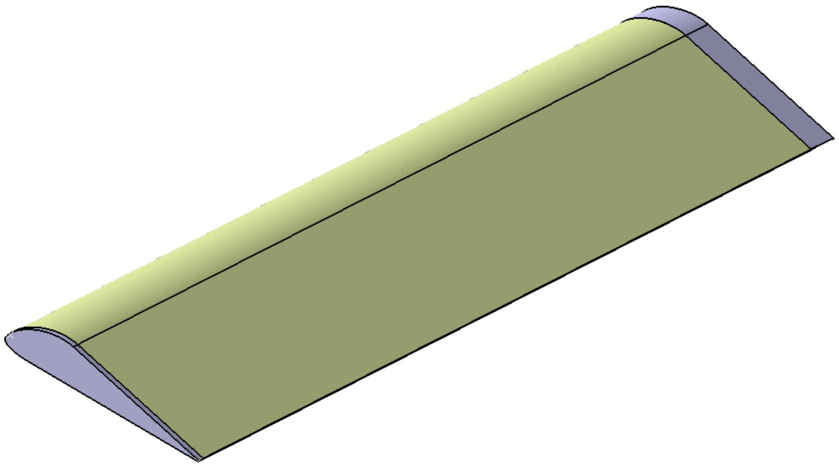
julie.piquee@aer.mw.tum.de

ANALYSIS OF SAILWING CONCEPT FOR WIND TURBINES



J. Piquee, B. Beguin, C. Breitsamter

Fakultät für Maschinenwesen

Lehrstuhl für Aerodynamik
und Strömungsmechanik

julie.piquee@aer.mw.tum.de

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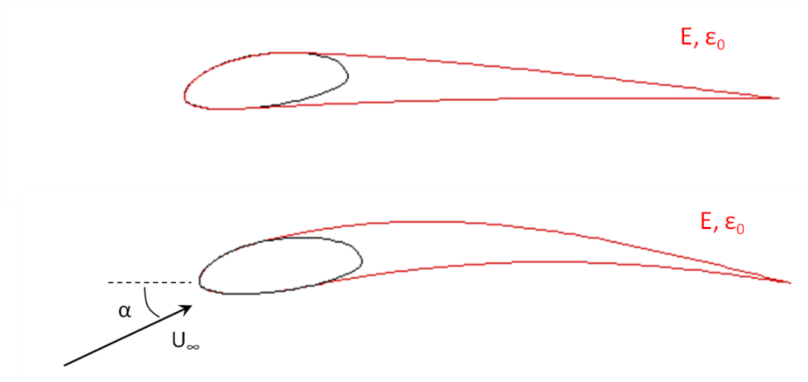
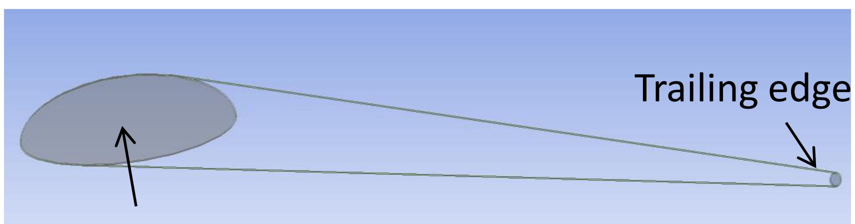
○ Description of the Sailwing Concept



- Rigid leading- and trealing-edge spar as inner structure
- Flexible membrane wrapped around the structure – surface passively adaptable to varying flow conditions



Fluid-Structure Interaction

Pressure distribution
+
Membrane deformation distribution

Passive flow control ?
Advantages ?

○ Challenge in energy supply

The "Erneuerbare Energie Gesetz" (20.12.2012) concerning the use of renewable energy for the electricity production in Germany :

80% produced in 2050 by natural resources

Expansion of wind energy activity

Wishes to reduce production costs for a wind turbine/ to produce more efficient wind turbine

- Diminution of structural loads (bending, torsion, fatigue)
- Material choices
- New technologies (passive or active)

Analysis of the effects produced by the use of a Sailwing on a wind turbine → Does the sailwing propose advantages compared to a normal wing?

