THE TROPOSPHERIC WIND LIDAR TECHNOLOGY EXPERIMENT (TWiLiTE): AN AIRBORNE DIRECT DETECTION DOPPLER LIDAR INSTRUMENT DEVELOPMENT PROGRAM

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1. Introduction – Global measurement of tropospheric winds is a key measurement for understanding atmospheric dynamics and improving numerical weather prediction. Global wind profiles remain a high priority for the operational weather community and also for a variety of research applications including studies of the global hydrologic cycle and transport studies of aerosols and trace species. In addition to space based winds, a high altitude airborne system flown on UAV or other advanced platforms would be of great interest for studying mesoscale dynamics and hurricanes. The Tropospheric Wind Lidar Technology Experiment (TWiLiTE) project was selected in 2005 by the NASA Earth Science Technology Office (ESTO) as part of the 2004 Instrument Incubator Program. TWiLiTE will leverage significant research and development investments in key technologies made in the past several years. The primary focus of the project is on integrating these sub-systems into a complete molecular direct detection Doppler wind lidar system in order to advance the TRL of the key component technologies and sub-systems. These technologies include: 1) the single frequency, conductively cooled Nd:YAG laser transmitter; 2) a high throughput, high spectral resolution Fabry Perot etalon; 3) small efficient direct detection Doppler receivers and 4) novel holographic optical element telescope/scanners. These technologies will be advanced in the three year program to an exit TRL of 5 or 6.

The TWiLiTE instrument is designed for autonomous operation on a high altitude aircraft so that the nadir viewing lidar will be able to profile winds through the full troposphere. TWiLiTE is a collaboration involving scientists and technologists from NASA and NOAA as well as university and industry partners. The integrated airborne Doppler lidar instrument will be the first demonstration of a airborne scanning direct detection Doppler lidar and will serve as a critical milestone on the path to a future spaceborne tropospheric wind system. The completed system will have the capability to profile winds in clear air from the aircraft altitude of 18 km to the surface with 250 m vertical resolution and < 2m/s velocity accuracy. The TWiLiTE Doppler lidar will have the capability to profile winds in clear air from the aircraft altitude of 18 km to the surface with 250 m vertical resolution and < 2m/s velocity accuracy. Preliminary measurement requirements are listed in Table 1. The instrument design, technologies and predicted performance will be presented.

Parameter	
Velocity accuracy (LOS projected) (m/s)	2.0
Range of regard (km)	0-18
Vertical resolution (km)	0.25
Horizontal resolution (km) (completion of 1 step stare scan cycle)	25
Aircraft Groundspeed (m/s)	200
Nadir angle (deg)	45
Scan pattern	8 to 16 pt step-stare
Horizontal integration per LOS (seconds)//ground track (km)	10//2

Table 1 - TWiLiTE preliminary measurement requirements.

2. TWiLiTE Design and Expected Performance –

The TWiLiTE Doppler lidar is a molecular direct detection system operating at a wavelength of 355 nm. The Doppler frequency shift is measured with a molecular double edge receiver implemented in a design that is similar to those described previously[1,2]. The double edge method utilizes two high spectral resolution

	Typical
Wavelength	355 nm
HOE Telescope/Scanner Aperture	0.38 m
Laser Linewidth (FWHH)	<150 MHz @ 355 nm
Laser Energy/Pulse	30 mJ
Etalon FSR	16.7 GHz
Etalon FWHH	2.84 GHz
Etalon Peak Transmission	>60 %
Interference filter BW (FWHH)	120 pm
PMT Quantum Efficiency	25%

Table 2 - TWiLiTE instrument parameters

optical filters located symmetrically about the outgoing laser frequency to measure the Doppler shift. The molecular system operates in the ultraviolet at 355 nm in order to take advantage of the λ^{-4} dependence of the molecular scattering. Many of the design elements of theTWiLiTE lidar have been demonstrated and validated in ground-based lidar measurements [2,3].

The TWiLiTE lidar system baseline performance characteristics are summarized in Table 2. The transmitter will be a single frequency, Nd:YAG laser frequency tripled to the third harmonic wavelength of 355 nm. The laser pulse energy will be nominally 30 mJ at 355 nm and the pulse repetition frequency will be 200 Hz. The laser will be injection seeded using a ramp-and-fire resonance locking technique[4]. The ramp and fire technique is particularly suitable for airborne operation as it is relatively insensitive to vibration. The telescope and conical scanning functions will be accomplished with a 38 cm clear aperture, rotating holographic optical element (HOE) transceiver [5, 6]. The HOE transceiver subsystem performs both functions of transmitting the laser beam and receiving the atmospheric backscattered signal. The TWiLiTE transceiver contains a 40-cm diameter rotating HOE, laser beam steering and collimating optics, and a fiber optic interface to the Doppler receiver. The HOE aperture determines the receiver collecting area. It is designed to direct the beam at a nadir angle of 45˚. Rotation of the HOE repeatedly sweeps the transmitted laser beam and the receiver's FOV through a 45˚ cone about the axis of rotation. The scanner will step in azimuth to specified angles, normally 8 to 16 positions per scan cycle. After moving and settling to each fixed azimuth position the system will integrate signal for a period of 10 seconds (2000 shots). The backscattered signal collected by the HOE will be focused to a 200 micron core diameter multimode fiber optic which brings the collected signal to the Doppler receiver.

