Gasteizko Ingenieritzako Unibertsitate Eskola
Escuela Universitaria de Ingeniería de Vitoria-Gasteiz

ERASMUS + IESRES
INNOVATIVE EUROPEAN STUDIES on RENEWABLE ENERGY SYSTEMS
PROGRAMME OF TEACHING/LEARNING ACTIVITY 08th – 12th May 2017, KLAIPĖDA, LITHUANIA

Funded by the Erasmus+ Programme of the European Union

Unai Fernández Gámiz

UNIVERSITY OF THE BASQUE COUNTRY

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www.ehu.es/get

Green energy aldea

Wind Turbine Aerodynamics

Floting platforms

WT rotor Aeroelasticity (E. Zulueta)

CFD - Hydraulic Machinery

CFD Heat Transfer

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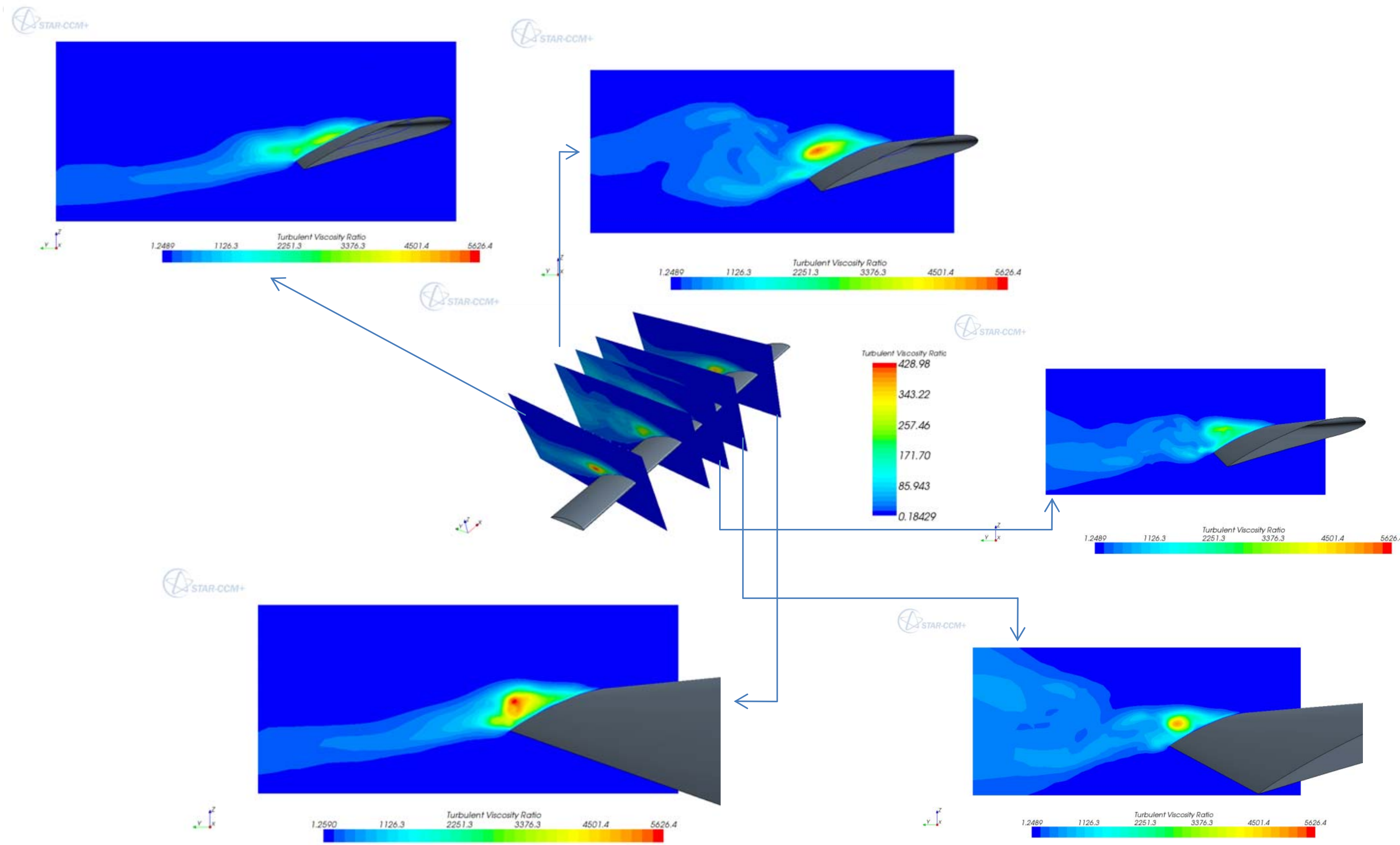
Aerodynamic studies



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ACTIVE/PASSIVE DEVICES FOR FLOW CONTROL

DEVICES:
- -TE flaps
- -AJVG
- -Fences
- -Microtaps
- Gurney flaps
- -VG

ACTUATORS:
- -Piezoelectric
- -Motors
- -MEMs
- -Fluidics

FLOW CONTROL PHENOMENA

CONTROLS:
- -Neural network
- -Adaptive
- -Physical model based
- -Optimal control theory

SENSORS:
- -Conventional
- -Optical
- -MEMS

*Energy Harvesting and Energy Efficiency, Springer 2016. ISBN 978-3-319-49875-1

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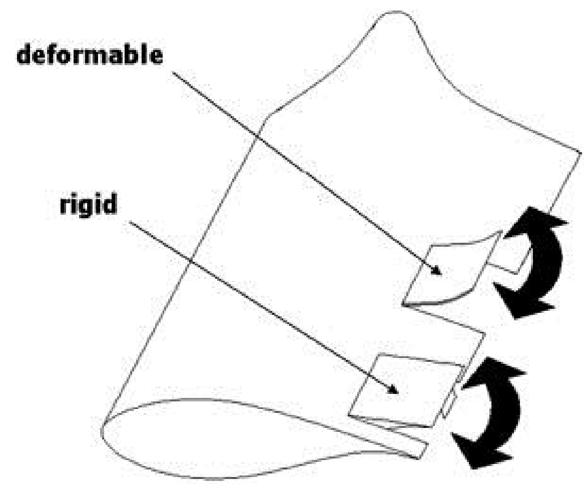
http://www.springer.com/cn/book/9783319498744

Traditional Trailing-Edge Flaps

- Geometric device
- TE - located at the trailing edge of the blade
- capable of deploying in both directions and therefore can adjust the lift curve up and down
- operates by changing the deflection angle in a steady-state manner.

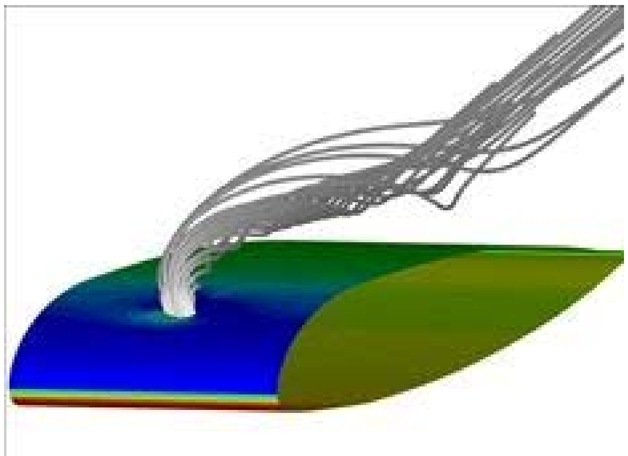
* Stuart, et al. 1996, numerical control case study using ailerons is presented along with simulations investigating the use of actively controlled devices for load reduction

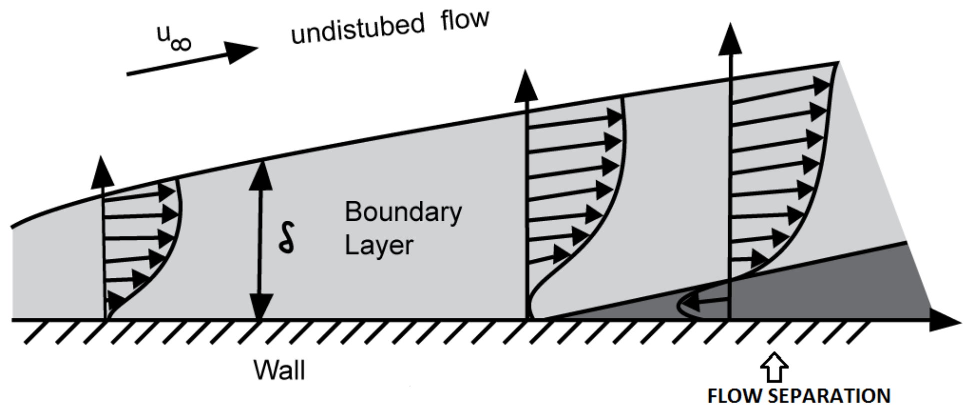
*Jonkman PI control scheme using the aeroelastic analysis code FAST



Trailing-edge flaps

Air Jet Vortex Generators





- Vortex generator jets (VGJs) are jets of air that pass through a wall (the skin of an airfoil) and into a crossflow to create a dominant streamwise vortex

