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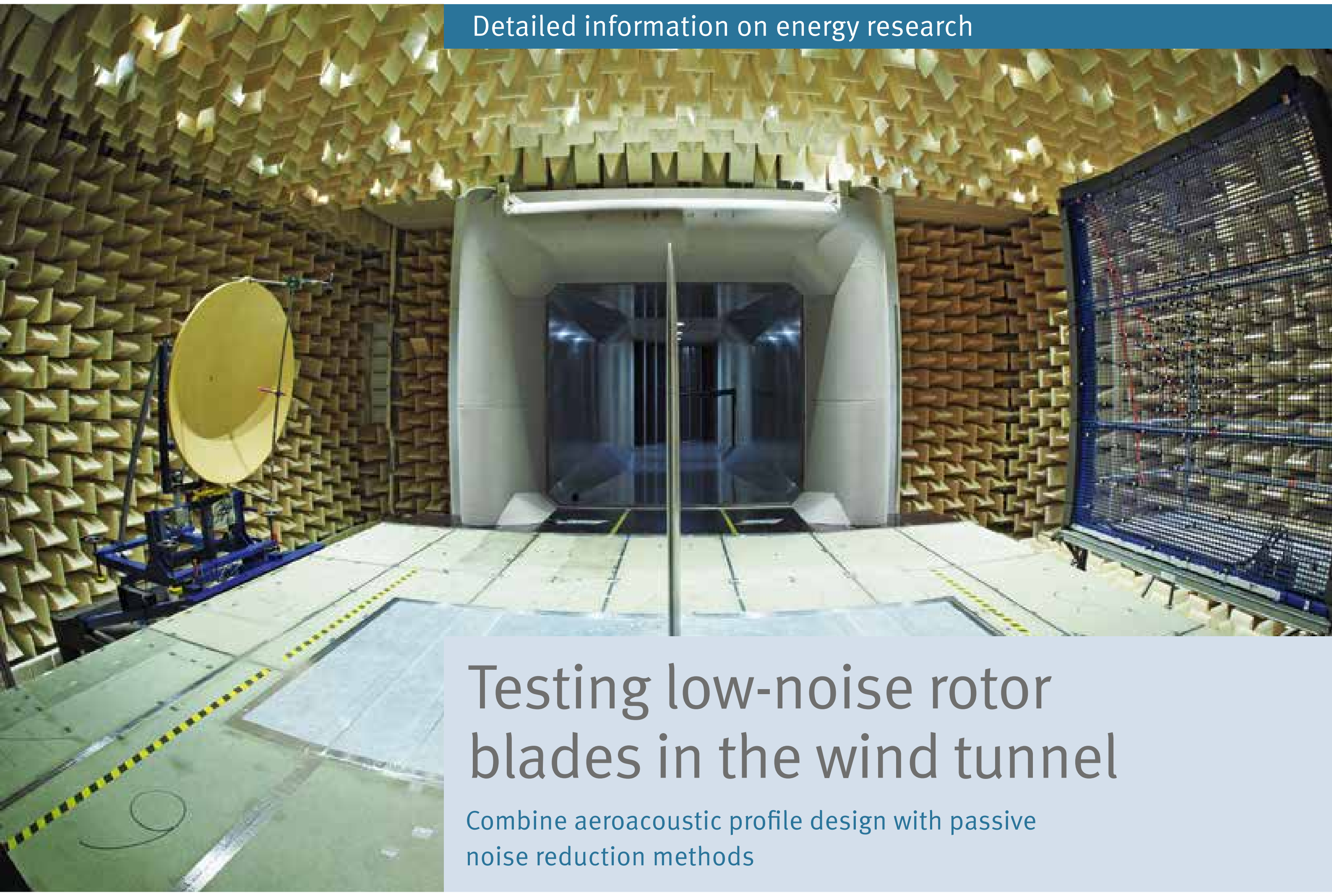
Detailed information on energy research



Testing low-noise rotor blades in the wind tunnel

Combine aeroacoustic profile design with passive noise reduction methods

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The expected noise emissions and the resulting necessary distance to residential buildings are of great importance in the approval of wind farms. In order to reduce these emissions, scientists have designed a powerful rotor blade profile that is as low-noise as it is aerodynamically efficient and have tested the corresponding specimens in wind tunnels. These specimens were combined with passive reduction technologies on the trailing edge and modified blade tips. During the experiment, subject to the operating conditions, noise reductions of up to eight decibels were achieved.

