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Design Revision of Walters Probes—High Sensitivity Differential Temperature, CT2, Probes for Atmospheric Optical Turbulence Characterization

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Abstract

As the Department of Defense (DoD) and industry continue to advance the development of high energy laser (HEL)–based directed energy weapon (DEW) systems, the need for modernized test and evaluation (T&E) and experimentation capabilities for DEW has become critical. This will allow airborne, ship-based, and land-based HEL systems to be tested against air and surface targets in a well-understood atmospheric environment. T&E capabilities in maritime test arenas and land environments will be enhanced by instrumenting open-air test ranges with advanced sensor systems, including atmospheric optical turbulence measurement systems, which play a critical role in HEL device beam and fire control. Teknicare, Inc. has conducted extensive reverse engineering of an existing differential temperature sensor previously used in data collection at various locations including Starfire Optical Range, Los Alamos National Laboratory, Nevada Test Site, Nellis Air Force Base, San Nicolas Island & Point Mugu NAWC on the PMSR as well as China Lake NAWC. This effort has included detailed requirements analysis as well as research of related designs, schematics, theses and reports conducted at Naval Postgraduate School by Dr. Donald L. Walters and his students. The devices, now known as Walters Probes, make use of precision fine wire thermocouples separated at a known distance to provide a measurement of temperature difference. The associated electronics provide necessary amplification and sampling rate to ensure a measurable ensemble average is obtained to determine CT2 at the Walters Probe location. These systems are capable of low noise operation and hence measurement of CT2 values that render atmospheric optical turbulence at extreme values indicative of terrestrial neutral events, therefore they can easily measure values expected in the near maritime environment. Revisions to the design to enhance reliability, sustainability, operability and maintainability have been undertaken to ensure the Walters Probes meet T&E mission OPTEMPO requirements.

Motivation

The Department of Defense (DoD) and industry continue to advance the development of high energy laser (HEL)–based directed energy weapon (DEW) systems. Consequently, there is a need for modernized test and evaluation (T&E) and experimentation capabilities for DEW that has become critical. These capabilities will allow airborne, ship-based, and land-based HEL systems to be tested against air and surface targets in a well-understood atmospheric environment. T&E capabilities in maritime test arenas and land environments will be enhanced by instrumenting open-air test ranges with advanced sensor systems, including atmospheric optical turbulence measurement systems, which play a critical role in HEL device beam and fire control.

Background

Teknicare, Inc. has conducted extensive reverse engineering of an existing differential temperature sensor previously used in data collection at various locations including Starfire Optical Range, Los Alamos National Laboratory, Nevada Test Site, Nellis Air Force Base, San Nicolas Island, and Point Mugu NAWC on the PMSR as well as China Lake NAWC. This effort has included detailed requirements analysis as well as research of related designs, schematics, theses and reports conducted at Naval Postgraduate School by Dr. Donald L. Walters and his students. The devices, now known as Walters Probes, make use of precision fine wire thermocouples separated at a known distance to provide a measurement of temperature difference. The associated electronics provide necessary amplification and sampling rate to ensure a measurable ensemble average is obtained to determine C_T^2 at the Walters Probe location. These systems are capable of low noise operation and hence measurement of C_T^2

values that render atmospheric optical turbulence at extreme values indicative of terrestrial neutral events, therefore they can easily measure values expected in the near maritime environment. Revisions to the design to enhance reliability, sustainability, operability and maintainability have been undertaken to ensure the Walters Probes meet T&E mission OPTEMPO requirements.

Theory

The index-of-refraction structure parameter is a mean-square statistical average of the difference in the index of refraction between two points in space which are separated by the distance r_{12} (Walters, 1981). It is defined by

$$C_n^2=\langle(n_1-n_2)^2\rangle/r_{12}^{2/3},$$

where angled brackets stand for an ensemble average. The differences in index of refraction stem from density fluctuations induced by the velocity fluctuations in the atmosphere. These differences are caused by the mixing in a turbulent velocity field of passive contaminants such as heat and moisture. C_n^2 is quite difficult to measure directly. It is usually more convenient to measure the temperature structure parameter C_T^2, which is related to C_n^2 (neglecting humidity effects, which may have some contribution in maritime environments) by

$$C_n^2 = (79 \text{ X } 10^{-6}\ P/T^2)^2\ C_T^2$$

where P is the atmospheric pressure in millibars and T is the atmospheric temperature in Kelvins (Tatarski, 1961). C_T^2 is defined in a similar manner as C_n^2

$$C_T^2=\langle(T_1-T_2)^2\rangle/r_{12}^{2/3}.$$

This temperature structure parameter is commonly measured using a pair of fast response temperature probes as was done by Dr. Don Walters with his original devices shown in Figure 1.

