. The clutch also serves as a protective overload device during space deployment or retraction. A single failure of any of the six clutch assemblies will result in a clutch torque greater than the maximum-anticipated deployment torques.

Soft Coupling

When the radiometer is in the deployed position, the soft coupling takes up the backlash in the system and maintains a positive force by pressing the arms against hard stops. After the arms have engaged the stops, the motor continues to drive until the soft coupling has reached a preset deflection, providing a torque of 62.2×10^6 to 79×10^6 dyne-centimeters (186×10^6 to 237×10^6 dyne-centimeters at the main drive shaft). When the desired torque level is reached, a limit switch is actuated to remove power from the motor. The spring action is developed by three double-leaf springs made from beryllium copper.

Arms, Tapes, and Cams

The deployment arms are fastened to the drive shaft at one end and, through a pivot assembly, to the radiometer-attachment fittings at the other end. The pivot assembly (fig. 6), consisting of the upper cams, the Dyflon bushings, and the torsion springs, provides a positive torque about the radiometer pivot, which maintains tension in the tapes and provides the force for the angular motion of the radiometer during retraction. The torsion springs are made from chrome vanadium and coated with molybdenum disulfide. Each of the two springs produce a torque of 13.6×10^6 dyne-centimeters (12 inch-pounds) at the retracted position and 21.5×10^6 dyne-centimeters (19 inch-pounds) at the deployed position.

The tapes are made from a cobalt-nickel alloy called Elgiloy. This nonmagnetic material provides a high resistance to set, fatigue, and corrosion. The tapes measure 0.01 centimeter by 0.96 centimeter by 0.92 meter and provide an ultimate tensile strength of 2×10^9 newtons/meter^2 (300 000 psi).

As the radiometer deploys, the Elgiloy tapes bear against the stationary lower cams and the rotating upper cams. The cams are cut so that the counterrotating motion of the radiometer prevent it from entering the field of view of the infrared scanner.

Flexible Cables

The electrical interface to the radiometer is made through two flat flexible cables. The cables were designed to be flexible, electrically shielded, and impervious to ultraviolet radiation. The basic cable consisted of highly stranded circular copper conductors imbedded in a soft silicone rubber; a layer of Kapton was then put over the cable. The Kapton provides exceptionally good puncture resistance. A radio-frequency shield was then added over the Kapton, and the entire cable was covered with a fiber-glass boot. The fiber-glass was impregnated with black silicone rubber for ultraviolet radiation protection. The radio-frequency shield was soldered directly to the connector shells at both ends.

TESTING

A counterbalance was attached to the radiometer to facilitate deployments in a one-g field. The counterbalance consists of a large yoke, which attaches to the radiometer side fittings and permits movement within the yoke. Steel cables were run through pulleys mounted in the 10.36-meter (34 foot) ceiling of the high-bay area and then were run to a dead-weight. A balance within 0.91 kilogram (2 pounds) was achieved.

Vacuum-thermal testing is done with a lightweight dummy radiometer and dumbbell weights cantilevered off the deployment arms. The prototype deployment subsystem was successfully vacuum-thermal tested for qualification. The temperatures were cycled between the limits of 262.15° to 318.15° K (-11° to 45° C) and deployments were made at the temperature plateaus. The testing was performed at a pressure of 1.33×10^{-4} N/m^2 (10^{-6} torr) for a duration of 6 days. The prototype subsystem was also installed on a structural-dynamics model spacecraft, and the spacecraft vibrated with both sinusoidal and random inputs. The flight deployment subsystem was also successfully vacuum-thermal tested for 6 days at 1.33×10^{-4} N/m^2 (10^{-6} torr) at the temperature levels of 265.15° to 313.13° K (-8° to 40° C).

CONCLUDING REMARKS

A unique radiometer-deployment subsystem has been designed, developed, and qualified for use on the Nimbus E weather satellite. The flight subsystem is presently being integrated into the spacecraft.

DISCUSSION

J. H. Parks:

Requirements for ground-test simulation of such zero-gravity deployment devices frequently impose loading conditions such that these loads can become the governing loads for sizing of structural components. Did such a problem arise in your design?

