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REMOTE SENSING OF ATMOSPHERIC WINDS USING A COHERENT, CW LIDAR AND SPECKLE-TURBULENCE INTERACTION

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Abstract

Speckle-turbulence interaction has the potential for allowing single-ended remote sensing of the path averaged vector crosswind in a plane perpendicular to the line of sight to a target. If a laser transmitter is used to illuminate a target, the resultant speckle field generated by the target is randomly perturbed by the atmospheric turbulence as it propagates back to the location of the transmitter-receiver. When a crosswind is present, this scintillation pattern will move with time across the receiver.

A continuous wave (cw) laser transmitter of modest power level (a watt or two) in conjunction with optical heterodyne detection has been used to exploit the speckle-turbulence interaction and measure the crosswind. The use of a cw transmitter at 10.6 microns and optical heterodyne detection has many advantages over direct detection and a double pulsed source in the visible or near infrared. These advantages include the availability of compact, reliable and inexpensive transmitters; better penetration of smoke, dust and fog; stable output power; low beam pointing jitter; and considerably reduced complexity in the receiver electronics. In addition, with a cw transmitter, options exist for processing the received signals for the crosswind that do not require a knowledge of the strength of turbulence.

From previous work, the time lagged covariance (TCL) function using the joint Gaussian assumption is given for the focused case by

$$C_I(\overline{P},\tau) = \left\langle \Big(I(\overline{P}_2,t_2) - \langle I\rangle\Big)\Big(I(\overline{P}_1,t_1) - \langle I\rangle\Big) \right\rangle \tag{1}$$

$$= \langle I\rangle^2 \exp\left[-\frac{P^2}{2\alpha_o^{\,2}} - \frac{32}{3\rho_o^{\,5/3}} \int_o^1 \left|(1-w)\overline{P}-\overline{V}\tau\right|^{5/3} dw \right] \tag{2}$$

where $\overline{P}_1$ and $\overline{P}_2$ designate the location of two detectors in the receiver plane; $\overline{P} = \overline{P}_2 - \overline{P}_1$; $\tau = t_2 - t_1$; α_o = Transmitter Beam Radius; ρ_o = Transverse Phase Coherence Length; $\overline{V}$ = Vector

Wind Velocity; and W = Normalized Path Length from the Transmitter-Receiver to the Target. As can be seen from Eq.(1), if two detectors are separated by a vector distance $\overline{P}$, the time delayed covariance can be measured; and from Eq.(2) it can be seen that the measured quantity will be a function of the crosswind velocity.

Some of the options that exist for processing the data include: The Briggs method which measures the time delay at which the autocovariance and the time-lagged covariance curves cross; The delay-to-peak method, which measures the time delay where the time-lagged covariance reaches its peak value; The width of the autocovariance method which measures the time delay at which the autocovariance curve decreases to 67% of its peak value; and The slope method which measures the slope of the time-lagged covariance function at zero time delay. All of these methods have been used for the line of sight case and appear to have applicability to remote wind sensing using speckle turbulence interaction.

In addition some new methods have been developed that use both the autocovariance function and the time lagged covariance. Formulation for these quantities are functions of both the crosswind and ρ_o the transverse phase coherence length. By combining them and also averaging the results for several different time delays, both the crosswind and ρ_o can be measured. One result for the crosswind which was used to process the data presented in Figure 1 is

$$V = \frac{1}{N} \sum_{i=1}^{N} \frac{P}{\tau_i} \left[\frac{\ln C_{IN}(o, \overline{v}\,\tau_i)}{\ln C_{IN}(\overline{P}, o) + p^2/2\alpha_o{}^2} \right]^{3/5} \tag{3}$$

where τ_i = i^{th} time delay; C_{IN} = Normalized (to the mean squared) time lagged covariance; N = Number of time delays used; and where the direction of the crosswind is determined by the skewness of the TLC.

So far only a small amount of data has been taken. Figure 1 is representative of that data. The results are encouraging and have very positive implications with respect to remote sensing of winds and turbulence in the atmosphere, including global remote wind sensing from a satellite. The in situ data shown in Figure 1 were taken using a Campbell Scientific, CA-9, path averaging laser anemometer. The spring and summer of 1986 it is planned to obtain a significant amount of data at a variety of turbulence levels and ranges which will be processed using several of the above methods for comparison. The results of this work will be presented during the talk.

The transmitter/receiver system is shown in Figure 2. The source is a CO_2 waveguide laser. The beam is first directed through a 3X beam expander and then part of the laser radiation is split from the main beam for use as an optical local oscillator (LO). The remaining part of the beam is directed through an acoustooptic modulator (AOM) where its optical frequency is shifted by 37.5 MHz and then passed through a 10X beam expander that is focused on the target. The half-wave plate rotates the polarization of the beam from vertical to horizontal to match the AO modulator and the quarter-wave plate provides a circularly polarized output beam.

One of the difficulties in designing a cw, optical heterodyne system is obtaining sufficient optical isolation between the transmitted beam and the LO beam. In order to accomplish this, a novel technique was used wherein a second AOM operated at 42.5 MHz was used in the LO path. This allows an intermediate (signal) frequency of either 5 MHz or 80 MHz to be used and provides an isolation that results in an equivalent fed through optical signal from the transmitter that is 170 dB below the LO power level.

The transmitted beam is scattered diffusely by a 4 foot × 4 foot sandblasted aluminum target. The returning radiation is directed by two one-inch mirrors onto lenses that focus it on the detectors. The effective area of the receivers is approximately one-half square inch and the transmitted power is around one watt, resulting in a useful range of around 3,000 meters.

