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# Innovative approach to computer-aided design of horizontal axis wind turbine blades

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**Abstract**

The design of horizontal axis wind turbine (HAWT) blades involves several geometric complexities. As a result, the modeling of these blades by commercial computer-aided design (CAD) software is not easily accomplished. In the present paper, the HAWT blade is divided into structural and aerodynamic surfaces with a $G^1$ continuity imposed on their connecting region. The widely used method of skinning is employed throughout the current work for surface approximation. In addition, to ensure the compatibility of section curves, a novel approach is developed based on the redistribution of input airfoil points. In order to evaluate deviation errors, the Hausdorff metric is used. The fairness of surfaces is quantitatively assessed using the standard strain energy method. The above-mentioned algorithms are successfully integrated into a MATLAB program so as to enhance further optimization applications. The final surfaces created by the procedure developed during the present study can be exported using the IGES standard file format and directly interpreted by commercial CAD and FE software.



*Keywords:* Computer aided design; Wind turbine blade; Skinning; Compatibility of section curves

## 1. Introduction

The wind turbine blade, in terms of functionality, can be divided into structural and aerodynamic zones (see Fig. 1) [1]. The main objective in designing an aerodynamic zone is to convert the kinetic energy of wind into differential lift and drag forces which eventually result in main shaft torsional moment. On the other hand, the structural region is designed to sustain large amount of bending moments which are maximized on the blade root.

The design of wind turbine blades entails the selection of a series of airfoils with specified geometrical parameters, i.e. the airfoil type, chord length, twist angle as well as the position of airfoil centers in each radial section. There are numerous standard airfoils which can be chosen from open access databases according to the given requirements. These airfoils have a unit chord length and are commonly available with their x- and y-coordinates. For example, Fig. 2 shows the data points of the S182 airfoil developed for wind turbine blade applications [2].

For large wind turbine blades, the optimization process is also performed on the two-dimensional airfoil data in order to achieve better aerodynamic performance, alleviate loads on the structural section, and reach an extended fatigue life. In this regard, a very remarkable effort is reported by Mauslere [3], who introduced a flexible B-spline fitted to a set of given airfoil points. The algorithm for improving aerodynamic performance was then proposed and investigated.

During the first design stages of a wind turbine blade, the 2D airfoils are scaled and twisted according to the designer's intent. However, the wind flow experienced by any section along a blade is on a conical surface, which could be simplified to a cylinder [4]. By knowing the radial distance of the airfoil section to the center of rotation, it is possible to transform the original 2D airfoil into a 3D airfoil, which could improve aerodynamic performance [4]. The 2D to 3D conversion is is obtained by wrapping the planar airfoil to its virtual rotating cylinder [5,6].

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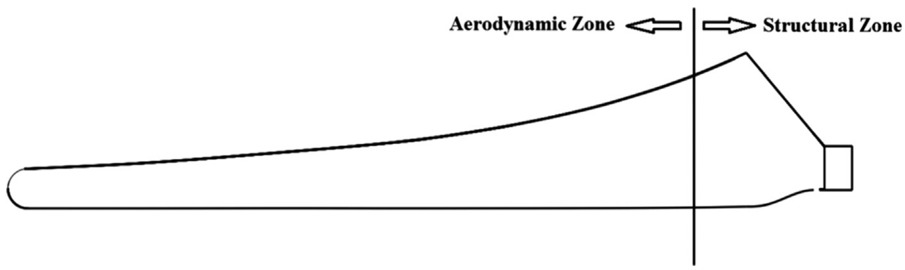


Fig. 1. A typical horizontal axis wind turbine blade.

The next step is to fit a parametric B-spline curve to 3D points which represent a 3D airfoil. Fitting a B-spline curve to a set of data points is usually defined by interpolation or approximation methods. In interpolation, the curve is precisely passed to the all data points. However in approximation, usually the sum square error between the data points and the corresponding points on the curve is minimized [7].

