Naval Prototype Optical Interferometer (NPOI) upgrade with light-weight telescopes and AO: a status update.

Sergio R. Restaino[1], Ty Martinez[1], Jonathan R. Andrews[1], Christopher C. Wilcox[1], S. Teare[2], Robert Romeo[3], Robert Martin[3], D. Wick[4]

[1]Naval Research Laboratory, Remote Sensing div. code 7216
3550 Aberdeen SE, Albuquerque NM 87117 USA
[2]New Mexico Tech., EE Dept., Socorro NM USA
[3]Composite Mirrors Applications
1638 S. Research Loop #100, Tucson AZ 85710 USA
[4]Sandia National Laboratories,
Albuquerque NM, USA

ABSTRACT

In this paper we present some preliminary results of an ultra-light weight telescope manufactured entirely with Carbon Fiber Reinforced Polymer (CFRP), including the optics, coupled with a light weight Adaptive Optics (AO) system. This research has many scopes, ranging from long baseline interferometry to laser communications. In this paper we will examine some of the mechanical properties of the telescope and describe the testing that the system is undergoing.

INTRODUCTION

The US Naval Research Laboratory (NRL) in conjunction with the US Naval Observatory (USNO) have developed and the functional Naval Prototype Optical Interferometer (NPOI) in Flagstaff, AZ. In the framework of upgrading the NPOI to larger apertures with AO, a vigorous program of research on light weight telescopes and AO systems was started a few years ago at NRL. Our attention and efforts have focused on the use of CRFP material for the optics and structure. The entire program is designed with a step-wise approach. The ultimate goal for this program is to produce at least three 1.4 meter class telescopes equipped with AO systems. The necessity for light weight structures is derived from the fact that the NPOI can be reconfigured by rearranging the collecting apertures in different stations in order to adjust the ultimate resolution of the instrument. In Figure 1 a schematic layout of the NPOI is shown. The squares represent existing stations where apertures can be located. The circled squares and diamonds represent existing apertures. The step-wise approach was used in order to insure that the capabilities and manufacturing process of such material for optics were well controlled. The first step was the production of a 16” diameter prototype Optical Telescope Assembly (OTA). In this paper we will describe two systems, both constructed around the prototype 16” OTA, as this aperture class will be the most useful for laser communications. The first is an OTA mounted on a modified 8” Celestron mount. The mechanical properties of this arrangement will be described and analyzed, and we will describe briefly our portable AO system that can be used in conjunction with this telescope. Finally we will describe the all CRFP mount and OTA with incorporated AO system. This system is currently under construction and will be available for testing by May of 2006.

