Improving blade aerodynamics

Selection of ECN's portfolio of blade improvements

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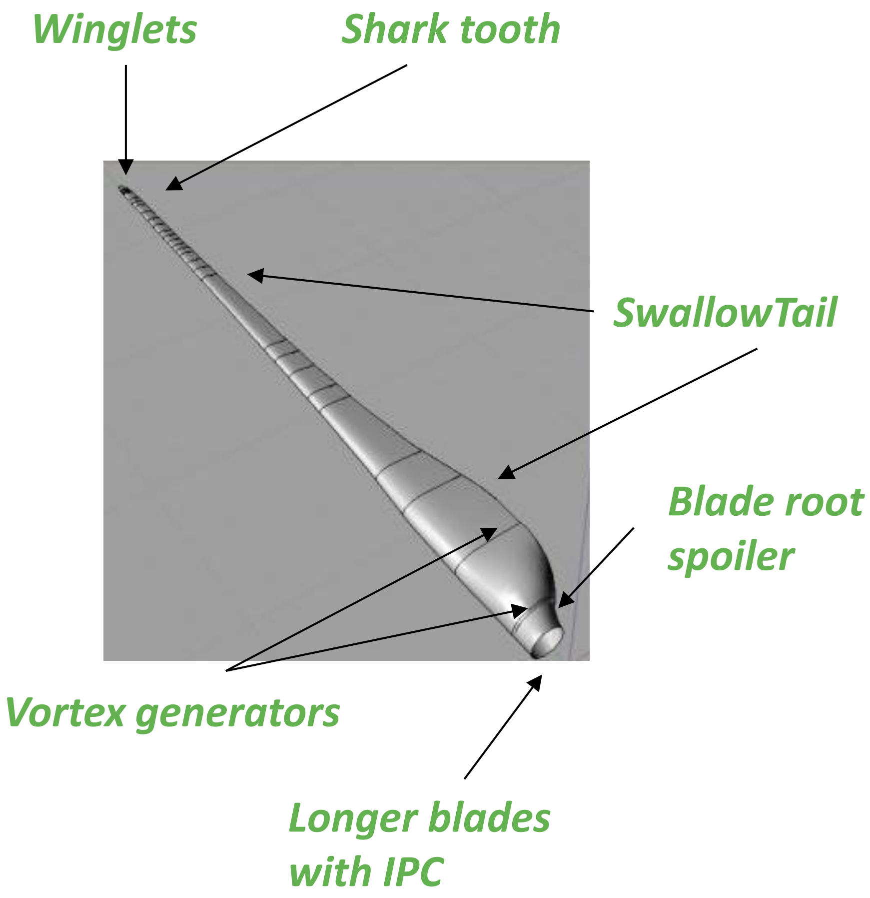
Content

Introduction

- Over the years ECN has developed a portfolio of technologies and development tools that enable us to assist major OEMs as well as blade design companies with their blade designs.
- ECN's blade design team has selected the following technologies:
  - Blade root spoiler (p. 5)
  - Swallowtail (p.6)
  - Shark tooth (p.7)
  - Winglets (p.8)
  - Vortex generators (p. 9)
  - Blade extensions (p. 10)
- In this discussion document we will highlight each of these technologies and describe the potential benefits of each modification.



ECN

What is it?

- The blade root spoiler is a simple strip that is attached to the root section of the blade.

What problem does it solve?

- At the root section the blades of almost all wind turbine have a (mostly) cylindrical shape. A cylinder moving through the air creates drag, which has a negatively effect on the energy production of the turbine.

How does it work?

- By adding a simple strip at the right position the root section starts to create lift instead of drag.

Benefits

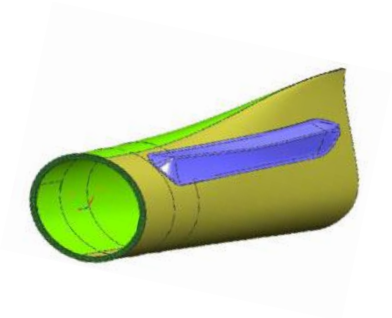
- The expected yield increase (Annual Energy Production or "AEP") will typically range from 0.5% to 1.0%

IP position

- This technology is patented by ECN.
- ECN has licensed this technology to Senvion and LM Wind. LM does not offer this technology as a retro-fit solution, but incorporates the technology in their own blade designs. Senvion is no longer actively offering this product, but nowadays uses LM blades.

