Smart Wind Turbine Rotor Blades

Luiz da Rocha-Schmidt, Felix Stroscher, Bin Wei, Horst Baier

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- Smart / Adaptive Wings: Aircraft, Helicopter
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Motivation

- Wind Power is a well established, clean energy source
- Efficiency aim: build larger wind turbines
  - Largest to date: Enercon E-126, d=126m, P=7,5MW
- Size limitation (among others):
  - Structural loads due to gravity and wind
  - Lifespan impact: instationary gust loads

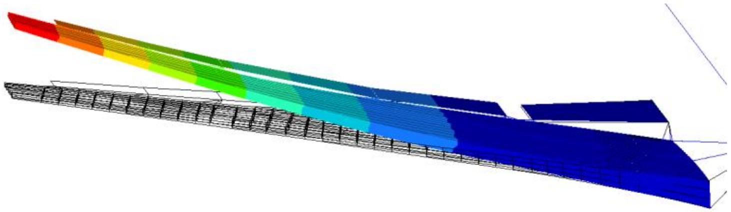
Smart / Adaptive Structures

Sensor → Controller → Actuator

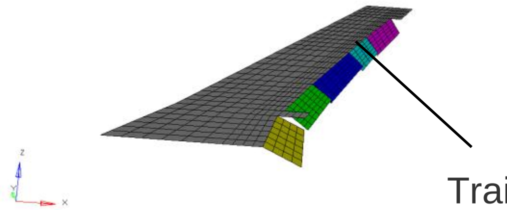
- Sensor: observe a disturbance
  - e.g. wind, acceleration, strain sensor
- Controller: determine reaction to achieve desired result
  - e.g. feedback / feedforward controller
- Actuator: execute controller command
  - e.g. blade pitch axis rotation, control surface

Dynamic Load Alleviation (aircraft)

- Structural wing model
  - Finite Element Method



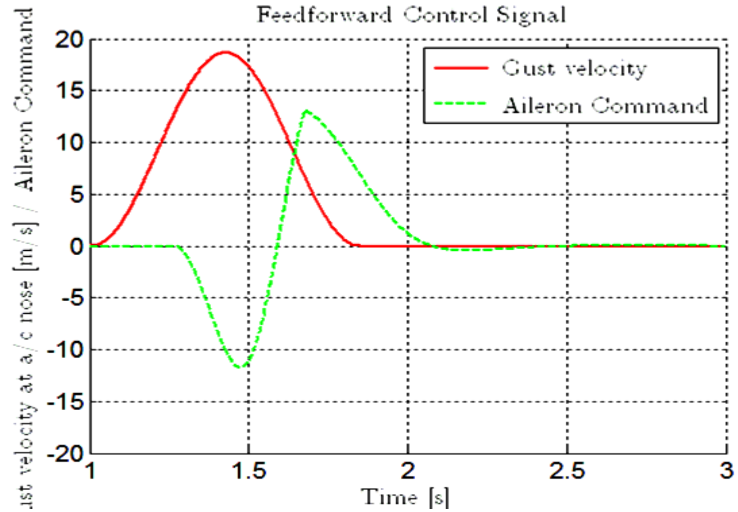
- Aerodynamic Wing Model
  - Doublet Lattice Method



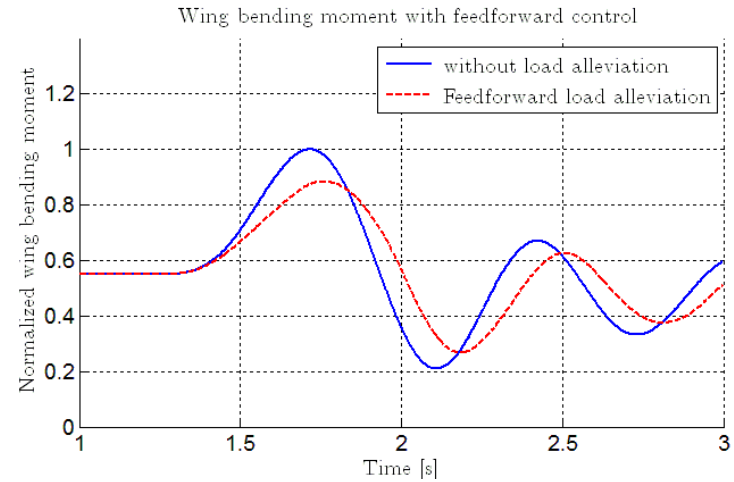
- Coupled Aero-Elastic analysis
  - time domain

