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Helicopter downwash measured by continuous-wave Doppler lidars with agile beam steering

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Abstract

A ground-based remote sensing short-range WindScanner with agile beam steering based on a modified ZephIR continuous-wave wind lidar (LIght Detection And Ranging) and a double prism arrangement has recently been developed at the Department of Wind Energy at the DTU Risø campus. The WindScanner measures the line-of-sight component of the wind and by rapid steering of the line-of-sight and the focus position, all locations within a cone with a full top angle of 120° can be reached from about 8 meters out to some hundred meters depending on the range resolution needed. By using three such WindScanners, all three components of the wind can be retrieved.

Here, the first mean 2D turbulent wind fields measured in a horizontal and a vertical plane below a hovering search and rescue helicopter are presented. The line-of-sights of two synchronized WindScanners were scanned within the plane of interest. Since both line-of-sights always were inside the plane scanned, the influence of the wind component perpendicular to the plane was avoided. The results indicate that the flow field below a helicopter can be characterized remotely, which can support helicopter optimization regarding, for example, minimizing the risk to aircraft and personnel when operating in a search and rescue role.

The results from the application of the short-range WindScanner technology to the complex and turbulent helicopter downwash demonstrates the possibilities also within less demanding flows encountered within complex terrain and wind energy related research for which the WindScanner technology primarily has been developed.

1 Introduction

For a long time there has been a vision about rapid 3D measurements of turbulent flows in complex environments [1]. Now, a ground-based remote sensing short-range WindScanner with agile beam steering based on a modified ZephIR (manufactured by Natural Power, UK) coherent continuous-wave wind lidar (LIght Detection And Ranging) and a double prism arrangement has been developed at the Department of Wind Energy at the DTU Risø Campus in Denmark. The WindScanner operating at a wavelength of about 1.5 micrometer measures the line-averaged [2] line-of-sight component of the wind and by rapid steering of the line-of-sight and the focus position, all locations within a cone with a full top angle of 120° can be reached from about 8 meters out to some hundred meters depending on the range resolution needed. By using three such WindScanners, all three components of the wind can be retrieved without taking into account any assumptions about the flow.

In order to challenge the WindScanner by an extremely turbulent and complex flow, a proof-of-principle trial in the downwash flow below a search and rescue helicopter was undertaken. Here, we report about these first mean 2D complex turbulent wind field measurements that also is of interest for the aviation community since knowledge about the helicopter downwash structure under a search and rescue helicopter is crucial for safe rescue operations.

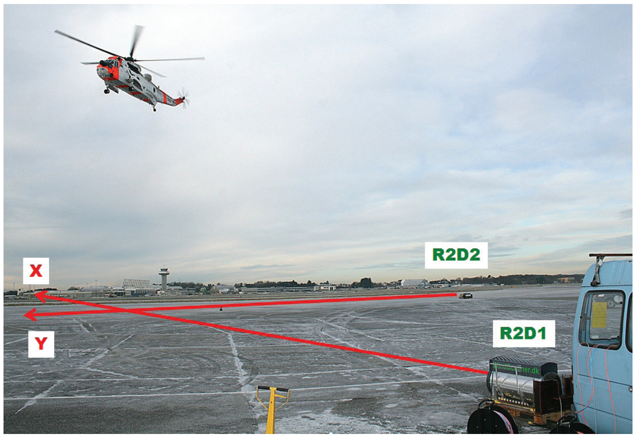


Figure 1: The experimental setup for scanning a horizontal plane below the helicopter.

2 The experimental setup

At the December 2011 helicopter downwash trial, two different configurations were used with the purpose of measuring the flow field in a horizontal plane close to the ground and in a vertical plane below a hovering search and rescue helicopter by two WindScanners. The particular short-range WindScanners used were the units called R2D1 and R2D2. Since only two WindScanners were available, the line-of-sights of the two WindScanners were made sure to be inside the planes scanned such that the influence of the wind component perpendicular to the plane of interest was avoided.