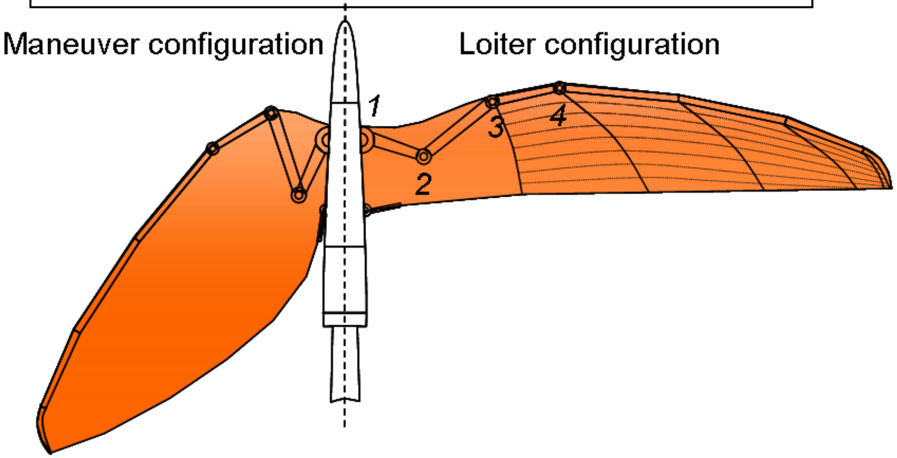
○ Background: Elasto-flexible morphing wing [1]

Motivation

- Analysis of the change of the geometry
- Analysis of the deformation of the pre-stressed membrane

What are the effects on the performance?

1st source Inspiration: Pterosaur wing



Aerodynamic surface passively adapts to varying flow conditions

Experimental model

- Force measurements (aerodynamical balance)
- Deformation measurements (3D photogrammetry)

[1] B. Béguin, C. Breitsamter, N. Adams, “Aerodynamic Investigations of a Morphing Membrane Wing”, AIAA Journal, Vol. 50, No. 11, 2012, pp. 2588 – 2599

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Geometry definition: Numerical investigation[1]

Input Parameters:
- Membrane elasticity
- Airfoil geometry
- Angle of attack, wind speed

