Optimization Of Maximum Lift To Drag Ratio On Airfoil Design Based On Artificial Neural Network Utilizing Genetic Algorithm

Article *in* Applied Mechanics and Materials · January 2014

DOI: 10.4028/www.scientific.net/AMM.493.123

5 authors, including:

Ismoyo Haryanto
Universitas Diponegoro
41 PUBLICATIONS **29** CITATIONS

Nazaruddin Sinaga
Universitas Diponegoro
79 PUBLICATIONS **26** CITATIONS

Citra Asti Rosalia
Universitas Diponegoro
1 PUBLICATION **4** CITATIONS

Aditya Pratama
Institut Teknologi Sepuluh Nopember
2 PUBLICATIONS **5** CITATIONS

Applied Mechanics and Materials Vol. 493 (2014) pp 123-128
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.493.123

Optimization Of Maximum Lift To Drag Ratio On Airfoil Design Based On Artificial Neural Network Utilizing Genetic Algorithm

Ismoyo Haryanto[1,a], MSK Tony Suryo Utomo[1,b], Nazaruddin Sinaga[1,c], Citra Asti Rosalia[1,d], Aditya Pratama Putra[1,e]

[1]Department of Mechanical Engineering, Diponegoro University, Kampus Tembalang, Semarang 50275, Indonesia

[a]Ismoyo_h@undip.ac.id; [b]msktonysu@yahoo.co.id; [c]nazarsinaga@undip.ac.id; [d]citraastirosalia@yahoo.com; [e]aditionaler_mech@yahoo.com

Keywords: Aerodynamics, airfoil, Artificial Neural Network, CFD, Joukowski Transformation, Genetic Algorithm.

Abstract. This paper deals with an alternative design method of airfoil for wind turbine blade for low wind speed based on combination of smart computing and numerical optimization. In this work, a simulation of Artificial Neural Network (ANN) for determining the relation between airfoil geometry and its aerodynamic characteristics was conducted. First, several airfoil geometries were generated through transformation of complex variables (Joukowski transformation), and then lift and drag coefficients of each airfoil were determined using CFD (Computational Fluid Dynamics). In present study, the ANN training was conducted using airfoil geometry and its aerodynamic characteristics as input and output, respectively. Therefore, lift and drag coefficients can be directly determined only by giving the airfoil geometry without having to perform wind tunnel experiment or numerical computation. Moreover, the optimization was conducted to obtain an airfoil geometry which gives maximum lift to drag ratio (C_L/C_D) for specific Reynolds number. For this purpose Genetic Algorithm (GA) was applied as optimizer. The results were validated using commercial CFD and it can be shown that the result are satisfactory with error approximately of 6%.

Introduction

Wind is one of renewable energy resource that being developed rapidly nowadays. Extraction of this energy resource can be conducted using wind turbine installations. Nevertheless, according to study results conducted by LAPAN, the development of wind power plant in Indonesia deals with main problems in association with low wind speed (average 2,5 – 6 m/s) [1]. On the other hand, low wind speed causing the wind turbines are unable to operate optimally since it produces relatively small kinetic energy. Although some researchers have developed diffuser augmented wind turbine to improve wind turbine efficiency for low wind speed [2][3], but from construction point of view and economical consideration this construction is complicated as well as expensive. Therefore, for optimizing the use of wind energy in Indonesia, a developing of wind turbine which able to operate at low wind speed is needed. For this purpose high performance gains from the wind can be accomplished through aerodynamic optimization of wind turbine blades. Because the profile of the blade has a great influence to the efficiency of the rotor in increasing the lift for generating sufficient torque and since the blade in the flow fields also produces drag which is perpendicular to the lift and its presence must be minimized, maximizing of wind turbine blade power can be performed by choosing airfoil shape having maximum lift to drag ratio (C_L/C_D) [5,6,7,8,9].

