1992ESOC...42..543E

# STATUS OF THE ADVANCED ELECTRO-OPTICAL SYSTEM (AEOS) TELESCOPE PROGRAM

**Richard Elder II**

The Advanced Electro Optical System (AEOS) is a Congressionally-directed program to upgrade the current Air Force Maui Optical Station (AMOS) located atop Mount Haleakala on the island of Maui, Hawaii. The current schedule calls for a thirty-month technical effort to design, fabricate, manufacture, integrate, and install the AEOS telescope. The system will be housed in a new facility completely integrated into the existing AMOS site and will utilize an advanced adaptive optics atmospheric compensation system. The Air Force procurement of a 3.67 meter (12.04 feet) astronomical and tracking telescope is essential to the required mission of AMOS. The telescope procurement process was started with an evaluation of primary mirror technologies. One of the requirements placed on the primary mirror was to minimize its thermal mass. Existing technologies, mirror lightweighting techniques, and new technologies were considered. A lightweight, low thermal expansion, thin meniscus primary was the final selection for the primary mirror. This mirror is made of Zerodur by Schott Glaswerke of Mainz, Germany and has a diameter of 3.694 meters and a thickness of 15 centimeters. Once complete, the facility will be used for satellite discrimination, rocket, missile, and aircraft tracking, and astronomical observations. The facility is anticipated to be open to both DoD and non-Dod users. This will allow the international astronomical community access to this unique site.

As noted, the AEOS telescope is a thirty-month technical effort. AEOS is anticipated to achieve operational first light in Summer 1995. To accomplish this robust schedule, the program is composed of numerous sequential and parallel activities including environmental assessments, construction, fabrication, mirror generation, and design work.

The major subsystems consist of (1) a 3.69 meter telescope structure containing the primary, secondary, and tertiary mirrors; (2) an elevation over azimuth gimbal set which contains bearings, angular position sensors, electrical drive motors, cabling and fluid service lines, air lines for the primary mirror support cell and thermal conditioning of the primary mirror, and the optical coudè path; (3) the gimbal system electronics which contain angular position sensor reading and servo electronics and motor drive power amplifiers; and (4) the control console which contains a display of information related to the position, motion, and status of the gimbal, a keypad for inputting commands, an analog signal input device for manual control of the gimbal position, an interface to input control commands to the control console from the user's computer, and the primary mirror figure control.

The unvignetted field of view (FOV) of the telescope will be circular with an angular radius of 1000μR (2.0 mR full field angle) at the Cassegrain focus. All of the optical elements and all of the structure of the system will support this unvignetted FOV for all focus positions from 3.5 km to infinity.

The mechanical and optical structures will, during any one hour period, be thermally and mechanically stable such that the optical line of sight will be repeatable with respect to the gimbal readouts to better than ±20μR peak for ambient atmospheric temperature variations of ±2.78°C (±5.0°F) or less and no wind and to better than ±100μR peak for any temperature between -6.67°C and 30.00°C (20° and 86°F).

The gimbal system will be capable of directing the angular position sensor line of sight along the trajectory of a satellite in a 250 km high circular orbit when the trajectory passes 5.5° from zenith in such a way that the optical axis angular position sensor line of sight never deviates more than 40μR, peak, from the actual line of sight profile at any point along the satellite's trajectory. Furthermore, the gimbal system will be capable of directing the angular position sensor line of sight along the path of a star that passes within 1° of zenith with an angular position sensor line of sight error that never exceeds 5μR, peak, at any point along the path. The additional requirement for angular velocity and acceleration profiles will include the capability to track a rocket launched at or from nearby facilities. The velocity and acceleration profiles for the satellite and rocket launches are as follows: azimuth axis velocity--17.0°/s; azimuth axis acceleration--5.0°/$s^2$; elevation axis velocity--4.75°/s;elevation axis acceleration--2.25°/$s^2$.

