APPROVED FOR PUBLIC RELEASE

High-resolution Assessment of Radiance And Measurements for Beam Experiments

MIDN Mark Dely MIDN Andrzej Korlacki MIDN Sean O'Dowd MIDN Sean Oser MIDN Lucas Wright

Prof. Marshall Millett Prof. John Burkhardt Prof. Cody Brownell Prof. Charles Nelson

USNA MECHANICAL AND NUCLEAR ENGINEERING
DESIGNING THE FUTURE

Problem Statement

Developing accurate and cost-effective models for assessing optical turbulence in maritime environments poses a significant challenge, particularly in the context of laser applications, due to the complexity and expense of testing and modeling for optimal laser performance in real-world contexts.

Background

Optical turbulence is a phenomenon that greatly affects the performance of optical systems, such as laser weapons and communications through disturbances and irregularities in the atmosphere. Optical turbulence generators (OTGs) are designed to induce this phenomenon on a much smaller scale to replicate a larger operating environment in a smaller laboratory setting for scientific study. Existing devices are limited in their flexibility, so there is great interest in a design which allows for multi-temperature air flow and the integration of aerosols to further research in this area.

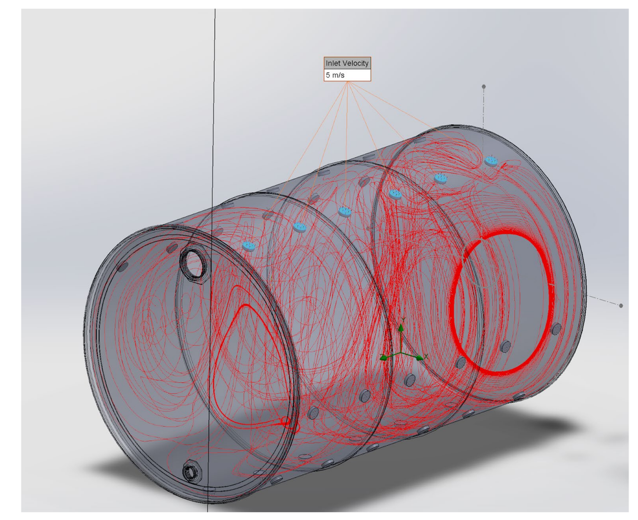
Use of Laser Systems in Military Applications.

Customer Requirements & Engineering Characteristics

The final design must integrate the following characteristics:

- The ability to measure the Scintillation Index (σ_I^2), or the normalized variation of irradiance fluctuations generated by the atmosphere.
- Minimized boundary effects seen in the OTG.
- Measurable characteristics within the OTG, such as temperature.
- Easily transportable.
- Allows for the possibility of introducing aerosols to increase the complexity of the possible environments simulated.
- Cost effective fabrication and implementation.

Prototyping



The original idea that was created was using a hexagonal prism design, such as the one featured above (left). This design was ultimately used as a proof of concept, and subsequently replaced by a more elegant solution using a 55 gallon barrel due to fabrication considerations. The refined concept is modeled above (right).

Testing & Evaluation

To test the design, the team used two methods of evaluation. For the first technique, thermocouples were installed perpendicular to the beam path, 1 cm apart, in order to record the air temperature at 1 second intervals. A constant, D_T was calculated for each thermocouple.

$$D_T = \langle |T_2 - T_1| \rangle^2$$

In a Kolmogorov turbulence scheme, the relationship between this D_T constant and the spacing between the thermocouples raised to the 2/3 power is expected to be linear.

$$D_T(r) = C_T^2 r^{2/3}$$

A regression is performed on the above equation between the distance between thermocouples (r) and the D_T constant, the slope for which is the C_T^2 constant, which, using the ambient temperature and pressure can be related to the index of refraction structure constant or C_n^2 .

$$C_n^2 = (77.8 \times 10^{-6} \frac{P}{T^2})^2 C_T^2$$

The other technique involves measuring the intensity of the laser using a camera to determine how much the intensity of the laser changes at particular points.

