

Status of the TWiLiTE airborne molecular Doppler lidar project

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ABSTRACT

The Tropospheric Wind Lidar Technology Experiment (TWiLiTE) is a three year program to advance the technology readiness level of the key technologies and subsystems of a molecular direct detection wind lidar system by validating them, at the system level, in an integrated airborne lidar system. The TWiLiTE Doppler lidar system is designed for autonomous operation on NASA high altitude research aircraft such as the WB57 or ER-2. These aircraft are capable of flying well above the mid-latitude tropopause so the downward looking lidar will measure complete profiles of the horizontal wind field through the lower stratosphere and the entire troposphere. The completed system will profile winds in clear air from the aircraft altitude of 18 km to the surface with 250 m vertical resolution and a velocity precision of < 3 m/s. In this paper we will describe the new technologies developed as part of the TWiLiTE program and present an update on the status of the airborne lidar system development.

1. Introduction –

In the summer of 2005 the Tropospheric Wind Lidar Technology Experiment (TWiLiTE) project was selected by NASA's Earth Science Technology Office as part of the Instrument Incubator Program. The objective of the TWiLiTE program is to develop the key technologies and subsystems of a molecular direct detection Doppler wind lidar and integrate them into an airborne testbed to validate, at the system level, both the technologies and the measurement approach. In this paper we will describe the new technologies that are in development as part of TWiLiTE. These technologies,

include the laser transmitter, Doppler receiver, high resolution optical filters and conical scanning telescopes all designed for efficient operation in the ultraviolet at 355 nm.

To realize the full benefit of the demonstration, the target platform is one of the NASA high altitude aircraft including the WB57 and ER-2. Both of these aircraft fly at altitudes > 18 km so that the nadir viewing lidar will be able to profile winds through the full troposphere. This will provide a capability to simulate the downward viewing geometry of the

Table 1-TWiLiTE Instrument parameters

Wavelength	355 nm
HOE Telescope/Scanner Aperture	0.38 m
Laser Linewidth (FWHH)	<150 MHz @ 355 nm
Laser Energy/Pulse	35 mJ
Laser pulse rep frequency	200 pps
Etalon FSR	16.7 GHz
Etalon FWHH	2.84 GHz
Etalon Peak Transmission	>60 %
Interference filter BW (FWHH)	220 pm
PMT Quantum Efficiency	25%

spaceborne lidar and to investigate the effects of clouds, aerosols and other atmospheric phenomena on the measurement. The TWiLiTE project represents a

critical milestone on the path to a future spaceborne tropospheric wind system [1]. The TWiLiTE program objectives are consistent with the NASA technology development roadmaps for both direct detection and hybrid (combined direct and coherent) Doppler lidar spaceborne wind lidar implementations. The TWiLiTE airborne scanning direct detection molecular Doppler lidar system will be the first of its kind, and as such, can be flown as a stand alone instrument or with existing, or future, aerosol Doppler lidars to explore the potential synergies of data products, systems and shared technologies of the hybrid approach.

The TWiLiTE project is a collaboration involving scientists and engineers from NASA Goddard Space Flight Center, NOAA, Utah State University Space Dynamics Lab, Michigan Aerospace Corporation, Fibertek Inc and Sigma Space Corporation. The TWiLiTE instrument will be the first demonstration of an airborne scanning direct detection Doppler lidar and will serve as a critical milestone on the path to a future spaceborne tropospheric wind system. In addition to being a technology testbed for space based tropospheric wind lidar, when completed the TWiLiTE high altitude airborne lidar will be used for studying mesoscale dynamics and storm research (e.g. winter storms, hurricanes) and can be used for calibration and validation of satellite based wind systems such as ESA's Aeolus Atmospheric Dynamics Mission [2]. 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 < 2 m/s velocity precision.

