Design of the Discovery Channel Telescope mount

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ABSTRACT

The Discovery Channel Telescope is a 4.2-meter clear aperture telescope undertaken by the Lowell Observatory in Flagstaff, Arizona. It will feature an interchangeable secondary assembly to allow the use of either a prime focus instrument or a secondary mirror. In addition, it will have an active optical system and provisions for a wide range of instruments. This paper describes the design of the telescope mount and drive systems. Particular challenges associated with the design include: consideration for the weight of the 3500 lb Prime Focus Assembly (PFA) instrument; interchangeable secondary assemblies; and providing thermal and mechanical stability in between updates to maintain alignment between optical elements.

Keywords: Discovery Channel Telescope, Ritchey-Chretien

1 INTRODUCTION

The Discovery Channel Telescope (DCT) is a 4.2-meter clear aperture telescope undertaken by the Lowell Observatory in Flagstaff, Arizona. It will be installed near Happy Jack, Arizona, outside of Flagstaff. It is expected to have first light by the end of 2010. General Dynamics SATCOM Technologies (GDST) has considerable experience with this class of mount, having designed, fabricated, and installed the mounts for SOAR and VISTA. This paper describes the challenges posed by the design of the DCT mount and the responses to those challenges. The DCT mount is shown in Figure 1.

The DCT will be designed for two different optical configurations. The first is a Ritchey-Chretien design. In addition to a secondary mirror and Cassegrain rotator, this configuration will include support for both Bent Cassegrain and Nasmyth instruments. Light is directed to the latter instruments with a tertiary mirror on a rotator, supported off the M1 cell. The second optical configuration is a Prime Focus Assembly (PFA) that will replace the secondary mirror in the RC configuration. The RC secondary mirror and the PFA will be mounted on removable assemblies that can be removed and replaced, in a repeatable manner, as needed. The current project effort is to build the Ritchey-Chretien configuration, but the design effort will include all the necessary work to enable the PFA to be added at a later date.

The DCT has been able to achieve economies in its design by leveraging portions of the design from successful prior designs. GDST has had previous successes with the SOAR and VISTA mounts, and elements from these designs were re-used to reduce cost and performance risk. These designs include:

- Azimuth bearing
- Elevation, azimuth, and Cassegrain rotator drives
- Elevation, azimuth, and Cassegrain rotator encoders
- Cassegrain cable wrap

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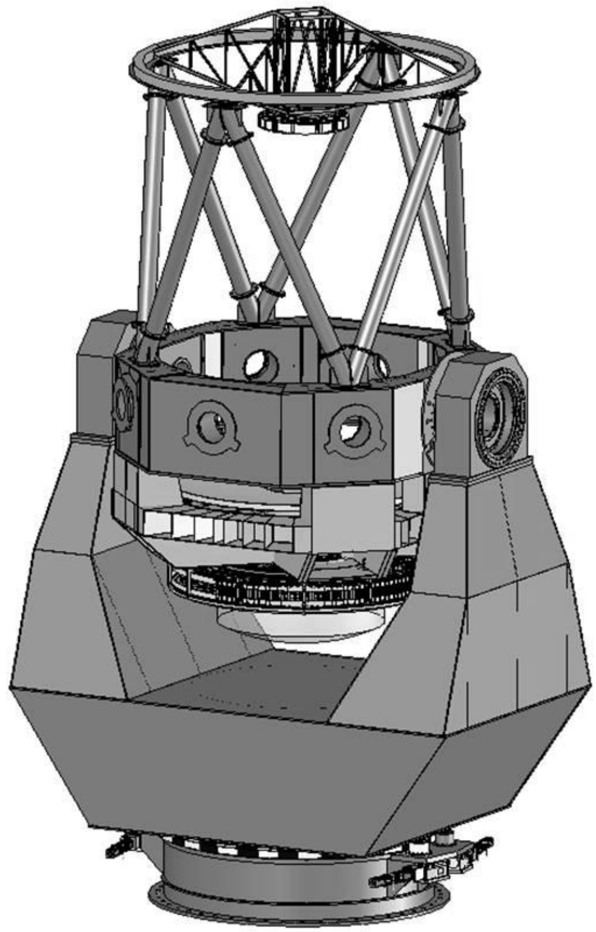

Figure 1 - The Discovery Channel Telescope

2 DCT MOUNT DESIGN OVERVIEW

2.1 Optical Support Structure (OSS)

The DCT Optical Support Structure (OSS) is shown in Figure 2. It is the structure that rotates in elevation and supports the primary mirror, top end assembly (either the secondary mirror or the PFA), the Cassegrain rotator, and the Bent Cassegrain instruments. The central feature of the OSS is the elevation ring, which supports all the other elements of the OSS and is itself supported by a pair of elevation axles. Figure 2 shows the major subassemblies that make up the OSS.