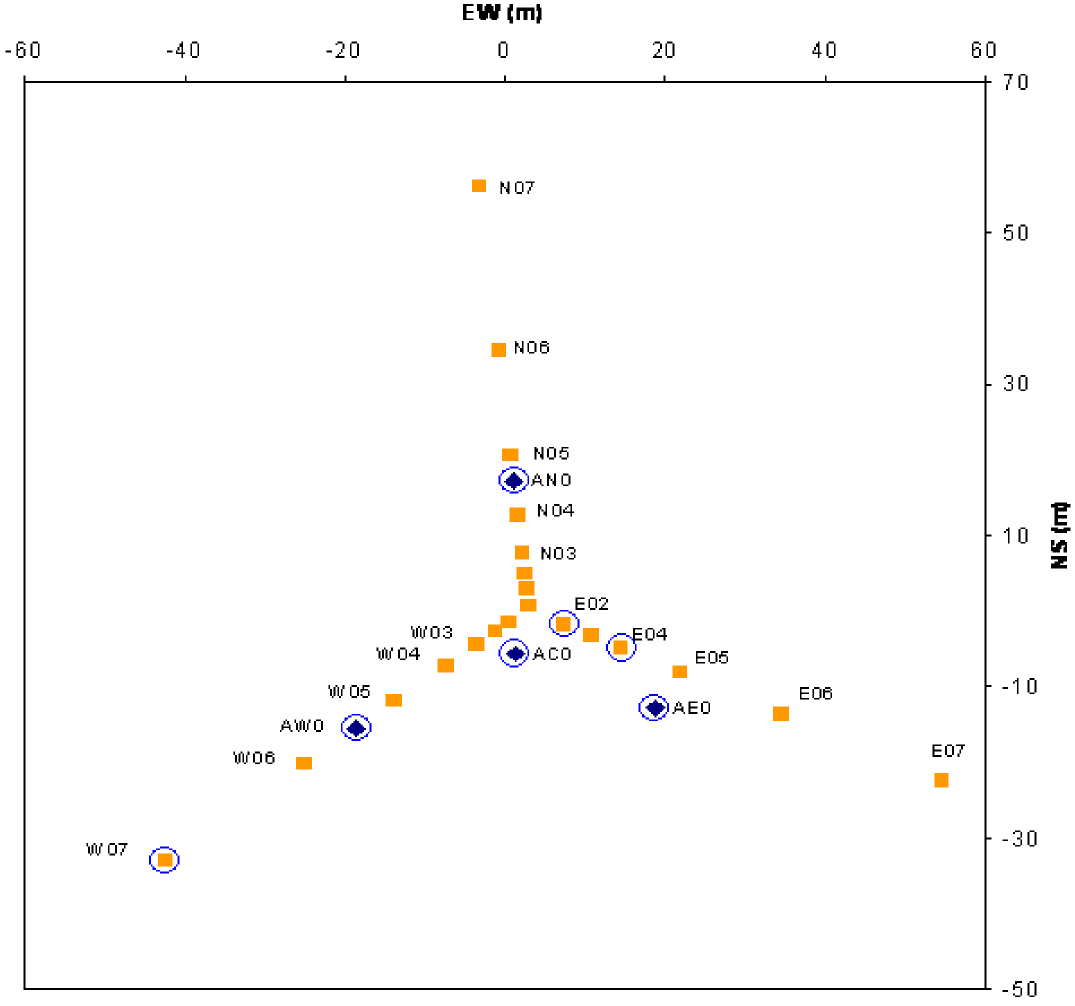

Figure 1: Schematic lay-out of the NPOI. The squares represent existing piers where apertures can be located. The circled squares and diamonds represent the existing apertures.

TELESCOPE DESCRIPTION

The 16” telescope is a standard Cassegrain telescope and the OTA is shown in Figure 2. There are several reasons for choosing CRFP material for both the optics and the structure. The CRFP is 1/3 to 1/10 the total mass of conventional mirror technologies, thus reducing the weight of the total OTA considerably. CRFP exhibits lower Coefficient of Thermal Expansion (CTE) than invar and since both optics and structure are made of the same materials this eliminates CTE mismatch that plague conventional telescopes. Replication, coupled with state-of-the-art techniques developed by CMA, lend themselves to repeatability in the production of numerous high precision surfaces from a single replicating tool. The replication process adds significant cost savings to the fabrication of optical mirrors. CFRP mirrors produced from a single mandrel exhibit radius of curvature matching to within 0.5 microns of each other, making the process ideal for segmented mirror systems. Composite mirrors are also very rugged and nearly unbreakable. Along with the near zero CTE, they are both vacuum and cryogenically stable. Composite mirrors can be fabricated from a wide range of composite materials allowing cost and design flexibility for a given application. Finally, this material is already in use for various aerospace applications, making an entire optical system constructed from CFRP highly interesting for both civilian and military applications.