Dynamic Load Alleviation (aircraft)

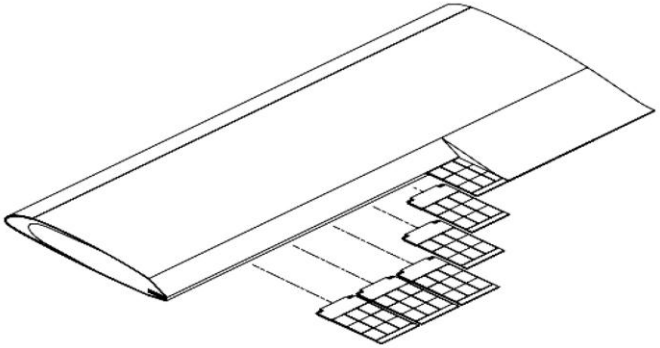
- Feedforward controller
  - „Gust sniffer“ in front of the wing
  - Control command on the flaps



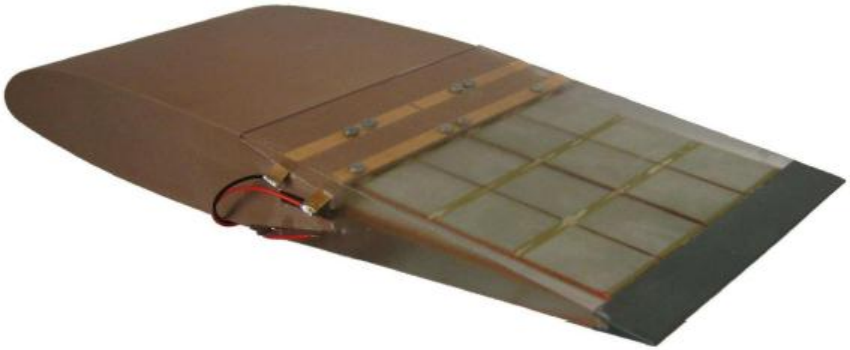
- Structural response
  - 30 % peak load reduction



Dynamic Load Alleviation / Noise Reduction (Helicopter Blade)

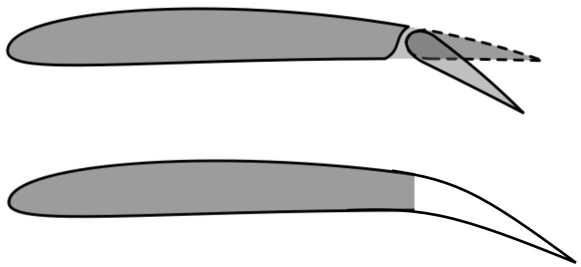


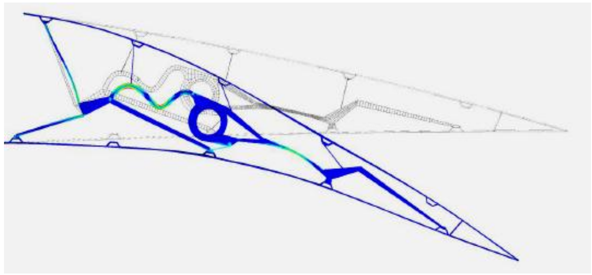
- „Smart“ Helicopter rotor blade
  - Piezo-actuated Trailing edge
    - +/- 6° deflection
  - Reduced Blade loads
  - Reduced Noise Level

