INSTITUTE OF PHYSICS, ACADEMY OF SCIENCES OF THE CZECH REPUBLIC (CZ)

At ASCR modeling and characterizing of shape memory alloys. Measurements which were performed include:

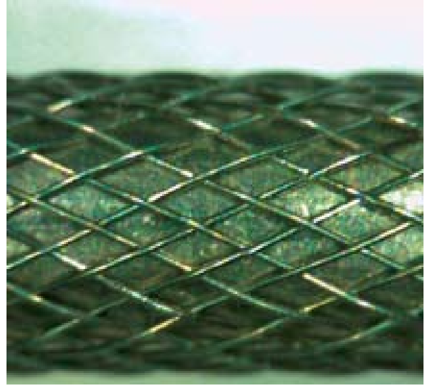
- Mechanical properties;
- In-situ electrical resistivity;
- Recovery stress tests;
- Fatigue properties.

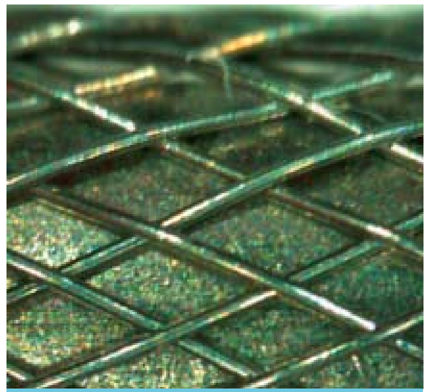
Furthermore, a new SMA-based actuator has been developed.

Such a wire architecture was designed in order to meet the requirements on fast cooling of the actuator allowing to increase response time and actuation frequency. The use of this actuator design leads to an increase of actuator surface and hence it improves the cooling by convection. The thermo-mechanical properties of the actuator will be tested at IT ACSR.

RESULTS AND EXPECTATIONS

The project will provide at least one working concept for dynamic load alleviation and increased aero-elastic damping of a turbine blade. The concept must be able to significantly control the loads and be a low maintenance solution. This will be demonstrated in at least two experiments: one with a rotating rotor model of about two meter diameter. The primary goal of this demonstrator is to show that the dynamic loads can actually be mitigated. A second, non-rotating, experiment will be conducted on a blade section that is of the same order of magnitude of a full sized blade section (in cord and thickness) and several meters wide. The goal of this demonstrator is to show that the integrated actuators can sufficiently change the aerodynamics around the section to achieve the performance on a full scale blade demonstrated in the rotating experiment. Beside this, several experiments will be conducted on noise and the smart blade-hub coupling and aero-elastic models of blades and turbines with load control will be developed. For now, the partners have chosen to focus on trailing edge flaps and camber control as aerodynamic devices, as well as bend-twist coupling and the active blade-hub interface as other load alleviation devices.





Picture (top) and close-up (bottom) of a novel SMA-wire actuator.

UpWind

SIXTH FRAMEWORK PROGRAMME

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- Risø National Laboratory – Technical University of Denmark (DTU)
- Energy Research Centre of the Netherlands (ECN)
- SWE University of Stuttgart
- LM Glasfiber A.S.
- Fundación Robotiker
- Technical Research Centre of Finland (VTT)
- Instytut Podstawowych Problemow Techniki (IPPT)
- Institute of Physics, Academy of Sciences of the Czech Republic

Photography: EWEA - Vestas

Smart rotor blades and rotor control

THE CHALLENGE

Almost all loads on the components of the wind turbine are derived from the loads at the rotor blades. Therefore it is very important to keep these loads as low as possible and to control them as much as possible.

Modern rotor control technology has its limitations: only the rotor speed, and the pitch angle of the blades can be varied. With the increasing size, the local angle of attack of the blade may vary considerably because of the effect of varying wind speeds along the blade due to turbulence, wind shear and other effects. So, for large blades it does not make sense to pitch the blade as one single rigid piece as has been the case until now. A much more detailed control is necessary to alleviate blade loads, to control them at any moment and any position in the rotor plan, and to add aerodynamic damping when necessary. To achieve this, the blades will be equipped with aerodynamic control devices distributed along the span of the blade. Airplanes have similar devices: the flaps at the wings.

The specific objectives are to obtain lower loads and to improve stability. The stepping stones towards a full concept are to:

- establish the potential of embedded control by aerodynamic/aero elastic analysis;
- specify the requirements of the sensors, actuators and control equipment, to select the most promising options and verify them by means of component-prototypes;
- develop and verify design codes (models) for the aerodynamic & control aspects of composite structures including smart materials;
- verify the load alleviation and increased stability by wind tunnel experiments;
- verify the robustness of the construction, by the design and the construction of a representative part of a blade;
- verify the aerodynamic performance of this blade section by non-rotating tests in a wind tunnel.

This R&D programme builds on many disciplines. These include aerodynamics and aero-acoustics, adaptive materials and dynamics and control. As such, this programme constitutes an integrating, multi-disciplinary approach.

