

## 3D Analysis of Machining of Wind Turbine Blade Using CAD/CAM Software Part 2. Wind Turbine Blade Modelling

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*Received January 25.2016; accepted January 26.2016*

**Summary.** This work is an analysis of construction and creation of a 3D model of a wind turbine blade in a CAD environment, using SOLIDWORKS on the basis of forces influencing the blade, which were determined using WIATRAK 1.1 software. The presented process is related to the issues of 3D modelling of a wind turbine blade and simulation of fabrication process in the CAM environment.

**Key words:** geometry, blade, aerodynamic forces, calculations.

stall, the airflow breaks away from the upper surface of the blade, which results in a lift loss [1, 12].

Turbines that can modify the angle of attack of their blades analyze the incoming wind pressure and modify the AOA in such a way as to maintain the nominal production of electricity [3]. In case the nominal production is not reached, the blades are twisted by an angle of incidence  $\varphi$ , which is analytically calculated using specialized aerodynamic software used in aviation and wind power sector [7, 19, 20].

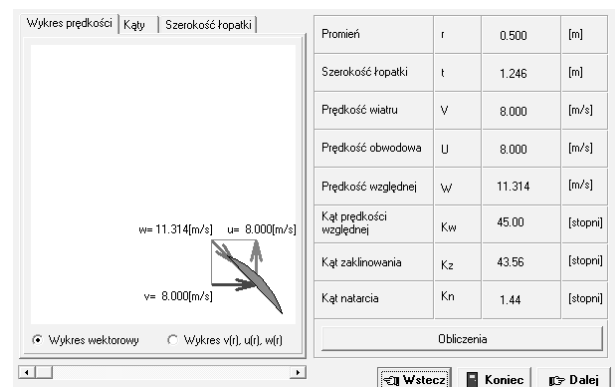
### INTRODUCTION

The basic assumption for manufacturing a wind turbine blade is creation of a solid and light structure with parameters correlated with the aerodynamic assumptions [8, 17]. The required shapes of aerofoil profiles used in constructions with a horizontal rotation axis are certainly non-linear [6, 11]. This determines that the shapes are unique and difficult to produce. Additionally, most blades are twisted and their longitudinal section forms a cone which adds to the complexity of the designed solid [9, 13, 14]. The production method that meets these requirements consists of two parts: the creation of main spars of the wing and the external cladding. The cladding ensures the required aerodynamic properties and the spar carries the whole construction.

The twisted shape of the blade which correlates to the increase of their radius is realized in order to optimize their work [10, 16]. This solution is especially important in case of turbines characterized by a fixed angle of attack – regulated using servomechanisms. The lower the angle the higher the required wind pressure to maintain the lift force on the blade [4, 18]. The larger the angle, the larger the force that moves the blade, however this relation is maintained only up to the critical angle of attack, after which the lift force is steeply decreased. This phenomenon is called a stall. In case of a

### GEOMETRY AND AERODYNAMIC FORCES

Geometric and aerodynamic calculations have been performed for sections of the blade all along its length. The figures below present the calculation scheme for extreme cases, i.e. the beginning and end of a given element. Figures 1-6 present the construction parameters of the blade and resultant speeds at a given wind; Figures 7 and 8 present the aerodynamic forces present on the CLARK Y profile.



**Fig. 1.** Speed graph for initial part of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

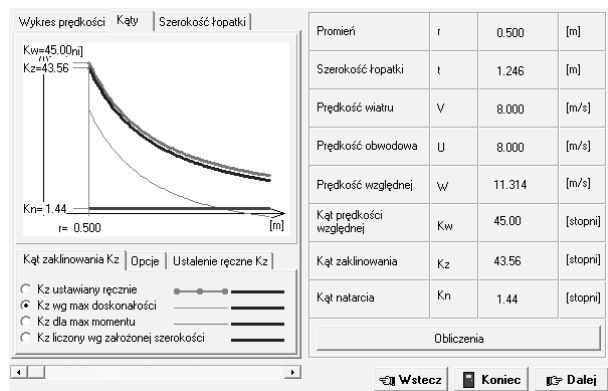


Fig. 2. Determination of initial angles of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

The angle of incidence in relation to the perfect L/D angle determines the optimal and desirable operating conditions for a wind turbine blade [2, 5]. This is due to the fact that the relative speed curve is identical to the curve of the perfect L/D angle