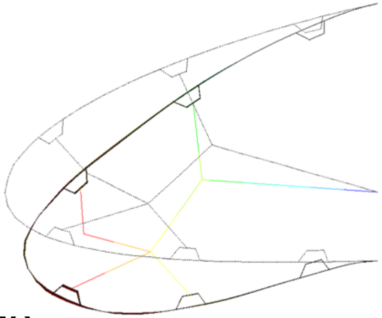


Morphing Control Surfaces

- Plain flaps vs. Morphing Flaps



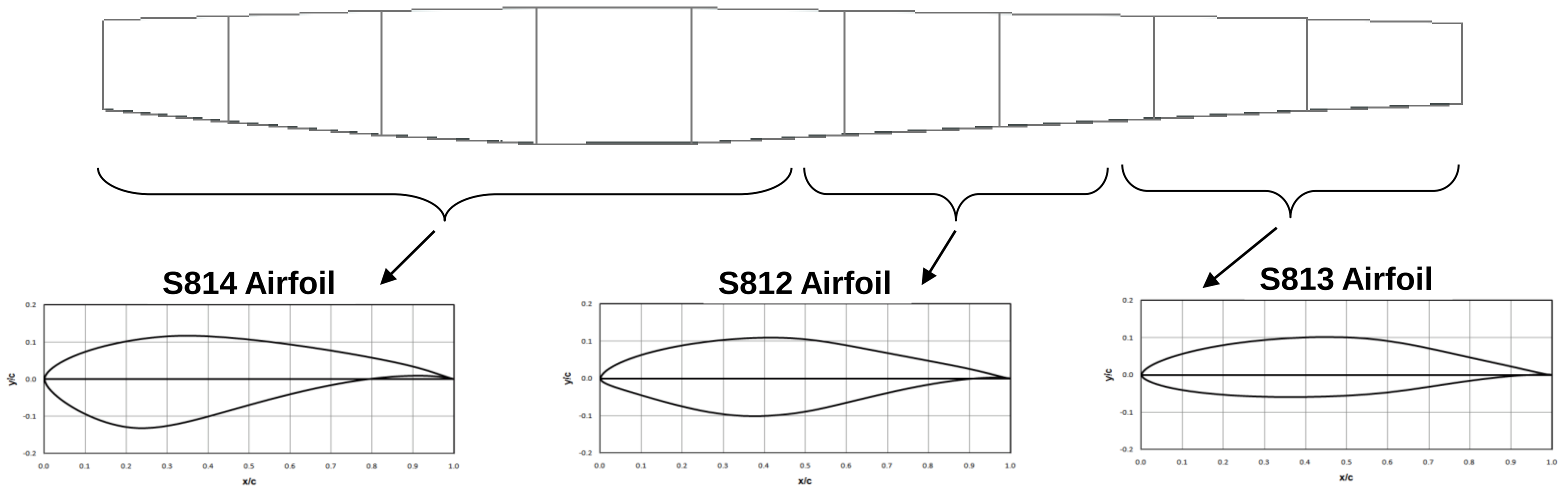




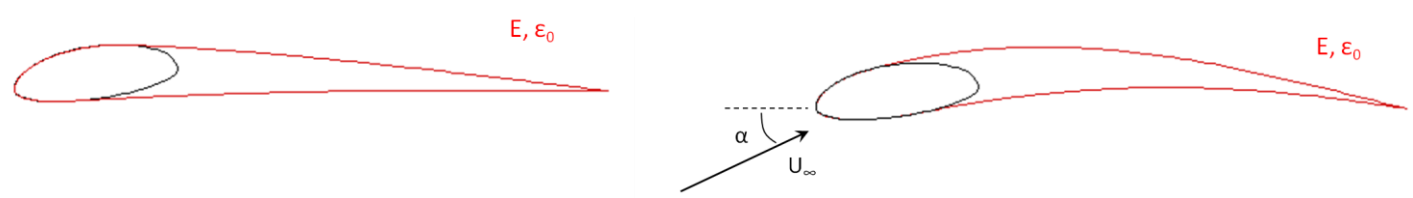
- Benefits:
  - Reduced Drag, increased Lift
  - More generated power with same structural loads