An overview of the setup used during the scanning in the horizontal plane is given in Fig. 1. In order to be able to measure as close to the ground as possible, a special mount with easily adjustable legs as seen in Fig. 1 was designed that allowed for the scanning beam to emanate from a height of about only 32 cm above the EUR-pallet on which it was standing. This means that the scanning horizontal plane was about 46 cm above ground. The EUR-pallet arrangement made the WindScanner easily movable by a lifting fork.

The horizontal scanning pattern was a spiral that spiraled outwards during 10 seconds to a radius of about 30 meters and then back to the center during 2 seconds along a line between the two WindScanners with the helicopter hovering at a height of 90 feet approximately above the origin of the coordinate system used. Almost along the return line in the scanning pattern a sonic anemometer sampling at 100 Hz was traversed while the averaged wind Doppler spectra were acquired at a rate of almost 400 Hz by each WindScanner.

For the scanning of the vertical plane, the location of the two WindScanners were almost the same as for the scanning of the horizontal plane. However, for the vertical plane measurements the scanners were turned such that they were directed towards each other with a distance of 78.8 meters in between and with the helicopter hovering at a height of 70 feet above the center of the line between the two WindScanners.

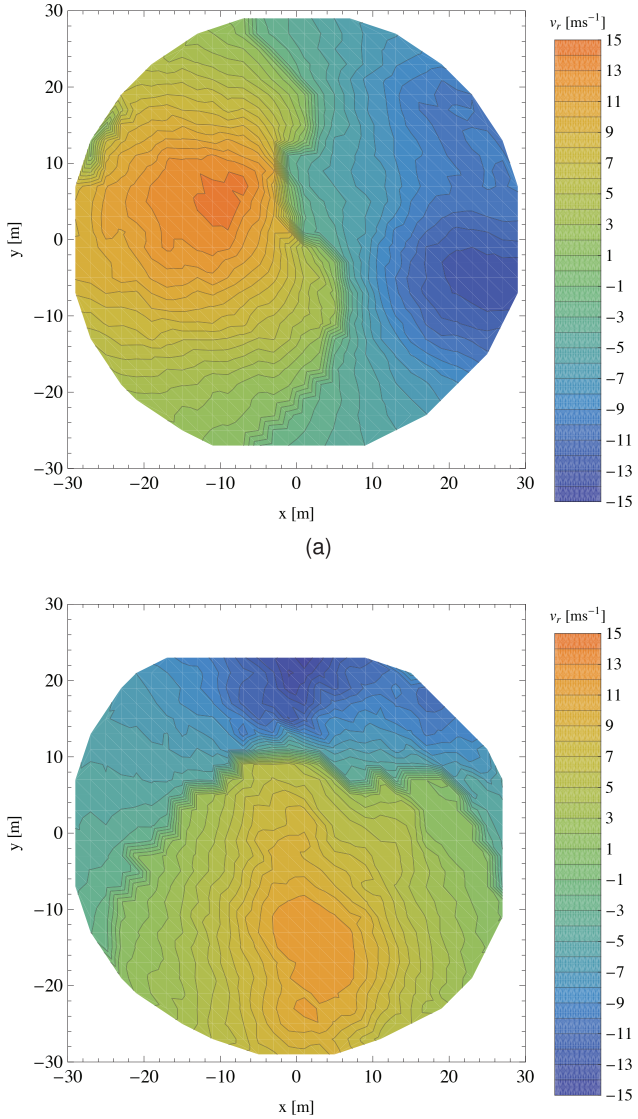
3 Analysis procedure

The first step in the data analysis is to synchronize the wind Doppler spectra obtained with the correct measurement positions in the atmosphere. Then, the spectra is divided by a noise background spectrum in order to flatten out the spectra such that structures in the spectra that are due to the measurement system itself becomes flat in the normalized spectra. In order to increase the apparent spectral signal-to-noise ratio, several spectra are averaged. In the method used, the spectra are sorted into grid cells with the size of 2 m by 2 m in the horizontal scan and 2 m by 0.5 m in the vertical scan. Subsequently, the median value in each frequency bin is calculated from all the spectra obtained in such a grid cell during a certain time resulting in a so-called median spectrum with less noise.

