Turbulence and Uncertainty for Future Renewable Energy Reliability

P. Tavner and D. Zappalá

Abstract Current climate change concerns accelerate interest in developing reliable renewable energy sources. Two of the most significant, in the wind and sea, are subject to turbulence, where its mathematics are at the forefront and the topic of this Conference.

At the heart of renewable energy extraction are aero/hydrodynamic and electrical/mechanical/control machines, all subject to fault processes, some initiated by that turbulence. Humans, animals and plants are also subject to fault processes and health degradation, but plants and animals have cellular structures, incorporating growth and self-repair, dependent on genes. Machines of human construction, however, do not have these benefits, but there are similarities. Renewable energy extraction reliability depends on:

- Application: such as wind or tidal turbines, or wave devices. Figure 1 shows an early wind power spectrum while Figs. 2 and 3 show the turbulence encountered by renewable devices;
- Design: by virtue of device rating, load and materials used;
- Physics: energy transfer by thermodynamically reversible processes accompanied by irreversible fault processes, mitigated by design, but degrading energy conversion through uncertain failures.

In time, these irreversible loss processes, or root causes, accumulate, worsening machine reliability and triggering conversion failure, a stochastic integration process. Brand et al. [2] point out the gap in the Fig. 1 spectrum is absent over land, the wind speed distribution is non-Gaussian under unstable maritime conditions, and off-shore

P. Tavner (✉)
Department of Engineering, Durham University, Durham, UK
e-mail: peter.tavner@durham.ac.uk

D. Zappalá
Faculty of Aerospace Engineering, TU Delft, Delft, Netherlands

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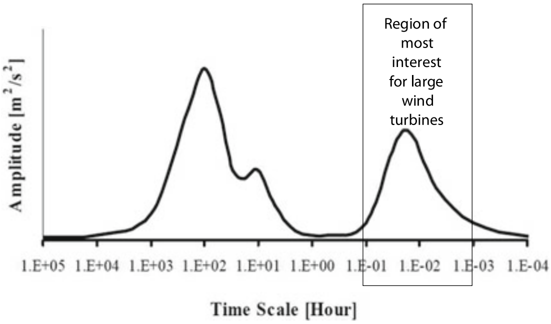


Fig. 1 Classical wind speed time variation assumption [1]. This is expressed as *fS(f)*, not *S(f)* as used in current turbulence work, thus Kolmogorov decay in double-log presentation would be $f^{-2/3}$, as expressed in current turbulence concepts, [2–3]

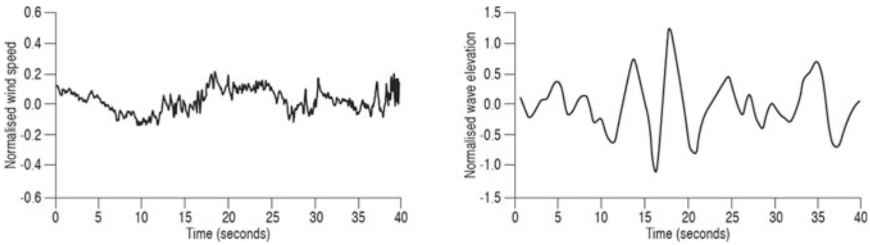
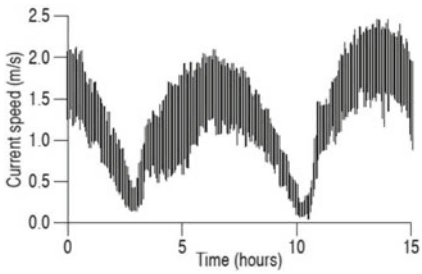


Fig. 2 Practical turbulence encountered by an onshore wind turbine (left) and an offshore wave energy device (right), [4]

Fig. 3 Practical, unpredictable tidal energy device turbulence superimposed on predictable diurnal variation, [4]



wind speed profiles differ from onshore. Recent insights from Nandi et al. [3] confirm some of Fig. 1's turbulence assumptions.

However, the purpose of this brief paper is to draw turbulence researchers' attention to the connection between the mathematical continuity of turbulence and the integration of uncertain failure physics processes. The intent is to explain the impact on wind and sea renewable energy extraction of aero-dynamic and hydro-dynamic turbulence and the integrating effect of subsequent uncertain irreversible failure processes on those renewable energy devices.

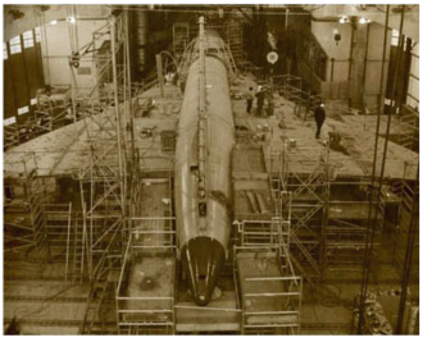


Fig. 4 Concorde full-size fatigue air-frame test, Aerospatiale/BAe, Farnborough, UK, 1973–75, [5]

This is not new, scientists and engineers experienced similar issues in the early days of transonic jet aircraft flight, summarized by:

- Slow fuselage skin stress variation, due to pressurization or depressurization, as aircraft descend from or ascend to high altitude, initiating low-cycle skin fatigue failure;
- Rapid air-frame and skin stress changes as aircraft accelerate or decelerate through the sound barrier, initiating high-cycle fatigue failure.

Figure 4, from the 1970s [5], shows for the Concorde supersonic aircraft airframe how such structural issues were resolved, by full-size physical fatigue and pressurization/depressurization tests.

We make this comparison between the aeronautic and renewable industries, emphasizing structural fatigue failure in the former, whereas renewable industry failure processes penetrate further into the device than the structure, because these devices are fully robotic and risk overall failure if one part fails, whether in the structure or conversion system.

To analyze such issues cost-effectively, devices cannot be subjected to full-size, Concorde-like tests but must be modelled. To do that for wind and sea renewables we need a mathematical understanding that links turbulent causes to uncertain cumulative consequences, not only in device structures but also in their energy collection systems, generators, electronics and controls. There needs to be a mathematical connection between the continuity of turbulence mathematics and the integration processes of uncertain failure physics, across combined structural, mechanical, electrical and control technologies [6]. A first attempt at this process has been taken by Lin et al. [7].

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