Noise is a matter that affects new wind farms as well as the repowering of systems and has a huge impact upon acceptance among the population. To date, noise thresholds have often been the reason why wind farms have to maintain a considerable distance to settlements or have to restrict operations during the night. A reduction of the sound emissions by 1, 2 or 3 decibels (dB) numerically increases the possible number of wind turbines in a farm by 25 %, 58 % or 100 %. This opens up freedom of design in the case of repowering.
Scientists from the German Aerospace Center (DLR) in Braunschweig have jointly investigated the options for aeroacoustic improvement with partners in the research project, “BELARWEA – Blade tips for efficient and low-noise wind turbine rotors”. The aim is to reduce noise without the output suffering. The results are used for increasing aeroacoustic methods, in particular the development of simulation tools for the design-supporting evaluation of complex geometries (e.g. winglets) and for the demonstration of existing capabilities in the aeroacoustic profile design.

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Get simulation results on the test field

In modern wind turbines, the nacelles are so well encapsulated that the sound of the blades, particularly the trailing edges, are the dominant sources of noise. At the same time, the outer 20 – 25 % of the rotor blade is important because it is there that the flow velocities are the highest.

For years, increasingly longer rotor blades have been used in wind turbines. It is expensive to test these blades on test rigs during the development phase. Therefore, an increasing large part of the development and testing work is performed with the aid of simulation software. This saves time and money. Validated software tools optimally show the results of previous tests so that – ideally – there is a possibility of comparing variants on the computer and making a pre-selection.

Aeroacoustic optimisation is a central development objective for a new blade design. Conventional industrial methods to predict a turbine's total noise emissions are mainly empirical. They are based on measurement data with limited scope and primarily include noise estimations for the profiles present in the outer blade area. In the case of noise sources with line source characteristics, e.g. trailing edge noise, modelling of this kind based on 2D sections is possible. However, the objective is to increase the room for manoeuvre for design beyond the conventional degree and physics-based, largely non-empirical 3D simulation methods must be applied in order to also assess e.g. innovative blade tip forms or noise reduction measures with complex flow already during the preliminary design stage.

This provides the starting point for the BELARWEA project: Phase 1 starts with the design of a new profile geometry, whereby non-empirical computational aeroacoustic methods (CCA) from aviation applications are already used to support the design process. The variant that came out best in the simulation was selected for a comprehensive test programme in various wind tunnel environments and combined with passive noise reduction technology (Fig. 1). The primary objective of the investigations was to get precise validation data for existing 2D and newly developed 3D simulation approaches. Furthermore, passive noise reduction measures were pre-selected for their later deployment in wind turbine rotors.

The new profile

The profile geometry is crucial for sound generation because it determines up to what point the air current has a laminar flow, from what point it becomes turbulent and where it separates from the profile. Also the flow angle on the leading edge, the flow velocity, potential small manufacturing defects and dirt on the blade have an impact.

The researchers in Braunschweig designed an aeroacoustically favourable profile named RoH-W-18%c37 (hereinafter: RoH). They compared it to the NACA 64-618 standard profile. For scientific comparisons, the so-called NREL 5MW reference wind turbine is often used; its geometry and performance data are accessible to the public. The aforementioned NACA standard profile is situated in the outer 20 – 25 % of this wind turbine. Comparisons are first simulated on the computer and then verified by way of measurements. In the larger wind tunnel (DNW NWB), the outer 20 % of the NREL 5MW rotor blade at a 1:6 scale was used as comparison geometry (Fig. 2). Due to the lack of rotation in the wind tunnel test, the geometry was adjusted; in particular the blade twist was removed.

The blade tips of today's modern wind turbines have little impact on the generation of noise on the rotors because in this area rotor output is often forgone for acoustic and structural reasons. Winglets or spiroids could increase the rotor output by up to 4 %. Therefore, two winglet designs were also included in the tests and integrated in the wind tunnel model with RoH profiling (Fig. 2, 3).

Passive technologies for noise reduction

One objective was to further exploit the potential of passive technology on the trailing edge. It includes trailing edge serrations, aeronautically proven porous materials and different types of trailing edge brushes. To date, only the serrations have been put into practice. The measurements of the various modifications showed that in ideal conditions in laboratory tests the potential to reduce noise of the individual technologies is between 3 and 10 dB depending on the frequency. The brush extension, which was particularly considered in the tests, can achieve approx. 6 dB over a wide selection of operating ranges (Fig. 1, 3).