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FENCES on Aircrafts

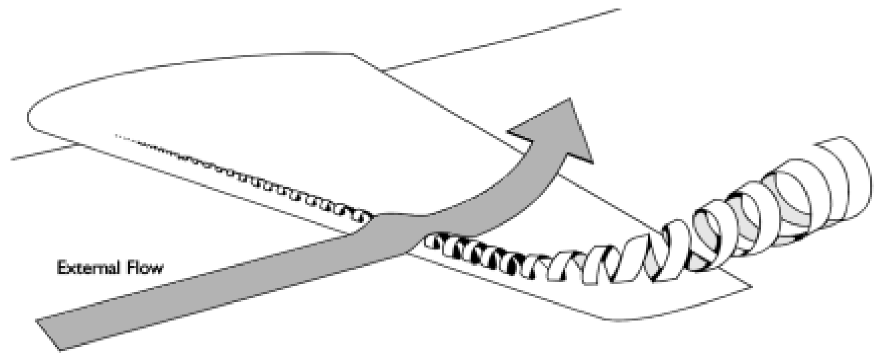

Imagen -Flujo transversal

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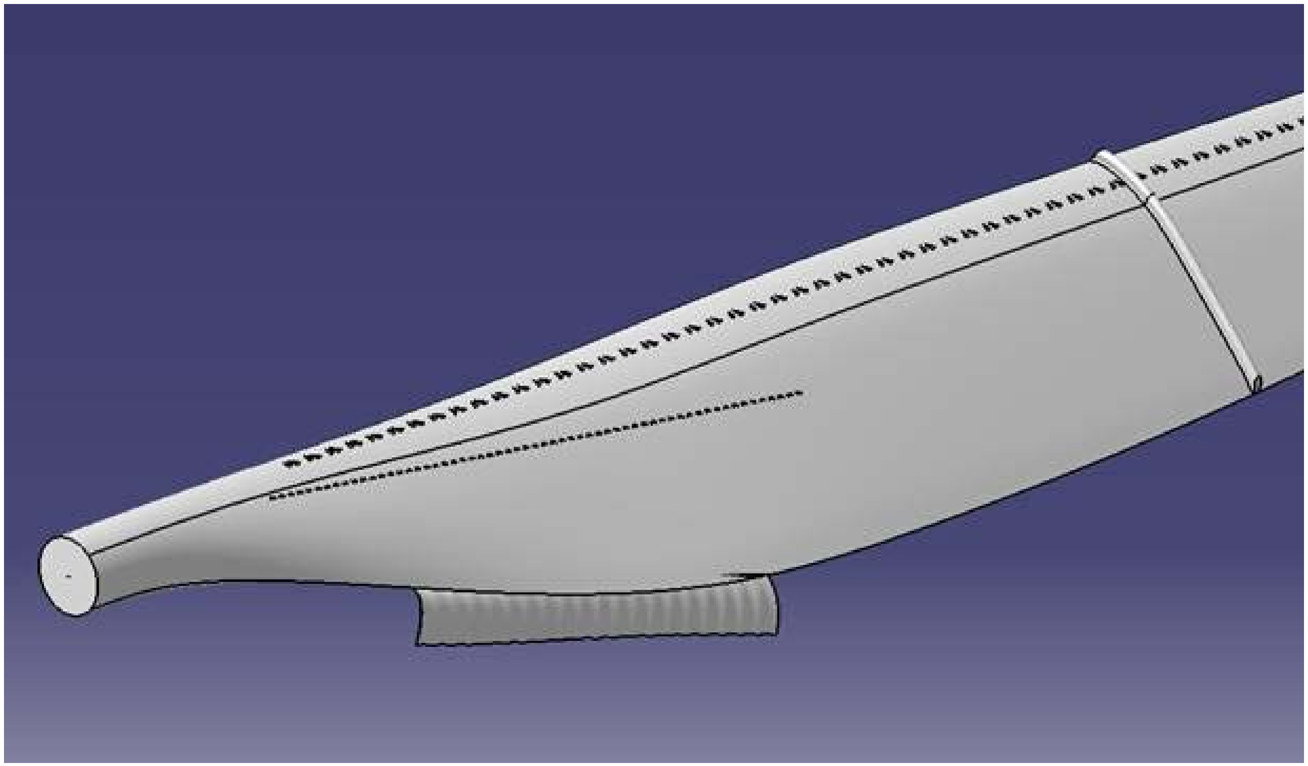
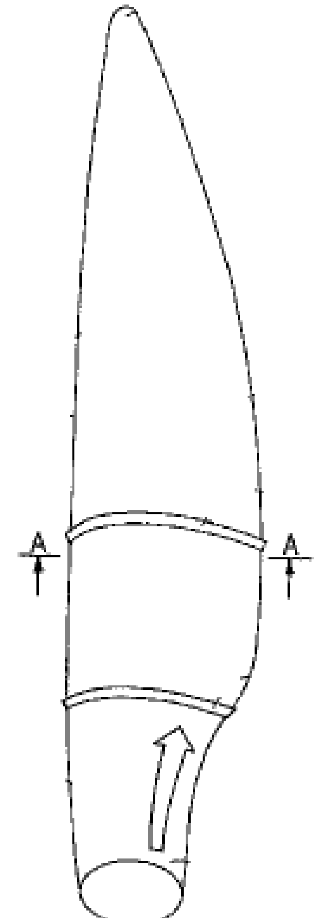
FENCES on Wind Turbines





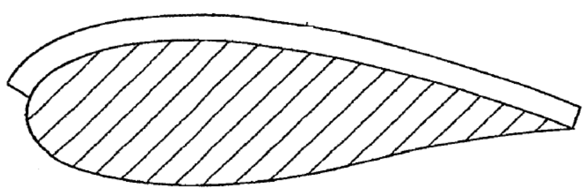


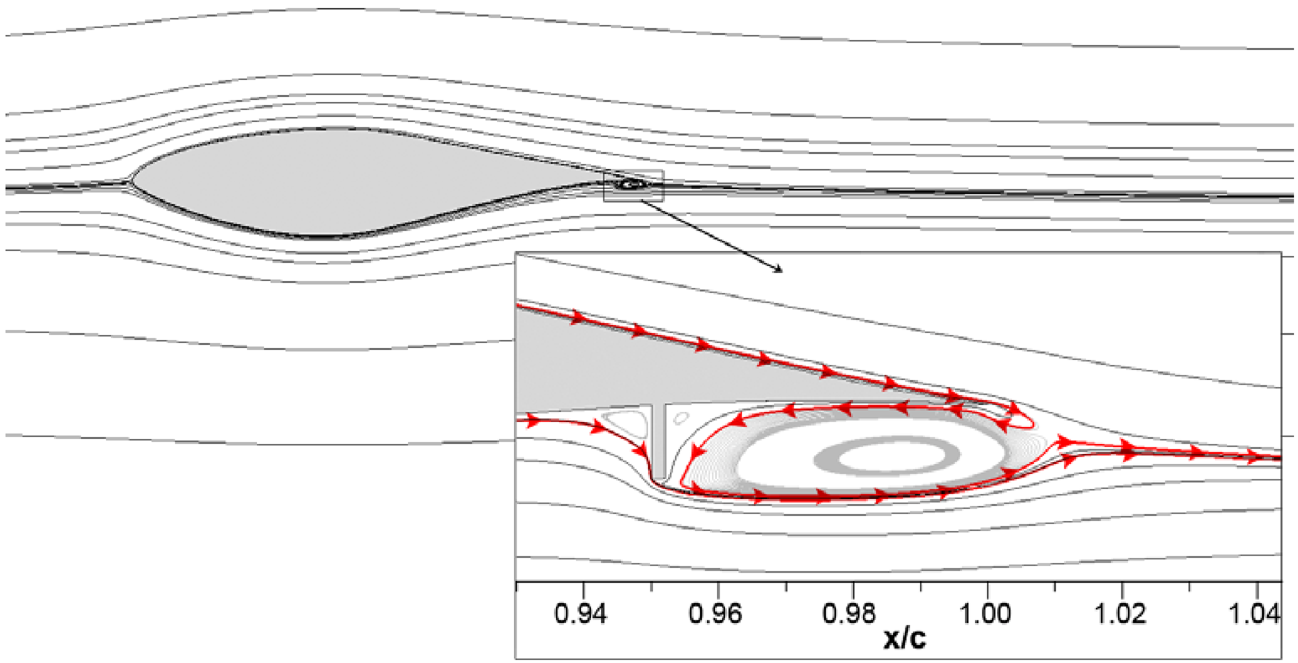
Imagen -Pala: Sección A-A

Source: SIEMENS PATENT US20120051936 A1

MICROTAPS

Device for active load control applications.

- similar to Gurney
- Lift enhancement is achieved by deploying the tab on the pressure (lower) surface and lift mitigation is achieved by deploying the tab on the suction (upper) surface.



Ref.: Scott et al. 2008 SANDIA Report Active Load Control Techniques for Wind Turbines

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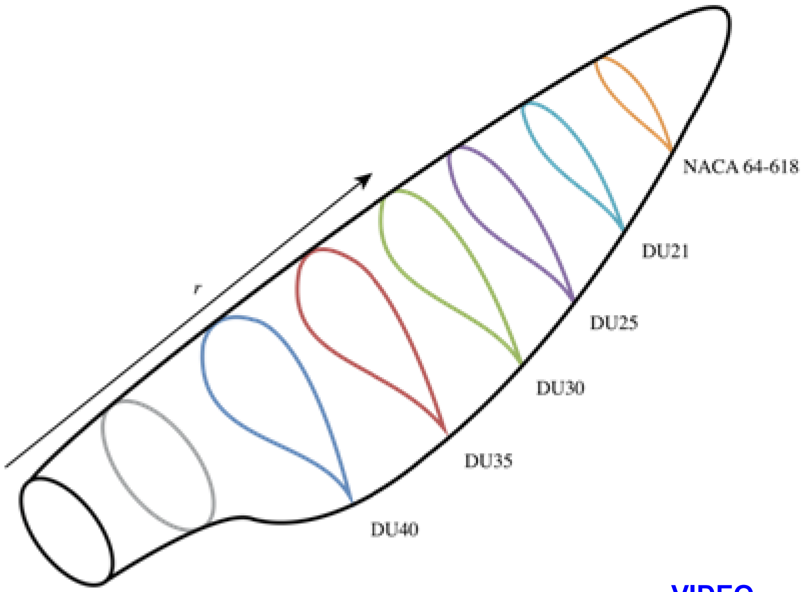
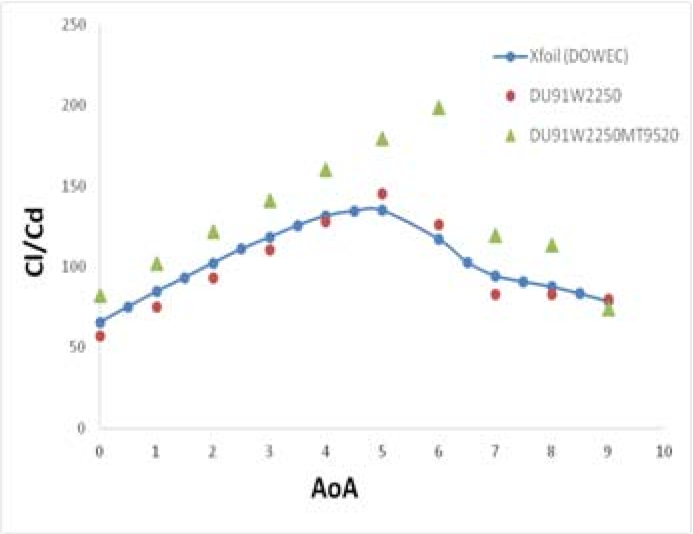
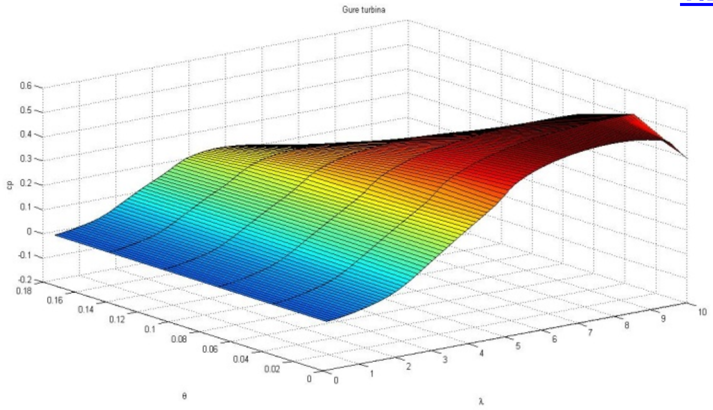
Microtab design and implementation on a 5MW wind turbine



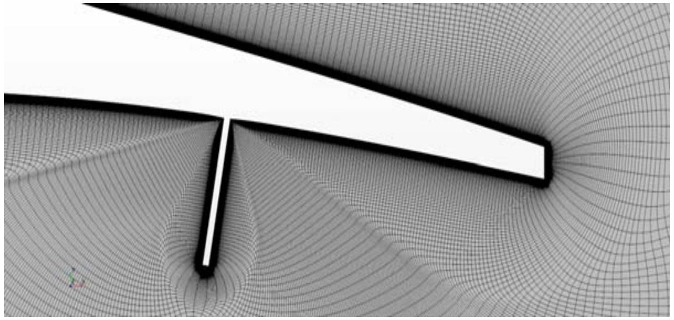
*Ayerdi-Zaton et al. ECRES2017 Istambul 2016.