Design of wind turbine blades nowadays is conducted by selecting airfoil with specific aerodynamic characteristics [10]. The main weakness in this design procedure is that the optimization performance may be limited because the airfoil is determined in advance and not changed during the optimization process so that the airfoil shape can not be used as a design variable. As a result, the obtained optimum solution may not truly optimum. An alternative method of airfoil design for wind turbine blade has been developed in this study. This method utilizing smart computing using ANN so that determination of aerodynamic characteristics can be obtained directly by giving coordinate point to the trained network without analyzing using CFD or conducting wind tunnel measurement. Therefore, in designing of wind turbine blades the airfoil shape is no longer limited and the design process can be conducted more freely with optimum result. In this study, as an optimizer a Genetic Algorithm (GA) was applied.

Methodology

As mentioned before that by applying ANN the aerodynamic characteristics of airfoil can be obtained only by giving coordinate point as input to the trained ANN. For this purpose, a transformation of complex variable named Joukowski transformation was applied for generating an airfoil profile by transforming a specific circle. A different airfoil profile can be obtained by taking different centre coordinate of the circle. Furthermore, a number of airfoil profiles generated by Joukowski transformation are analyzed using CFD to obtain coefficients of lift, drag, and aerodynamic moment. A selected ANN then can be trained based on a database which relates centre coordinate of the circle as input and the aerodynamic characteristics as output. Using this trained ANN, for a given specific centre coordinate of circle the aerodynamic characteristic for related airfoil profile can be determined directly without conducting wind tunnel measurement or numerical computation. An optimization process may be carried out to find airfoil shape having highest value of maximum C_L/C_D. Because of its ability to reach global optimum solution [11], in this study the Genetic Algorithm (GA) was applied.

Airfoil Modelling

In this work, the Joukowski transformation was applied for generating airfoil geometry. This transformation has the property of transforming circles in the z-plane into shapes that resemble airfoils in the w-plane [12]. The circle in the z-plane is defined by the equation

$$z = be^{i\theta} \tag{1}$$

where b is circle radius, and θ ranges from 0 to 2π. It has to be noted that z in Eq. 1 is complex variable and can be expressed as $z = x + i\,y$, where $i = \sqrt{-1}$. The Joukowski transformation is then formulated as [12]

$$w(z) = z + \frac{\lambda^2}{z} \tag{2}$$

Where w is the function in the transformed plane. The resulting shape of the transformed function is determined by the transformation parameter, λ. The airfoil shape is realized by creating a circle in the z-plane with a centre that is offset from the origin. The desired transformation parameter then is given as [12]

$$\lambda = b - |s| \tag{3}$$

Where s is the centre coordinates of the circle. The x coordinate of the centre of the circle therefore determines the thickness distribution of the transformed airfoil. If the centre of the circle in the z-plane is also offset on the y axis, the Joukowski transformation yields an unsymmetrical, cambered airfoil. In other word, the y coordinate of the circle centre determines the curvature of the transformed airfoil. This transformation is illustrated in Fig. 1. The different profile of airfoils can be obtained by changing centre of the circle on Joukowski transformation.

ANN Architecture

Fig. 2 shows ANN architecture used in this study in which the centre coordinates of the circle (x,y) as input and the aerodynamic coefficient obtained from CFD analysis as output. The training of the ANN was conducted using various layer configuration and training algorithm with MSE target of 2.10^{-3} and maximum epochs of 10,000. More detail explanation can be found in Ref. [13].

Fig. 3 illustrated the comparison between CFD analysis result (target) and present method of C_L - α and C_L - C_D in which the centre of the circle of z = (-0.0960 + 0.1140i) was chosen as a case study. In Fig. 3 the remark of variation *a* until variation *d* indicate the layer configuration and the training algorithm used in the ANN of this study as explained in Refs. [13,14]. It can be seen that the present method, although using various layer configuration and training algorithm, met to the results of the CFD analysis. Therefore, utilizing this ANN one can determine aerodynamic characteristics of Joukowski airfoil with satisfaction without conducting CFD analysis or experimental measurement.