Speight:

Yes. Many of the load-bearing elements of the design were sized according to the stresses developed with the system deployed in a 1-g field without the aid of a counterbalance. For instance, the Elgiloy tapes are sized to support in excess of 227 kilograms of tensile load, whereas only 4 kilograms are required in flight.

R. J. Peterson:

Did you consider using a harmonic drive to achieve the high reduction of the gearhead?

Speight:

Both a harmonic drive and a wabble-type drive were considered in the conceptual phase of the design. A conventional gearhead of the type previously flight proven on earlier Nimbus vehicles was selected for reliability, cost, and expediency reasons.

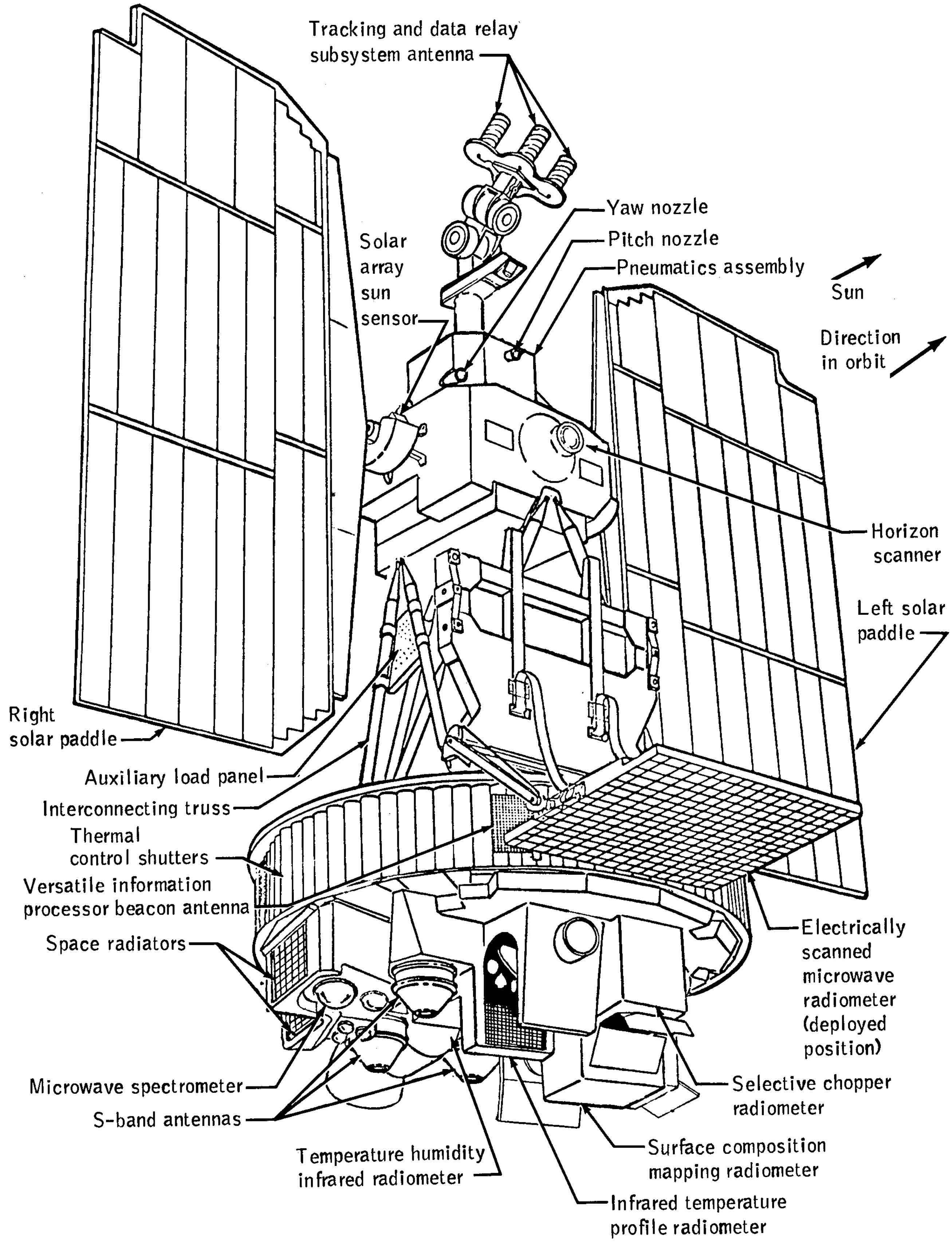

Figure 1. - Nimbus E satellite.