↓

XFOIL : Pressure Distribution

↓

MATLAB : Membrane Deformation

↓

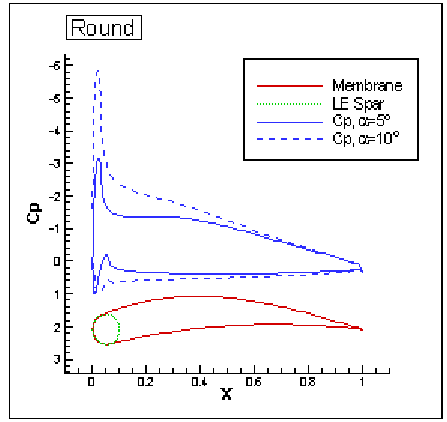
XFOIL : Pressure Distribution

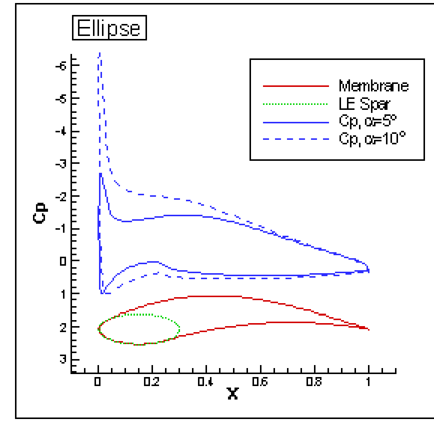
↓

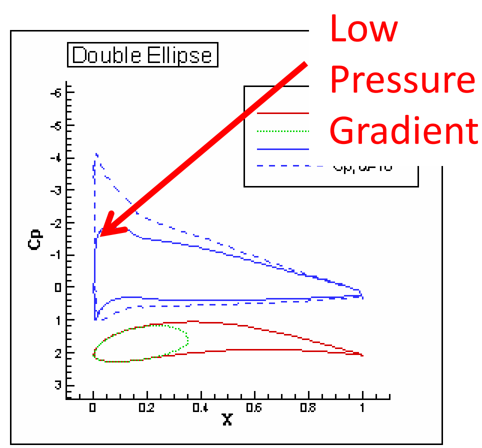
MATLAB : Convergence Check

NO → back to MATLAB : Membrane Deformation

YES → Final Deformation and Final Pressure



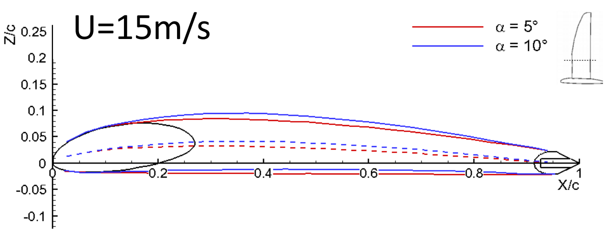


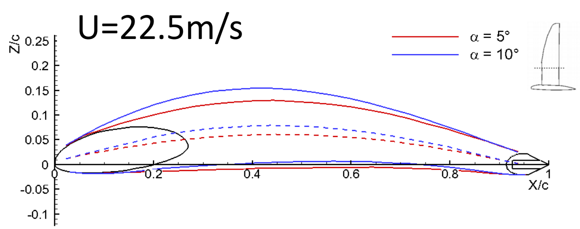


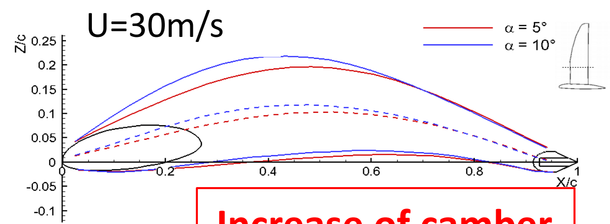
[1] B. Béguin, C. Breitsamter, N. Adams, “Aerodynamic Investigations of a Morphing Membrane Wing”, AIAA Journal, Vol. 50, No. 11, 2012, pp. 2588 – 2599

Membrane deflection at y/b = 0.3 for different free stream velocities[1]

- Averaged from 100 instantaneous measurements
- Membrane pre-strain approx. 7%



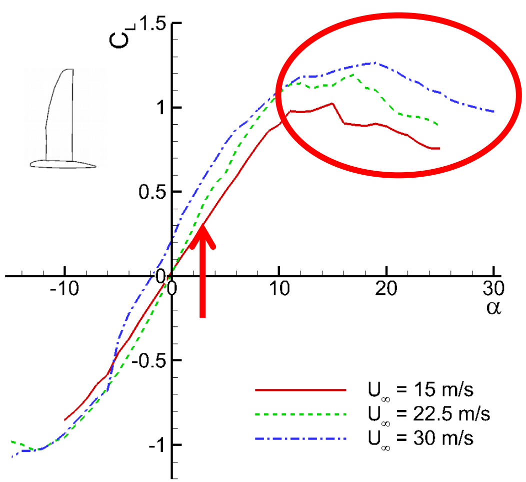


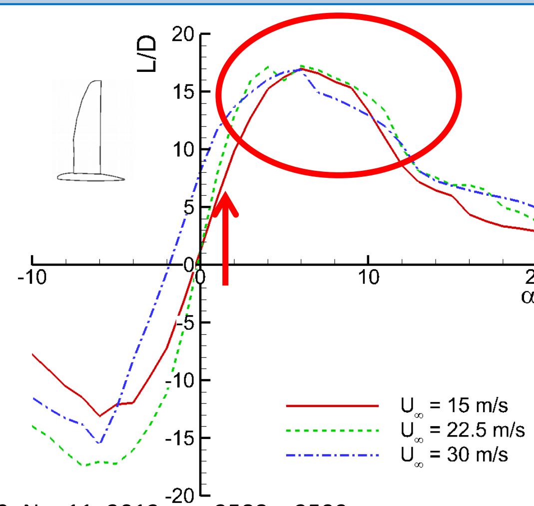


Increase of camber with free stream velocity

Aerodynamical characteristics[1]

