Compliant Baffle for Large Telescope Daylight Imaging

Steven Griffin, Andrew Whiting, Shawn Haar
The Boeing Company

Stacie Williams
Air Force Research Laboratory

ABSTRACT

With the recent interest in daylight imaging, a baffle was needed to reduce background light during the day but not impact wind loading induced jitter on the 3.6 m telescope. Analysis was performed to design a compliant baffle out of a synthetic fabric that satisfied these requirements. Initial testing showed that static loading increased as predicted by classical wind drag analysis techniques, and wind induced jitter remained the same or decreased slightly. This paper will present further testing to quantify this effect and offer a physical explanation based on the design analysis models and wind pressure data collected with and without the baffle installed. The metric used to quantify jitter will be a comparison of angular rate sensors and accelerometers mounted on the telescope.

1.0 INTRODUCTION

Unsteady wind loading is the largest dynamic loading on most large ground telescopes. The maximum operational wind speed not only sets requirements on the wind load rejection performance of the mount control system but also is a significant driver for tracker error rejection. In addition, turbulence due to the wind contributes to wavefront distortion. With the recent interest in daylight imaging, introduction of a baffle that reduces background light during the day may further accentuate wind loading on the 3.6 m telescope. The initial daylight configuration of the telescope has been to operate without a baffle and to use operational constraints to avoid angles close to the sun. This configuration offers reasonable daylight performance but is susceptible to stray light that limits achievable signal-to-noise ratio. Currently under test is a unique baffled configuration where the telescope is shrouded with a compliant fabric to increase image signal-to-noise ratio. Traditional, relatively rigid baffles increase jitter and wind loading due to increased exposed area to the wind and increase wavefront distortion due to thermal gradients introduced by the baffle. The 3.6 m telescope baffle has been designed out of an opaque, compliant fabric to limit the negative impacts on jitter and wavefront distortion while increasing signal-to-noise ratio for daylight imaging. The intent of the design is to limit high frequency transmission of wind loading by the relatively compliant fabric and to allow some circulation using the fabric's porosity and low thermal mass to limit thermal gradients. This paper presents measured static loading, dynamic pressure data, and analytical results predicting jitter and mount control performance with and without a baffle.

ANALYSIS

A finite element model of the 3.6 m telescope shown in Fig. 1 was constructed. It includes the structural components and mechanisms of the azimuth and elevation axis as well as a model of the fabric baffle. The baffle derives its stiffness from the preload exerted by the ratcheted straps that attach the baffle. In order to perform a modal analysis of the telescope, a static analysis was required to calculate the increase in stiffness associated with the preload. The resulting modal analysis provided mode shapes and frequencies of the telescope for use in a state space model using mode superposition [1]. The state space model has disturbance force loading on the baffle and azimuth and elevation motor torques as inputs and elevation and azimuth angle tilts as outputs. A modal analysis of the same finite element model without the baffle was also performed for comparison. Despite inclusion of the preload on the model with the baffle, the large expanse of fabric introduced 99 additional modes over the unbaffled case below 15 Hz. State space models of both the baffled and unbaffled cases provided a means of studying the dynamic wind loading in each case. Representative servo loops were closed on the elevation and azimuth axes in the state space model, so that the impact on closed-loop behavior could be examined.