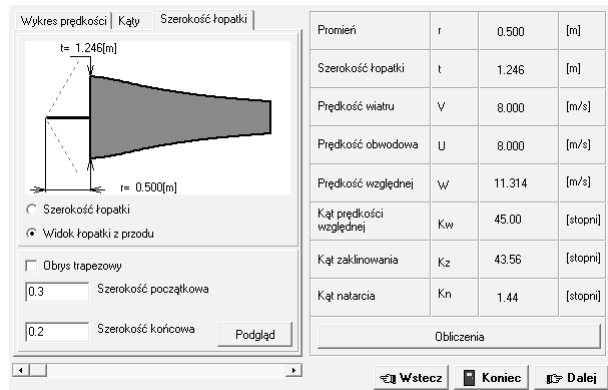


Fig. 3. Initial width of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

The initial width of a wind turbine blade is the largest width and is the closest to the rotor’s axis. Such geometrical conditions determine the largest value of mechanical load present at that point.

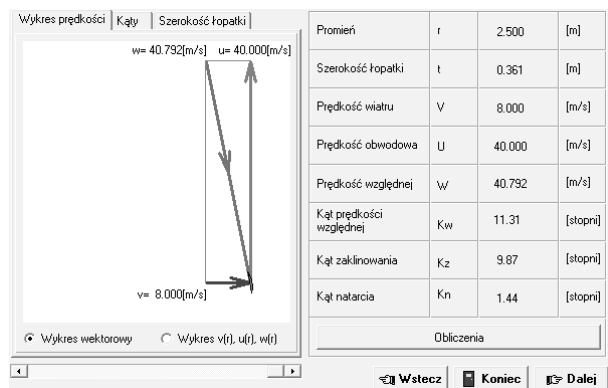


Fig. 4. Speed graph for final part of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

As we see the speed vectors in the final profile of the wind turbine blade are much larger than in its initial part.

This is due to the larger moment of inertia and increased radius from the investigated point from the rotor’s axis.

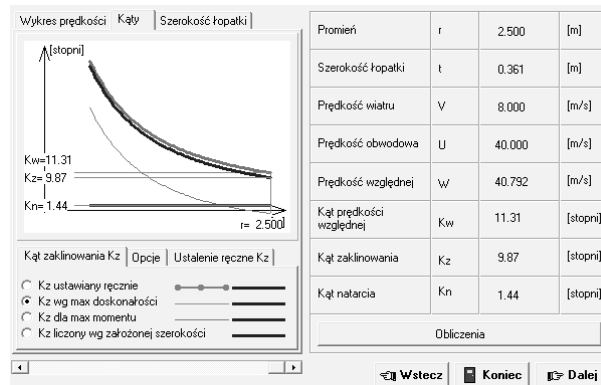


Fig. 5. Determination of the final angles of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

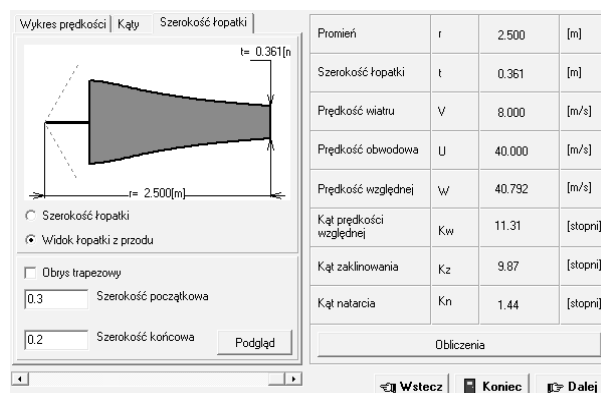


Fig. 6. Final width of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

The final section of the blade, apart from high speeds, is characterized also by the lowest width of the section and the largest change in the angle of incidence. These values are presented in Fig. 6. The figures below present the forces resulting from the wind at a given speed.

In Figures 7 and 8, apart from the wind forces impacting the blade’s section, the total forces impacting the whole wind-wheel were calculated – which is shown in Figures 7 and 8. These are constant values for the whole section of the wind engine, that’s why they have the same value for the final sections of the blade.