[VIDEO]

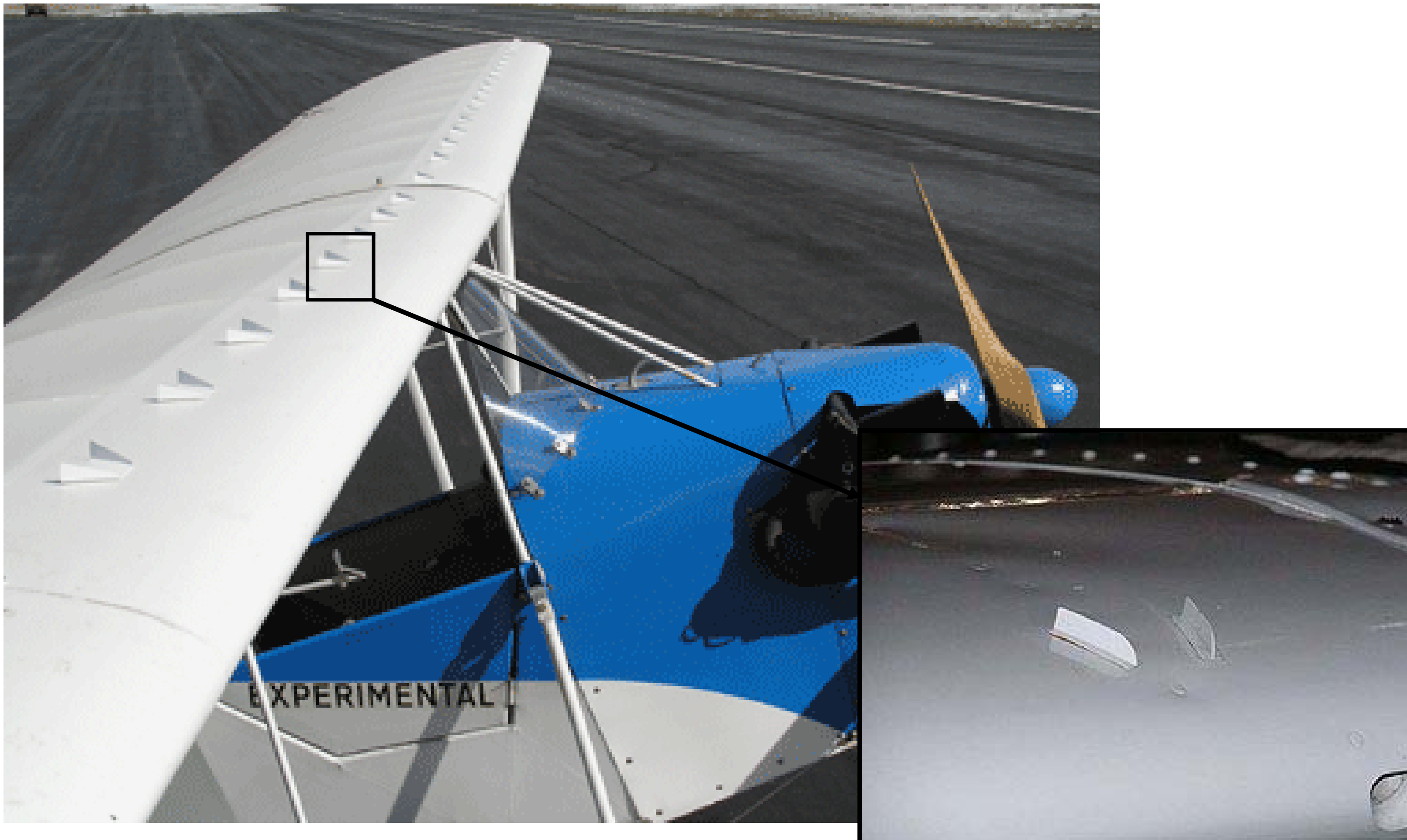


*Author: E. Zulueta.



Vortex generators

Applied aerodynamics on aircraft wings



Source: Vortex generators on the wing of an airplane at the Air Force Museum of the German Federal Armed Forces in Berlin. Image credit: Wikimedia Commons
http://phys.org/news/2012-09-scientists-purpose-vortex.html#jCp

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Vortex generators Embraer ERJ 145 Bilbao - Lisboa

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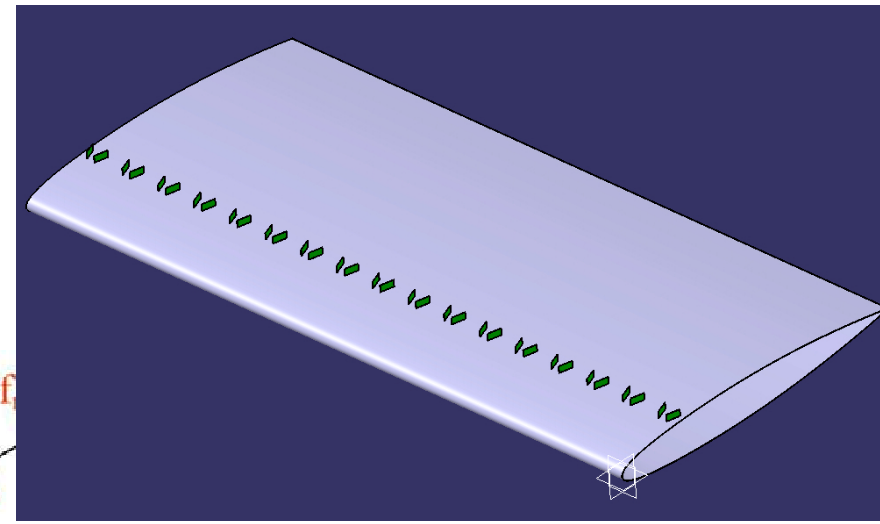
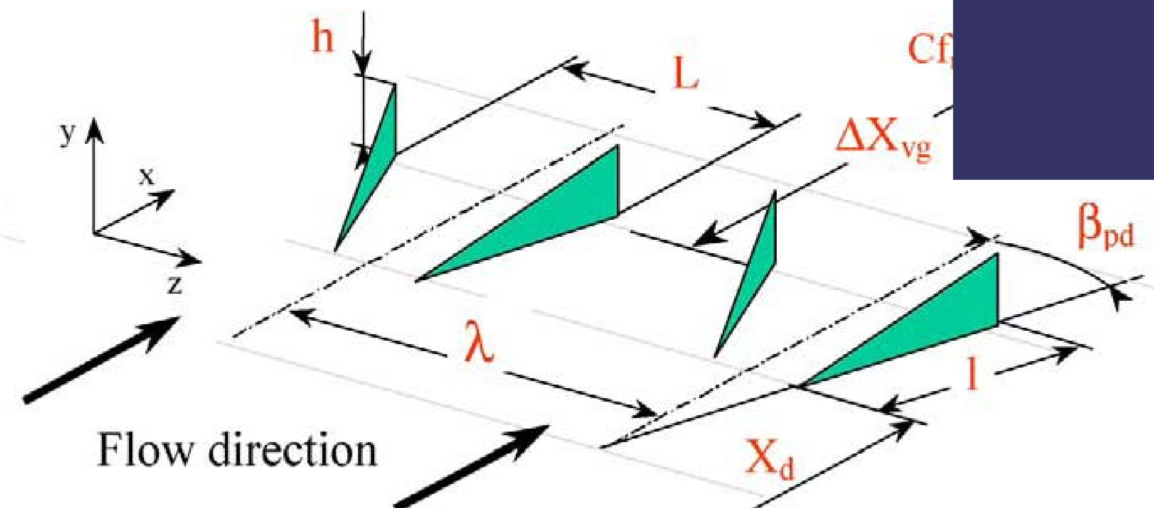
VGs on Airfoils

- GEOMETRY: triangular or rectangular vanes.
- Dimensioned : to the local boundary layer thickness.
- Lay-out: in cascades in groups of two.



Ref.: Author design 2013



Ref.: G. Godard , M. Stanislas 2005

Figure 3: Counter rotating passive device configuration.

VGs on Airfoils

- Main functionality:
  - to delay or prevent separation of the flow.

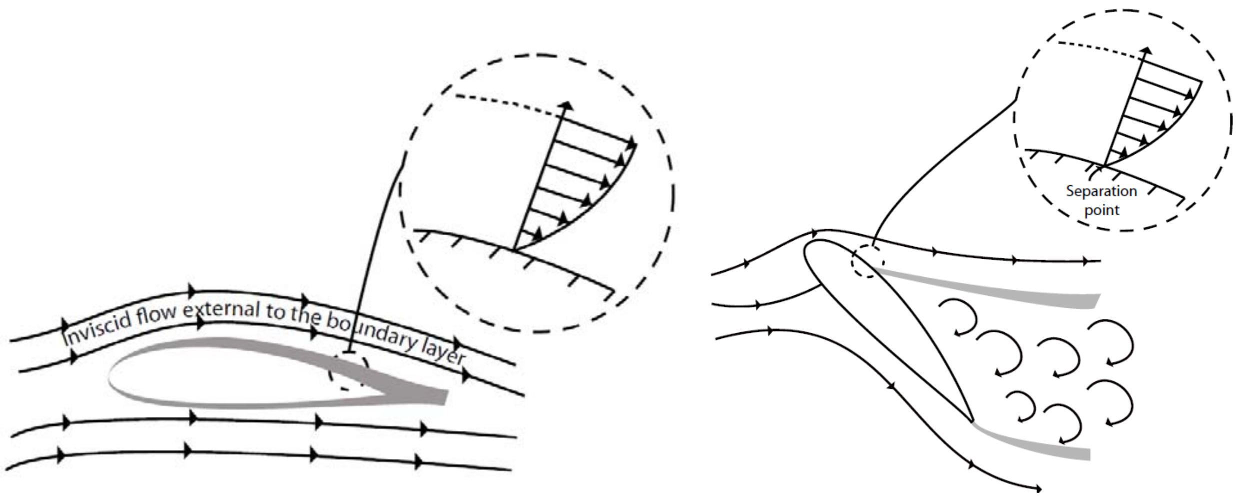


Figure 4: (a)Flow across an airfoil. (b) Separated flow over the top surface of an airfoil)

SOURCE: J.D. Anderson Jr., Brief History of the Early Development of Therotical an Exp. Fluid Dynamics Willey&Sons 2010

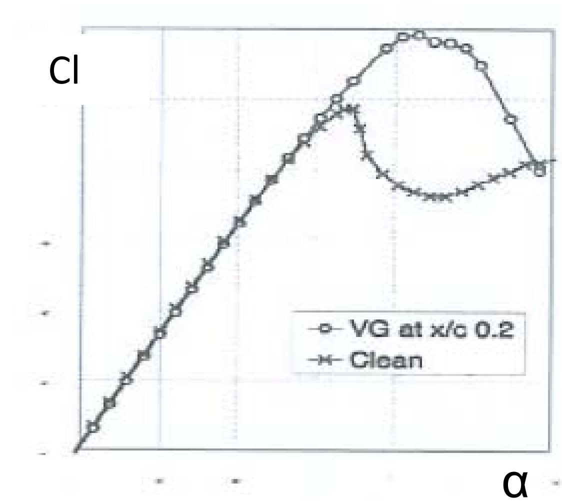


Figure 5:: effect of vortex generators on the performance of DU 97-W-300.