The 4.3m main mirror is supported by 120 axial and 36 lateral actuators. In this project's organizational structure, the M1 cell structure is considered a part of the mount, but not the mirror or its supports. The mirror cell will be designed to accommodate the space envelope of the actuators and be stiff enough to give adequate backing for the actuators. The mirror cell will also support the M3 mirror and its rotator. The configuration that will be built initially includes a light baffle in the place of the M3 mirror. However, the M1 cell is being designed to accommodate the mounting interface and the complete mass properties of the M3 mirror subassembly. In addition to housing the mirror supports, the M1 cell will also accommodate the M1 cold plate and the associated coolant lines.

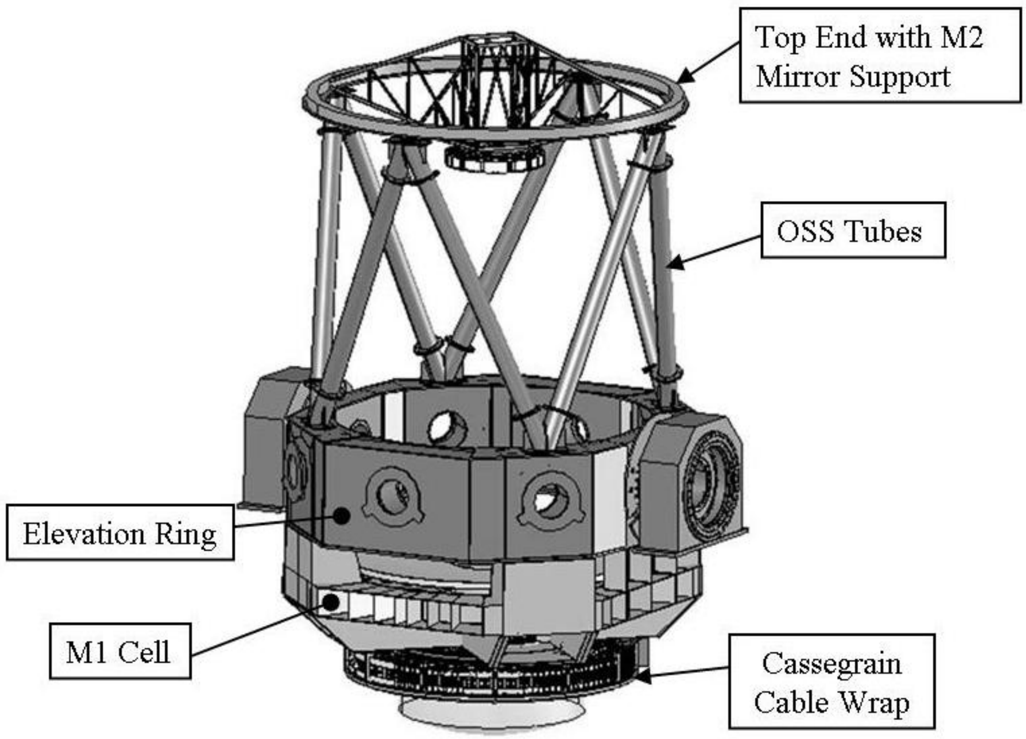

Figure 2 - DCT Optics Support Structure with RC Configuration

The M1 cell will be designed so that, with the M1 mirror intact, it can be to be detached from the OSS and lowered to the ground floor of the facility with the OSS horizon pointing. From there it can be transported to the nearby auxiliary building for resurfacing the M1 mirror. There will be a repeatable connection between the M1 cell and the elevation ring to facilitate removal and reattachment of the M1 cell. One of the design constraints on the M1 cell will be keeping its weight below the rating of the dome crane.

