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# POINTED TELESCOPE SUBASSEMBLY FOR THE UARS HIGH RESOLUTION DOPPLER IMAGER

Robert D. Renken*

## ABSTRACT

The Pointed Telescope Subassembly (PTS) consists of a telescope, its Coudé relay optics, a two-axis gimbal mechanism, and a cover/caging device. These components, their mechanisms, the requirements, and some of the trade-offs leading to the final design are described in this paper. The PTS supplies light to the interferometer of the High Resolution Doppler Imager (HRDI) to be used to study upper atmospheric wind velocity.

## INTRODUCTION

The PTS is a major subassembly of the HRDI, an instrument which will be flown on the Upper Atmospheric Research Satellite (UARS). The PTS is being built for the University of Michigan by Ball Aerospace Systems Division (BASD). Its function is to gather light from the upper atmosphere and supply it to the interferometer using the telescope and relay optics which are mounted on a two-axis gimbal. The interferometer will measure upper atmospheric wind velocity by measuring the Doppler shift of the light. The PTS is on the side of the satellite facing the Earth, with its azimuth axis directed toward the Earth and its zenith axis perpendicular to it as shown in Figure 1. Each axis has its own bearings, motor, optical encoder, and flexible lead assembly. In addition, there is a telescope cover and caging mechanism. The design is now complete, hardware is being manufactured, and testing is scheduled for mid-1987.

## REQUIREMENTS

The PTS is required to collect light from a specific region of the atmosphere as directed by the Principle Investigator. The telescope must have a wide field of view that is rectangular, 0.12 deg by 1.37 deg and a selectable narrow field of view that is 0.12 $\deg^2$. The collected light is required to be routed through the gimbal to the interferometer. The telescope boresight placement is to be within 3 arc minutes. Position knowledge and repeatability are to be within 72 arc seconds for the zenith axis and 54 arc seconds for azimuth. During a typical scan operation, the telescope will be pointed to twenty different positions, each 3 arc minutes from the previous position. Required rotational travel is 350 deg for azimuth and 90 deg for zenith, although the zenith axis is rotated an additional 45 deg for caging.

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* Ball Aerospace Systems Division, Boulder, Colorado

The telescope's cleanliness is extremely important, as is its stray light rejection ability, because any extraneous light introduced into the system masks the intended data. Environmental requirements are typical for space vehicles launched on the Shuttle. The gimbal mechanism is to be operated in the vacuum of space and protected from thermal extremes through the use of thermal blankets and heaters. The major structural requirement is that launch resonant frequencies be above 35 Hz; however, the control system requires at least 40 Hz during operation. Weight, although a serious consideration, did not prove to be a design driver.

## TELESCOPE

A sectional view of the 7-in. off-axis modified Gregorian telescope and its baffle system is shown in Figure 2. The first three mirrors are all off-axis parabolas. Light is reflected from the primary mirror through the field stop to the secondary mirror, then through the Lyot stop to the tertiary mirror. Finally, the light is folded and imaged on the end of the fiber optics bundle. The fiber optics serves two purposes: it routes the light from the telescope to the zenith axis centerline, and it changes the beam shape from rectangular to circular. The entrance aperture of the fiber optics bundle is nominally 0.83 mm (0.033 in.) by 8.8 mm (0.349 in.) and contains 151 fibers. The exit aperture is round and is 3.05 mm (0.120 in.) in diameter. The fibers are made from fused silica and are coated with an antireflection coating. The telescope field-of-view selector is shown in Figure 3. When actuated, it places a narrower slit in front of the field stop. A brushless partial-rotation direct-current torque motor is mounted on flex pivots and used to rotate the slit to the narrow field-of-view position. Position is sensed by a light-emitting diode and photocell combination by placing a blade between them when the motor is actuated. The mechanism is returned to the wide field-of-view position by the spring force in the flex pivots. Thus, it is powered continuously to operate in the narrow field of view and, in the event of electrical failure, will automatically return to the wide position.

Stray light avoidance became a major design driver for the telescope. This consideration led to the selection of an off-axis design instead of a simpler on-axis design. It also led to the use of a proprietary black antireflective coating supplied by the Martin Company for the interior of the baffle. There is more experience in applying this coating, called Martin Black, to 6061 aluminum so this material was selected for the baffle. However, a sample of 5083 aluminum was coated with excellent results. The stray light consideration also led to stringent cleanliness procedures for both particles and films during assembly. These contaminants on mirrors scatter light and allow unwanted light into the system. Therefore, the baffle was thoroughly cleaned and vacuum baked prior to assembly. Once the telescope is assembled and optics are aligned, it will be covered and the cover is not to be removed except for functional testing in the assembly area and during thermal vacuum testing.

## RELAY OPTICS

The relay optics transmits the light from the telescope fiber optics to the end of a light pipe at the input of the interferometer as shown in Figure 4. The light beam exiting the fiber optics expands in the shape of the cone with a 15-deg half-angle. The elliptical mirror (RM 1) collects the light and provides a beam that is nearly collimated. The light is then reflected with a series of flat mirrors through a field lens to a second elliptical mirror which reimages it on the end of the light pipe. Optically, the relay optics has several interesting characteristics: (1) the path length has two identical halves, with the field lens in the middle, (2) the two elliptical mirrors are identical, and (3) each elliptical mirror has one focal point on the end of the fiber optics (or light pipe) and the other focal point at the center of the field lens.