Airfoil morphing

Sample reference rotor: AOC 15/50 – Layout and airfoils:



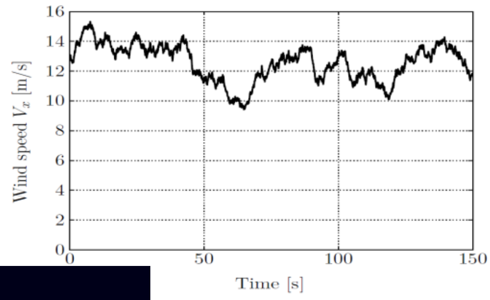
Adaptation using a generic ***elastoflexible*** airfoil

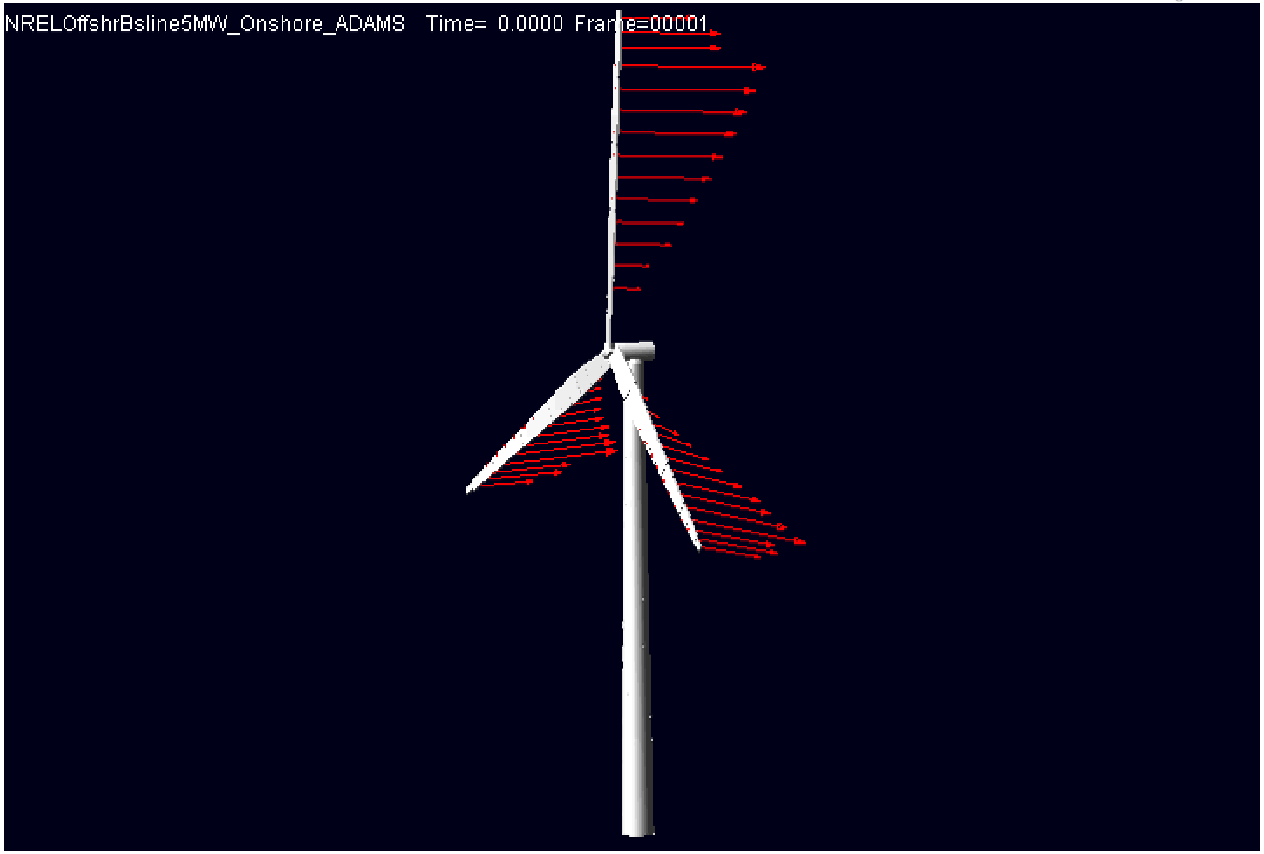


See Poster by Institute of Aerodynamics and Fluid Mechanics!