Figure 1. Original Walters Probe with a Fixed Separation of 50 cm Between Thermocouples

Note: The rear plate is removed providing access to the device electronics. The horizontal arms each extend to a thermocouple used in tandem to measure temperature differences and calculate C_T^2 through an ensemble average. This configuration includes the option of power from an AC source. For transport, a protective assembly slides down each arm, is locked with a nylon screw and capped as shown on the right side.

Reverse Engineering

The original devices were documented only in an indirect manner (Holdaway, 2000; Hoover, 1991; Richardson, 1997; Roper, 1992) Related devices were described in theses and technical papers written by Dr. Don Walters' students. However, the devices acquired by Teknicare, Inc. had no direct documentation. Therefore, reverse engineering was necessary to determine function of these devices. It is important to note that these devices were used to gather data for research purposes in specific climatic conditions (mostly desert) and specific time durations (short term calibration of other turbulence measurement systems). As such, Teknicare, Inc.'s Senior Electrical Engineer had the daunting task of reverse engineering the devices to determine a jumping off point for modernization.

Requirements Development

In order to modernize these devices, it was necessary to understand their projected functional and non-functional requirements. A variety of operational environments were anticipated to include near maritime (on the shore) as well as possibly maritime (on a buoy). In addition, deployment duration was to be extended beyond the short-term calibration times used in the past. Requirements were developed through a stakeholder analysis with NAVAIR Pt. Mugu Geophysics Branch as well as the Teknicare, Inc. Senior Combat Systems Engineer. Both parties are experts in atmospheric characterization particularly when applied to laser propagation.

Design Revisions

A dual approach was taken to apply interim revisions in anticipation of modernized design.

First, the existing devices were improved against the maritime environment by sealing possible ingress locations where possible. In addition, the operational procedure was modified to include a gentle rinse of the thermocouples exposed to salt spray with distilled water. This was done each time the devices were rotated out of the measurement cycle on ~a daily basis.

Second, a single device was radically altered to provide a variable thermocouple separation capability. This alteration provided the developer a capability to determine if there was a more optimum thermocouple separation than that of the original design. It also provides the user with the option of exploring the nature of atmospheric optical turbulence in, say, the maritime environment to determine whether or not it conforms to the accepted Kolmogorov theory.

Interim Variable Separation Test Prototype

A simple approach was taken to provide a means of effectively varying the separation between the thermocouples so that they would remain fixed during a given test series. This approach consisted of fitting tubing with fittings that allowed freedom of movement and routing of the appropriate circuitry from the electronics box to the thermocouple location at each end. The arrangement is shown with thermocouple arms extended in Figure 2. The arrangement with the thermocouple arms folded for transport is shown in Figure 3.

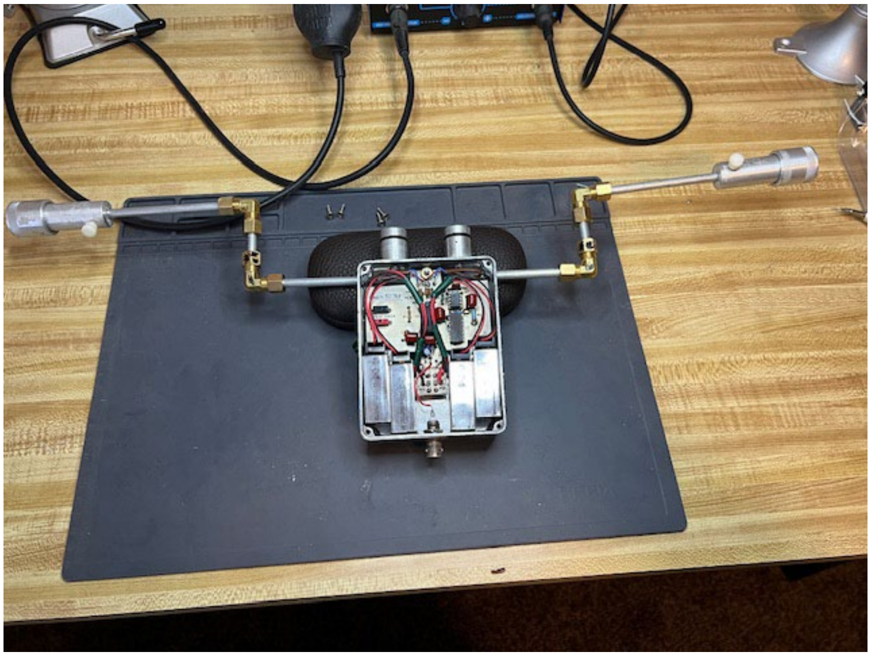

Figure 2. Interim Variable Separation Test Prototype with Thermocouple Arms Extended to maximum Separation