The relay optics concept chosen was the result of several design iterations. The original concept used light pipes throughout the drive with corners turned by small elliptical mirrors. In a later concept, the corners were turned by pairs of parabolic mirrors. These two concepts were not selected for several reasons. First, they would not transmit enough light. Second, we were concerned that a single broken light pipe would result in the failure of the experiment. Third, the spacing between the ends of the light pipes and the elliptical (or parabolic) mirrors was extremely critical, which meant that the structural thermal distortions would alter the amount of light transmitted. The system with mirrors is relatively insensitive to thermal distortion because the beam is nearly collimated, so separation distances become less critical. The beam is also relatively large, so small lateral or angular misalignments are less critical. Also, it transmits more light and is less susceptible to breakage.

All of the mirrors and the lens are mounted on solid pads which are machined to give tilt adjustment. They are mounted using oversize holes with pins that are bonded to prevent motion after final alignment.

## ZENITH DRIVE ASSEMBLY

The zenith drive assembly is shown in Figure 5. The telescope is attached structurally to two short shafts which are supported by the zenith bearings. The bearings on one side of the telescope are a duplex pair, mounted face-to-face. There is a single radial bearing on the other side of the telescope. All bearings are mounted with light interference fits so that any possible mechanical shift during launch is avoided. Also, they are preloaded to remove internal freeplay. The duplex pair is manufactured with a preload of 58 newtons (13 lb). The radial bearing is also loaded axially to 58 newtons by a diaphragm. Because the preload on the radial bearing is reacted by the duplex pair, the two bearings in this pair are loaded unequally, one with more than 58 newtons, the other with less, but not less than zero.

There are several reasons for this zenith bearing configuration. The duplex pair is designed to support all axial launch loads, which means that one yoke arm needs to be stronger than the other because of the unequal loading. The duplex pair is mounted face-to-face to make it free to accept small angular misalignments. The single radial bearing was chosen to provide radial support to the telescope. The diaphragm limits axial loads and also gives this bearing the capability of accepting angular misalignment. The telescope is driven by a brushless two-phase dc motor mounted on one side. Angular position is given by a 16-bit optical encoder which is mounted on the other side. The motor is commutated electronically by taking the angular position from the encoder and generating the required sine and cosine current for the motor. Electrical connections are made with a flexible lead assembly which is mounted inside the optical encoder. Both the flexible lead assembly and optical encoder are purchased as modular components. They have their own bearings and are connected to the zenith axis with couplings that provide for some misalignment.

## YOKE STRUCTURE

The structure connecting the zenith and azimuth drive assemblies is the yoke, shown in Figure 6. The configuration that was selected forms a riveted aluminum box beam, with two machined aluminum face plates connected by inner and outer skins which were formed from sheet metal. Caps are riveted to the tops of the arms to provide the interface to the zenith housings and doublers are riveted to the bottom to provide an interface to the azimuth drive shaft.

The riveted aluminum structure was selected after several other concepts were reviewed, including welded titanium, riveted titanium, and welded aluminum. The aluminum structure was selected because the design was driven by stiffness (i.e., the resonant frequency had to be held) rather than strength. The riveted, rather than welded, construction was selected even though it is slightly heavier, because riveting could be done in-house and no thermal residual stresses would be introduced. The riveted structure relies on the rivets to fill the rivet holes, to give a rigid structure and to avoid motion between the parts. A disadvantage of the aluminum is that it has to interface with the titanium bearing housings and shafts. Shrink fits are used at those interfaces that are tight enough so the fit never gets loose during thermal extremes.

## AZIMUTH DRIVE ASSEMBLY

The azimuth drive assembly is shown in Figure 7. It consists of a shaft mounted on bearings supported by the housing and driven by a brushless dc torque motor. There is an optical encoder identical to the zenith encoder and a flexible lead assembly. Two angular contact bearings are used in a back-to-back configuration, preloaded to 267 newtons (60 lb) against each other with a diaphragm. The diaphragm is snubbed to limit its axial travel to 0.076 to 0.152 mm (0.003 to 0.006 in.) during launch. The optical path is through the center of the shaft, with the field lens supported by the shaft. As in the zenith drive, interference bearing fits are used to preclude any possible shift during launch or thermal cycling.

This bearing mounting concept was selected after several designs were considered. The original design used the two bearings rigidly mounted against each other to achieve maximum stiffness. In this concept, preload is controlled by carefully machining the bearing clamping ring to within a few ten-thousandths of an inch. This concept is adversely affected by temperature changes unless the bearing separation distance is set equal to $D/\tan\beta$, where D is the bearing pitch diameter and $\beta$ is the mounted contact angle. Preload in any solidly mounted bearing scheme is adversely affected if there are pronounced thermal gradients. In an attempt to eliminate the extreme sensitivity of the bearings to temperature changes and to mounting tolerances, a concept using a preload diaphragm was investigated. First, the diaphragm was placed in line with the bearing outer race. However, analysis showed that the drive became less stiff with the overall resonant frequency dropping approximately 5 Hz. Then, the plane of the diaphragm was moved to be in-line with the point at which the lines of contact converge as shown in Figure 8. Further analysis showed that with this concept, the resonant frequency dropped approximately 1 Hz. The concept was analyzed for the extremes of the bearing contact angle, which were found to have a negligible effect on resonant frequency.

## COVER AND CAGING DEVICE

The cover serves both to shield the telescope aperture from dust and to cage the zenith and azimuth drives during launch. These devices are shown in Figure 9. The cover is sealed to the telescope with an O-ring seal and it has a filtered vent to allow the telescope to breathe. Early in the design phase, we recognized that even though the caging device would prevent gimbal rotation, there would still be motion during launch along the axis of the telescope. Therefore, the cover is allowed to float in this axis and is held against the telescope with a set of springs. The center of the cover also has a window and a light so the interferometer can be exercised with a known light source.