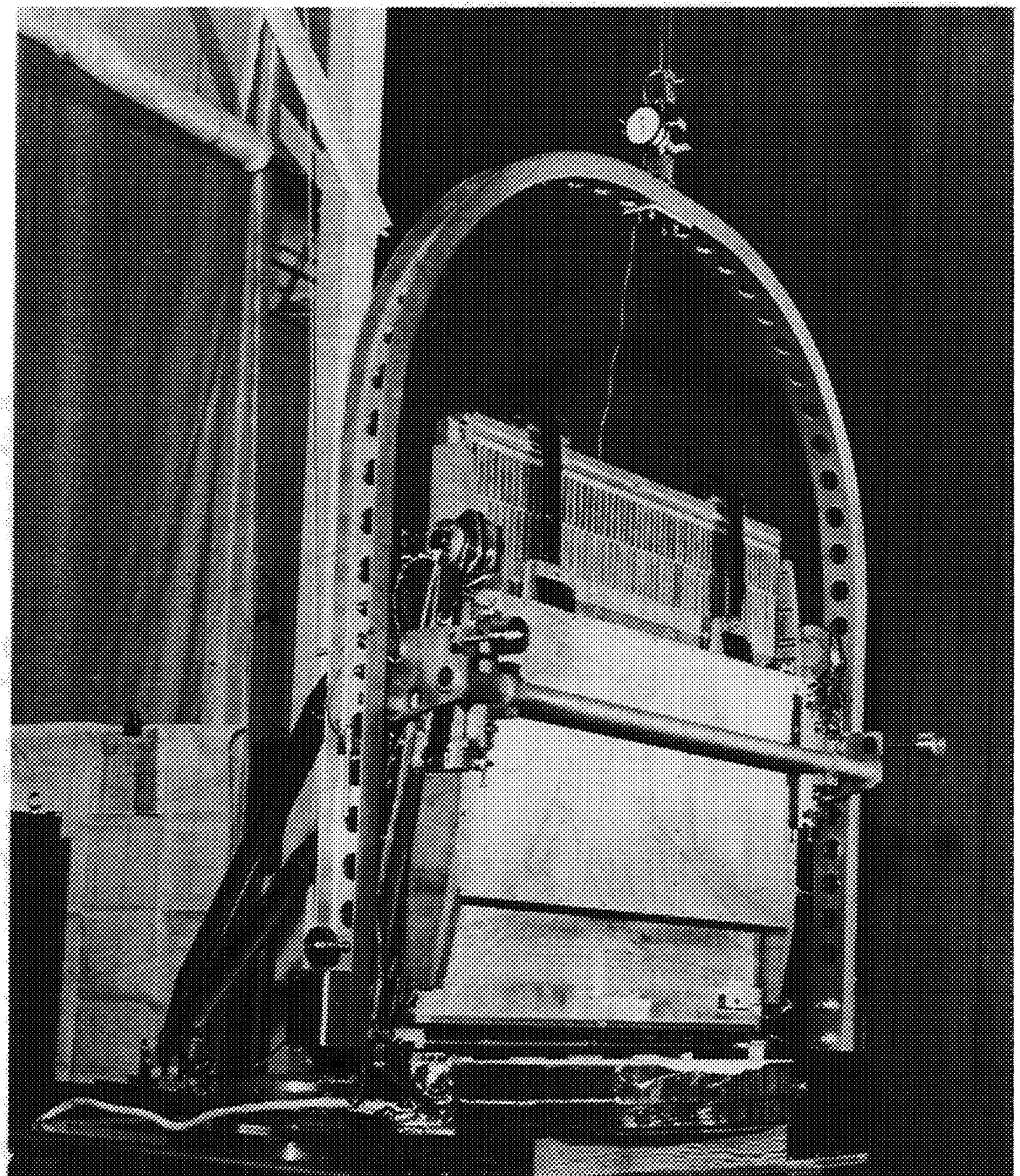

Figure 2. - Retracted radiometer.