Ref.: van Rooij R. P. J. O. M. and Timmer W A "Roughness Sensitivity Considerations for Thick Rotor Blade Airfoils". AIAA-paper 2003-0350.

VGs on Airfoils

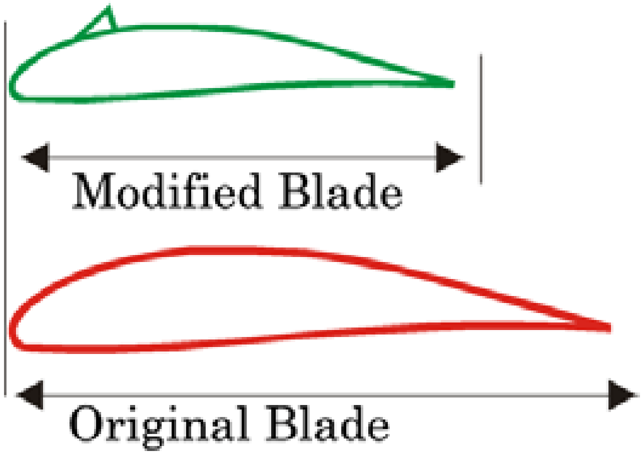


Fig 01 : Airfoils with comparable lift generation. (Source: Corten)

Fig. 01 demonstrates the difference in chord length between the redesigned, or modified, blade and the original blade. The idea can be more easily explained by analyzing the lift equation:

$$L_{\max} = C_{L_{\max}} \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot c$$

If CLmax is increased by a DS device, then the chord, *c*, could be reduced a comparable amount so that the generated lift still equals that of the original blade.

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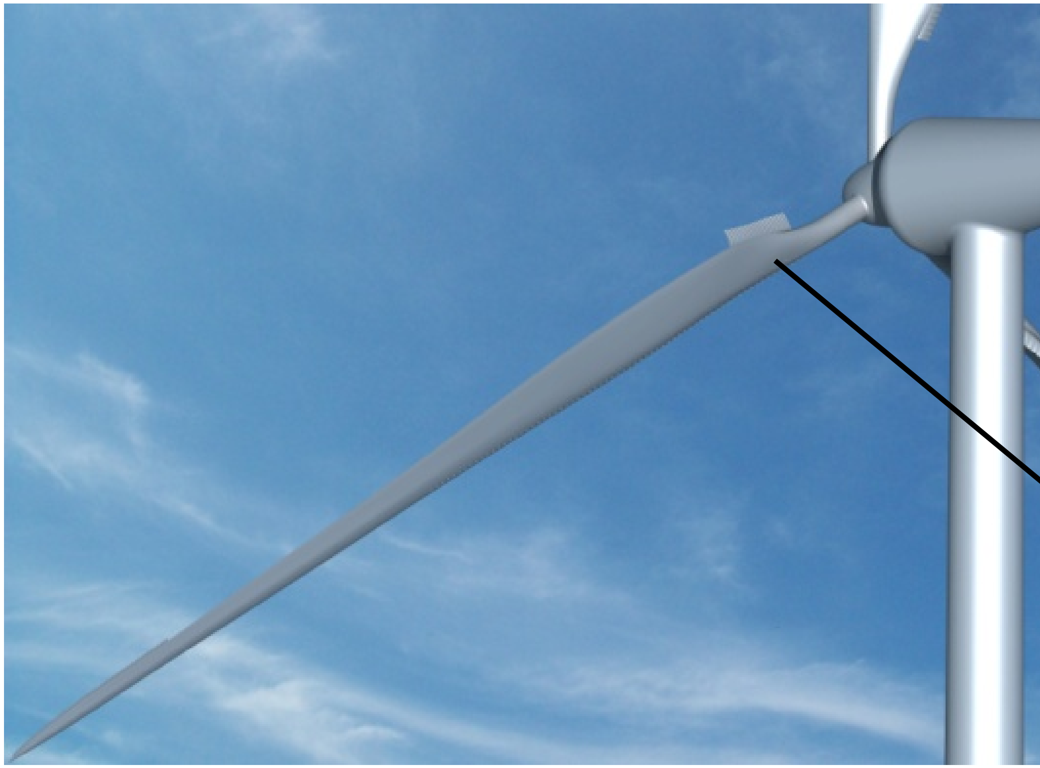
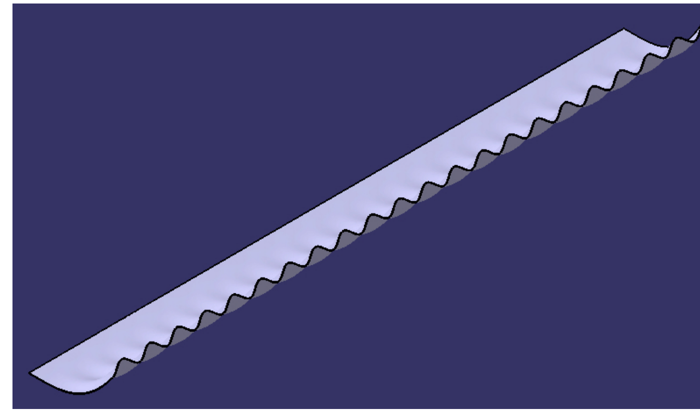
SPOILERS





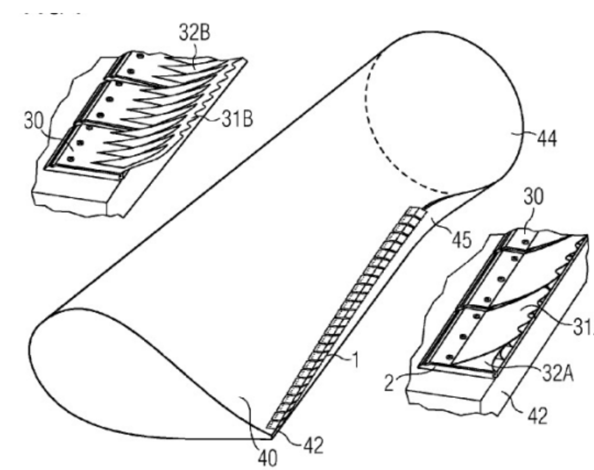
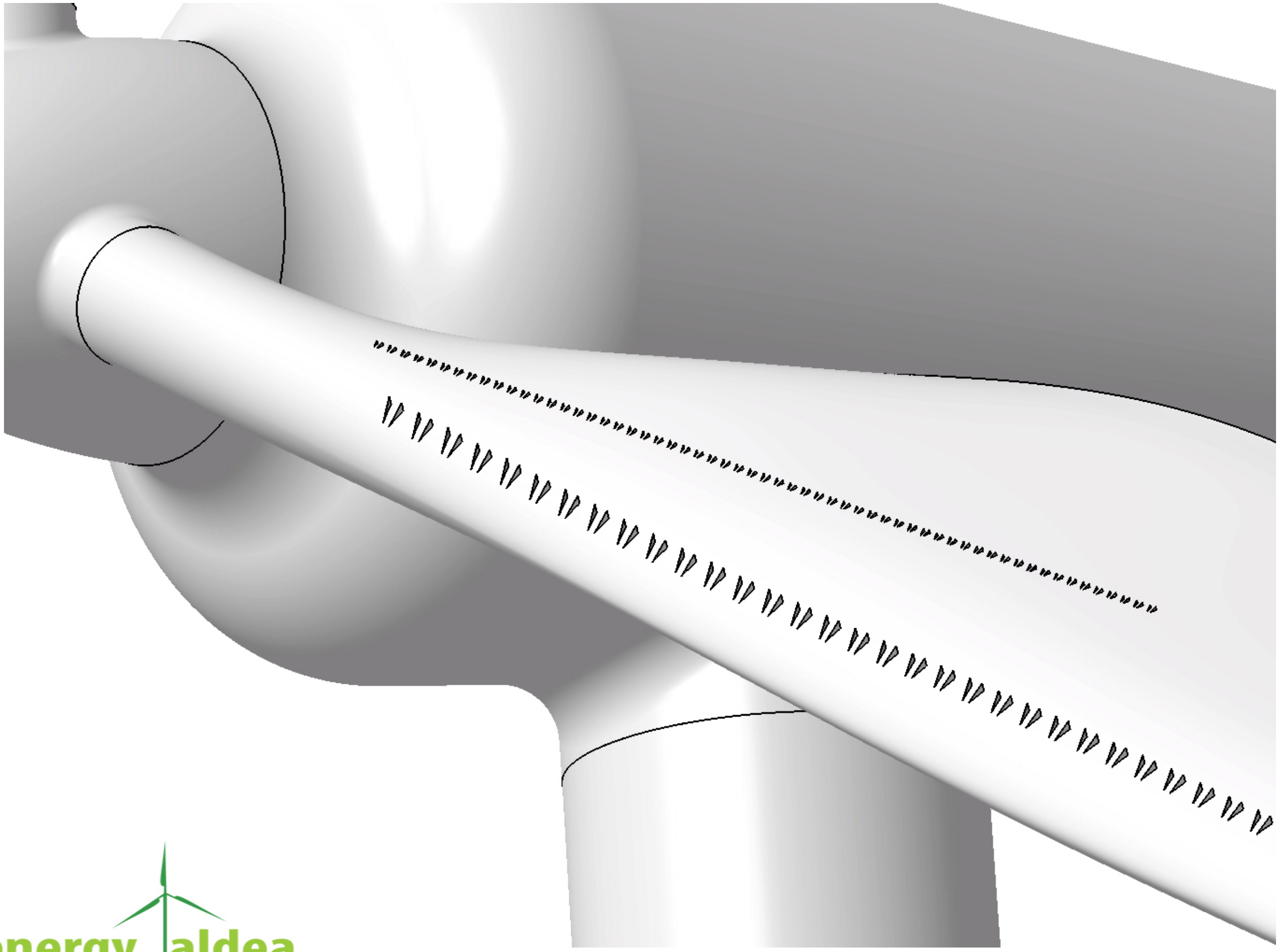


Fig. : Wind turbine blade having a spoiler with effective separation of airflow.

Ref.: LM GLASFIBER Patent: (EP 2 141 358 A1)

VGs on Wind Turbines



[VIDEO]

VGs on Wind Turbines

Increased wind turbine performance from implementing VGs on the blades has also been confirmed through various field tests.

