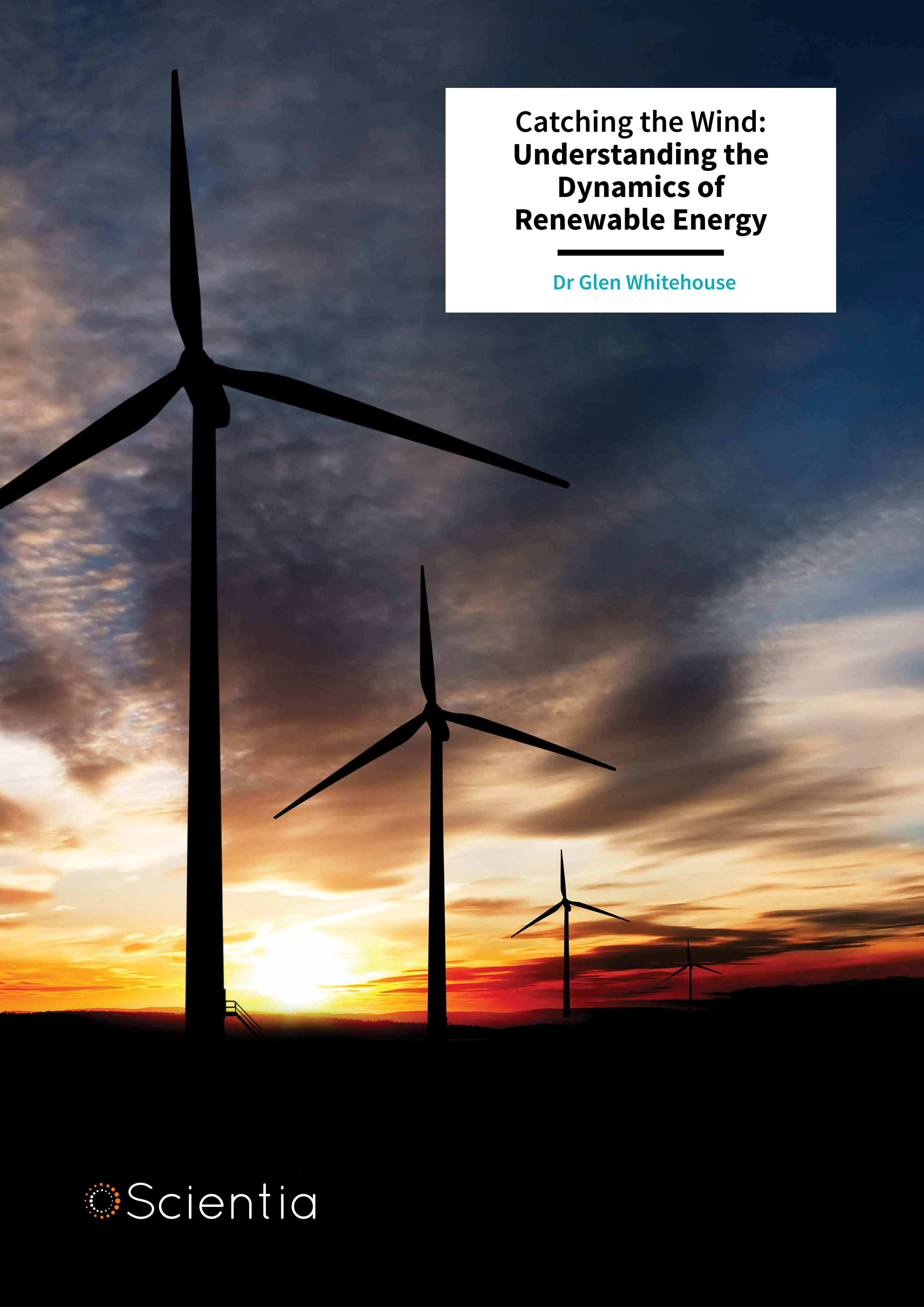

Catching the Wind: Understanding the Dynamics of Renewable Energy

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Scientia

CATCHING THE WIND: UNDERSTANDING THE DYNAMICS OF RENEWABLE ENERGY

As renewable energy sources such as wind, wave, and solar become more ubiquitous, the importance of understanding the detailed mechanisms of their operation is essential. In particular, with a dynamic and turbulent energy source like wind, an accurate way of modelling the flow and interaction with the wind turbine is highly desirable. **Dr Glen Whitehouse** and the team at Continuum Dynamics Inc. have been developing innovative ways to do just this.

The pressing issue of climate change, and the urgency to decrease our reliance on fossil fuels has sparked major developments in the clean energy industry, including the advancement of technology to harness wind power. As of 2016, the power globally generated from wind sources exceeds 450,000 megawatts, and the Global Wind Energy Council predicts that by 2030, nearly 20% of the world's electricity will come from wind power alone.

