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GENERIC MODEL OF WIND TURBINE BLADES

GENERIČNI MODEL LOPATIC VETRNE TURBINE

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Abstract

A wind turbine is a device that extracts energy from the wind, which has been shown to be one of the most viable sources of renewable energy. Current manufacturing technology enables the low-cost production of wind energy turbines, which is competitive with conventional sources of energy, especially in steady wind areas. The rotor blade is a key element in a wind turbine system. Most commercially available blades incorporate airfoil-shaped cross sections, which have been found to be very efficient at lower wind speeds. Computational fluid dynamics solve and analyse problems involving fluid flows. Many airfoil shapes are combined and analysed in order to achieve efficient blade design. In order to prepare various geometrical solutions for computational fluid dynamics analysis, time-consuming and error-prone work has to be done. In this paper, the automation of the process of preparing the various geometrical models for computational fluid dynamics analysis of wind turbine blade is described.

Povzetek

Vetrna turbina je naprava, ki pridobiva energijo iz vetra in izkazano eden izmed najbolj uspešnih obnovljivih virov energije. Aktualna tehnologija proizvodnje vetrnih turbin omogoča nizko ceno in stroške vetrne energije, ki je konkurenčna znanim konvencionalnim virom energije, posebej na območjih s stalnim vetrom. Lopatica rotorja je ključni element v sistemu vetrne turbine.

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Večina komercialnih vetrnih turbin ima lopatice v obliki profila letalskega krila, za katere je ugotovljena večja učinkovitost pri nižjih hitrostih vetra. Numerična dinamika tekočin omogoča reševanje in analizo tokov tekočin z uporabo računalniških numeričnih metod. Da bi dosegli učinkovito obliko lopatic je mogoče geometrijske oblike lopatic kombinirati in analizirati. Pripravljanje geometrije lopatic za numerične analize je zamudno in natančno delo. Članek opisuje avtomatizacijo procesa priprave različnih variant vetrnih turbinskih lopatic primernih za numerične analize dinamike tekočin.

1 INTRODUCTION

One of the major challenges in this century is the efficient use of energy resources, as well as the growing production of energy from renewable sources. There are several alternative forms of energy that have been explored and developed, including geothermal, solar, wind and hydroelectric power. The affordability and performance of renewable energy technologies is the key to ensuring its availability to the market.

A wind turbine uses the aerodynamic force of the lift to rotate a shaft, which in turn aids in the conversion of mechanical power to electricity by means of a generator. For large networks, modern wind turbines are connected to the grid in a wind farm in order to reduce the total electrical load. One significant downside of wind as a resource is its variable speed and fluctuating electrical output. The most common design of a wind turbine is the horizontal axis wind turbine, in which the axis of rotation is parallel to the ground, as shown in Figure 1.

Figure 1: *Wind farm in Lower Saxony, Germany, [1].*

The rotor consists of the hub and the blades for the wind turbine. These components are often considered the most important for cost efficiency. Today, most designs have three blades, and for better performance some designs implement pitch control for the angle of rotated blade. The turbine blades are manufactured from composite materials, including fiberglass-reinforced plastic, epoxy and wood laminates.

To achieve the maximum power from a given wind situation, the geometry of the blade is designed to provide the maximum power coefficient from the wind side, usually taking into consideration the average wind speed. Numerical solutions based on analytical equations are adequate tools for the design of a wind turbine blade in order to get maximum power from a given wind, [2].

Wind turbine blades' conceptual design is inherently a multi-disciplinary design process that involves numerous disciplines and forms of expertise. In this paper, how high-end CAD software can be used to automate the creation and preparation of different varieties of wind rotor blades' geometry for computational fluid dynamics analysis is investigated.

The generic model that is developed in this regard is able to automate the process of the creation and modification of the wind blade geometry, based on a series of parameters that define the geometrical characteristics of wind blades using V5 CATIA software.

2 WIND TURBINE AERODYNAMICS

During the operation of a horizontal axis wind turbine, the properties of the wind flowing around it are constantly changing in relation with the distance upstream or downstream of the flow field. Far upstream from the turbine, a circular boundary region starts forming, giving a cylindrical shape to the flow field. Such a boundary is marked by the rotor blades sweeping around the turbine axis, and it defines the so-called actuator disc concept, [2]. The NACA airfoil series were generated using analytical equations that describe the curvature of the geometric centre line of the airfoil section, as well as the section's thickness distribution along the length of the airfoil. Some researchers have used blended wings with two different types of airfoils in order to achieve the desired design.