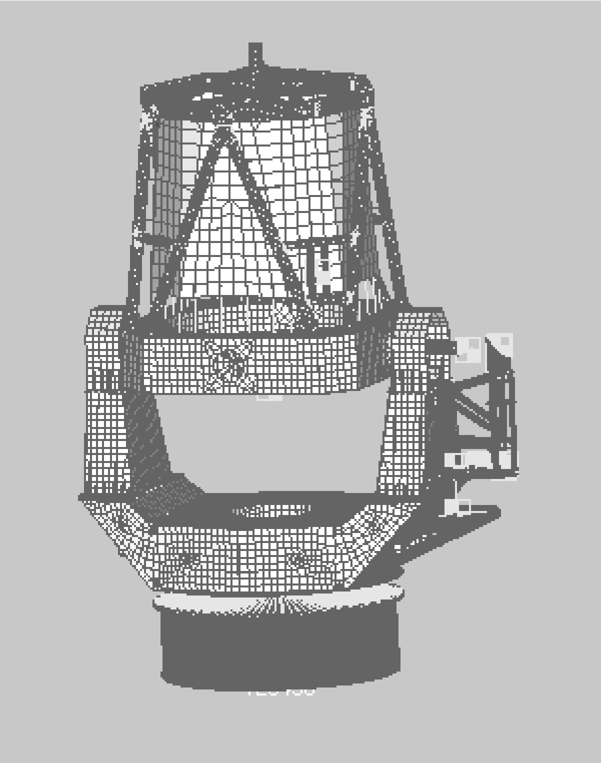

Fig. 1 Finite element model of the 3.6 telescope

A conservative assessment was performed to estimate the static wind load imparted to the telescope with the baffle installed in order to determine the maximum acceptable wind speed for operations. As the wind speed increases the gimbal motors will be required to increase the applied torque (proportional to wind speed squared) in order to hold the gimbal at the commanded angle. In addition the surface area of the baffle exposed to the wind will vary with gimbal angle with zenith pointing approximating normal incidence and a nominal worst case. For this analysis the elevation axis gimbal was of primary concern since it has only 20% of azimuth torque capability and 27% of the inertia. For the coefficient of drag, we used the value for a standard cylinder of 1.2. The baffle in a 25 mph wind has a approximate Reynolds number of 3×10^6 where the drag coefficient for a smooth cylinder is between 0.4 and 0.6. Since the baffle is a relatively short cylinder and it is the drag on the end that is important for the Torque, it is unclear how significant this drag reduction will be.   Therefore, to be conservative in the estimated torques, the drag coefficient was held constant. The expected wind torque with the baffle installed was between 1.7 and 2.5 times the torque on the open truss configuration. With the baffle installed, elevation axis torque demand was measured over the range of elevation angles from 0-90 deg in a 25mph wind condition with the telescope pointing upwind, downwind, and perpendicular. The resulting measured torque demand is shown in Figure 2. It is clear that the drag reduction presents itself in the measured data as likely in the range of 0.5 at 25mph. Torque demand was well within the gimbal motor capabilities and allows for telescope operation with the baffle under the standard wind limitation.

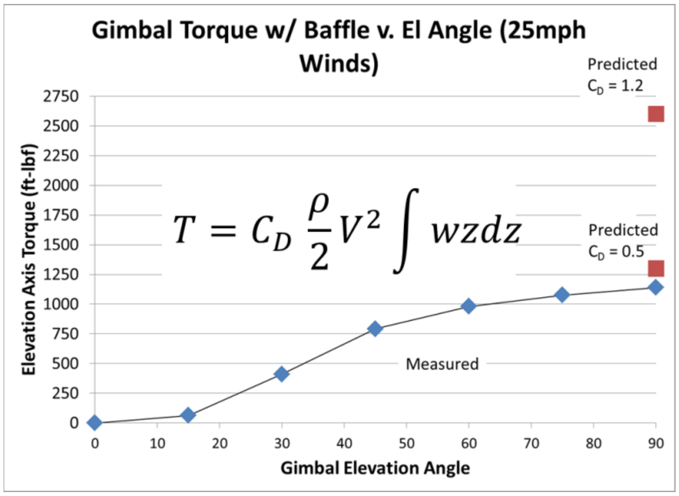

Fig. 2 Static wind load torque demand for cylinders vs. measured baffle

Wind buffeting on large, unbaffled telescopes has been shown to be accurately predicted by considering symmetric loading on the uppermost part at or near the secondary mirror [2]. Based on this assertion, the unbaffled state space model was used to predict the transfer function between a force applied on the structure supporting the secondary mirror and the resulting closed-loop tilt in the elevation axis. As mentioned previously, the elevation axis has considerably less inertia than the azimuth axis and is expected to be more susceptible to wind loading, so elevation axis tilt was used exclusively for comparison. Initial work [3] showed a comparison of baffle and no baffle transfer functions. In Figure 3, resulting transfer functions from two baffle fabric densities were modeled with one having 2x the density of the first.

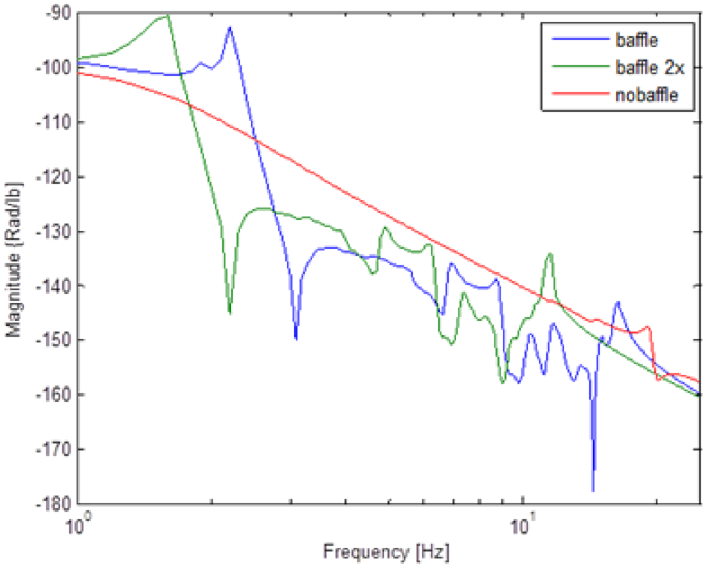

Fig. 3 – Predicted closed loop tilt transfer functions with the baffle (2 cases) and without

In the range of frequencies from approximately 2 to 10 Hz, the baffle clearly provides an attenuation of the load path. Below 2 Hz, the baffle appears to amplify the response. The increase in the density of the fabric selected appears to shift the amplification peak to lower frequencies. While this method of wind loading provides a good comparison between the baffled and unbaffled behavior of the telescope, it has the disadvantage of not exciting asymmetric telescope behavior in the elevation axis, which will tend not to be rejected by the elevation axis servo control and may contribute to absolute jitter levels. This is a limitation of this technique and a more complete analysis would require a distributed wind loading.