An additional challenge is to develop the technology which needs to be maintenance-free, extremely reliable during a very long time, and low cost.

UpWind

WP1A1
WP1A2
WP1A3
WP1B1
WP1B2
WP1B3
WP1B4
WP2
WP3
WP4
WP5
WP6
WP7
WP8
WP9

THE RESEARCH ACTIVITIES

The research activities are being carried out by eight different institutions, each with a specific task based on their specific scientific skills.

DELFT UNIVERSITY OF TECHNOLOGY (NL). AERODYNAMIC LOAD CONTROL EXPERIMENTS, AERO-ELASTIC MODELLING AND ACTUATOR DESIGN.

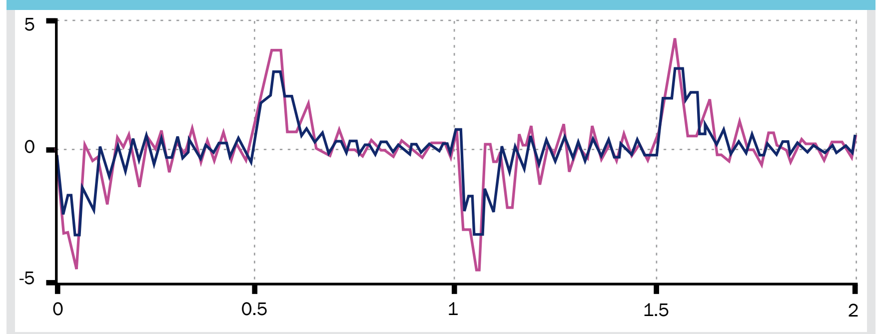
In order to realistically evaluate the potential for load reduction and benchmark design concepts, first order wind tunnel experiments have been performed. The design of the blade was performed within several strict design constraints: high strength, low eigen-frequency and limited geometric possibilities (thin aerodynamic profile). The blade was constructed out of glass fiber reinforced epoxy (GFRP) because this would allow for precise tuning of the mechanical properties. The blade was equipped with piezo electric activated continuously deforming trailing edge flaps in the outboard section and active feedback control was applied for the alleviation of fluctuating loads. It has been shown that strains on the blade root induced by dynamically scaled excitations can been considerably reduced by applying feedback control on the flaps motion. This comprises a novel result in feedback control, which provided necessary knowledge for future experiments on actually rotating model rotors.

Test set-up of the load mitigation experiment at TUDelft.

Models able to evaluate the potential for load reduction in smart rotor control have been developed. The aero-servo-elastic model, which was developed, serves as a prediction tool, but also as a controller design platform.

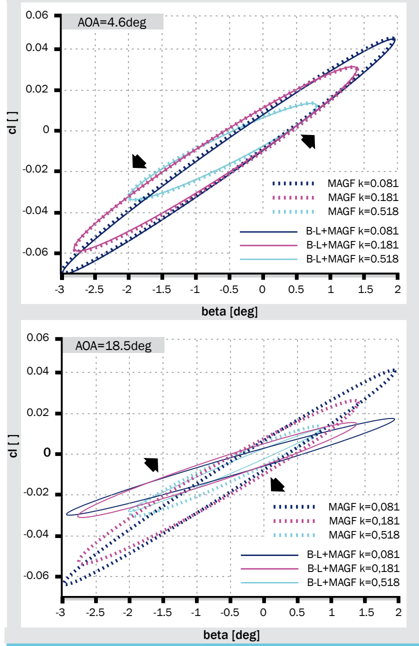
In establishing a knowledge base, an evaluation of the available adaptive materials was performed. Adaptive materials in this case are described as materials which show a mechanical response under a non-mechanical stimulus, and can thus act as embedded actuators. Shape memory alloys (SMA) and piezo electric materials are identified as the adaptive materials with most potential.

Strain at the root of the blade as a result of a step on the angle of attack.
When comparing the response with feedback control (blue line) to the one without control (red line), a lower peak and faster decay of the vibrations can be observed with control.



RISØ NATIONAL LABORATORY (DK). AERODYNAMIC MODELS FOR AEROFOILS WITH DEFORMABLE CAMBER

At Risø, modelling as well as experiments into the unsteady aerodynamics for aerofoils with adaptive camber lines, has been performed. The most recent work performed has been on the performance of airfoils with deformable trailing edges with trailing edge separation. The results were compared with previous experiments.



ΔCL loops as function of β for AOA at 4.6° (left) and 18.5° (right). The trailing edge deflection β ranges from -3° to 1.97° for reduced frequency k=ωc/(2Uo)=0.081, for β= -2.8° to 1.3° the k=ωc/(2Uo)=0.181 and finally for β = -2° to 0.76° the k=ωc/(2Uo)=0.518.
Arrows indicate the orientation of the loops in time.

