Lidar Wind Sensing for Improved Precision AirDrop and Gunship Wind Sensing

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Abstract: To mitigate threat risk and improve fuel efficiency, Air Force operations are desired at higher altitudes. Military gunship and airdrop missions share a need for accurate and timely wind measurements to improve targeting solutions, especially from high altitudes. The Air Force Research Laboratory (AFRL) has been researching ground-based and airborne Lidar and Radar sensors to provide real-time wind profiles to improve aiming solutions for airdrop payloads and gunship munition trajectories. A systems engineering approach incorporating multiple technology demonstrations were performed using Commercial-Off-the-Shelf (COTS) systems to mature technology. Demonstration data has been used to evaluate how these systems could be used to improve Precision AirDrop (PAD) and Gunship Wind Sensing (GWS) operations. Results from these demonstrations will be presented along with analysis of wind effects on airdrop and gunship missions.

1. Introduction

The United States Air Force core missions of rapid global mobility and global strike share a need for timely and accurate wind knowledge for successful mission execution. Uncertainty in the winds between aircraft and ground can cause large errors in many of these operations. As these operations are pushed to higher altitudes for aircrew safety and fuel efficiency reasons, the error in mission accuracy from wind uncertainty only becomes more pronounced. This paper addresses improved wind knowledge through collection and application of wind data for unguided Precision AirDrop (PAD) and Gunship Wind Sensing (GWS) programs. Previous work has shown that wind sensing technology can significantly reduce the amount of error for Air Force missions [1, 2]. This work done by Air Force Research Laboratory (AFRL) is meant to build upon previous work using current Commercial-Off-the-Shelf (COTS) wind sensor systems.

2. Wind Sensing for AirDrop Missions

To support the need of Air Mobility Command (AMC) to improve airdrop precision, AFRL is exploring different technologies to measure the wind between aircraft and ground for better Computed Air Release Point (CARP) calculations. In order to assess the state of current COTS wind sensor systems and how they could improve CARP calculations, a series of demonstrations were planned and executed. A systematic approach was designed to identify and analyze system capabilities and apply wind data collection to the airdrop solution. Through the Precision AirDrop Wind Sensing (PAWS) demonstrations, COTS wind sensor systems were evaluated in a rugged mountainous terrain in an unmodified ground-based configuration. Two of the systems were selected and modified to meet AirDrop requirements and tested during a third demonstration. Three PAWS (PAWS1, PAWS2, and PAWS3) demonstrations have been executed. Each demonstration consisted of ground-based Lidar and/or Radar sensors provided by different vendors. Dugway Proving Grounds, a United States Army test range chosen for its unique terrain features and extensive meteorology instrumentation capabilities, was used as the demonstration site for the first two PAWS demonstrations. The third demonstration was held at Yuma Proving Grounds due to the large amount of parachute testing that could be leveraged during the PAWS3 demonstration. Each range was instrumented with meteorological towers and/or weather balloons. Air Force Weather Agency (AFWA) forecasts for the test locations and times were also recorded. Additionally, PAWS2 and PAWS3 demonstrations were supported by live airdrops including dropsondes, windpacks, and instrumented training bundles. Windpacks and dropsondes are small parachuted sensors that are thrown from the aircraft to measure wind from aircraft to ground by tracking its horizontal displacement while falling via Global Positioning System (GPS).

Data collected from these demonstrations were used within both the AFRL-developed Weather Integrated Stochastic Simulation (WISS) and the operational mission planner Consolidated AirDrop Tool (CAT), to perform analyses on how wind Lidar/Radar can improve PAD accuracy. CAT is an AirDrop planning system used by aircrews to produce a release point based on pre-mission information (e.g. forecast, bundle, and aircraft data) and updated winds from dropsondes when available. WISS is a physics-based model that computes an impact point for a given release point using planned and actual winds. Using these two tools allows for a complete trajectory to be modeled from CARP calculation to impact on the ground. They also provide a measure for AirDrop improvement by quantifying the difference between impact points when varying initial parameters.

Significant conclusions from these demonstrations can be summarized by the following:

- Forecast wind values perform poorly when looking at a specific time and place and should not be the sole source of wind data for any given drop.
- Forecast wind data at high altitudes are commonly accurate and can give a good overview of general winds in the area, thus forecasts should not be discarded.
- In complex terrain, winds at lower altitudes tend to be more turbulent. This turbulence creates an even larger uncertainty in the forecast wind values thus increasing the need to accurately measure and report local low altitude winds.
- A single sounding from any source (dropsonde, weather balloon, Lidar) may not be a good representation of the winds through which a payload may pass during descent. Multiple soundings should be used for a CARP calculation to increase confidence in the solution.
    - If multiple soundings are available from a single location the variance from these soundings can be used to quantify bundle dispersion and miss distance.
- No single location, by itself, regardless of distance from the drop zone (DZ), can guarantee an accurate representation of the winds over the DZ. Thus, when using an airborne sensor, winds measured along the flight path do not always represent winds at the DZ.
    - Winds measured closer to the DZ are not necessarily more representative than those measured farther away.
- Sensor range is affected by power, atmospheric conditions, and scanning geometry. Wind Lidar and Radar depend on particulates in the air to create a signal feedback. At higher altitudes the amount of particulates diminishes especially above the planetary boundary layer.
    - Higher powered Lidars tended to perform better at longer ranges, except in cases of precipitation which, at times, blacked out the Lidar, but allowed for a stronger signal and longer range for the Radar.
- Multiple scanning configurations for an airborne sensor have been studied. More testing is required to define the trade space between such configurations as it applies to PAD.

During each PAWS demonstration wind data was successfully collected from each system in a variety of weather conditions including rain, snow, high wind, clear air, and cloudy. This variety of conditions demonstrated the strengths and weaknesses of each technology. Lidar and Radar systems specifically designed for AirDrop are currently being developed for further long-term testing.

3. Wind Sensing for Gunship Missions

Similar to PAD, a series of demonstrations were performed to assess COTS systems for use in improving Gunship first-shot accuracy. This work builds upon work done in 1997 by James Hawley and George Koerner which concluded that first-shot accuracy would improve significantly when using Lidar technology [2] to provide updated wind data. The AFRL gunship demonstrations sought to verify similar improvements using today's COTS technologies.

The first Gunship Wind Sensing demonstration (GWS1) was a ground-based demonstration located at the top of Sapphire Peak in DPG. The wind sensors were aimed downward along an instrumented line of site toward a designated target on the ground approximately 20 kilometers away. The second and third demonstrations (GWS2 and GWS2A) were airborne demonstrations with a wind sensor mounted aboard a Twin Otter aircraft and a commercial C-130A aircraft respectively. The sensor during these demonstrations was pointed out of the rear port side window with a fixed downward angle toward a fixed target on the ground. Multiple flights were conducted for each demonstration where the aircraft circled in a fixed orbit to simulate a realistic gunship orbit. Since the wind sensor was mounted at a fixed angle with respect to the aircraft, the movement of the aircraft provided the necessary angular diversity to calculate vector wind profiles. Several different orbit altitudes and locations were demonstrated.

After each demonstration, aircraft motion was removed from the wind data and vector wind profiles were calculated using MATLAB® software. Wind profiles were then used in PRODAS® (Projectile Rocket Ordnance Design & Analysis System) in order to simulate how the wind would affect trajectories and impact points of munitions. PRODAS was chosen due to its high fidelity 6-Degree of Freedom (DOF) model and its ability to model how different wind profiles affect the ballistics of different munitions. For all studies, a 30mm PGU13A round was used in the simulation. For simplicity during simulation, a nominal aircraft velocity of 200 knots true and a nominal aircraft bank of 5 degrees were chosen for all simulations.

The phase 2 and 2A Gunship demonstrations showed that using a fixed scannerless Lidar during an orbit is a viable solution to measure wind profiles from the aircraft altitude to the ground. A concern with this installation method was if representative wind profiles could be measured during an unsteady aircraft orbit. If the roll in particular is not stable then the cone over which the Lidar would be measuring wind would not be well defined. During the GWS2 demonstration such a condition was experienced. A portion of the aircraft orbit with calculated Lidar Line-Of-Sight and ground impact points is presented in Figure 1. Vector wind profiles calculated from the depicted orbit are also displayed in Figure 1. The Google Earth image in Figure 1 shows that due to a variable aircraft roll angle the Lidar was not always pointed directly at the target area and frequently was pointed at a location far removed from the target. This variability can cause a large amount of change between consecutive calculated vector wind profiles (represented by the colored dots in the plots of Figure 1) since vector wind profiles are an average of the measured wind over a section of the orbit, in this case 360 degrees. As can be seen in Figure 1 the