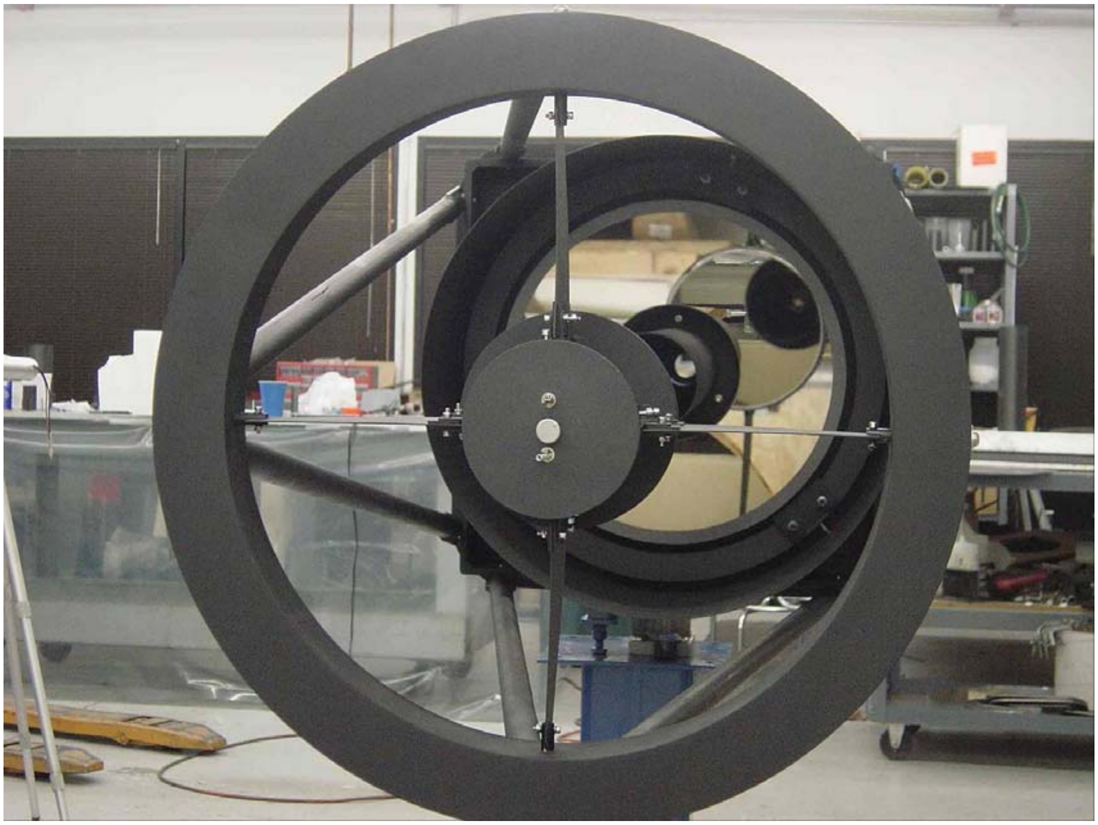

Figure 2: The Optical Telescope Assembly of the 16” telescope.

The weight of the entire OTA is 20 lbs, nearly equivalent to that of the standard 8” Celestron telescope, so the decision was made to modify the Celestron mount to accommodate the larger aperture. Composite Mirror Applications (CMA) developed an “extension” bracket that allowed us to mount the 16” OTA onto the 8” Celestron mount, leaving room for instrumentation, as shown in Figure 3. Attachments were included for a counter weight to offset the difference between the center of gravity and the mechanical axis of rotation of the telescope.

Figure 3: the 16” OTA mounted on the 8” Celestron mount.

The controller for the mount and the AO system is also a novel system based on USB protocol and described on a paper presented at Free-Space Laser Communications V [1].

MECHANICAL PROPERTIES

The first order of business was the measurements of the mechanical properties of the mount. We performed both static (i.e. impulse response) and dynamic (i.e. during tracking) tests using commercial accelerometers. The results of these measurements and analysis are briefly reported in this section. For the impulse measurement we used a lead mass to measure dampening constant of the OTA. Figure 4 shows an example of the measured decay

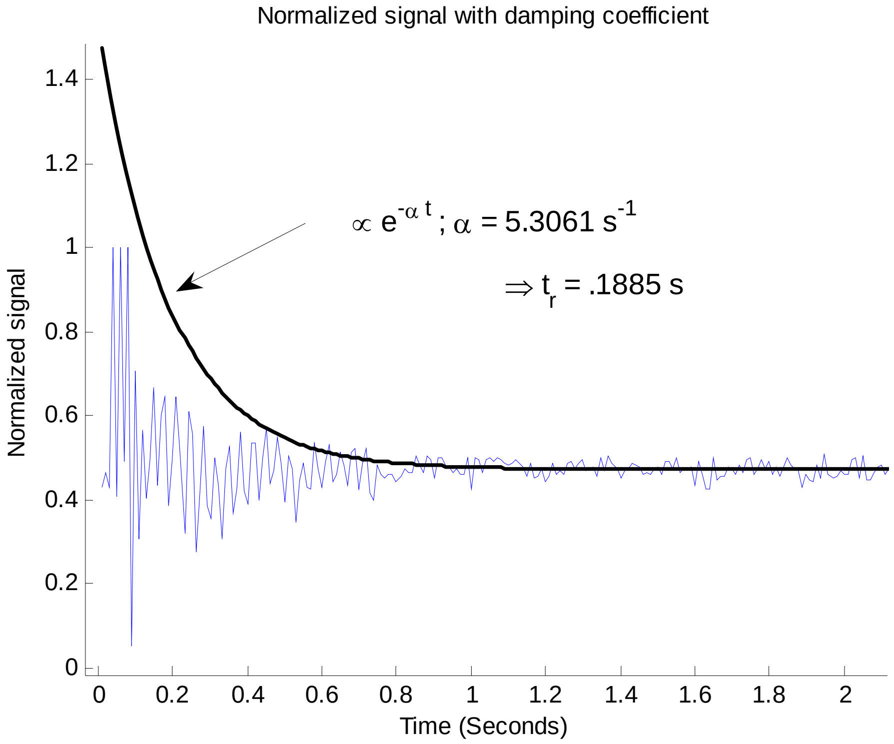

Figure 4: Accelerometer response to impulse signal with damping curve fit.

