Investigating the Design Parameters of Maple seed's Aerodynamic Force by Taguchi Method to Apply to Wind Turbine Blades

Hung-Son Dang*, Hoai-Nam Lai

Abstract - ***In the present study, the wing of the seed of the green maple was used as the imitated object, and the shape of the seed wing was analyzed. The setup of experiment and parameters design of the bionic wind turbine blade was then progressed by Taguchi method and the ANSYS Fluent simulation software was used to perform the numerical computations of the aerodynamic and flow characteristics of the wing of maple's seed. Also, based on the experiment and simulation results, the Minitab17 software was used to analyze the data. The simulation results, by an inspection of the trend of the lift coefficient curves, indicated that the seed wing of the green maple has a larger range of angle of attack, 0^0 to 50^0, without a stall. The results for the optimal design parameters show a good agreement with the achievement for the best combination of the parameters are: A3 (the number of blade = 3), B3 (the swept area = 0.24 m^2), C2 (the angle attack = 15^0) and D2 (the steady headwind = 5 m/s., which shows an aerodynamic advantage. In addition, the wind tunnel experiments of the wind turbine, with 3 bionic blades, 0.24 m^2 swept area, 15^0 angles of attack, and 5 m/s steady headwind conditions showed that the highest wind/electricity power transform efficiency can be reached up to 37%.***

Keywords: ***Taguchi method, Bionic design, Passive wing, Winged seed, Wind/electricity power transform efficiency***.

I. INTRODUCTION

The problem of global warming has become a great issue in recent years. As a result, a green technology development is progressing and also drawing a great attention in the national policy of energy management. The study of the renewable energy sources is then a focusing area of research, both academically and industrially. The supply of wind from nature is clean and unlimited, with relatively mutual technologies, which leads the wind power to become one of the promising green power sources.

The core component in wind power facilities is the wind turbine, either in vertical or horizontal configurations, the number and profile of the blades affect the operation of the turbine. There are two operation modes, lift-driven (LD) with high rotational speed for electricity generation and drag-driven (DD) with high torque as windmill for grinding grains, of the wind turbine. From the aspect of aerodynamics, the design of the blades will strongly affect the dynamic performance of the turbine, which affects the wind/electricity transform efficiency for electrical power generation.

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In the aspects of aerodynamics [1], if the airspeed and/or the speed of the flying object is steady, then the aerodynamic characteristics are the same with either setting the object still in the air with steady airspeed moving toward it or letting the object moving steadily in a stationary air. It is so called the equivalent law of aerodynamics. Birds, insects, and bats are equipped with wings or named it the "active wings" (AW) because the wings provide power to move the air (wings to air) and to create aerodynamic forces for flying. Therefore, the design of wings, propellers or turbine blades of airplanes, are all made in the way of active wing configurations learned from those flying creatures. However, the wind turbine is driven by the power of the unsteady wind, hence the design of passive blades, or "passive wing" (PW), should be considered in responding this opposite way of power transfer (air to wings). Consequently, there are four modes of the design and operation of a wind turbine, which are (1) active wing lift-driven (AWLD), (2) active wing drag-driven (AWDD), (3) passive wing lift-driven (PWLD), and (4) passive wing drag-driven (PWDD).

In order to increase the wind/electricity power transform, despite the NACA [2] or animals' airfoils [3, 4] or the combination of both [5] are commonly used in blade design, a bionic PWLD blade design learned from the wing of the seed of the green maple [6], a kind of Samaras and wind propagating plants, is employed in the present study. The shape of the seed wing is imitated and analyzed to obtain the basic parameters design characteristics by Taguchi method, the ANSYS Fluent simulation software and based on the results from the simulation and experiment Minitab 17 was used to analyze data.

II. ANALYSIS AND EXPERIMENTS

The fruit of the green maple is a Samara, and the seed is clothed in the samara with the membrane. Two Samaras grow together and look like a pair of rotary wings as shown in figure 1. When a pair of samaras ripe, they would fall from branches and fly rotationally in the air, just like a bamboo dragonfly.

In order to design a bionic blade based on the characteristics of green maple's samara, we imitated and sketched the wing contour of the Samara by using an optical microscope.



Figure 1. *The Samaras of a green maple*

In this study, we collected the parameters of the maple seed wing from 50 samples and combined with the review from previous papers [6-15] on the profile of the blades to identify the process parameters that may influence the performance of the operation of the turbine, A (the number of blade), B (the swept area), C (the angle attack) and D (the steady headwind), are selected to investigate their effects on the performance of the turbine, as shown in table 1.