Note: The thermocouples are protected by the caps on the end of each arm. Batteries (9V Lithium) are internal to this version. The BNC data connector is visible at the bottom of the electronics box. The electronics box is exposed during a work in progress with the cover plate removed.

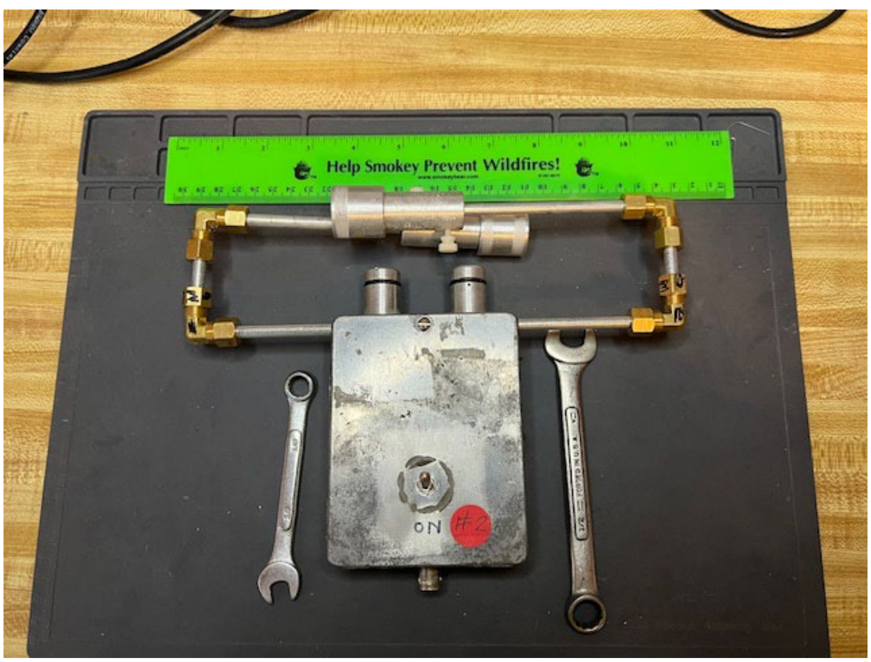

Figure 3. Interim Variable Separation Test Prototype with Thermocouple Arms Folded

Note: The thermocouples are protected by the caps on the end of each arm. The BNC data connector is visible at the bottom of the electronics box. The electronics box is now face up with the ON/OFF switch visible.

Summary/Conclusions

The modernization of the Walters Probe design is a continuing process. This work serves as a progress report along with an associated T&E report on the Interim Variable Separation Test Prototype (Nelson et. al., 2024). This test was conducted successfully and is detailed in that work.

Acknowledgments

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References

Holdaway, A.M. (2000). *Investigations of a single point temperature probe for measurement of atmospheric turbulence* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://hdl.handle.net/10945/28319

Hoover, C.R. (1991). *Turbulence profiles and outer length scale determination in the atmosphere using balloons* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://hdl.handle.net/10945/9361

Nelson, D., Edwards, K., Lee, J., Garcia, R., Johnson, J., West, S, & Kelchner, B. (2024). Test & evaluation of revised concept walters probes—High sensitivity differential temperature, CT2, probes for atmospheric optical turbulence characterization. *21st Annual Acquisition Research Symposium, Naval Postgraduate School*.

Richardson, D. J. (1997). *Solar heating effects on balloon-borne microthermal probes for the airborne laser program* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://hdl.handle.net/10945/8977

Roper, D. S. (1992). *Investigation of systematic effects in atmospheric microthermal probe data* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://hdl.handle.net/10945/23938

Tatarski, V.I. (1961). *Wave propagation in a turbulent medium.* McGraw-Hill.

Walters, D. L., & Kunkel, K. E. (1981). Atmospheric modulation transfer function for desert and mountain locations: the atmospheric effects on r_0. *J. Opt.Soc. Am. 71*, 397–405.

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