$$\sigma_I^2 = \frac{\langle \boldsymbol{I}^2 \rangle - \langle \boldsymbol{I} \rangle^2}{\langle \boldsymbol{I} \rangle^2}$$

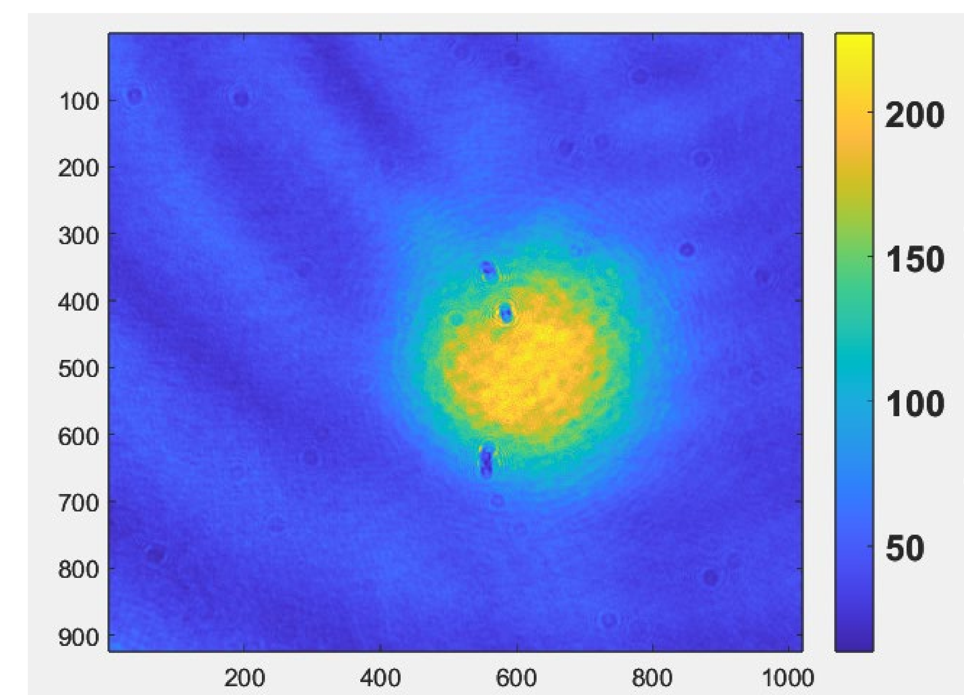
Evaluating the change in the intensity can be used to calculate the scintillation index (σ_I^2).

$$\sigma_I^2 = 1.23 C_n^2 k^{\frac{7}{6}} L^{\frac{11}{6}}$$

Using the above equation, the index of refraction structure constant can be calculated from the scintillation index.

