LandSafe® Precision Flight Instrumentation System, The DVE Solution

Elizabeth Dakin[1], Priyavadan Mamidipudi[2], Daniel Dakin[3], Timothy Bienlien[4], Donald Vang[5], and
Philip L. Rogers[6]
Optical Air Data Systems, LLC Manassas, Virginia

Abstract

Helicopter hover, landing, and take-offs in dust, fog, rain, snow, and high winds is an integral part of military and commercial flight operations. OADS has developed and flight-tested an LDV-based optical sensor suite capable of measuring height above ground, groundspeed, and air data at a FCS capable data rate from a helicopter platform under all environmental and weather conditions. This paper presents capabilities and flight-test results of this high-resolution standalone Precision Flight Instrumentation System.

Introduction

With shrinking budgets and increased operations in hostile environments, protection of aircraft and personnel operating in degraded visual environments (DVE) continues to be a highly relevant problem. There are multiple proposed mitigation techniques ranging from limiting the operational procedures of affected aircraft (a very near term option) to sensor fusion techniques that allow pilots to visualize the landing zone coupled with quantitative measurements of airspeed, groundspeed and height above ground; an approach still under development. Current operational procedures utilize a combination of restricted flight envelopes with the use of higher accuracy navigational aids. These aids, however, generally rely on enhanced GPS solutions to maintain accuracy and become unusable in GPS degraded environments. Also, the restrictions on flight maneuvers often leave the aircraft vulnerable to enemy fire while approaching the landing zone.

Rotorcraft in general are Visual Flight Rules (VFR) aircraft and rotorcraft pilots are “heads up”, trained to cue off of visual clues at all times during flight. This is in contrast to fixed wing Instrument Flight Rules (IFR) pilots, who are “heads down”, flying mostly with inputs from cockpit instrumentation. Rotorcraft have traditionally been “heads up” because helicopters are designed to operate at unimproved remote landing sites where instrumentation approaches are not possible. When helicopter pilots enter situations in which visual cues are not available, they can lose situational awareness, which can result in loss of assets. With this in mind, the ideal solution would involve providing the pilot with visual imagery of the terrain coupled to a digital autopilot, allowing the aircraft to land itself once the pilot has determined that the landing zone is clear.

Due to the unavailability of the ideal solution, the user community has been forced to develop approaches to minimize the risk to assets. One current approach and landing technique is to fly the aircraft to a specific GPS location, come to a hover above that point at approximately 200 ft above the ground, keeping the pilot’s view free of dust so that he can visually clear the landing zone, and then dialing down the altitude until the aircraft touches down while the aircraft is enveloped in the dust and the pilot loses all visual cues (and prays that he is not drifting). This approach, while currently in use, is non-ideal in combat situation when the aircraft is under hostile fire because the pilot has to come to a complete hover and gradually descend into a dust cloud, leaving himself very vulnerable. Also, this technique makes the assumption that the pilot is not drifting laterally over the ground during the descent, as low speed lateral drifts near the ground are difficult to identify, even with an enhanced GPS/INS solution. Lateral drifts of this kind are responsible for many helicopter rollover incidents over the last decade. Another technique is to keep forward airspeed at all times to overcome any drift and to stay ahead of the dust cloud. This approach is not ideal because it increases the area needed to land the fleet of aircraft and its efficacy decreases for all aircraft entering the landing zone behind the lead.

There is a debate within the community regarding a “see through” versus a “sense through” DVE solution. A “see through” solution generally uses a type of sensor that can penetrate the obscurant cloud and create an image for the pilot so that the pilot can have an unobstructed view of the landing zone. Generally these solutions are RADAR or Laser Detection and Ranging (LADAR) based three-

---

[1] Technical Director, bdakin@oads.com
[2] Chief Scientist, pri@oads.com
[3] Test Director, ddakin@oads.com
[4] Chief Pilot, tbienlien@oads.com
[5] Director of Maintenance, dvang@oads.com
[6] Founder, progers@oads.com

Presented at the American Helicopter Society 68th Annual Forum, Fort Worth, Texas, May 1-3, 2012.

dimensional imagers. A "sense through" solution is able to provide quantitative information about the aircraft ground speed, ground drift and height above ground digitally at a very high update rate. These solutions are generally Light Detection and Ranging (LIDAR) based and data from such sensors can be coupled to an autopilot. The ultimate solution would be a fused sensor approach where the pilot relies on the qualitative visual imagery to clear the landing zone and then utilizes the sense through data to precisely land the aircraft, with zero drift, either manually or through the use of an autopilot.

This paper focuses on the development and field-testing of a LIDAR based "sense through" solution. While this technology is complementary to the imaging techniques for DVE applications, it represents the first precision flight instrumentation system for rotorcraft designed to operate through all landing and take-off maneuvers of the aircraft without any external inputs such as GPS. This type of system, coupled with a laser based air data sensor designed to measure True Airspeed and relative wind down to zero knots, will allow both the development of a fully integrated DVE solution and the introduction of a steep approach instrument landing system (ILS) for helicopters. ILS type approaches will allow significantly increased descent rates, critical for operation of rotorcraft in urban and mountainous terrain, which also will allow safer entry into hostile territory. We will present data from a series of flight tests of the LandSafe® Precision Flight Instrumentation System (PFIS) under clear air and DVE conditions over multiple terrain types.

The system was developed as part of a six year Office of Naval Research (ONR) development program. Multiple EDM versions of the system were extensively tested in clear air on the OADS' UH-1H as well as a government CH-53E test platform at Patuxent River Naval Air Station and in the dust on the UH-1H and CH53-E at Creech Air Force Base and Yuma Proving Grounds (YPG). Data is presented in this paper from testing of the final EDM system in Northern Virginia and at YPG. Figure 1 depicts the OADS UH-1H flying out of a dust clout at the test range at Creech Air Force Base in Indian Springs, Nevada.

Figure 1 The OADS UH-1H flying out of a dust cloud at Creech Air Force Base in Indian Springs, NV.

