



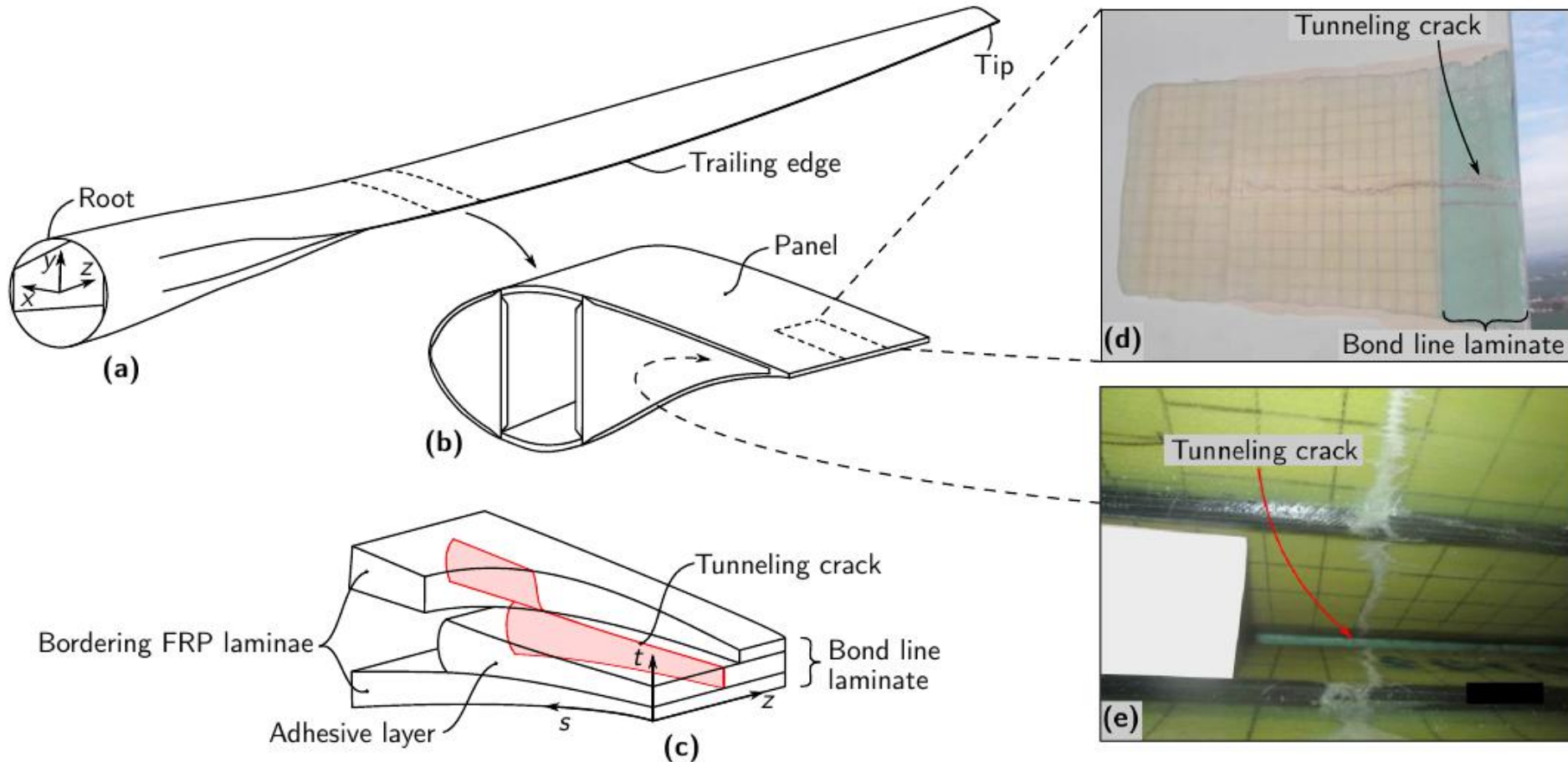
# Fatigue Impact of Mechanical and Thermal Residual Stresses on the Trailing Edge Bond Line of Wind Turbine Blades

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# Tunneling Cracks in the Trailing Edge Bond Line



