Relation between Broadband Noise and Vortex Shedding from Trailing Edge of Rotor Blade of Axial Flow Fan

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Long Abstract

Introduction

Low noise level is an important sales point of the various kinds of machines as well as high performance and miniaturization. This situation is also applied to axial flow fans used, for example, in air conditioners. The controlling noise source generated from an axial flow fan is turbulent noise due to vortex shedding when the fan is operated near the design operating point [1-2]. As a fundamental research on the generation of broadband noise from a rotating blade, the characteristics of the velocity field around a rotating flat plate blade were measured by hot-wire sensors which rotated with the same speed of the rotating blade. As a result it was made clear that even in the rotating flow field typical periodic velocity fluctuation was generated due to Karman vortex shedding. The frequency was constant at a fixed radius but it increased with the increase in the radius. Therefore, the spectrum of noise due to Karman vortex shedding became broadband. However, characteristics of vortex shedding from the trailing edge of rotor blade in the flow rate range at the design point are unclear in detail.

The purpose of the present study is to clarify the relation between broadband noise and Karman vortex shedding from trailing edge of rotor blade at the design operating condition. The coherent structure of Karman vortex and the prediction method of the spectrum of broadband noise are also discussed.

Experimental Apparatus and Procedure

We have experimentally studied the relation between the generated broadband noise and the velocity fluctuation in the near wake of a rotor blade of axial flow fan. The rotor blade has NACA 65 series profile sections designed by free vortex operation. The blade stagger angle at the rotor tip was 63.9 deg. The experimental measurements were carried out at the design operating condition of Φ=0.41 while rotational speed of the fan rotor was kept constant, 1000 rpm. The blade tip section of the rotor has the solidity of 0.65 and the chord length of 131 mm. Reynolds number based on the rotor tip speed and the rotor tip chord length was 2.5×10^5. The trailing edges of the rotor blades were semicircle shape which thickness δ_t were 2.0 mm over the whole span of the blades.

A schematic view of the experimental apparatus used in the present experiment is shown in Figure 1. The velocity fluctuation in the near-wake of a rotor blade was measured from a relative frame of reference fixed to the rotating blade by using an I-type hot-wire sensor which rotated with the same speed of the blade. The hot-wire was a tungsten filament wire of 5-μm diameter. The hot-wire sensor was traversed and fixed at pre-determined location by a computer controlled traversing system even when it was turning. The traversing probe was controlled by the three-dimensional traversing system, i.e., radial, axial and rotational directions, installed inside of the hub with traverse resolution of 0.3 mm. The outputs from these sensors were automatically sampled by a computer and the statistical values were calculated. The spectrum analysis of the velocity fluctuation was performed by using MATLAB. The characteristics of flow, such as the distribution of the velocity of the flow relative to the blade and its intensity as well as the spectrum of velocity fluctuation, were measured on the *L*-*Z* plane at various radiuses.

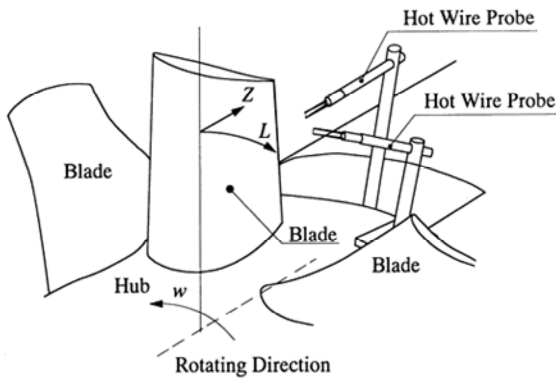

Figure 1. Schematic of test section

Summary

The sound pressure level due to a vortex shedding from a definite radius with a frequency of *f* is expressed as,

$$(SPL)_f = 10\log_{10}\left(\frac{\rho}{p_0 ar}\right)^2 U_0^6 S_t^2 \left(\frac{u'_{vortex}}{U_0}\right)^2 \left(\frac{\ell_s}{C}\right)^2 \ell_s^2 B$$

where ρ_0 is the density of air, p_0 the reference pressure to define the sound pressure level (2×10^{-5}Pa), a_0 the sound velocity, *r* the distance from the noise source to the observer, U_0 the main flow velocity, S_t the Strouhal number, u'_{vortex}/U_0 the coefficient of velocity variation due to vortex shedding, ℓ_s and ℓ_p the chord- and the span-wise correlation length, respectively. *C* and *B* are the chord length and the number of the rotor blade, respectively. The SPL, radiated from one cell of Karman vortex with a frequency of *f*, was determined by substituting the measured values of *St*, u'_{vortex} and ℓ_p into the above-mentioned equation.

We measured the characteristics of relative velocity and turbulence intensity in the near-wake of rotor blade. There were two regions where the velocity fluctuation became intense on both sides just downstream of trailing edge of rotor blade. No peak was formed in the spectrum of velocity fluctuation in the near-wake of rotor blade at design operating point. The broadband noise was caused by the weak periodic vortex shedding from the trailing edge of rotor blade of axial flow fan at the design operating condition. We determined the spanwise correlation length by considering that in-phase rate of velocity fluctuations corresponds to one cell size of Karman vortex. The predicted SPL is in good agreement with measured SPL.

References

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