Several fits to the data were made, where the analytic form of the expression varied from a standard exponential function of the form:

$$f(t) = Ae^{-\alpha t}$$

to more accurate forms like:

$$f(t) = Ae^{-\alpha t}\left[B\sin(\beta t) + C\cos(\gamma t)\right] + D\,.$$

In this case the constants are α=5.3601, β=14.6149 and γ=27.9204. In all cases the damping constant is the same. The values are quite reasonable and easy to control with an active control or through a feed-forward to our tip/tilt mirror system if higher stability is required.

THE AO SYSTEM

The development of a portable AO system was carried out under the same framework as the light weight telescopes. The first prototype is described in a previous publication [2]. Further refinement of the optical layout and physical form factor has generated a new design for the integration of the AO directly into the telescope structure. Figure 5 shows the CAD design of the telescope with integrated AO system.

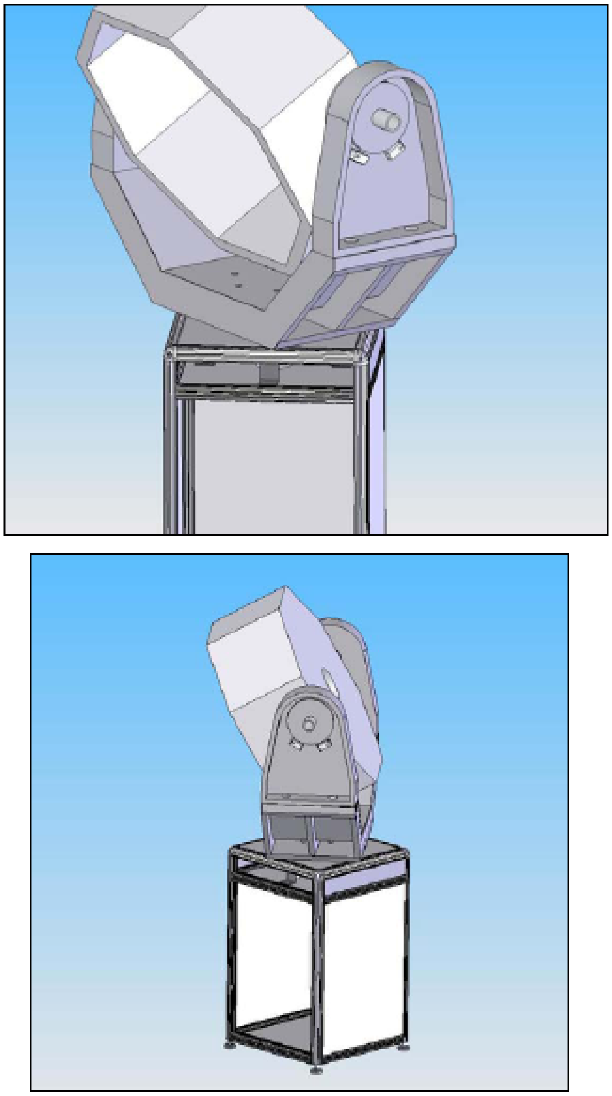

Figure 5: CAD design of the mount for the 16 telescope with AO. The AO system will be accommodated in the hollow portion of the octagonal mirror cell.

This compact design will allow for a fully transportable 16” telescope with AO. This design, we feel, will be uniquely suited to laser communications applications due to its agility and portability. The AO system will help to lower the required power of the laser and thus reduce the total power requirements, and it will decrease the Error-Bit-Rate caused by atmospheric turbulence.

SUMMARY

In this paper we have presented a novel light weight telescope that in conjunction with a light-weight AO system can become an extremely useful tool for laser communications. We envision the use of this telescope especially in the context of asymmetric laser communications where all burdens rest with the interrogator. By making the interrogator portable with atmospheric compensation, we can apply this investigation to military applications where the need for fast relocation is much higher than for civilian systems. As this prototype telescope will be scaled to a 1.4 meter telescopes for integration at the NPOI, one of our future goals for this program is to understand the limitations of scalability of these systems.

REFERENCES

1. J. Andrews, S. Teare, S. Restaino, C. Wilcox, D. Payne, “Characterization of Computer I/O Peripherals for use in Adaptive Optics”, S.P.I.E. Proc. 5892-22 (2005)

2. S. R. Restaino, G.C. Gilbreath, D.M. Payne, J.R. Andrews, “Experimental Results of a MEM based adaptive optics system”, JM3 **4,** 041601 (2005)