DOPPLER LIDAR DESCENT SENSOR FOR PLANETARY LANDING. Farzin Amzajerdian[1], Diego Pierrottet[2], Larry Petway[1], Glenn Hines[1], and Bruce Barnes[1], [1]NASA Langley Research Center (f.amzajerdian@nasa.gov), [2] Coherent Applications, Inc.

Introduction: Future robotic and manned exploration missions to the Moon, Mars, and other planetary bodies demand accurate knowledge of ground relative velocity and altitude in order to ensure soft landing at the designated landing location with high degree of precision [1]. To meet this requirement, a Doppler lidar is being developed by NASA-LaRC under the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project [2]. The range and velocity measurements provided by this lidar sensor will be used by an autonomous Guidance, Navigation, and Control (GN&C) system to accurately navigate the vehicle to the designated location and achieve soft landing. Compared with radars, such as the ones used by Pheonix and Mars Science Laboratory landers, this sensor offers several benefits including much lower mass and smaller size, higher precision and data rate, and lower fasle alarm rates as it eliminates heatshield signal clutter, pulse ambiguity, nadir peak contamination issues.

The Doppler lidar will begin its operation during the powered descent phase from an altitude of a few kilometers above the ground. The GN&C system processes the lidar data to improve position and attitude data from the Inertial Measurement Unit (IMU). The improved position and attitude knowledge along with the lidar precision vector velocity data enable the GN&C system to continuously update the vehicle trajectory toward the landing point. In addition to the precision trajectory determination, the lidar data will play important role in performing the soft landing maneuver. For example, large robotic or manned vehicles measurement accuracies to better than 10 cm/s in order to avoid the risk of tipping over and ensure a gentle touchdown. The coherent Doppler lidar, being described in this paper, exceeds these requirements by over an order of magnitude.

System Description: The Doppler lidar obtains high-resolution range and velocity information from a frequency modulated continuous wave (FMCW) waveform for which the laser frequency is modulated linearly with time. Figure 1 shows the transmitted laser waveform and the retuned waveform from the target delayed by t_a, the light round trip time. When mixing the two waveforms at the detector, an interference signal will be generated whose frequency is equal to the difference between the transmitted and received frequencies. This intermediate frequency (IF) is directly proportional to the target range. When the target or the lidar platform is not stationary during the beam round trip time, the signal frequency will be also shifted due to the Doppler effect. Therefore by measuring the frequency during "up chirp" and "down chirp" periods of the laser waveform, both the target range and velocity can be determined. The difference in up-ramp and down-ramp frequency provides the vehicle velocity and their mean value provides the range to the target.

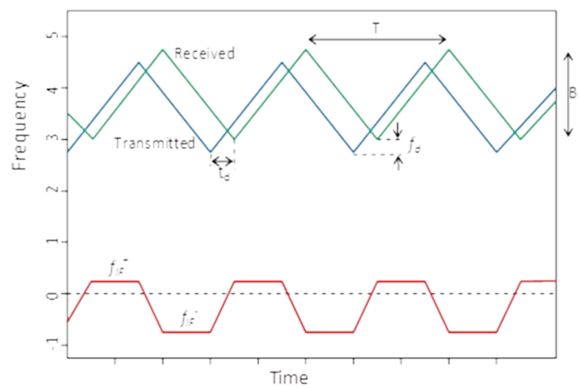

Fig 1. Linearly frequency modulated transmitted beam and returned signal, and the resulting intermediate frequency (IF) of the homodyne signal.

Figure 2 illustrates the system design utilizing an optical homodyne configuration. A relatively low power, single frequency laser operating at eye safe wavelength of 1.55 micron, is used as the master oscillator. The output of this laser is modulated per the waveform of Figure 1. Part of the laser output is amplified to be transmitted and the remaining is used as the local oscillator (LO) for optical homodyne detection. The lidar transmits three laser beams which are separated 120 degrees from each other in azimuth and are pointed 22.5 degrees from nadir. The signal from each beam provides the platform velocity and range to the ground along the laser line-of-sight (LOS). The three LOS measurements are then combined in order to determine the three components of the vehicle velocity vector, and to accurately measure altitude and attitude relative to the local ground. The 45 degrees separation between the transmitted beams was chosen as a compromise between horizontal velocity accuracy that favors large angles, and higher operational altitude that is inversely proportional to the beam nadir pointing angle.

