PO. 336

Comparison of Zephir and Windcube results in same complex flow field

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Abstract

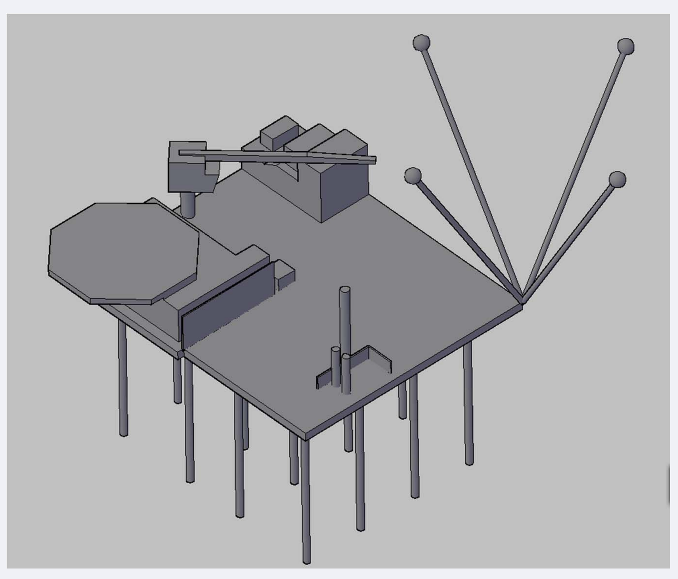
Offshore wind is the major growth area in the wind industry sector today. However, there remains a key, fundamental missing element - a thorough understanding of the offshore wind climatology and likely wind resource. In 2008 the EU FP7 funded project NORSEWInD was created with a remit to deliver offshore wind speed data at a nominal project hub height acquired in offshore locations in the North, Baltic and Irish seas.

Part of the NORSEWInD project is the use of LiDAR remote sensing (RS) systems mounted on offshore platforms to measure wind velocity profiles. The data acquired from the offshore RS measurements are fed into a large wind speed dataset suitable for use by the wind industry. One significant problem identified was the effect of platform interference effects on the RS data. Another significant effect on the quality of the data produced was the method by which the wind speed and direction was acquired as the method by which LiDARs measure the wind vector is significantly different from a point measurement. Whilst this will have no effect in a homogeneous flow field if there is significant flow distortion, which might be found in close proximity to a large structure or in complex terrain, then the effect of this spatially averaged measurement might cause a significant deviation from a point measurement.

This paper reports on the modelling of two different types of LiDAR, the Natural Power ZephIR and the Leosphere Windcube, in a computational fluid dynamics simulation of the flow around a large offshore structure. The paper discusses the difference in the measured wind vector when compared to a point measurement at the measurement height.

Method

To assess the effect of flow distortion on the output of a LiDAR the flow field over an offshore platform was modelled by computational fluid dynamics (CFD) The resulting data was then interrogated as if a LiDAR was actually present in the simulation which, in the case of a Leosphere Windcube, meant interrogating the flow field at four points on a cone expanding with height, figure 1a and, for a ZephIR interrogating the flow field at 50 points in a circle at the measurement height, figure 1b.



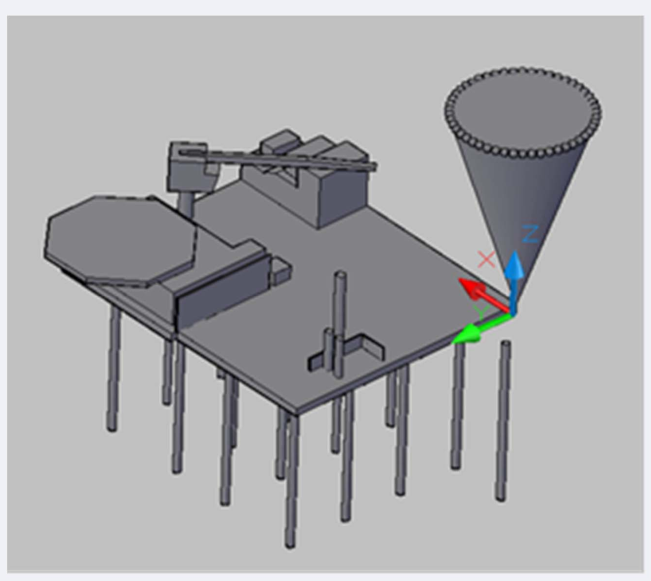


Figure 1a: Windcube Figure 1b:ZephIR
measurement locations

The LiDAR calculates the wind speed by measuring the Doppler shift in light reflected from particles entering a laser beam projected into space. The speed measured is the projection of the wind vector on to the unit vector in the direction of the laser beam, V_{los}, given in equation 1, Bingöl et al (2008).