The Problems Beyond DVE

In addition to landing in a DVE condition, pilots of rotorcraft often perform missions wherein knowledge of their low speed airspeed, wind speed and direction, and precise drift over the ground could mean the difference between success and failure. Search and rescue, fast roping, and heavy lift are all examples of these types of missions, especially when performed at night. In these activities it is necessary for rotorcraft pilots to hold a hover over a fixed point, with close to zero ground drift regardless of the wind and weather conditions, both for military and civilian purposes. In addition, precise knowledge of aircraft and weather parameters allows for a larger operational envelope and for landing in smaller, more remote landing zones.

Current landing zone requirements, both military and civilian, are restricted by inadequate knowledge of aircraft parameters and wind conditions at the landing zone. Aircraft descent rates and glide slopes are limited by inadequate knowledge of airspeed, making it difficult to land on top of buildings in urban canyons and in remote landing zones in mountainous regions. Also, in DVE operations, the requirement to land with forward airspeed dictates that a very large area is necessary to land a fleet of rotorcraft, limiting their usefulness in remote, mountainous regions, areas where GPS can also be degraded. Precise digital knowledge of airspeed, wind speed, height above ground, groundspeed and ground drift will allow steeper glide slopes, higher descent rates and smaller landing zones increasing the utility of rotorcraft for executive, personnel and cargo transport to remote and urban locations.

Main Body

LandSafe® Precision Flight Instrumentation System Overview

Optical Air Data Systems (OADS) L.L.C. has designed, prototyped, and flight-tested the LandSafe® Precision Fight Instrumentation System (PFIS) for rotorcraft operating in DVE conditions. This laser remote sensing system precisely measures and reports height above ground, groundspeed, ground drift, low speed airspeed, relative wind, and magnetic wind information to the pilot in real time under all visibility conditions. The solution takes into account a concept of operations that provides pilots with enhanced situational awareness from the point of descent all the way to the ground.

Unlike traditional RADAR and LADAR solutions that focus on providing 3-D imagery of the terrain below the aircraft, the LandSafe® PFIS is designed to output high power laser pulses capable of penetrating the obscurants and measuring terrain features at high data rates at fixed points below the aircraft. The sensor also outputs laser pulses ahead of the aircraft to measure airspeed as well as relative and magnetic wind information.

Laser Doppler Velocimetry

The LandSafe® PFIS system operates on the principle of Laser Doppler Velocimetry. With this technique, the sensor system simultaneously outputs multiple identical pulsed laser signals towards the ground as well as the air mass ahead of the aircraft. A block diagram of the system is shown in Figure 2. To measure air data information, the laser signals interact with atmospheric constituents such as dust, aerosols, and pollen, along with other particulates as the laser pulse travels through the atmosphere towards the target plane. These atmospheric scatterers reflect the laser light back towards the sensor system along the beam path based on the principal of Mie Scattering.

Mie Scattering

Performance of optical sensors for ‘see-through’ and ‘sense-through’ applications requires a strong understanding the scattering characteristics of obscurants. Particulates such as dust and fog are considered Mie scatterers.

Mie scattering theory defines differential scattering cross sections are defined in terms of the angular intensity functions *i*1 and *i*2, as given by the expressions:

$$\sigma'_{VV} = \frac{\lambda^2}{4\pi^2} i_1, \quad \text{and} \quad \sigma'_{HH} = \frac{\lambda^2}{4\pi^2} i_2, \tag{1}$$

The above two equations are averaged to define the differential scattering cross section for un-polarized incident light, which gives the relation:

$$\sigma'_{Scat} = \frac{\lambda^2}{8\pi^2}(i_1 + i_2)\,. \tag{2}$$

Intensity functions are calculated from the infinite series given by:

$$i_1 = \left|\sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)}\left[a_n \pi_n(\cos\theta) + b_n \tau_n(\cos\theta)\right]\right|^2 \tag{3}$$

$$i_2 = \left|\sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)}\left[a_n \tau_n(\cos\theta) + b_n \pi_n(\cos\theta)\right]\right|^2 \tag{4}$$

where the angular dependent terms π_n and τ_n are expressed in terms of the Legendre polynomials,

$$\pi_n(\cos\theta) = \frac{P_n^{(1)}(\cos\theta)}{\sin\theta}\ , \tag{5}$$

and

$$\tau_n(\cos\theta) = \frac{dP_n^{(1)}(\cos\theta)}{d\theta}\,, \tag{6}$$

and terms a_n and b_n are defined as:

$$a_n = \frac{\Psi_n(\alpha)\Psi'_n(m\alpha) - m\Psi_n(m\alpha)\Psi'_n(\alpha)}{\xi(\alpha)\Psi'_n(m\alpha) - m\Psi_n(m\alpha)\xi'_n(\alpha)} \tag{7}$$

and

$$b_n = \frac{m\Psi_n(\alpha)\Psi'_n(m\alpha) - \Psi_n(m\alpha)\Psi'_n(\alpha)}{m\xi(\alpha)\Psi'_n(m\alpha) - \Psi_n(m\alpha)\xi'_n(\alpha)}\,. \tag{8}$$

where α represents the scatterer size parameter.

The Ricatti-Bessel functions Ψ and ξ are defined in terms of the half-integer-order Bessel function of the first kind (Jn+1/2(z)), and ξ_n is defined in terms of the half-integer-order Hankel function of the second kind.

The total Mie extinction and scattering cross sections are then determined as[i]:

$$\sigma_{ext} = \frac{\lambda^2}{2\pi}\sum_{n=0}^{\infty}(2n+1)\,\mathrm{Re}(a_n + b_n) \tag{9}$$

and

$$\sigma_{scat} = \frac{\lambda^2}{2\pi}\sum_{n=0}^{\infty}(2n+1)\left(|a_n|^2 + |b_n|^2\right). \tag{10}$$

The extinction and scattering cross-sections are critical inputs for LIDAR design and analysis for both imaging as well as sense-though approaches.