The gimbal system will be an elevation over azimuth arrangement. The gimbal system's function is to support and position the telescope structure in response to commands of the gimbal system electronics. Motors will be installed to drive the gimbal axes. Shaft angle angular position sensors will be provided which will report shaft angles with sufficient accuracy and read-out bandwidth to meet all of the operating requirements. Specifically, the minimum acceptable bit value of the shaft angle angular position sensors will be 24 bits across 360°. The mechanical mount will have a yoke which supports the telescope structure, and a base which will provide for azimuthal rotation. The telescope structure will be made up of the trunnion box, truss, and primary mirror subassembly and will house a direct-drive drive system. The trunnion box will have sufficient torsional stiffness to transmit the torque loads of the elevation drive system to the telescope structure, and will have sufficient bending stiffness to maintain the alignment of the elevation axis. The trunnion shaft may be constrained in both yoke tines to prevent motion along its axis. One end of the trunnion shaft will have a minimum inner diameter suitable for the coudè path. The mechanical mount will be designed such that, excluding the rigid body modes, there will be no mechanical resonances below 20 Hertz for any subsystems and an overall system mechanical resonance mode not less than 10 Hertz.

The yoke tines will contain the elevation drive and angular position sensors. The height of the yoke tines will allow clearance of the primary mirror subassembly through the elevation rotation of ±320° in the azimuth direction and -5° to +185° in the elevation. The telescope structure will include a rigid open frame truss with a ring/spider assembly/secondary mirror assembly at its open end. The other end of the truss will be attached to the front of the trunnion box. The primary mirror subassembly will attach to the rear of the trunnion box. The primary mirror subassembly may be inserted into the trunnion box to meet thermal requirements or center of gravity requirements. The truss will correctly position and rigidly support the secondary mirror, secondary mirror mount, and focus mechanism. The truss will be designed to reduce the effects of thermal expansion of the telescope structure and will provide a electro-mechanical means of adjusting the positions of the secondary mirror.

Optical line of sight motion relative to the mechanical axis of the telescope/mount will be a smooth, repeatable, and modelable function. These requirements apply for all line of sight directions within the range required in the specification. "Modelable" in this context means predictable for future times. This future time would be defined as the time up to the point that additional information for the next modelable calculation has been input to the model. This time period will depend upon the system calibration update and operational periods/constraints/parameters.

The telescope structure will be designed and fabricated in a way which properly takes into account the need to minimize thermal stagnation in the optical path in front of the primary mirror. A face sheet purge of the primary mirror is one option to minimize thermal stagnation.

Additional provisions will be included to attach an alternative beam path at the Nasmyth focus (the "auxiliary beam path"). The auxiliary beam path mirrors and mirror mounts will be removable. All mirror mounts (except the primary mirror cell) will be adjustable as needed to smoothly bring the image of the optical axis of the telescope into coincidence with the gimbal rotation axes. This provision will allow a laser guidestar beam to be propagated along the line of sight of the telescope. Given the current beam directors and other telescopes at the AMOS site, this additional capability will allow for multiple illuminations of separately targetable bodies.

The telescope is to have multiple foci to allow optimum placement of sensors to match field-of-view or plate scale at sensor focal planes, or to allow best operation in specific wavelength bands. Table 4 summarizes the optical foci to be accommodated, the focal lengths and focal ratios and back focal distances desired, and the minimum unvignetted FOV required at each location.

The tertiary mirror and mount will be remotely adjustable (for alignment procedures) and provide adequate stiffness to meet the jitter specifications. The tertiary mount will be capable of pointing at the coudè focus and at the Nasmyth focus with reproducible accuracy. The switching of the tertiary between the coudè focus and the Nasmyth focus will not be more than ±10µrad out of alignment (object space). The tertiary mirror and mount will be removable so that the primary mirror is accessible for recoating.

Additional mounts will be provided to attach acquisition sensors, an aircraft detection radar, and a sun sensor. These additional mounts will not interfere with the rotation of the elevation axis nor will the additional mounts restrict the clear aperture of the system in any way. The gimbal system will be designed to minimize the angular position sensor line of sight jitter due to servo system drive errors and imperfections in the bearings that support the azimuth and elevation axes. The jitter will range from less than 10µR for 0.1-10 Hz to less than 50nR for 100-1000Hz.

The telescope will be configured with a single secondary mirror having a clear aperture NTE 45 cm and to provide a back focal distance of 30 ±1.0 meters measured from the secondary mirror vertex at the coudè focus. The telescope will employ selection mirrors and an optical reimaging system to allow various FOVs to be obtained. The Nasmyth 2 position will be dedicated to the laser illumination system. Nasmyth 1 will have a selector mirror tot position the image to one of three Nasmyth blanchard locations or the the coudè reimaging system.