$$V_{los} = u\sin\phi\sin\varphi + v\sin\phi\cos\varphi, + w\cos\varphi \qquad \text{Equation 1}$$

For the Windcube, from the four measurement points the velocity is calculated from equations 2, 3 and 4.

$$u = \frac{s_1 + s_3}{2\cos\emptyset} \qquad v = \frac{s_0 - s_2}{2\sin\emptyset} \qquad w = \frac{s_0 + s_2}{2\cos\emptyset}$$

Equation 2 Equation 3 Equation 4

For the ZephIR the fifty line of site velocities on a circular scan create a modified sine wave, figure 2. Equation 5 is now fitted to the data.

$$V_{los} = a\cos(\psi - b) + c \qquad \text{Equation 5}$$

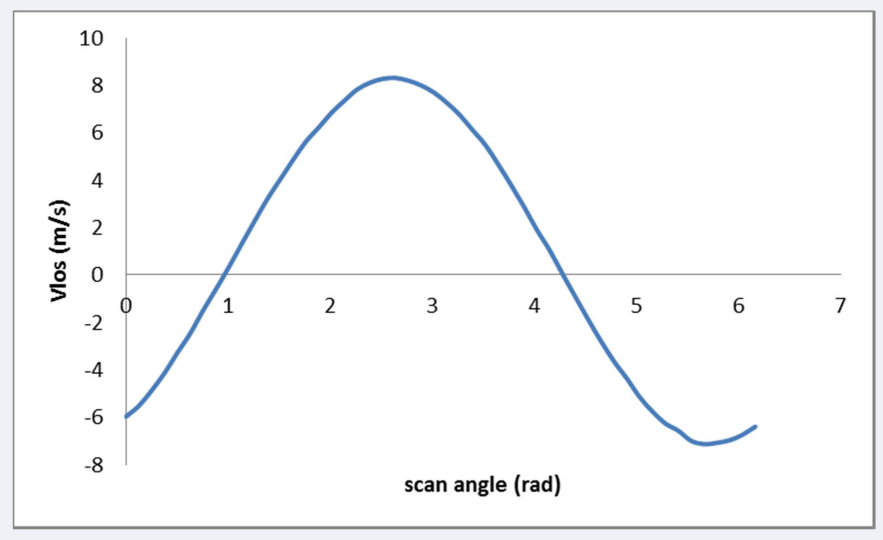


Figure 2: Vlos against scan angle

Where the coefficients a, b and c correspond to the horizontal wind speed, azimuth flow angle and vertical component of the wind speed as shown in equations 6, 7 and 8 respectively.

$$U_{horizontal} = \frac{a}{\sin\phi} \qquad b = \varepsilon \qquad w = \frac{c}{\cos\phi}$$

Equation 6 Equation 7 Equation 8

By interrogating the flow field above the platform in the CFD simulation it was possible to calculate what the output of a LiDAR would be. The velocity measured by the simulated LiDAR was then compared with the free stream at the measurement height and a non dimensional velocity magnitude in the horizontal plane determined by dividing by the free stream velocity, equation 9. Also, the difference between the measured and free stream azimuth angle determined, equation 10.

$$C_U = \frac{U_{LiDAR}}{U_{freestram}} \qquad \Delta\theta = \theta_{Freestream} - \theta_{LiDAR}$$