The caging mechanism is a double four-bar linkage which is stopped past top dead center. The linkage is driven by a motor gearbox assembly as shown in Figure 10. Two brush commutated dc motors drive a set of spur gears which turn the input crank of the linkage. This input crank and its associated link drive the other pair of links which rotates the cover. The springs that hold the cover in position also tend to drive the linkage to the caged and locked position. The motor gearbox is operated in the same direction of rotation for both caging and uncaging. The linkage input crank has a set of cam-actuated limit switches to sense its position and to shut off the motors at the end of travel.

The caging device is the only part of the PTS that has any redundancy. There are two dc torque motors, either of which will drive it to the open position. The gears and gearbox bearings have been deliberately oversized to minimize the chances of their failure. All of the pins in the caging mechanism have redundant sliding surfaces so that any one could seize and not cause the linkage to fail. A secondary use for the redundant motor is as a speed limiter; its windings are shorted when the motor is unused and it limits the speed of the primary motor, which minimizes brush wear. The caging device still operates satisfactorily if this speed limiting feature fails.

For recaging, the PTS is dependent on the gimbal's ability to point the telescope at the cover. In the event of gimbal failure, the PTS structure and bearings would support re-entry loads. However, the telescope would not remain clean.

## MATERIALS

Aluminum (alloy 5083 annealed) and titanium (composition 6Al4V) were the two primary structural materials for the PTS. The 5083 aluminum was used for telescope mirrors, the yoke, the adaptor, and the zenith housings. It was selected for these parts because dimensional stability was a concern and an annealed aluminum is relatively stable. Stiffness, not strength, was the primary structural concern. Because an annealed aluminum is more stable and as stiff as a tempered aluminum, the annealed material became a logical choice. The specific alloy 5083 was selected because strength remains a concern and it has a high yield strength in the annealed condition. For the mirrors, the aluminum was plated with nickel, then silver, and then coated with an anti-reflective coating. Titanium 6Al4V was used at all bearing interfaces, in the azimuth shaft and housing, and for the preload diaphragms. It was selected because its coefficient of thermal expansion nearly matches that of the bearing steel, and because of its low density, high strength, and good corrosion resistance. Other materials are 6061-T6 aluminum for the caging device and telescope baffle and both 440-C corrosion resisting steel and 52100 high chrome bearing steel in the bearings.

The bearings are lubricated with BASD's 36207 fluid lubricant, which is a polyfunctional ester with corrosion inhibitor/anti-wear additives. Creep is controlled by using low surface energy films on the material adjacent to the bearings. This lubricant was selected because of its low contamination potential. It also has corrosion inhibitors so the 52100 bearing steel could be used. The caging mechanism gearbox is lubricated with Braycoat 601 grease.

## CONCLUSION

The design described in this paper proved to be interesting and challenging in a number of areas because of the required pointing accuracy and the optics. These factors, along with the environment, led to the use of state-of-the-art materials and lubricants. The telescope and gimbal are designed to operate in the space environment for a minimum of 2-1/2 years and I believe the design will meet this challenge. The hardware is now being assembled and the test program to qualify this design will start in the near future.

## ACKNOWLEDGMENT

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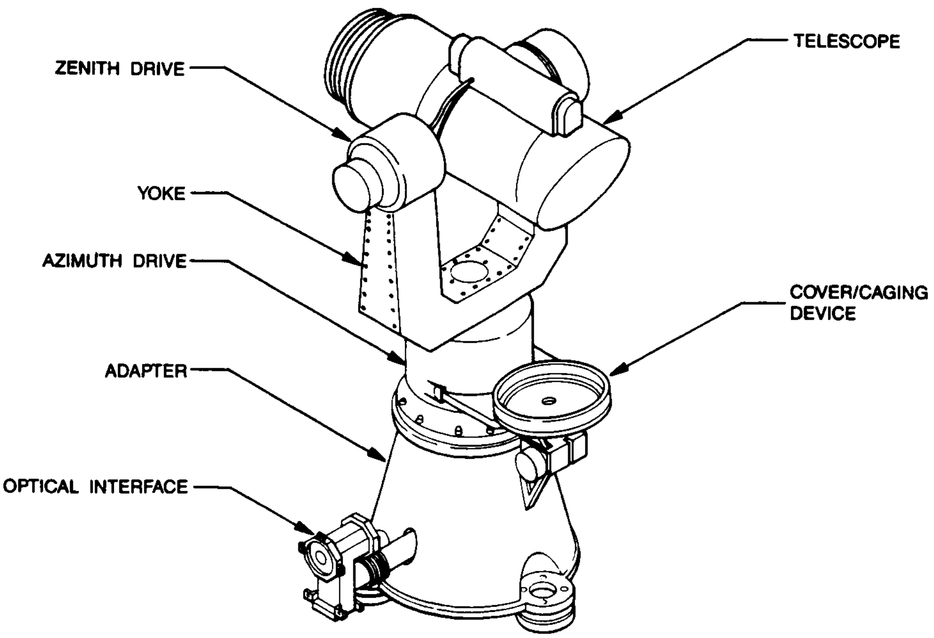