System Development and Tests: The capabilities of the Doppler lidar were evaluated and its performance characterized through two helicopter flight test campaigns facilitated by NASA-JPL, and were held at NASA-Dryden in California [3]. The first test was conducted in 2008 using a breadboard version of the lidar. For the second test in 2010, the lidar was engineered to a relatively compact package while improving its operational performance.

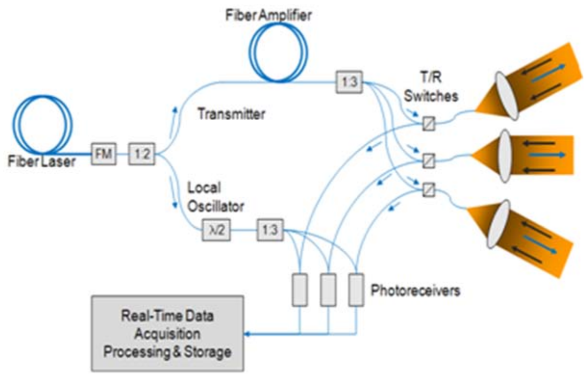

Fig. 2. Doppler lidar system configuration illustrating three transmitted beams and their corresponding receivers providing line-of-sight velocity and range measurements in three different directions.

The results of these testes indicated excellent agreement between the Doppler lidar velocity measunuments and the data from onboard instruments. For the later flight test, the mean value of discrepancy in magnitude of the vector velocity measurements provided by the Doppler lidar and a high-grade Inertial Measurement Unit (IMU) and GPS system was about 3.5 cm/sec. Quantifying the altitude discrepancies between the Doppler lidar and IMU/GPS measurements is challenging since one measures altitude with respect to the ground and the other relative to sea level. But, the difference between the two measurements was shown to be very small and within the scale of the ground surface roughness after compensating for the ground elevation.

Recently, a prototype version of the Doppler lidar was completed (Fig. 3) for integration into a rocket-powered terrestrial free-flyer vehicle, built by NASA-JSC, referred to as Morpheus. Operating in a closed loop with the vehicle's guidance and navigation system, the viability of this lidar sensor for future landing missions will be demonstrated through a series of flight tests by Fall 2012. The specifications of the prototype system is summarized in Table 1. Future development of an engineering unit calls for over 30% reduction in mass, size, and power, while increasing the operational range to 3500 meters.

Fig. 3. Prototype Doppler lidar system consisting of an electronic chassis and an optical head. All the lidar components, including transmitter laser, receiver, and real-time processor, are housed in the electronic chassis. The optical head, consisting of three transmit and receive lenses, is rigidly mounted to the platform body with a clear view of the ground and connected to the electronic chassis through a long fiber optic cable.

Table 1. Prototype Doppler lidar specifications.

Parameter		**Prototype Unit**
Operational Range		10 - 2500 m
LOS Velocity Accuracy		1 mm/sec
LOS Range Accuracy		10 cm
Data Rate		30 Hz
Power		150 W
Dimensions	Electronic Chassis	17.5"x15.2"x6.3"
	Optical Head	8" dia x 12" high
Mass	Electronic Chassis	41 lb
	Optical Head	13 lb

Summary: A fiber-based coherent Doppler lidar, utilizing an FMCW waveform, has been developed and its capabilities were demonstrated through two successful helicopter flight test campaigns. This Doppler lidar is expected to play a critical role in future planetary exploration missions because of its ability to provide the necessary data for soft landing on planetary bodies and for landing missions that require precision navigation to a designated location on the ground. Compared to radars, the Doppler lidar can provide significantly higher precision velocity and altitude data at a much higher rate without concerns of measurement ambiguities or target clutter. The viability of this technology for future landing missions will be further demonsttared later this year through a series of tests aboard a rocket-powered free-flyer platform. In these flight tests, the Doppler lidar will be operating in a closed-loop with the vehicle's guidance, navigation, and control (GN&C) unit.

References: [1] E. C. Wong and J. P. Masciarelli (2002), AIAA Atm Flight Mech Conf, Paper no. 4619. [2] C. D. Epp, E. A. Robinson, and T. Brady (2008), Proc. of IEEE Aerospace Conf, pp.1-7. [3] D. Pierrottet, F. Amzajerdian, L. Petway, B. W Barnes, and G. Hines (2011), Proc. SPIE Vol. 8044.