Pressure loading was measured in the vicinity of the secondary using an extremely low frequency microphone. Data was collected again with and without the baffle installed. The computed power spectrum of this pressure loading over the same frequency band of interest given by Fig. 3 is shown in Fig. 4.

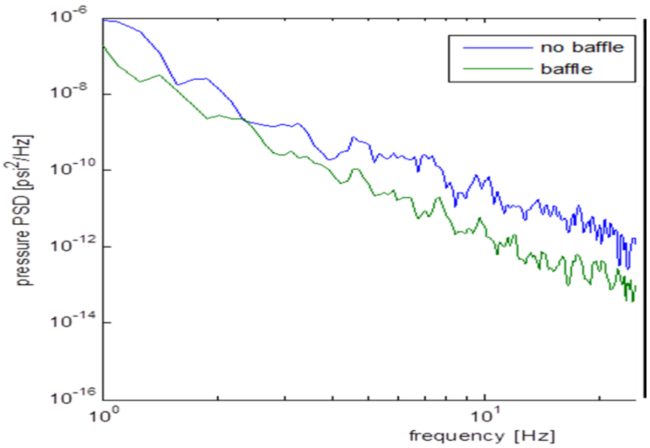

Fig. 4 – Measured dynamic pressure spectrum with and without baffle

The measured pressure was applied to the secondary structure and multiplied by the projected area of the supporting structure. This provided a force input to the no-baffle closed loop state space model, giving the predicted closed loop jitter result and back sum shown in Fig. 5.

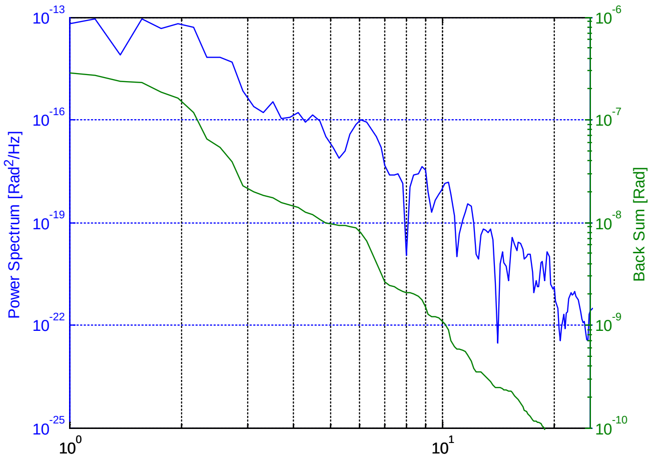

Fig. 5 Predicted jitter spectrum and backsum with and without baffle

The total predicted closed loop behavior due to wind loading is dominated by low frequency response. The prediction in Fig. 5 also shows that above 10 Hz, the contribution due to wind loading is negligible at around 1 nRad. In practice, wind loading is only a significant disturbance below 10 Hz. In future work, it is hoped distributed pressure measurements can be used to predict closed-loop elevation axis jitter with baffles of different densities and preloads.

2.0 CONCLUSION

Measurements were made of increased static current loads on the elevation axis motors that suggests the drag coefficient of the baffle is somewhere around .5, well below the recommended number for civil engineering structures of 1.2. A finite element method based dynamics model was used to predict closed-loop jitter due to wind loading on the 3.6 m telescope and to give a preliminary assessment on the impact of adding a baffle. Transfer functions produced by the model suggest that a load path through the baffle may see higher gain at low frequencies due to baffle resonances but generally lower gain at high frequencies due to the relatively compliant baffle's isolation of the load path between the wind and the telescope. A method for predicting elevation axis jitter was demonstrated using measured wind data, but distributed pressure measurements necessary for predicting elevation axis jitter with the baffle is planned in future work. A more extensive evaluation of compliant fabrics will allow for optimized design to minimize impacts to telescope jitter while maximizing stray light rejection.

3.0 REFERENCES

1. Huebner, K. et al, *The Finite Element Method for Engineers,* John Wiley & Sons, New York, NY. 2001.
2. MacMynowski, D et al., *Wind buffeting of large telescopes*. Applied Optics, 49 (4). pp 625-636, 2010.
3. Griffin et al., *Influence of Wind Buffeting on the 3.6 m Telescope*. Proc. AMOS Conference (2013).