2. TWiLiTE Design and Description –

The TWiLiTE Doppler lidar is a molecular direct detection system operating at a wavelength of 355 nm. The lidar system is composed of four major subsystems: 1) the single frequency pulsed laser transmitter; 2) The transceiver telescope and scanner; 3) The Doppler receiver and 4) the Command and Data Handling electronics that control the instrument functions and acquire and store the science data. System level integration of these components requires definition of mechanical, electrical, optical and thermal interfaces between the subsystems and from the system to the platform, in this case the WB57 aircraft. A common mechanical structure and electrical power distribution system is also being developed. A final requirement is the control interface. To be compatible with the WB57 or ER2 aircraft, which do not offer the option of flying an operator, the TWiLiTE Doppler lidar is designed to be fully autonomous in operation. There are only the top level commands to power the instrument on or off; allow or inhibit the laser firing and

begin data acquisition. All other functions are controlled internally in flight.

To profile winds, the lidar is mounted in a nadir viewing orientation and the co-aligned transmit and receive paths are pointed off nadir at an angle of 45 degrees.. The 355 nm laser pulse is transmitted to the atmosphere and a fraction of the energy is backscattered from molecules and aerosols back towards the lidar. The backscattered signal is collected by the telescope and directed to the Doppler receiver which analyzes the signal to determine the frequency shift introduced by the mean velocity of the scattering particles. The measured wind speed is the component of the horizontal wind velocity projected on the line of sight of the laser. In order to measure the u,v components of horizontal wind field the lidar is required to scan in azimuth in order to obtain radial winds from multiple directions.. The multiple azimuth perspectives provide the necessary information to determine profiles of the horizontal wind field.

TWiLiTE is a direct detection Doppler lidar designed to measure winds using the signal backscattered by molecules. The Doppler frequency shift is measured with a molecular double edge receiver implemented in a design that is similar to those described previously [3],[4]. The double edge method utilizes two high

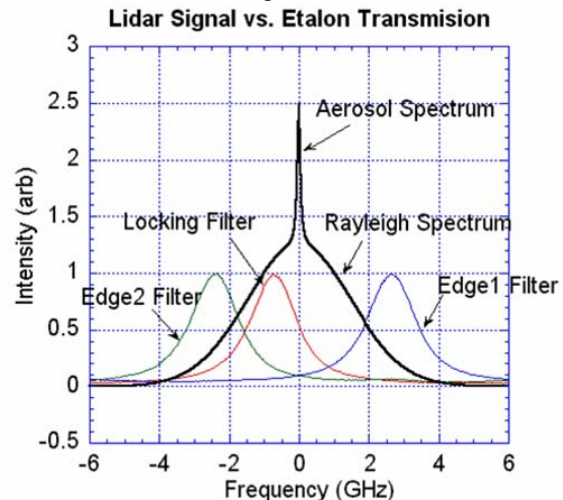


Figure 1 - Double Edge measurement concept. The two edge filter channels are shown symmetrically located about the outgoing laser frequency in the wings of the thermally broadened molecular backscattered spectrum

spectral resolution optical filters located symmetrically about the outgoing laser frequency to measure the Doppler shift. The double edge measurement concept is illustrated in Figure 1. A simulated atmospheric

molecular and aerosol backscattered spectrum is shown for reference.

To make the wind measurement, the two edge filter channels sample the intensity in the wings of the thermally broadened Rayleigh-Brillouin molecular backscattered spectrum. The ratio of the two edge filter transmission measurements will change in proportion to the speed and direction of the wind. Precise knowledge of the filter characteristics, detector properties and receiver optical throughput is obtained in calibration. The outgoing laser frequency is also measured to provide a zero Doppler reference.

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 the TWiLiTE lidar have been demonstrated and validated in ground-based lidar measurements [5]. The TWiLiTE lidar system baseline performance characteristics are summarized in Table 1.

