Offshore Low Level Jet Contribution to Wind Turbine Fatigue

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Motivation

As the wind industry moves offshore and turbines increase in size; the impact of wind phenomena such as Low Level Jets (LLJs) on wind turbines will become more of a concern. Design load cases stipulated by IEC 61400 use a simplified model of wind conditions which will not account for LLJ conditions. This work seeks to understand the loading implications which these, more complicated, wind conditions might have

Background

LLJs form during transition to stable atmospheric boundary layer (ABL) conditions. Onshore, this can happen diurnally with LLJs forming over cold desert surfaces at night in places such as the Great Plains of North America. Offshore, LLJs form seasonally in spring and early summer when warm air blows from the land over a cooler sea.

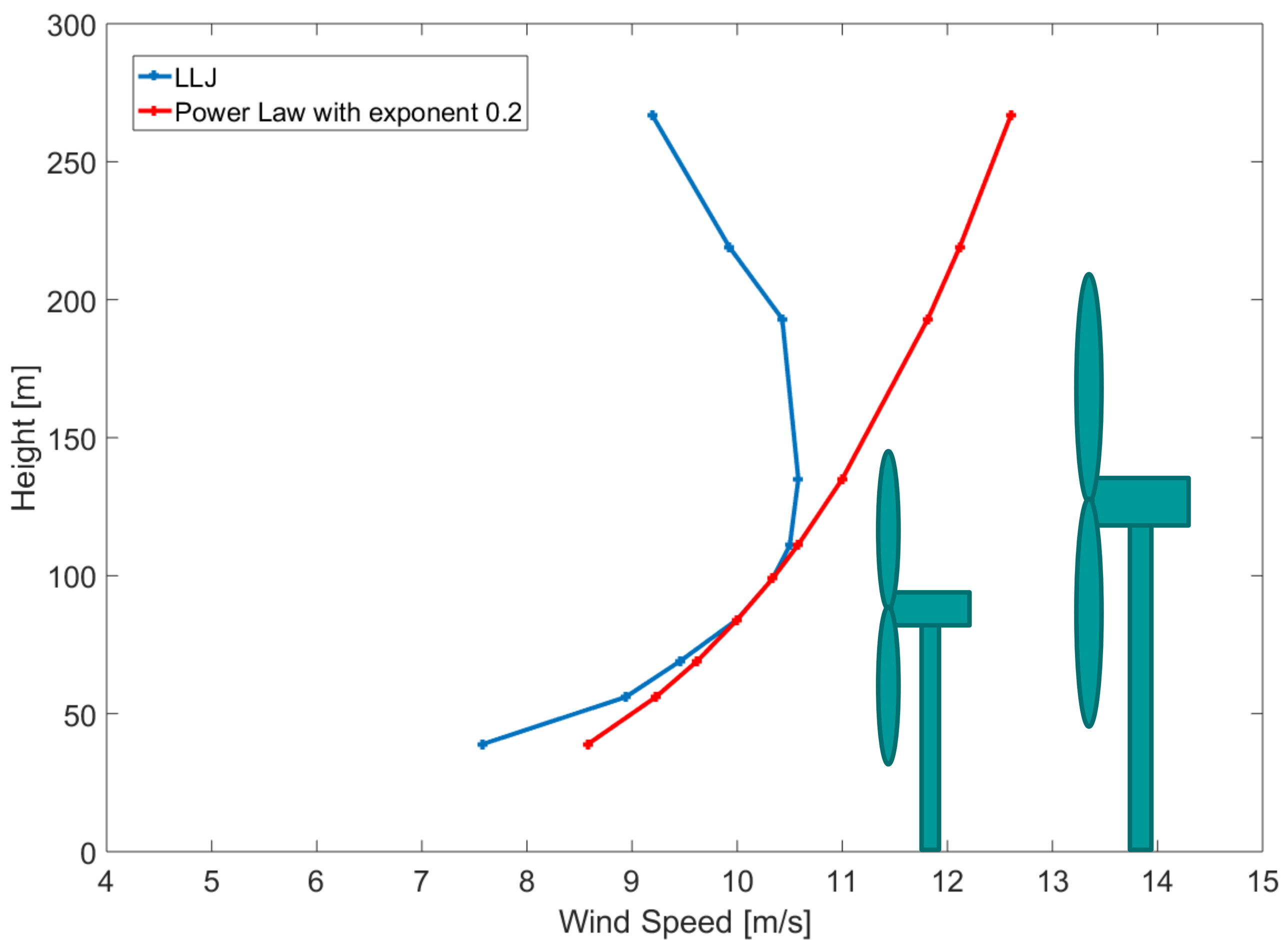

Figure 1 – Comparison of a LIDAR (10 minute averaged wind speed) measured LLJ in the North Sea with a standard power law profile as stipulated by the IEC 61400-1 With approximate sized 5MW and 8MW turbines for reference.