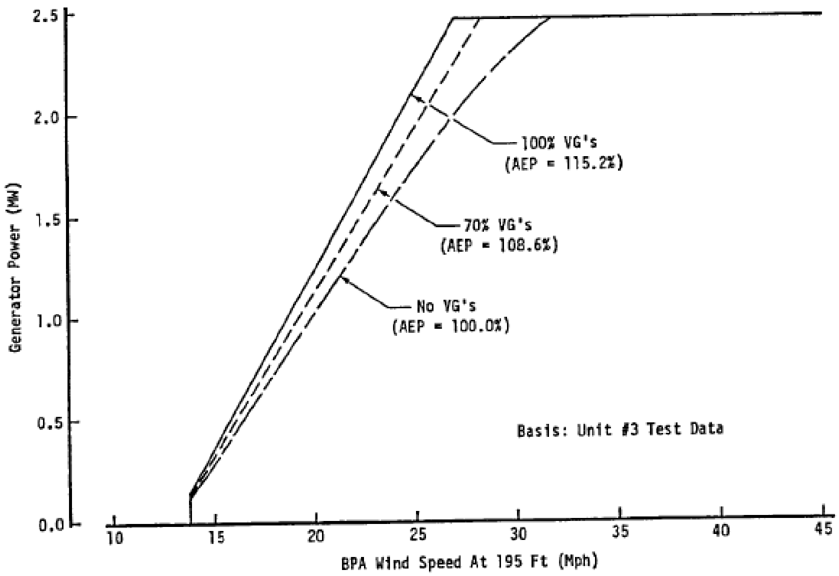


Figure 6 (a): Effects of VGs on a 2.5 MW wind turbine performance.

Ref.: Miller, G.E., “Comparitive Performance Tests on the Mod-2 2.5 MW Wind Turbine With and Without Vortex Generators,” NASA TM N95-27978, Presented at the DOE/NASA Workshop on Horizontal Axis Wind Turbine Technology, May 8-10, 1984, Cleveland, OH.

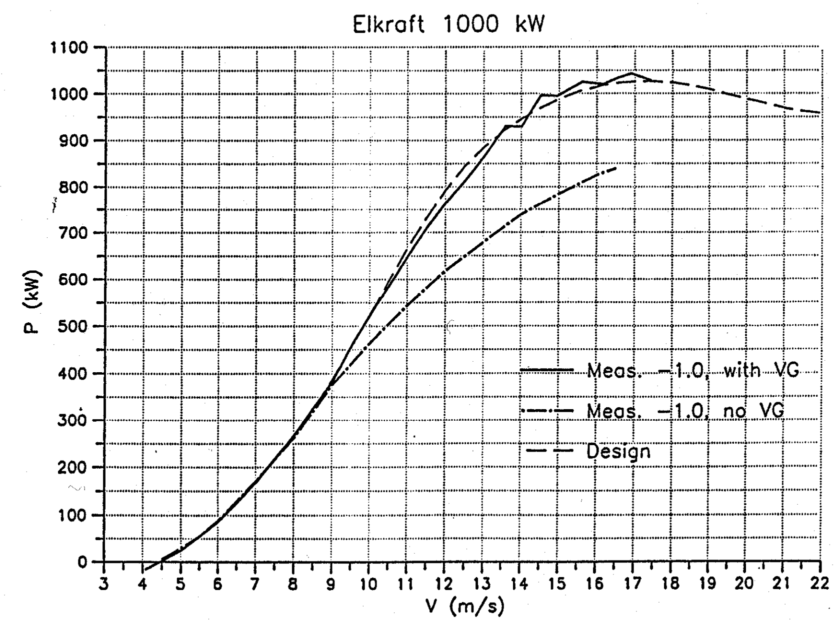
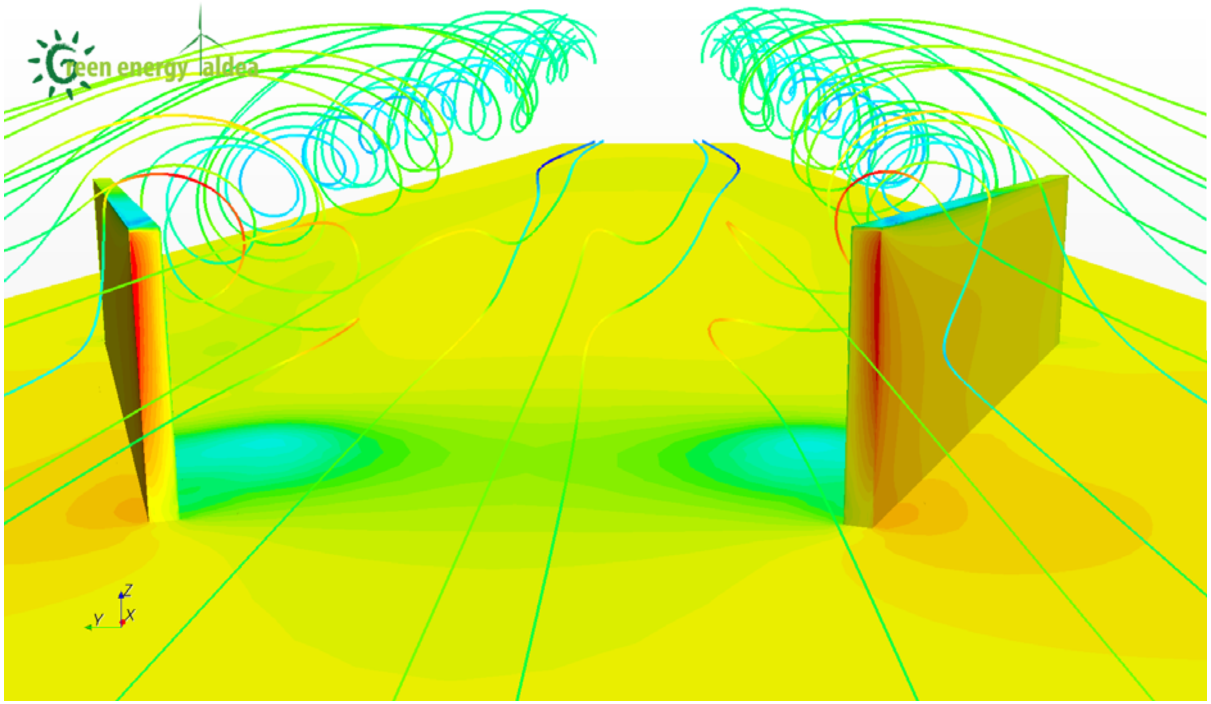
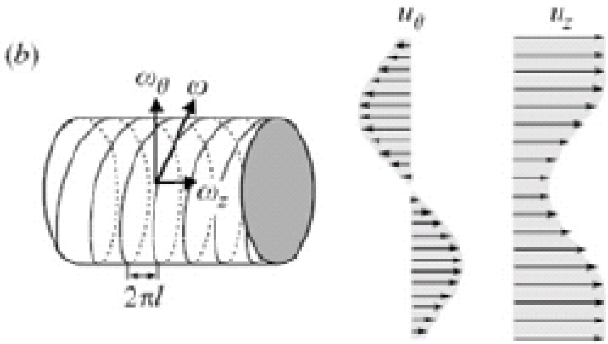


Figure 6 (b): Effects of VGs on a 1 MW wind turbine performance.

Ref.: S. Øye, The effect of Vortex Generators on the performance of the ELKRAFT 1000 kW Turbine, 9th IEA Symp. On Aerodynamics of Wind Turbines, 1995.

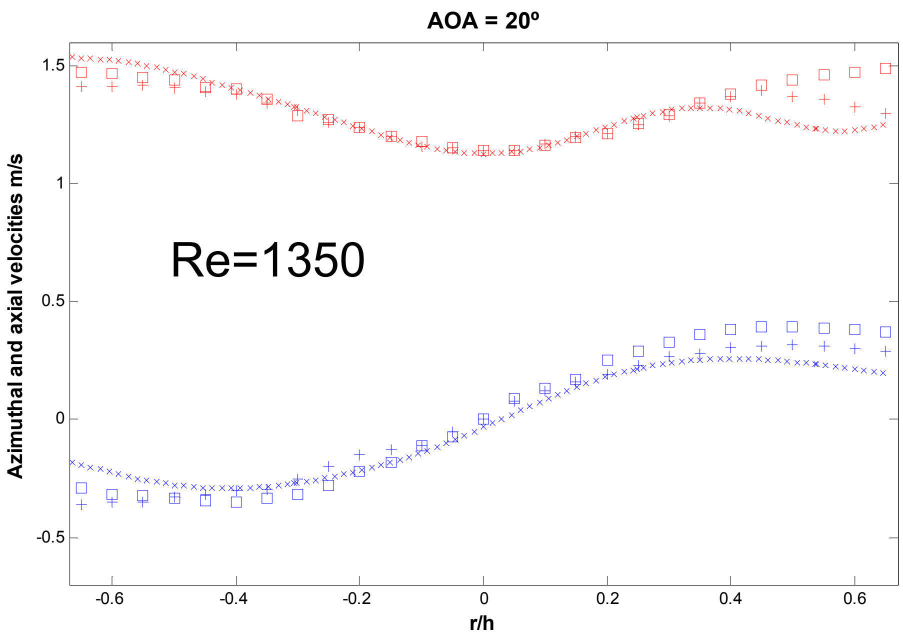
Analytical Model





* Analytical Model Velte et al. Helical structure of longitudinal vortices embedded in turbulent wall-bounded flow, J. Fluid Mech., 2009.

COMPARISON: Velocity Profiles



□ Analitical Model
X Exp
+ CFD

* U. Fernández[1] , P.-E. Réthoré[2], N. N. Sørensen[2] , Clara M. Velte[3] , F. Zahle[2] and E. Egusquiza[4] . PARAMETRIC STUDY OF THE DEVICE ANGLE DEPENDENCY OF A SINGLE VORTEX GENERATOR ON A FLAT PLATE. World Congress on Computational Mechanics 2012 Sao Paulo.

$$u_\theta(r,\theta,z)=\frac{\Gamma(z)}{2\pi r}\left[1-\exp\left(-\frac{r^2}{\varepsilon^2(\theta,z)}\right)\right];$$

$$u_z(r,\theta,z)=u_0(z)-\frac{\Gamma(z)}{2\pi l(\theta,z)}\left[1-\exp\left(-\frac{r^2}{\varepsilon^2(\theta,z)}\right)\right]$$

Together with the Batchelor vortex model four parameters:

ε(Θ,z), circulation *Γ(z)*,

$u_0(z)$ and *l(Θ,z)*

- Analytical Model Velte et al. Helical structure of longitudinal vortices embedded in turbulent wall-bounded flow, J. Fluid Mech., 2009

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CFD results of vortex evolution.