3 NUMERICAL SIMULATIONS

Computational Fluid Dynamics (CFD) has been developed from mathematical methods and become an essential tool for almost any problem in fluid dynamics. It is commonly recognised as a numerical solution (by computational methods) of the governing equations that describe fluid flow. As a developing science, CFD has received extensive attention throughout the international community. All CFD analysis starts by defining the geometry to be used.

Numerical solutions based on analytical equations that allow the design of a wind turbine blade are available tools that can be used to extract the maximum power from a given wind situation, [2]. Usually, the geometry of the blade is obtained to provide the maximum power coefficient from a wind site, using a proper average wind speed, which is the result of adequate wind data measurements. The analysis has to consider the fact that wind power is proportional to the cube of the wind velocity. A complete design of a wind generator is a complex problem that includes the design of an optimum blade and many other turbine components, such as the tower design. While the rotational velocity of the blade can be accurately predicted with analytical models, the same rotational velocity cannot be properly predicted for wind speeds below and above the rated wind speed, [5].

The CFD method is a well-known technique applied to the solution of more complex fluid problems. A performance evaluation of a wind turbine rotor is one of these difficulties, [6].

4 CAD AUTOMATION

This article focuses on the automation of the design process of complex geometry such as wind turbine blades. The wind turbine models are creating mostly in CAD systems using Graphical User Interface to create geometry from cross-sections. The use of customised application interfaces can accelerate preparations of a model, reduce the numbers of iterations in input and make the generation of models easier to achieve. Since we consider the models to be investigated by numerical simulations, the same approximations are performed during geometry model generation to accelerate the process of mesh generation.

The design of an airfoil cross-section is governed by parametric equations based on form generation standards (e.g. NACA series). The cross-sections are created by fitting spline curves through points generated from equations. The developed programs, called macros or scripts, are used to input points, create splines and finally generate loft surfaces and body. To input every single point by coordinates for every cross-section is very tedious and error-prone work. Modifications are even more difficult.

Macro programming is one of several automation techniques that are usually included within CAD systems. Available techniques could be classified in three types:

- *Kernel APIs* refers to a core functionality embedded within CAD systems. ACIS and Parasolid are two commercially available kernels that are used in CAD systems. The kernel functionality is made available through libraries of APIs, the functions of which can be called in programs written in a high-level programming language. They require knowledge of computer programming with high analytical content.

- *Macros* are scripted instructions that are executed in interpretive way by the process running simultaneously within CAD system. Many CAD systems have supplemented their original macro programming languages with VBA; consequently, the main advantage of using VBA is utilisation integration and simplification with other applications based on the Windows framework. Macro programming provides the possibility of executing the same operations that could be performed by the GUI. Macros execute more slowly than compiled code but still faster and more error free than manual work with such a cloud of points.

- *Knowledge-Based* automation tools have been developed to support the development of Knowledge-Based Engineering applications inside the CAD environment. The design process can be captured, leading to the reduction of redesign iterations for new designs. While macros emulate interactions with the CAD system, these tools emulate engineering processes that are related to creating new geometry or making changes to the existing one. Training and in-depth computer knowledge is required for these tools.

From the three described techniques that enable automation in the design process, the use of macros is best suited for our purpose. The other two tools are more complex and require

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programming skills with non-procedural programming languages and deep understanding the basic theory of solid modelling.

CAD automation is useful when the modelling tasks are practically impossible to do manually because the very large number of points, and great effort needed to create such geometry is time consuming, error prone and very precise and delicate work. Automation is welcome when there are more users who need to repeatedly reuse variants of the same components and when the automation process reduces the time needed for managing large numbers of models or models with such complex geometry with a large number of calculated points.

To obtain the geometry of the wind turbine blade, Excel is used as the starting application. In spreadsheets, it is easy to manage and prepare all necessary data for easier use of VBA macros in a suitable manner for transferring and managing data in CAD system, [4].