The bottom of the M1 cell structure supports the Cassegrain rotator and the Cassegrain cable wrap. The Cassegrain bearing interface will be considered the datum for aligning the optics. Both the M1 mirror and the removable secondary instruments will be located with reference to this datum. The Cassegrain rotator consists of a four-point contact slewing ring bearing with an external gear, driven by two torque biased motors. Cassegrain position will be measured by a tape encoder mounted to the rotating race of the bearing. The cable wrap is one of the areas where success from a previous design has been applied, in this case the VISTA design. The Cassegrain cable wrap rotates under its own power, using a gear drive slaved to the Cassegrain rotator drive.

The elevation ring accommodates other basic telescope functions. It has four ports for Bent Cassegrain instruments. In order to maintain the proper balance of the OSS, each Bent Cassegrain port will be occupied by either an instrument or a mass simulator. In addition, the elevation ring supports the M1 mirror cover. The mirror cover is a flower petal type design that will protect the mirror during maintenance. It is motorized, with provisions for manual actuation in the event of a power loss.

One of the unique features of the DCT is its interchangeable top end, as shown in Figure 3. The top of the OSS is designed to accommodate interchangeable instruments. Current plans are for either an RC secondary mirror or a Prime Focus Assembly (PFA). When first built, the DCT will feature an RC configuration, but both the M2 mirror and the PFA are being considered in the design effort. The PFA is the heaviest prime focus instrument planned for the DCT, so all other top end assemblies must match its overturning moment about the elevation axis. There is additional mass added to the M2 assembly to match the mass and cg of the PFA assembly. Any future instruments planned for the DCT will have to match this mass and cg as well.

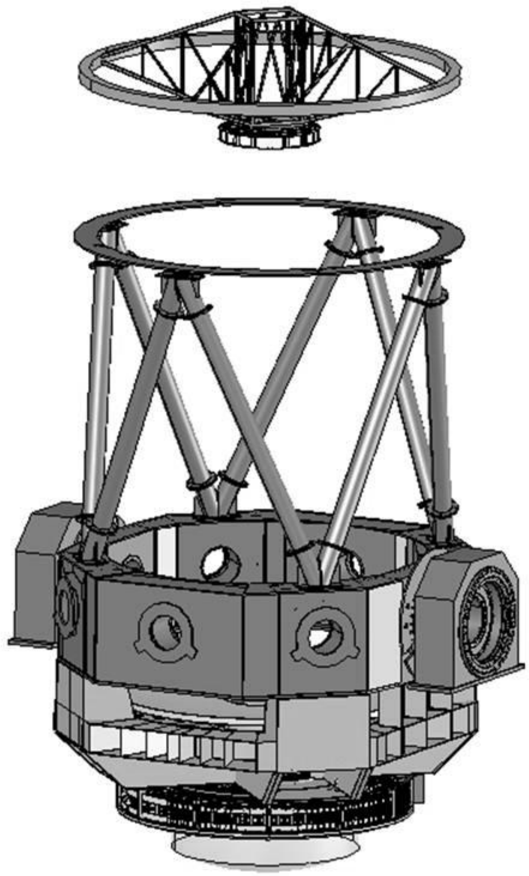

Figure 3 - Removable Top Ring for DCT Secondary

The OSS will include a moderate precision (100 micron) repeatable coupling interface to accommodate both RC and PFA top ends. The OSS repeatable interface can be used by any future top end that may be required for other optical configurations. The installation of any particular top end will be accomplished using the observatory dome crane with telescope horizon pointing. In order for the top end coupling to repeatably locate the top end with a known tolerance the load carried by the coupling will need to be controlled during installation. This will be accomplished using a load cell on the dome crane hook. The top end installation procedure will be to load the coupling to some percentage of the total top end load, which will provide the proper deformation to yield the repeatable coupling, and then secure the top end to the truss tubes using captive fasteners. The top end will then be released from the dome crane and the telescope can be placed into service.

The M2 mirror support consists of tensioned vanes supporting a central hub. The tensioned vanes are used to minimize the diffraction in the image. The M2 mirror assembly can be removed from the M2 mirror support for maintenance.

The optics in the OSS can be adjusted to accommodate differential deflections between them. The system can correct M1-PFA despace and compensate for PFA decenter by focus adjustment of the M1 actuators. It can correct M2 tilt and despace through secondary actuation of the M2 subassembly. M2 decenter errors are compensated by M2 tilt. Since the system does not rely exclusively on the stiffness of the OSS to maintain optical alignment, this allows material savings in the OSS structure. It also avoids the design effort of trying to reduce deflections without adding weight. This results in a lighter structure and reduces performance risk.