Doppler Shift and Detection

The velocity of these scatterers (which represents the speed and direction of the airmass) is imprinted on to the reflected laser signal based on the Doppler principle[ii],

$$\Delta f_{Doppler} = \frac{2\,\Delta\mathrm{V}}{\lambda}\cos\theta\,. \tag{11}$$

These return signals are analyzed by the sensor system along each beam and velocities along the beam axes are determined. Velocities are then combined and transformed to output three dimensional *volume-averaged* wind velocities in the desired frame of reference at multiple ranges ahead of the sensor. The same principle is applied to the measurement of the speed of the aircraft over the ground, where the laser interacts with the ground and the ground imprints the speed onto the reflected laser signal.

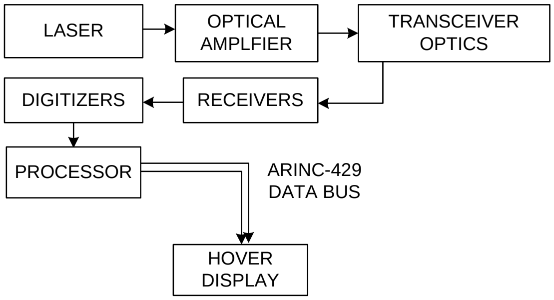

Figure 2 Block diagram

The laser altimeter is a time of flight system in which precisely timed laser pulses are reflected off of the ground and detected. The return trip time of the pulse is calculated., and corresponds to the aircraft distance above the ground.

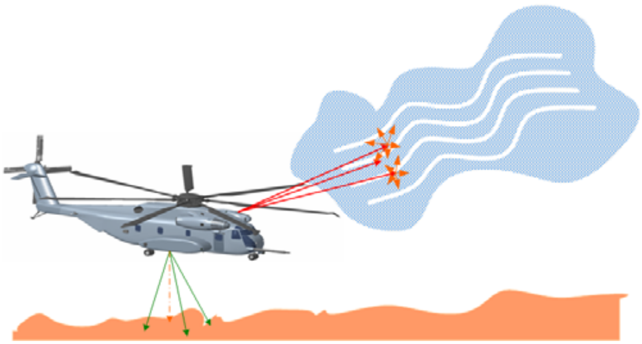

Figure 3 Operational Concept

The digital data from the sensor system is coupled to a multi-function display via ARINC 429, currently displaying a modified version of the V-22 hover page. The digital data can be output to any platform display. The display, shown in Figure 4 has standard ring and post symbology in the center to visualize groundspeed and drift coupled to a compass that displays aircraft heading. Around the compass are arrows that indicate the direction of the relative (green) and magnetic (blue) wind. The numerical readouts of the relative and magnetic wind values are displayed in the upper right and left corners respectively. The tape on the left side displays the airspeed with the numeric value directly below it, and the tape on the right side displays the laser altitude. In the lower right corner the groundspeed is displayed numerically. This system can also be coupled to a home plate hover page symbology, where a landing area is geo-referenced by GPS and the pilot can hover over a specific point on the ground or it can be fused into an image display.

Figure 4 The OADS UH-1H flight test display

The LandSafe® PFIS provides measured values of height above ground, three-dimensional groundspeed and ground drift, and three-dimensional airspeed down to zero knots, displayed as true airspeed and relative wind to the aircraft, and magnetic wind unlike traditional sensors such as EGI, which provides derived groundspeed from location and height above sea level, and a Pitot tube, which provides single axis airspeed traditionally above 40 kts. The LandSafe® system does not rely on any outside information (like GPS) to maintain accuracy, which is especially important in a GPS denied or degraded environment. Additionally, this sensor suite does not emit any RF radiation, is invisible to conventional IR cameras and I-squared devices, and has a negligible IR signature, making it an ideal solution for covert operations.

The airspeed portion of the LandSafe® PFIS, called the WindSceptor™ Optical Air Data Sensor Suite (OADSS), shown in Figure 5, can be installed independently of the other two subsystems.

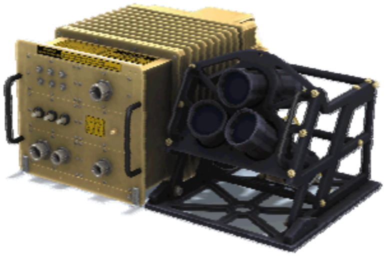

Figure 5 The WindSceptor™ Optical Air Data Sensor

The WindSceptor™ OADSS reports three-dimensional airspeed for rotorcraft as well as highly precise and accurate true airspeed, angle of attack, angle of sideslip for fixed wing aircraft. The system is currently in test on several commercial rotorcraft to measure highly accurate airspeed down to zero knots in order to increase the operational capability of the aircraft. The addition of highly precise airspeed measurements down to zero knots has the potential to significantly increase the usability of rotorcraft in urban environments. Due to airspeed measurement limitations, rotorcraft must follow a shallow slow descent route into a landing zone. In order to keep the aircraft out of a vortex ring state situation, an upper limit is placed on the descent rate of the helicopter due to the inability of the traditional airspeed measurement system to function adequately below a certain speed. With accurate knowledge of low speed airspeed, these descent restrictions can be set in a platform specific way and steeper descents can be allowed, making an urban ILS possible and opening up many new landing sites for rotorcraft. However, this benefit is not limited to urban settings and can be taken advantage of on offshore oil platforms and ships where inadequate knowledge of the wind restricts the conditions under which aircraft can operate. Furthermore, equipping the aircraft with a sensor that can accurately and remotely measure the wind will both allow safer aircraft operation and increase the operating envelope.

Additionally, operations in high, hot and heavy environments are enhanced by the situational awareness provided by the WindSceptor™ OADSS. Power available can be maximized by making takeoff and landings into the wind achieving translational lift sooner on takeoff and maintaining translational lift longer on approach with more accurate knowledge of wind velocity. This information will also help to avoid situations that can induce loss of tail rotor effectiveness.

How We Sense through Dust

LIDAR has a reputation for the inability to penetrate and "see" through the dust cloud. The wavelength of light traditionally utilized in LIDAR scatters off of particles in the atmosphere and is prone to scattering off of thick dust clouds. However, there are several mitigating factors that allow a LIDAR sensor to "sense" through a thick dust cloud. In the case of the groundspeed system, the laser beams must penetrate the dust cloud and the reflection from the ground must be measured. Two phenomena aid the detection of the reflected laser beam from the ground. The first is that the velocities of the particles within the dust cloud are all different whereas the velocity of the aircraft over the ground is nominally a single speed. Therefore, when the spectra from the returned light are analyzed, the returns from the dust cloud are smeared over a broad range of frequencies whereas the return from the ground is a sharp peak. Secondly, the returns from the ground reach the system after the returns from the dust and will always be the final return. These phenomena coupled to state of the art signal detection and processing, allow the returns from the dust to be filtered out and the ground returns to be detected with extremely high fidelity at very high data rates. These phenomena also apply to the laser altimeter sensor.