Figure 1 Pointed Telescope Subassembly

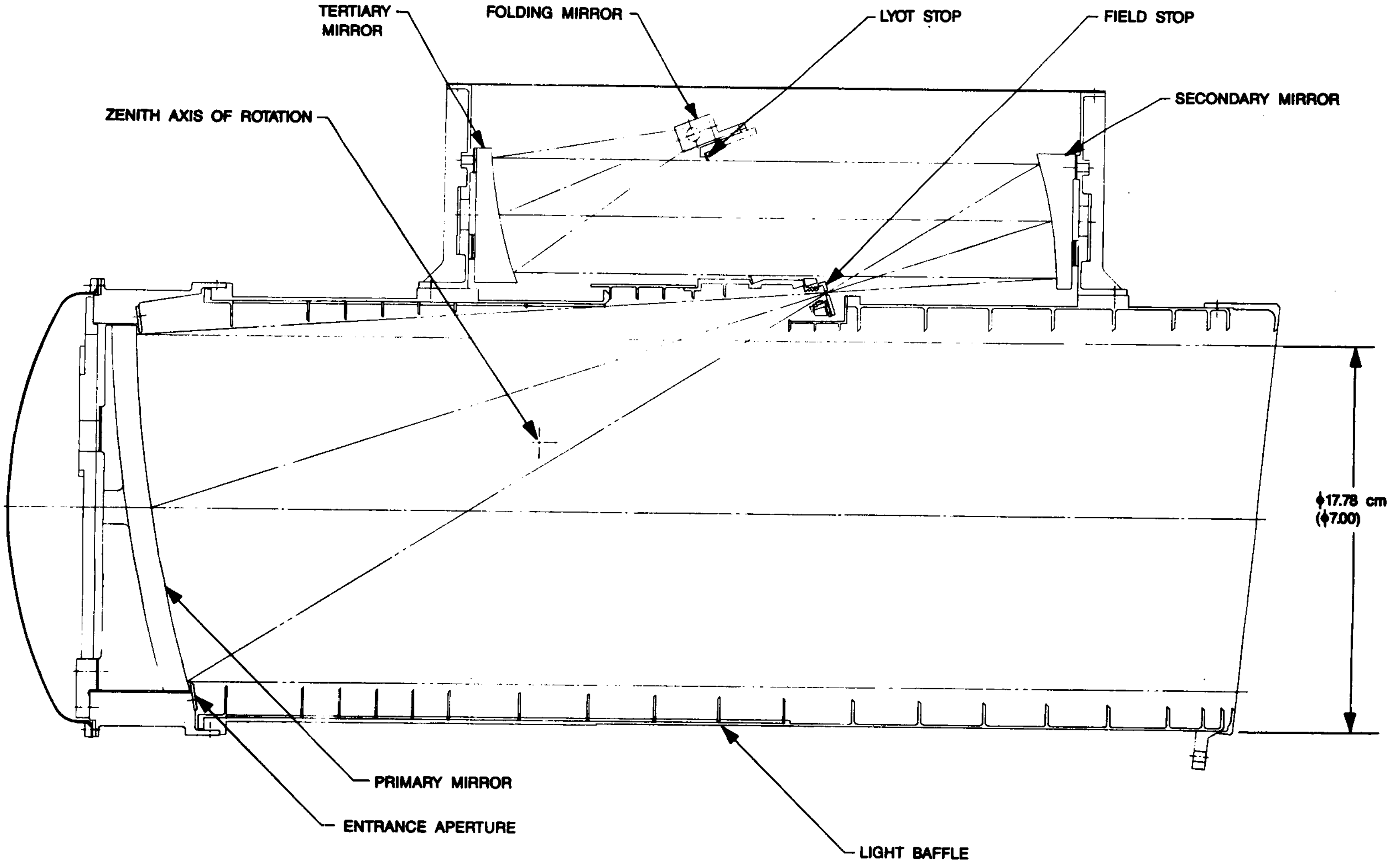

Figure 2 Telescope Cross Section

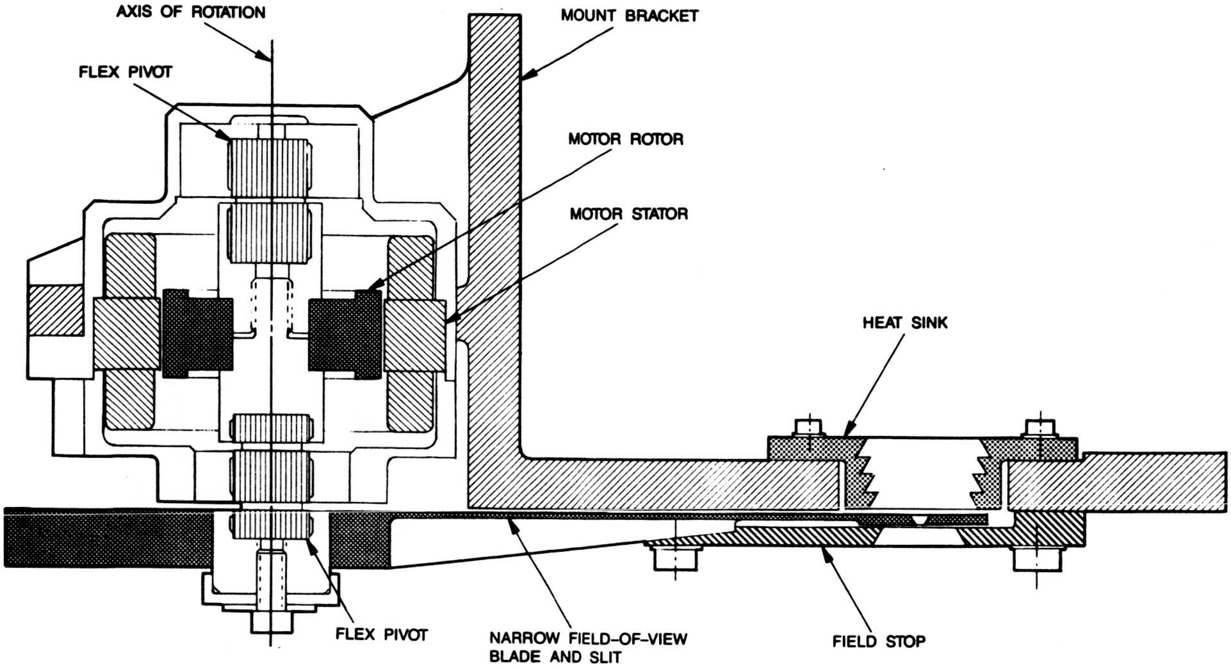