The blade's surface is constructed by skinning a B-spline surface through all approximated B-spline curves. Skinning is a process of blending the section curves to form a surface. Blending along the longitudinal direction can be achieved by interpolation or approximation; in interpolation the section curves are iso-parametric curves on the resulting skinned surface.

Some research has attempted to construct a desired surface with the given airfoil points. Perez et al. [8] focused on creating fairly accurate B-spline curves passing through airfoil points, but their process of surface construction was lacking. One drawback was the absence of a process for constructing compatible section curves, which is a crucial step before skinning [9,10]. Compatible section curves should have nearly the same knot vectors. Further details are found in Section 3. Hampsey [11] considered the problem of compatibility and solved it by selecting one airfoil type. Using the affine invariance property of the B-spline curve and surfaces, he constructed a blade surface for the aerodynamic zone without having analyzed curvature variations. Hampsey did not construct any surface for the structural zone.

The present work devotes attention to the process of constructing a smooth surface for the wind turbine blade so as to achieve minimal curvature variations. In the current study, compatible section curves are created by a novel method based on the redistribution of initial airfoil points. Due to the importance of curvature variations, the strain energy criterion is used to assess the fairness of approximated surfaces. The structural and aerodynamic sections are separately taken into consideration. A method of connecting aerodynamic and structural sections with the desired level of continuity is also presented. The proposed algorithms are successfully implemented in MATLAB V2012 software. The developed routine can export/import curves and surfaces to commercial CAD systems using the IGES format. This functionality is critical for blade optimization purposes. Further details are found in [12–14].

The present paper is organized as follows: Section 2 introduces basic definitions of B-spline curves and surfaces and also well-known approximation methods. The strain energy fairness criterion is also addressed in this section. In the next section, the skinning algorithm is stated and the proposed method of compatibility is introduced. The process of obtaining 3D airfoil points from standard 2D data is then explained. Section 4 describes the B-spline curve fitting method with the prescribed accuracy. The challenges of constructing assembled structural and aerodynamic surfaces are discussed in Section 5, followed by some examples demonstrating the applicability of the proposed method. The final section concludes with the set of algorithms developed for designing fair wind turbine blades.

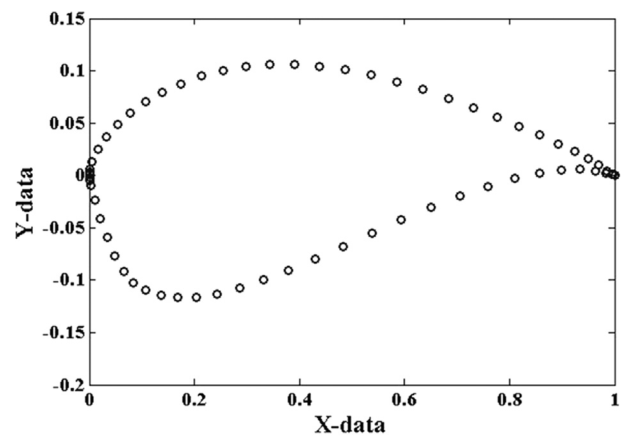


Fig. 2. Airfoil points of S182 NREL airfoil.

## 2. Basic definitions

B-spline theory is a parametric method of describing curves and surfaces. Outstanding properties and programming capabilities have made the method popular for CAD/CAM applications. A clamped B-spline curve is a piecewise polynomial which is expressed by [7]:

$$C(t) = \sum_{i=0}^{n} N_{i,p}(t) P_i \tag{1}$$

where $p$ is the degree and $P_i, \quad i = 0, .., n$ is the control polygon which is defined by $P_i = (x_i, y_i, z_i)$. The term $N_{i,p}(u), i = 0, \ldots, n$ represents B-spline basis functions that are defined on the knot vector, U:

$$\mathrm{U} = \underbrace{0, \ldots, 0}_{p+1}, t_{p+1}, \ldots, t_{m-p-1}, \underbrace{1, \ldots, 1}_{p+1} \tag{2}$$