The typical way in which wind energy is harnessed and electricity generated industrially is with a turbine. For wind turbines to be successful as an energy provider, the energy they yield must be maximised with favourable weather conditions, while operating costs must be minimised. As such, largescale arrays of turbines in a wind farm are preferred as they address both of these issues. However, other issues can arise from having several turbines arranged in a wind farm due to the flow of wind around the turbines becoming disturbed, resulting in turbine-turbine interactions.

The flow of wind through turbines induces forces on the structure, referred to as the 'aerodynamic loading', and much research has been undertaken to clarify the effect these loads have on the blades. The region of disturbed flow behind the turbine as the wind interacts with blades is known as the 'wake'. This interaction between the wake from one turbine on the aerodynamic loading of another results in a significant decrease in their efficiency. Not only this, but the interactions between turbines and wakes results in components fatiguing and becoming prone to fail, which leads to higher maintenance costs.

Who are Continuum Dynamics Inc.?

The research led by Dr Glen Whitehouse, Associate at Continuum Dynamics Inc., aims to put an end to the uncertainty surrounding current turbine analysis, by accounting for the intricate and complicated interactions of turbine blades in a cost effective first-principles manner. Continuum Dynamics Inc. was founded in 1979 as an engineering research and development company and service provider for government and industry, and they have expertise in a variety of areas related to fluid dynamics and fluid-structure interactions. Continuum Dynamics Inc. is also a world recognised authority on the unsteady aerodynamics of rotating machinery and wake vortices.

The main aims of Continuum Dynamic Inc. is to provide high-quality, cost-effective engineering services, and state-of-the-art technical solutions for government and industry. They have undertaken a wide spectrum of business activities including, contract research, software development and licensing, engineering and design services, smart materials and robotic systems development, and testing services. Their government and commercial customers come from a range of industries including: aerospace and defence, electric power generation, forest management, agrochemical application, and pharmaceuticals.

‘Continuum Dynamics Inc., in collaboration with Professor Marilyn Smith at the Georgia Institute of Technology, is developing an advanced, hardened, efficient easy to use suite of high-performance computing software for predicting wind turbine/ farm aeromechanics in the industrial environment’

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Prediction Problems

When trying to predict the behaviour and nature of flow around objects, where possible, wind tunnel experiments are used to give accurate insights. However, these methods are costly, and in the case of larger structures, cannot be readily scaled-up. On top of these limitations, wind tunnels also don’t account for other atmospheric conditions – therefore, for assisting the design of commercial sized wind farms, this method is impractical.

Currently, the computational design tools that are used to predict and optimise the performance of wind turbines only work for individual turbines. Dr Whitehouse explains that ‘contemporary design tools fail to account for the unsteady fluid structure interactions that drive costly fatigue’. They don’t take into account any of the turbine-turbine wake interactions that occur in reality, nor the unsteady stress and strain the components are subsequently put under. Therefore, predictions of the potential power that a wind farm can generate are usually overestimated. Often, these calculations are compensated by broadly imposing a 20% reduction factor. Yet occasionally, even this gross simplification still overestimates the power generated. This uncertainty surrounding the power output for wind turbines and the potential underperformance poses problems if wind turbines are going to be heavily invested in.

There are methods that use high performance computing, which will accurately account for these turbine-turbine interactions, but rely on a compromise between the accuracy of the calculation and the high expense and time required to perform. Accurate and high resolution models of aerodynamics require very large scale computations, and even when this is achievable, the complexity and cost of these methods means that their usefulness is limited. ‘Unfortunately, such tools require dedicated experts to generate reliable predictions and are too complicated and expensive for industrial use,’ says Dr Whitehouse. When applied to simulate real-world wind farms, modelling the wakes from turbine to turbine is so complex that it requires the latest high performance super-computers.

A Potential Solution

To combat this problem, Dr Whitehouse and Continuum Dynamics Inc., in collaboration with Professor Marilyn Smith and her graduate students at the Georgia Institute of Technology, are developing an advanced method for predicting the aeromechanics of wind turbines and farms. They do this by taking the best aspects of high-performance computing methods, and make them adaptable to industry.

A significant barrier that hinders the application of these high-performance computer calculations to any commercial adaptation is that that the software used is unique and cannot be adapted or reused in an industrial setting. Continuum Dynamics Inc. is developing software with a standardised user interface that no longer requires a dedicated team of experts to operate.

The benefit of this industrially applicable software is that it could be used in many multidisciplinary areas of wind turbine design and analysis. The tools that Dr Whitehouse and Continuum Dynamics

Inc. are creating will directly address the current limitations of predicting unsteady loads on wind turbine blades, and other real-world conditions. The team's software is also being applied to other applications, such as helicopters.