Airspeed sensing through the dust presents a different challenge. In the airspeed system, the lasers beams are sent through the dust cloud to a volume of clear air, outside of the rotor wash. The system is single point reporting so that the detector does not detect the returns from the dust cloud; thus, there are no issues of differentiating the dust cloud from the clear air return. However, the dust cloud significantly attenuates the beam and therefore the returns from the clear air can be extremely weak. State of the art signal processing was developed in order to detect these weak returns from the clear air outside of the dust cloud at high data rates with exceptionally high detection probability.

Test Method

System Configuration

The LandSafe® PFIS is a fused sensor system that consisting of a Doppler LIDAR Airspeed system, a Doppler LIDAR Groundspeed system and a laser altimeter sensor. Each system consists of a laser/processor avionics line replaceable unit coupled to a lens assembly via rugged fiber optic cables. Each system's lens assemblies can be mounted together on chandeliers as they were during the specific flight tests reported herein, or they can be distributed around the aircraft. The lens assemblies are protected by a window in front of each lens that is coated with a hard transparent coating allowing it to be cleaned by simply wiping it down with a rag. No special cleaning procedures were employed on the lens assemblies during any of the flight tests.

Airspeed

The airspeed subsystem measures the relative air velocity along three fixed axes at a preset measurement distance and utilizes three independent lens assemblies to detect the relative speed of particulates entrained in the air outside of the rotor wash. The velocity of the air along each measurement axis is measured and calculated in real time and then coordinate transformed to a three-dimensional airspeed measurement in the aircraft frame. All three dimensions of the relative wind information are recorded, however only the forward airspeed and horizontal relative wind were displayed to the pilot during testing. The lenses are separated by an opening angle of 30 degrees translating to an overall system accuracy of better than 1 knot and less than 1 degree over the entire speed regime.

Groundspeed

The three-axis groundspeed subsystem utilizes three fixed laser beams, located on a chandelier mounted in the "hellhole" under the transmission to measure the speed of the helicopter relative to the ground with an accuracy of less than 1 knot. A photograph of the installed lens assemblies is shown in Figure 6. As is evident from the figure, the location of the chandelier in the "hellhole" caused the lenses to quickly get coated with transmission fluid and oil during flight operations and once covered with the oily film, the lenses were then coated with a layer of dust during all DVE operations. It is important to note that even with the coating of oil and dirt, the lenses functioned through the entire flight without being cleaned.

Figure 6 The groundspeed lens assemblies mounted on the OADS UH-1H following a dust test flight.

Laser Altimeter

The single axis laser altimeter system used in the flight tests utilized a single bistatic lens assembly pointed downwards and mounted in the center of the groundspeed chandelier as seen in Figure 7. The groundspeed and laser altimeter system shared an avionics box for this test, but can be separated (as they are in the current installation) for ease of integration. The laser altimeter system determines the range to the ground along the line of sight of the laser beam and utilizes the onboard Attitude Heading and Reference Sensor (AHRS) to convert this measurement to report the height above ground of the aircraft. It is possible to have more than one lens assembly for the laser altimeter sensor, which would enable the system to determine both the height above ground and ground slope of the landing zone.

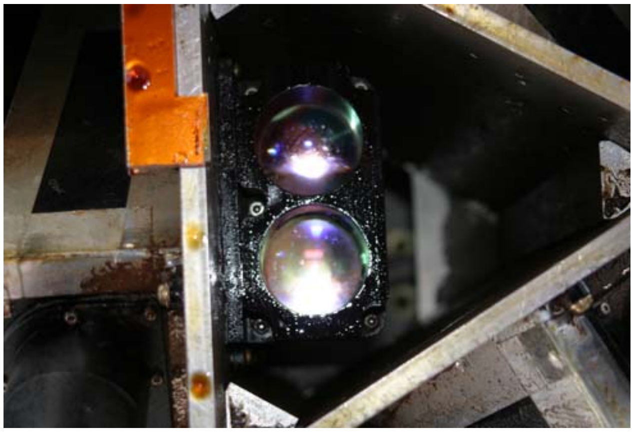

Figure 7 The laser altimeter sensor mounted on the OADS UH-1H. The lenses, coated with a layer of oil and dirt, remained functional throughout the flight test.

UH-1 Installation and Configuration

The system was installed in the OADS UH-1H in Manassas, Virginia in February 2010 for local clear air flight-testing. The EDM LandSafe® system consisted of two 19 inch rack mountable chassis located in a flight test rack in the cabin of the aircraft, the airspeed lens assemblies mounted on a chandelier on a platform attached to the side of the aircraft and the groundspeed and laser altimeter lens assemblies mounted on a chandelier in the “hellhole” of the aircraft. The mounting configuration of the chassis and airspeed lenses are shown in Figure 8.

Subsequent to initial flight-testing of this EDM LandSafe® system, a preproduction prototype LandSafe® PFIS has been installed in the UH-1H. This system represents a significant size, weight, power and cost reduction while increasing the speed and height above ground envelope of the system. The new system consists of separate boxes for the three subsystems, each located in an avionics mounting area of the aircraft.

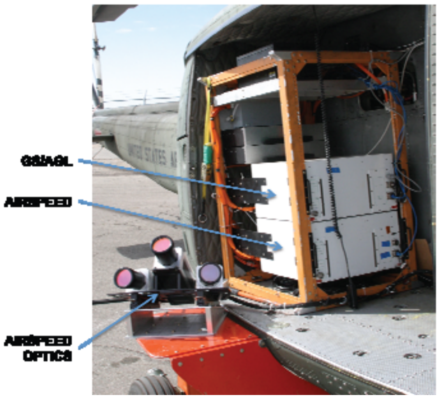

Figure 8 The installed EDM LandSafe® chassis and Airspeed lens assemblies.