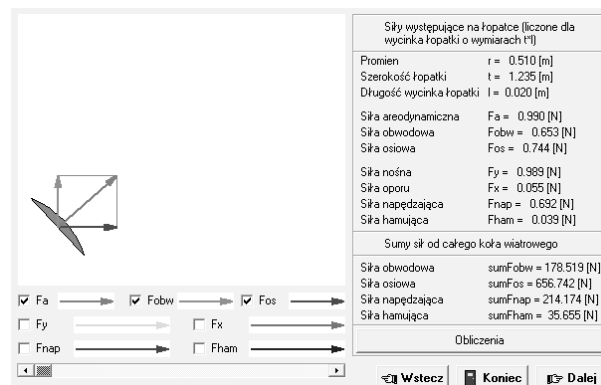


Fig. 7. Forces on initial part of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

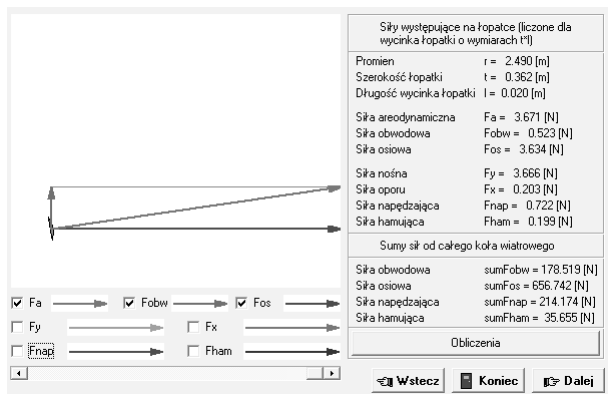


Fig. 8. Forces on final part of a wind turbine blade – WIATRAK 1.1 software [own elaboration]

CREATION OF A BLADE IN CAD SYSTEM

On the basis of the calculated geometric and analytic parameters, a 3D model of a given blade will be created. The process starts with the creation of the aerodynamic profile curve. This size of the curve is adapted to the first section of the blade which is located nearest to the rotor’s axis, which is shown in Figure 9.

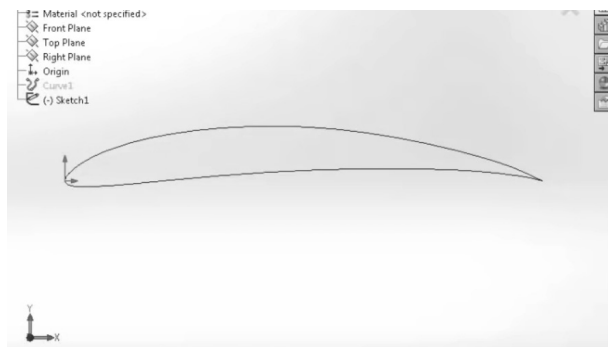


Fig. 9. CLARK Y profile curve – SOLIDWORKS software [own elaboration]

Next, based on the knowledge of the parameters of the last section of the blade and its angle of incidence, its geometry is created on the surface at the distance equal to the given length of the blade (Fig. 10).

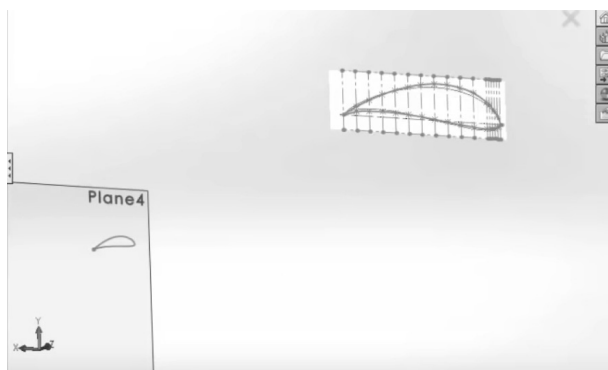


Fig. 10. End sections of a wind turbine blade – SOLIDWORKS software [own elaboration]

Having the two characteristic sections, when creating a given solid, it is possible to create the required section of the blade when connecting the two surfaces (Fig. 11).

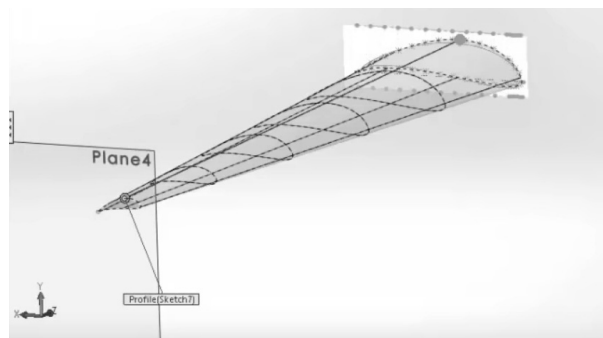


Fig. 11. Extension of surfaces making a wind turbine blade – SOLIDWORKS software [own elaboration]

The last part is the creation of connection between the blade and the rotor. This element was constructed in a schematic manner in order to visualize its existence. It is not the subject of the research and shall not be subjected to machining (Fig. 12).