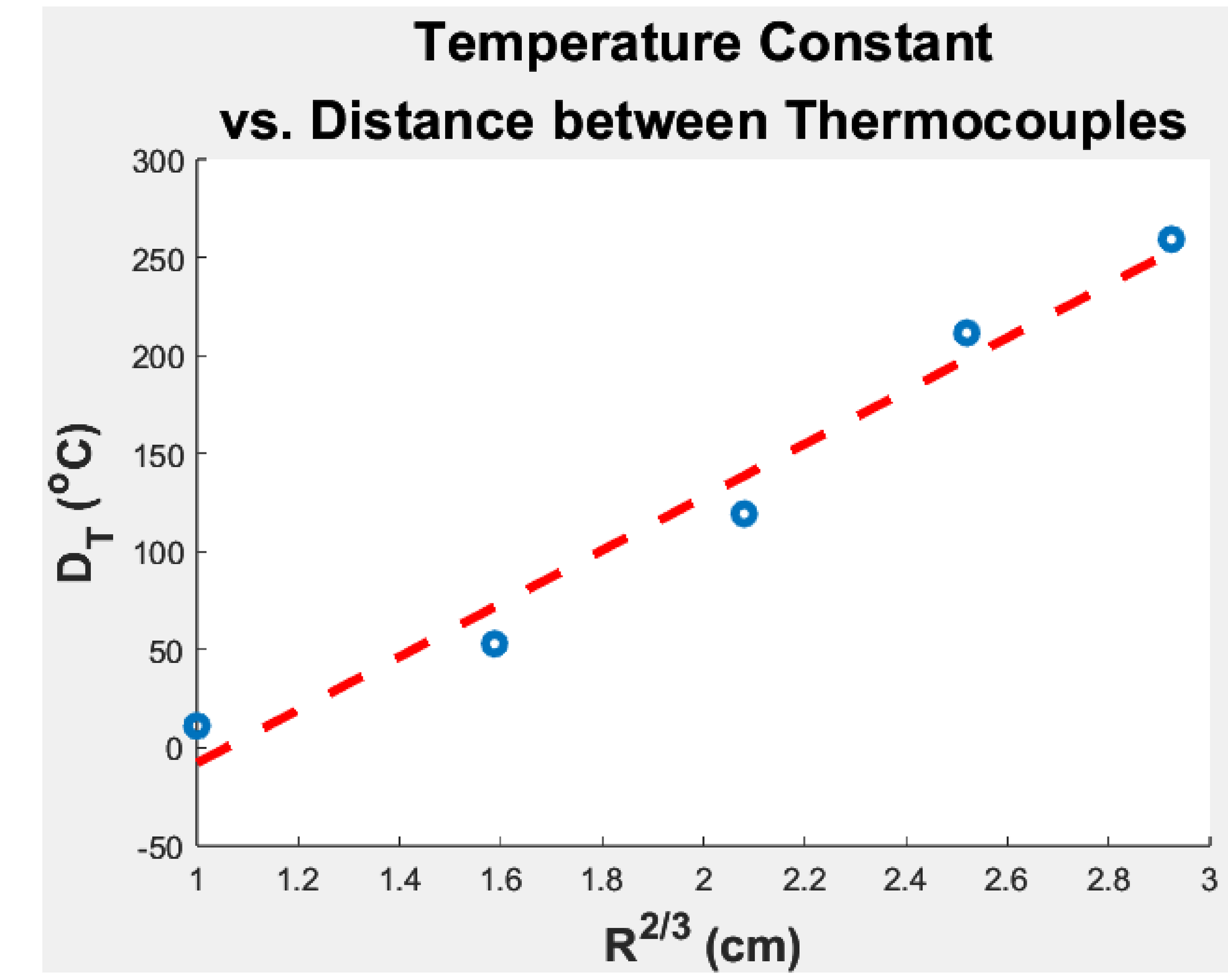
Results

A number of experimental configurations of the design were tested. As a consequence of the device's modularity, a full characterization of the chamber was not within the scope of the project at this time. Nonetheless, several different setups were tested. Both laser intensity and thermocouple temperature data were collected as the hot air inlet temperature was altered. **For the plots shown, the flowrates were kept constant while the temperatures were varied from 200°F to 600°F at 100°F increments.**



The heatmap shows the intensity of the laser as captured by the camera averaged over the course of the run. From the variance in the intensity, the scintillation index σ_I^2 was calculated. Using the wave number of the laser and the length of the chamber, the index of refraction structure constant was calculated.

