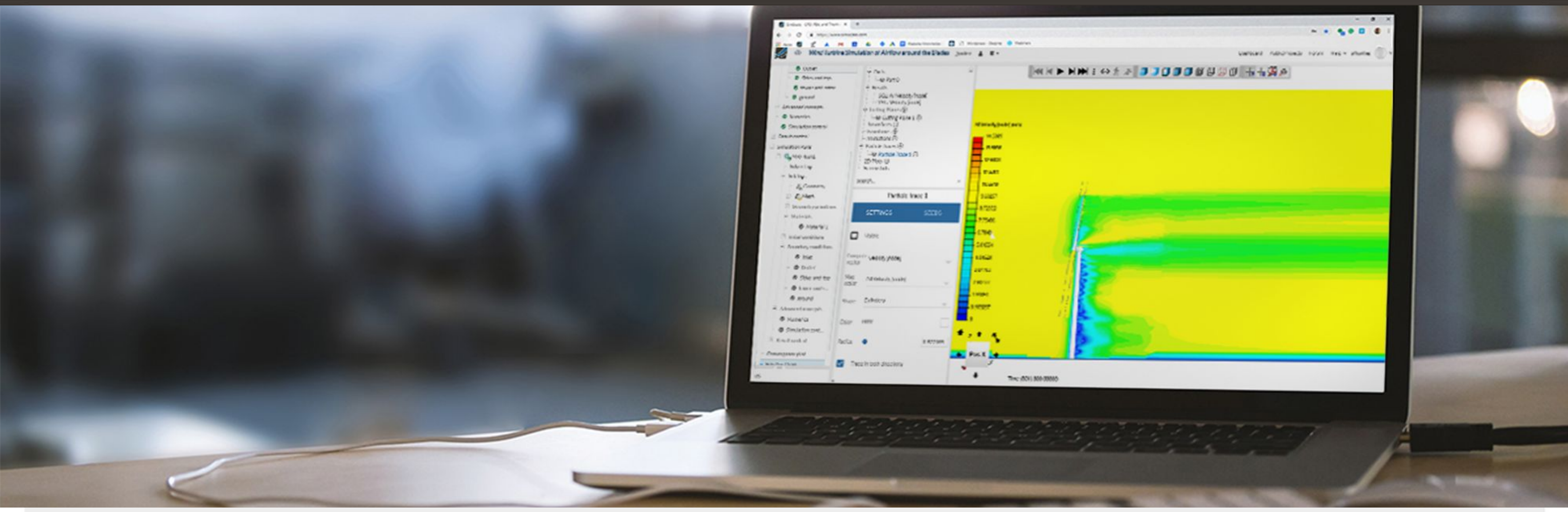
WHITE PAPER

THE BENEFITS OF CFD ANALYSIS IN WIND TURBINE DESIGN

This white paper explores the challenges faced in wind turbine design and how computer-aided engineering (CAE) can help overcome them. A key focus in this white paper is how computational fluid dynamics (CFD) can be used to support wind turbine blade design with testing methods for increased efficiency, performance, and lifespan.



Content

Introduction

As the world searches for renewable energy sources, the wind sector is growing. But the technologies behind wind turbines are by no means a modern concept. Windmills have been used for grinding grain or pumping water for centuries, some Persian windmills even dating back 1000 years.

Innovation and developments in wind engineering gained momentum throughout the 1900s, with many highlights such as the first megawatt-size wind turbine being connected to the public grid and key inventions including aerodynamic tip breaks.

Many view the 1973 Oil Crisis as a key moment in the history of commercial wind power as it led to new legislations and investment for alternative sources. The crisis demanded a commercially viable alternative to depleting resources that could efficiently provide energy to the masses. Today, similar concerns are once again boosting technological innovation in wind energy and design methods.

Balancing Cost and Efficiency

The wind energy sector has grown rapidly in the last 10 to 15 years, with private and public investors financing R&D of wind technologies. In wind turbine design, the main aim is efficiency, which can be separated into three main categories:

1. Aerodynamic Efficiency;

ensuring a turbine is designed in a way that recovers the most power possible from energy in the form of wind power without restricting flow by taking too much. This mainly affects the number of blades chosen, the blade length, airfoil chord length, twist angles and the weight of the materials used.

Offshore HAWTs with three rotor blades

2. Levelized Cost of Efficiency;

weighing the average total cost of a turbine, from initial design until it is retired, against the total energy output throughout its lifetime. The LCOE of a turbine is based on parameters such as costs for design, materials, construction, installation, maintenance, and energy storage; local financing conditions; predicted lifetime; and geographic conditions that may impact operating costs or increase machine wear—offshore or mountainous terrain, for example.