ENERGY RESEARCH CENTRE OF THE NETHERLANDS -ECN (NL). SYNTHETIC JETS

ECN focuses on the aerodynamic performance of synthetic jets and assists in the aero-elastic modelling of turbines. With synthetic jets, air is sucked in, and blown out at the blade's surface at a very high rate. This creates an obstruction for the flow in the boundary layer which is jetted away from the surface, thus changing the circulation and thus the lift, for a low drag penalty.

UNIVERSITY OF STUTTGART (D)

At the University of Stuttgart two separate branches of research are conducted. At the Endowed Chair of Wind Energy (SWE), the feasibility of a bend-twist coupled blade is researched and at the Institute of Aerodynamics and Gas Dynamics (IAG) the noise generated by aerofoils with both rigid flaps and deformable camber line are being researched, as well as the quality of the boundary layer. The first results on noise indicate that there is little difference between the two.

FUNDACIÓN ROBOTIKER (E)

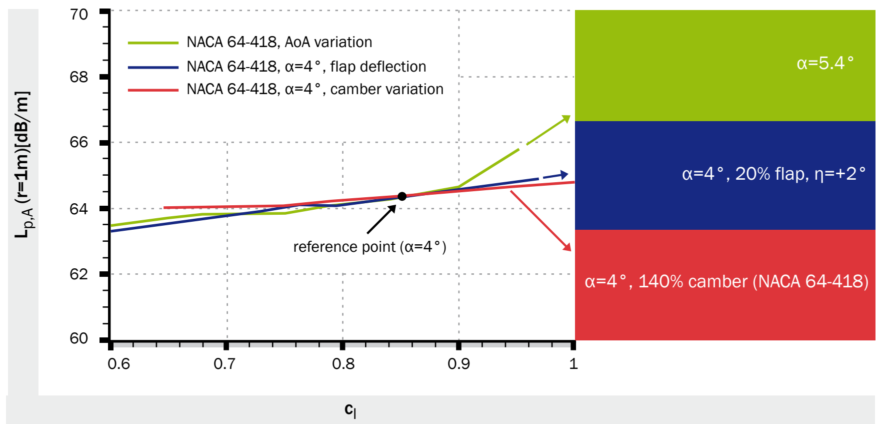
Fundación Robotiker develops and analyses control concepts and sensors. In the first phase of the activities an overview of the different available sensor systems and considerations has been made.

VTT TECHNICAL RESEARCH CENTRE OF FINLAND (SF)

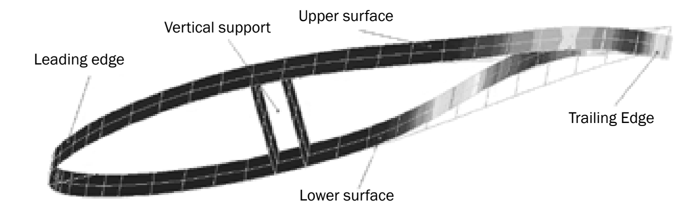
At VTT the continuous deformable camber line concept is being implemented in an aerofoil that is actuated by embedded shape memory alloy wires.
An adaptive wing profile was designed, manufactured and tested. New tools for designing and manufacturing of SMA actuated FRP composite structures were developed and demonstrated. The performance of the system was measured in laboratory conditions and also in wind tunnel. The developed control system works accurately enough for the shape control purpose of the airfoil in laboratory conditions. The changes in lift obtained are very large.

INSTYTUT PODSTAWOWYCH PROBLEMOW TECHNIKI -PAN (PL)

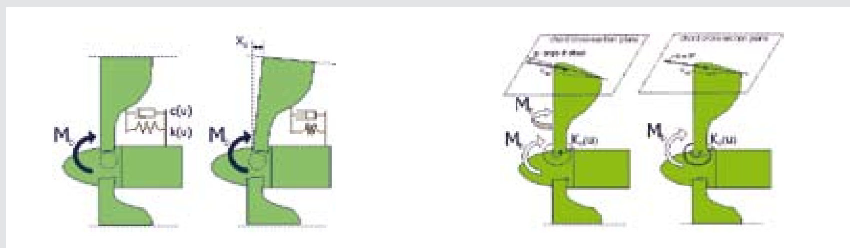
At IPPT a smart blade-hub interface is being researched. The first aim was to obtain a concept whereby the blade would alleviate peaks in the root bending moment by allowing itself to tilt backwards when a gust hits. Later, a concept where the blade were allowed to pitch, thus changing the angle of attack and the aerodynamic loading, was added.



Noise generated by a baseline, a discretely rotated flap and a continuously deformable trailing edge flap (camber variation).



FE model and test set-up of a aerofoil with embedded SMA wire actuated camber control.



Active blade-hub interaction though tilting (left) or rotating the blade (right).
With the second, rotating is done around the longitudinal axis of the blade, changing the angle of attack. In both cases the stiffness of the interface is controlled.