Grand Challenges

The Collaborative Computational Project in Turbulence and the UK Turbulence Consortium (CCP Turbulence and UKTC)

To fulfil the ambition of triple wind energy production in 25 years, CCP Turbulence aims to enhance the UK capabilities to simulate complex turbulence problems, whilst UKTC will bring together complementary expertise and strategies to understand, predict and control turbulent flows in High Performance Computing

The Community

UK TURBULENCE CONSORTIUM

www.ukturbulence.co.uk

CCP Turbulence aims to considerably enhance the UK capabilities to simulate complex turbulence problems that were until very recently beyond imagination. Software developments and collaborative activities will not only give UK researchers a unique opportunity to be the first to explore new physics but also be able to answer questions regarding the physics and modelling of turbulent flows found across a range of engineering, physiological and geophysical applications. The UK Turbulence Consortium (UKTC) brings together complementary expertise and co-ordinates activities to look at coherent, rational and strategic ways of understanding, predicting and controlling turbulent flows using High Performance Computing.

The Challenge

To maximize energy output and reduce costs and inefficiencies by actively addressing the issue of the phenomenon known as 'wind theft'

Over the past decade, the UK has solidified its position as a global leader in wind energy, with total installed capacity increasing from 13.6 GW in 2015 to around 30.4 GW in 2024, based on both onshore and offshore wind production. This expansion aligns with the UK Government's Industrial Strategy, which designates Clean Energy Industries as one of eight key sectors driving innovation and economic growth. The strategy emphasizes the beneficial role of wind energy in achieving net zero targets, supporting regional development, and creating high-value jobs. According to the International Energy Agency, the UK aims to deploy up to 50 GW of offshore wind by 2030, with projections suggesting that total wind capacity could reach 100 GW by 2050, potentially supplying over half of the UK's electricity demand alone.

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To fulfil the ambition of triple wind energy production in 25 years, major challenges need to be addressed to maximize energy output and reduce costs and inefficiencies. An ever-present problem with wind farm development is the issue of wake interactions among turbines, significantly impacting the farm's total power output. Recently, due the increasingly larger size of farms, the issue has expanded at the inter-farm wake interactions level, creating a phenomenon known as "wind theft". Wind theft occurs when upstream wind farms reduce wind speed and energy availability for downstream farms by creating large wakes extending up to 100 km downstream. This has been observed from satellite images of large wind farms across Europe and Asia. Wind theft can lead to reduced energy yield for downstream farms causing economic losses and potential legal disputes between operators. Moreover, inefficiencies in regional energy planning also need to be addressed. Recent studies have highlighted how this issue is becoming more prominent in the North Sea, where dense offshore wind development is underway.

The Solution

To design mitigation strategies and digital twins of real wind farms with high fidelity CFD modelling and simulation methods

To address the challenge of wake interaction at turbine-to-turbine, wind farm, and inter-farm levels, high-fidelity simulations across all these scales—from metres to hundreds or even thousands of kilometres—are essential to design mitigation strategies. These simulations must also incorporate realistic atmospheric flow conditions, complex terrain, and accurately resolved turbine geometries. The vision is to create digital twins of real wind farms so that they can be studied in various configurations. Digital twinning is the creation of a real-time virtual replica of a physical system, that uses data from sensors and other sources to mirror and simulate the behaviour of its real-world counterpart for monitoring, analysis, and optimization purposes.

Modelling and simulation, particularly through high-fidelity Computational Fluid Dynamics (CFD), have been instrumental in supporting wind engineering. Within this context, the UK Turbulence Consortium (UKTC) and the CCP Turbulence have played and continue to play a pivotal role in advancing wind engineering research in the UK, particularly with high-performance computing (HPC), high-fidelity Computational Fluid Dynamics (CFD), and increasingly, AI-based methods. To optimise the power output of wind farms, there is a clear need for reliable physics-based simulation methods that can faithfully replicate realistic scenarios.

Importantly, to address the challenge of inter-farm wake interactions high fidelity CFD modelling will be a fundamental tool. High-fidelity simulations of an entire wind farm under realistic atmospheric flow conditions and in complex terrain where turbine geometry is well resolved will be mandatory and these will need to interact with regional air flow modelling capable of correctly resolving wake interactions between farms. This will only be possible with exascale and beyond HPC systems and the integration of physical modelling with AI tools for optimization, digital twinning and advanced forecast modelling.

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The Outcome

A suite of advanced modelling tools essential to the future security of the UK's wind energy production

As wind energy scales up, these advanced modelling tools will be essential for ensuring fair resource sharing, maximizing output, and supporting evidence-based regulatory frameworks for the future of the UK's wind energy production. These developments will help to inform coordinated planning between neighbouring wind farms.

More Information

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