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ScienceDirect

Energy Procedia 80 (2015) 294 – 301

Energy Procedia

12th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2015

Spline based mesh generator for high fidelity simulation of flow around turbine blades

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Abstract

Mesh generation involving complex geometries, such as wind turbine blades, is highly complicated. The problem is generally addressed using tetrahedral meshes, or hybrid meshes with hexahedral elements close to the body and tetrahedral elements elsewhere. The popularity of such mesh generators can be attributed to their associated ease of use and relative eutomation, which comes at the cost of numerical accuracy in the subsequent analysis. Added to this, such meshes can generally not represent the true geometry. Isogeometric analysis (IGA), offering an integration of analsis and CAD geometry through use of the same basis functions, has been catching up since 2005. The method offers demonstrably better accuracy, as well as an exact geometric representation. Since its inception, the method has been applied to problems from both fluid and structural mechanics. The availability of NURBS-based surface modeling software such as Rhinoceros has made it possible to create complex geometries with relative ease, but the lack of a volumetric spline-based mesh generator proves a bottleneck. In this paper we describe a mesh generator that has been developed at the Applied Mathematics Department of SINTEF ICT which can generate spline based block structured meshes of high quality for subsequent fluid or structural simulations.

Peer-review under responsibility of SINTEF Energi AS

Keywords: Mesh generation, Wind turbine blades, Computational fluid dynamics, Variable turbulent intensity

1. Introduction

This work presents an automatic block-structured spline-based mesh generator for wind turbine blades being developed to streamline the workflow from CAD modeling to simulation and analysis. It was developed initially for the NREL 5MW reference blade, but with a modular approach that will allow it to handle other geometries as well.

The whole procedure can be subdivided into two steps: solid modeling or blade construction and volumetric mesh generation. The mesh generation is performed using cubic splines everywhere, and the spline order is then adjusted in the final step before output, to also allow the creation of linear or quadratic models.

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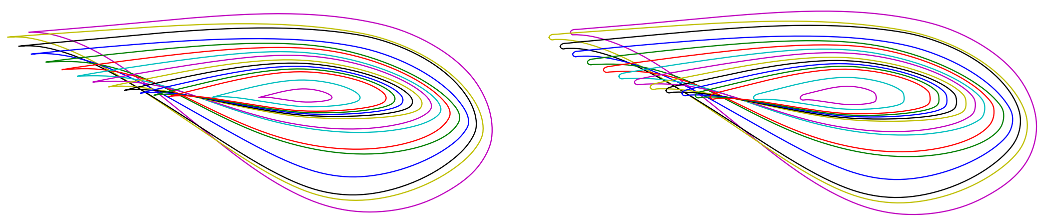
Peer-review under responsibility of SINTEF Energi AS
doi:10.1016/j.egypro.2015.11.433



(a) Sharp trailing edge

(b) Trailing edge modification (exaggerated)

Fig. 1: Airfoils for the NREL 5MW wind turbine blade.

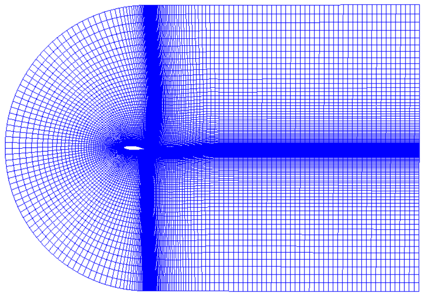


Fig. 2: A "C-mesh."

2. Methodology

2.1. Trailing edge modification of airfoils

The NREL 5MW reference blade [1] is defined in terms of cross-sectional data at 19 points along the blade axis from 2 m to 62.9 m. At each point is defined the airfoil shape (in terms of an ordered point cloud), the chord length (an isotropic scaling factor), the aerodynamic center and the twist angle. The innermost airfoils (until about 10 m) are cylindrical, the middle (until about 40 m) are Delft University airfoils of various kinds, and the remaining cross sections are NACA64 airfoils. See Figure 1a.

Each airfoil is defined as a sequence of points

$$\boldsymbol{x}_i = (x_i, f(x_i)) \pm \boldsymbol{n}_i t_i,$$

where $0 \leq x_i \leq 1$ is the chordlength parametrization, and f is a function defining the shape of the central line, on which the vector $\boldsymbol{n}$ is always normal. The numbers t_i then give half the thickness of the airfoil at each point.

The defining characteristic of the airfoils is a sharp trailing edge. Typically, this forces the construction of a "C-mesh" (Figure 2) with a large waste of degrees of freedom in regions where they are not required (above and below the trailing edge). In order to create a more efficient "O-mesh", we introduce a modification to produce rounded trailing edges, as seen in Figure 1b. This is realized as a modification to the thickness values, $\tilde{t}_i = t_i + \delta x_i$ will produce a trailing edge gap of width δ. A semicircle is then fitted in this gap with the required continuity to complete the modified airfoil.

Typically the trailing edge is chosen to be of uniform physical size, independent of the chord length, which means in practice that, for some airfoil with chord length c, the unscaled gap width δ must be chosen as $\delta(c) = \delta_0/c$. We have found small (around 1 cm) modifications to have negligible effect on observables (drag and lift). This corresponds to a modification that is between 0.22 % and 1.4 % of chord length. Figure 1b shows the effect exaggerated by a factor five.