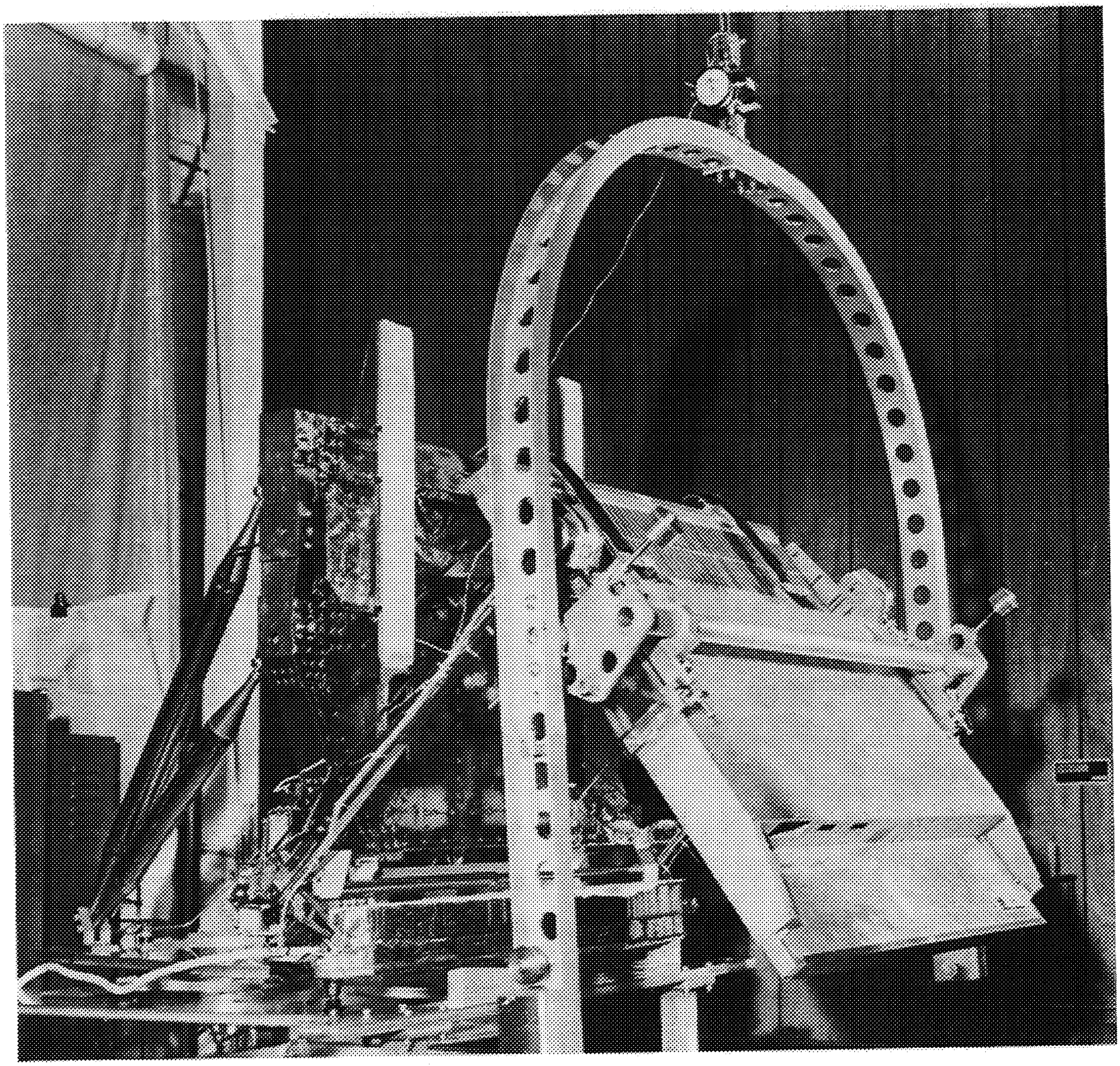

Figure 3. - Partially deployed radiometer.