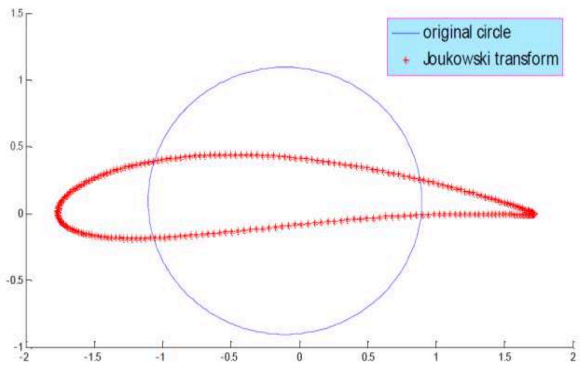


Figure 1. Joukowski Transformation

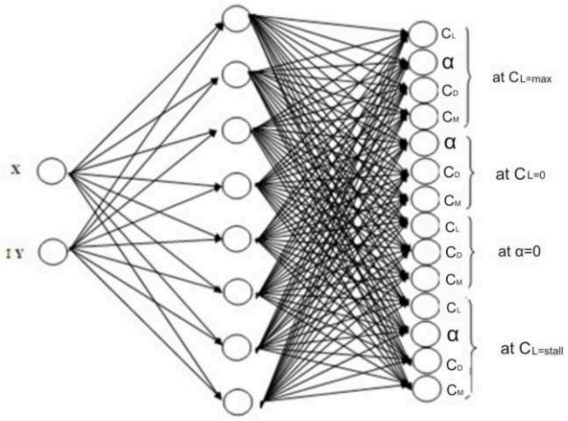
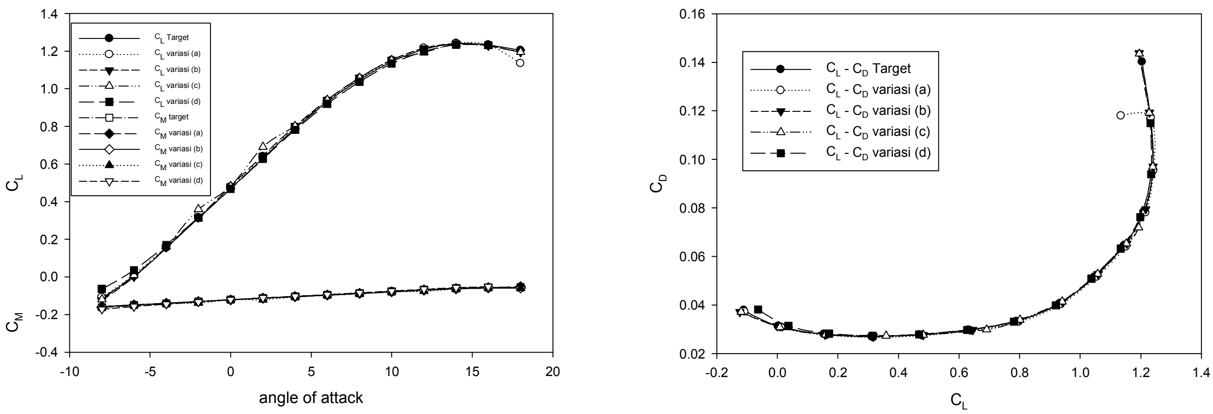


Figure 2 ANN Architecture



(a) (b)

(a) Figure 3. Comparison of (a) C_L - α and (b) $C_L - C_D$ of CFD (target) and present method

Optimization Results

Formulastion of the optimization problem to obtain the airfoil shape having greatest value of maximum C_L/C_D for specific Reynolds number can be stated as follow

$$\begin{aligned} &\text{Find } (x,y) \text{ such that} && \text{Maximize } C_L/C_D)_{max} \\ &\text{Subject to} && -1.0 < x < 0 \\ & && 0 < y < 1.0 \end{aligned} \tag{7}$$

Eq. 7 is an constrained optimization formulation with x and y as design variables and $C_L/C_D)_{max}$ as objective function. The constraints $-1.0 < x < 0$ and $0 < y < 1.0$ in Eq. 7 may be added to ensure that the Joukowski tranformation results give airfoil profile form. The GA was chosen to obtain optimum solution of Eq. 7. Tabel 1 shows parameters of GA which were applied in this study. Meanwhile, Fig. 4 illustrates the best fitness and the mean fitness of present optimization.