- Effect of the passive camber adaptation to the flow condition leads to larger lift and smoother stall at large U_∞
- Similar $(L/D)_{max}$ at all U_∞, but α-range shifted due to camber modifications



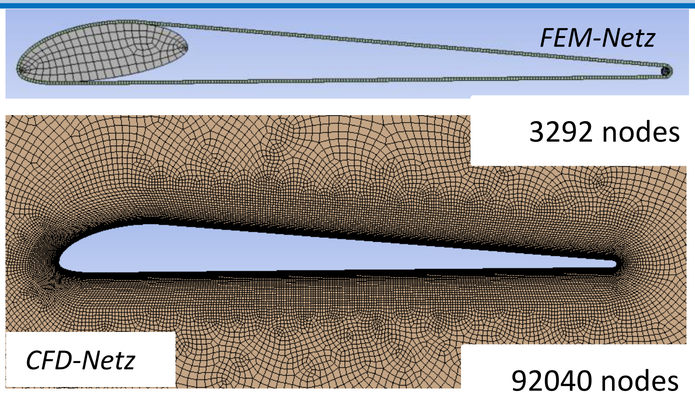


[1] B. Béguin, C. Breitsamter, N. Adams, “Aerodynamic Investigations of a Morphing Membrane Wing”, AIAA Journal, Vol. 50, No. 11, 2012, pp. 2588 – 2599

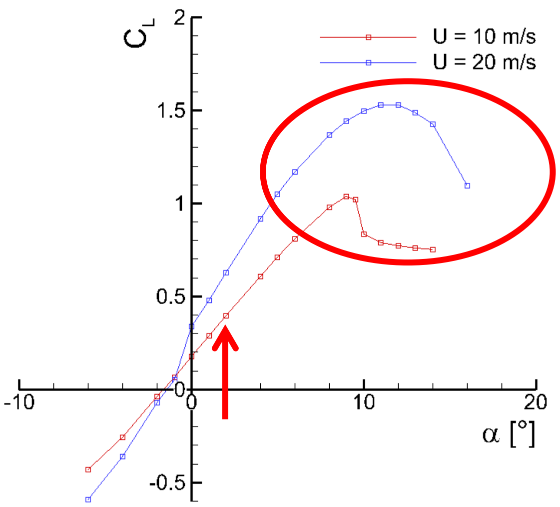
Numerical simulation (ANSYS)[2]

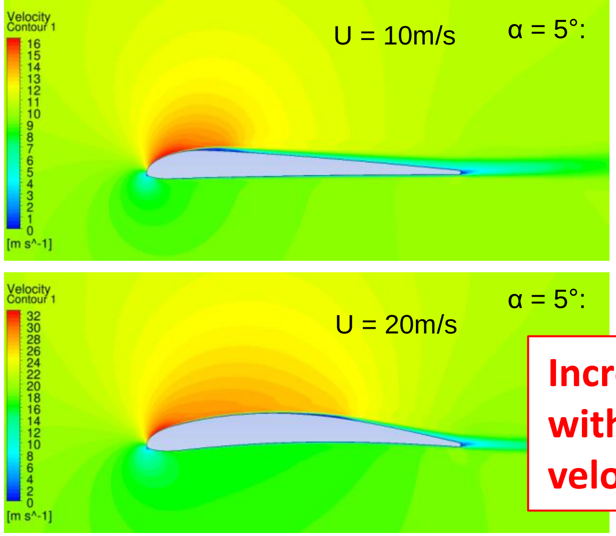
FEM coupled with CFD

- two-dimensional model
- membrane thickness 0.5 mm
- $Re_{cr} \approx 1.5{\cdot}10^5$ - $3 \cdot 10^5$
- SST turbulence model with γ-θ transition prediction model
- pre-strain: 7 %
- linear elastic material with E = 2.1 MPa