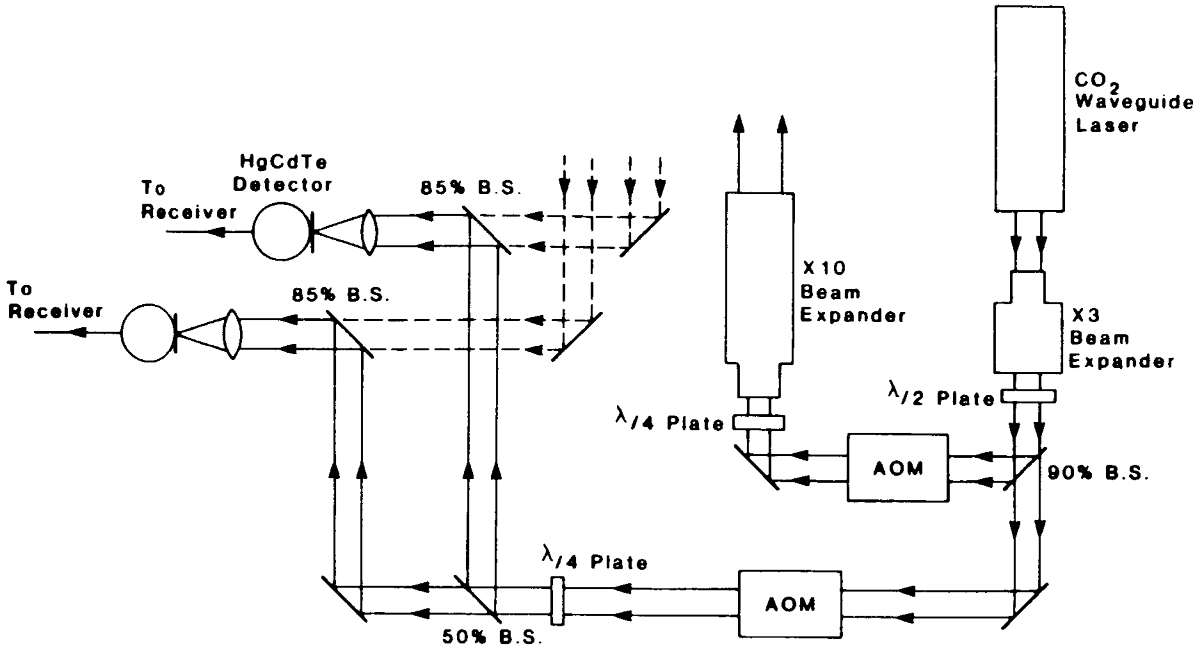

Figure 1 - Transmitter/Receiver System

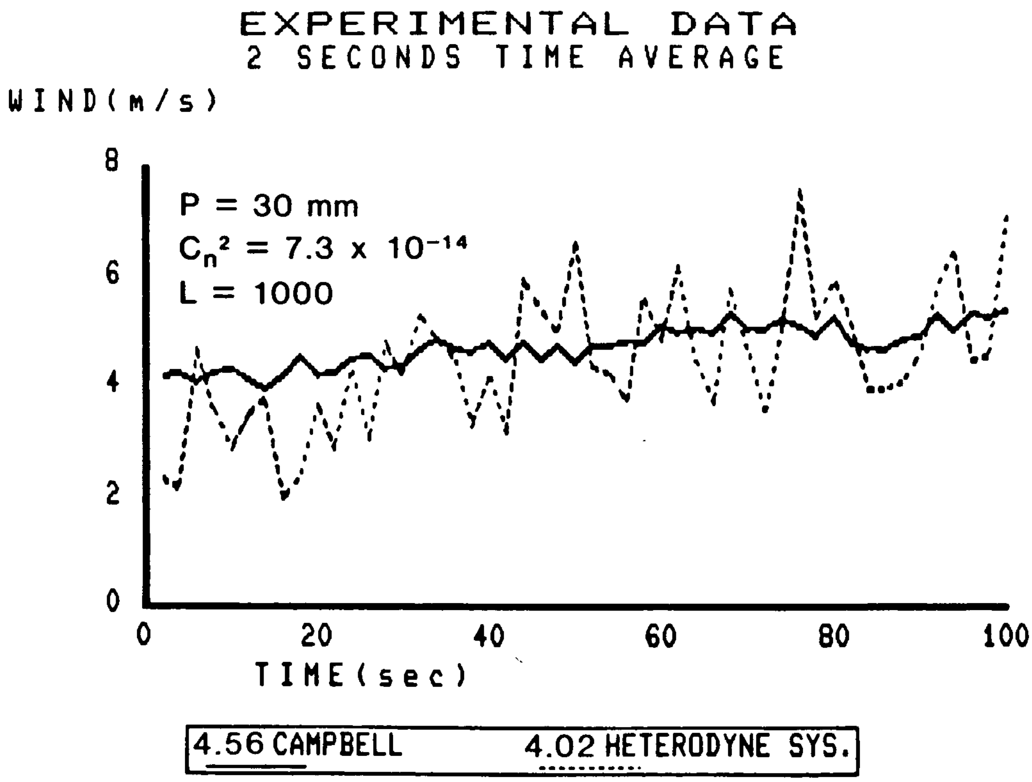

Figure 2 - 1000 Meters Experimental Data