Low Level Jet Properties & Fatigue Implications

Low Level jets have several properties which deviate from the normal wind model defined by IEC standards. Figure 1 shows how a LLJ shear profile can deviate from the, normally used, power law shear profile.

Characteristic	Impact
'Background Turbulence'	Unstable atmospheric boundary layers, with high levels of turbulence compared to stable ones, impart larger fatigue loads on the turbine tower [1].
Shear Gradient	Steep shear gradients found in low level jets impart increased fatigue loading on turbine blades. The height of the jet core also impacts blade loads with the worst case being when the jet core is at tip height.[1][3][4]
Veer	Wind directional change across the rotor is increased in a low level jet. This can impart some additional loading to the blades at 2P but there is little research into this in literature to date.
Coherent Turbulence	As opposed to background turbulence, coherent turbulent structures occur at the jet core as Kelvin Helmholtz waves build up and then burst. These structures impart high energy at high frequency into the turbine blades and can significantly increase blade loading.[2]

Methodology

The project has access to 2 years of 10-min averaged LIDAR measured wind data from the North Sea extending to a height of 267m. 'Typical' LLJs are identified in this data set and wind models are constructed using TURBSIM or Bladed to be used as inputs for aeroelastic simulation.

Individual LLJ characteristic's impact on loading are investigated individually. The below results compare a measured LLJ shear profile with a power law profile (shown in figure 1) for a 5MW turbine. The turbulence, veer and rotor equivalent wind speed properties are held constant to isolate the loading impact of the shear profile.

Results

The plots show that the LLJ increases component DELs and this increase is most significant on the blade out-of plane bending moment. The loading is 'seen' by the blade at twice the rotational frequency. This is as expected for a LLJ here the jet core is within the rotor swept area.