In the Doppler receiver, the collected signal is split into a total of four channels. Three of these beams are directed along parallel paths through a high spectral resolution tunable Fabry-Perot etalon which is used as the edge filter. As shown in Figure 1, the etalon has three sub-apertures corresponding to the filter bandpass functions labeled Edge1, Edge2 and Locking. The etalon channels have slightly different bandpass center frequencies but otherwise nearly identical optical properties e.g. peak transmission, finesse, free spectral range. To make the wind measurement, the two edge filter channels are located symmetrically about the outgoing laser frequency in the wings of the thermally broadened Rayleigh-Brillouin spectrum. The separation of the two edge filter center wavelengths is chosen so the velocity sensitivity of the broader molecular signal, defined as the change in the ratio of the two edge channel transmittances for a Doppler shift of 1 m/s, is equal to the velocity sensitivity of the narrower aerosol signal. Matching the velocity sensitivities in this way greatly reduces the effects of aerosols on the wind measurements. The two etalon 'edge' channels have PMTs operating in photon counting mode. These channels provide the information used in the atmospheric Doppler shift measurement. The locking etalon peak is located such that the outgoing laser frequency is aligned to the half height point of the locking filter bandpass. This third etalon channel is used to sample the outgoing laser frequency and will be used as a reference in the Doppler shift measurement to correct for small frequency drifts of the laser or etalon. The fourth channel is an energy monitor used to provide intensity normalization of the respective etalon channels. The photon counting signals are binned in a multi-channel scalar, integrated for a selectable number of shots and stored.

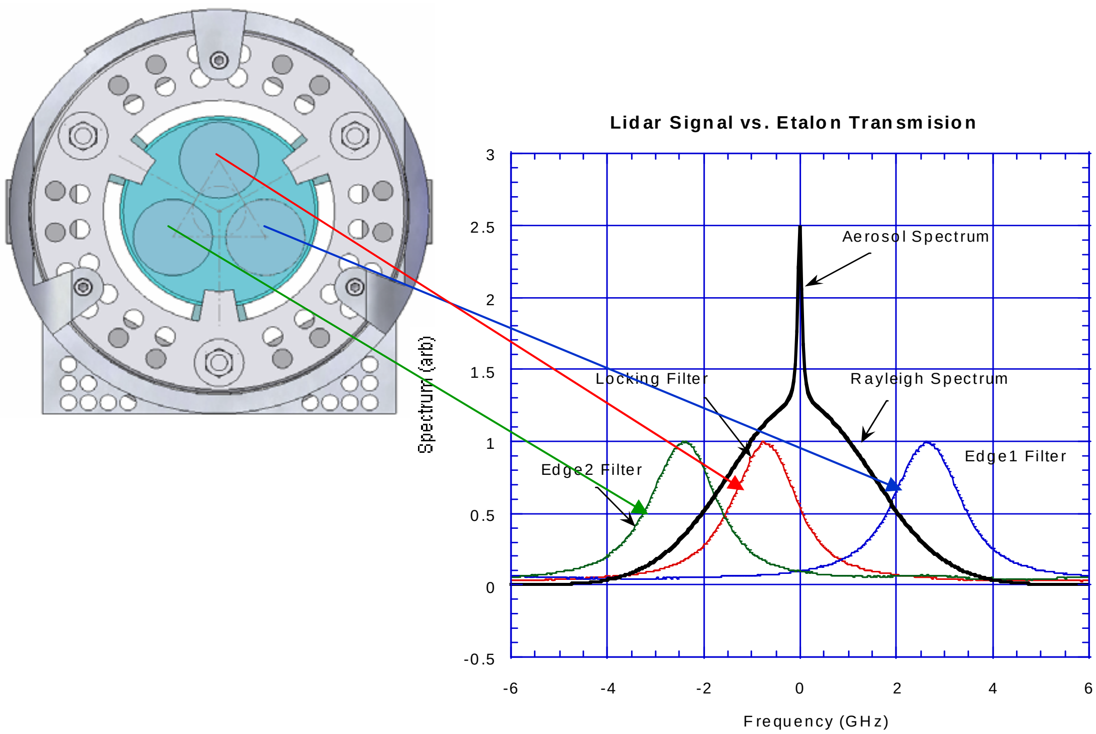

Figure 1 – The TWiLiTE Fabry Perot etalon (left) has three sub-apertures with bandpasses separated in frequency to produce the molecular double edge measurement arrangement. The location in frequency space of the three bandpasses, labeled Edge 1, Edge 2 and Locking, are illustrated to the right along with the spectrum of the atmospheric ackscattered signal.