Tabel 1 Parameter of Genetic Algorithm

Parameter	Function or Value
Population type	Double vector
Population size	20
Generation	100
Selection	Stochastic uniform
Crossover	Scattered
Fitness scaling	Rank

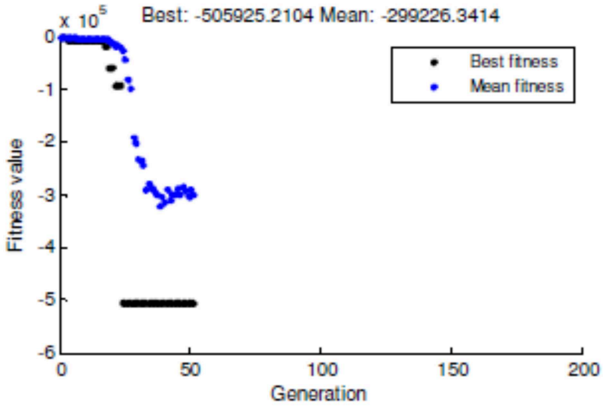


Figure 4. Best and mean fitness

A comparison of optimization results obtained from GA and based-gradient methods in present study is depicted in Table 2. It can be seen that GA give better resluts than based-gradient method which is indicated by the value of $C_L/C_D)_{\max}$ of 31.101 by the GA and 29.960 by the based-gradient methods. In generally optimum lift coefficients obtained from GA is greater than those obtained from base-gradient method, while the values of the coefficient of drag in optimum condition almost similar for both methods. It is iteresting to be noted that although the value of the angle of attack at zero lift obtained from GA is greater than the angle of attack at same condition obtained from based-gradient method, that values are almost similar for both methods in condition of maximum lift. Because in design of an airfoil the aerodynamic parameter of $C_L/C_D)_{\max}$ is most important than the others, thus it can be concluded that the GA give better results than the based- gradient method. Fig. 5 shows that optimum shape of airfoil obtained from GA is different by those obtained from based-gradient method.

For ensuring the satisfaction of the results obtained in present study, the optimum results were validated with CFD analysis. Figs. 6 show the comparison of aerodynamic characteristics in optimum condition of present method (solid lines) and CFD analysis (dotted lines). In Fig. 6a the both values of C_L at the angle of attack of 0° to 8° are visibly coincide, but the state of stall occurs at a different angle. In this figure it also can be seen that the maximum values of C_L and related angle of attack obtained by present method are lower than those obtained by CFD analysis. In contrast, the values of C_D between the two graphs are almost entirely coincide as shown in Fig. 6b. Fig. 6c illustrates the relation between C_L and C_D for optimum airfoil. It showed that although the values of C_D obtained from both method give a good accordance, the present method in generally give lower results of C_L. Meanwhile, Fig. 6d shows curves of the relationship between the value of C_L/C_D against the angle of attack. In this figure one can see that the maximum value of C_L/C_D obtained from present method is smaller than those obtained from CFD analysis with the difference is about 6 %. It can be seen also that the maximum value of C_L/C_D obtained from present method occurs at about 5° angle of attack, while for CFD analysis it occurs about 5.5° angle of attack.

Table 2 Optimization results

Aerodynamic Parameter		Based-Gradient Method	Genetic Algorithm
$\alpha = 0$	C_L	0.184	0.500
	C_D	0.022	0.027
$C_L = 0$	α	-1.172°	-5.467°
	C_D	0.018	0.029
$C_L = C_{L\ \max}$	α	12.377°	13.333°
	C_L	1.172	1.370
	C_D	0.071	0.081
$C_L/C_D)_{\max}$		26.960	31.101
Centre of circle (z)		-0.111 + 0.103 i	-0.111 + 0.038 i