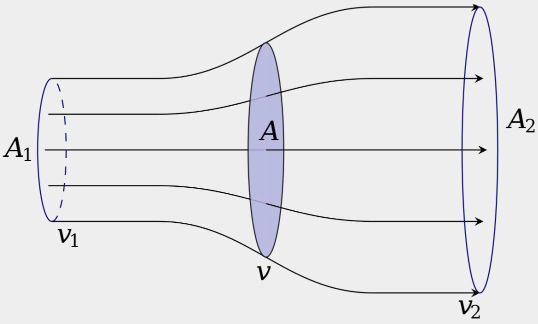
3. Environmental Efficiency;

providing a sustainable source of power without impacting on local wildlife or the environment such as with visual or noise pollution. A turbine should offer a sustainable and eco-friendly alternative to exhaustible, environmentally harmful energy source such as fossil fuels.

A turbine should be cost-efficient, provide maximum energy extraction power, and be durable and reliable to maximize lifespan. This all comes down to design.

Designing for Efficiency

The maximum power extraction of a wind turbine, according to the Betz limit, is 59.3% as some kinetic energy is absorbed by the blades. Betz law is a simple way to test the turbine for overall efficiency, which compares the velocity and density of air downstream and upstream of the turbine, signifying the transfer of kinetic energy from the wind to the turbine blades. This signifies the amount of rotational power created.



“Tube” of air passing through a disc actuator, according to Betz law

In wind turbines, greater speeds mean more power extraction. To ensure safe and efficient energy production, an engineer must take into account wind roughness, turbulence, fluctuating velocities, and blade radius in proportion to the turbine tower.

The optimal tip speed ratio (TSR), defined as the ratio of the speed of the rotor tip to the incoming wind speed, depends on the rotor blade shape profile, the number of blades, and the conditions in which it operates; mainly, wind speed and air density.

A Savonius drag-type VAWT

Usually, in commercial wind farms, horizontal axis wind turbines (HAWTs) are chosen over vertical axis wind turbines such as Savonius or Darrieus types. This is due to their ability to harness aerodynamic lift, for greater rotational speeds and a better energy input/output ratio.

Blade Design: Key Aspects

In order for these factors for efficiency to be realized, engineers require an understanding of the external flow of air around the disc radius created by the rotating blades. For optimized energy extraction, the key consideration is blade design.

When fluid moves over an airfoil, both lift and drag is produced. The airfoil of the common lift-type HAWT blade is created in such a way that it produces an area of lower pressure by curving one side of the blade. Air attacking the flat edge at a higher pressure naturally moves towards the lower pressure air pocket and thus the blades rotate, turning the rotor shaft, and converting rotational energy into electrical power via a generator.

Common HAWT rotor blades are also curved with a twist angle to counteract the steepening angle of attack towards the root of the blade which, if too steep, could stop the blade giving lift and cause it to stall.

Curved rotor blade of a common HAWT

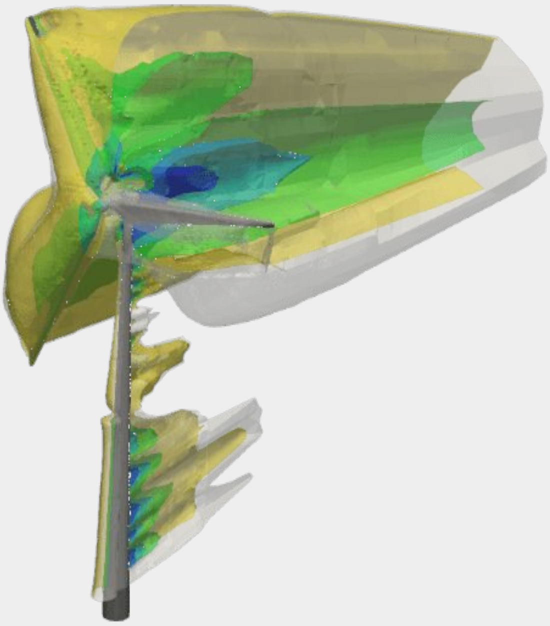
Many common HAWT rotor blades are tapered in order to maintain structural balance, meaning that the airfoil changes from root to tip. The taper and airfoil relation must be precisely calculated to ensure that more lift is produced and evenly distributed over the blade.