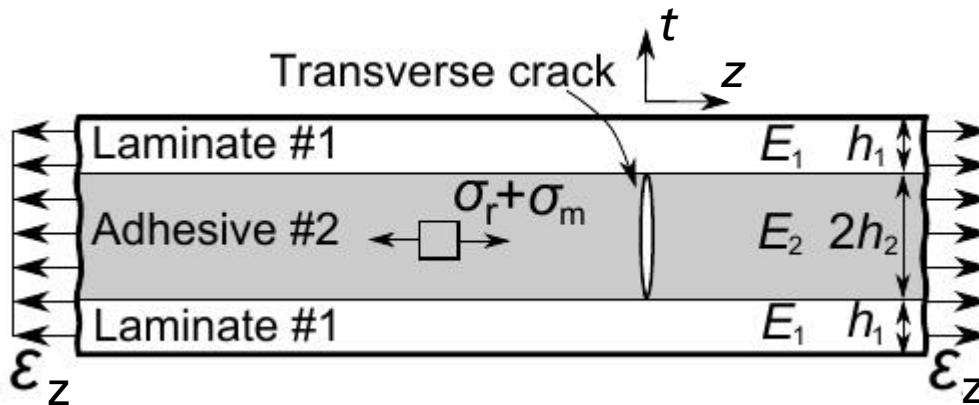
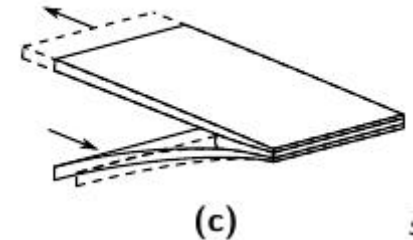
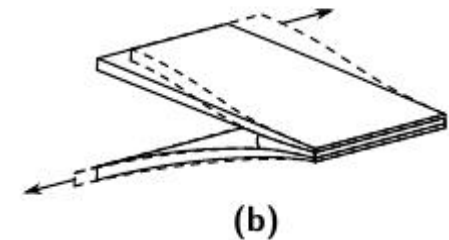
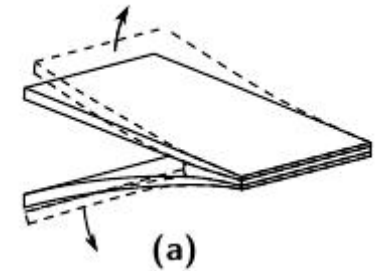
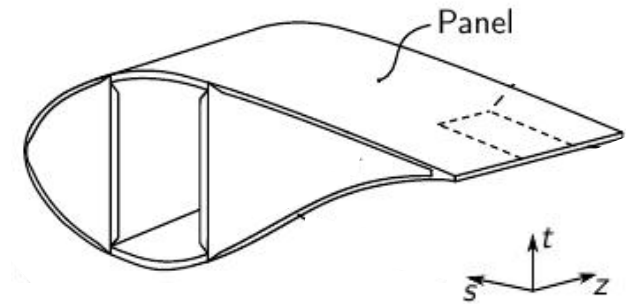
The crack shown was observed on an anonymous blade.

# Research question

How significant is the contribution of:

- mechanical stresses and
- thermal residual stresses

on the bond line fatigue of the adhesive layer, i.e., the initiation of a transverse tunneling crack?



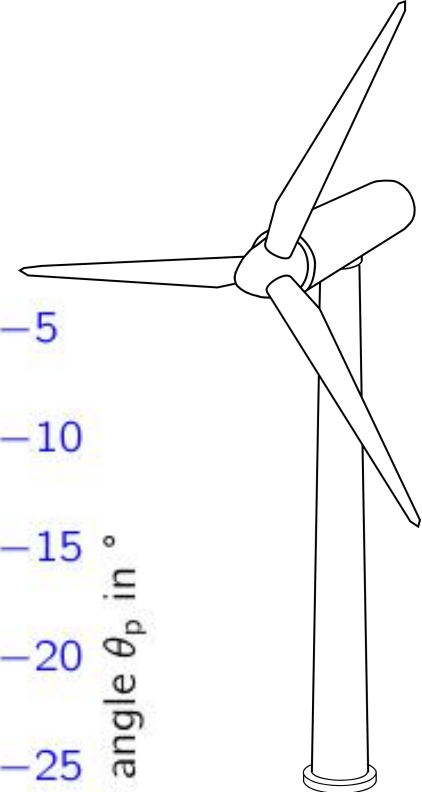
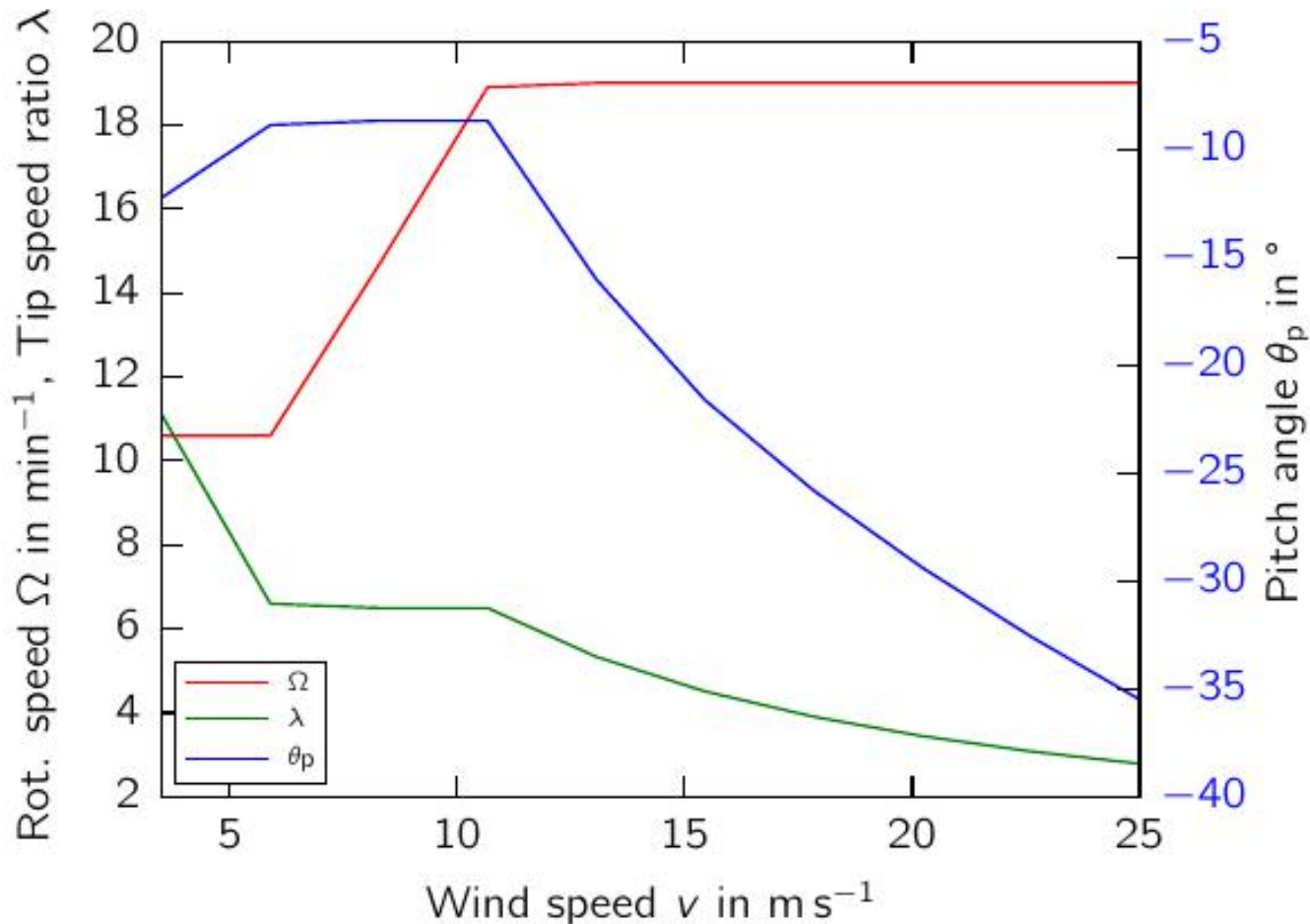
Jørgensen, J. B., Sørensen, B. F., & Kildegaard, C. (2017).  
Adhesive Joints in Wind Turbine Blades.