Transient Wind Loads (Video)

NREL 5 MW reference turbine
hub height: 90 m, rotor diameter: 126 m, mean wind speed: 12 m/s





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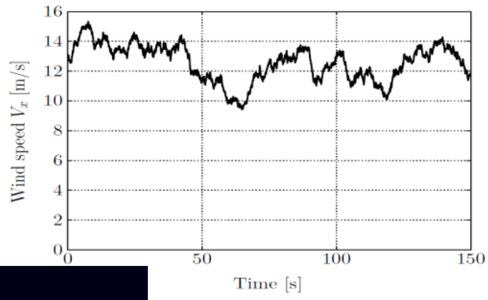

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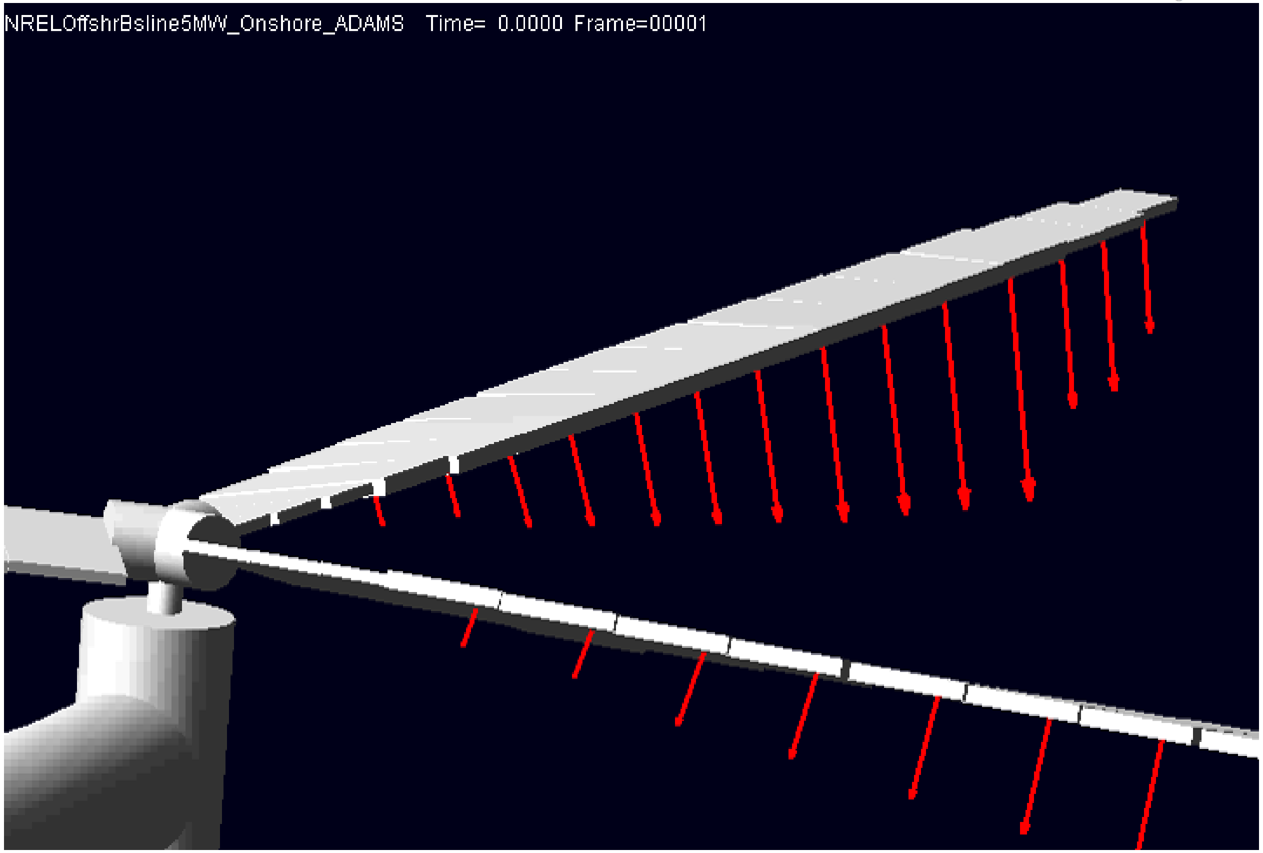
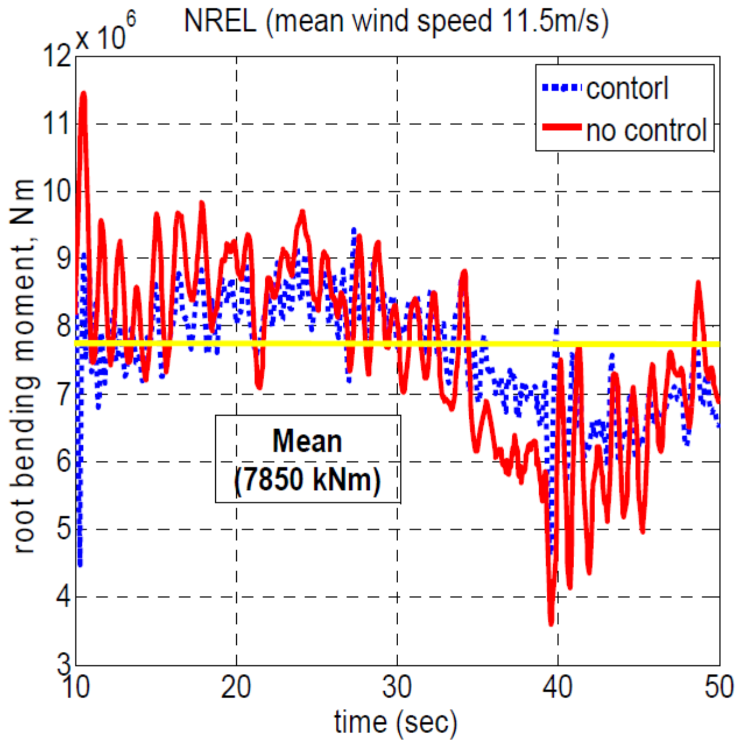
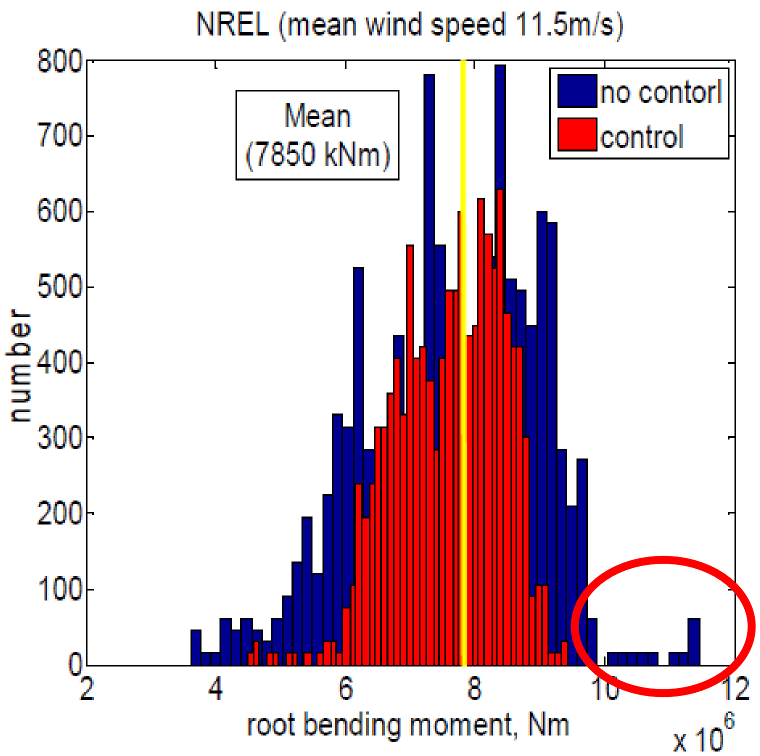


