How to blow away a wind turbine

Extreme gust loads for tall wind turbines

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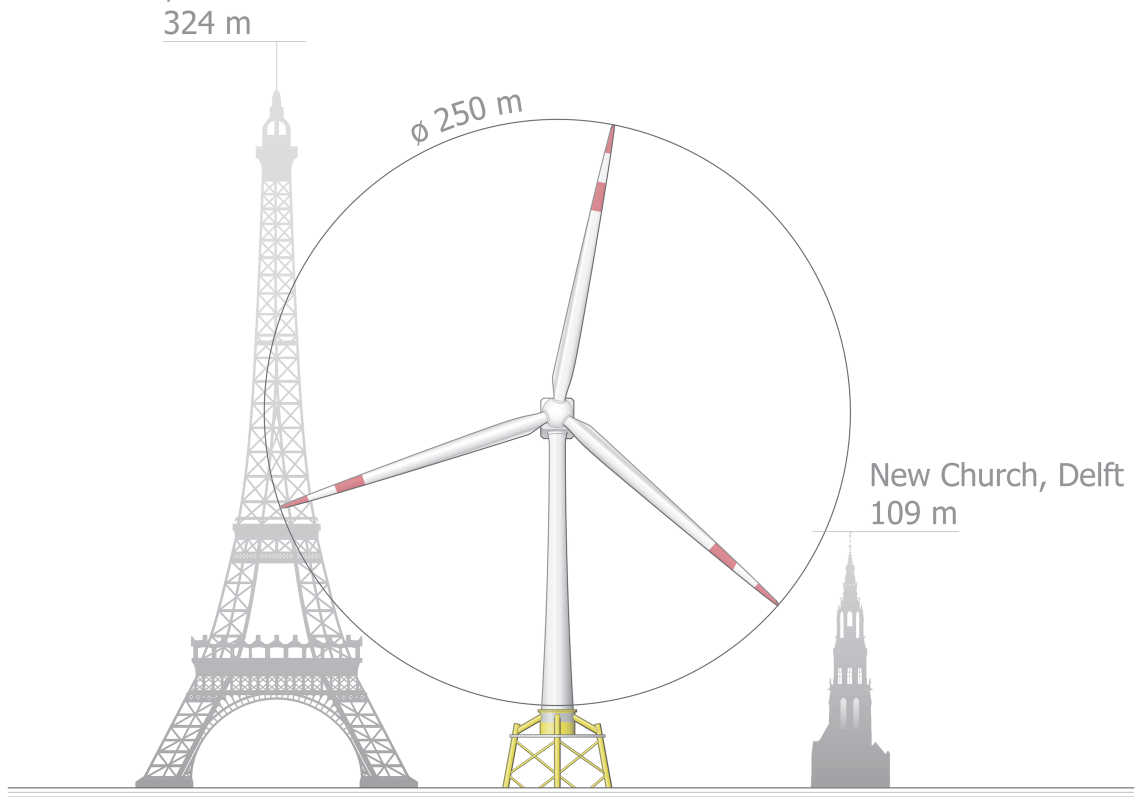
Abstract

OVER THE PAST DECADES, there has been a strong trend towards larger wind turbines. Today, 8 MW machines are entering the market while 10–20 MW concepts already lie on the drawing board.

For rotors of this size, weight requirements are very strict and there is little to no room for overdimensioning. It is therefore crucial to make a good prediction of the long-term extreme loads. Generating realistic responses makes it very important to correctly grasp the true nature of atmospheric gusts. One way to achieve this is through **constrained stochastic simulation** (Bierbooms, 2005), which is an established tool that can be used to generate a time series given some specific constraint. Over the course of this PhD project, this method will be extended in order to make it suitable for very large wind turbines.

How tall is *tall*?

Wind turbines have been gradually scaled up to find the optimum between capital costs, O&M costs and energy yield. Feasibility studies in the scope of the UpWind project (2011) have shown that a big jump towards a **20 MW offshore turbine** is technically feasible, which would imply a rotor diameter in the order of **250 m**. This is the scope of the 5-year INNWIND project; an EU initiative coordinated by DTU, featuring TU Delft and 25 other European partners.



Everything breaks

"Anything that can go wrong — will go wrong."
Murphy's Law

No design is perfect, and everything is bound to fail sooner or later. However, a designer can aim for a certain return value that results in the most economical probability of failure. Wind turbine design standards prescribe the **50-year extreme gust load**. Formally, this is the highest aerodynamic load that a turbine would experience in 50 years of operation in a turbulent wind field.

