

# Validated performance gains from **Aerodynamic Upgrades**

Newly developed Aerodynamic Upgrades for wind turbine blades boost annual energy production (AEP) by up to 1.2%\* in IEC3 class conditions

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## **Designed to increase the energy output of wind turbines**

Vestas' Aerodynamic Upgrades consist of vortex generators and gurney flaps, which are applied to wind turbine blades either together or separately, depending on the individual blade design. Based on our extensive knowledge of wind turbine blades and advanced CFD modelling, we have identified the optimal configurations for different blades. For optimal performance, Vestas V90 and V100 blades receive the full add-on package.

In this paper we describe the theory behind Aerodynamic Upgrades and demonstrate their value with a field test report. Based on simulated power curves that have been validated through an extensive verification programme, Aerodynamic Upgrades deliver 1.0% improvement on V90-1.8/2.0MW and V100-1.8/2.0MW, and 1.2% on V90-3.0MW in IEC3 class conditions.

The Aerodynamic Upgrades have been certified by DNV-GL and are in accordance with the Type Certificate in IEC3 conditions.

## **How Aerodynamic Upgrades enhance wind turbine blades**

Over the years, vortex generators have routinely been used as passive flow control devices in multiple fluid engineering applications. For example, on fixed-wing aircraft, power-plant nacelle strakes, turbo-prop air-intakes and automotive, to name a few.

More recently, the wind industry has benefitted significantly from their application in preventing or delaying the onset of blade air-flow separation – critically, in the inner area of the blade. This helps to regulate the aerodynamic and aero-elastic performance of wind turbine blades.

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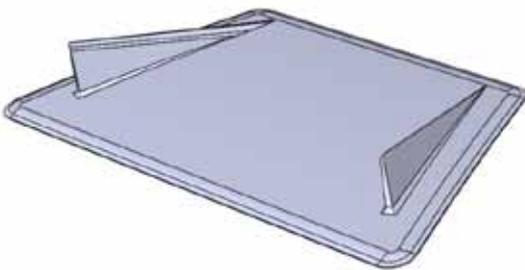
### Quick Facts: Aerodynamic Upgrades

- Comprise two types of blade add-ons
  - Increase AEP by up to 1.2%\* in IEC3 conditions
  - Power improvements and noise validated in field tests
  - Certified by DNV-GL in accordance with Type Certificate (IECS)
  - Designed for Vestas V90-1.8/2.0MW, V90-3.0MW, and V100-1.8/2.0MW
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\*Based on V90-3.0MW power curve with Aerodynamic Upgrades

Vortex generators exist in different sizes and types. Counter-rotating vortex generators are the most effective and are usually used for wind turbine applications.

They comprise a pair of small delta fin wings, mounted equidistantly, opposite each other on the suction (leeward) side of the blade. The delta fin wings are inclined to the incoming flow to produce a pair of counter-rotating vortices that are swept downstream to re-energise local, low-momentum flows.



**Figure 1** Example of a counter-rotating vortex generator

The shed vortices help to suppress or delay blade flow separation, which enhances the blade segment's power output and captures power previously lost through early flow separation and stall.

Vestas has developed vortex generators through extensive wind tunnel testing and field measurements, examining a wide range of wind speeds to increase the wind turbine's power output.

Systematic testing under both controlled and field environments allowed us to verify predictions in flow separation and flow separation control. In turn, this assisted our delivery of cost-effective, durable, reliable and simple-to-install devices.

Vestas 3D flow simulations also helped identify the best positioning of vortex generators near to the root of different blade types – taking into account their individual flow characteristics to improve upon.

Blades with large inner rotor separated flow regions can benefit strongly from vortex generators. However, vortex generators are less effective in blades with lower flow separation, such as the V90 and V100 blades. In this case we also employ gurney flap devices to improve energy yield.

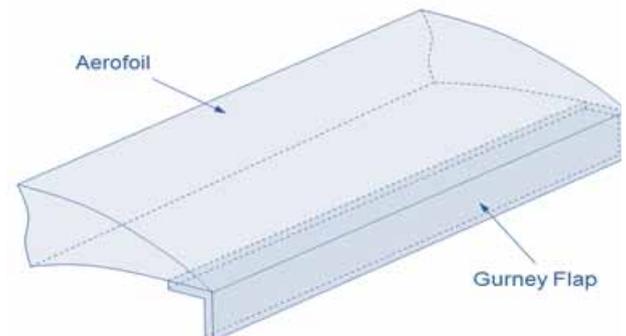
Typically, gurney flaps, named after American race car driver Dan Gurney, are small, flat plates fitted at a right angle to the windward side of the blade along the trailing edge.

The gurney flap effectively changes the camber of the aerofoil near the trailing edge, which can increase lift substantially without significant drag penalty.