# Content

- Methods
  - Load cycle calculation
  - Load calculation
  - Structural bond line model
- Results
  - Mechanical stresses
  - Thermal residual stresses
- Conclusions

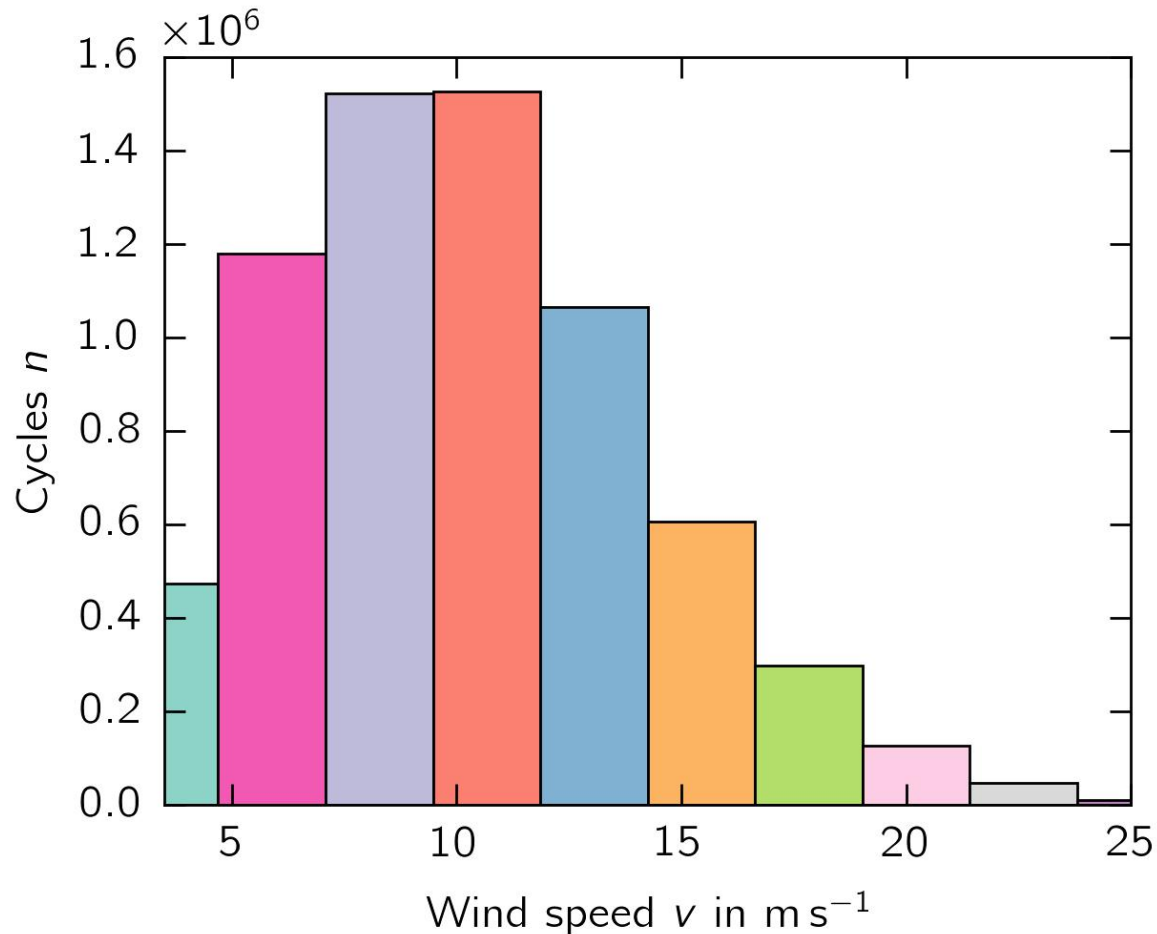
# Methods

## Operating conditions of 1.5 MW turbine



# Methods

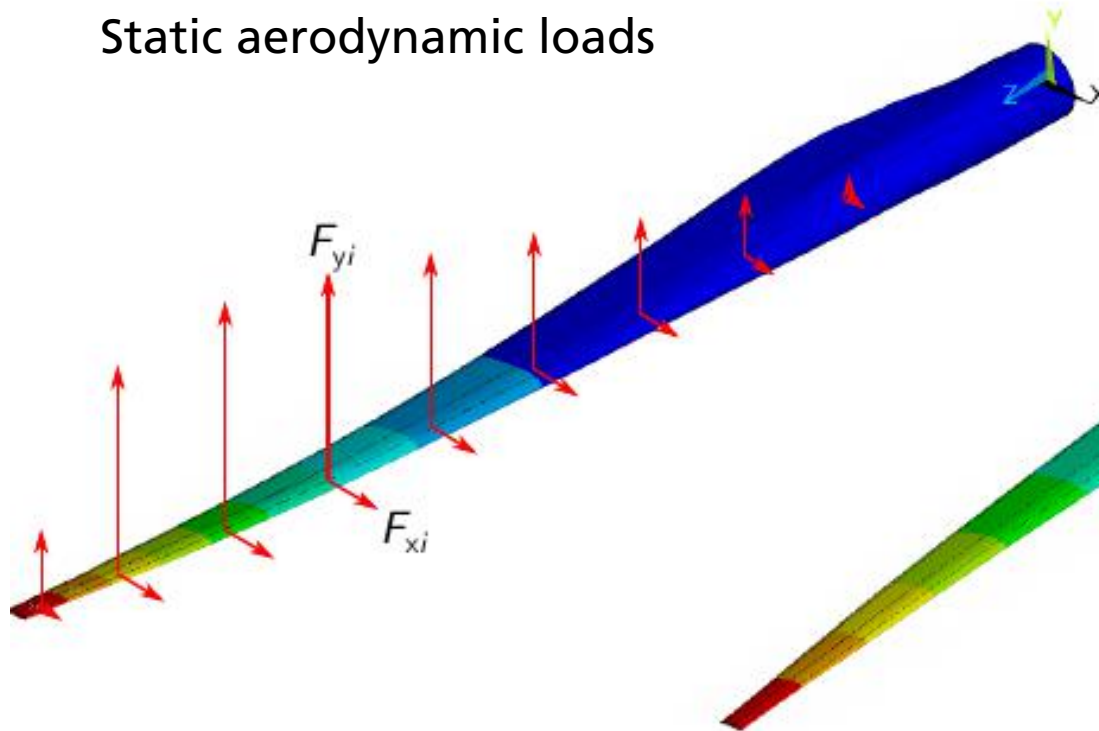
## Lead-lag cycles for 1 year of operation