Fig. 1 *The measurement of the noise sources is performed in the wind tunnel (DNW-NWB) using a directional microphone arrangement (elliptic mirror) and 2 measurement arrays: The left field has a diameter of 3 m, 140 microphones and is facing the suction side. The right field has a diameter of 1 m, 96 microphones and is located next to the mirror on the pressure side. Measurement object is an airfoil with brush extension.*

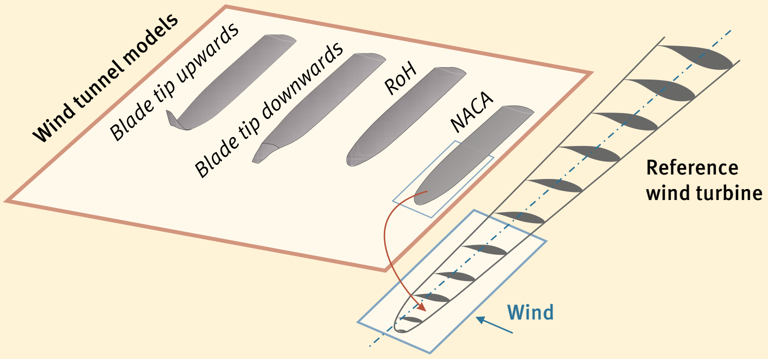

Fig. 2 *Overview of the tested model variants without trailing edge modifications. The two left blade tips on the wind tunnel models show winglets bent up and down.*

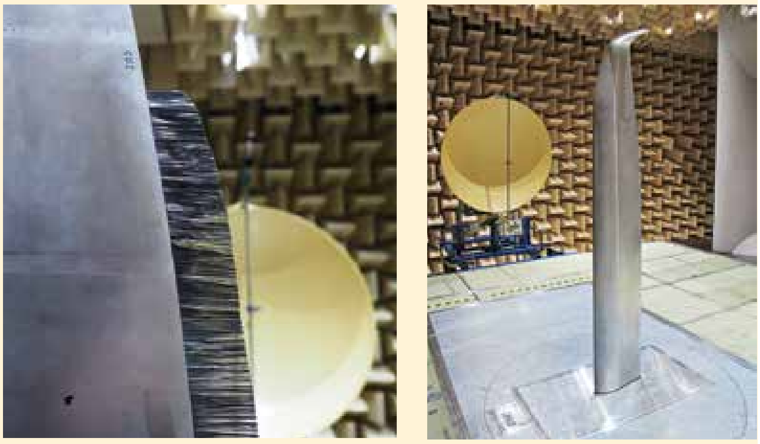

Fig. 3 *A modified trailing edge with brush extension – model configuration with winglet*

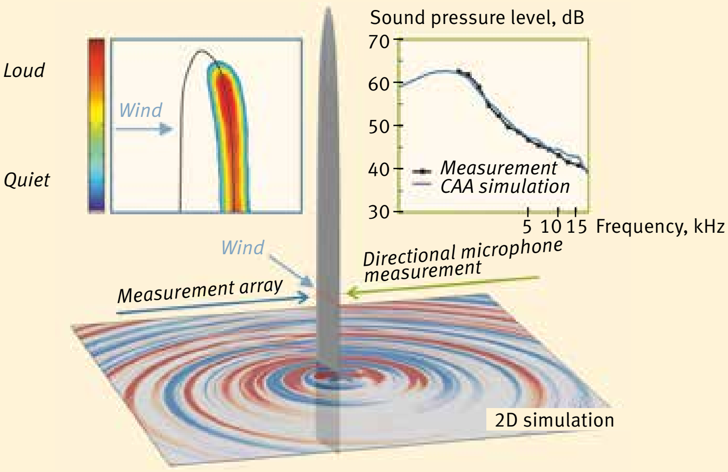

Fig. 4 *"Snapshot" of the sound field from 2D simulation of trailing edge noise (bottom). Example of source map from array measurement at 2.5 kHz with line source distribution along on the trailing edge (top left) and comparison of measured vs. simulated noise spectrum (top right).*

Wind flows over the rotor blade

Presented in a very simple form: the wind with different flow angles collides with the leading edge of the blade. The velocity reduces as a result of the friction of the air flow against the surface. It is zero directly on the blade's surface. This "braked" air is called the boundary layer and characterises the majority of noise emissions.
On the first partial route over the blade surface, the boundary layer ideally has a laminar flow, i.e. the individual air particles move in parallel. From a changing point, which depends upon the geometrical design, the pressure conditions and the friction, there is increasingly strong turbulence (vortex) on the way to the trailing blade and the boundary vortices becomes thicker. At the end, the air flow separates from the profile again, which causes turbulence in the wake of a wind turbine. The objective of the constructors is to keep the energy content of the boundary layer turbulences in the area of the trailing edge as small as possible. This also means that the flow separations before the trailing edge (Fig. 5) are to be avoided for the wind turbine's biggest possible operation area.

