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Blockage corrections in wind tunnel tests of small horizontal-axis wind turbines

T.Y. Chen *, L.R. Liou

Department of Aerospace Engineering, Tamkang University, Taiwan, ROC

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ABSTRACT

This study quantitatively investigates the effects of tunnel blockage on the turbine power coefficient in wind tunnel tests of small horizontal-axis wind turbines (HAWTs). The blockage factor (BF), $\left(\frac{U_T}{U_F}\right)^3$, was determined by measuring the tunnel velocities with and without rotors using a pitot–static tube under various test conditions. Results show that the BF depends strongly on the rotor tip speed ratio (TSR), the blade pitch angle (β), and the tunnel blockage ratio (BR). The larger the TSR and BR are, the smaller the BF is. The BF approaches a constant value when the TSR exceeds a certain value. No blockage correction is necessary for small TSR under all of the investigated conditions, and for the investigated blade pitch angle of 25°. This study also shows that the blockage correction is less than 5% for a BR of 10%, which confirms that no blockage correction for a BR less than 10% in literatures is acceptable.

1. Introduction

Many aerodynamic designs, such as aircrafts, automobiles, high-rise buildings, and wind turbines, are based on the combined results of experimental, theoretical, and computational methods. A wind tunnel is the most important tool in experimental aerodynamics. Wind tunnels make model studies possible and can provide a large amount of reliable data to support design decisions. Wind tunnels also save time and money in the design process. However, the flow conditions in a wind tunnel are not the same as those in an unbounded air-stream; mainly because the wind tunnels test section is finite in size. Consequently, wind tunnel tests must consider some effects, including horizontal buoyancy, solid blockage, wake blockage, and so on [1]. In an ideal case, the solid blockage (the ratio between the model frontal area and the test-sectional area) for a solid model, such as an aircraft model, is 5% or less. Higher blockages require corrections. This research focuses on experimental blockage studies in wind tunnel tests of rotating rotors.

The development and application of renewable, clean energy have become a very important issue in recent years due to the serious effects of global warming and rapid depletion of fossil fuel. Wind energy technologies have become one of the fastest growing energy sources in the world. Many factors play a role in the design of a horizontal-axis wind turbine (HAWT), including rotor aerodynamics, generator characteristics, blade strength, and so on. Rotor aerodynamics plays a particularly important role in wind energy extraction. Many researchers have conducted rotor performance experiments in wind tunnels. As noted above, when a wind turbine operates in a closed wind tunnel, the tunnel walls constrict the airflow. This constraint forces air to flow through the turbine faster than it would normally, meaning the turbine produces more power than when operating in an unbounded environment. This tunnel blockage effect is generally a function of the rotor blockage ratio (BR), and the power produced by rotors [2]. The power produced is dependent on the tip speed ratio (TSR) and the rotor pitch angle (β). The BR is the ratio between the rotor disk area and tunnel test-sectional area, the TSR is defined as the ratio between the blade tip speed and the free stream velocity, and the β is the angle between the blade chord line and the rotor rotating plane.

In wind turbine experimental studies, it seems that no blockage correction is required for a rotor blockage ratio of around 10%. Schreck et al. [3] conducted their 10.1 m diameter of rotor performance studies in the NASA Ames 80 ft × 120 ft wind tunnel with a rotor blockage ratio of 9.3%, and they made no blockage correction. Hirai et al. [4] conducted wind tunnel experiments to understand the basic aerodynamics of a HAWT. The rotor blockage ratio in their study is around 10% in a wind tunnel with cross section area of 30 m^2. Also, they made no blockage correction.

Watkins and Walter [2] performed a wind tunnel study of a wind generator and associated electronics for its performance characteristics in the RMIT industrial wind tunnel. The tested wind turbine had an external diameter of 1.1 m, and the closed-jet type wind tunnel had a 2 m high, 3 m wide, and 9 m long test section. The rotor blockage ratio was 16%, and correction methods have been applied to the data presented in their report to account for this effect. Bahaj et al. [5] measured the power and thrust of an 800 mm diameter model of a marine current turbine in a cavitation

* Corresponding author. Address: Department of Aerospace Engineering, Tamkang University, Taiwan 251, ROC. Tel.: +886 2 26294728; fax: +886 2 26209746.
E-mail address: tychen@mail.tku.edu.tw (T.Y. Chen).

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