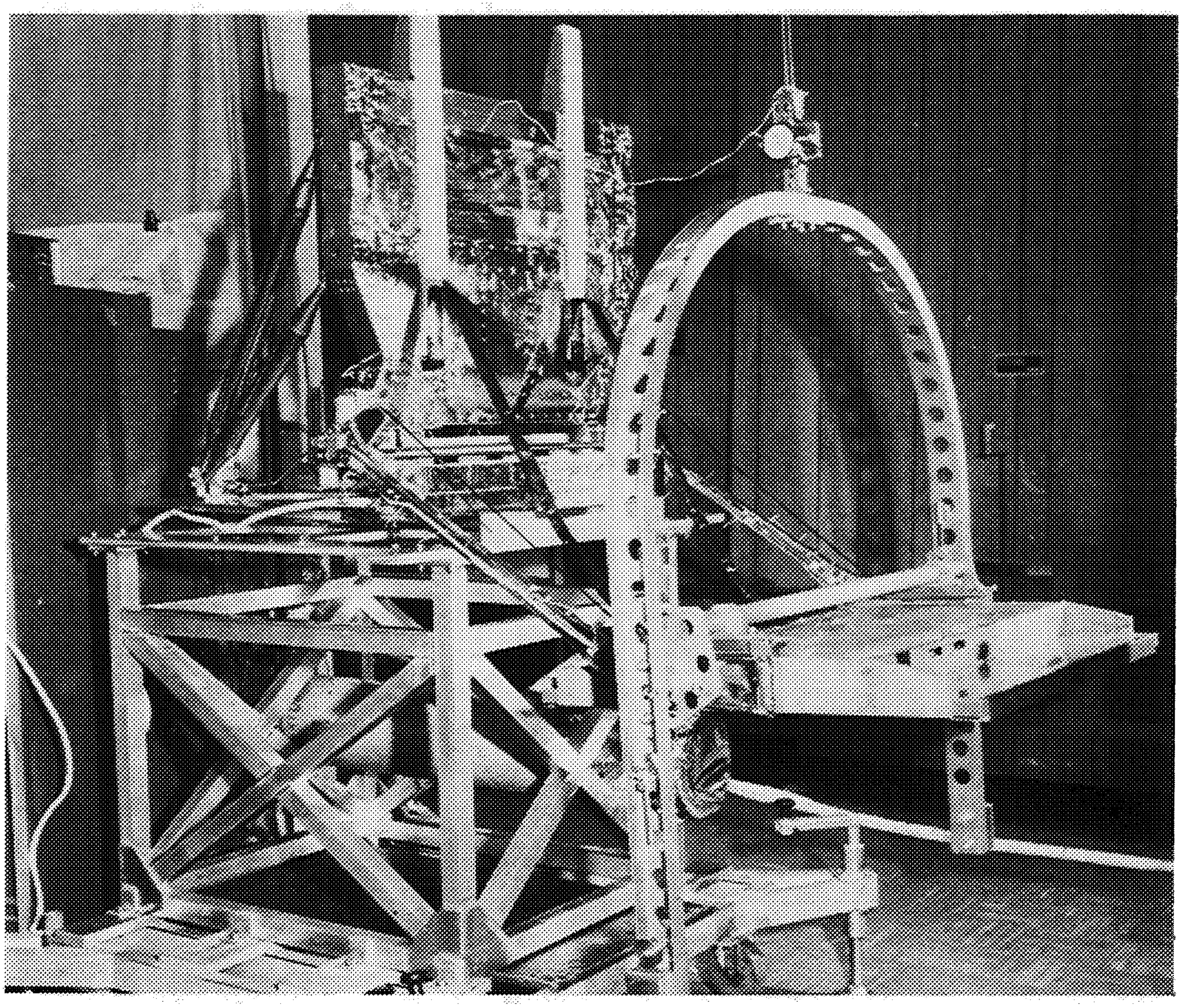

Figure 4. - Fully deployed radiometer.