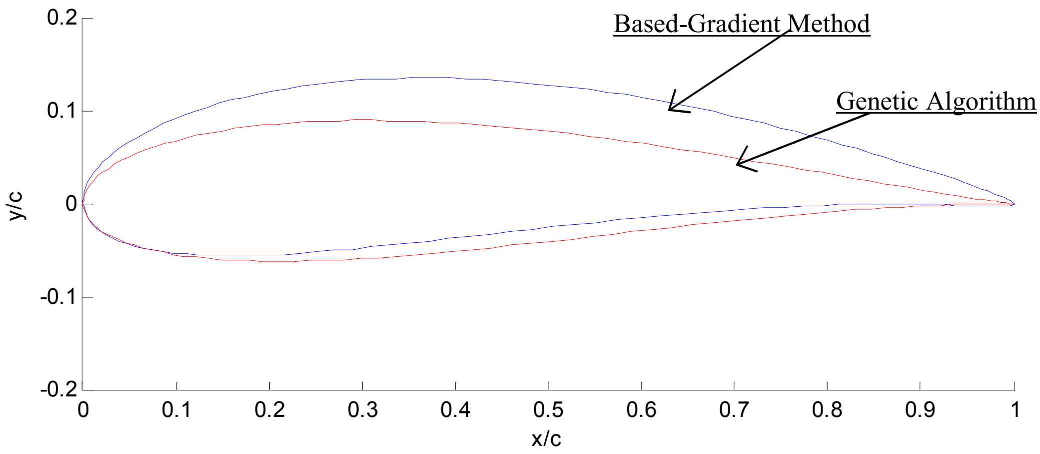


Figure 5. Optimum shape of airfoil

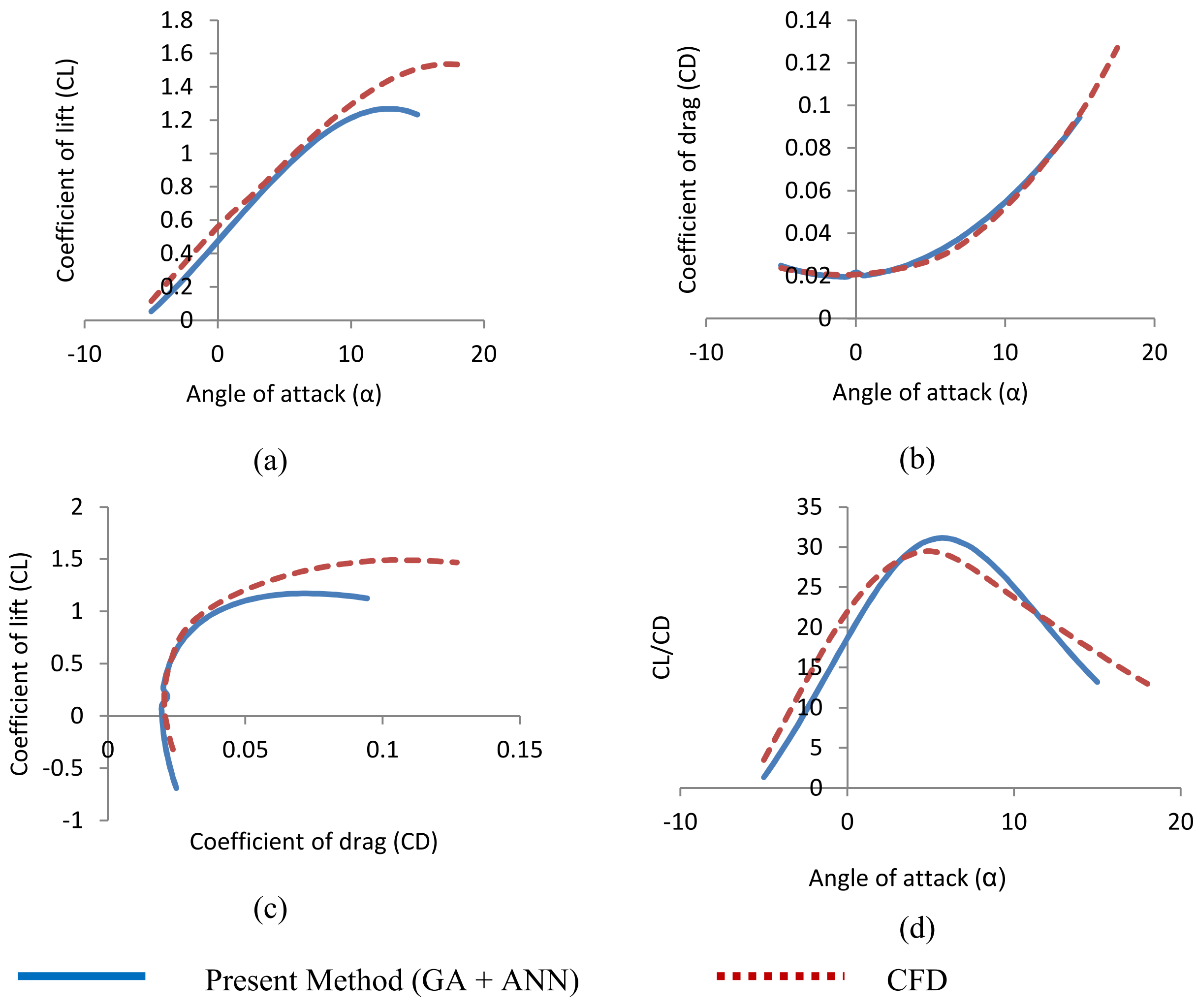


Figure 6. Comparison Aerodynamic characteristics of optimum airfoil

Conclusion

An optimization of airfoil shape has been conducted. The objective of this optimization is to obtain the shape of airfoil which having maximum lift to drag ratio. In order to avoid the difficulties in determining the aerodynamic characteristic quantities during optimization process, an alternative method based on ANN has been applied. In this method, the geometry of the airfoil was determided using Joukowski transformation. This transformartion transforms a circle in *z*-plane to the airfoil shape in *w*-plane. The ANN was built with the centre coordinates of the circle as input and the quantities of the aerodynamic characteristic of related transformed airfoil obtained from CFD analysis as the output. For further analysis the determination of the aerodynamic characteristics can be conducted only by specifying the centre coordinate of the circle without conducting CFD analysis or wind tunnel measurement. In present study, the GA also has been embedded to the ANN. Comparing to the based-gradient method the GA showed better results in optimization and by comparing to the CFD analysis results the present method seems in a good accordance.

References

[1] Kementerian Negara Riset dan Teknologi, Indonesia 2005 – 2025: Buku putih energi, Jakarta 2006.

[2] Badawy, M.T.S., Aly, M.E., Gas dynamic analysis of the performance of diffuser augmented wind turbine, Sadhana, Vol. 25(5), 2000, 453-461

[3] Schaffarezyk, A.P., Philips, D., Design principles for diffusor augmented wind turbine blade, Proc. EWEC 2001, Copenhagen, Denmark, 2001.