The structural performance specifications of the OSS were established in an earlier study. The OSS alone should have a natural frequency of 7.5 Hz or greater. The previous study showed that the OSS structure is stiff enough to satisfy the optical deflection criteria. In addition, the optical path blockage from the RC and PFA top ends meet the requirements. The RC top end will use tensioned vanes to improve upon that value.

2.2 Yoke & Pedestal

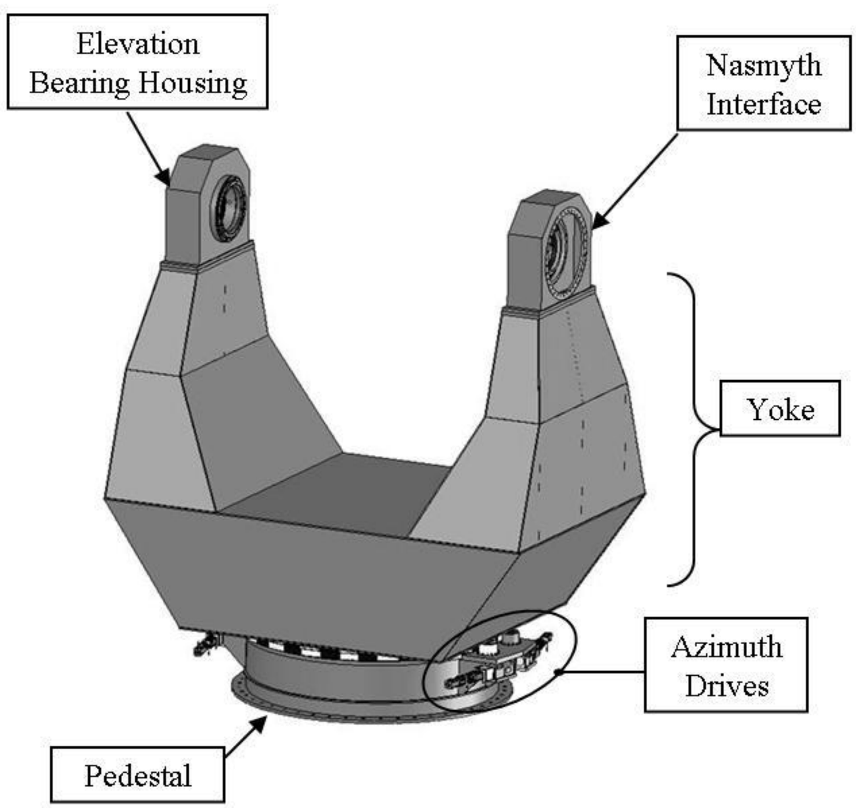

Figure 4 - DCT Yoke and Pedestal

The OSS is supported by a yoke and pedestal structure, shown in Figure 4. The outboard side of each elevation bearing housing has an interface for the Nasmyth instruments. The DCT will be using a single Nasmyth instrument. For telescope operations with a single Nasmyth instrument, the yoke will be balanced by a Nasmyth mass simulator on the opposite side. The interior of the yoke forms the movable side of the azimuth encoder and the azimuth cable wrap.

The yoke also provides an interface to the DCT facility. There will be a platform at the bottom of the yoke arms at the same level as the observing floor. It will provide maintenance access to the Cassegrain rotator and M1 cell. In addition, the yoke will support two electronics cabinets.

2.3 Elevation and azimuth drives

The drive axes carry forward legacy designs that were proven on SOAR and VISTA. Due to their success in these applications, these designs have carried forward with little modification.

The DCT elevation drive is shown in Figure 5. The optical clear path for the Nasmyth instrument determined the layout of the elevation drive. The elevation axes are hollow forgings with an inner diameter larger than the optical clear path. The axes are supported by a pair of tapered roller bearings in a kingpost design and driven on the end by a direct drive motor.

