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Carbon Fiber Reinforced Polymer (CFRP) Telescope Program at the Naval Research Laboratory

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Introduction: The Navy Prototype Optical Interferometer (NPOI) is actively involved in a program to upgrade its collection apertures from a few tens of centimeters to 1.4 meters. This will dramatically increase its light collection capabilities and thus improve the sensitivity from 6th to nearly 12th magnitude, opening up a much larger selection of observable stars. This program leverages the use of lightweight carbon fiber reinforced polymer (CFRP) for telescope construction, allowing each telescope to be moved from one location to another, providing a reconfigurable array of telescopes[1] rather than a large number of fixed telescopes.

There are several advantages to using CFRP as the construction material for telescopes, including an order of magnitude decrease in weight, which supports easier transportation from station to station on the array. As all components of the telescope, including optics, are constructed from composite materials having a low coefficient of thermal expansion, dimensional changes due to temperature variations can be minimized. A major benefit to this approach, which requires multiple, identical optical components, is that they are made from a single, high-precision tool, allowing a much shorter production cycle than traditional steel and glass telescopes[2] and keeping all replicated components identical and interchangeable. Composite materials provide a structurally stiff and very durable telescope that has superior performance to glass in harsh environments such as space.

Lightweight Telescope: Construction of optical quality surfaces from composite material required an iterative process to meet the near-diffraction-limited performance required in the design. The first step was to construct a prototype 0.4-meter telescope (Fig. 7). This provided a fully functional telescope available for testing and troubleshooting while the 1.4-meter telescope was under development.

The development of the 1.4-meter telescope will require adaptive optics (AO) to correct for the effects of the atmosphere in degrading the optical wavefront quality. Novel AO systems have been developed and tested that make use of technological advancements in computer controls and microelectromechanical systems (MEMS) hardware that have reduced the size and cost of an AO system.

Prototype 0.4-meter CFRP Telescope and Mount with Integrated AO: The prototype 0.4-meter CFRP telescope has been under development since 2004. The final weight of each component is given in Table 1. This system could be reconfigured with the electronics box setup in a fixed location to maintain lower weight of the optical telescope assembly (OTA), mount, drive motors, and AO. As a comparison, the 0.4-meter Meade telescope weighs 104 kg without an AO system, mount, or counterweights.

A direct drive system was chosen for maximum stiffness and pointing precision. This drive system is realized with ultrasonic piezoelectric motors driving a static ceramic ring. This unique drive configuration is possible because of the low mass (and low rotational inertia) of the system. This system has realized a maximum slew speed in excess of 15 deg/s with tracking speed exceeding 1 deg/sec. The encoders and feedback system have so far produced a pointing accuracy of 1.5 arcseconds, but ongoing work on mount characterization should realize a further reduction in error.

The 1.4-meter CFRP Telescope: The 1.4-meter telescope, currently under development at Composite Mirror Applications Inc., is anticipated to have a weight of 120 kg, including all optics (Fig. 8). A traditional steel and glass telescope of comparable size can easily weigh more than a ton. The current telescope design, when used to populate the NPOI array, will track at sidereal rate; however, the drive system is capable of dramatically exceeding sidereal rate.

A hexapod structure is used to adjust the secondary mirror for alignment with six degrees of freedom. In order to keep the weight near the center of gravity as much as possible, piezoelectric screw-drive motors were designed into the telescope base as shown in Fig. 9. Computer control will allow adjustment of the secondary mirror in x, y, and z translation, as well as tip, tilt, and piston. Additionally, temperature sensors and accelerometers will be fitted into the support structure of the 1.4-meter telescope. This will allow real-time measurement of critical performance parameters.

Conclusions: The CFRP optics and telescope program at NRL will provide a significant improvement to the sensitivity of the NPOI measurements. The need for enhancing the performance of the NPOI has driven many of the advances and improvements in CFRP optics and telescope assemblies. These improvements have already generated the 0.4-meter telescope with integrated AO and a 1.4-meter telescope for use on the array. The advances in CFRP technology

have spawned the development of CFRP deformable mirrors, and current efforts include analysis of the performance and long-term stability of these devices.
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References

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[2] J.R. Andrews, F.E. Penado, S.T. Broome, C.C. Wilcox, S.R. Restaino, T. Martinez, S.W. Teare, and F. Santiago, "Characterization of the Lightweight Telescope Developed for the NPOI," *Proc. SPIE* **6267**, 6267EQ (2006).

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TABLE 1 — Mass of 0.4-meter Telescope Components

OTA with CFRP optics	10 kg
Mount, electronics box (no electronics)	80 kg
White AO box	16 kg
Breadboard	7 kg
AO optics	<10 kg
Counterweights	8–10 kg

FIGURE 7
Exploded view of the 0.4-meter telescope's optical telescope assembly (OTA) with all CFRP components, and the fully constructed 0.4-meter telescope with mount and integrated adaptive optics (AO) box.

FIGURE 8
Fully constructed 1.4-meter CFRP telescope with hexapod controlled secondary ring.

FIGURE 9
Piezoelectric screw-drive actuators for control of hexapod secondary ring.