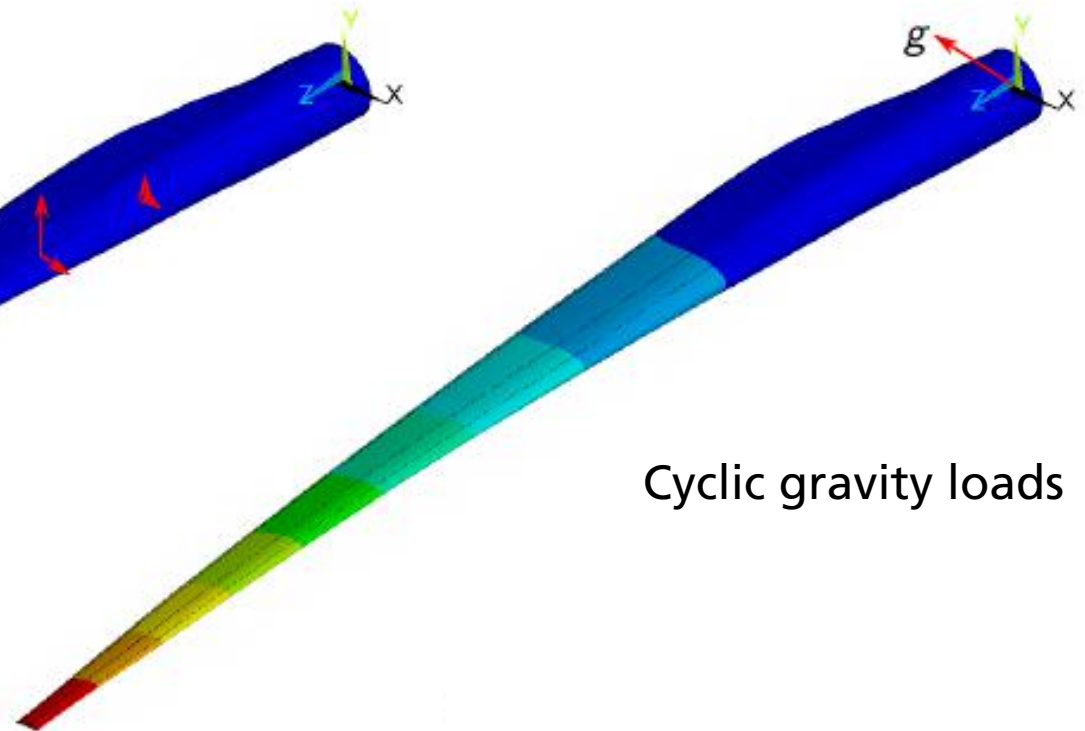
# Methods

## Finite element model of a 34 m commercial blade

Static aerodynamic loads