Figure 3 Field-of-View Selector - Cross Section

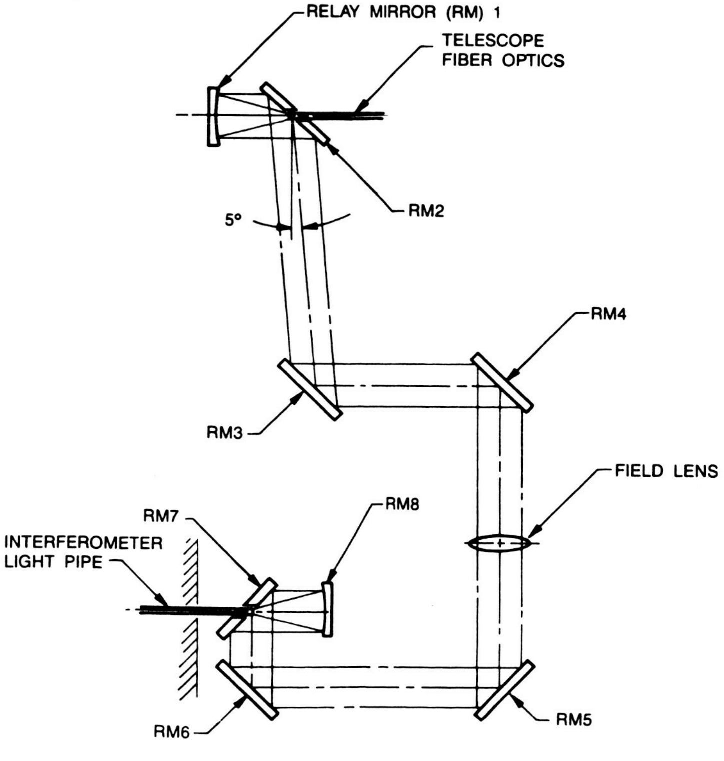

Figure 4 Relay Optics