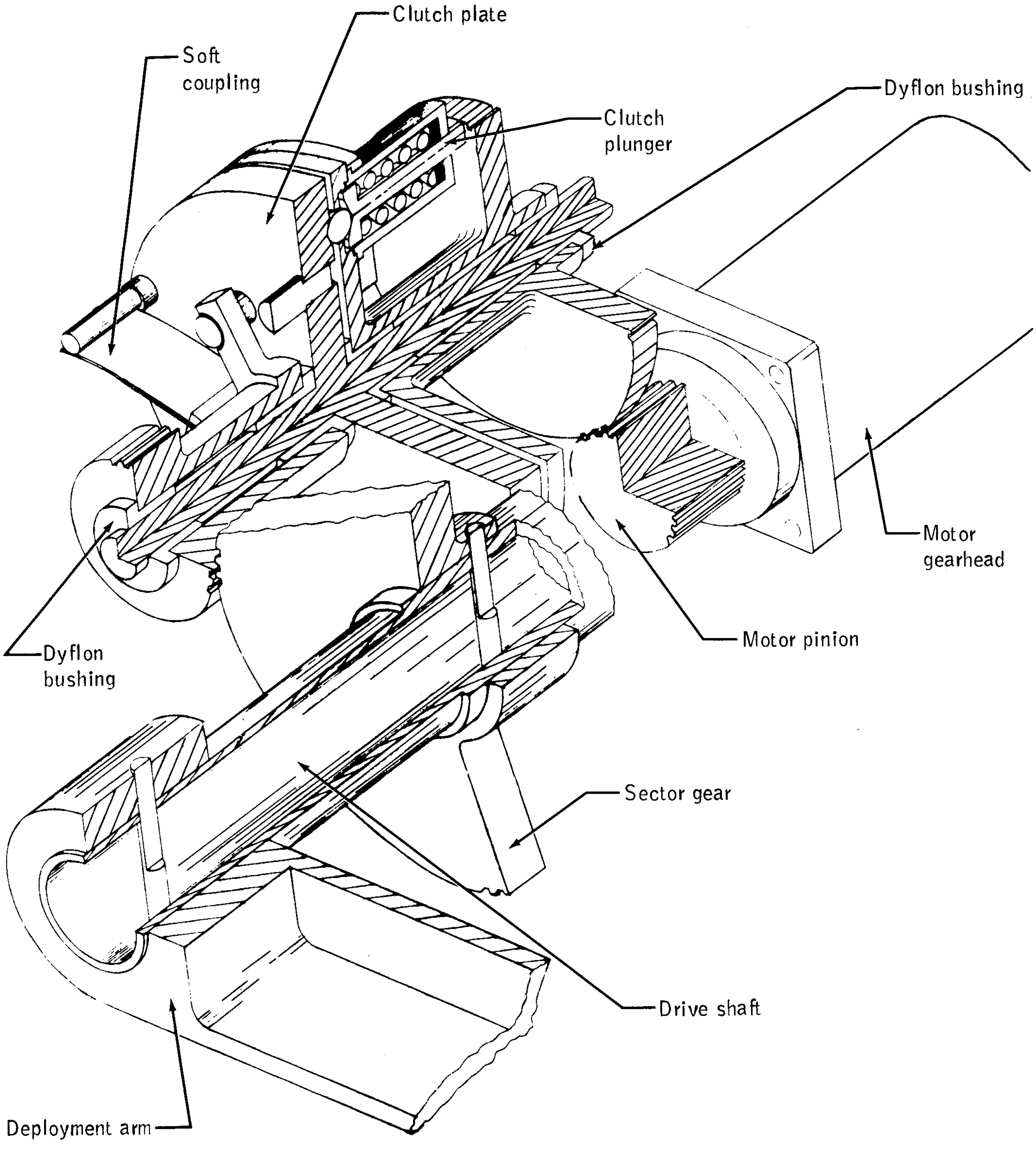

Figure 5. - Electrically scanning microwave radiometer drive assembly.