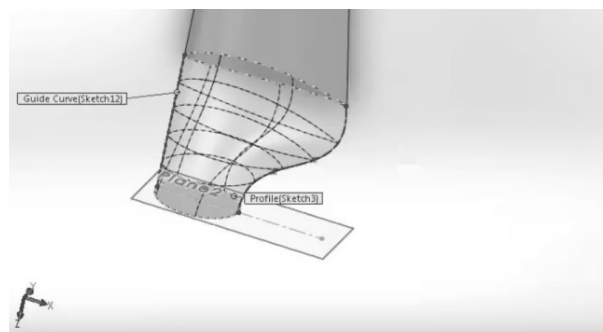


Fig. 12. Extension of surfaces making a wind turbine blade’s connection – SOLIDWORKS software [own elaboration]

The prepared 3D model was visualized on 4 projection planes in sketch view and realistic view in Figures 13 and 14. The first visualization shows the construction lines of the element, the existing angle changes and the support structure, and the next visualization shows the general view of the geometry of the construction and its factual appearance.

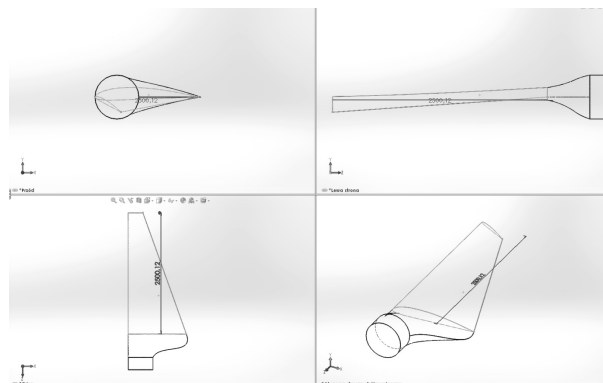
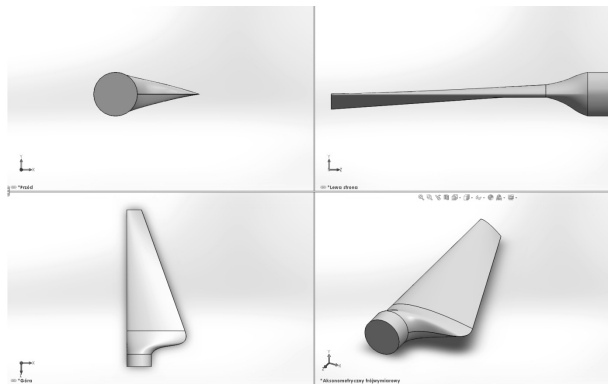


Fig. 13. Sketch view of a wind turbine blade – SOLIDWORKS software [own elaboration]



**Fig. 14.** Realistic view of a wind turbine blade – SOLIDWORKS software [own elaboration]

### CONCLUSIONS

1. The wind turbine blade for the chosen CLARK Y, due to its geometry may be used for wind engines of small power. This results from the fact that the diameter of the rotor is 5 m, i.e. it does not exceed 15-20 m, which is the limit value for such constructions.
2. For the chosen wind speed  $V_0 = 8$  m/s and the fixed angle of attack  $\alpha = 1.44$ , the resultant aerodynamic forces on the sections are from  $F_a = 0.990$  N for the initial section nearest the axis, up to  $F_a = 3.671$  N in its final section. These values are also directly determined by the change in the angle of incidence  $\beta$  between  $9.87 - 43.56^\circ$ . With its increase, the aerodynamic force increases, however this trend is continued only to a certain critical point, above which a drastic fall of the lift force is observed. In the present research this point was not reached, which is a condition for the desired operation of the blade.
3. All the above parameters imply the proper dimensions of the designed element. Its length is 5m and its width is variable: at its thickest point, i.e. the initial section it is 1.246 m and in the final section it is 0.361 m.
4. The 3D model of the analyzed element was created using SOLIDWORKS software. It offers complex, 3D modelling of the machined elements and is one of the most commonly chosen software suites in the engineering world. The aim of its selection was achieving the highest possible accuracy and precision in the representation of the calculated geometry of the blade. Additionally, the resultant CAD file is compatible with CAM software, which enables the use of the said file during the simulations of the manufacture process.

