SMART ROTOR BLADES & ROTOR CONTROL

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SIXTH FRAMEWORK PROGRAMME

UpWind

Introduction –Presentation Outline

Introduction

- What is a "Smart Rotor"
- UpWind work package 1B3

Aerodynamic devices

- Concepts
- Ongoing work

Adaptive aerofoils / Integrated Structures

- Concepts
- Ongoing work

Sensors and control

Conclusions

Introduction –Smart Rotor Blades

Work package 1B3: Smart Rotor Blade for Wind Turbines

Goal:

Controlling the blade ṡ loading through active control of the aerodynamics with spanwise distributed devices

Why?

With increasing rotor size for (future) off-shore turbines will cause more fatigue issues:

- Mass effects
- Increasing fluctuations in flow field

Logical solution: use the aerodynamics to control these fluctuations

Introduction –Smart Rotor Blades

In order to be "Smart" one must sense, compute a reaction and react. For this accurate knowledge of the system (aerodynamics and structure) is needed.

So the issues/research areas are:

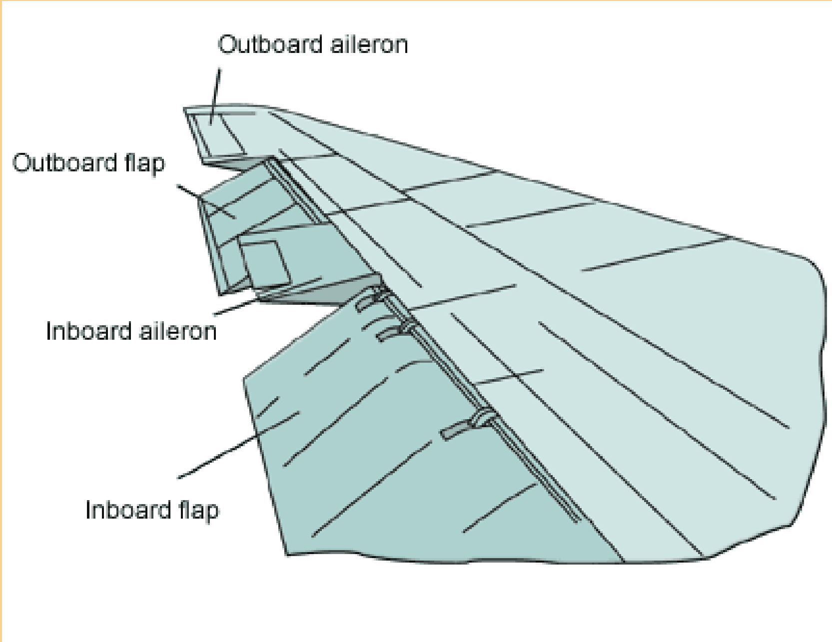
- Aerodynamics
- Structural integration/Actuators
- Sensing
- Control

Moreover, a integrated solution is wanted.

Introduction –Smart Rotor Blades

In other words

We want this control capability …



…without compromising the robustness of current blade technology

Introduction –UpWind WP 1B3

Work package 1B3: Smart Rotor Blade for Wind Turbines

Partners:

- Risø National Laboratory (DK)
- Energy research Centre of the Netherlands -ECN (NL)
- University of Stuttgart (D)
- LM Glasfiber A.S. (DK)
- Fundación Robotiker (E)
- VTT Technical Research Centre of Finland (SF)
- Instytut Podstawowych Problemow Techniki -PAN (PL)
- Institute of Physics, Academy of Sciences of the Czech Republic (CZ)

Aerodynamics

Requirements

- Significant change in C_L
- Little aerodynamic delay (related to control)
- Small power consumption
  (related to actuator possibilities)

Aerodynamics

Possibilities

Options often inspired by helicopter rotor research:

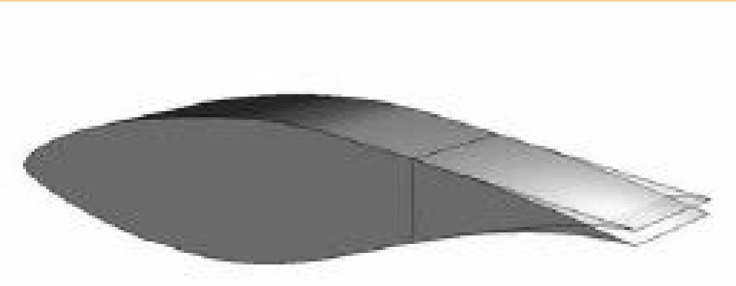
- Bend-twist coupling
- Individual pitch control (full and partial span)
- Trailing edge flaps
- Camber control
- Active blade twist
- Micro tabs
- Boundary layer control

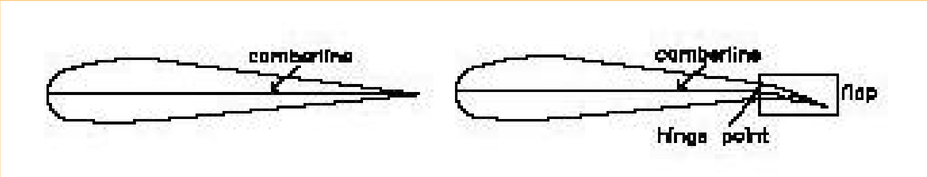
Many option are passive, too slow or require extremely large actuator power. Feasible candidates are…

Aerodynamics –state of the art

Trailing edge flaps and camber control

At Risø: Model and experiments into aerofoils with (partially) deformable camber:



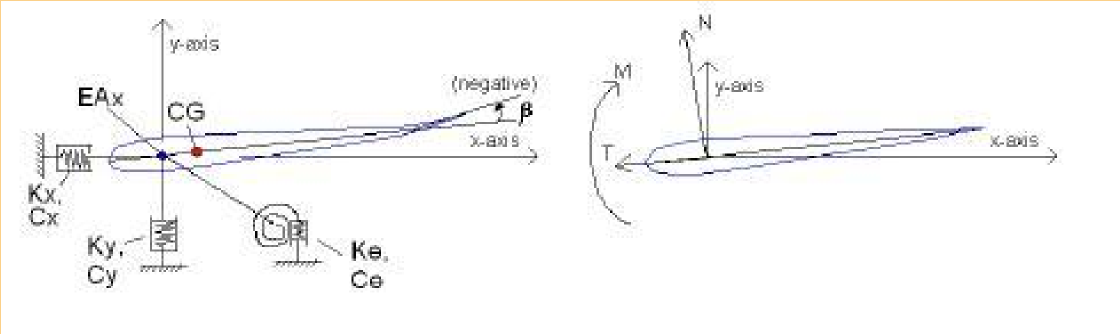


For wind turbines aft part: continuous deformable trailing edge flaps (no hinges)

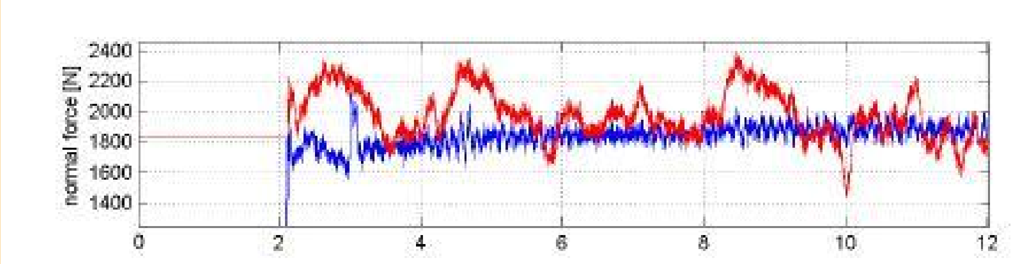
Aerodynamics –state of the art

Trailing edge flaps and camber control

At Risø: Model and experiments into aerofoils with (partially) deformable camber: structural model