The groundspeed and laser altimeter avionics boxes are located in the rear avionics compartment and connected to the lens assemblies by rugged fiber optic cables, as shown in Figure 9. The WindSceptor™ OADSS airspeed system and associated lens assemblies are mounted in the nose of the aircraft and all emanate from a single 80 mm window aperture in the nose of the helicopter as shown in Figure 10. The final production version of the system is expected to be less than 10 lbs per subsystem.

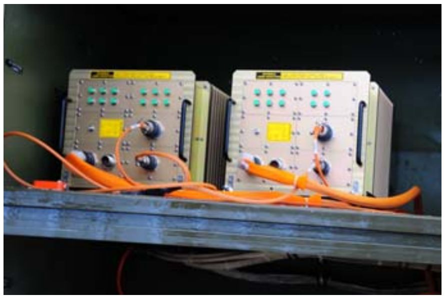

Figure 9 The preproduction prototype LandSafe® groundspeed and laser altimeter avionics boxes.

Roll/Pitch Angle Limits and Data Update Rate

In a permanent installation, the lens assemblies would be distributed around the aircraft so that they are operational at all roll and pitch angles. The data update rate for the testing was fixed at 20 Hz for all conditions including DVE in all flight regimes. This update rate can be increased in order to couple the system to an autopilot.

Figure 10 Flush mounted airspeed preproduction prototype on the OADS UH-1H.

Flight Test Methodology and Clear Air Flight Testing

Several flight tests were performed to ensure system accuracy and data reliability. Accuracy testing is conducted during ground runs, where wind measurements are compared to airport measurements to ensure system accuracy for the wind system. The groundspeed and ground track angle system is tested against the airspeed system during forward and backward slide maneuvers with and against the wind and against the GPS groundspeed.

The system was then flown over dry and wet tarmac, concrete, grass and water in clear air to ensure performance over all types of terrain. These tests were conducted locally at the Manassas Regional Airport in Manassas, VA, at Warrenton-Fauquier Airport in Warrenton, VA and over Lake Manassas in Gainesville, VA. The flight maneuvers performed during the clear air and DVE flights were low hovers (5 ft) high hovers (100 ft), pedal turns, slow taxis forward from hover (10 ft, 10 kts), right slides from hover (10 ft, 10 kts), left slides from hover (10 ft, 10 kts), 45 degree slides right and left forward from hover (10 ft, 10 kts), and slow taxis in fixed direction (30 ft, 5 kts). High speed, fast rate of ascent takeoffs were also evaluated. Once these tests demonstrated 100% data fidelity at the required 20 Hz data rate, the system was declared ready for DVE flight-testing. The OADS UH-1H was then flown to Yuma Proving Grounds (YPG) with the system still installed and was flight-tested in DVE conditions.

The maneuvers were chosen so that the system would encounter the worst DVE environment possible. When an aircraft comes to a hover in a dust situation, the dust becomes entrained in the rotor wash of the helicopter, thus surrounding the helicopter in a dusty wall, causing degraded visibility for the pilot. This phenomenon is a result of the force exerted on the ground by the rotors as they create lift for the aircraft. The amount of lift generated as a function of blade area is referred to as disk loading[iii] and therefore, the higher the disk loading on a specific platform, the more force those blades are going to exert on a specific area of the ground and the more dust that will be entrained. Thus, different helicopters will create different amounts of dust in the same environment and different sized dust particles will be entrained for different aircraft. However, due to the mechanism for entraining the particulates, the dust cloud does not form evenly under the rotorcraft, but rather forms a donut shape cloud with a clear center. Therefore, with the groundspeed and laser altimeter lenses located under the transmission, during a hover maneuver in the dust, the groundspeed and laser altimeter lenses were sensing through lighter dust. However, if the aircraft comes to a hover and then begins to taxi slowly at a low altitude, the donut smears and the system must continually sense through the thickest region of the dust cloud. The airspeed system reacts to the two maneuvers in the opposite manner. In a hover, the airspeed system must sense through the thickest part of the dust cloud and measure the clear air velocity outside of the rotor wash, creating the most attenuation for the system. In the hover to slow taxi maneuvers, the airspeed beams did not have to penetrate the thickest part of the cloud, which remained behind them, in order to measure the clear air outside of the rotor wash. Both hovers and slow taxis from hovers were performed in the DVE environment ensuring 100% data fidelity at the 20 Hz update rate in even the worst dust conditions for all three LandSafe® PFIS subsystems.

Flight Testing

Clear Air Flight Testing

Local clear air flight-testing was conducted over dry pavement, wet pavement, grass and large bodies of water. The laser altimeter subsystem outputs values in increments of 1 ft so the data from the system will not be continuous in height but rather step up in single foot increments. Figure 11 shows laser altimeter, groundspeed and airspeed from a pedal turn maneuver in clear air over tarmac, the solid green line represents groundspeed data, the dotted blue line represents airspeed, the dashed line red line represents laser altimeter and the dashed-dotted line represents the heading. The groundspeed reads zero during the entire maneuver indicating that the aircraft was not moving laterally over the ground, while the airspeed changes from positive to negative as the wind changes from coming from the nose to the tail. A full 360^0 turn was completed over the 45 seconds shown even though the heading is only displayed over the range –45 to 45 degrees.