Lift characteristics:



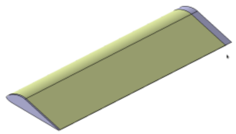


Increase of camber with free stream velocity

[2] Klaus Heller, Numerische Untersuchung des aerodynamischen Verhaltens eines elasto-flexiblen Membranprofils unter Böenlast, TU München, Semesterarbeit, 2013

julie.piquee@aer.mw.tum.de

○ Adaptation to a Wind Turbine



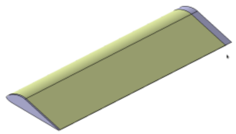
Analysis of the characteristics of a Sailwing adapted to a wind turbine

Princeton Windmill Programm (March 1973)

´Sailwing rotor continues to be highly competitive in performance with its rigid-bladed counterparts´[3]

[3]M.D. Maughmer, Optimization and Characteristics of Sailwing Windmill Rotor, Princeton University, Final report, 1976

○ Adaptation to a Wind Turbine



Analysis of the characteristics of a Sailwing adapted to a wind turbine

Choice of a material for the elasto-flexible membrane

Numerical investigations :

- Fluid Structure Interaction (CFD + FEM) (2D + 3D)
- Performance (Cp-Lambda curves)

Experimental investigations

- Force measurements
- Deformation measurements

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Performance comparison with AOC 15/50[4]

Important Data	
Rotor Diameter	15 m
Performance	50 kW
Rotation Speed	65 rpm
Wind Velocity	12 m/s
Type of wind turbine	Fixed pitch, Stall regulated

National Wind Technology Center,
Boulder, Colorado

[4] Christian Franzmann, Elasto-flexibel blade structures for wind turbines, TU München, Bachelorarbeit, 2012

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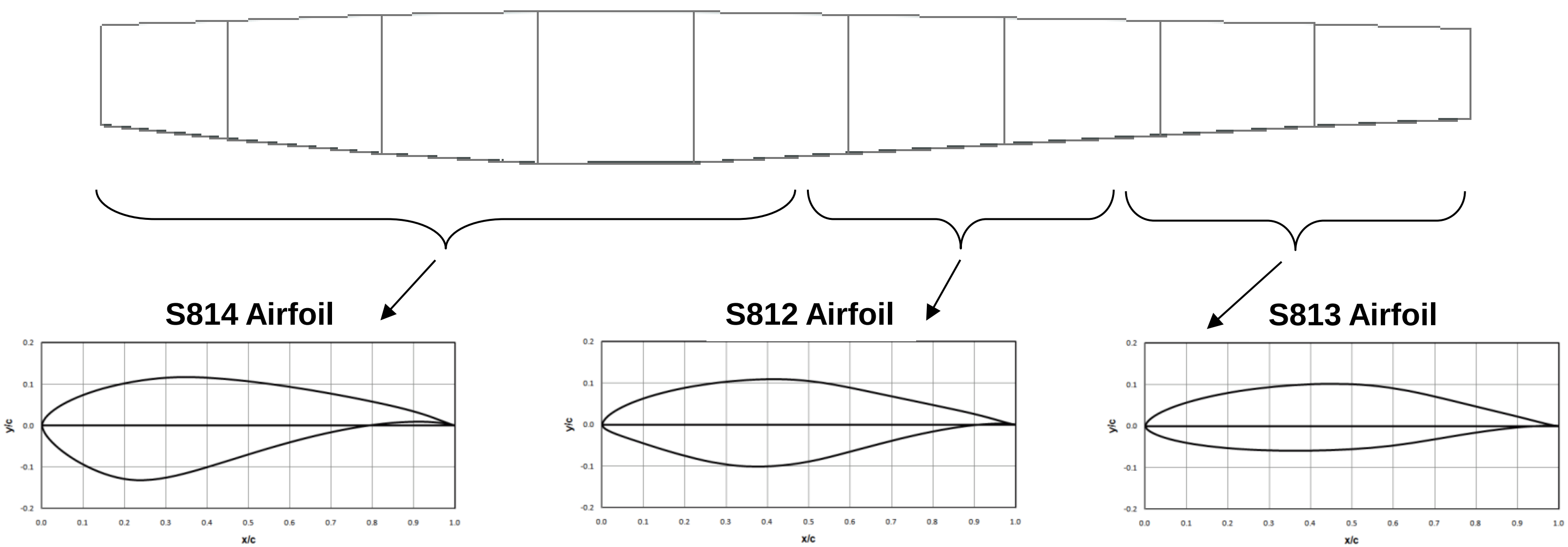
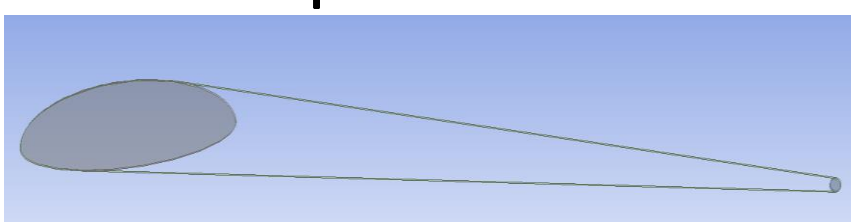
Performance comparison with AOC 15/50[4]