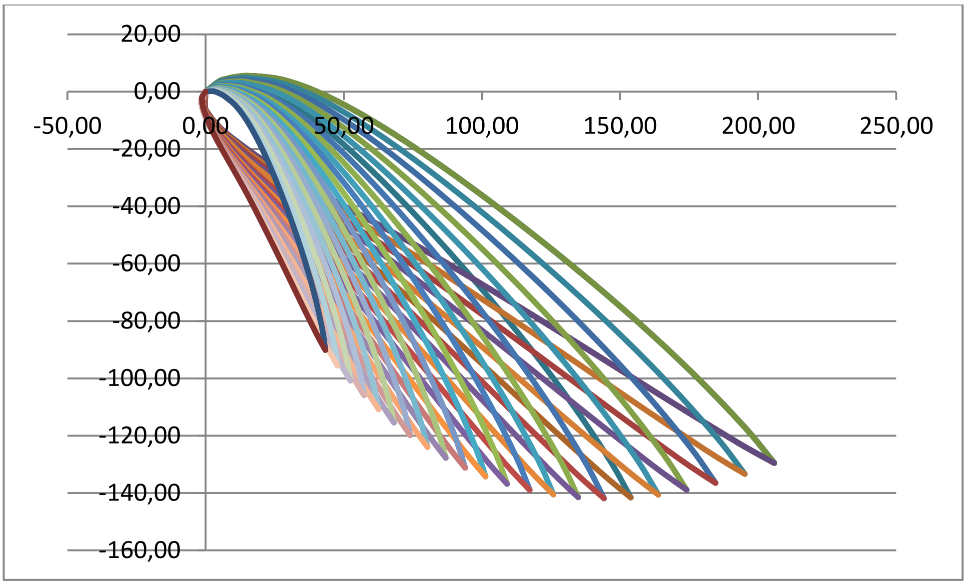

Figure 2: *Blade profiles from NACA 4415.*

In CATIA, the VBA Integrated Development Environment is used to read all data in proper order for further processing through program structures. A high level of understanding of how to access and manipulate the underlying object structure of a CATIA parametric model is needed. The base of the program is obtained using the Macro Recorder to create code snippets that can be implemented into macros to reduce the time for development.

The process involves the automatic creation of a parametric model using user inputs through the VBA programming interface. The user input in CATIA is running the macro and inputs the data file. The model is built from scratch, and all the changes are performed in the Excel data file. Such automation is useful when the part's geometry is defined by physical equations.

Design steps from 1 to 4 are performed in Excel, from 5 to 9 executing a macro within CATIA, and remaining steps with GUI in CATIA.

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1. set up NACA profile generator;
2. generate points (X,Y) of profile on different layers (Z) from equations;
3. rearrange points to start and finished numbering with outlet edge;
4. generate names of points incrementally;
5. pass point coordinates to CATIA;
6. generate airfoil sections with spline, starting and finishing in outlet edge with no closing – the result is a sharp edge needed for numerical analyses;
7. generate guidelines, from points with the same name on different layers;
8. loft sections using guidelines;
9. close surface into solid body;
10. add the blade into the assembly with prepared shaft and perform circular pattern;
11. save result in IGES format for numerical analyses.

Section geometry is based on the four-digit NACA series, the parametric equations for which are given in Figure 3. These equations are set up on an Excel sheet to create points on a section profile based on a NACA number (4415 in the example in Figure 3) and a cord length. Profile point coordinates are updated on the spreadsheet based on each cord length and passed back to CATIA to create splines on each sketch layer. Sketches are lofted (multi-section solid or surface feature in CATIA) using the leading and trailing edges as guide curves to create the final model of the airfoil.

In Figure 4, versatile models that were generated using automated processes are shown.