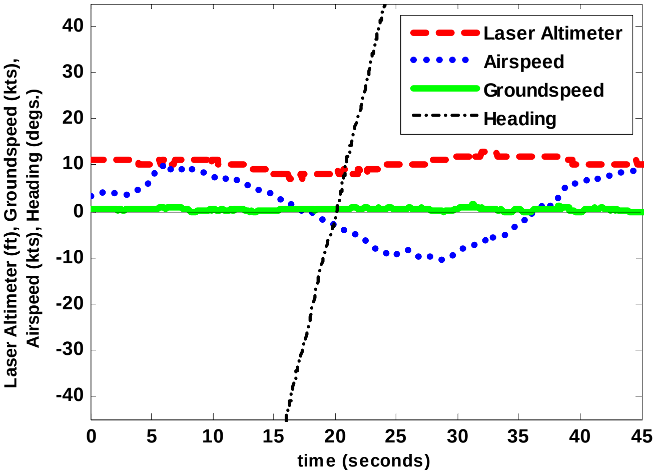

Figure 11 Data from a pedal turn maneuver, the solid green line represents groundspeed data, the dotted blue line represents airspeed, the dashed line red line represents laser altimeter and the dashed-dotted line represents the heading. The groundspeed reads zero during the entire maneuver indicating that the aircraft was not moving laterally over the ground, while the airspeed changes from positive to negative as the wind changes from coming from the nose to the tail. A full 360^0 turn was completed over the 45 seconds shown.

Figure 12 demonstrates a rapid ascent followed by a rapid descent. Again, the solid green line represents groundspeed, the dotted blue line represents airspeed, and the dashed-dotted red line represents height above ground. The data clearly show measurement of both airspeed and groundspeed from zero knots through 65 kts.

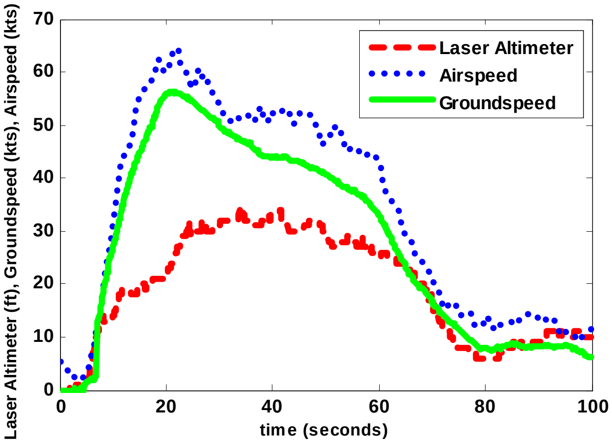

Figure 12 Data from a rapid ascent followed by a rapid descent in clear air, the solid green line represents groundspeed, the dotted blue line represents airspeed, and the dashed-dotted red line represents height above ground. The airspeed sensor measures accurate True Airspeed down to zero knots.

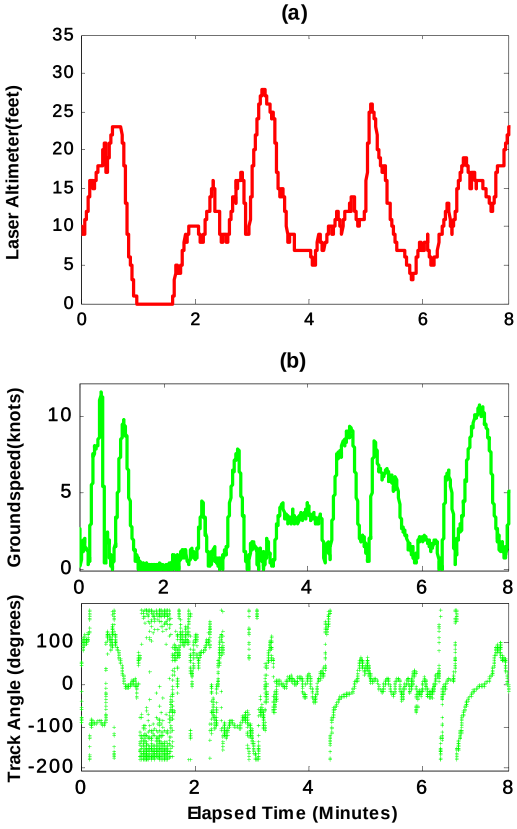

Figure 13 Data from clear air test flight over tarmac; (a) accurate height above ground measurements, and (b) corresponding groundspeed and ground drift data. Ground drift data is presented in terms of measured track angle over the ground.

Figure 13 (a) and (b) show 8 minutes worth of height above ground, groundspeed and ground track angle data from a flight over tarmac, respectively. The system demonstrated 100% data availability over the entire flight profile while maintaining a 20 Hz update rate and with no degradation of measurement accuracy.

Figure 14 shows the same 8 minutes of data for airspeed, relative wind and relative wind angle, note that the wind speed measurement was valid all the way down to zero knots.

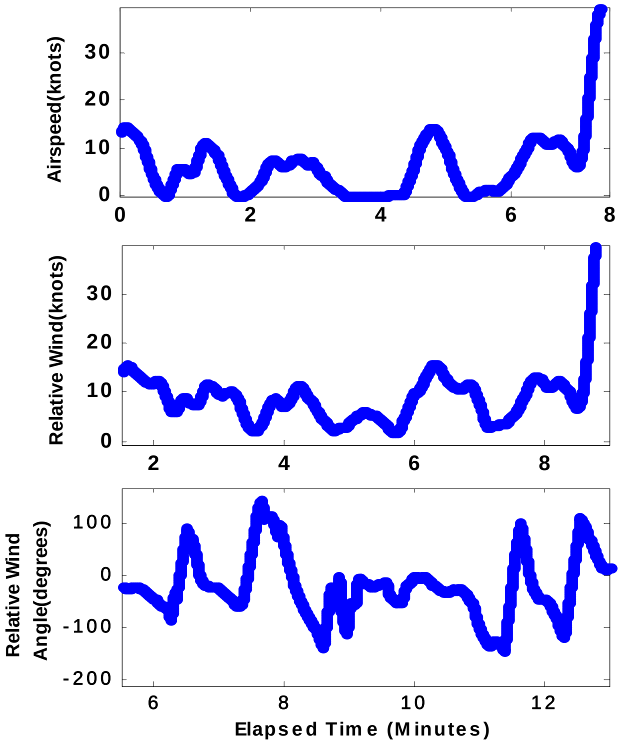

Figure 14 Data from clear flight over tarmac, corresponding to the data shown in Figure 13: (top) True Airspeed, (middle) Wind speed relative to aircraft, and (bottom) Direction of wind relative to the aircraft orientation.