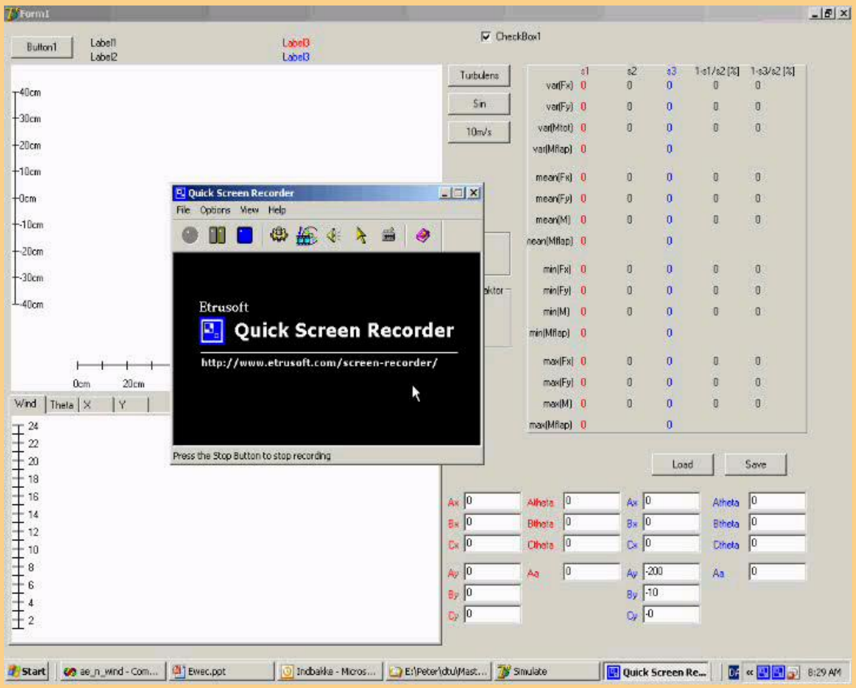
Result: potential reduction in bending moment



Aerodynamics –state of the art

Trailing edge flaps and camber control

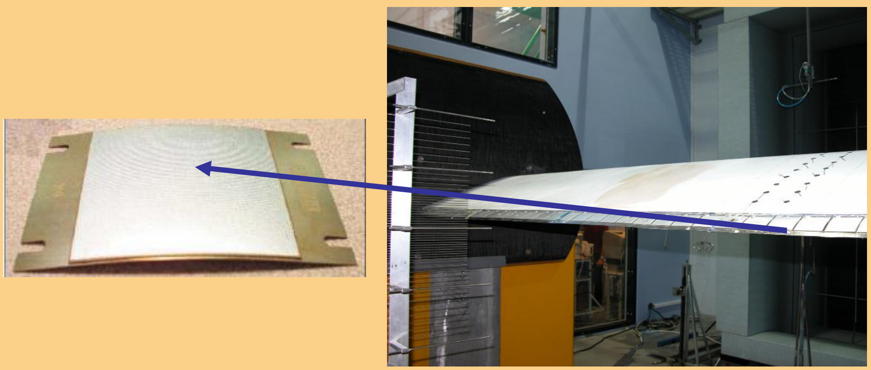
At Risø: Model and experiments into aerofoils with (partially) deformable camber: result

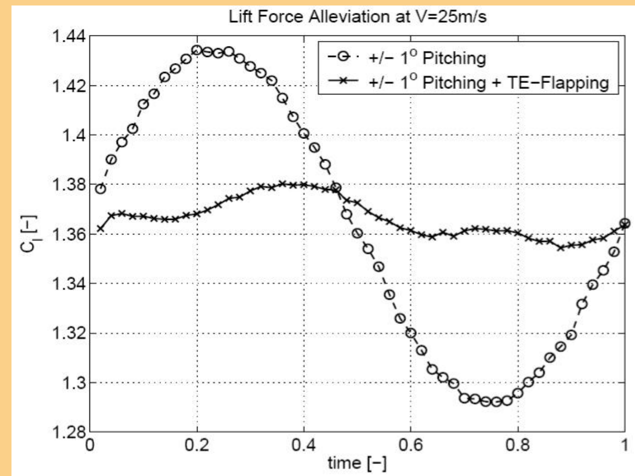


Aerodynamics –state of the art

Trailing edge flaps and camber control

At Risø: Model and experiments into aerofoils with (partially) deformable camber: 2D experiment