The expected performance of the TWiLiTE lidar system has been simulated using detailed instrument models that fully describe direct-detection Doppler lidar systems[7]. The instrument models have been verified using the GLOW ground based Doppler lidar system, and it is found that simulated performance matches actual system performance to 3-5% accuracy. Basic simulations have been performed using single profile aerosol model atmospheres. The simulated molecular and aerosol backscattered photon returns can be used along with a knowledge of the Doppler receiver characteristics to predict shot noise limited velocity accuracy. Solar background is also included to estimate expected daytime performance. The solar background is calculated using a worst case of a fully illuminated cloud (albedo values of 1.0) scene.

Figure 2 shows a simulation of expected wind velocity errors of the molecular Doppler lidar instrument flying on the WB57 aircraft flying at an altitude of 18 km. As shown, line-of-sight wind errors are less than 2 m/s from 18 km down to the surface for two possible laser average power levels, 6W and 8W.

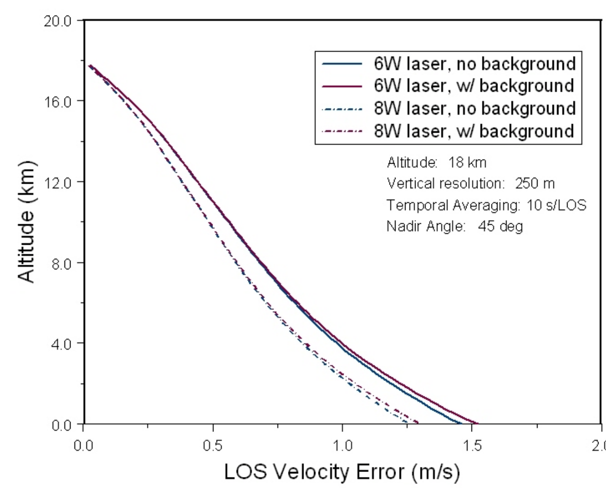

Figure 2 – Simulated line of sight velocity errors shown for two laser average power levels: 6W(30 mJ, 200 pps) and 8W (40 mJ, 200 pps). Errors with and without solar background are shown to represent day and night time performance.

3. Summary

While many of the of the design features and technologies of the TWiLiTE lidar have been demonstrated and validated in ground-based lidar measurements the TWiLiTE airborne lidar will present several new and challenging problems. A major challenge in the TWiLiTE design will be reducing the overall size of the instrument and integrating the instrument functions to run autonomously in a relatively demanding environment. The WB57 payload bay is not environmentally controlled and temperatures on the ground may be greater than +40 degrees C while at altitude the temperature may be as low as -60 degrees C. Pressure at altitude will be 35 mbar. The TWiLiTE project is nearing the end of the first year of a scheduled three year effort. The first year has primarily concentrated on the design of the system, the hardware for the major sub-systems will be built and assembled in 2007 and system integration and testing, including initial test flights of the TWiLiTE Doppler lidar, will be in 2008.

4. Acknowledgement

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References -

[1] Flesia, C. and C. Korb, "Theory of the double-edge molecular technique for Doppler lidar wind measurement", *Appl. Opt.*, **38**, 432-440,1999.

[2] Gentry, B., H Chen and S. X. Li , "Wind Measurements with a 355 nm Molecular Doppler Lidar", *Optics Letters*, **25**, 1231-1233, 2000.

[3] Gentry, B., H. Chen, S. X. Li, S. Mathur, J. Dobler, W. Hasselbrack, J. Comer , "Wind Profiles Obtained with a Molecular Direct Detection Doppler Lidar During IHOP_2002", *Proceedings of the 22nd International Laser Radar Conference,* Matera, Italy, 2004.

[4] Hovis, F., B. Gentry, M. Rhoades, R. Burnham, H. Chen and S. Li, "Single Frequency Lasers for Doppler Wind Lidar", *30th International Symposium on Remote Sensing of Environment*, Honolulu, HI, Nov. 10-14, 2003.

[5] Schwemmer, G. K., "Holographic Airborne Rotating Lidar Instrument Experiment," *19th International Laser Radar Conference*, NASA/CP-1998-207671/PT2, pp. 623-626, Annapolis, Maryland, 6-10 July 1998.

[6] Schwemmer, G., T. Wilkerson, and D. Guerra , "Compact Scanning Lidar Systems Using Holographic Optics," *SPIE Conf. Optical Remote Sensing for Industry and Environmental Monitoring*, Beijing, China, 14-17 September 1998.

[7] McGill, M.J. ,W.D. Hart, J.A. McKay, and J.D. Spinhirne , "Modeling the performance of direct-detection Doppler lidar systems including cloud and solar background variability,", *Appl. Opt.*, 38, 6388-6397, 1999.