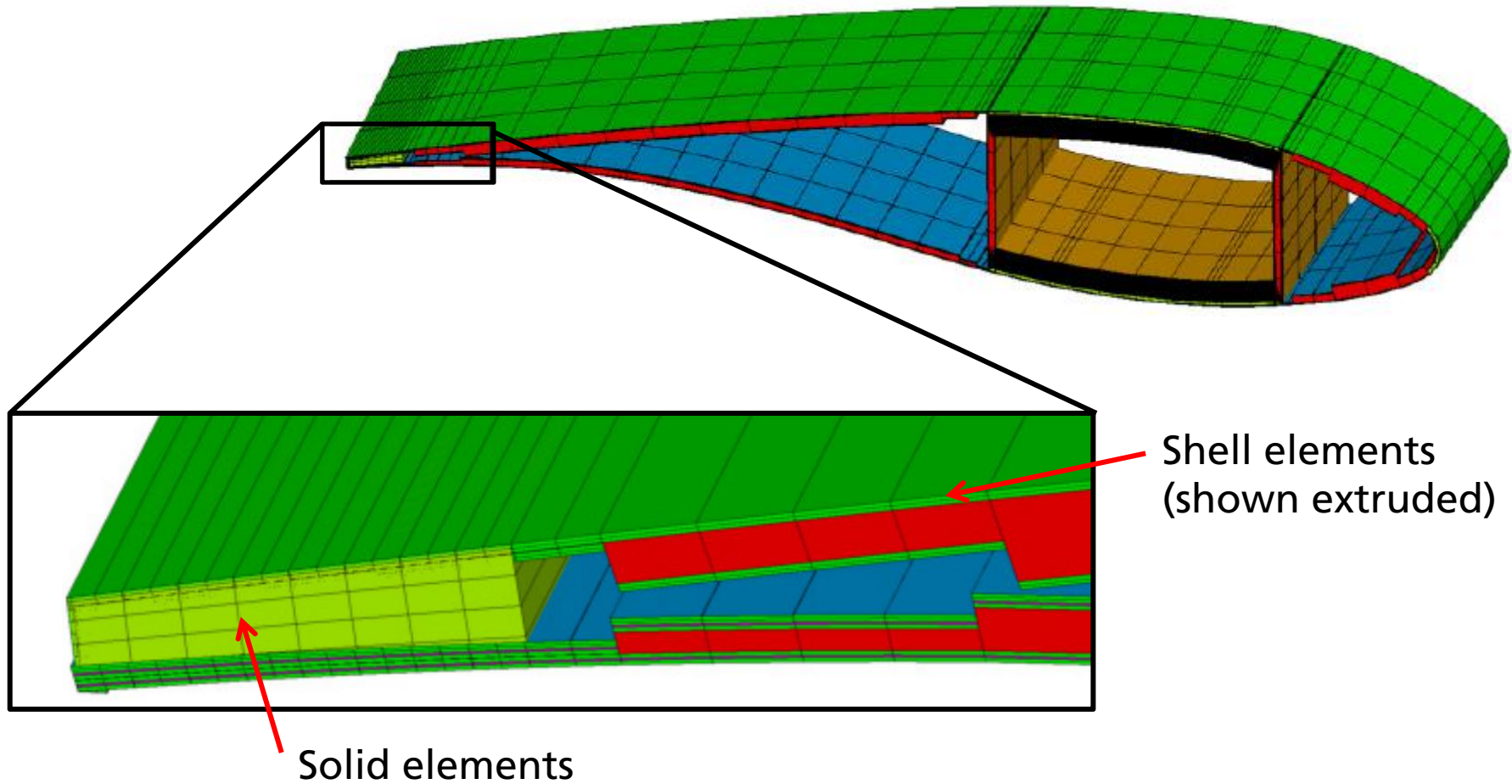
Cyclic gravity loads





# Methods

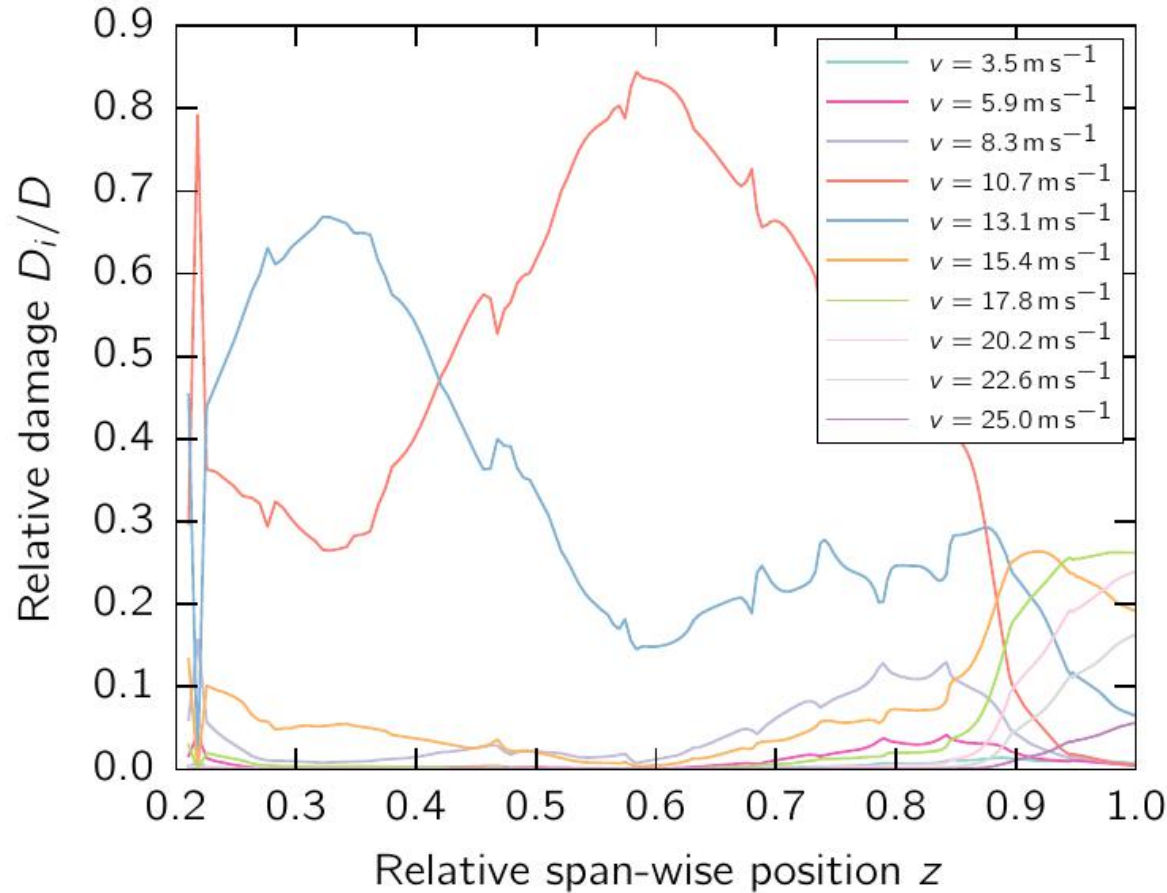
## Structural bond line model