Pioneering Results

In order to address the difficulties in modelling the flow of wind (also known as computational fluid dynamics), Dr Whitehouse, Continuum Dynamics Inc. and the Georgia Institute of Technology have recently developed a unique hybrid approach. This approach makes use of a piece of open source government software from NASA called 'FUN3D'. This software has the ability to predict the flow of wind near the turbine (including the turbine blades and its tower), and was coupled to software developed by Continuum Dynamics Inc., VorTran-M, to predict the wind turbine's wake. This integrated solution was then coupled further with a computational structural dynamics code which is able to predict any deformation that would occur in the turbine's blades. This approach is completely unique, and because it accounts for the downstream wake from the turbines, it means that computational effort can be focussed on the regions of interest. In this way, detailed predictions of the turbine blade performance can be made at a fraction of the cost of traditional high performance computing methods.

These innovative methods were then applied to various problems that result from wake-based interactions. Key successes from these studies include the accurate prediction of fluid dynamics phenomena known as 'vortex rings' using more than an order of magnitude less computing power than traditional methods. Additionally, unsteady wind turbine aeroelasticity was successfully simulated with less than 50% of the computational cost usually required by traditional high-fidelity numerical solvers, such as FUN3D applied without VorTran-M.

Public Benefit

The potential of the team's pioneering computational method for modelling wind turbine wakes is that an easy-to-use system would be in place to design and analyse robust new turbines. These turbines would have increased performance and lifetime, reducing the costs of wind farm projects. Also, the team's modelling would lead to quieter turbine designs and a reduction in the maintenance costs, which would encourage their integration into communities.

Integrating wind farms into communities is hugely advantageous as they greatly benefit local economies, particularly in rural areas where the majority of the most efficient land-based wind sites are found. The design of modern wind turbines is such that farmers would still be able to work the land as the acreage turbines use is minimal. As well as this, the landowners receive additional income from the wind farm's owners.

Another concern is the interaction of the wind turbine wakes with power lines. These wakes can sometimes induce an adverse phenomenon known as galloping, where the power lines can be damaged or broken. In this assessment, distances of more than a mile between the wind turbine and power lines may need to be modelled.

Finally, the ability to accurately predict wakes at low computational cost and over long distances would enable offshore wind farms to be analysed in greater detail than current methods. Precise prediction and analysis of offshore wind farms is especially important, as any maintenance that would be required is far more difficult to carry out compared to land-based turbines.

Future Prospects

Because of the complexity of a system that takes into account atmospheric conditions, the flexibility of the rotating blades, and the flow field induced by neighbouring turbines in a wind farm, the integrated software by Continuum Dynamics Inc. is being updated. 'Continuum Dynamics Inc. is currently halfway through the two year United States Department of Energy sponsored research and development effort, and is now focusing on software integration, debugging and testing,' Dr Whitehouse tells Scientia. The CDI-GT team is aiming to improve their software by hardening the interface, making it generally more robust, and by improving the usability and functionality. Dr Whitehouse also mentions that 'the next steps are to commence with deployment and testing of the software by partners in the wind industry and in other industries interested in vorticity dominated flows and rotary-wing aeromechanics'.

Ultimately, a major goal of these developments is to work towards making the wind power more cost competitive than conventional energy sources. Despite the cost of wind power decreasing dramatically over the previous decade, the technology and infrastructure still require a larger initial investment than fossil-fuel generators. The importance of the team's work is that by predicting the uneven aerodynamic loading on the turbine blades, superior and more robust wind farms can be designed with lower maintenance costs. This will drive down the cost of investment in the long run. Not only this, but if the efficiency of wind farms could be accurately predicted at low cost and computing power, investors would be far more drawn to them as an alternative energy source to begin with.

Meet the researcher

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Dr Glen Whitehouse is an Associate with Continuum Dynamics, Inc. He received his BS degree in Aeronautical Engineering from Clarkson University in 2000 and his PhD and DIC in Aeronautics from Imperial College London in 2004. While at Imperial College, he gained extensive experience modelling rotor aeromechanics and wake dynamics with both traditional inflow based analysis codes and high fidelity CFD techniques. The UK government's Engineering and Physical Sciences Research Council described his doctoral work as 'internationally leading'. Dr Whitehouse's later research focused on predicting rotor performance in and out of ground effect and during wake interactions. He has authored or co-authored of over 90 technical reports and papers related to rotary-wing research and development. Dr Whitehouse has been a member of the Aerodynamics Committee of the American Helicopter Society since 2005, and was the Chair from 2012 until 2014. He is an Associate Editor of the Journal of the American Helicopter Society, and was the Technical Chair for the 2016 Annual Forum of the American Helicopter Society.

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