Equation 9 Equation 10

Results

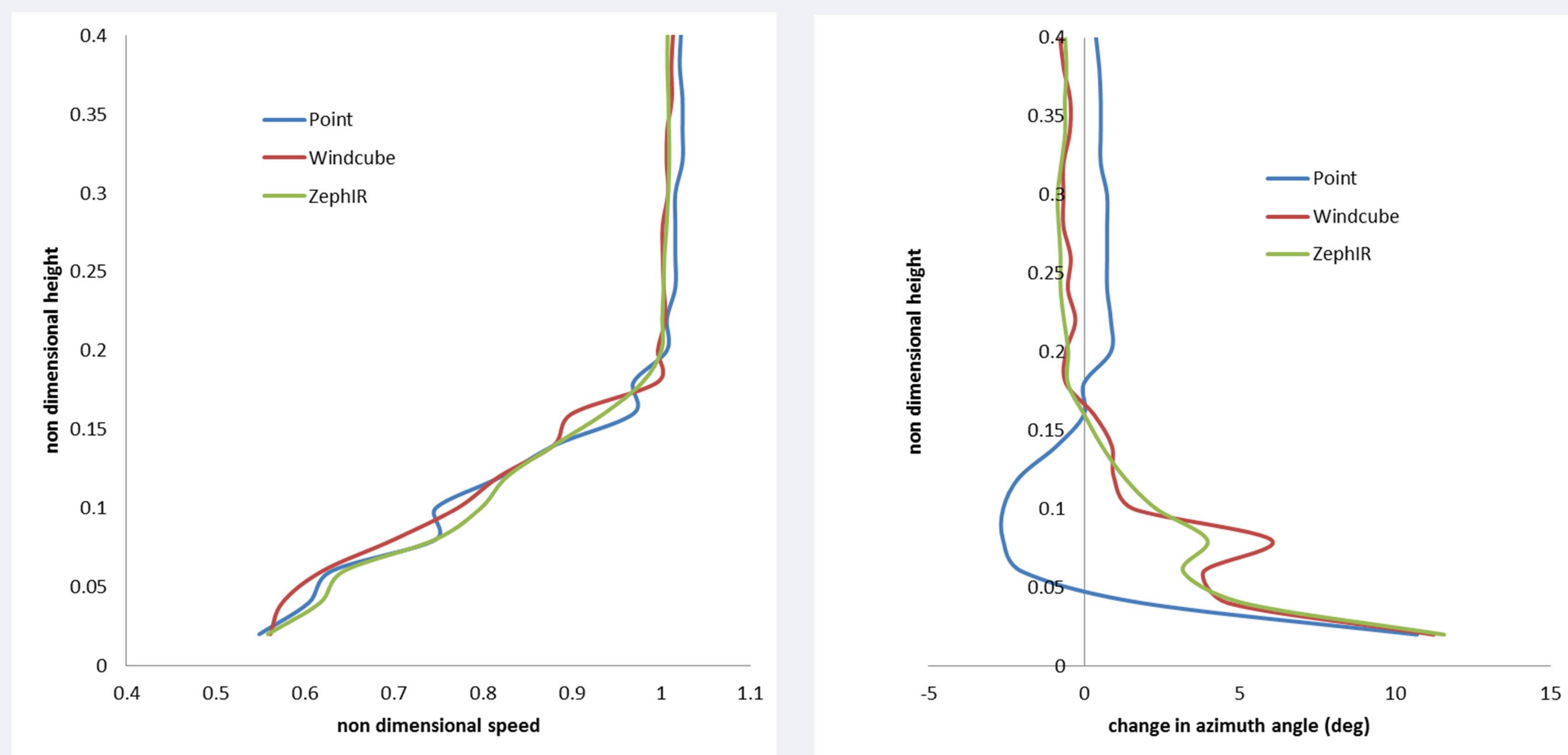


Figure 4: Comparison of point, Windcube and ZephIR simulations

Figure 4 shows the non dimensional wind speed and flow angle error against non dimensional height where the height has been non dimensionalised by the platform deck height. Also plotted on figure 4 is the velocity direction at a point directly above the LiDAR at the LiDAR measurement heights and represents the output that could be expected from a cup and vane type anemometer. From figure 4 it may be seen that both the ZephIR and the Windcube estimate the free stream velocity magnitude more accurately than a point measurement above the LiDAR location. This was due to the LiDAR measurement technique which samples the flow field at several locations which were outside the distortion field of the platform. The same may be said for the estimation of the free stream flow angle where the sampling outside the distortion field again produced a better estimate.

Conclusions

A technique by which the effect of flow distortion, on the measurements made by ZephIR and Windcube LiDAR, can be determined has been presented. It has been shown that both LiDARs give a better estimation of the free stream velocity magnitude and direction than a single point measurement.

References

LiDAR error estimation with WAsP Engineering F Bingöl, J Mann and D Foussekis 14th International Symposium for the Advancement of Boundary Layer Remote Sensing. IOP Conf. Series: Earth and Environmental Science 1 (2008) 012058