# Results

## Relative damage impact of wind speeds along span

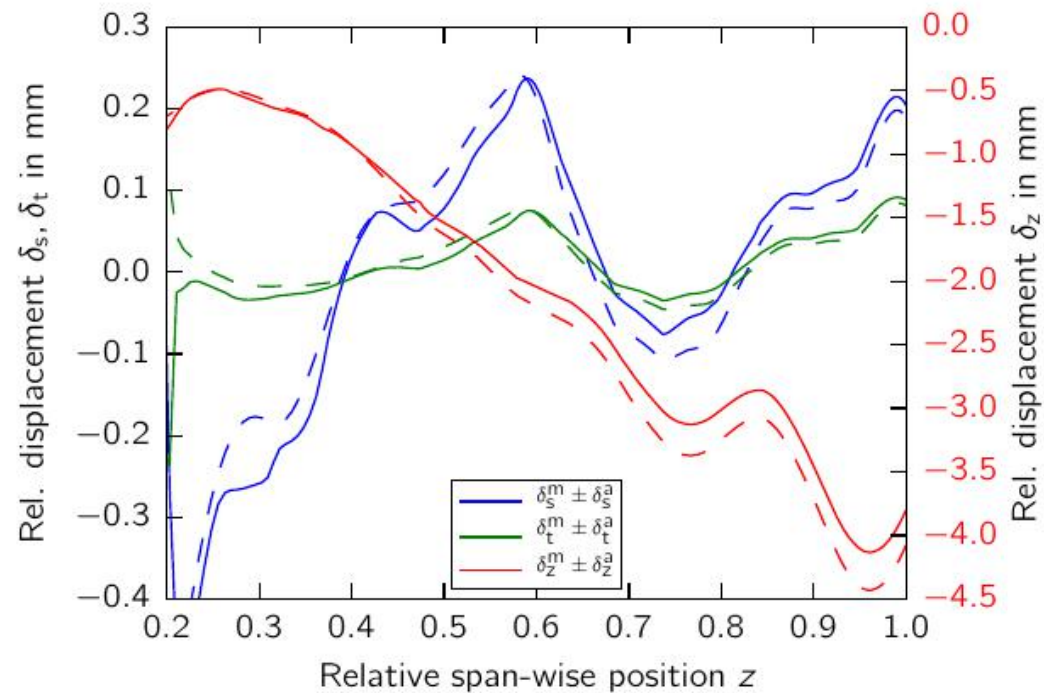
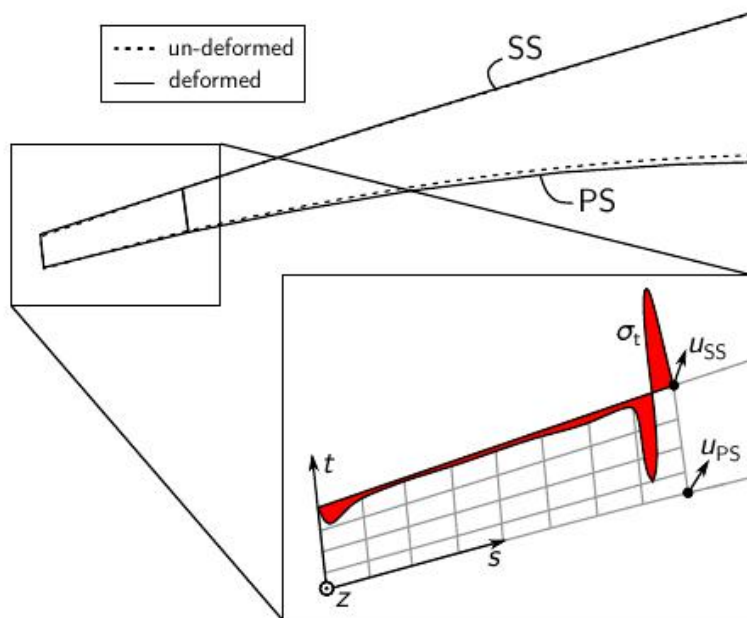