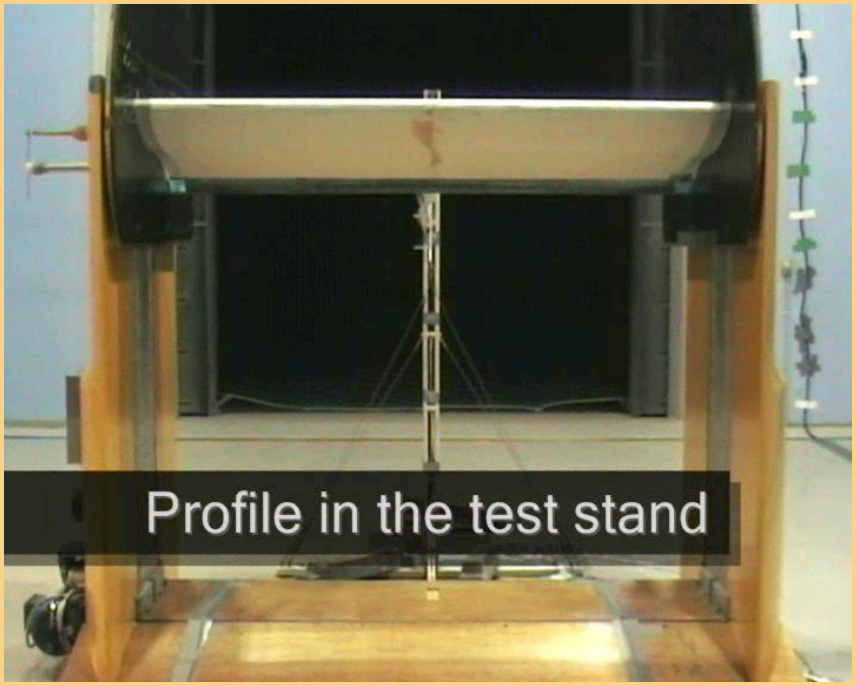


- 2m blade section, 0.66m chord, 36 piezoelectric actuators as flaps (10% chord length).
- Pitch +/- 1 deg. with and without (opposite) flap deflection
- Reduction in change of lift 82%

Aerodynamics –state of the art

Trailing edge flaps and camber control

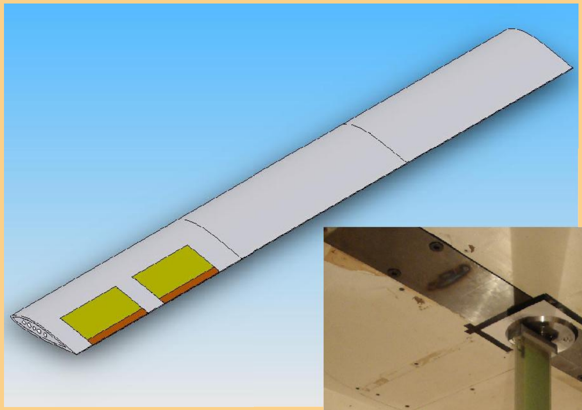
At Risø: Model and experiments into aerofoils with (partially) deformable camber: 2D experiment