The transmitter is a single frequency, Nd:YAG laser frequency tripled to the third harmonic wavelength. The laser pulse energy is nominally 35 mJ at 355 nm and the pulse repetition frequency is 200 Hz. In order to obtain single frequency, narrowband output pulses the laser is injection seeded using a ramp-and-fire resonance locking technique [6]. The ramp and fire technique is particularly suitable for airborne operation as it is relatively insensitive to vibration.



Figure 2 - Single frequency 355 nm Nd:YAG laser (gold) and Laser electronics unit (black)

The laser is a master oscillator power amplifier (MOPA) configuration designed and built by Fibertek, Inc. The design has heritage to the High Brightness Laser, a NASA SBIR project that Fibertek completed in 2003. Since that time Fibertek has built several generations of this type of laser. Figure 2 shows a view of completed laser. The laser optics module is the gold

irradiated pressure canister shown to the right and the laser electronics unit is the black box on the left. The laser optics module has dimensions of 31 cm x 25 cm x 14 cm. The laser draws about 480 W of electrical power from the aircraft 28V supply.

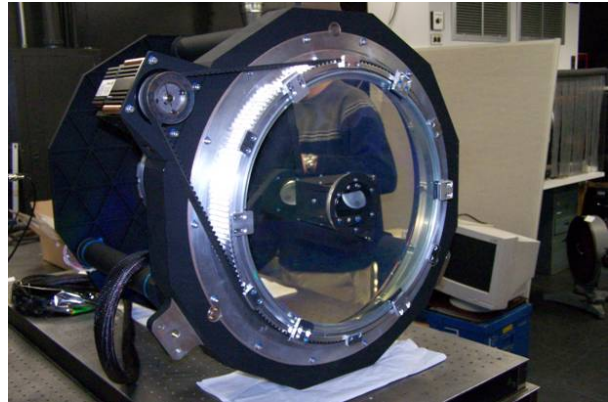


Figure 3 - Rotating Holographic Optical Element transceiver

The telescope and conical scanning functions are accomplished with a 38 cm clear aperture, rotating holographic optical element (HOE) transceiver [7]. The HOE transceiver subsystem performs both functions of transmitting the laser beam and receiving the atmospheric backscattered signal. The TWiLiTE transceiver, shown in Figure 3, 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. The lidar measures the Doppler shift of the component of the wind projected on the line-of-sight of the laser beam. In order to resolve the horizontal wind the HOE telescope 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, typically 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 laser 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 4, the etalon has three sub-apertures corresponding to the filter bandpass functions labeled Edge1, Edge2 and Locking in Figure 1. The etalon channels have slightly different bandpass

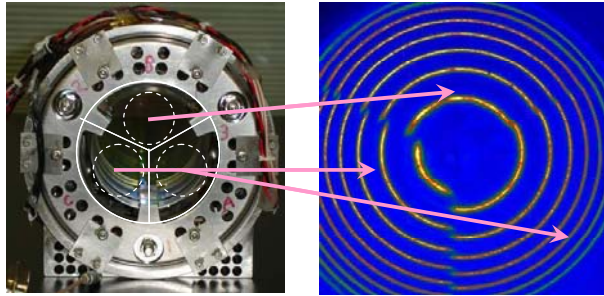


Figure 4 -The TWiLiTE Fabry Perot etalon (left) has three sub-apertures with bandpasses separated in frequency to produce the molecular double edge measurement arrangement described in the text. The three spectral regions are clearly seen in the full fringe image of the Fabry Perot circular ring pattern shown on the right

center frequencies but otherwise nearly identical optical properties e.g. peak transmission, finesse, free spectral range. 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. In each of the detector channels there are three Hamamatsu photomultiplier tubes sharing the incoming signal to that channel in the intensity ratio of 90:9:1. This arrangement allows the signal dynamic range of the photon counting PMT’s to be increased by two orders of magnitude. When the signal on the high signal detector (90%) exceeds the maximum incident counting rate of 50 Mcts, the signal from that detector can be excluded from the wind analysis. The photon counting signals are binned in a multi-channel scalar, integrated for a selectable number of shots and stored.