These factors present challenges when calculating aspects such as chord length and analyzing the aerodynamic properties of a wind turbine airfoil.

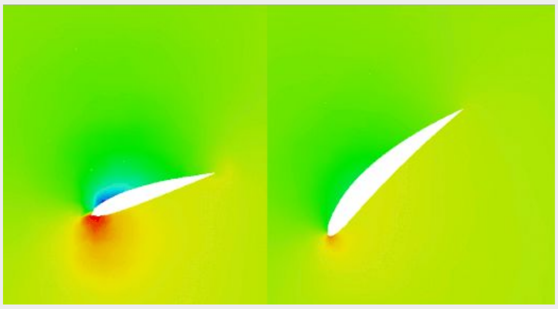
Blade Design with CFD

Carrying out CFD analysis of a rotor blade design allows an engineer to virtually assess how the turbine will function in real life conditions once constructed. For example, designs can be tested under varied conditions by simply changing the boundary conditions to mimic fluctuating temperatures and average wind speeds.

For blade design, engineers can use simulation to analyze how blade length, chord length of the blade airfoil, the twist angle in the blade, or pitching to adjust the angle of attack, affect the overall performance of a turbine.



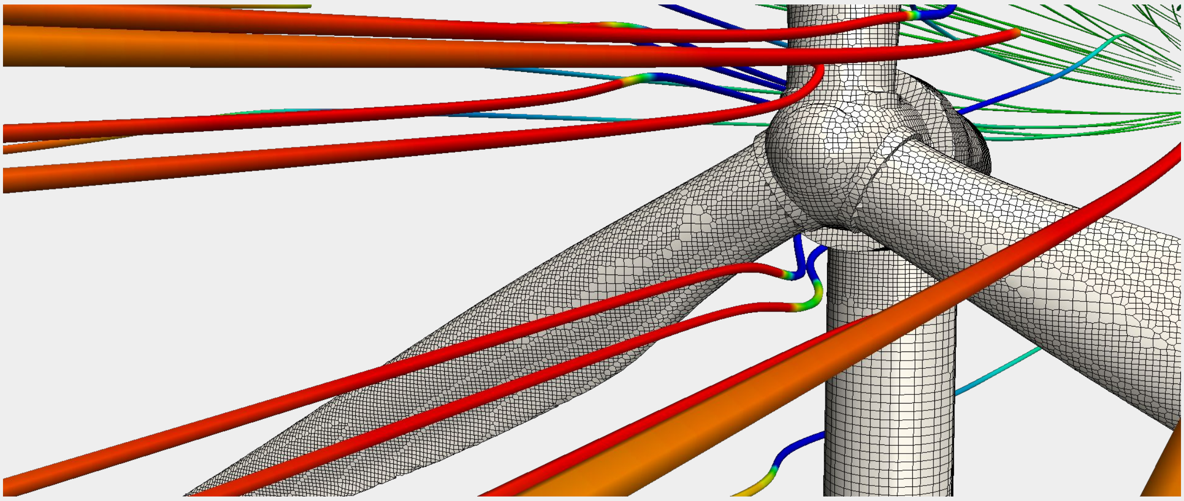
These factors can then be adapted according to the simulation results, for example by changing the number of blades or adjusting their length or width. An updated CAD model of the new design can then be evaluated with the same boundary conditions applied.



CFD analysis of airfoil aerodynamics (Source: SimScale)

CFD provides the ability to identify optimization potential in a wind turbine design. Engineers can quickly produce design iterations to understand which design is the most efficient in terms of input/output ratio and make informed decisions on the design, manufacturing, and installation of the wind turbine. But many companies are not aware of the modern online offering now available to them. The next page explores new capabilities provided by web-based tools for CFD and aerodynamics analysis.