- **AOC 15/50: Distribution of profiles along the blade**



- **Formvariable profile**



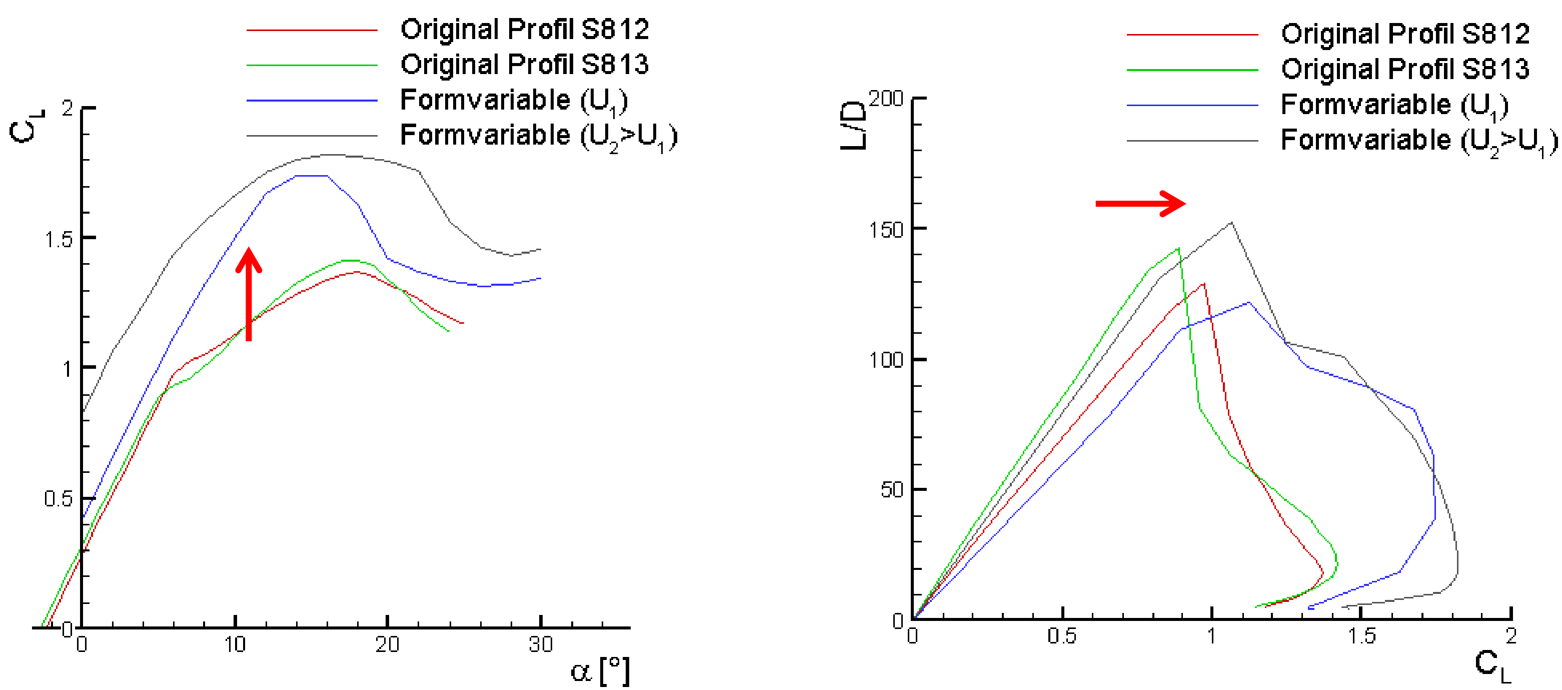
Mechanical properties of the membrane:
E = 2.1 Mpa
ρ = 500 kg/m³