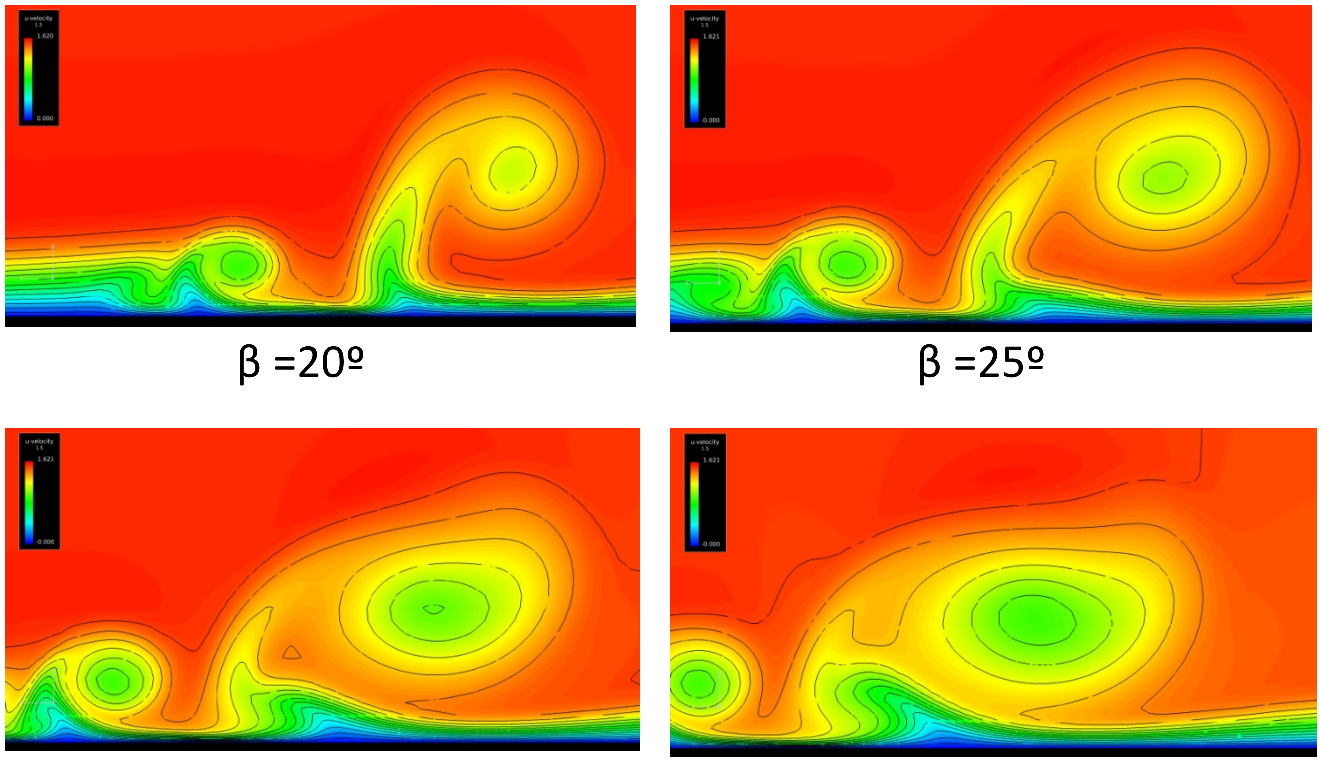

Fig.: CFD results of vortex development downstream the VG with four different angles of attack.

* Martinez-Filgueira et al. Parametric study of low-profile vortex generators
Article in International Journal of Hydrogen Energy · April 2017

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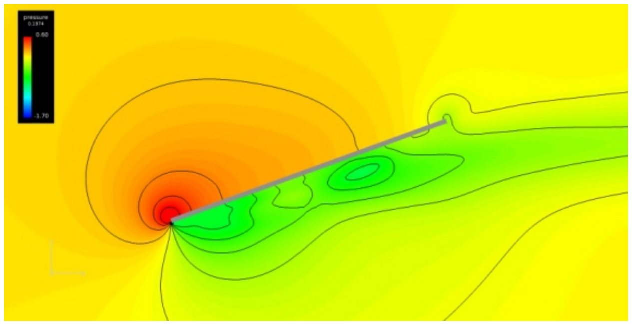
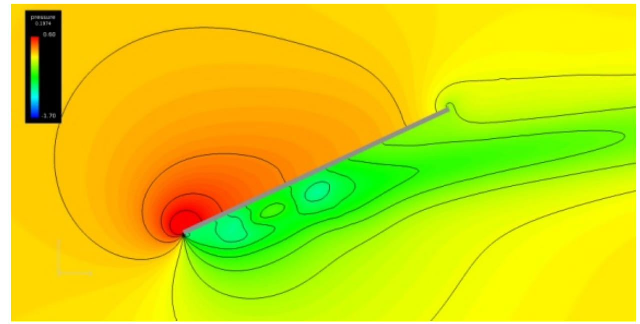
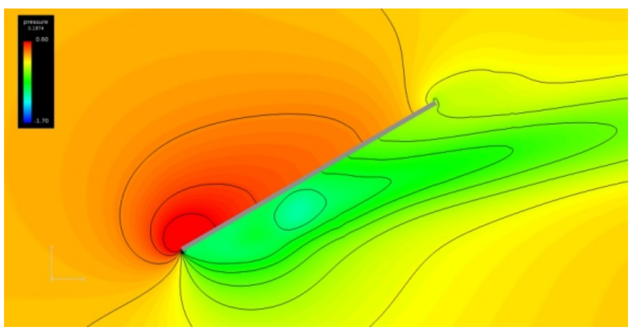
CFD results of vortex evolution.



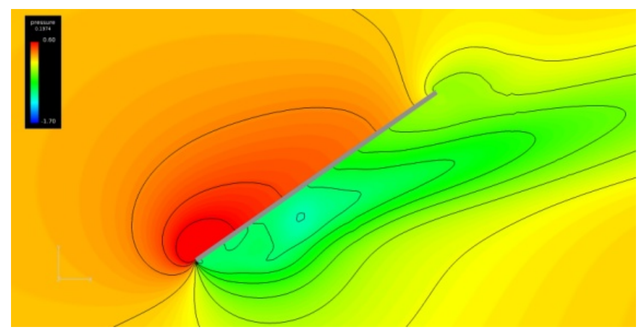
β =20º



β =25º



β =30º



β =35º

Fig. 7.3 Top view of the VG with four different angles of attack.

Actuator VG Model.

- **<u>Objective</u>**: The implementation of the BAY model into the StarCCM+ CFD code.
- **BAY Model** (founders: Bender-Anderson-Yagle 1999).

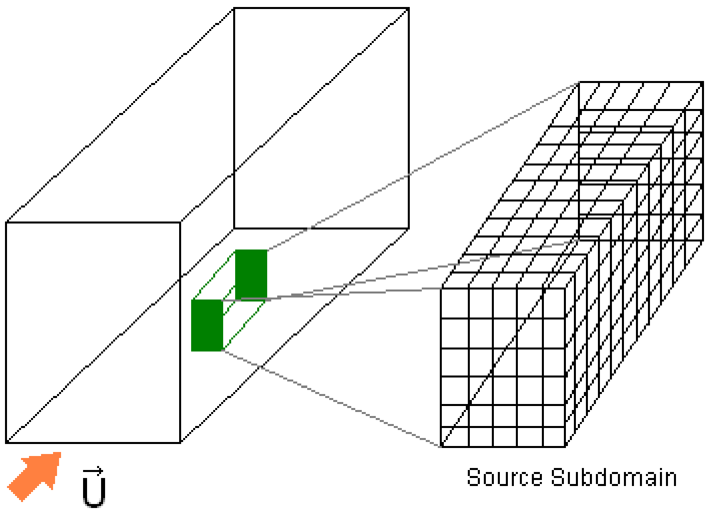
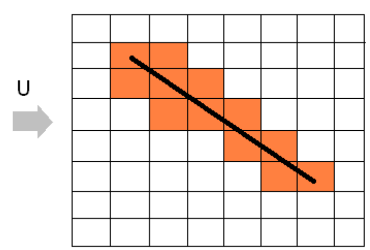


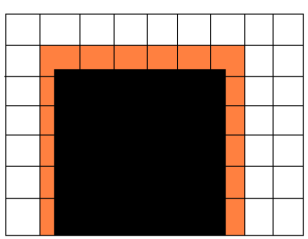
Fig. 5.5: BAY model source subdomain.

$$V_i \frac{\Delta(\rho \vec{U})}{\Delta t} = \sum_j F_{Mj} S_j + L_i$$

$$V_i \frac{\Delta(\rho E)_i}{\Delta t} = \sum_j F_{Ej} S_j + L_i$$

$$L_i = c_{VG} \cdot S_{VG} \cdot \left(v_i \Big/ \sum_j v_i \right) \cdot \alpha \cdot \rho \cdot U^2 \cdot \hat{l}$$





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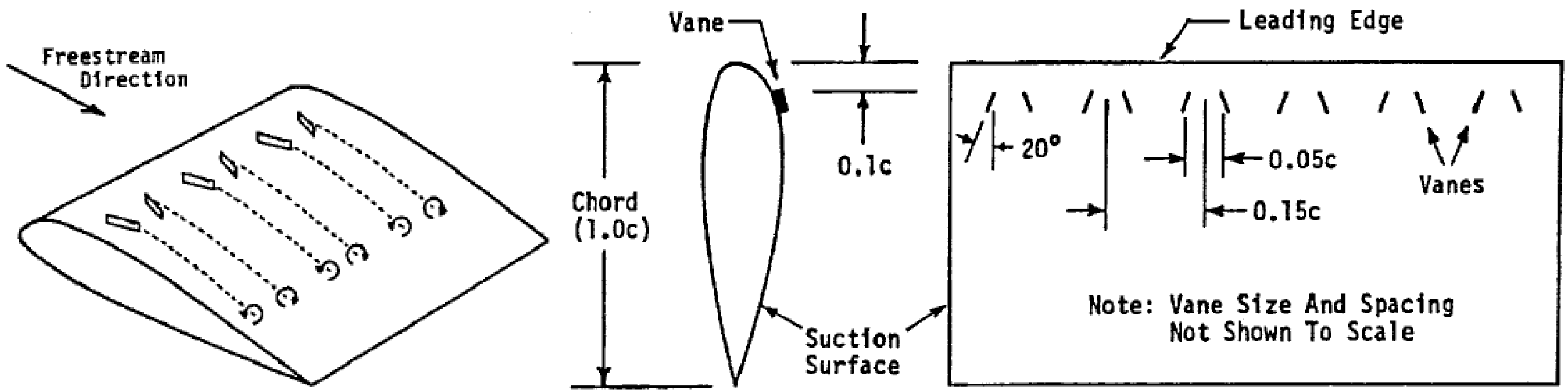
Pros and Cons of VGs

- Pros
  - Efficient
  - Easy and fast practical implementation
  - Inexpensive
  - Can be integrated part of blade design
  - Can also be applied as retrofits to improve existing designs
- Cons
  - ‘Small’ parasitic drag
  - Require detailed understanding to be applied correctly
  - Need to be optimized for every specific flow/geometry