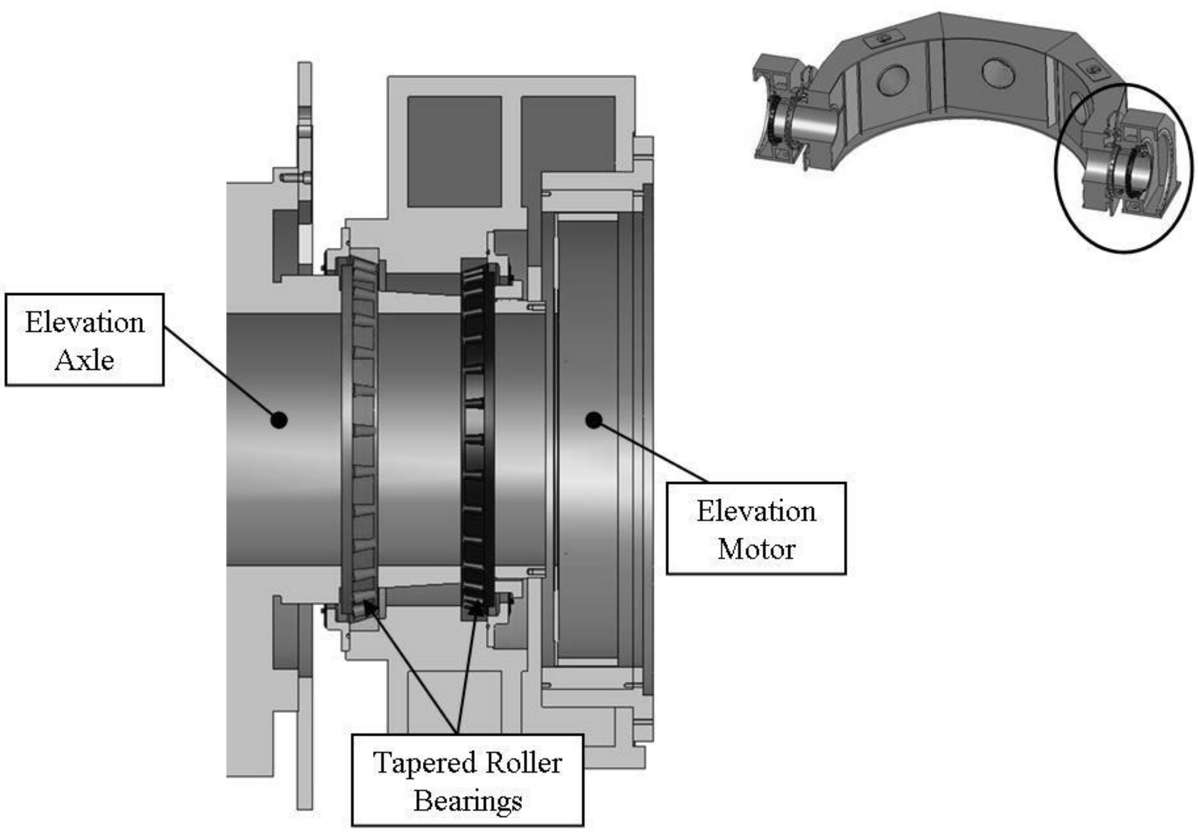

Figure 5 - DCT elevation drive

Elevation position is measured with tape encoders with multiple read heads. There are two tape encoders in elevation, mounted to a sector wheel on each axle. In addition to providing position information, the encoders also commutate the elevation motors. In addition to the elevation encoders, this area includes a stow pin to hold the OSS in place during maintenance, M1 cell removal, and top end assembly changes.

The DCT azimuth drive is shown in Figure 6. The azimuth drive consists of a helical gear on a rolling element bearing and four counter torqued drives. The rolling element bearing has independent load paths that constrain the telescope axially and radially. It features an integral helical gear cut into the rotating race. The advantage of helical gear teeth is that there are multiple teeth engaged at the same time. This high contact ratio gives greater stiffness and smoother operation. However, helical gear teeth also produce axial loads whose effect must be considered in the design. This design handles that effect by placing pairs of drives together to react out the axial load over as short a space as possible. The drives are torque biased against each other to eliminate backlash. In addition, the gearboxes for the azimuth drive are a special design to minimize friction and maximize stiffness.

