Numerical and experimental studies of airfoils suitable for Vertical Axis Wind Turbines and an application of wind-energy collecting structure for higher performance

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ABSTRACT: Numerical simulations and wind tunnel experiments were carried out to study airfoils and a wind-energy collecting structure (wind-lens) suitable for Straight Wing Vertical Axis Wind Turbines (SWVAWT). The aim of this study is to increase the output power coefficients of SWVAWT. The numerical method is a direct numerical simulation (DNS) based on the finite difference method. The results of DNS revealed that symmetry airfoils are better than asymmetry airfoils for the output performance. In the wind tunnel experiment, the results of output performance test showed that the best airfoil is NACA0024. We designed a wind-lens and applied it to SWVAWT. In the wind tunnel experiments, the output power coefficients of SWVAWT with a wind-lens were more than 2 times as large as those of a SWVAWT only. We made clear the effect of the wind-lens on the output performance by DNS.

KEYWORDS: Straight Wing Vertical Axis Wind Turbine, Airfoil, Wind-energy collecting structure, Direct numerical simulation, Wind tunnel experiment

1 INTRODUCTION

Small-type wind turbines are used in many ways as an independent electric source. Among them, Straight Wing Vertical Axis Wind Turbine (SWVAWT, Fig.1) is popular for the independency of the wind direction and its simple structure. However, the output performance of SWVAWT is generally lower than that of Horizontal Axis Wind Turbine (HAWT).

Our purpose is to increase the output power performance of SWVAWT. For this purpose, we have studied the shape of an airfoil and a wind-energy collecting structure (we call it "wind-lens") suitable for SWVAWT. In the past studies, suitable airfoils were investigated by Seki [1] and Ishimatu et al. [2]. However, it is still unclear about suitable airfoils. The wind-lens can accelerate the approaching wind to a wind turbine (Fig.2). It has been developed in our laboratory. Fivefold increase in output power of a HAWT with a wind-lens compared to conventional HAWTs is achieved [3]. Therefore, we tried to apply it also to SWVAWT (Fig.3).

2 NUMERICAL METHOD AND WIND TUNNEL EXPERIMENT

2.1 *Numerical method*

The governing equations consist of the continuity and incompressible Navier-Stokes equations. Table 1 shows the overview of the present numerical simulation method. Fig.4 shows an airfoil (MEL002) approximated by rectangular grids for numerical simulations.

Table 1. Simulation code and calculation conditions

Calculation method	DNS based on finite-difference method
Coordinate system	Two-dimensional orthogonal coordinate
Variable arrangement	Staggered arrangement
Reynolds number	About 6.2×10^4 based on an airfoil chord
Grid generation	Non-uniform grid
Approximation of the shapes of airfoils and a wind-lens	Rectangular grid approximation (for airfoil, chord length consists of 80 points grid)
Expression of rotating airfoil	Giving zero-velocity to the grids within the area of a rotating airfoil

2.2 *Wind tunnel experiment*

For wind tunnel experiments, a large boundary-layer wind tunnel with the measurement section of 3.6m(W)×2.0m(H)×15m(L) was used. We performed experiments on output performance of SWVAWT. The approaching wind speed, U, is 6m/s. The Reynolds number, Re, is about 6.2×10^4 based on the airfoil chord (0.15m).

For the experimental method, a torque transducer (the rating 0.5N・m) was connected to the lower position of a SWVAWT where an AC torque motor brake was set for the loading. We measured the torque Q N・m and the rotational speed m Hz of the SWVAWT in a condition where the turbine loading is gradually applied from zero. The output power coefficient, C_W, is defined as $C_W=2\pi mQ/(0.5\rho U^3 A)$

3 RESULTS AND DISCUSSION

3.1 *Comparison between numerical and experimental results*

Fig.5 shows the comparison of the power coefficient curves (C_W) between DNS and wind tunnel experiment. The horizontal axis is the tip-speed ratio, λ $(=r\omega/U)$. Both results show a qualitative agreement in the C_W variations with λ and airfoil thickness.