Aerodynamics -UpWind coproject

Trailing edge flaps and camber control

At TU Delft: Experiments including structural dynamics and control

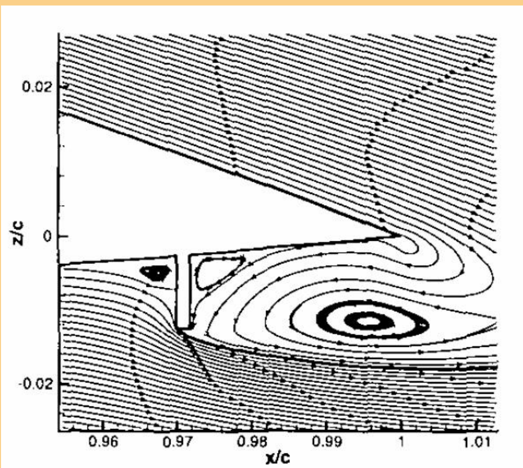


- Blade with tailored dynamics
- Fast pitch excitation to simulate the scaled dynamics of a full scale blade
- Real time feedback controller designed with system identification
- PZT based flexible flap
- Experiments are on-going, results are possitive and being processed

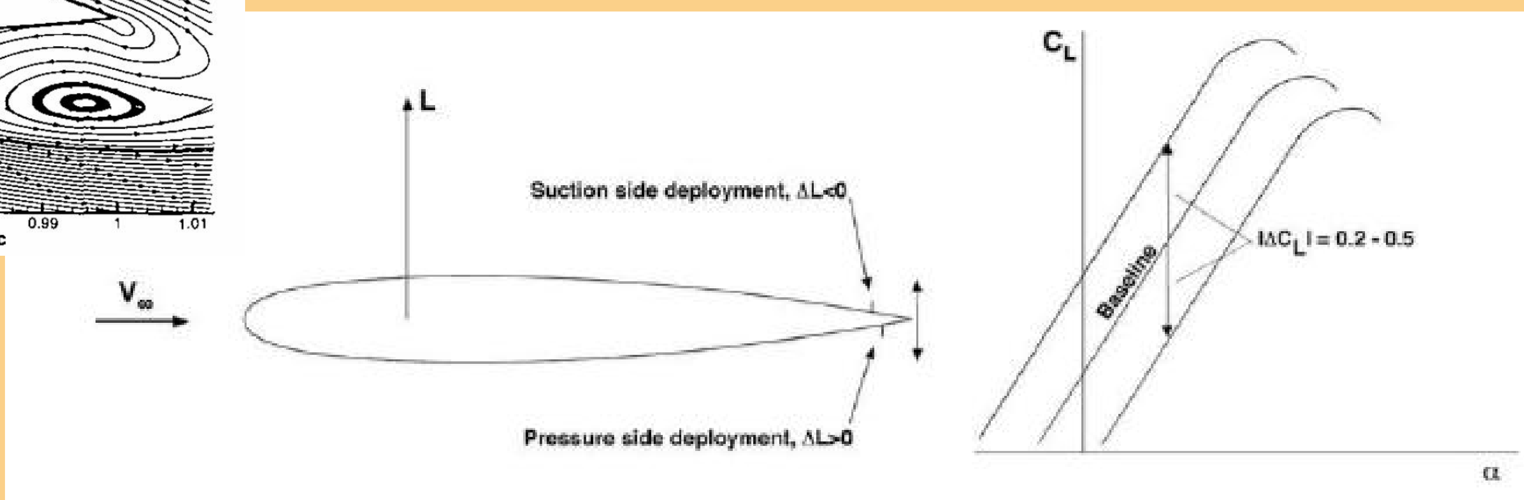
Aerodynamics –state of the art

Micro Tabs:

By disturbing the boundary layer near the trailing edge…



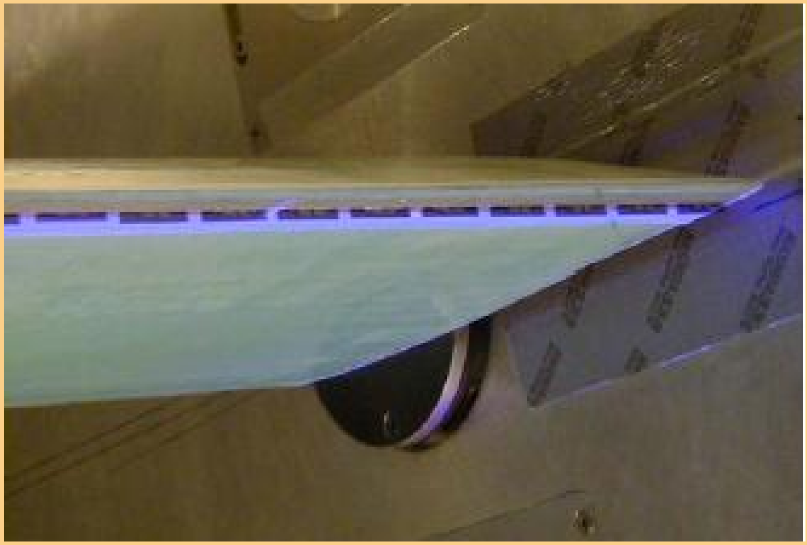
…the lift can be controlled

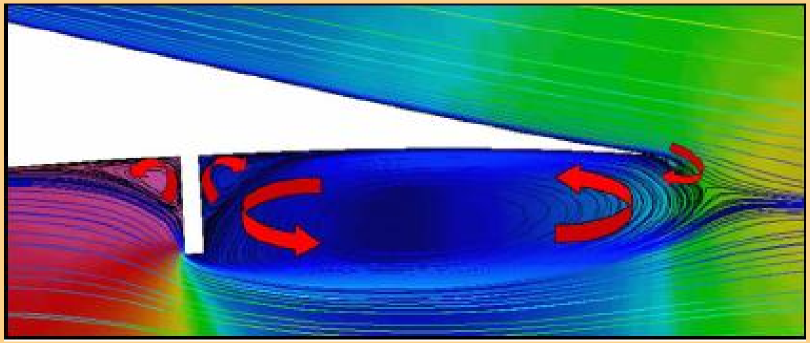


Aerodynamics –state of the art

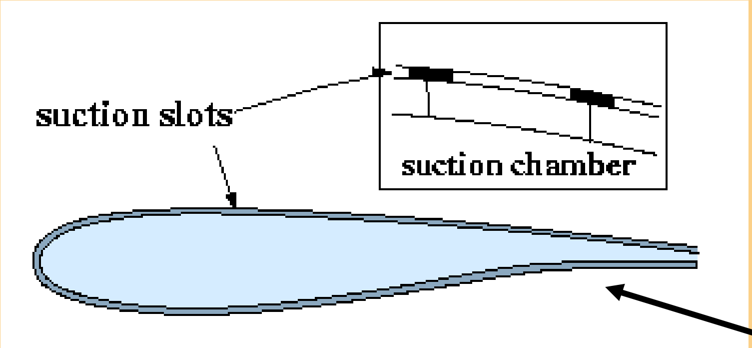
Micro Tabs:

- Small (1-2%c), simple, lightweight, inexpensive
- Fast response, easily controllable, small required movement
- Great relative aerodynamic performance: it effectively changes sectional camber and modifies trailing edge flow (the Kutta condition)