Damage:

$$D = \sum_i D_i = \sum_i \frac{n_i}{N_i}$$

# Results

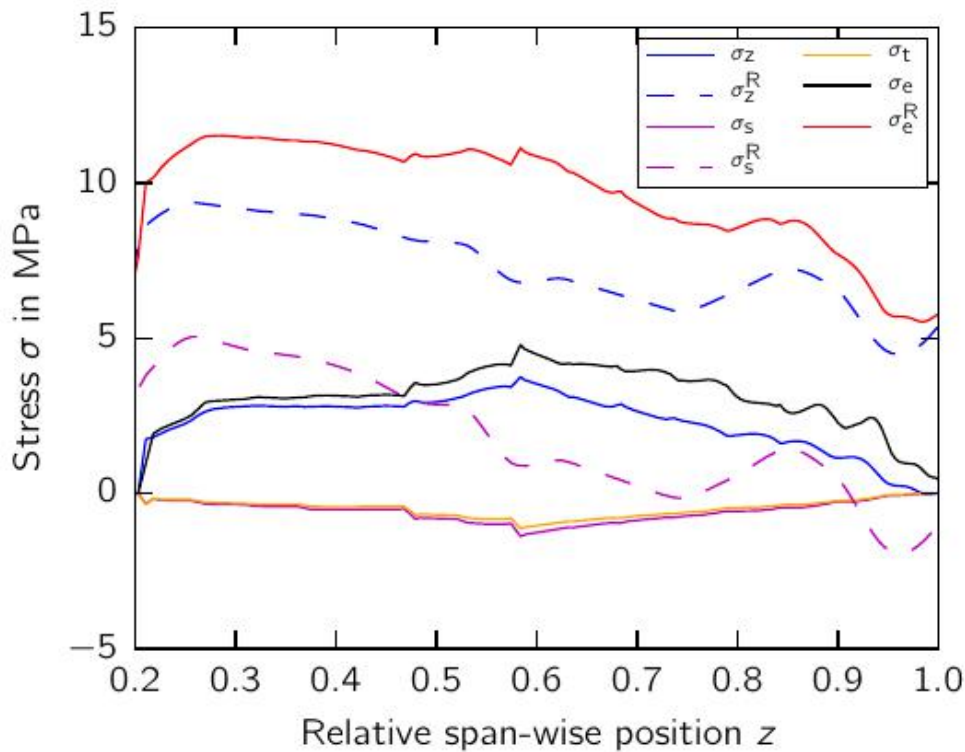
## Relative deformation of inner bond line edge



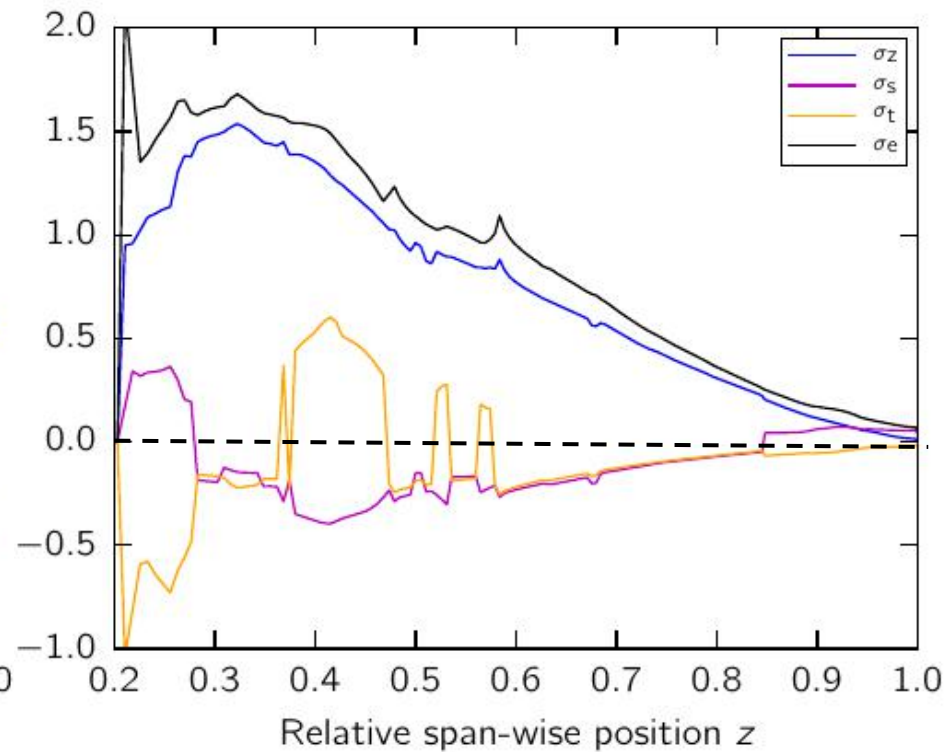
Relative displacement:  $\delta = u_{SS} - u_{PS}$