The efficacy of a gurney flap depends on the height of the device and span-wise position along the length of the blade. The gurney flap's dimensions must be chosen carefully to balance the increased load and performance of the blade.

For wind turbine blade applications, gurney flaps are most effective on the inner part of the blade, where a relatively thick aerofoil section benefits from the additional lift provided by the flap. The gurney flap works best when operating in attached flow, where it combines beneficially with vortex generators.

Our wind tunnel test measurements further helped optimise gurney flap geometry and performance.



**Figure 2** Example of gurney flaps on a wind turbine blade

### **Materials selection and installation quality are key for lasting results**

Aerodynamic Upgrades are subject to the harsh conditions wind turbines experience out in the field. Using quality components and carrying out installations in line with Vestas' specifications are critical in ensuring these upgrades are long-lasting and work most effectively.

The materials we select for our Aerodynamic Upgrades are based on extensive industrial and field-support experience.

The gurney flaps also have additional structural bonding at the trailing edge to ensure maximum hold, and a sealant is applied to prevent water ingress into the bond.

Each component has been designed to withstand stronger winds and handle greater loads than those encountered in the field. The components are of the highest quality, and have passed a series of tests including accelerated life-time testing, UV tolerance, exposure to extreme hot and cold weather, as well as heavy rain, hail and ice build-up, as well as the impact of sand and dust.

The installation process follows well-defined guidelines produced by highly-experienced engineers and field technicians. This guarantees instruction clarity and bonding quality. We have already installed Aerodynamic Upgrades on hundreds of turbines, both in the field and in factory conditions.

### **Noise testing confirms upgrades have no impact on turbine sound power levels**

Acoustic emission is often considered the most significant environmental impact from wind turbines. As a result, many projects must meet strict noise requirements, set by local and national authorities. If noise levels exceed permitted limits, individual turbines may be banned from operating at certain noise modes.

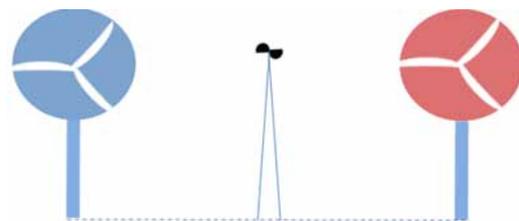
Aerodynamic Upgrades have undergone a series of noise tests in the field for a range of wind speeds in partial and full load. Our tests confirmed that sound power levels don't exceed the guaranteed limits for the turbines. These tests were conducted for noise mode 0 and in accordance with the IEC 61400-11 ed.3 guidelines

### **Validating the increased power performance of Aerodynamic Upgrades**

In designing products and upgrades, such as the vortex generators and gurney flaps, Vestas uses state-of-the-art simulation tools to model power curves and annual energy production. These simulations are then validated in field tests, using a relative power curve measurement campaign.

We use a relative power curve measurement campaign instead of an absolute measurement because the latter's uncertainty levels can be up to 5% – too high to validate gains of around 1%.

To validate the improvement in annual energy production that Aerodynamic Upgrades deliver, we designed a detailed relative power curve measurement campaign, using a pair of turbines and a met mast. The power curve measurements were carried out in accordance with our internal guidelines and the IEC 61400-12-1 norms. Together with the data analysis and the measurement sector choice, this reduced the measurement's uncertainty.



**Figure 3** Illustration of verification test setup with a reference turbine (left), test turbine (right), and met mast

A suitable test site was located in the United States' Midwest, with ideal conditions for power curve testing at various wind speeds up to and beyond rated power. The selected wind farm is located in flat and homogenous terrain, with a met mast equidistant to the test and reference turbines.

Both the test and reference turbines were Vestas V100-1.8MW MK7 variants, and were free of any up-wind terrain obstructions, including neighboring turbines.

Before the verification campaign, a historical assessment of the turbines' relative annual energy production also proved statistically that the turbines had a similar performance over time.

#### **Field test validates power performance of Aerodynamic Upgrades in real conditions**

Our actual verification campaign spanned more than three months, during which a total of 350 hours of data were collected to establish the reference power curve and the upgraded test power curve.

In addition to sensor checks, outlier removal and wind resource filtering, we only collected valid data when both test turbines presented the same operational characteristics. This meant any normal operational stops or maintenance windows were disregarded.

The measured power curves from the reference and test turbines allowed us to establish a power curve delta. This was used to validate the simulated power curves for the different turbine types, and to compute the relative increase in annual energy production for generic wind classes.

The verification programme's final results indicate that the test turbine with Aerodynamic Upgrades achieved improved annual energy production of 1.1% more than the reference turbine in IEC3 conditions. This is a slight increase over the simulated power curve, which suggested an improvement of 1.0%. The uncertainty of the field measurement is  $\pm 0.3\%$ .