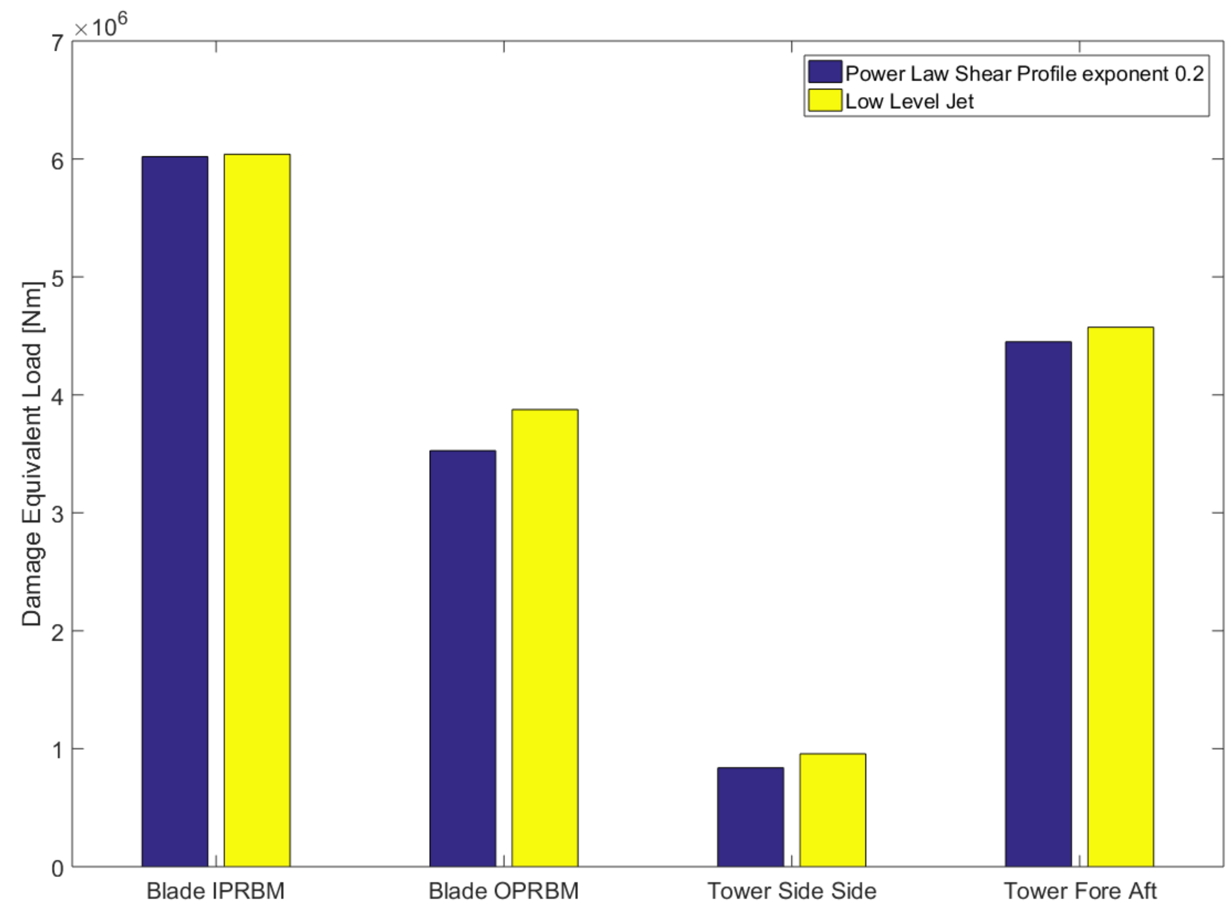

Figure 2 – Damage equivalent load comparison of a Power law shear profile and a LLJ for a 5MW turbine at a wind speed of 10m/s. DELs of Blade In-Plane and Out of Plane root bending moments and Tower fore-aft and side-side Base bending moments shown.

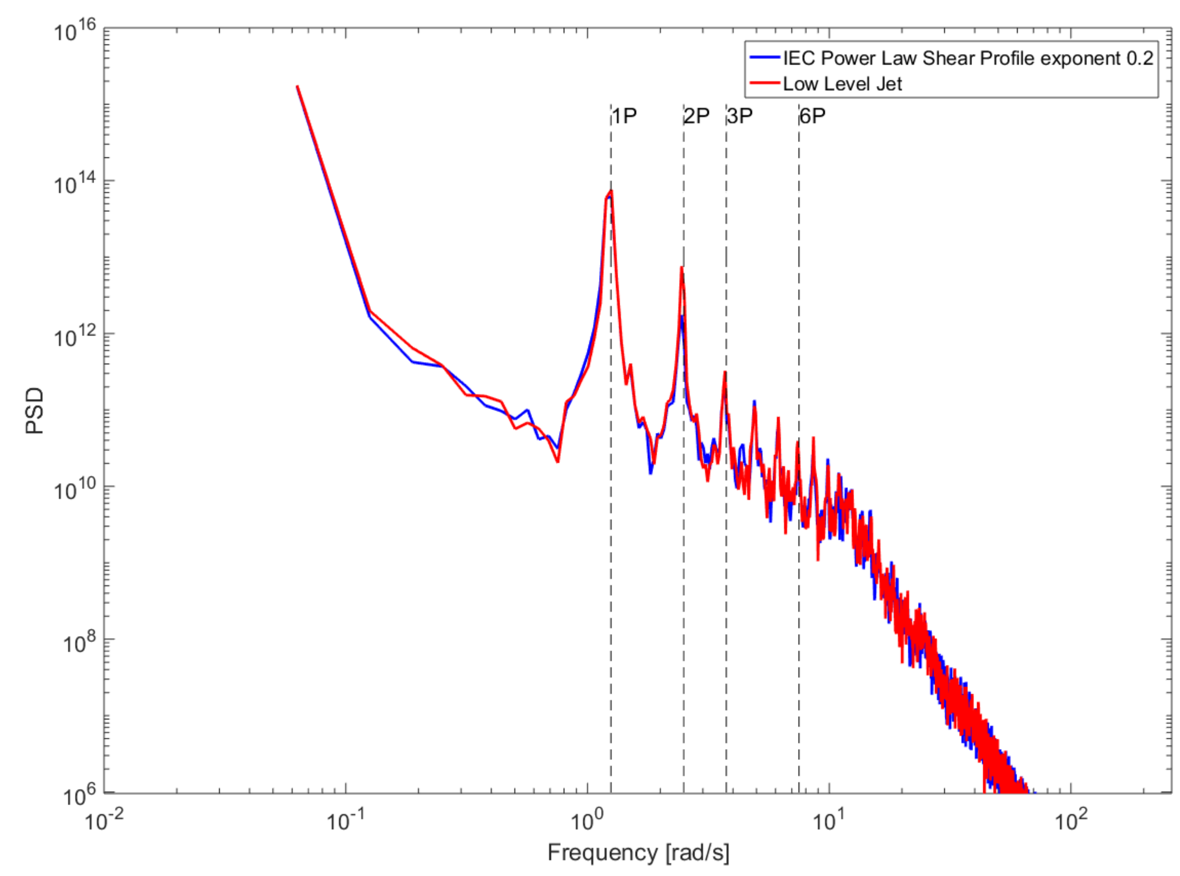

Figure 3 – Power Spectral density of the Blade out of plane root bending moment for the above case.

References

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