Performance comparison with AOC 15/50[1]

- **Aerodynamical Properties :**

⟶ Lift for an angle of attack of 0° and maximal lift are higher

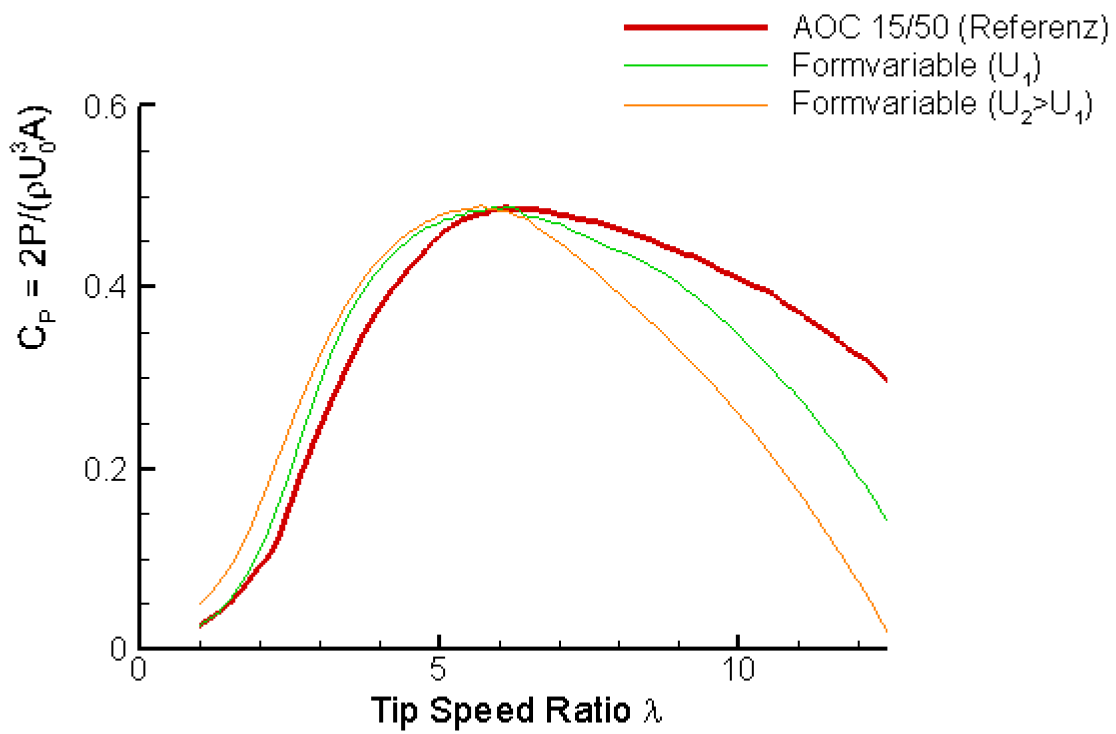
⟶ Shift of the lift/drag ratio to higher lift coefficient