The results of the field verification campaign validate the simulations performed at Vestas' R&D department during the development stage of both the V90 and V100 blades, which are part of the same aerofoil family and blade-build technology.

#### **A part of Vestas PowerPlus™**

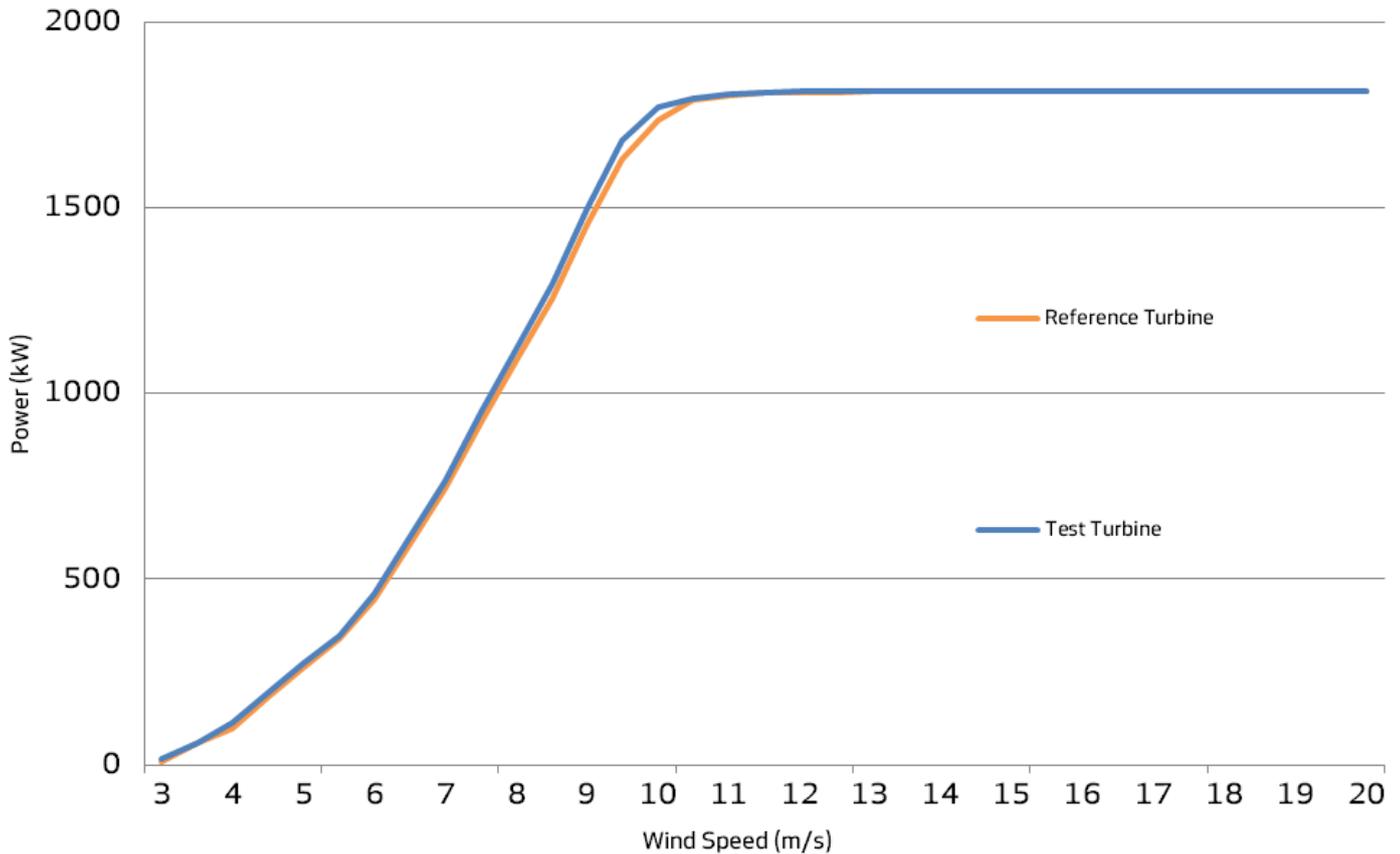
Vestas PowerPlus™ is a suite of products designed to improve the annual energy production of previously-installed wind turbines by incorporating the latest innovations in the wind industry.

In addition to Aerodynamic Upgrades, Vestas PowerPlus™ includes Power Uprate, Extended Cut Out and Power Performance Optimisation software. Vestas PowerPlus™ upgrades have been implemented on more than 1,300 wind turbines worldwide, delivering up to 5%\* more energy.

If you would like to learn more about how Aerodynamic Upgrades and Vestas PowerPlus™ can benefit your business, please contact your local Vestas Services office.

\*Dependent on wind and site conditions

**Figure 4** Validated improvement delta of a V100-1.8MW with Aerodynamic Upgrades compared to baseline



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