Current status of development

- TRL9, technology is available in the market.



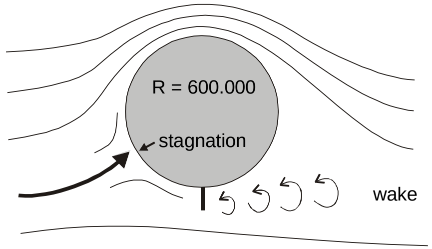


Figure 1: Cylinder in cross flow.
(ref: Hoerner, Fluid Dynamic Lift)

"... the spoiler enhances aerodynamic-lift performance without substantially increasing resistance or drag"
--- LM Wind Power CTO, Frank Nielsen (January 2012)

ECN

What is it?

- The Swallowtail is a blade add-on that is attached at the flat back of the trailing edge of the airfoil.

What problem does it solve?

- The airflow near the blunt trailing edge is unsmooth (picture above). This negatively effects yield, creates noise and disturbs the flow. The latter increases load on the blades and is the prime cause of fatigue.

How does it work?

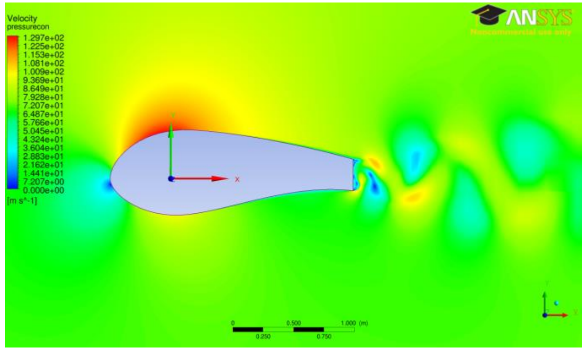
- By its shape, the added 'swallowtail' (picture in the middle) significantly reduces the disturbance in the trailing edge flow field that normally occurs. This leads to a reduction in noise, base drag and flow unsteadiness.

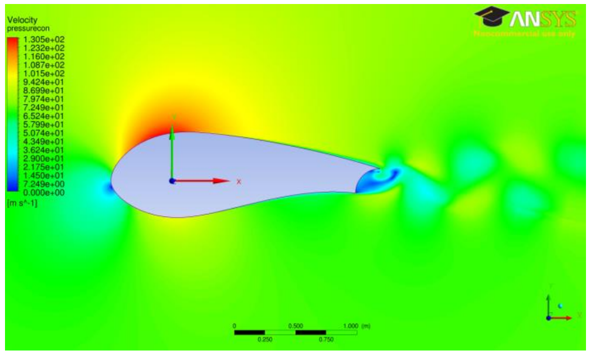
Benefits

- Preliminary numerical studies indicated an increase in the efficiency (lift/drag: design parameter) of around 50% which would presumably correspond with an AEP increase of 0.1% to 0.3%. However recent numerical studies with a high order numerical model (Ansys CFX, Unsteady) indicate that the efficiency increase is ca. 200% instead of 50%. There are no known examples in literature in this order of magnitude, ECN is therefore not able to provide a reliable estimate of the actual yield increase. This requires wind tunnel / field testing.
- Only known solution that increase yield without increasing loads on the blade. This is due to the fact that the Swallowtail increases the efficiency only by reducing the drag.

IP position and TRL

- Patent pending, TRL 3-5, next step: field demonstration





What is it?

- The 'shark tooth' add-on introduces a tooth like shape at the tip of the blade.

What problem does it solve?

- The wake effects in a wind farm typically cause a loss in power of 6-14% over the lifetime of a turbine. The Shark Tooth add-on helps to reduce this effect.

How does it work?

- The tooth-like structure creates vortices that help to mix the airflow and decrease the wake effect. Although this slightly lowers the yield of the first turbine, the turbine or turbines behind the first turbine compensate this with a higher yield. The overall yield of the wind farm increases.

Benefits

- The effect that can be achieved is dependent on different factors such as the lay-out of the wind farm, the dominant wind direction and the distance between the turbines. Based on a numerical study for an existing offshore windfarm, we believe a yield increase of 0.5% is realistic.