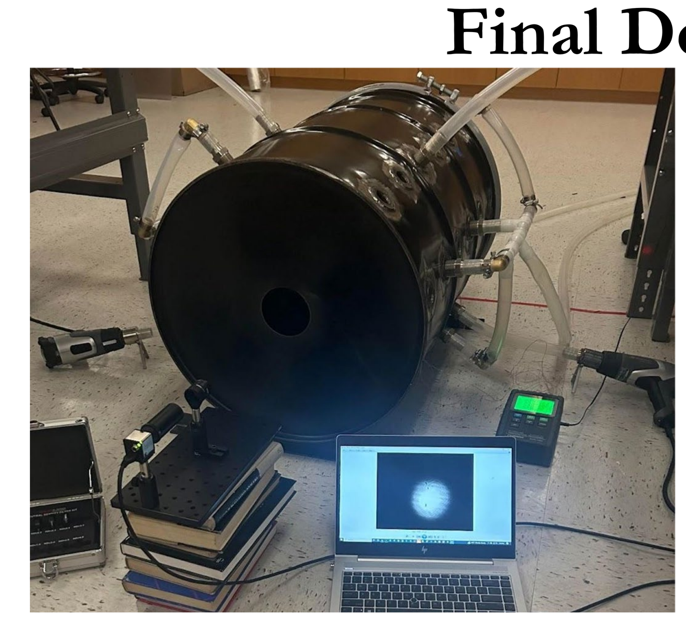
The temperature data from the same experiment were also analyzed. Using the equations listed under the Testing and Evaluation section, the D_T constant was calculated for each temperature range, which was used to determine the temperature structure constant. The plot shows the D_T constant plotted against the spacing between the thermocouples taken to the 2/3 power for a **heat gun setting of 400°F** for the hot air, which was then used to calculate C_n^2 as described in Testing and Evaluation.

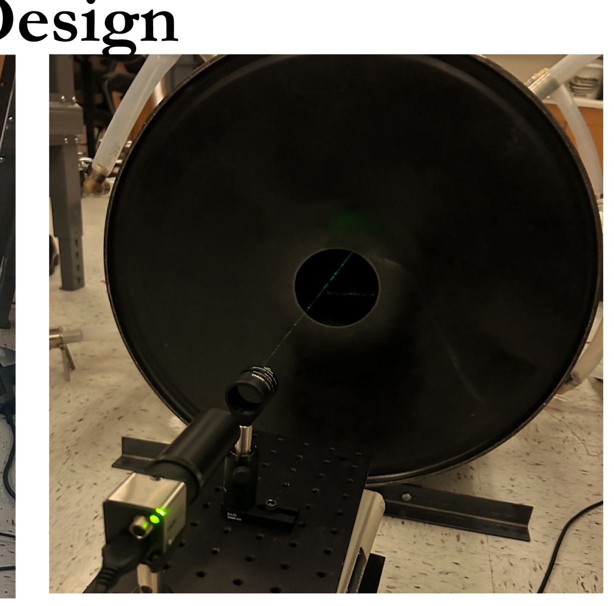


The results of the two sources of data were compared for accuracy. **Both produced C_n^2 values generally within the same order of magnitude on the scale of 10^{-11} to 10^{-10}.** Depending on the temperature setting, **the percent difference between index of refraction structure constants derived from the laser and temperature data ranged from 13.42% to 131.46%.** Further work is needed in order to develop a stricter and more accurate characterization of the system, and better understanding which dataset, if either, provides a more accurate measure of the optical turbulence being produced.

Most notably however, these **preliminary results support a successful conclusion of this project. The C_n^2 values calculated for this system were generally between 100 and 10,000 times larger** than those determined in Nelson et. al. which is within the desired range insofar as the distance being covered is approximately 1000 times shorter than the range over which the data in Nelson et. al. were collected.

Final Design





The final device is a modular cylindrical design with attachments that allow variations in air inlet temperature, location, and flow rate. Further, this design allows for the introduction of aerosols to study atmospheric particulates that have not been integrated into this research until now.

References

C. Nelson, et. al, "Measurements and comparison of the probability density and covariance functions of laser beam intensity fluctuations in a hot-air turbulence emulator with the maritime atmospheric environment", 2012.

L. Jolissaint, "Optical turbulence generators for testing astronomical adaptive optics systems: a review and designer guide", September 27, 2006.

T. Cherubini, S. Businger, "Another look at the refractive index structure function", February 1, 2013.

APPROVED FOR PUBLIC RELEASE