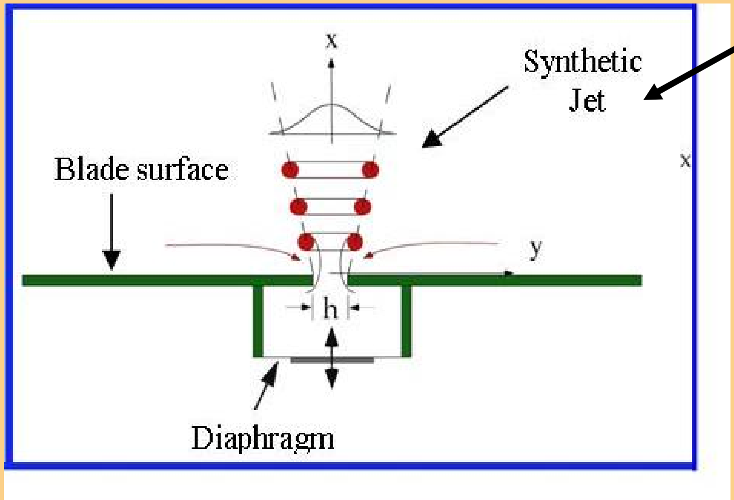


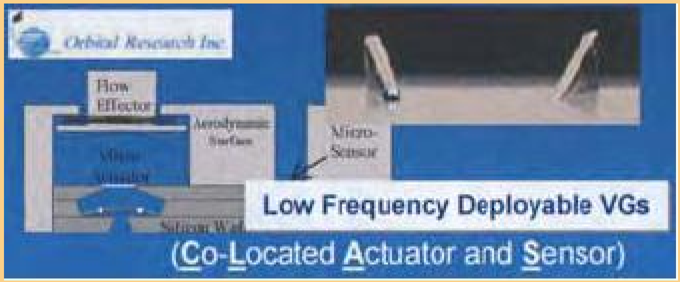


Boundary layer control



- Mainly used to reduce flow separation
- Can achieve "virtual effective camber" control
- Suction / Blowing
- Synthetic Jets
- Active Vortex Generators





Structural integration – state of the art

- Simple design
- Low maintenance requirements

} Integrated solution: Adaptive Materials

Adaptive Structure: Embedding or externally applying materials that deform under a non-mechanical stimulus.

Advantages:

- Lower weight
- Lower maintenance

Structural integration – state of the art

Often mentioned adaptive materials:

- Piezo electric materials.
- Ionic polymers.
- Electrostrictive materials.
- Magnetostrictive materials.
- Shape memory alloys.
- Shape memory polymers.
- Magneto-rheological fluids.

But there are force, deformation and bandwidth requirements

Structural integration – state of the art

Force: Sufficient force must be exerted to deform the structure and to withstand aerodynamic loads

Deformation: The force must be applied over a certain range.

Bandwidth: The speed of the actuator must be high enough (at least 1-3Hz for the Smart Rotor).

Suitable candidates:

Piezo electrics (However, low strains: $\sim 10^{-4}$)

SMAs (However, low bandwidth: depends on cooling, hard to control)

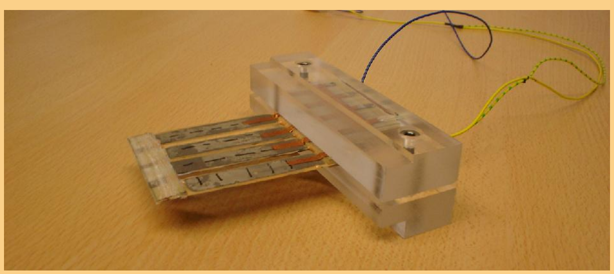
Structural integration – state of the art

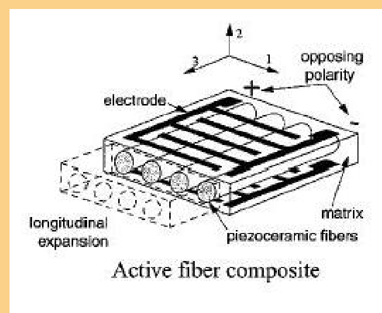
Piezo electrics: crystals that deform under an electric field

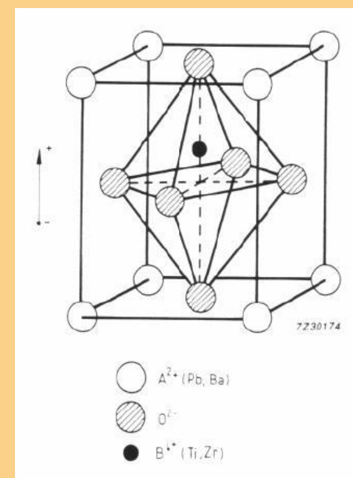
Often supplied in plates: high field through the thickness

Many ways of increasing deformation/deflection:

- In benders
- Using "3-3-effect" (stacks, active fiber composites)
- Mechanical amplification







Structural integration – state of the art

SMAs: Temperature triggered phase transition causes recovery of certain amount of strain

- Deforming at low T: material goes from twinned to detwinned martensite
- Heating : materials transforms to austenite and recovers its original shape
- Cooling : material returns to twinned martensite (unless restrained) without shape change
- At high T: recovery is constantly "on": pseudo elasticity

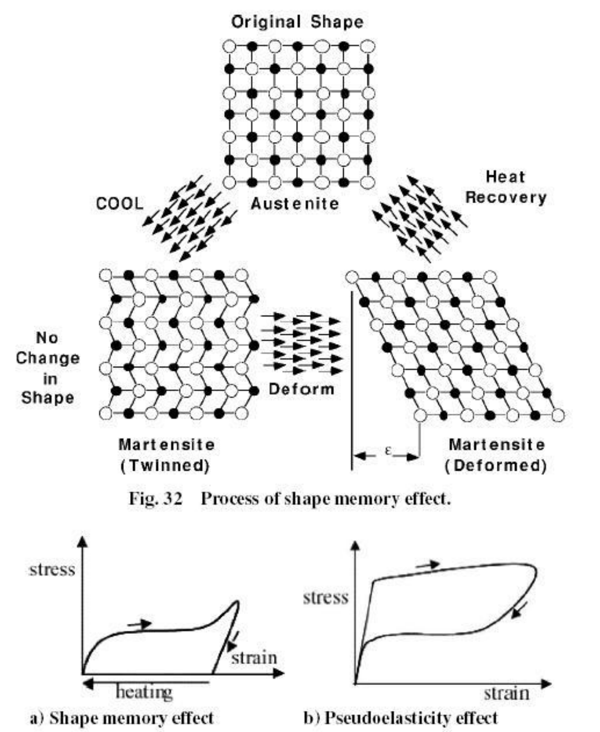


Fig. 32 Process of shape memory effect.

a) Shape memory effect b) Pseudoelasticity effect

Structural integration

SMAs: Temperature triggered phase transition causes recovery of certain amount of strain

Bandwidth issues:

- Cooling strategy
- Use of the R-phase (low strains, but high rates because of higher and smaller temperature band)

Control:

- Models of Academy of Sciences of the Czech Republic
- Work on application and embedding

Structural integration – state of the art

SMAs: Temperature triggered phase transition causes recovery of certain amount of strain

Example: SMA wire actuated trailing edge at VTT

Sensors and Control – state of the art

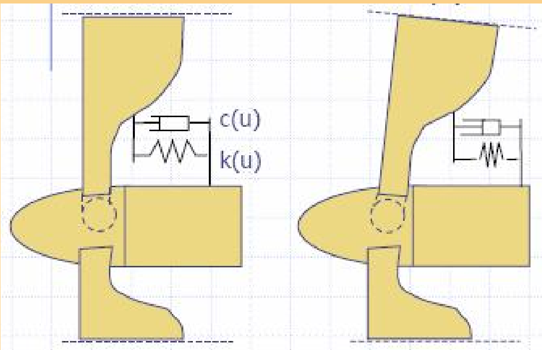
Sensoring: Robotiker

Possibilities for feedback: Measure for instance…

- incoming flow field,
- tip deflection / acceleration,
- strain along the blade, especially at the root,

Control: IPPT

Threshold-based root bending alleviation through hinged blade root



Control: TU Delft

Feedback control on aerodynamic devices & actuator concepts

Conclusions

- We 're aiming for an integrated solution where minimal actuation power (small devices) will result in a maximal effect (ΔCL)
- Aerodynamic devices: most effective near trailing edge
- Actuators: SMA or piezo based, either embedded (deformable surface), or as external actuator.
- Current and future research into advanced aerodynamic and structural modeling, as well as control

Conclusions

So in the future…

Questions?

Conclusions

So in the future…

Questions?