The reimaging system is comprised of an ellipsoid to achieve the proper focal length, a perforated flat located near the elevation axis, and a flat for focusing the image to the coudè path. The telescope has two bent Cassegrain locations. Located outside the trunnion box, each position has a selector mirror which allows imaging to one of the two instrumentation locations (for a total of four bent Cassegrain instrumentation locations). One of the four positions will be dedicated to a wavefront sensor.

The optical elements (referencing all elements except the primary mirror) will impose a total combined static wavefront error of less than 0.20 $\lambda$ RMS at a wavelength of 0.6328 µm on the wavefront passing through the telescope. Furthermore, the optical quality of these elements will be such that when used with the primary mirror in the telescope the final on-axis image will have a FWHM not to exceed 0.15 arc seconds with 80% of the energy in a 0.30 arc second diameter circle. The total combined static wavefront error will be less than or equal to 0.20 wave RMS at a wavelength of 6328Å. Also, the small scale optical surface roughness will result in a loss of light in the image due to wide angle scatter not to exceed 0.5% at a wavelength of 0.6328µm. The optical elements will all be fabricated of a low thermal expansion material and be polished with a scratch-dig surface quality of 40-20. Coated with enhanced silver, the minimum reflectivity will be 98% with an uncoated surface roughness of 10Å.

The final polished quality of the primary mirror will be less than or equal to 0.10 λ RMS wavefront at 0.6328 μm with the maximum FWHM image NTE 0.125 arc seconds. The maximum peak-to-valley (p-v) mirror surface deviation will not exceed 1 wave p-v at 6328Å wavelength at any location or at any spatial frequency within this specified effective clear aperture. Any micro-cracks in the primary mirror will be treated by annealing, etching, or polishing. The mirror's surface figure will be tested interferometrically with an approved null lens and associated test and data reduction equipment and procedures.

Final testing and figure certification will be conducted with the mirror in the telescope mounting cell. Mirror orientation for these tests will be such that the mirror optical axis is vertical. Calculations of mirror deflection and wavefront error resulting from operation in other mirror/cell orientations will also be accomplished. Figure testing conducted after receipt of the mirror at the AMOS site facility will be in the operational mirror cell.

The surface will be polished with surface quality of 80-50 and have uncoated surface roughness of 20Å RMS or better. The mirror will be vacuum coated with pure aluminum. The minimum acceptable coating will have an 87% reflectivity at 6328Å. The reflectance will be measured with a minimum of eighteen witness samples which will be coated in the same run as the primary mirror. The primary mirror will have a FWHM NTE 0.125 arc sec with 80% of the incident energy from a 0.6328μm point source wavelength on-axis at infinity into a 0.25 arc second diameter circle at the image plane.

When completed, the AEOS telescope and facility will offer users from around the world the opportunity to engage and illuminate objects previously undetectable. It is anticipated that the information to be learned about quasars alone will significantly advance the research in this field. While a Government project, this telescope represents the ability for the world scientific community to utilize a resource most would have previously predicted unattainable. This window of opportunity can only enlarge given the cooperation of the various astronomical communities, both Government and academic. The Phillips Laboratory is committed to pursuing this cooperative endeavor.

| Focus Location | Focal Length (cm) | f/# | Limiting Aperture (cm) | FOV (mrad) | BFD (cm) |
|---|---|---|---|---|---|
| Primary | 550.5 | 1.50 | N/A | N/A | N/A |
| Coudè | 25,000 | 68 | 35 (elevation axis bearing ID) | ±0.15 | 3000 ±100 (BFD from secondary mirror vertex) |
| Bent Cass | 4933 | 13.4 | 47 (primary mirror) perforation) | ±1.0 | 300 +0 -40 (BFD from primary mirror vertex) |
| Nasmyth 1 | 4933 | 13.4 | 35 (bearing ID) | ±1.0 | 20 (BFD from Nasmyth blanchard) |
| Nasmyth 2 (with Focal Reducer) | 3000 | 8.2 | 20 (bearing ID)<br>(30 is goal) | ±1.5 | TBD |

Table 1: Optical Configurations for 3.67 Meter Telescope