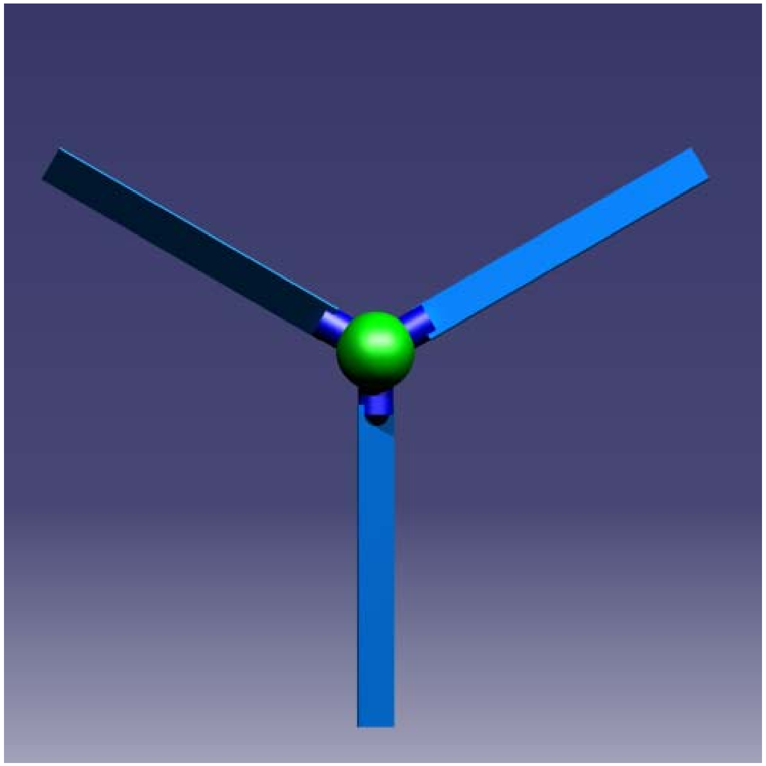
Parametric studies

- Requires (some) knowledge about the base flow
- VG cascade geometry optimization
  - Many degrees of freedom (angle, interspacing, orientation, height, length...)
  - Very important for VG performance
- VG row positioning on blade
  - Cord/span
  - Aeroelasticity considerations



*Ref.: Miller 1995

FULL-ROTOR Simulations



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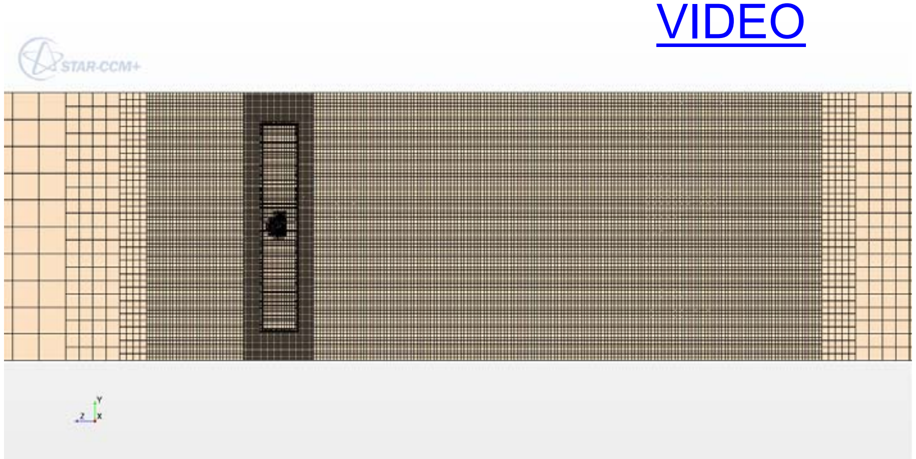
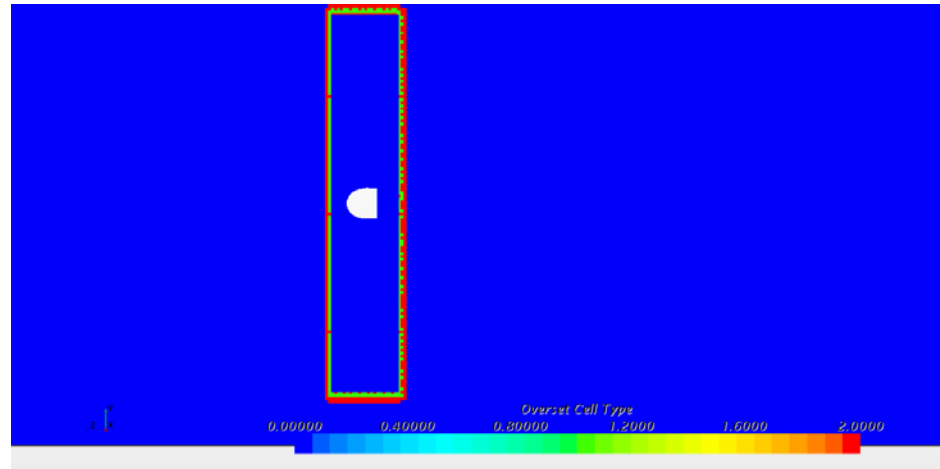
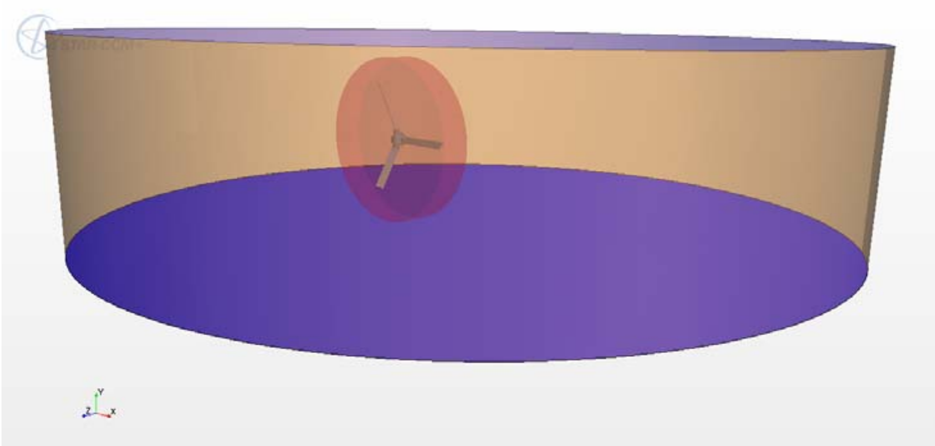
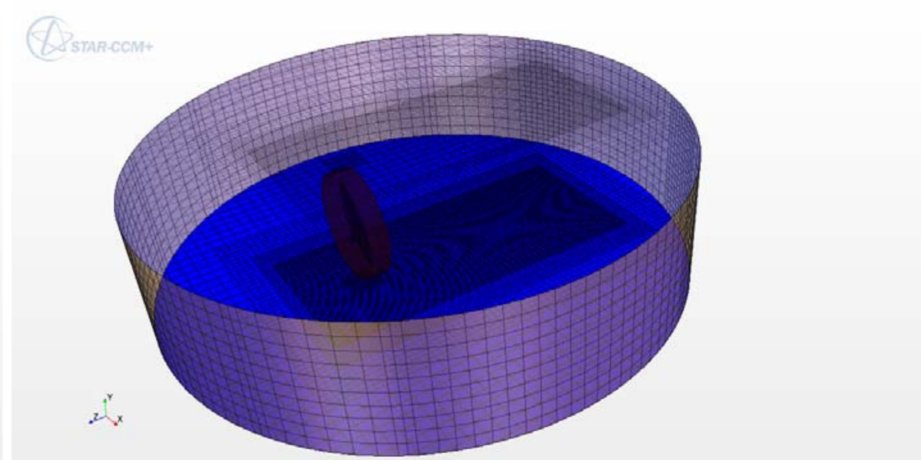
COMPUTATIONAL DOMAIN