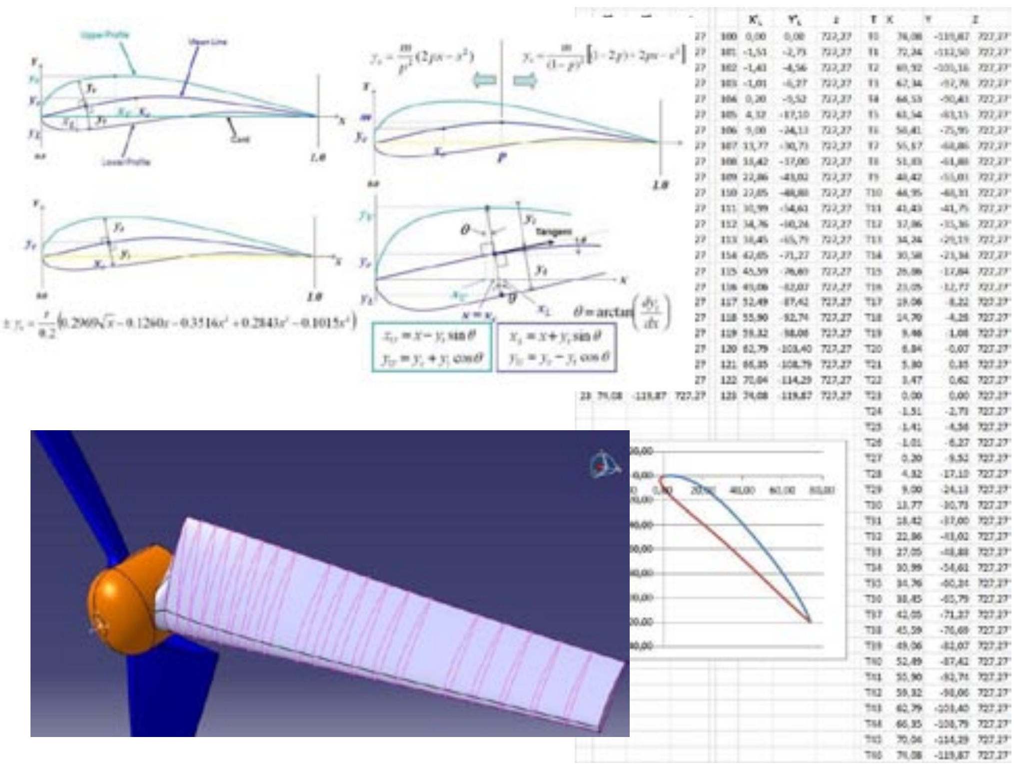

Figure 3: *Parametric equations for generating NACA airfoils [3]; generated and manipulated data of wind turbine blade; wind turbine geometrical model.*

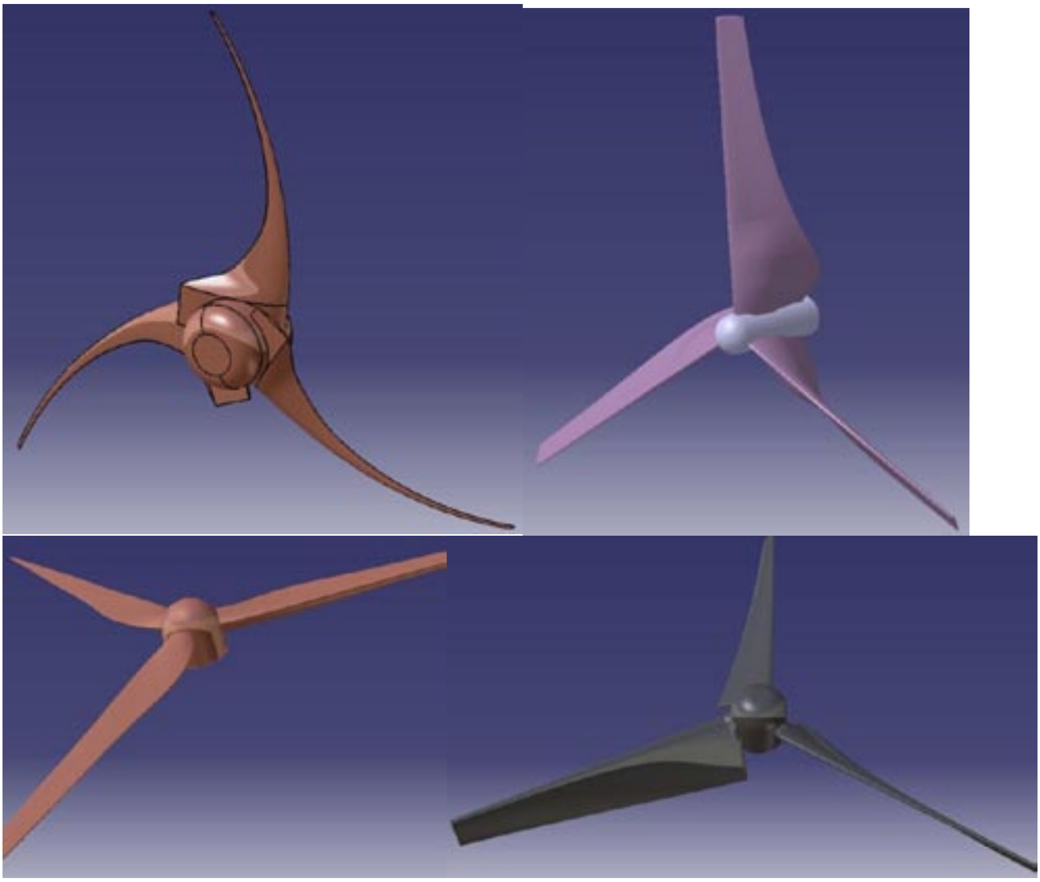

Figure 4: *Examples of generated wind turbines.*

5 CONCLUSIONS

This paper presents CAD automation involving skills developed for VBA programming in Excel to encompass the use of VBA in creating and manipulating parametric 3D CAD models in CATIA. It is important to note that there is a strong correlation between programming and 3D parametric modelling. For example, variables in programming are conceptually similar to the parameters that control size and shape in a CAD model.

The process of the generation of geometry of wind turbine blades is adapted for the next step in the validation process, the CFD. The experience in numerical analyses preparation, i.e. structural meshing of the domain, creating the surfaces needed to implement boundary and initial conditions, is integrated into the macro-programme.

Process automation works for versatile types of airfoil designs, including wings, spoilers, propellers and wind turbines.

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