# Experimental Predicition of Peroformances and Broadband Noise of a Wind Turbine by a Blade Element Theory

Soichi Sasaki, Graduate School of Engineering, Nagasaki University, Japan
Shinsuke Mukai, Graduate School of Engineering, Nagasaki University, Japan
Ken Tushima, Nagasaki Prefecture Industrial Promotion Foundation, Japan

**Long Abstract**

## Introduction

The master plan of the energy in Japan met a big turning point as the "Great East Japan Earthquake" caused the accident of Fukushima No. 1 nuclear power plant. After Japan experienced this big disaster, the government went to use renewable energy aggressively to achieve the flexible structure of energy demand and supply. Moreover, because the wind turbine is the object of Feed-in Tariff that has been executed from July, 2012 in Japan, the technology of the wind turbines is identified as a good candidate for commercial application. The installation of wind turbines in the environment stresses the need for low-noise design methods. Recently, a numerical simulation by CFD using a commercial code has solved the whole flow around the impeller of the wind turbine; but such an effort remains expensive. Considering less ambitious but fast methods such as analytical means dedicated to the efficiency and noise of high performance wind turbines, the two-dimensional blade-element theory appears as a suitable way of achieving preliminary design. However, studies based on the blade-element theory very seldom address the aerodynamic noise, more especially broadband. This is achieved in the present work with an analytical model of broadband, that noise being recognized as the dominant contribution for wind turbines. First of all, the actual performance and noise of an isolated blade are measured in a wind tunnel. The broadband noise of the blade element in the wind turbine is predicted by the blade-element theory; it is stated how this theory helps analyzing the flow around the impeller. Finally, the broadband noise generated from the wind turbine is predicted using as input data the flow parameters deduced from the blade-element theory.

## Experimental Setup

The schematic view of the test bench of the wind tunnel is shown in Fig. 1. The cross-section of the duct is 0.4 m square. The blade force components and noise are measured in the wind tunnel. The force acted to the blade is measured by the load cell which has the capacity of 25 N ( Tech-gihan, TL2B09-25N). Figure 2 is picture of the prototype impeller of the wind turbine. The radius of the impeller is 10 m, the rotation speed is the 30 rpm and the pitch angle is the 12 deg. The output power of the wind turbine becomes 20 kW if the performance is estimated by the wind turbine in Ref [1].

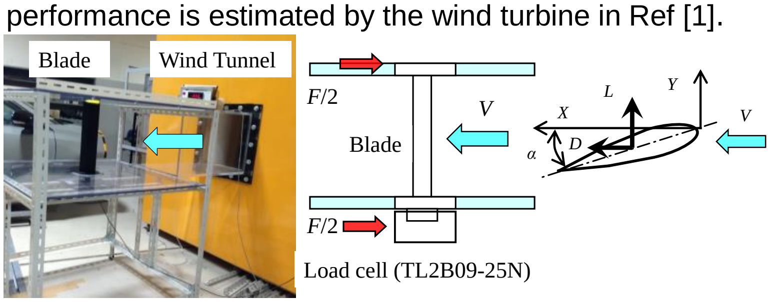



Fig. 1 Test bench of the isolated blade

Fig.2 Prototype of the impeller

### Analytical Prediction Method

It is assumed that the flow passages through the impeller in strips of different radii are independent of each other so that they are described in circular stream tubes (see Fig. 3). The quantities a $V_\infty$ and a' r Ω are the velocity components induced by the blade element on the impeller at the radius *r* (see Fig. 4).