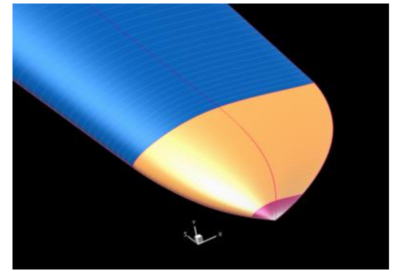
IP position

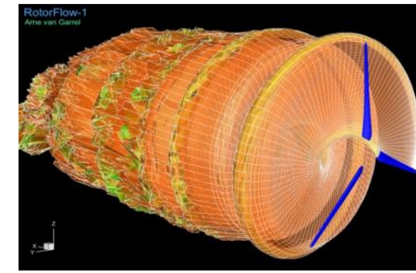
- Patent pending

Current status of development

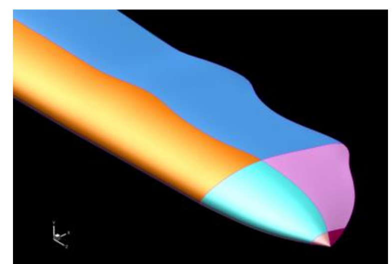
- TRL 3-5, next step: field demonstration

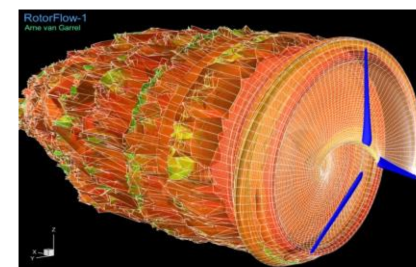
Conventional tip and wake





Shark tooth tip and reduced wake effect (there is considerably more mixing in the wake)





What is it?

- A winglet or wingtip is a vertical extension of a blade tip

What problem does it solve?

- The tip vortex causes losses at the tip of the blade, which reduces the power output. Moreover, the unsteady nature of the tip vortex contributes to vibrations at the turbine blade tips. Winglets are used to reduce the influence of the tip vortex which results in increase in yield.

How does it work?

- The winglets reduce the strength of the tip vortex and changes the location of it. As a result, the flow at the tip region becomes 2D and this increases the power output by reducing the drag.

Benefits

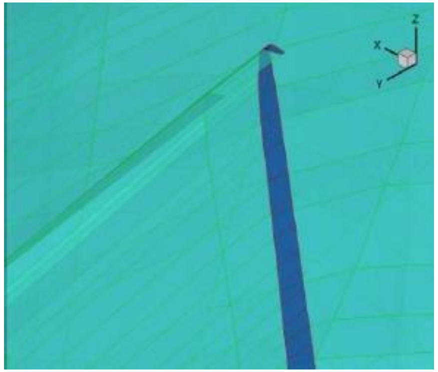
- Winglets can be adopted to reduce the drag and the noise at the tip of the blade. Current studies in literature[1] suggest improvements in AEP of around 1.0% to 2.8%. According to our studies these values might be too optimistic in real applications therefore we conservatively assume 0.5%

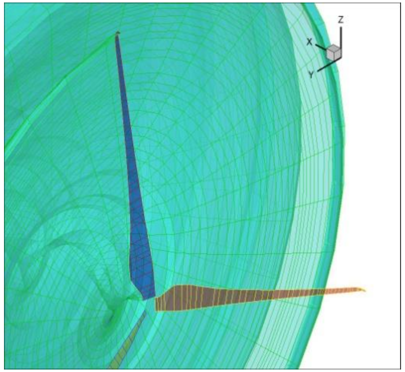
IP position

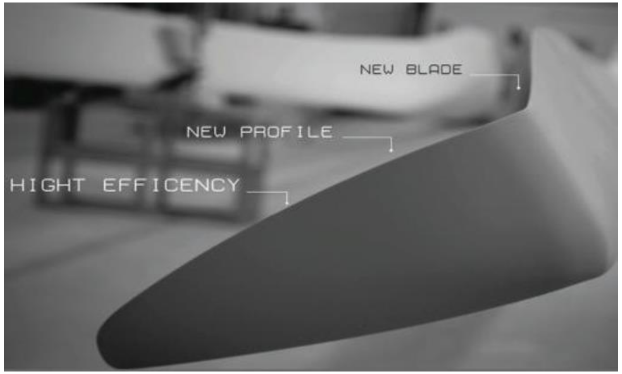
- Winglets are common in aviation, patenting is therefor very difficult. In wind energy winglets are less common. There are no companies that ECN is aware of that offer winglet retro-fits on existing turbines.
- ECN has the expertise and the design tools to develop advanced tailored winglets.

