Isogeometric Structural Analysis of Offshore Wind Turbine Blades

Master's Thesis in Marine Structures by David Vågnes
davidvaa@stud.ntnu.no
Supervisor 1: Assoc Prof Josef Kiendl
Supervisor 2: Assoc Prof Erin Bachynski

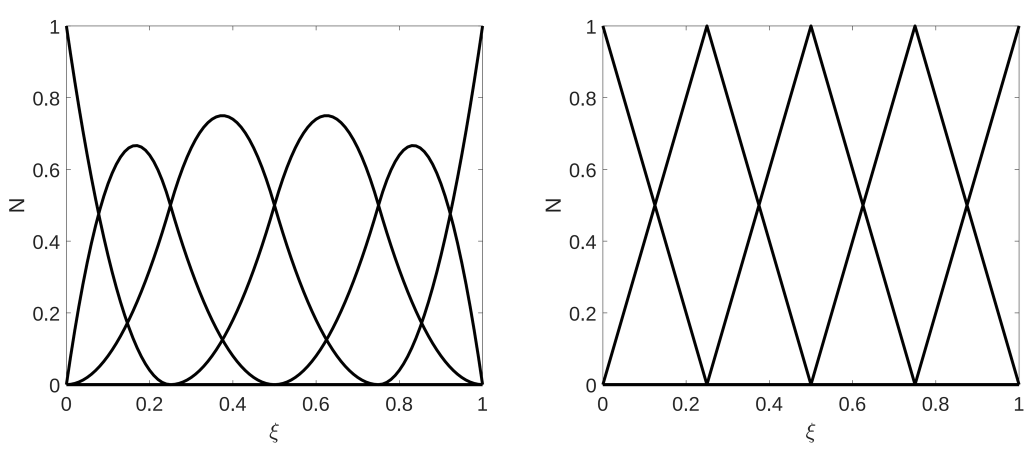
NTNU

Introduction

Isogeometric analysis, or IGA, is an alternative approach to finite element analysis, which can be directly performed on CAD models without creating an extra FEM model. The general concept can be applied to all fields of engineering mechanics, including structural analysis, computational fluid dynamics (CFD) and fluid-structure interactions (FSI). Since the concept first was introduced, the number of publications on the subject has increased exponentially, which implies that researchers finds the topic very interesting [1],[2].

In a traditional engineering design process, the geometry is modelled in a CAD system. This model represents the *exact* geometry of the structure, and is the foundation for the analysis model. In finite element analysis, the geometry model is represented by several elements in a *mesh*, and then the model is analysed as multiple sub-problems. FEM is the conventional method used in structural analysis, and provides a good approximation of the solution.

For simple geometries, automatic meshing procedures are very efficient. However, most structures has curvature in multiple directions and are to be considered as complex. Here the meshing procedure becomes much more complicated, as it has to be edited and manipulated manually by the analyst. The mesh generation accounts for more than 80% of the overall design-analysis process, and is considered as a bottleneck in the industry. Also, the mesh is only an *approximation* of the geometry. The reason for this situation is rooted in the fact that CAD and FEM uses different mathematical descriptions of the geometry. The term *iso*-geometric refers to the geometrical description of the two modelling conventions, which is the *same* in both design and analysis. The representation in CAD and FEM are typically based on different shape functions, respectively smooth splines (left) and Lagrange polynomial (right):



The idea of IGA is to use the same spline functions used to describe the exact geometry as basis functions for the analysis. Non-Uniform Rational B-Splines (NURBS) are mathematical representations of free form curves and surfaces that has become the standard in CAD. By using the NURBS basis functions in the analysis framework, the meshing procedure is omitted and analysis is performed on the exact geometry created in CAD. Spline basis functions have shown to perform as higher-order FEM but with improved accuracy and efficiency.

In this thesis, an IGA model of a reference wind turbine blade, designed for offshore siting is obtained and the results of the structural simulations are compared with conventional finite element analysis.