The wind speed is given by the Doppler shift frequency which is straightforward to calculate in the case of a spectrum corresponding to a constant steady wind speed with low turbulence and good signal-to-noise ratio which means that there is a single narrow peak and the location of that peak corresponds to the velocity that is to be retrieved. However, in a turbulent flow below a helicopter the Doppler peak broadens and it becomes more challenging to find the corresponding mean wind speed during the sampling period and therefore a frequency estimation procedure based on a Gaussian-fit is used.

Based on the two simultaneously measured line-of-sight wind speeds, the combined 2D wind vector can be retrieved as long as the two line-of-sights are not coinciding.

4 The flow field in a horizontal plane close to ground



(a)

(b)

Figure 2: The 10-minute average line-of-sight wind component measured by (a) the R2D1 WindScanner and (b) the R2D2 WindScanner in a horizontal plane close to ground.

The 10-minute average line-of-sight wind component measured by the R2D1 WindScanner in a horizontal plane about 46 cm above ground in the time interval 13:01-13:12 on Wednesday 2011-12-07 while the helicopter was hovering at a height of 90 feet is displayed in Fig. 2a. The R2D1 WindScanner was placed at x = -60 m and y = 0 m which explains why the sampled component of the wind vector in the left part of Fig. 2a is positive meaning that the flow away from the helicopter is directed towards the WindScanner and in the right part the flow is away from the WindScanner resulting in a negative wind speed component measured by the R2D1 WindScanner.

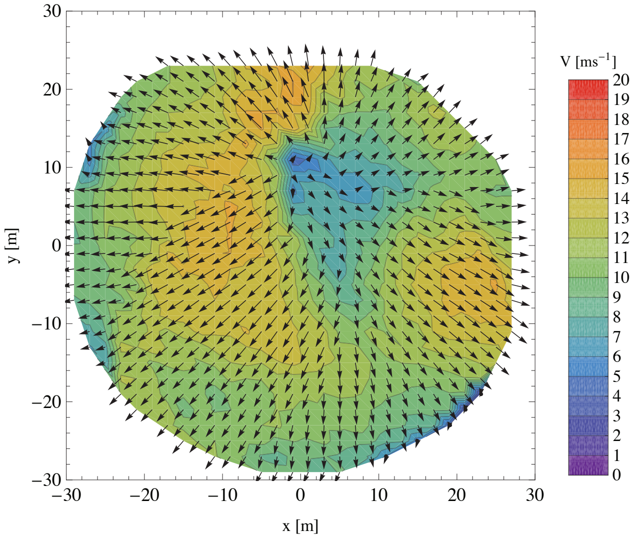


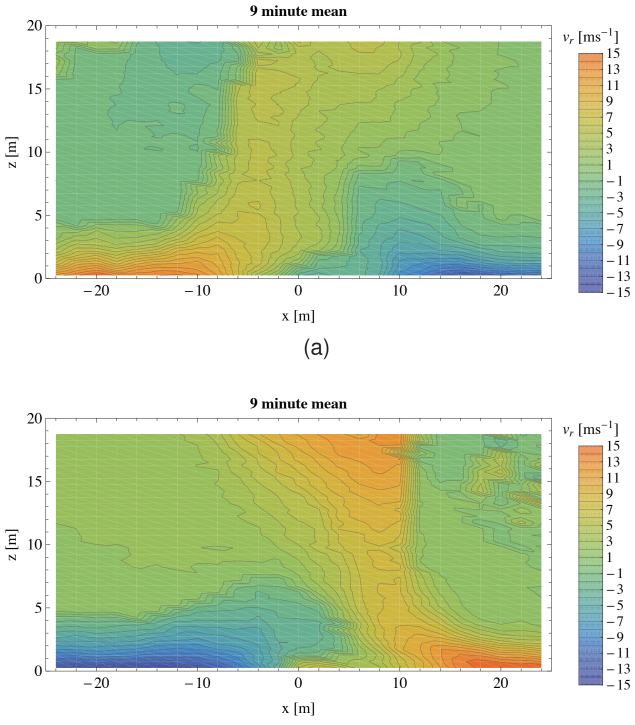
Figure 3: The retrieved 2D wind field in a horizontal plane close to ground.