Current status of development

- TRL9, commercially available for new blades.







1) http://proceedings.ewea.org/ewec2007/allfiles2/344_Ewec2007fullpaper.pdf

What is it?

- Vortex Generators (VGs) are small objects / obstacles that are placed mostly on the root and midsection of the blades.

What problem does it solve?

- Every airfoil has a maximum angle of attack at a certain wind speed. Increasing the angle above this point will cause the airflow to detach from the blade. This causes stall, power reduction and instabilities if it occurs close to the blade tip.

How does it work?

- VGs improve the performance of the blades by 'attaching' the flow to the surface of the blade and thereby reducing flow separation.

Benefits

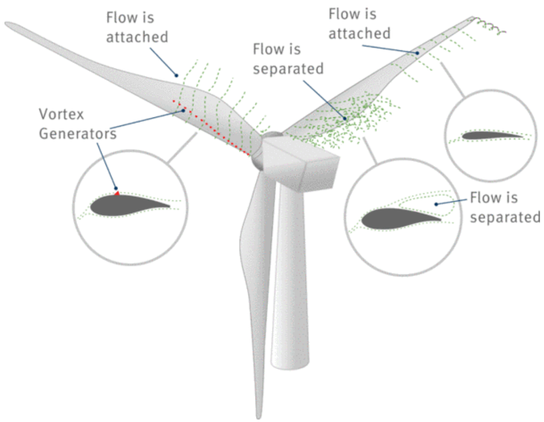
- VG allows for a higher angle of attack and enables the blade to extract more energy from the wind. It also reduces stress loads (fatigue).

IP position

- VGs are not patented by ECN, but ECN has the expertise and the design tools to support Suzlon in optimizing the blade performance

Current status of development

- TRL9, commercially available for new blades and for retro-fitting.



What is it?

- ECN has much experience developing Individual Pitch Control (hereafter: "IPC"), which is a load control system that pitches the blades on an individual basis.

What problem does it solve?

- The length of the blades is limited by the design specifications of the tower and other components. A longer blade (relative to the tower) would result in a larger 'swept area', and thus higher energy yield. However, taller blades improve the loads on the WTG.

How does it work?

- ECN has developed a IPC controller in close collaboration with XEMC Darwind and recently demonstrated that this can reduce the loads with 20%. This allows the use of relatively longer blades on the same tower.

Benefits

- ECN has demonstrated that a 20% load reduction can be achieved. This allows the extension of the blades with 6% of the original size. A 6% longer blade will produce up to 13% more energy.

IP position

- Proprietary know-how and source code.

Current status of development

- ECN has developed an IPC controller, which has been tested in the field. The IPC controller requires accurate and reliable load measurements for feedback mechanisms to the turbine controller. ECN is currently testing its proprietary and patented optical load sensor. Further R&D is necessary to bring IPC to the market (e.g. higher wear and tear of pitch motors)

Prototype of ECN's patented fiber optical load sensor

Calculation of increase in top line revenues for windfarm operators

Based on an assumed overall yield increase of 2.5% we estimate the increase in top line revenues (per WTG) for a wind farm operator:

All amounts in € 1,000	1,0 MW	2,0 MW	4,0 MW	6,0 MW	8,0 MW	Comments
Average capacity factor	30%	30%	30%	30%	30%	Onshore 28%, off-shore around 40%
Yield increase	2,5%	2,5%	2,5%	2,5%	2,5%	Assumption / case specific
Hours per year	8760	8760	8760	8760	8760	
Added annual pow er production	66 MWh	131 MWh	263 MWh	394 MWh	526 MWh	
Electricity price (€/MWh)	80,00	80,00	80,00	80,00	80,00	Assumption: average Feed-in-Tariff in Europe and US: on-shore 80 EUR/MWh, offshore 140 EUR/MWh
Additional annual income per turbine	**5,3**	**10,5**	**21,0**	**31,5**	**42,0**	
Cumulative extra income over 20-year liftetime	*105*	*210*	*420*	*631*	*841*	

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