[4] Singh, R.K., Ahmed, M.R., Blade design and performance testing of a small wind turbine rotor for low wind speed application, Renewable Energy 50 (2013) 812 – 819.

[5] Mayer, C., Bechly, M.E., Hampsey, M., Wood, D.H., The starting behaviour of a small horizontal-axis wind turbine, Renewable Energy 22 (2001) 411 – 417.

[6] Lissaman, P.B.S., Low-Reynolds-number airfoils. Annual Reviews of Fluid Mechanics 15 (1983) 223 – 239.

[7] Lanzafame, R., Messina, M., Design and performance of a double-pitch wind turbine with non-twisted blades. Renewable Energy 34 (2009) 1413 – 1420.

[8] Guglielmo, J.J., Selig, M.S., High-lift low Reynolds number airfoil design, Journal of Aircraft 1997; 34.

[9] Ahmed, M.R., Blade sections for wind turbine and tidal current turbine applications – current status and future challenges, International Journal of Energy Research 44 (2012) 829 – 844.

[10] Fuglsang, P., Madsen, H.A., Optimization method for wind turbine rotors, Journal of Wind Engineering and Industrial Aerodynamics 80 (1999) 191 – 206.

[11] Goldberg, D.E., Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley Pub. Co.1989.

[12] Benson, T.J., Interactive Educational Tool for Classical Airfoil Theory, Cleveland, Ohio: NASA Lewis Research Center, Oct. 30, 1996.

[13] Haryanto, I., Suryo Utomo, M.S.K.T., Labib, M.N., Pengembangan perancangan airfoil sudu turbin angin kecepatan rendah berbasis komputasi cerdas, Rotasi, Vol. 11, No. 4, Oktober 2009.

[14] Adam, R., Pengembangan metodologi perancangan airfoil sudu turbin angin kecepatan rendah berbasis direct design method menggunakan ANN, Tugas Sarjana, Jurusan Teknik Mesin, Universitas Diponegoro, 2010.