# Results

## Thermal residual stress state and multi-axial mechanical stress state



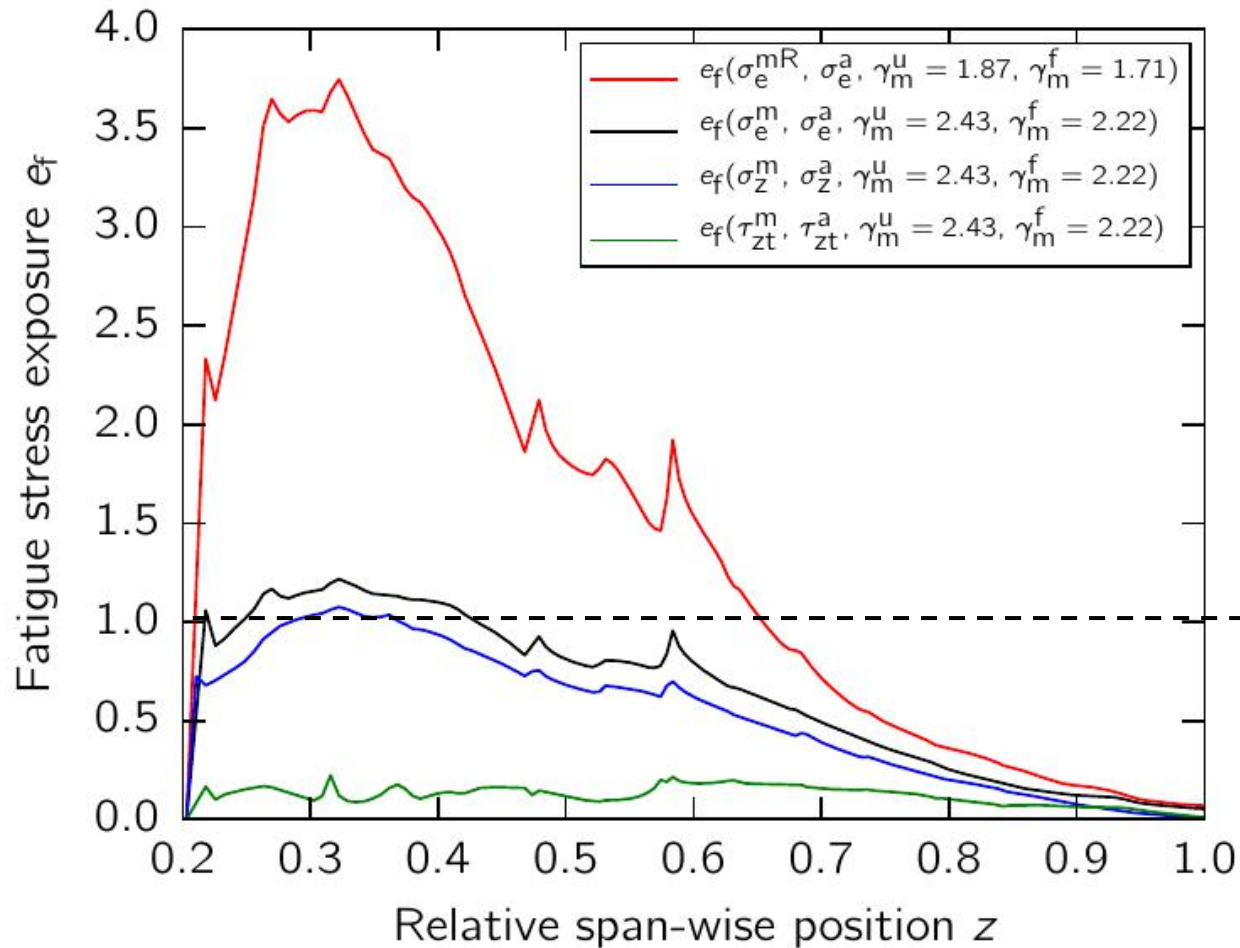
mean load



amplitude load

# Results

## Total fatigue stress exposure



theoretical  
crack initiation  
after 20 years

# Conclusions

- If the design analysis took residual stresses into account with a safety reduction factor instead of a thermal stress calculation using a classical laminate plate model, this approach would become design critical if transverse tunneling cracks were not tolerated at all.
- For the critical location of the blade considered, the thermal residual stresses contributed 70% to the fatigue stress exposure.
- Besides the longitudinal stress, peel and transverse stresses contributed up to 10% to the multi-axial fatigue stress exposure.
- For modern blades, the contribution of peel and transverse stresses is expected to be more significant due to higher elasticity and larger gravity loads.



**Thank You For Your Attention**

**Any questions?**

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