3.2 *Airfoil suitable for SWVAWT*

3.2.1 *DNS*

First, we consider which airfoil is better, symmetry airfoils or asymmetry ones. Therefore, we carried out DNS to investigate power coefficients of SWVAWT with NACA0024 (a symmetry airfoil) and MEL002 (an asymmetry airfoil). Note that MEL002 is attached to the supporting arm in two ways, one is that the upper surface faces the axis and the other is that the lower surface faces the axis. The number of blades is two and the tip-speed ratio is 1.5 at which SWVAWTs show the highest power coefficients.

Table 2. Comparison of power coefficients of three types of SWVAWTs (DNS, the tip-speed ratio=1.5)

Airfoil of SWVAWT	C_W
NACA0024	0.217
MEL002 (upper surface toward axis)	0.134
MEL002 (lower surface toward axis)	0.094

Table 2 shows the power coefficients. A SWVAWT with NACA0024 shows the highest power coefficient. To make clear the reason why there is the difference in power coefficients among airfoils, we compare the torque coefficients, $C_T(=C_W/\lambda)$, along the rotation angle (Fig.6) between the SWVAWT with NACA0024 and that with MEL002 (Fig.7). At θ 20°, the SWVAWT with NACA0024 generates the largest torque and the one with MEL002 (lower surface toward axis) generates the smallest torque. At θ -135°, the SWVAWT with NACA0024 generates the largest torque and the one with MEL002 (upper surface toward axis) generates the smallest torque. It is found that a SWVAWT with symmetry airfoils generate its torque efficiently and show higher power coefficients than that with asymmetry airfoils.

3.2.2 *Wind tunnel experiment*

As mentioned above, we have found that symmetry airfoils show high power coefficients. To investigate what a degree of airfoil thickness is better for high performance, we have made some experiments using symmetry airfoils, NACA0012, NACA0018, NACA0024 and NACA0030. Fig.5 shows the power coefficients curves. From this figure, the highest power coefficient is obtained when NACA0024 is used. It means that there is an optimal thickness for higher performance.

3.3 *Application of wind-lens*

3.3.1 *Wind tunnel experiment*

We designed a wind-lens and applied it to the SWVAWT (Fig.2). Fig.8 shows the power coefficient curves of a SWVAWT with a wind-lens compared to those of SWVAWT only. The maximum power coefficient of the SWVAWT with a wind-lens shows more than 2 times as large as that of the SWVAWT only.

3.3.2 *DNS*

To make clear the effect of the wind-lens, we compare the time-averaged streamlines (Fig.9) and the torque coefficients (Fig.10) between a SWVAWT only and a SWVAWT with a wind-lens. Fig.9 shows the wind-lens collects and accelerates the wind toward the SWVAWT. Fig.10 shows that when the wind-lens is applied, larger torque is generated in the upstream of the axis and also in the downstream of the axis.

4 CONCLUSIONS

We studied airfoils suitable for SWVAWT and applied a wind-lens (wind-energy collecting structure) to SWVAWT for higher performance.

It is found that symmetry airfoils are better than asymmetry ones for the output performance. The SWVAWT with NACA0024 airfoil shows the highest output performance.

For the application of a wind-lens, in the wind tunnel experiment, a SWVAWT with a wind-lens shows more than twofold increase in power coefficient compared to a SWVAWT only. The wind-lens collects and accelerates the approaching wind and a larger torque is generated in the upstream of the axis and also in the downstream of the axis.

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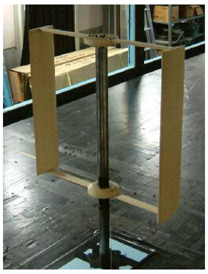

Figure 1. Straight Wing Vertical Axis Wind Turbine.

Figure 3. SWVAWT with wind-energy collecting structure.

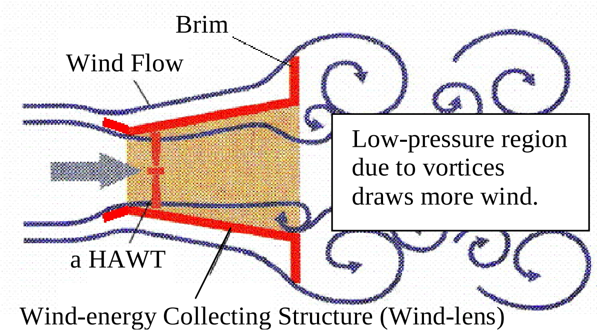

Figure 2. Mechanism of accelerating the approaching wind speed.