TABLE 1. PARAMETERS AND THEIR VALUES CORRESPONDING TO THEIR LEVELS

Parameters Factors	**Levels**		
	1	2	3
A: The number of blades	1	2	3
B: The swept area (m^2)	0.8	0.16	0.24
C: The angle of attack	5	15	25
D: Inlet steady headwind (m/s)	3	5	7

The relation between the design parameters is considered. There are four factors with three levels; There are 44 degrees of freedom (five repetitions) owing to there being four design parameters. Once the required degrees of freedom are known, the next step is to select an appropriate OAs to fit the special task. The degrees of freedom for the OAs should be greater than or at least equal to those for the design parameters. For this reason, L_9 and L_{18} and L_{27} are suitable for our study, to adopt the requirement of this study, L_9 is chosen for investigated as shown in table 2.

TABLE 2. ORTHOGONAL ARRAY L9

No. Ex	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

ANSYS fluent was used to simulate the aerodynamic properties of the bionic. The setup of material used for the bionic blade is aluminum and with air as the working fluid, the k-ε turbulent model is applied to simulate the flow fields. The ambient steady wind speed is set to be the entrance condition of the flow field, and Air flows freely out of the simulation space is assumed to be the exit condition.

Base on the analysis of the simulation results by using Minitab 17, the best parameters combination was: A3 (the number of blade = 3), B3 (the swept area = 0.24 m^2), C2 (the angle attack = 15^0) and D2 (the steady headwind = 5 m/s) which shows an aerodynamic advantage. Factor C has the significant effect on the aerodynamic performance of the blade.

For simulation implement, the best combination parameters data has constructed a model of the bionic blade, as shown in figure 2.

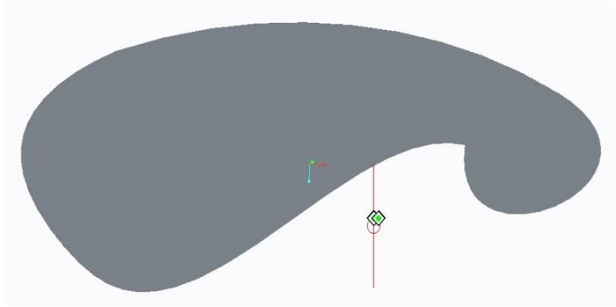


Figure 2. *The contour of the bionic blade*

Meanwhile, for experiment implement, a set of bionic blades were fabricated to build a small scale horizontal axis wind turbine (HAWT) according to the best combination parameters design. The enlarged span of the blade is 235 mm and the blades were cut from a 0.3 mm thick aluminum plate. To enforce the stiffness of the blades, a wood stick, with 5x10 (mm) cross-sectional area, was fixed to the back surface of each blade. A manufactured bionic blade is present in figure 3. The HAWT, with 0.24 m^2 swept area of the bionic blades, was tested in a wind tunnel (800x800 (mm) cross area of the test section) to explore the correspondence between aerodynamic characteristics and the wind/electricity power transform efficiency.



Figure 3. *The bionic blade used in a HAWT*

III. RESULTS AND DISCUSSION

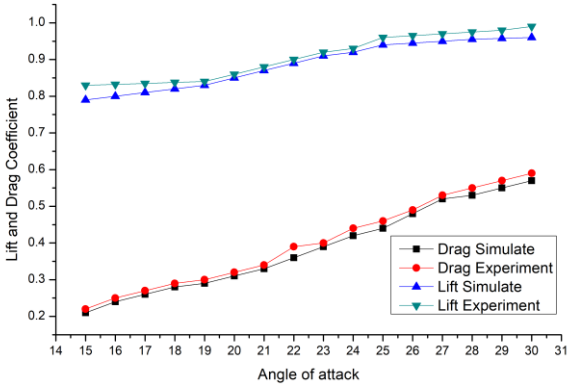


Figure 4. *Lift and drag coefficients of simulation and experiment with variable angle attack*

The best combination parameters of the blade were used to obtain the numerical simulation results mentioned above. One might doubt that those numerical simulation results could be different from the experiment of the bionic blade. Therefore, we make a comparison of the aerodynamic characteristics between the simulation and experiment used in HAWT. The lift and drag coefficients with the various angle of attack of the original and enlarged bionic blades are shown in figure 4.

Under the same inflow wind speed and computational setting of the flow field. It can be seen that those two results are very close, and the relative error is in the range of 2%.

Next, we would like to present the experimental results of the HAWT with our bionic blades. The wind turbine was set in a wind tunnel and the testing wind speed was ranged from 3 to 6 m/s because the year average wind speed is 5 m/s in Taiwan. Each testing condition (wind speed and angle of attack) was repeated five times to confirm the repeatability of the experimental results. The error bars were plotted to present the reliability of the experimental measurements.