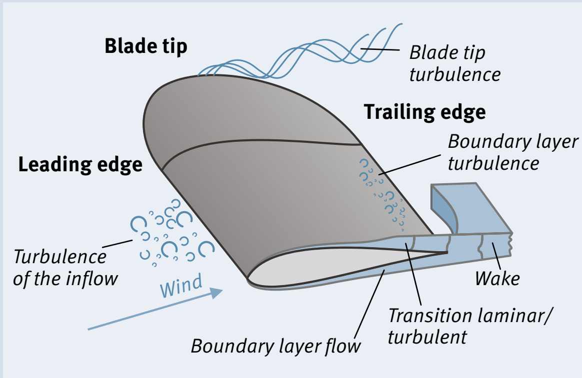

Fig. 5 *Noise sources on the rotor blade with boundary layer flow around a profile (boundary layer thickness is vastly elevated)*

Approaches for practical applications

Thanks to the conclusion of the aerodynamic and acoustic measurement program, a unique data base now exists. Through the combination of various wind tunnel environments and measurement technology, the parameter range of previous tests was clearly extended. This relates to flow velocities (40 – 80 m/s), blade angles over wide operating ranges and also the valid frequency ranges of the acoustic measurements. These measurements were accompanied by surface pressure and wind tunnel balance measurements. Through the selection of a relatively small model specimen in a large wind tunnel, an excellent data quality could be achieved that could not have been achieved with larger test specimens.
The data are now being used to validate new 3D CAA simulation methods. Since these are physics-based and not empirical, a transfer to full scale wind turbine blades through the simulations is possible on the computer. A non-empirical 2D methodology used in Braunschweig to predict trailing edge noise has already been successfully validated in the project and is being applied to support the design process (Fig. 4). In the wind tunnel test, the new RoH profile achieved a noise reduction of 2 dB compared to the NACA reference and therefore confirmed the researchers' predictions. Likewise, the expected, improved aerodynamic characteristics of the profile were experimentally proven.
The use of modified trailing edges has proven to be an even more effective noise reduction method. In the future, it will be possible to determine a ranking order of the methods. In the project, the first 3D simulations of noise emissions from the various blade tip geometries were performed. An interesting result is the very different radiation directivity of the blade tip noise in the case of the winglets – a result of the detailed measurements of the farfield sound for these components. In the future, 3D simulation software is to support constructors even in the pre-design phase.
The researchers in Braunschweig are planning a phase 2 of the project, in which they would like to work together with industry partners to modify the outer blade area of an existing wind turbine. Depending on the wind turbine types and the design philosophy, the now positively-tested simulation technology, the demonstrated skills in profile redesigns and also passive reduction technologies should be put to use. Under typical site conditions, a blade of a modern wind turbine that has been modified in this way should generate at least 3 dB less noise than the original blade. This objective sounds modest, however, it is equal to halving the sound power, which is extremely challenging in terms of technology.

Active methods for less noise

An optimised profile and blade design, wing attachments and modified trailing edges are among the passive technologies for wind turbine noise reduction. Their strength is that they do not need any additional energy in order to be effective. The results are also relevant for the development of quieter turbomachines and cooling fans.
In a complementary project, scientists from the Institute of Aerodynamics and Gas Dynamics at the University of Stuttgart are researching active technologies for noise reduction. In the research projects, ActiQuiet and ActiQuieter, they have investigated the active, flat suction of the boundary layer on the rotor blade. This suction is performed using one or more suction pumps that are integrated in the rotor. The strength of this method is that it can be optimally adapted to the respective flow conditions of the blade. The objective is to avoid as much noise as possible with the smallest possible energy demand and without impairing the wind turbine's performance capability. In the first stage, the method is experimentally tested on a profile and is also numerically tested with a CFD simulation program. The result was a suction configuration, in which the suction strength and position of the air outlet are optimised.
On the basis of these promising results, the second stage was about adapting the method to the conditions of a conventional, industrially manufactured wind turbine. The tests have been very promising. The active suction via a broad range of possible operating conditions leads to noise reduction and improved aerodynamics. With a calculated noise reduction of up to 5 dB, the increase in the wind turbine's power generation was higher than the additional energy expenditure for the suction pump. Only if a noise reduction of more than 5 dB is intended and the pump output has to be correspondingly high does a negative overall energy balance occur. A possible counter strategy could be found in the installation of several smaller pumps rather than one big pump. The objective of this investigation was to be able to make a decision about a prototypical implementation on the basis of scientific and industrial results. With the active and passive methods, there are technologies in development that could contribute to further sinking the noise emissions of wind turbines in the future.

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