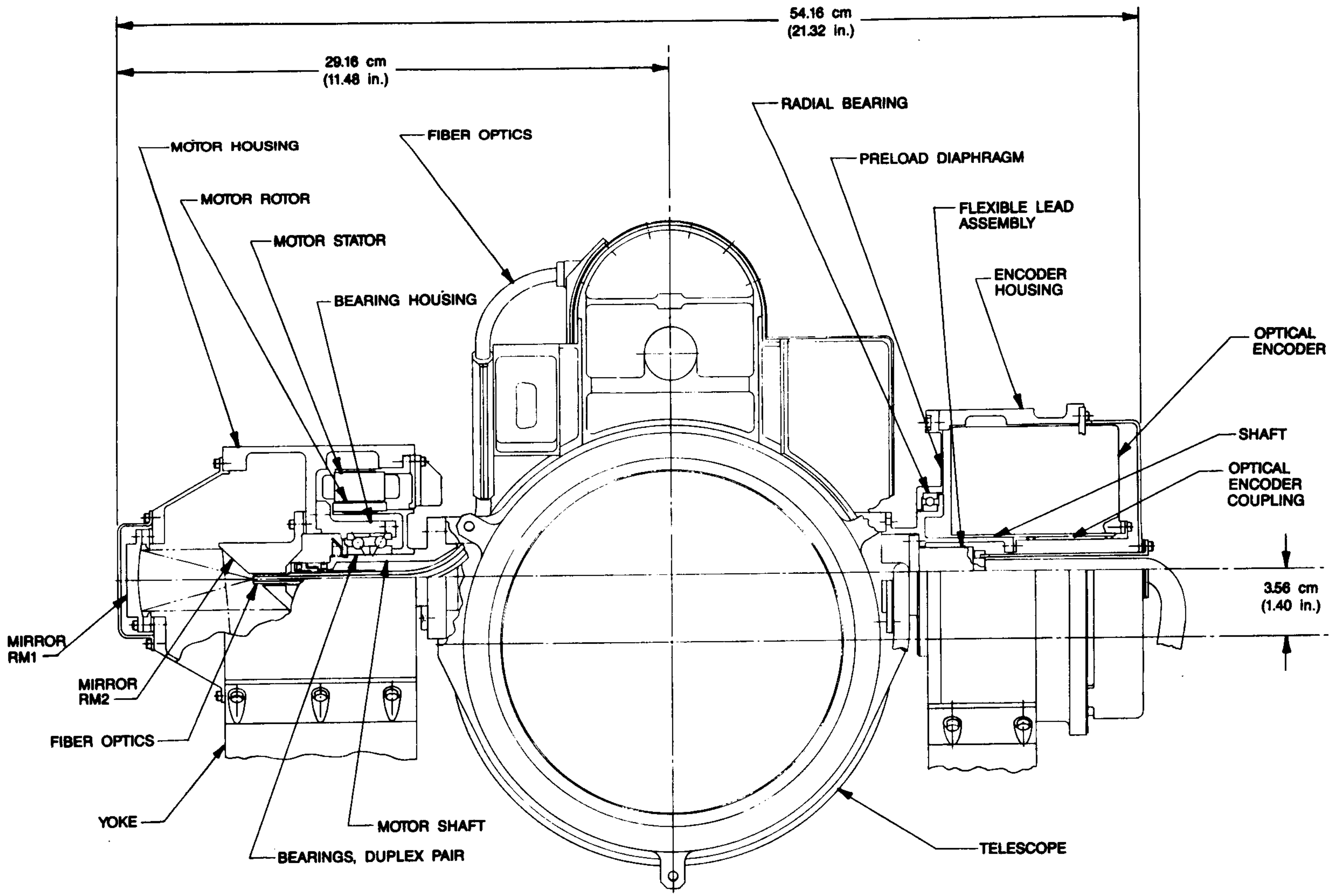

Figure 5 Zenith Drive Assembly

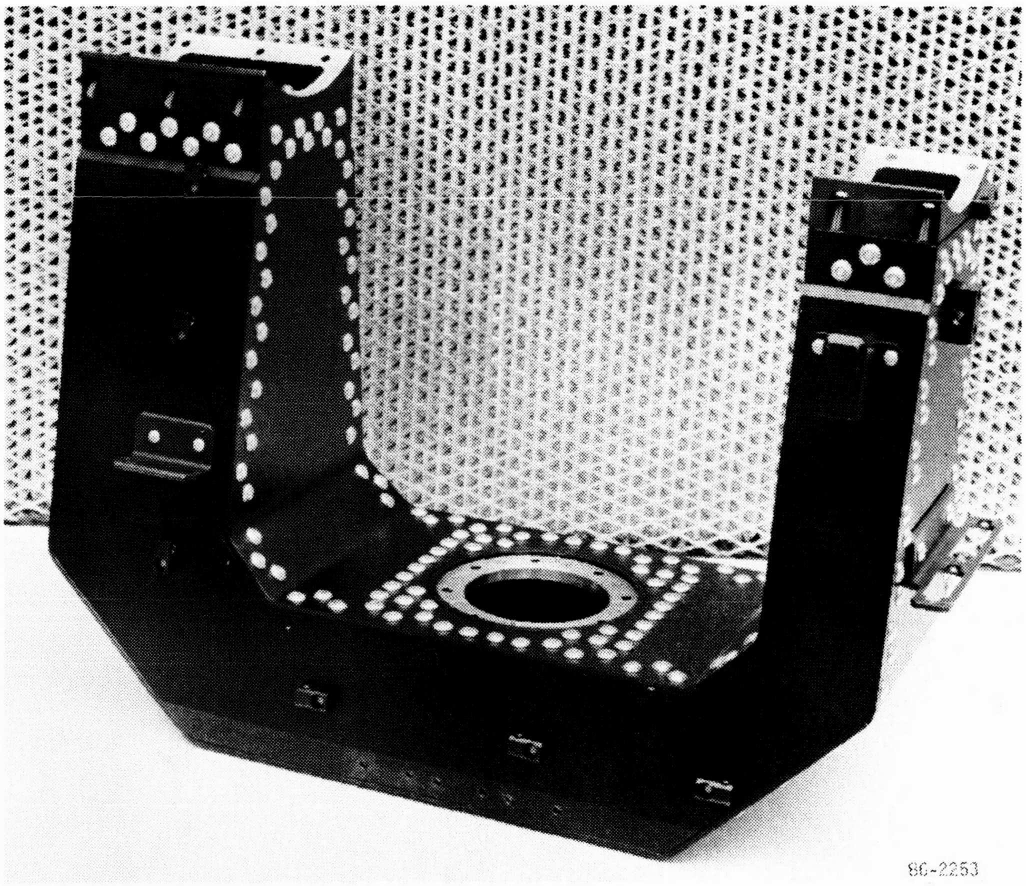

Figure 6 Yoke

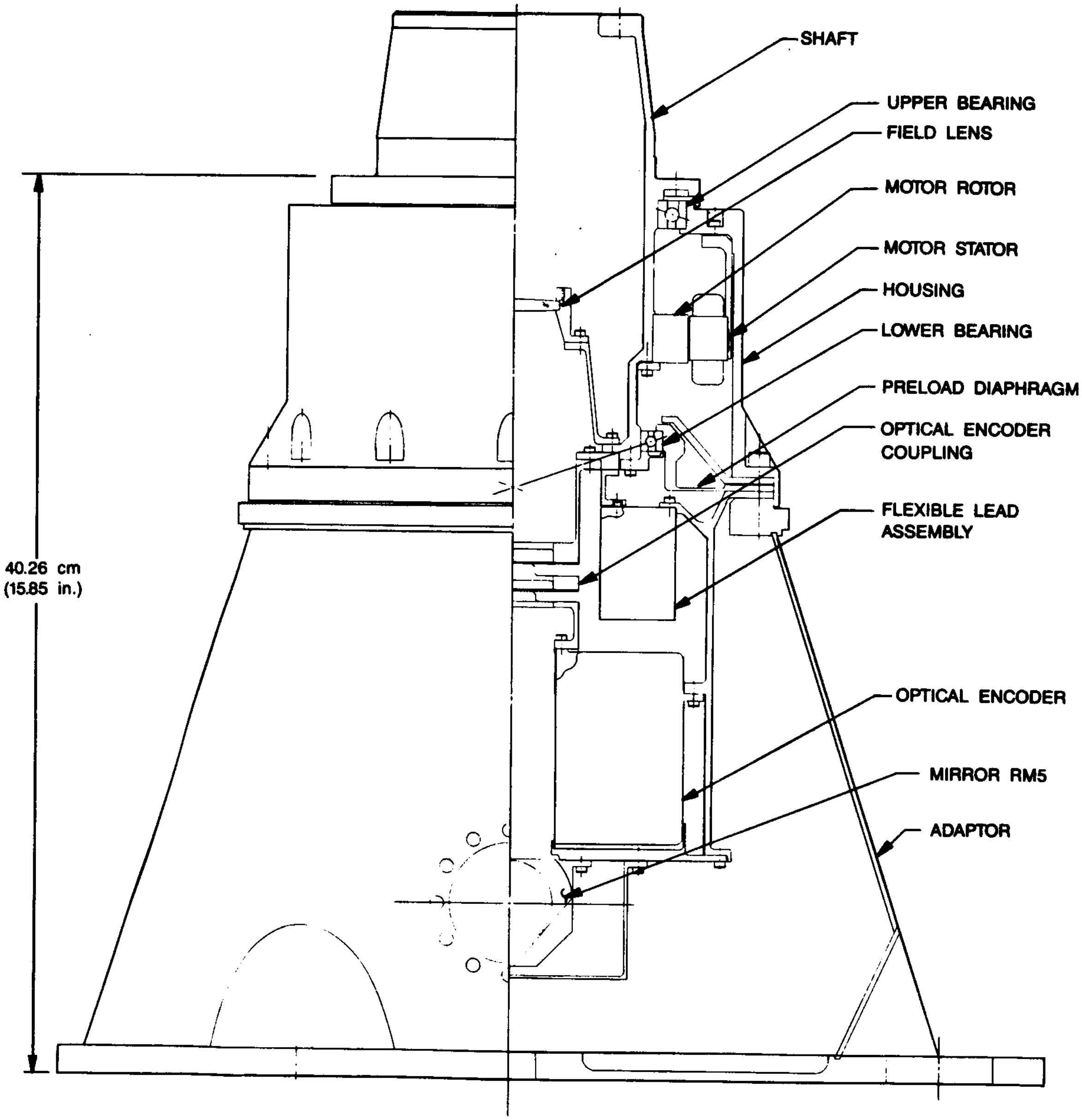