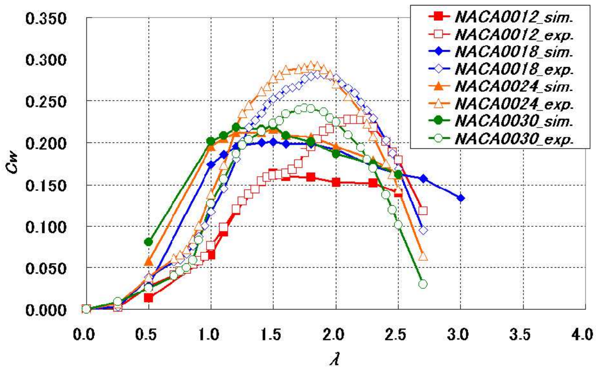

Figure 5. Comparison of power coefficient curves between numerical simulations and wind tunnel experiments.

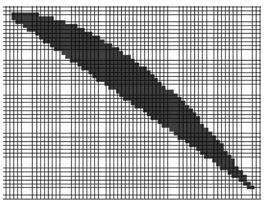

Figure 4. Approximated airfoil (MEL002)

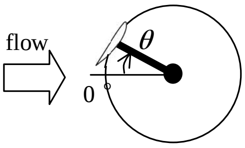

Figure 6. Rotation angle

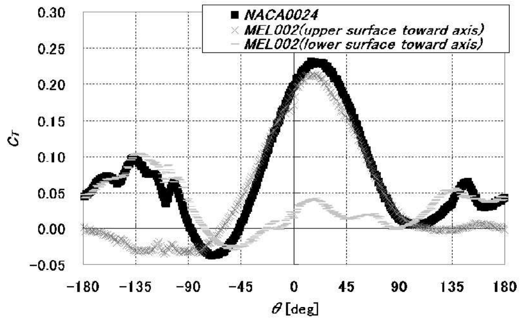

Figure 7. Comparison of time-averaged torque coefficients along the rotation angle (DNS)

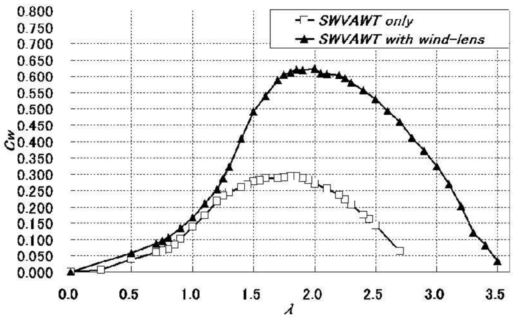

Figure 8. Comparison of power coefficient curve between a SWVAWT only and a SWVAWT with a wind-lens (wind tunnel experiment)

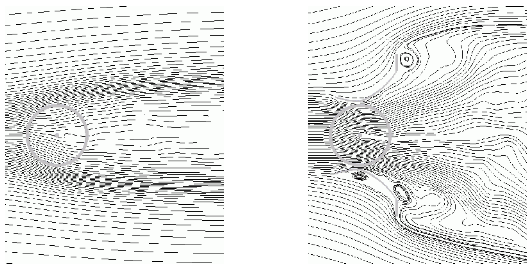

Figure 9. Comparison of the time-averaged streamlines between a SWVAWT only and a SWVAWT with a wind-lens (DNS)

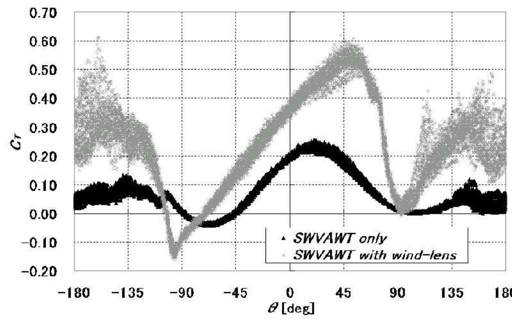

Figure 10. Comparison of torque coefficients along the rotation angle between a SWVAWT only and a SWVAWT with a wind-lens (DNS)