Effects of gust load alleviation on a wind turbine blade

- NREL 5 MW reference turbine, Lee et. al., KAIST, Daejeon, Korea





Challenges

- Reliability
  - If the control system fails, the turbine can not be operated without the risk of damage
- Cost
  - Additional hard- and software is needed
- Power Requirements
  - Energy consumption of the controller and the actuators must be kept low

Conclusion

- Smart Rotor Blades are able to
  reduce peak loads
- Aerodynamically efficient control surfaces:
  Morphing Flaps
- Combined:
  Larger and *more efficient* wind turbines

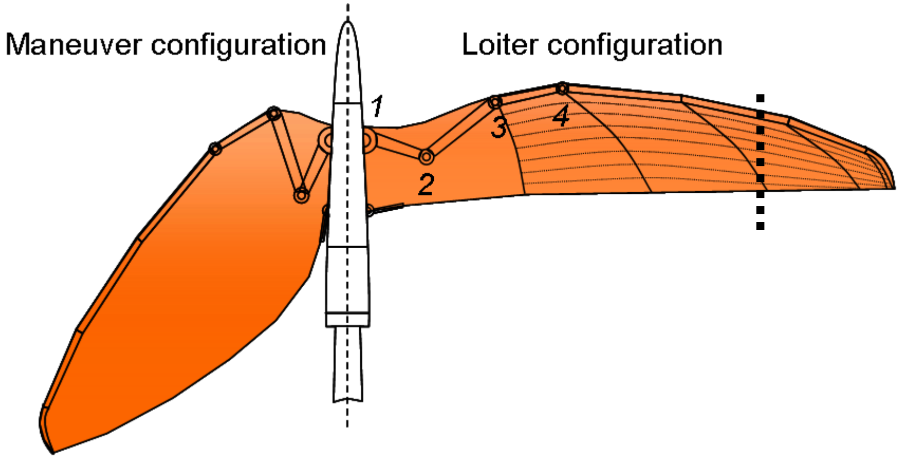
Thank you – Questions?

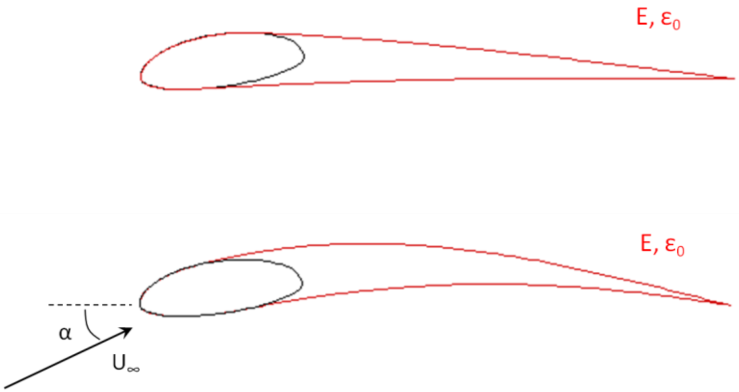
BACKUP SLIDES

Passive Solution: Elastoflexible wing

Concept
- Internal Support Structure
- Elastic membrane skin as aerodynamic surface

Reasoning
- Large shape variations are possible with low effort
- passive flow control through load-dependent membrane deflection