VIDEO



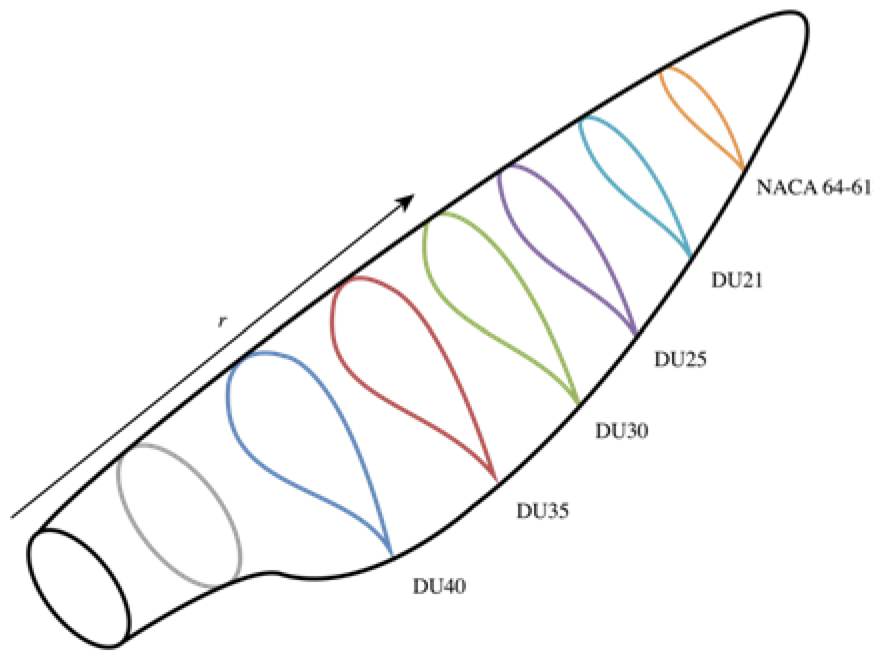


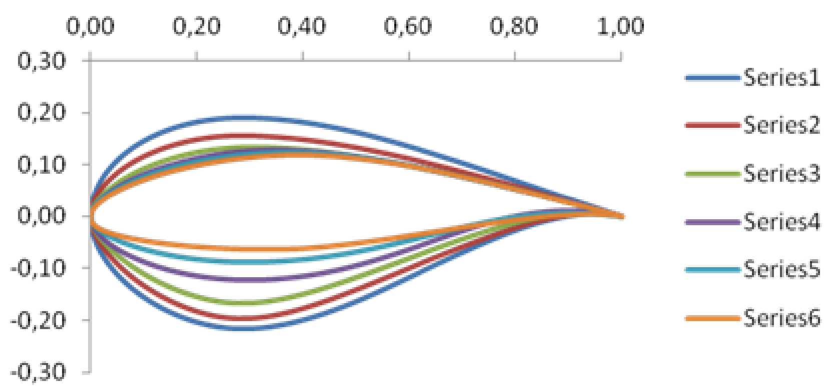




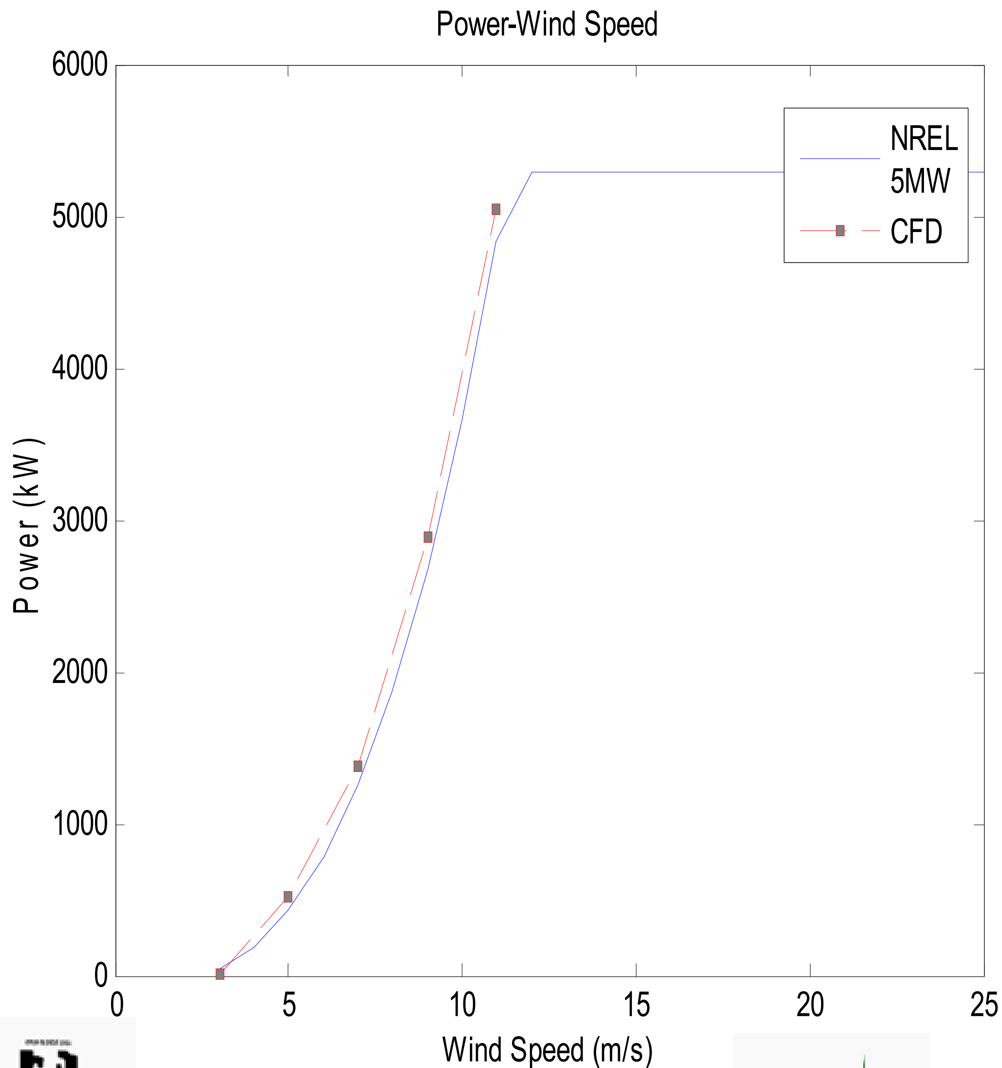
NREL 5MW Ref. Wind Turbine

STATION	RNodes	Airfoil
1	2.8667	Cylinder1
2	5.6000	Cylinder1
3	8.3333	Cylinder2
4	11.7500	DU40
5	15.8500	DU35
6	19.9500	DU35
7	24.0500	DU97W300
8	**28.1500**	**DU91W(2)250**
9	**32.2500**	**DU91W(2)250**
10	36.3500	DU93W210
11	40.4500	DU93W210
12	44.5500	NACA64XX
13	48.6500	NACA64XX
14	52.7500	NACA64XX
15	56.1667	NACA64XX
16	58.9000	NACA64XX
17	61.6333	NACA64XX





Obtención de la curva P-v

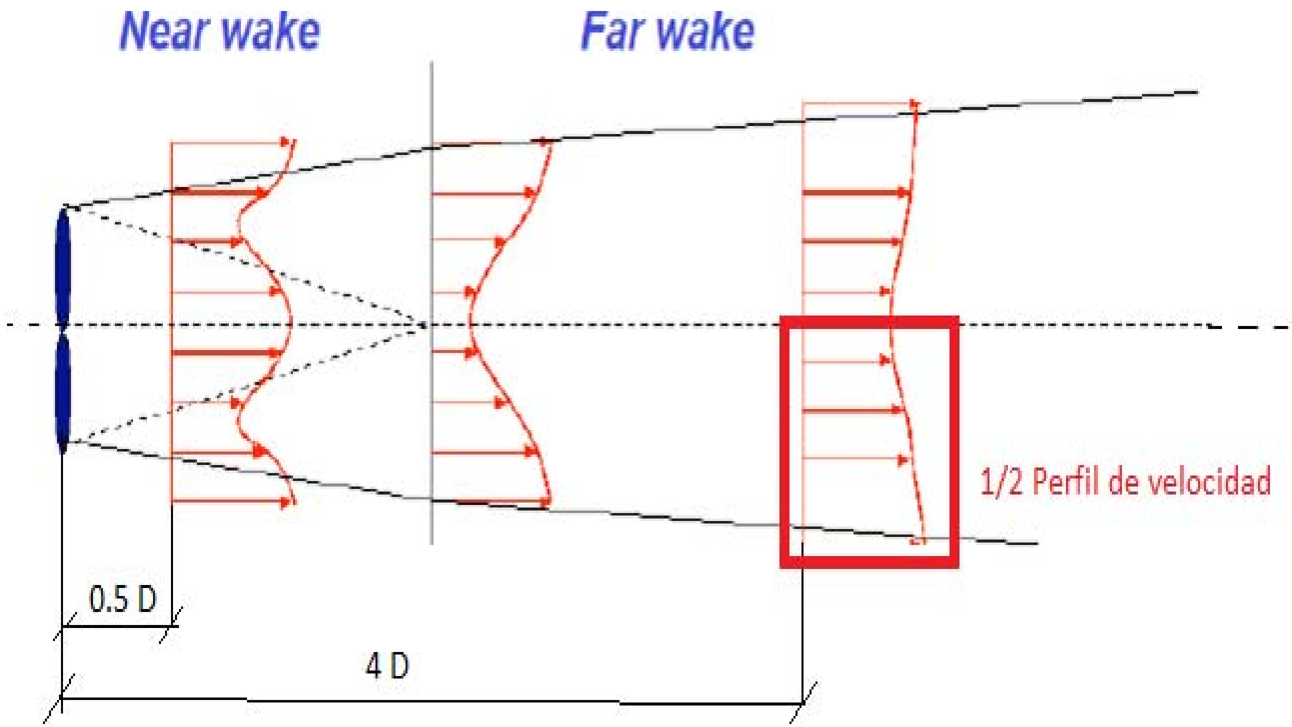


*Choya et al. ECRES 2017Istambul 2016.

*J. Jonkman, S. Butterfield, W. Musial and G. Scott, "Definition of a 5 - MW reference wind turbine for offshore system development"

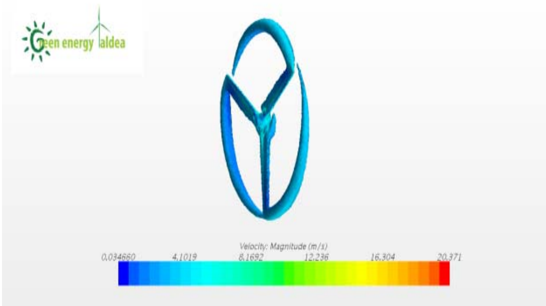
U_∞	Potencia prevista (kW)[3]	Potencia obtenida (kw)	Error relativo (%)
3 m/s	42.9	7.5	-82.52
5 m/s	427.9	518.1	21.1
7 m/s	1257.6	1380.5	9.77
9 m/s	2668	2887	8.21
11 m/s	4833.2	5036.4	4.2

Perfil de velocidades en la estela[4]



[4]M. L. Aitken, "Wind turbine wake characterization with optical remote sensing and computational fluid dynamics".

Análisis Cualitativo-Estela



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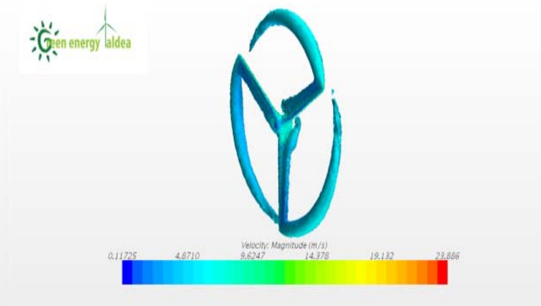
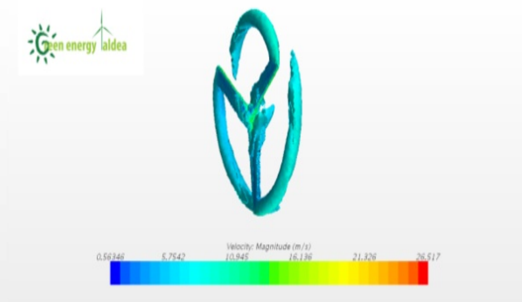
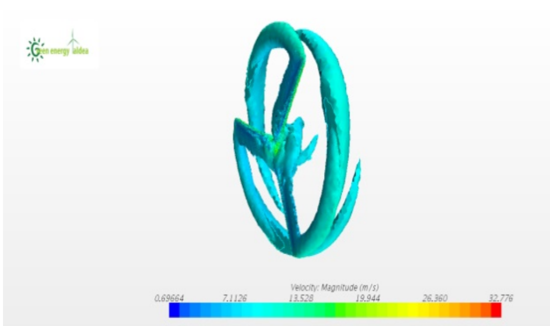


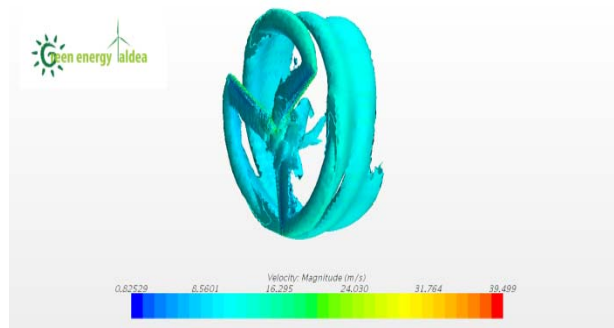
5 m/s



7 m/s



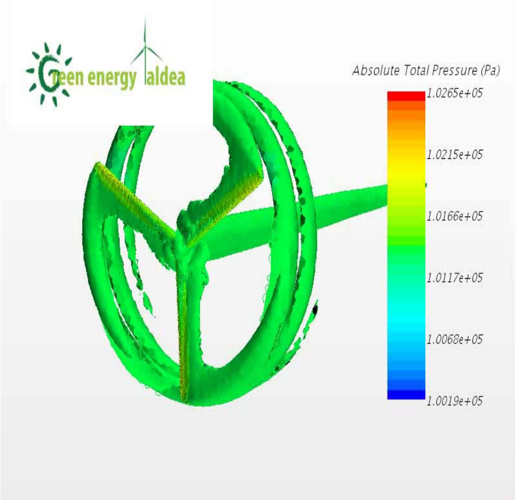
9 m/s



11 m/s

Isovorticity=0.2675/s

Subjects for colaboration:



1. Moving Flaps (Rigid).
2. Flexible flaps.
3. Serrated T.E. 3D
4. Innovative geometries of VGs.
5. Gurney flaps (Size Parametric study).
6. 5MW Wind Turbine: Full rotor computations.
7. VG effects on an DU airfoil.
8. BAY model implementation in OpenFoam (C++).
9. 2D active MTs – Control loop for CL/CD max

Eskerrik asko zuen arretagatik!
Dėkojame už Jūsų dėmesio
¡Muchas Gracias por vuestra atención!

eman ta zabal zazu

Universidad del País Vasco
Euskal Herriko Unibertsitatea

Green energy aldea