The correspondence between the wind speed and the wind/electricity power transform efficiency of a three-blade wind turbine is explored in figure 5.

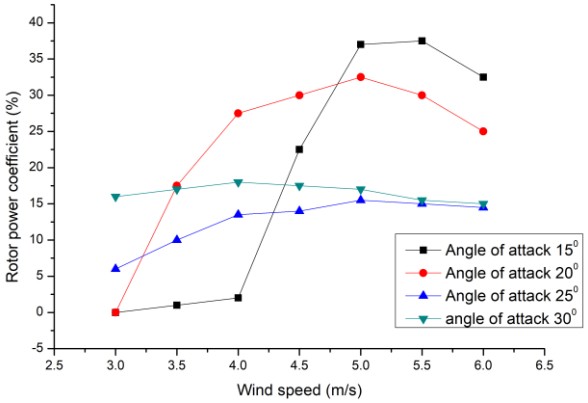


Figure 5. *Wind/electricity transform the efficiency of the three-blade bionic wind turbine at a various angle of attack vs. wind speed*

The geometric angle of attack of the blades is set to be 15^0, 20^0, 25^0 and 30^0. Each curve in the figure is obtained at a fixed angle of attack. When the angle of attack is 15^0 and 20^0, the activation of the wind turbine is harder. It indicated that a larger activating wind speed is needed at a smaller angle of attack. However, the average wind/electricity power transform the efficiency of the wind turbine exceeds 30% when the wind speed is 5 m/s with 15^0 and 20^0 angles of attack. On the contrary, the wind turbine is easy to activate but the wind/electricity power transform efficiency is 20% lower when the angle of attack is 25^0 and 30^0.

The correspondence between the wind speed and the lift-drag ratio of a bionic blade is explored in figure 6.

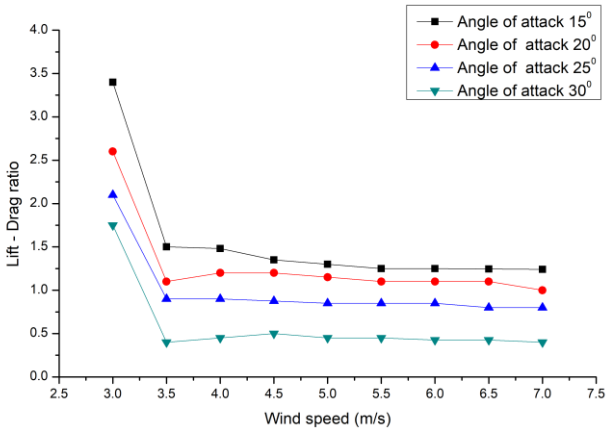


Figure 6. *Lift-drag ratio of the bionic blade at a various angle of attack vs. wind speed*

One might observe that the bionic blade with 15^0 angles of attack could obtain higher lift-drag ratio at various wind speeds. In addition, when the wind speed exceeds 4 m/s, the lift-drag ratio of the bionic blade at a various angle of attack is close to constants, which indicate that the ratio is independent of wind speed.

IV. CONCLUSION

In the present study, the samara of the green maple was used as the imitated object, and the shape of the Samara was analyzed to obtain the basic aerodynamic characteristics of the bionic blade by using Taguchi method. The study figured out the best combination for the blade aerodynamic was: A3 (the number of blade = 3), B3 (the swept area = 0.24 m^2), C2 (the angle attack = 15^0) and D2 (the steady headwind = 5 m/s).

The numerical results obtained from ANSYS Fluent, by an inspection of the trend of the lift coefficient curve, indicated that the seed wing of the green maple has a larger range of angle of attack, 0^0 to 50^0, without a stall. In addition, the wind tunnel experiments of the wind turbine with three blades configuration, 0.24 m^2 swept area, 15^0 angles of attack, and 5 m/s steady headwind conditions showed that the highest wind/electricity power transform efficiency is up to 37%.

There are some research subjects about the bionic blade that could be focused in the future works:

1. Studying the wind/electricity power transform the efficiency of the bionic wind turbine at higher wind speed range (greater than 6 m/s).
2. Optimizing the aerodynamic performance of the bionic blade by including the imitation of the cross-sectional profiles.
3. Investigating the aerodynamic characteristics of the bionic blade and performing experiments of the turbine at unsteady wind speed (simulations and experiments).
4. Enhancing the mechanical strength of the bionic blade structure from the frames and microstructure.

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