To ensure system functionality, testing was also conducted over multiple types of grass. Grass presents an interesting challenge for the system in that the grass flutters in response to the rotor wake as the helicopter approaches the ground. This can result in multiple signal returns from the blades of grass as well as the hard ground beneath them. The same signal processing used to distinguish the ground return from the dust clutter is used to separate the motion of the grass from the aircraft speed over the ground. Figure 15 shows data from a hover and flight over the grass and shows that the systems display high-resolution data down to zero feet and zero knots over the grass.

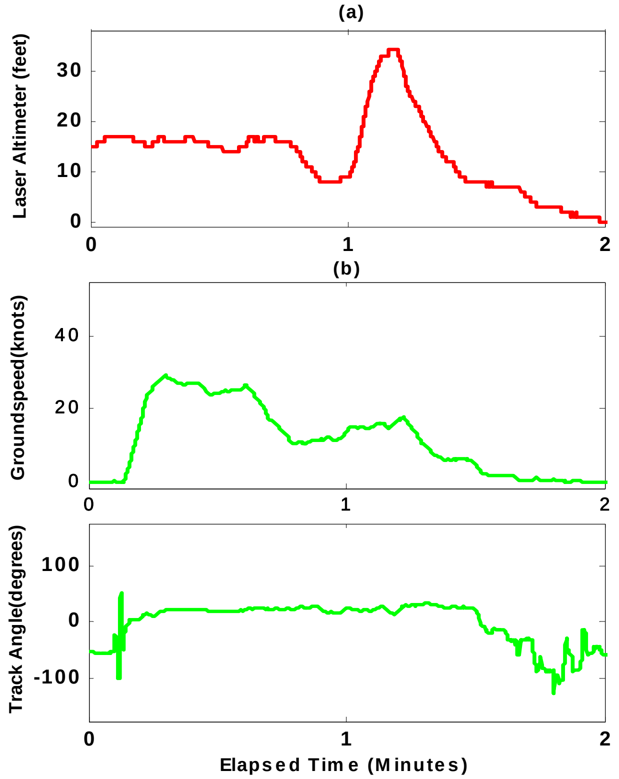

Figure 15 Height above Ground and corresponding groundspeed and ground track angle over grass. The flight profile involved forward level flight from a 15-foot hover followed by two changes in altitude, concluding in a gradual landing on grass.

Dust Testing

The LandSafe® PFIS system was flown to YPG hard mounted in the OADS UH-1H and thus was subjected to a heavy vibration environment and the system survived the trip, a testament to the all fiber optic architecture. During flight-testing, system parameters were tuned so that at the end of the testing period, the entire LandSafe® PFIS system performed with 100% data availability in all dust conditions.

The dust tests were conducted at the dust range at YPG, on the same course and concurrently with the HELO Product II tests (April 2010). The system was flown in the dust for approximately 15 hours between April and June 2010 and had over 50 successful landings and take-offs solely by reference to the LandSafe® EDM flight test display.

Figure 16 (a) and (b) show ARINC 429 data for the airspeed system for two representative dust flights at YPG, the latter flight flown by a NAVAIR CH-53E test pilot. The top graph in both figures depicts the forward airspeed of the aircraft and it is important to note the range of speeds down to zero knots the system encountered during the flight.

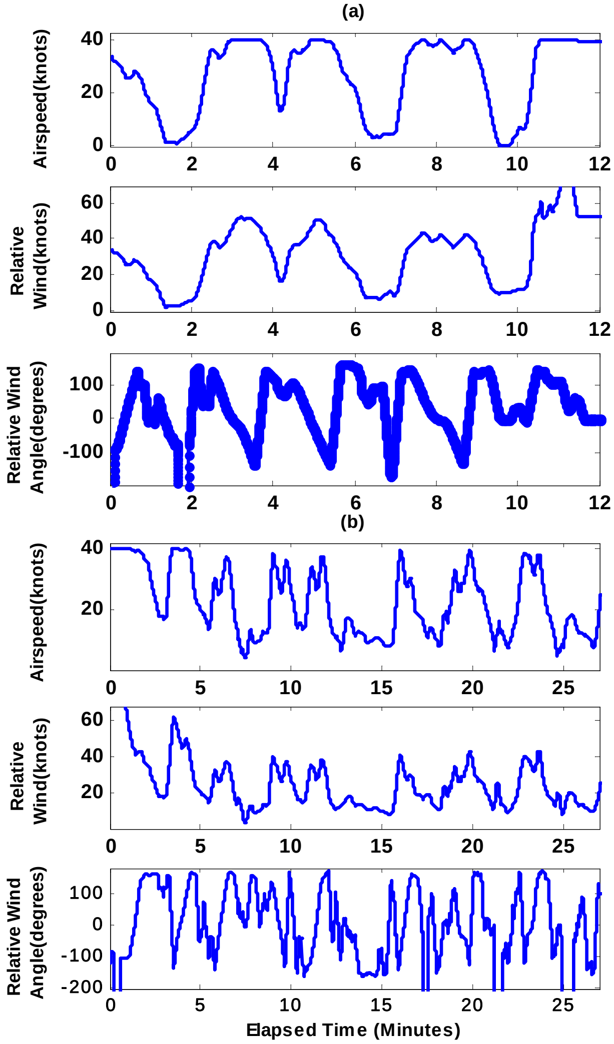

Figure 16 (a) and (b) Airspeed data from two representative dust flights at YPG. The top graph in both figures depicts the true airspeed of the aircraft, the middle graphs show the horizontal relative wind speed to the aircraft and the bottom graphs depict the relative wind angle to the aircraft in DVE conditions. Note that the system performed through the full range of speeds.

The second graph in the figures represents the relative wind to the helicopter during the maneuvers and the third graph is the relative wind angle. Again note that the system was exercised over a wide variety of relative wind speed and angle values.

Figure 17 (a) and (b) depict ARINC 429 data for the groundspeed subsystem for the same two representative flights as the airspeed subsystem. The full dynamic range of the system was exercised during the maneuvers and the system did not lose update rate or accuracy in the presence of severe dust along the line of sight of each laser beam.