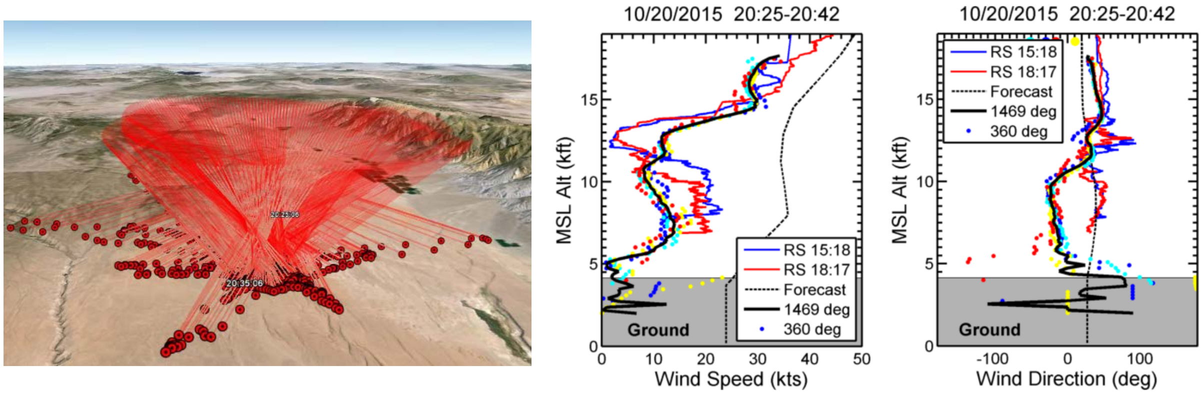

Figure 1: Example Lidar Line-Of-Sight with accompanying wind profiles

successive profiles agreed well with each other with the largest disagreements occurring at low altitudes. The solid black line in Figure 1 represents the wind profile calculated from all of the radial winds captured during the entire orbit. Points below ground level are an artifact of the inconsistent roll angles. Solid red and blue lines are wind profiles measured with weather balloons launched near the orbit site. For safety reasons balloons were launched before and after the aircraft operated in the demonstration area.

One desired objective during this demonstration was to determine how much of an orbit would be required for the aircraft to traverse before a reliable vector wind profile could be calculated. To address this question, radial wind data was divided into 30, 45, 60, 90, 180, and 360 degree sectors. Wind vectors calculated from these sectors were then compared. A sample of the vertical wind speeds calculated from the 45, 90, and 180 sector arcs are displayed in Figure 2, represented by the different colored dots. Vertical wind speeds are typically small when compared to horizontal speeds thus large vertical velocities can be attributed to errors from insufficient signal feedback or insufficient angular diversity.

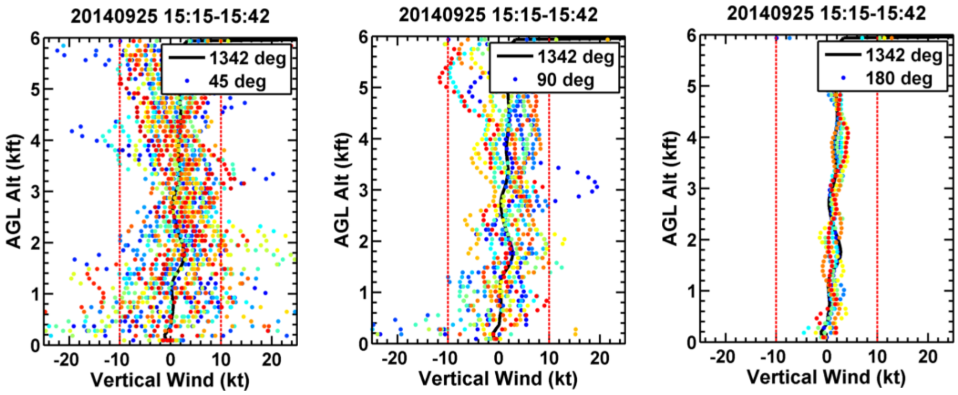

Figure 2: Vertical wind speeds calculated from different arc lengths

Sector size was inversely proportional to wind variability. Smaller sectors demonstrated a higher variability and magnitude in vertical wind speeds than did the larger sectors. Consistency between consecutive 180 and 360 degree arc profiles suggests that the wind was fairly stable over the collection time. This implies that variations in wind profiles from smaller arcs are more likely due to spatial variability or an insufficient number of particle reflections while collecting radial wind measurements. Since wind spatial variation tends to decrease with altitude and the variability from the smaller arcs tends to remain constant with altitude, the variability seen in the above plots is most likely due to low particle reflections. Because of this, smaller sector arcs are not good representations of the wind. A minimum of 180 degrees is recommended for gunship wind sensing orbit collection duration.

4. Conclusions

Multiple demonstrations have been performed for both PAD and GWS showing that Lidar and Radar can effectively measure wind between aircraft and ground and produce timely wind profiles for algorithms that calculate corrected aim points. Both ground-based and airborne sensors have been demonstrated using COTS wind profiling systems. This technology shows promise to increase accuracy of both AirDrop and Gunship missions allowing the Air Force to operate at higher altitudes thus increasing safety for the aircraft and the airmen. Work is still on-going on how best to implement this technology into current or future Air Force operations.

5. References

[1] Kathleen M. Yerdon, "The Impact of a Wind Profiling Capability on AirDrop Accuracy," in AIAA 15th Aerodynamic Decelerator Systems Technology Conference, Toulouse, France (1999).

[2] James Hawley and George Koerner, "*Gunship Ballistic Winds Remote Wind Sensor*," Final Report WL-TR-97-1099, Wright Patterson Air Force Base (1997).