Mini-Project 2: Optimum Blade

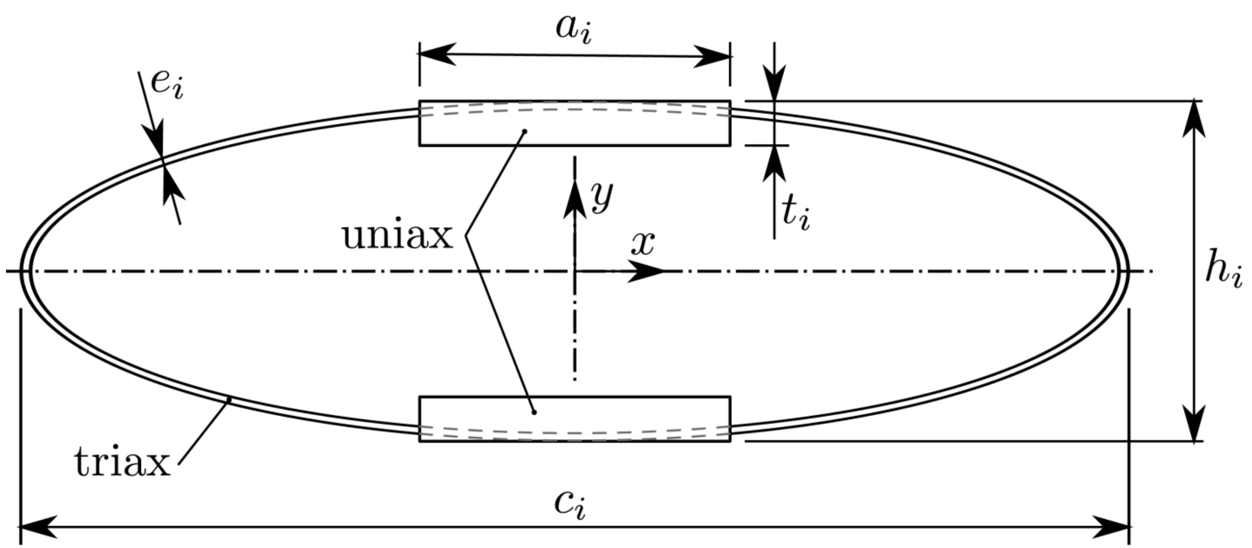
46415 - Structural analysis and design optimization of wind turbine blades

*All information on these slides, **and more**, is contained in the Mini-Project description on DTU Inside*

DTU Wind Energy
Department of Wind Energy

Introduction

- Mini-Project 2 builds on Mini-Project 1 introducing the following changes and new concepts:
  - A 3D beam finite element model is now used.
  - The thin-walled ellipse is added to the cross section as a representation of the airfoil.
  - The wall thickness of the ellipse is added as design variable.
  - A edgewise bending load case is added.
  - Eigenfrequency constraints are added.



Optimization Problem

$$
\begin{aligned}
\underset{\mathbf{a},\mathbf{t},\mathbf{e} \in \mathbb{R}^N}{\text{minimize}} \quad & m(\mathbf{a}, \mathbf{t}, \mathbf{e}) \\
\text{subject to} \quad & \delta(\mathbf{a}, \mathbf{t}, \mathbf{e}) \leq \delta^{\max} \\
& \varepsilon_i(a_i, t_i, e_i) \leq \varepsilon^{\max} \qquad i = 1, \ldots, N \\
& \eta_i(a_i, t_i) \leq \eta^{\max} \qquad i = 1, \ldots, N \\
& f_j^{\min} \leq f_j(\mathbf{a}, \mathbf{t}, \mathbf{e}) \leq f_j^{\max} \qquad j = 1, \ldots, k
\end{aligned}
$$

Finite Element Model

- The blade is now modelled using N=20 beam finite elements (1 element per “section”).

- The 4-noded beam finite elements are from FRANS, which comes with DTU Wind Energy’s cross section analysis software BECAS (www.becas.dtu.dk)

- A description of the beam finite element model is contained in the description of mini-project 2, which can be downloaded from DTU Inside.

Notes

- The code computes the cross section stiffness properties of “the caps” and “the ellipse” separately and then adds them.
  - This is fine for longitudinal stiffness and bending stiffness, but “incorrect” for shear stiffness and torsional stiffness.
  - This is not a problem due to the simplifications made regarding shear stiffness and torsional stiffness. (E.g. the torsional stiffness contribution of the caps is ignored.)
  - See the description of Mini-project 2 for further details.
- While the optimizer runs the first and second eigenfrequency may “switch places”.

Notes

- The cap buckling constraint is treated in the same way as in Mini-project 1 except that the thickness used is that of the caps plus the ellipse.
  - As in Mini-project 1 it was assumed that the caps carry the entire bending moment, the buckling constraint is now (where the ellipse carries a part of the Mx bending moment) very conservative.
- fmincon's derivative checker (`problem.options.optimizer.check_derivatives=1`) does not always do a very good job and may issue error messages even though your gradients are fine. If necessary you may find it necessary to write your own derivative checker that compares the gradients to finite difference approximations.

Tasks for Mini-project II

- Download the Matlab program for solving the optimization problem from DTU Inside.

- Study the description of the project and the Matlab code (basis for the final project).

- A small part of the program is missing and needs to be completed:
  - Computation of the gradients of the eigenfrequencies in `analysis/compute_frequency.m`

- Check your implementation of the gradients using the finite difference checks in fmincon. If necessary implement your own finite difference checker of the user supplied gradients.

- Perform a sensitivity analysis on the lower and upper bounds on the frequency constraints by solving a number of different optimal design problems. What happens to the optimal design? What happens to the optimal mass?

- Perform the sensitivity analysis on the design driving constraints outlined in the project description using Lagrange multipliers.

Report requirements

- Maximum 2 pages

- **Deadline 13th of June 2018 at 13.00.**

- The report should include:
  1. A short abstract
  2. A section on the problem formulation and the methodology
  3. Derivation of the expressions for the frequency gradients
  4. Brief description of the implementation
  5. Discuss the effect of tightening or loosening the frequency constraints
  6. Discuss the results of the Lagrange multiplier sensitivity analysis
  7. Brief conclusions

Good luck!