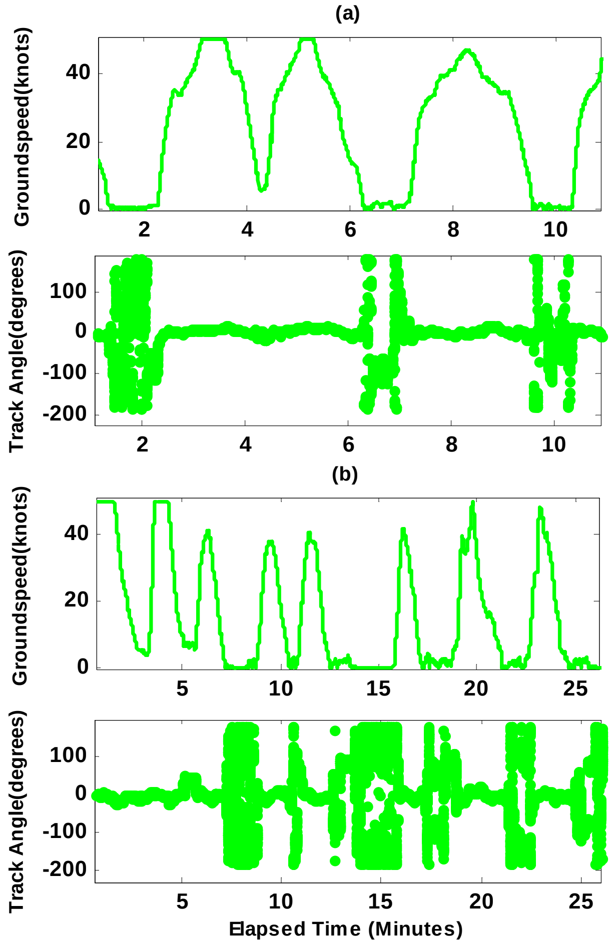

Figure 17 (a) and (b) show groundspeed and ground track angle data from two representative dust flights at YPG. The top graph in both figures depicts the groundspeed of the aircraft; the bottom graphs display the ground track angle to the aircraft in DVE conditions. Note that the system performed through the full range of speeds in the presence of severe dust in the line of sight of the laser beams.

Figure 18 (a) and (b) illustrate the ARINC 429 data for the laser altimeter subsystem for the same two representative flights as the groundspeed and airspeed subsystems. The blue curve spikes indicate situations in which the helicopter roll angles exceeded the limits and the data was not displayed to the pilot. The roll angle limits were determined based on the installation angle of the lens assemblies as the angle at which the lenses would no longer hit the ground. In a permanent installation, the lens assemblies would be distributed around the aircraft to ensure continuous performance over all operational landing maneuvers. Again, the system performed through the full range of altitudes in the presence of severe dust in the line of sight of the laser beam.

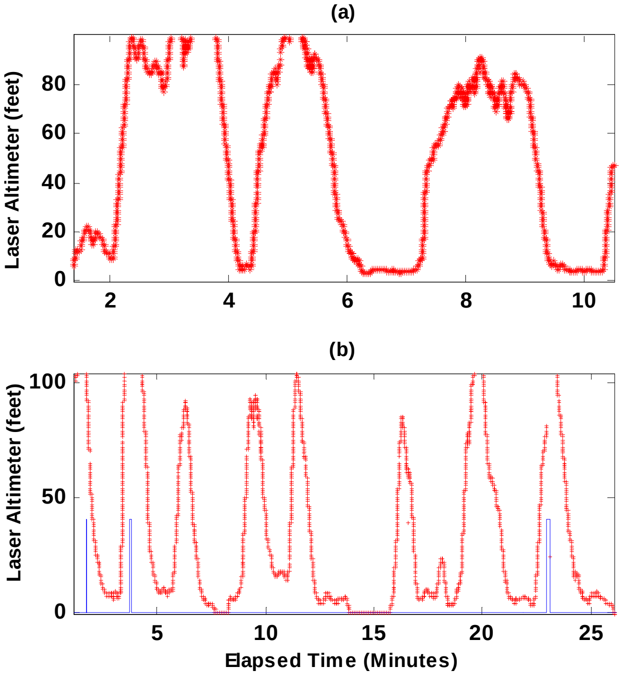

Figure 18 Laser altimeter data from two representative dust flights at YPG. Note the system performed through the full range of altitudes in the presence of severe dust in the line of sight of the laser beam.

Conclusions

The flight testing of the LandSafe® PFIS represents the first time, to our knowledge, that a system has been installed on a rotorcraft and successfully measured the height above ground all the way to the ground, the groundspeed to zero knots with no external data inputs and the three dimensional airspeed down to zero knots with no data dropouts both in clear air and in dust conditions. The addition of this capability will result in expanded operational envelopes while making flights safer for pilots, crew, passengers and cargo. The data clearly show that the system was able to successfully sense through the heaviest parts of the dust clouds with zero data dropouts at a 20 Hz data rate for all tested maneuvers.

Since the last series of DVE flight tests, the technology from this system has been transitioned to develop commercial remote wind measurement systems that have been deployed on Utility Scale wind turbines on multiple continents, off-shore buoys for wind resource assessment and weather model validation, and used in the 33rd America's Cup race as both a hand held and ship-mounted system. Also, the airspeed measurement system is currently being deployed to aid in enhancing impact point accuracy of ballistics and cargo drop applications. Finally, pre-production prototypes of the WindSceptor™ OADSS are under flight-test and certification for use as optical air data sensors for fixed and rotary wing aircraft.

Acknowledgements

The authors would like to acknowledge the generous support of the Office of Naval Research for funding the research and development of this system. Also, we would like to thank the entire staff at OADS for their tireless effort in support of the design, engineering and flight test of the LandSafe® PFIS and all of the follow on efforts. Finally we are grateful for the continuing guidance and support of Dr. J. Gordon Leishman.

References

---

[i] Measures, R.M., *Laser Remote Sensing: Fundamentals and Applications*. Krieger Publishing Company, Malabar, Florida, 1992.

[ii] Jelalian, A.V., *Laser Radar Systems*. Artech House, Norwood, MA, 1992.

[iii] Leishman, J.G., *Principles of Helicopter Aerodynamics*. Cambridge University Press, New York, NY 2006.