Wind Turbine Design and Online Simulation

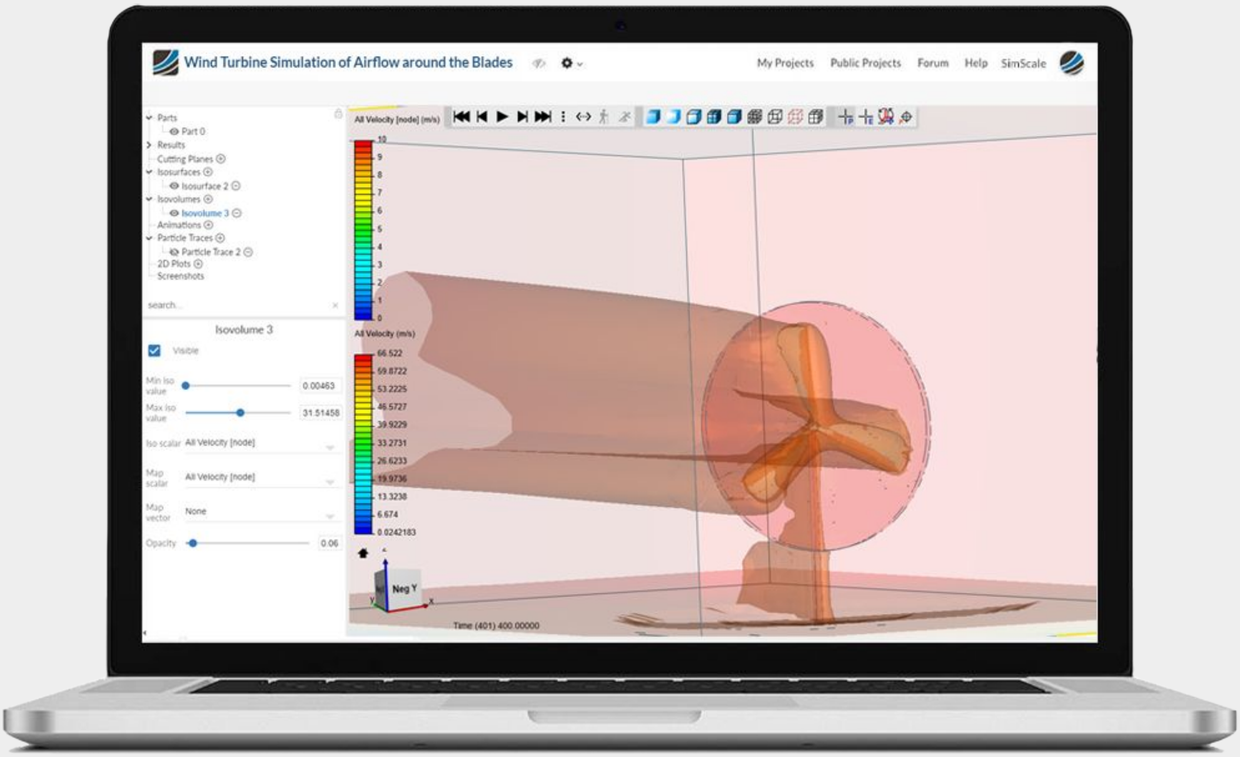


While CFD has supported the wind energy sector for some time now, a lack of affordable tools, and specialist knowledge required to successfully use them, has inhibited its widespread adoption.

Traditional, resource-heavy methods of prototyping wind turbines and blades can be detrimental to overall LCOE of the wind turbine, and therefore lessen the overall economic viability for commercial energy production. Testing, validating, and optimizing efficiency in the design of wind turbines is much more cost-efficient with CFD simulation, which offers engineers the ability to test designs virtually, reducing cost outlay for physical prototypes.

Recent efforts to democratize CFD technology through the emergence of user-friendly, cloud-based tools with flexible pricing made it now much easier for private companies to tap into its full potential. Compared to heavy, on-premises software, cloud-based CFD tools are easy to implement. And, with a huge number of templates, tutorials, and online support, onboarding for smaller companies or those new to CFD is much easier.

As LCOE is one of the main concerns for the wind energy sector, online fluid flow simulation holds great promise. Engineers of all levels designing for efficiency now also have scalable, flexible, and efficient design methods to support them.



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About SimScale

SimScale is a cloud-based CAE platform that gives instant access to **FEA**, **CFD**, and **thermal simulation** technology for quick and reliable testing and optimization of designs for machines and components such as wind turbines and blades.

By harnessing the power of the cloud, SimScale is revolutionizing the simulation industry, and allowing engineers and designers in wind energy to virtually test and optimize designs online.

With SimScale, you can run complex fluid dynamics and solid mechanics analyses on the entire wind turbine, the blade, an airfoil, or any parts without leaving your web browser.

Why SimScale?

Collaborative: Get instant access to a premium cloud-based platform for simulation that enables you to virtually collaborate with others to test and optimize multiple designs, end-to-end in a web browser—from anywhere, anytime.

Cost-efficient: As an SaaS application, SimScale requires zero investment in high-performance hardware, licenses or maintenance. The yearly subscription is a fraction of the cost of on-premises CAE software.

For everyone: Having access to dedicated support and learning resources, you get reliable results fast, with no need to hire an expert.

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