The corresponding average of the line-of-sight wind component measured by the R2D2 WindScanner placed at x = 0 m and y = -50 m is displayed in Fig. 2b. It is a similar pattern as in Fig. 2a except that it is, as expected, turned 90°

The resulting combined 2D flow field in the horizontal plane is presented in Fig. 3 where it clearly can be seen that it emanates from a location slightly above and to the right of the center of the plot where the helicopter seems to have been located. The measured flow field exhibit, as expected, a shape similar to a doughnut with some complex structures and maximum speeds at about some 15 meters from the center of the calm area below the helicopter.

5 The flow field in a vertical plane below the helicopter

The 9-minute average line-of-sight wind component measured by the R2D1 WindScanner in a vertical plane below the helicopter in the time interval 16:50-17:00 on Wednesday 2011-12-07 while the helicopter was hovering at a height of 70 feet can be



(a)

(b)

Figure 4: The 9-minute average line-of-sight wind component measured (a) by the R2D1 WindScanner and (b) by the R2D2 WindScanner in a vertical plane below the helicopter.

seen in Fig. 4a. The center of the scanner head of the R2D1 Windscanner was placed at x = -39.4 m and z = 0 m which explains why the sampled component of the wind vector in the lower left part of Fig. 4a is positive, since the flow away from the helicopter hovering above approximatively x = 0 m is directed towards the R2D1 WindScanner in that region whereas in the right part the flow is away from the R2D1 WindScanner giving a negative wind speed component measured by the R2D1 WindScanner.

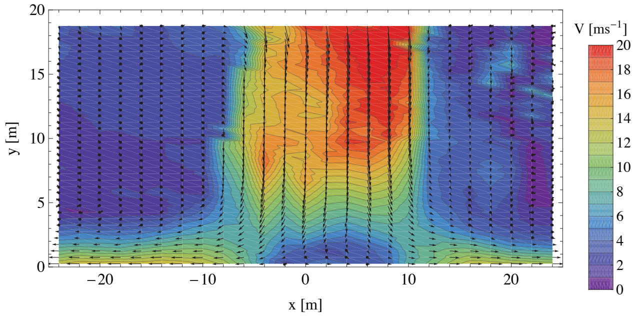


Figure 5: The retrieved 2D wind field in a vertical plane below the helicopter.

The corresponding average of the line-of-sight wind component measured by the R2D2 WindScanner placed at x = 39.4 m and z = 0 m is displayed in Fig. 4b and the resulting combined vertical 2D flow field is presented in Fig. 5. It can clearly be seen that the mean flow below the rotor is directed downwards and confined within a radius of about 10 m and that the flow deflects outwards as it approaches the ground. The helicopter location seems to be slightly off-centered in the positive x-direction.

6 Discussion and Conclusions

The particular results here presented indicate that the complex and turbulent helicopter downwash flow field below a helicopter can be characterized remotely by a short-range WindScanner. This suggests that the WindScanner technology can support helicopter optimization regarding, for example, minimizing the risk to aircraft and personnel when operating in a search and rescue role. Furthermore, it can be concluded that the WindScanner technology advances the possibilities of studying flows encountered within complex terrain and wind energy related research for which the WindScanner technology primarily has been developed.

Acknowledgments

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