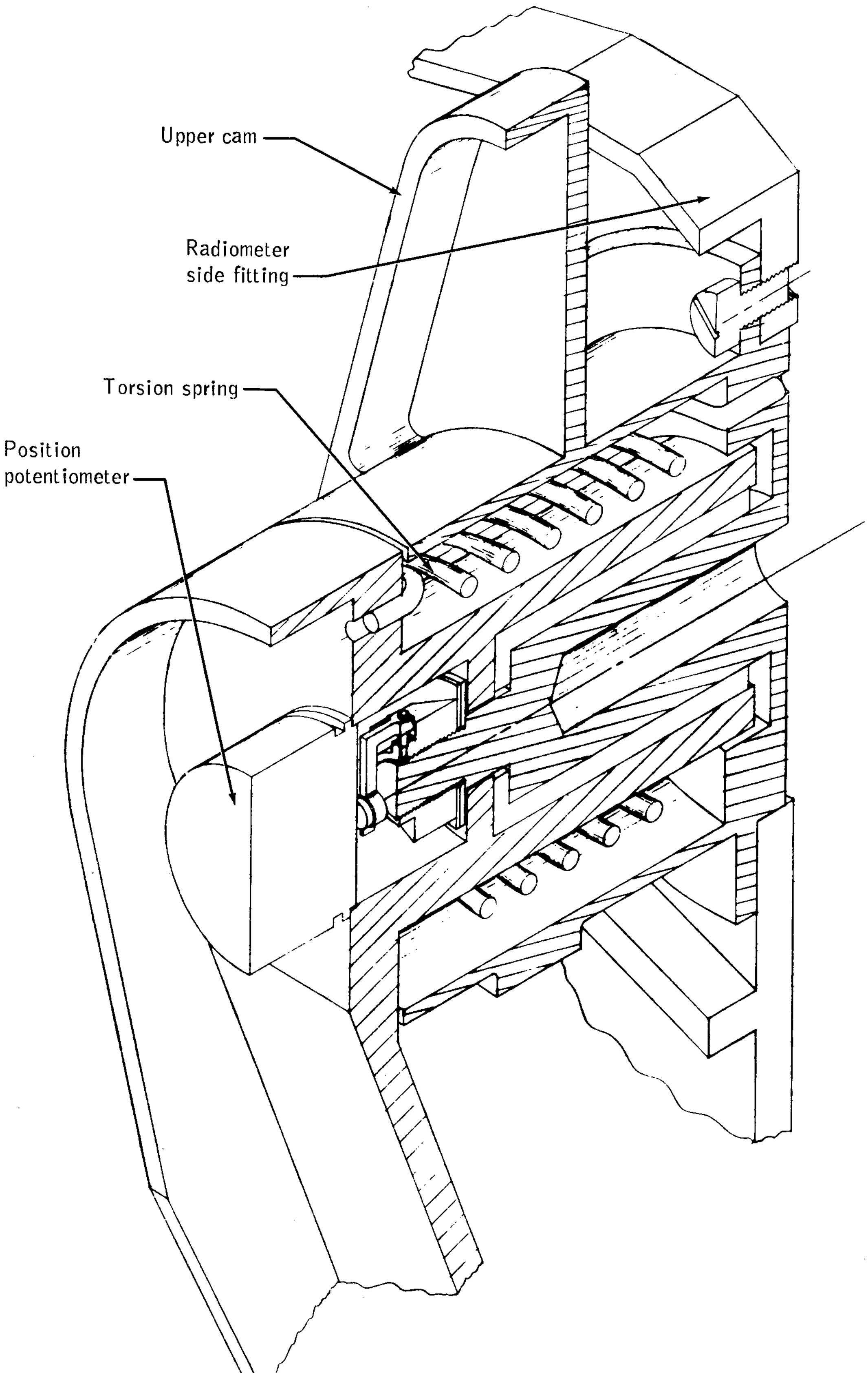

Figure 6. - Upper pivot assembly.