### REFERENCES

1. **Ablamowicz A., Nowakowski W. 1980.** Podstawy aerodynamiki i mechaniki lotu. Wydawnictwo Komunikacji i Łączności. Warszawa.
2. **Afungchui D., Kammoun B., Chauvin A. 2003.** Development of a Wind Turbine Blade Profile Analysis Code

Based on the Singularities Method. Journées Internationales de Thermique.

3. **Barzyk G. 2001.** Układ sterowania oraz model siłowni wiatrowej, Politechnika Szczecińska.
4. **Bazilevs Y., Hsu M.C., Akkerman I. 2010.** 3D simulation of wind turbine rotors at full scale. Part I: Geometry modeling and aerodynamics, International Journal for Numerical Methods in Fluid.
5. **Chandrala M., Choubey A., Gupta B. 2012.** Aerodynamic Analysis Of Horizontal Axis Wind Turbine Blade. International Journal of Engineering Research and Applications (IJERA).
6. **Draganov B., Kozyrskiy V. 2013.** Towards the analysis of process fluctuation in wind turbine. Annals of Warsaw University of Life Sciences – SGGW. Agriculture No 62 (Agricultural and Forest Engineering). 81-84.
7. **Gretchen E., Luscher D.J. 2011.** Modeling the Structural Dynamic Response of Wind Turbines. Mid-Project Review Intelligent Wind Turbine Laboratory Directed R&D Los Alamos National Laboratory.
8. **Griffith D.T., Carne T.G. 2010.** Experimental Modal Analysis of Research-Sized Wind Turbine Blades. Sound&Vibration.
9. **Hansen O. 2008.** Aerodynamics of Wind Turbines (2nd Edition). Earthscan.
10. **Ishihara T., Ishii H., Nishio M. 2011.** Maximum wind loads on a wind turbine under operating conditions. EWEA.
11. **Jafri S. M., Eltaher A. 2011.** Dynamics of Offshore Wind Turbines, International Offshore and Polar Engineering Conference. Maui. Hawaii. USA. June 19-24, 2011.
12. **Manwell J.F., McGowan J.G., Rogers A.L. 2002.** Wind Energy Explained – Theory, Design and Application. American Wind Energy Association. Washington DC.
13. **Pawlak M. 2004.** Aerodynamic forces and Horizontal Axis Wind Turbines, 6th International Scientific Conference. Applied Mechanics. Slovakia.
14. **Pawlak M., Czapla T. 2006.** Zagadnienie interakcji pomiędzy aerodynamicznym i strukturalnym modelem elektrowni wiatrowej. Modelowanie inżynierskie.
15. **Roos R., Timmer T. 2014.** Design of Airfoils for Wind Turbine Blades. DUWIND. Section Wind Energy.
16. **Schubel P. J., Crossley R.J. 2012.** Wind Turbine Blade Design. Energies.
17. **Świtoński E., Jureczko M., Mężyk A. 2007.** Optymalne projektowanie kompozytowych łopatek elektrowni wiatrowej. Acta mechanica et automatica.
18. **Wizelius T. 2007.** Developing wind power projects: theory and practice. Earthscan.
19. [www.airfoildb.com/foils/1406](http://www.airfoildb.com/foils/1406) – dostęp na dzień 27.02.2016.
20. [www.en.gammaenergy.it/windpower/main-components.html](http://www.en.gammaenergy.it/windpower/main-components.html) – dostęp na dzień 27.02.2016.
21. **Verelst D. 2006.** Flexible wind turbine blades: a FEM-BEM coupled model approach. Delft University of Technology.

ANALIZA 3D OBRÓBKI SKRAWANIEM ŁOPATKI  
TURBINY WIATROWEJ PRZY WYKORZYSTANIU  
OPROGRAMOWANIA CAD/CAM  
CZ. 2.: MODELOWANIE ŁOPATY TURBINY  
WIATROWEJ

**Streszczenie.** Praca stanowi analizę konstruowania i wykonania modelu 3D łopaty turbiny wiatrowej wykonanego w środowisku CAD za pomocą systemu SOLIDWORKS w oparciu o działające na niego siły, które zostały wyznaczone przy pomocy programu WIATRAK 1.1. Przedstawiony proces dotyczy zagadnień z zakresu modelowania 3d łopaty turbiny wiatrowej oraz symulacji wytworzenia zaprojektowanego elementu w środowisku CAM.

**Słowa kluczowe:** geometria, łopata, siły aerodynamiczne, obliczenia.