Figure 7 Azimuth Drive Assembly

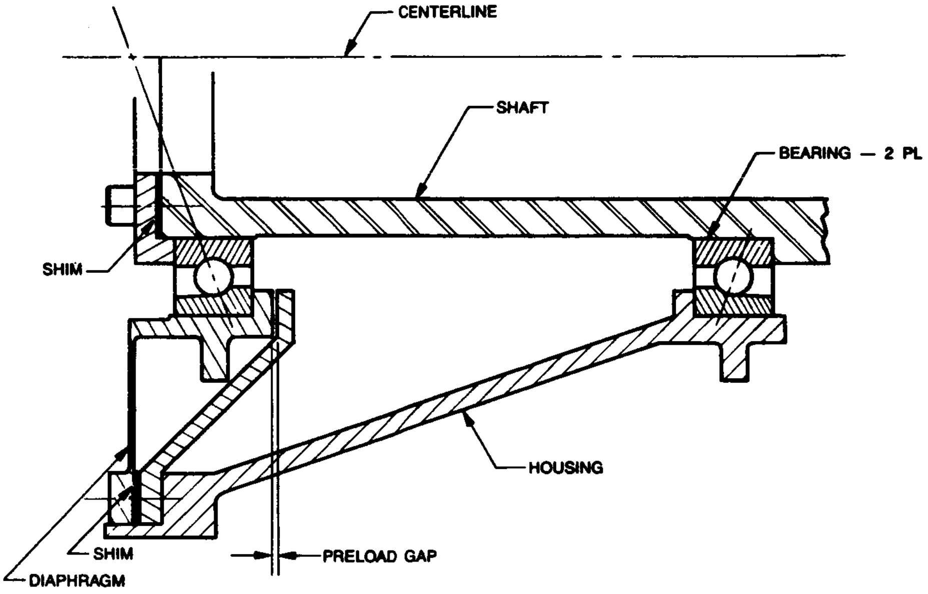

Figure 8 Bearing Diaphragm Placement