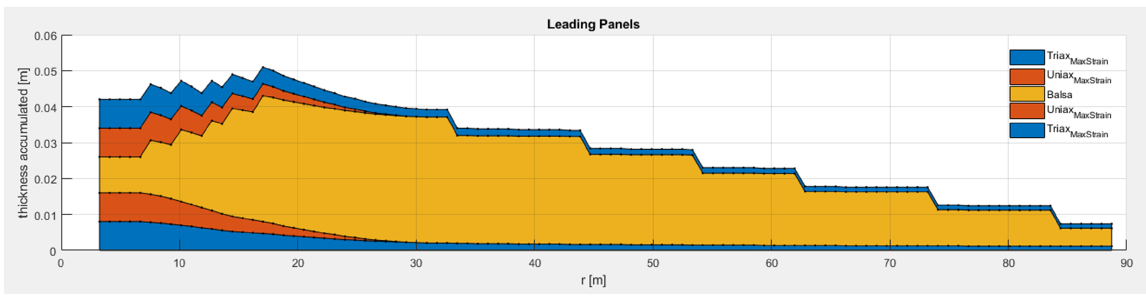
Modelling

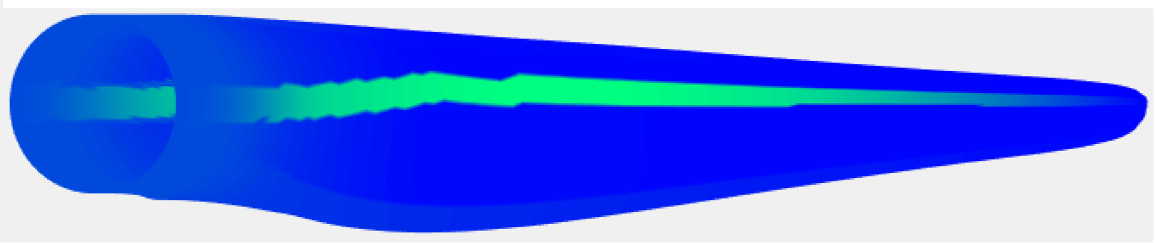
The wind turbine blade used in this thesis is from the 10MW reference wind turbine designed by DTU [3]. The isogeometric model of the wind turbine blade is created in the NURBS-based CAD software *Rhino*. The scope of the geometry modelling is to create a model that is analysis friendly. This means that the blade is separated into five well-defined surfaces called *patches*, where the two first are the airfoil surface and the trailing edge, and the three remaining patches represent the internal webs of the blade.

The IGA model is to be investigated with fewer numbers of degrees of freedom than the reference model. Since the number of control points used to define the geometry is quite huge, a model coarsening algorithm has to be applied. This is done with the *Rebuild* function in *Rhino*, which allows the user to coarsen and refine a surface while calculating the tolerance. The final step in rhino is to export the control points, and rearrange the coordinates to fit in the *Matlab* environment.

Method

In this thesis, a NURBS-based Kirchhoff-Love shell element developed by Josef Kiendl [4] is used for the isogeometric analysis. The code used for the analysis is the research Matlab code developed by Davide Proserpio. For the analysis, a composite of varying properties along the span is applied. The layup of the leading panels is shown as an example of how the thickness and material varies along the span. Also, the longitudinal effective stiffness is shown in the contour:

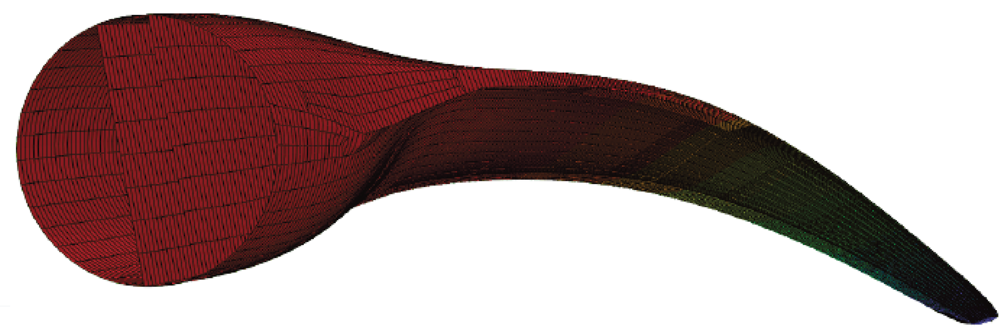


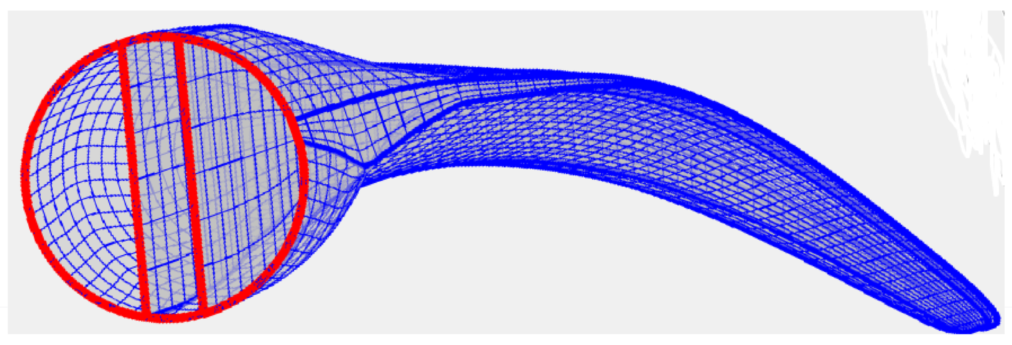


Results

The blade is exposed to two different load cases, which is gravity force of the self weight in negative and positive direction. The converged solution for the FEM analysis has 616 000 degrees of freedom, whereas the IGA counts 14 500 degrees of freedom.

Load Case	Tip Displacement FEM	Tip Displacement IGA	Deviation
Gravity: -9.81 m/s^2	-1.3023	-1.2979	0.34%
Gravity: 9.81 m/s^2	1.3023	1.2979	0.34%





Conclusions

- A coarsened NURBS model of the DTU RWT Blade is created in Rhino.
- Omitting the meshing procedure in IGA has been exploited throug geometry manipulation of a simple model.
- A reference finite element analysis is performed for two load cases, where tip displacement is reported as the output.
- Isogeometric structural analysis is performed on the balde model created in Rhino and compared with the reference tip displacement.
- The IGA model performs well, has much lower number of degrees of freedom and the tip displacement differentiates with 0.34% from the reference model.

Acknowledgements

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