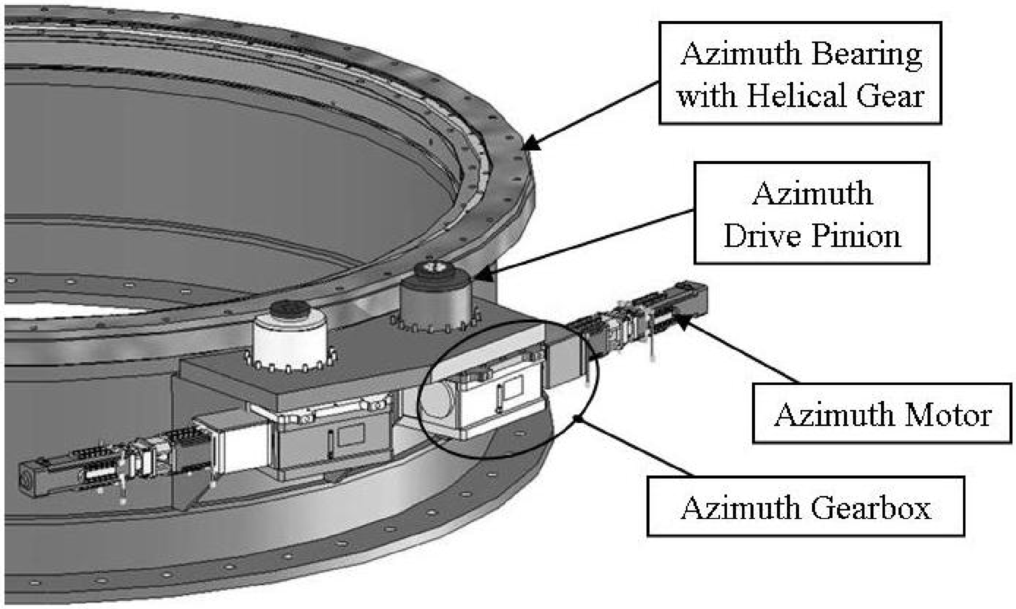

Figure 6 - DCT Azimuth Drive

All driven axes of the DCT utilize high accuracy quasi-absolute tape type optical encoders to provide axis angular position feedback. These tapes contain closely spaced unique reference marks that require a very small rotation to determine absolute position upon power up. Each axis angular position is determined by averaging positions obtained from four (4) read heads. The azimuth encoder configuration places the tape mount ring on the structurally isolated center of the pier. The tape ring is supported on the opposite end from the pier by a centering (pintle) bearing mounted in a flex plate arrangement. The encoder read heads are mounted inside of the yoke and rotate with the azimuth axis about the stationary tape ring. This encoder configuration on the azimuth axis provides very repeatable position feedback and has been used on other fielded telescopes. The elevation and Cassegrain axes hold the read heads stationary while the tape rotates with the axis.

2.4 Thermal Control of the Mount

Thermal stability is an important part of mount design. The mount design achieves thermal control by three means: insulation, air flow through the mount, and cooling of heat generating components.

Surfaces on the yoke will be insulated with rigid foam insulation.

A fan mounted on the facility floor will pull ambient air through the mount and into the facility mezzanine level. The OSS will be designed with air passages that will allow a blower mounted on the facility floor to pull air through the OSS starting at the top end, through the OSS tube truss and elevation ring, and exhaust it through the facility fan. The yoke will be designed to take in air through the elevation bearing housings and move it through the yoke structure and exhaust it through the same fan. Exhaust air from this fan is then vented to the outside by means of the enclosure air circulation system.

All components that generate more than 100 W of heat will be cooled by a glycol/water mixture. These components include the drive motors on the elevation, azimuth, Nasmyth, and Cassegrain axes (both the rotator and the cable wrap). Each component of the azimuth drive train will be individually plumbed for cooling lines. Each instrument on the mount will be cooled as well, many of them, such as the PFA and the Cassegrain rotator instruments, being designed with their own cooling system. Finally, the electronics cabinets supported on the yoke will also be glycol cooled.

3 PROGRAM MANAGEMENT

The design, fabrication, and installation of the DCT is being managed to provide maximum efficiencies in schedule and cost.

The critical path on the schedule is defined by the long lead times of the bearings, both azimuth and elevation. The current worldwide demand for bearings in the wind turbine industry has created a large backlog at every bearing manufacturer. The azimuth and elevation bearings were ordered at the beginning of the project and will be delivered directly to the point of assembly. In the case of the azimuth bearing, that will mean delivery directly to the installation site.

The project realized cost savings by leveraging off of the success of previous designs. Portions of the design are nearly build-to-print. These details include the elevation bearing housings, cable wraps, elevation and azimuth drives, encoder mounts, and elevation and azimuth bearings. In addition to savings in design, this approach provides savings in fabrication and testing.