References

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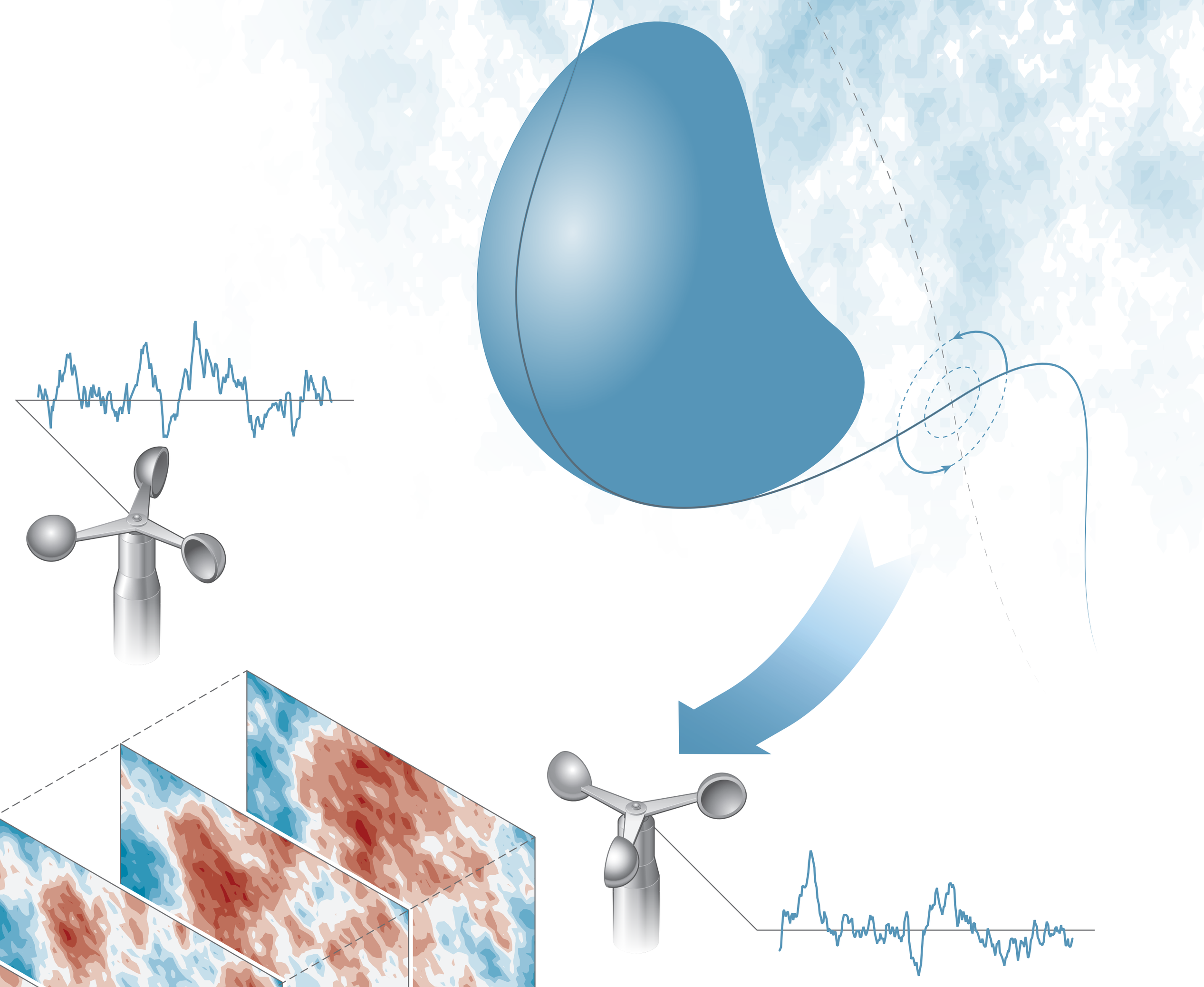
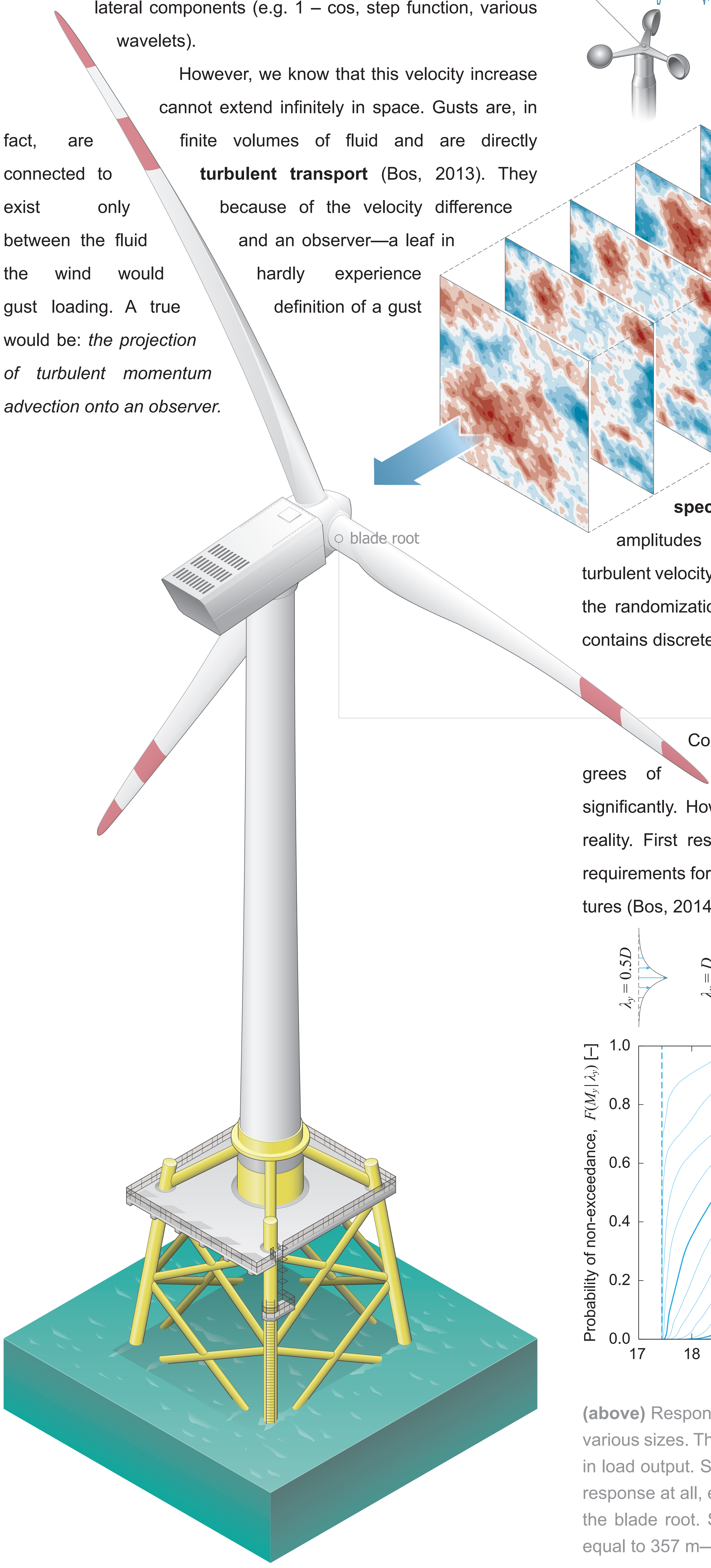
What is a gust?