These subsystems comprise the working elements of the TWiLiTE lidar system. In Figure 5 the subsystems are shown integrated on a mechanical structure compatible with the WB57 aircraft payload pallet. The laser and telescope are rigidly mounted to an optical bench to maintain bore sight and alignment. The instrument pallet also includes the laser electronics, command and data handling electronics, thermal management system and power distribution and control system. The estimated mass of the instrument is 515 lbs

3. TWiLiTE Development Status

The TWiLiTE IIP project officially will end on August 1, 2008. The last of the major design reviews, the Critical Design Review, was completed on May 1, 2007. The major subsystem deliveries began in June, 2007 with the delivery of the etalon and controller , followed by the HOE telescope and Doppler receiver. The final stage of the IIP project involves ground testing of the subsystems, completion of the command

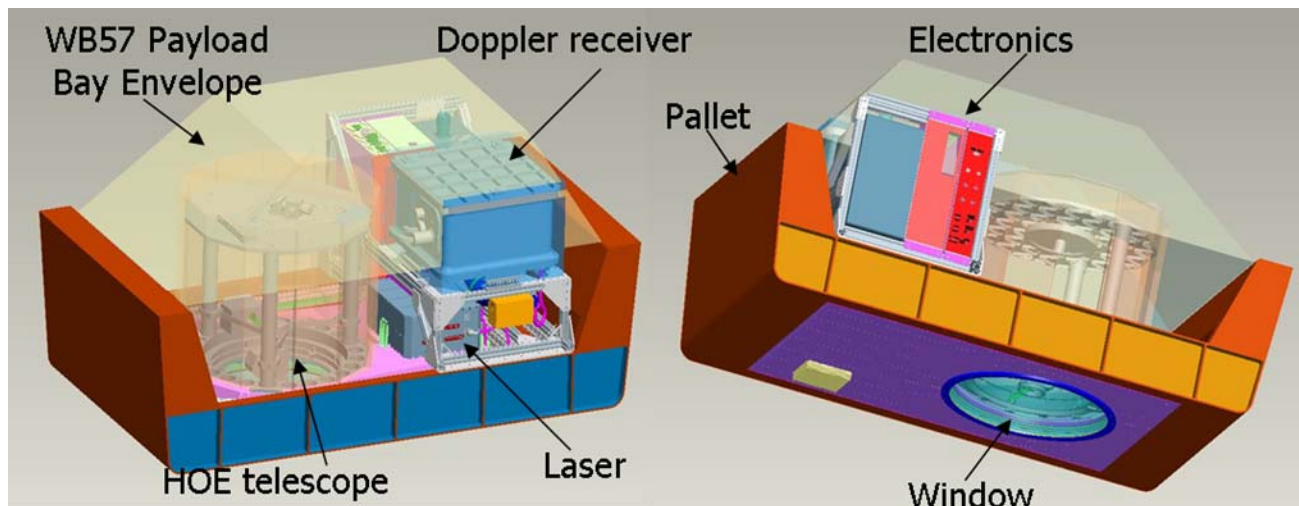


Figure 5 - Two views, side/top and side/bottom, of the TWiLiTE lidar system integrated on the WB57 three foot pallet

and data handling hardware and software and integration of all the modules into the complete instrument package. At that point in time we will be ready for the initial flight testing of the instrument.

4. Summary

The design features and key technologies being developed as part of the Tropospheric Wind Lidar Technology Experiment (TWiLiTE) IIP project have been described. The TWiLiTE airborne lidar will present several new and challenging problems. A major challenge in the TWiLiTE design is integrating the instrument technologies into an end-to-end Doppler lidar system that functions 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 -70 degrees C in the free air stream. Pressure at altitude will be 35 mbar. As of February 2008, all major subsystems including the laser, telescope, etalon and Doppler receiver are completed. Integration of the TWiLiTE instrument and ground characterization and testing will be completed in 2008.

5. Acknowledgements

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