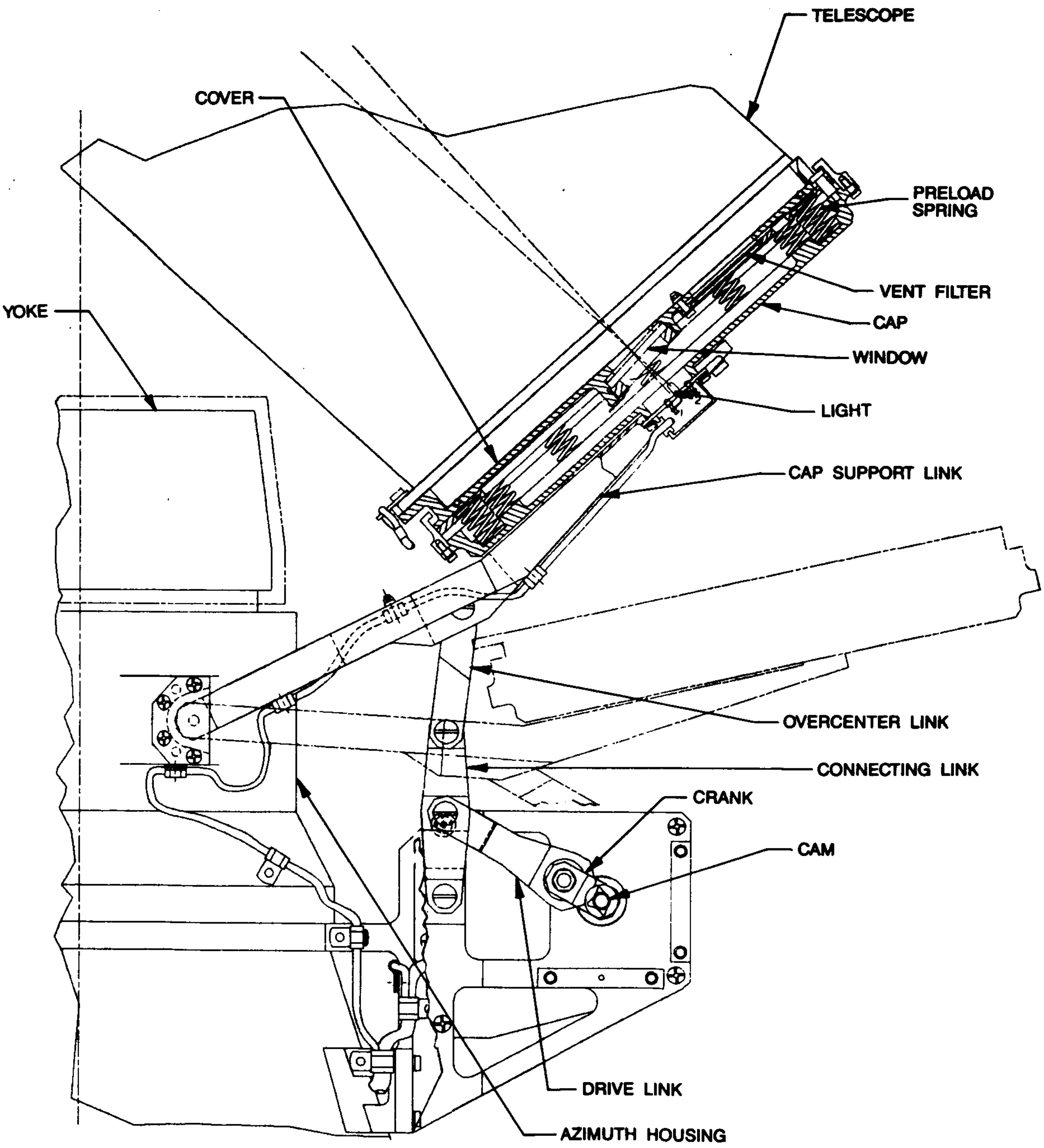

Figure 9 Cover and Caging Device

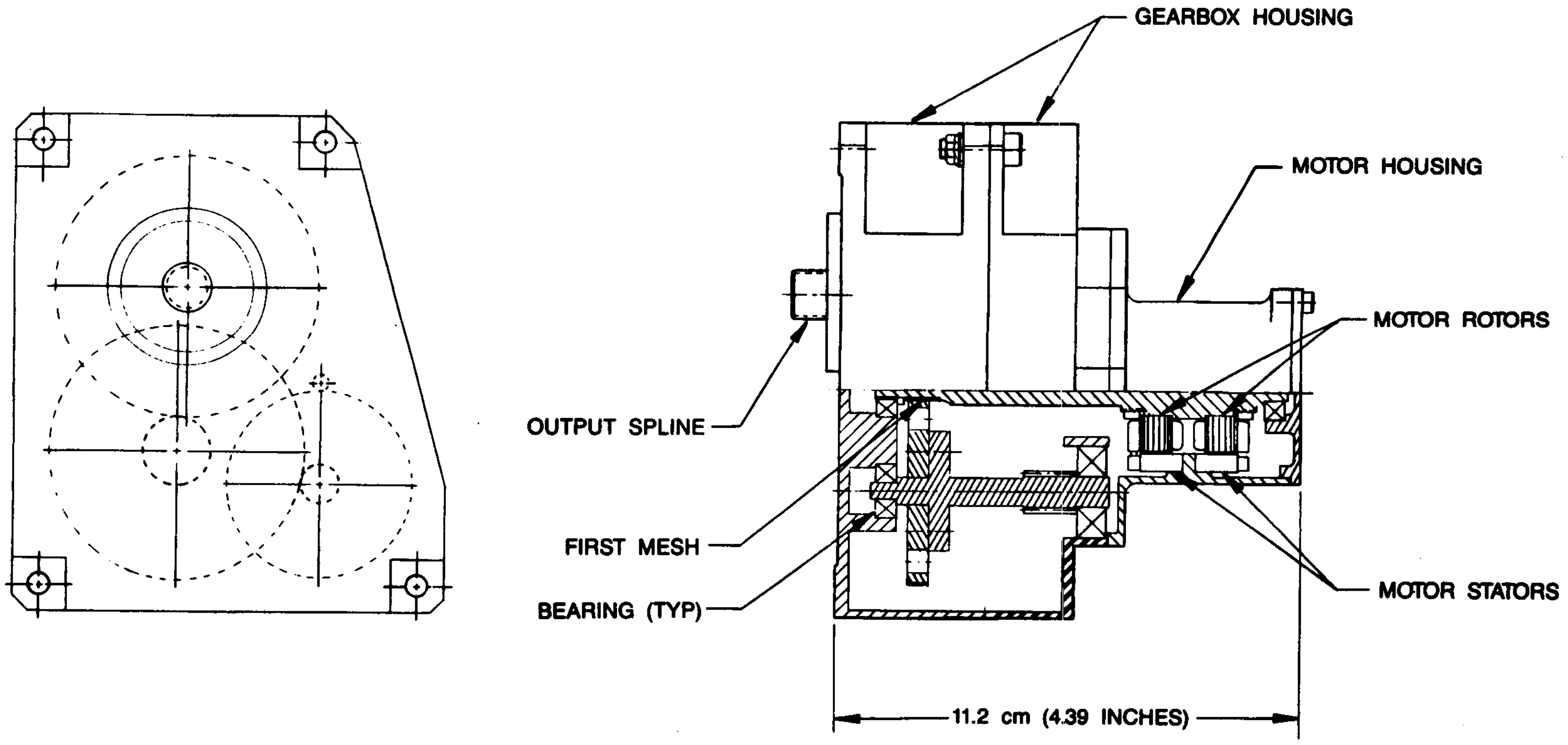

Figure 10 Caging Motor Gearbox Assembly