[1] B. Béguin, C. Breitsamter, N. Adams, "Aerodynamic Investigations of a Morphing Membrane Wing", AIAA Journal, Vol. 50, No. 11, 2012, pp. 2588 – 2599

Performance comparison with AOC 15/50[1]

- **Power Coefficient Curve**



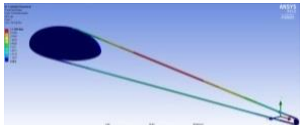
- Similar power coefficient at TSR=6

[1] B. Béguin, C. Breitsamter, N. Adams, "Aerodynamic Investigations of a Morphing Membrane Wing", AIAA Journal, Vol. 50, No. 11, 2012, pp. 2588 – 2599

Sailwing concept for Wind Turbines : Summary and Next Steps

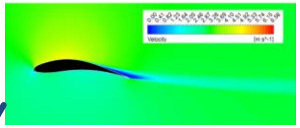
- Description of a Sailwing
- Background
  Elasto/flexibel morphing wing:
  - Geometry definition
  - Force and deformation measurements (capability of deflection -> higher lift coefficient and smoother stall region with higher free stream velocities)

Choice of material for the membrane

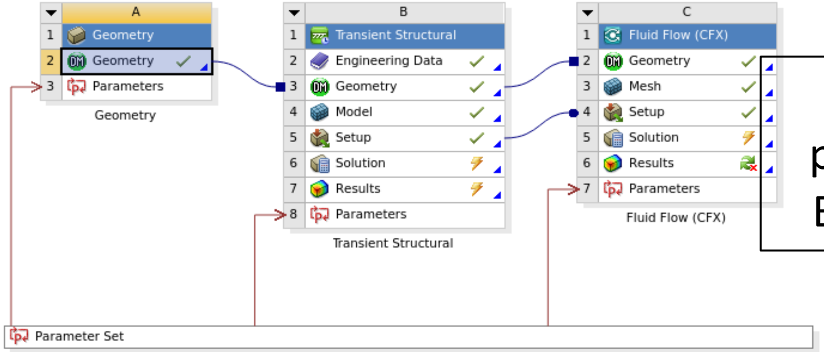


Experimental Analysis : Forces and deformation measurements with new model

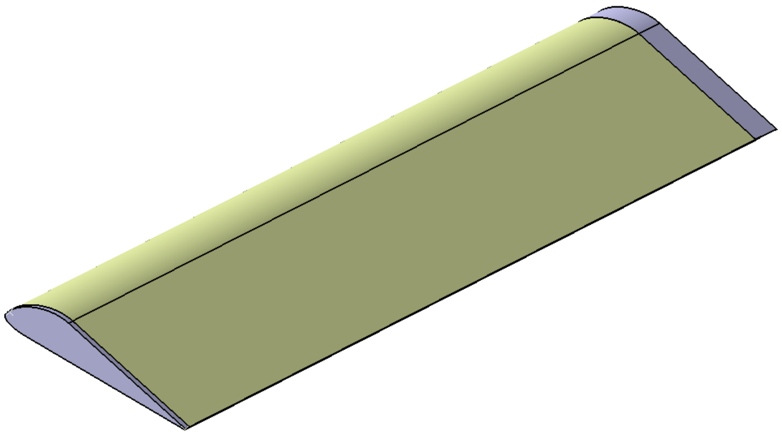
2D and 3D FSI Simulations : Modelisation of the concept



Evaluation of the performance of a Sailwing Blade and a Wind Turbine



SAILWING CONCEPT FOR WIND TURBINES



Thank you
for your
attention