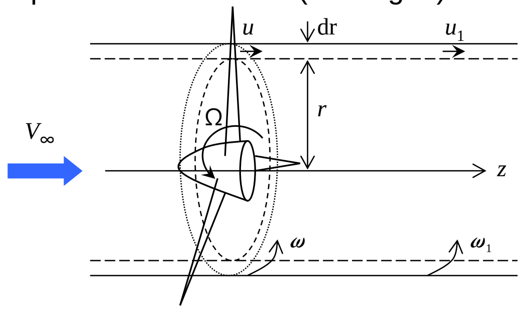



Fig. 3 Flow model in a stream tube

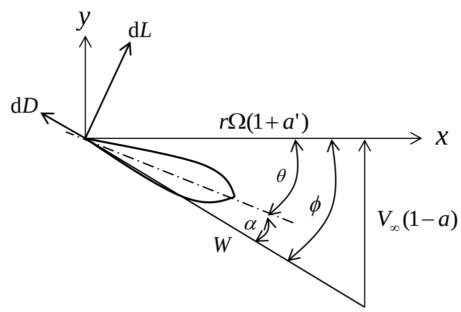
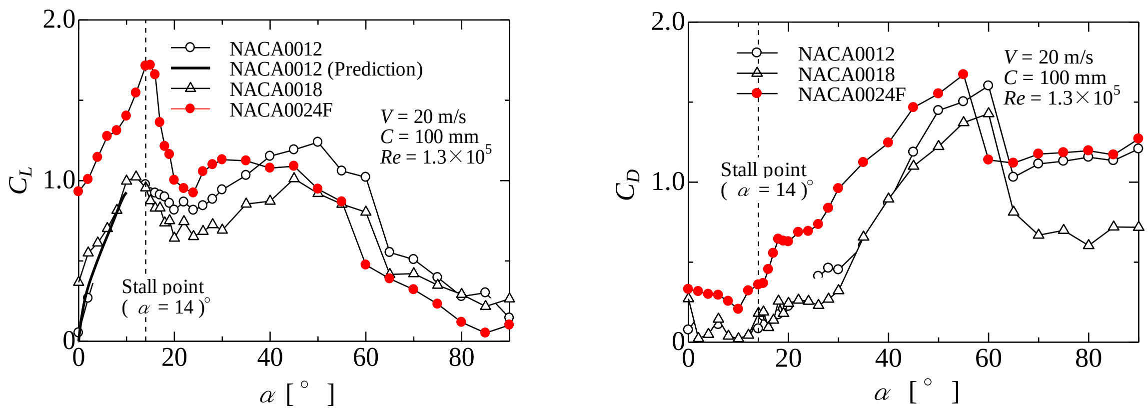



Fig.4 Blade element at radius r

In the blade-element theory, the coefficients *a* and *a'* are determined by the "Successive Approximation Method". When the yaw angle $\phi$ is obtained from these coefficients, the angle of attack on the relative flow can be inferred from the relation of the pitch angle $\theta$ as

$$\alpha = \phi - \theta\,,\ \tan\phi = \frac{1}{\lambda}\frac{1-a}{1-a'}\,,\ \lambda = r\Omega / V_\infty \qquad (1)$$

If the attack angle of the blade is analyzed by the blade element theory, the fluidic forces are determined by the property of the blade (see Fig. 5). The blade element method can also analyze the fundamental flow parameters for the predication of the broadband noise.




(a) Lift coefficient

(b) Drag coefficient

Fig. 5 Fluidic force of the isolated blade

Trailing-edge noise is the dominant broadband self-noise in the middle and high-frequency range. It has been assessed using Amiet's analytical model [2] readdressed by Roger & Moreau [3]. The approximate expression of the far-field pressure PSD generated by one boundary layer on a single blade element reads

$$S_{pp}(\omega) = \left( \frac{\omega\ c}{2\pi\ a_0\ R} \right)^2 L\ \Phi(\omega)\ \ell_y(\omega) \left| \aleph\left(\frac{\omega}{W}\right) \right|^2 \qquad (2)$$

where $\Phi$ is the wall-pressure spectrum close to the trailing edge, *L* the wetted span of the element and $l_y(\omega)$ the span-wise correlation length. $\aleph$ is an analytical transfer function detailed in [3]. In absence of direct measurements, all quantities are estimated from the data of the wind tunnel experiment by the blade-element theory. Details of the blade-element theory and of the predicted broadband noise will be given in the full-length paper, together with measured performances and noise of the isolated blade.

## References

[1] Y. Nii., et al., Acoustic noise generation by a 28m diameter constant speed wind turbine (in Japanese), The Journal of the Acoustical Society of Japan, 49(3), pp. 169-175, 1993

[2] R.K. Amiet, Noise due to turbulent flow past a trailing edge, *Journal of Sound and Vibration,* 47 (3), pp. 387–393, 1976

[3] M. Roger & S. Moreau, Back-scattering correction and further extensions of Amiet's trailing-edge noise model; part I: theory, *J. Sound & Vib*. 286, pp. 477-506, 2005.