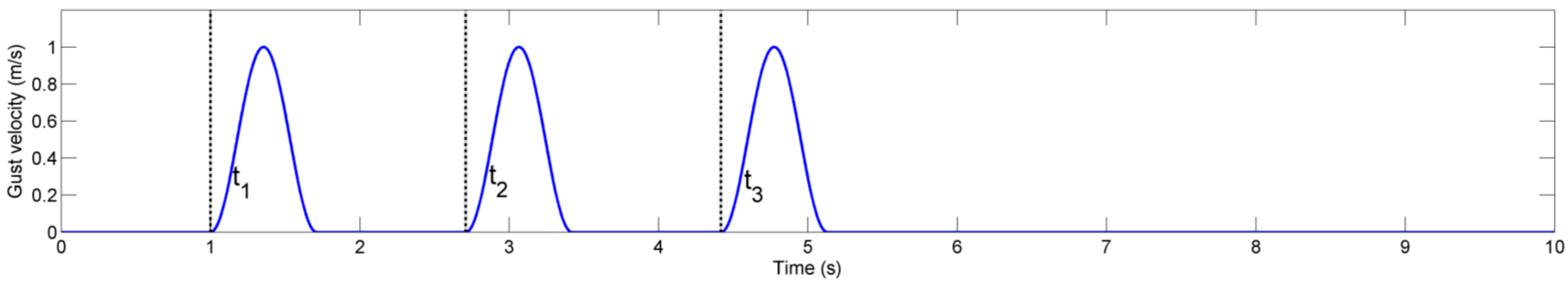




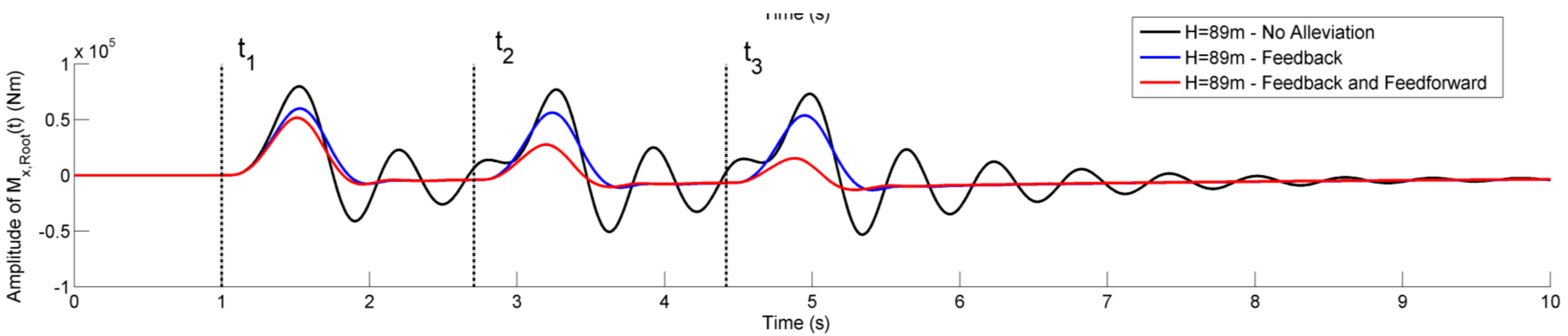
Source: TUM Institute of Aerodynamics and Fluid Mechanics & TUM Institute for Computational Mechanics

Dynamic Load Alleviation (aircraft)

Feedforward adaptive filtering → Learning capabilities for specific input signal



→ Response on discrete gust triplet with adaptive filtering



→ Peak reduction increases with time, as filter parameters are adapted

→ ~ 50% Peak reduction

Windenergieanlagen: morphing / adaptive rotors

Membrane wing – “Morphing“ (Airfoil adaptation; passive load control)

Dynamic Load Alleviation of wing-like structures in unsteady flow fields

→ **Feedback controller**

- Feedback of acceleration sensor signal at the wingtip
  - 2nd order transfer function for damping of the 1st bending mode
- Control Command on Trailing Edge Devices

→ **Structural response:**

- ~10% reduction of first peak in bending moment, but very strong reduction of following peaks
- Highly efficient damping of a steady vibration
- Low efficiency of highly transient response