Wind gusts are often described as a sudden, brief increase in wind speed. This makes sense, seeing as most of what we know about gusts is derived from **single-point** measurements (e.g. cup anemometers). It also closely matches our own perception, since we as humans are merely small in comparison to the integral length scale of atmospheric turbulence. Therefore, it should come as no surprise that most gust models are **transient waveforms** with no lateral components (e.g. 1 – cos, step function, various wavelets).

However, we know that this velocity increase cannot extend infinitely in space. Gusts are, in fact, are finite volumes of fluid and are directly connected to **turbulent transport** (Bos, 2013). They exist only because of the velocity difference between the fluid and an observer—a leaf in the wind would hardly experience gust loading. A true definition of a gust would be: *the projection of turbulent momentum advection onto an observer.*



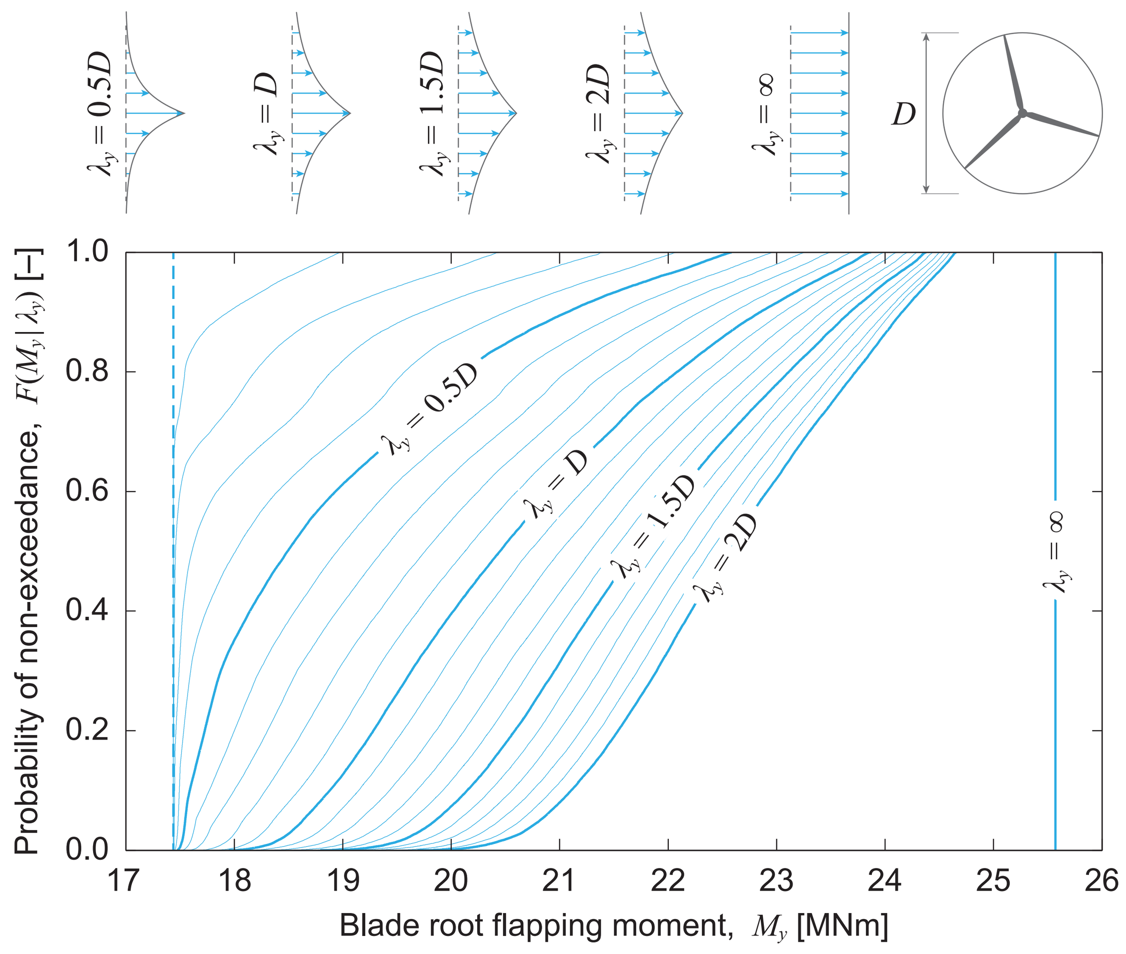


Model

Using a sensor array makes it possible to cross-correlate wind speed measurements, which can be Fourier-transformed and matched with a **3D spectral model**. Shuffling the wave numbers and amplitudes then allows one to generate a fully stochastic turbulent velocity field. Though, when imposing certain constraints on the randomization, the field can be tailored in such a way that it contains discrete events (gusts) that satisfy certain requirements.

Effect on loads

Constraining gusts in space introduces many new degrees of freedom that increase the computational burden significantly. However, the resulting predictions lie much closer to reality. First results indicate that it may considerably loosen the requirements for extreme loads, leading to lighter and cheaper structures (Bos, 2014).



(above) Response of the DTU 10 MW reference turbine to a gust of various sizes. The size of the gust has a large impact on the variation in load output. Smaller gusts have a high probability of triggering no response at all, either by missing the rotor blades or landing close to the blade root. Striking is how even the largest gusts—here *2D* is equal to 357 m—remain far below the level of the uniform case.