Noise Prediction of a Counter-Rotation Propfan

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Abstract

A CALCULATION method for predicting the acoustic field of the counter-rotation propeller operating in the flow of a pylon has been developed. The results of sample calculations have demonstrated the capability of estimating the noise caused by the aerodynamic interactions such as wake interaction and potential interaction between two rotors or between pylon and rotor.

Prediction Scheme

The prediction scheme consists of two parts, the aerodynamic code and the acoustic code. This method is an extension of the authors' previously developed code for a single-rotation propeller.[1] The distribution of airloading over the counter-rotation propeller (CRP) blade obtained by the aerodynamic code is inserted into the acoustic part of the code as the noise source term. Then the acoustic field can be calculated by integrating it at the retarded time.

The aerodynamic code is based on the local circulation method (LCM).[2] This is basically an incompressible, curved lifting line code incorporating two-dimensional airfoil characteristics where the compressibility and/or viscous effect can be included to some extent. The control point of the blade element moves around the three-quarter chord, depending on the lift curve slope of the respective blade element.

The velocity deficit in the wake of the front rotor blade or of the pylon causes the unsteady fluctuation of the blade surface pressure and generates noise. The wake model incorporated in the aerodynamic code is based on the two-dimensional model proposed by Ramaprian's experiment.[3] According to this model, the velocity deficit is assumed to have an "exp $[-x^2]$"-type profile where x is a traverse coordinate. The wake depth and width are defined by the momentum balance of the profile drag obtained from the two-dimensional experimental data. Axial decay or mixing of the wake is simulated by introducing the Reynolds number defined by the axial position and the eddy viscosity.

The acoustic sources are formulated according to the well-known Ffowcs-Williams and Hawkings equation[4] from the blade shape and the airload distribution obtained from the aerodynamic code. These sources on the moving blade surfaces are integrated to give the acoustic pressure at a given observer time and position.

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Thus, by using the prescribed wake model, the present method can treat the effect of not only the potential interaction but also the wake interaction between two rotors or between pylon and rotor. These interactions are significant noise sources in CRP or pusher propeller configurations. However, the applicability is limited in the subsonic range because this method is constructed by the incompressible and quasisteady aerodynamics and the linear acoustics (the acoustic source consists of the thickness noise and the airloading noise). Other assumptions included in the present method are the following:

1) The effect of the spinner or the centerbody of the propeller flowfield is neglected.

2) The reflection of sound by the propeller blades or by any objects such as centerbody, pylon, wing, or fuselage is neglected.

3) The generated sound radiates into a uniform flow.

Calculation Results

The calculation of the acoustic waveform generated by a 4×4 (blade numbers of front and rear rotors) CRP during one revolution is shown by the solid line in Fig. 1. The helical tip Mach number is 0.9, and the observer is located in the plane of the rear rotor one rotor diameter from the shaft axis. The effect of wake interaction is clearly observed as the spikes that are apparent by comparison to the calculation without wake, as shown by the broken line in the same figure.

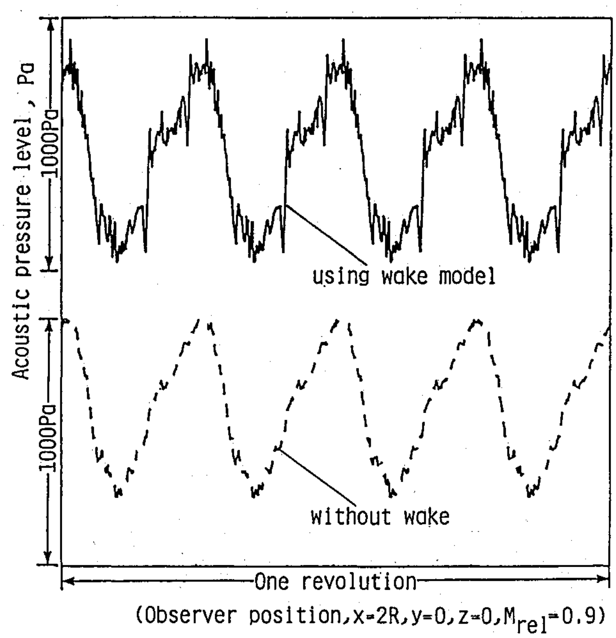

Fig. 1 Total noise waveform of 4×4 CRP.

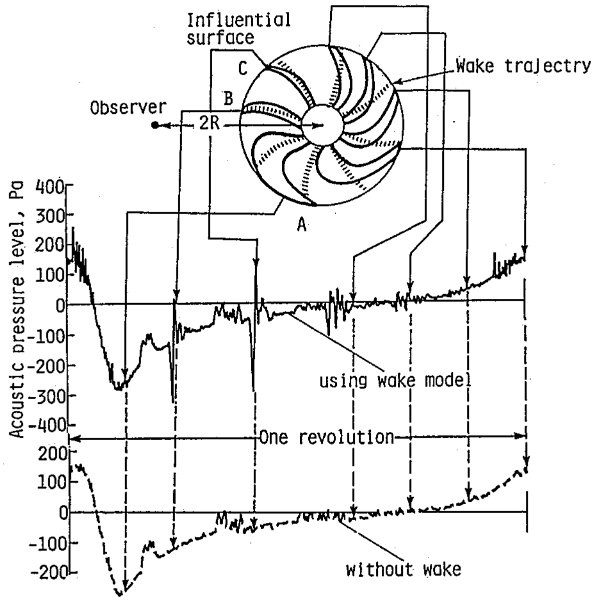

Fig. 2 Acoustic waveform of rear propeller.

These waveforms are constructed by superposing the acoustic wave generated by each blade (eight blades in this case). In other words, they can be decomposed into the eight waveforms of each respective blade. Figure 2 shows an example waveform of a rear rotor blade for one revolution. Again, the solid line shows the result with the wake interaction, whereas the broken line shows the result without wake interaction. The "influential surface" at different observer times is also indicated in this figure. The observer receives and hears as sound the acoustic wave emitted from all sources distributed on the influential surfaces defined by a given observer time. It can be seen that the influential surface of the blade approaching the observer is elongated (having longer apparent chord length), whereas the blade influential surface while retreating is shrunken (having less chord length) due to the blade motion.

Because the acoustic pressure is proportional to the multiple of source intensity and the source area (influential surface area) in the near field, or proportional to its time derivative in the far field, the dominant fluctuation of acoustic pressure is likely to occur at the observer time corresponding to the instance when the influential surface area or its time derivative becomes maximum, as indicated by A in the figure. This forms a one-per-revolution fluctuation with a rather smooth shape.

On the other hand, the wake interaction generates very peaky spikes, especially when the influential surface coincides with the wake trajectory, such as point B or C in the figure. These spikes push up the high frequency content in the spectrum, as is usually observed in CRP noise measurements.

The pylon wake causes and additional acoustic source. Figure 3 shows an example of calculated results of such noise

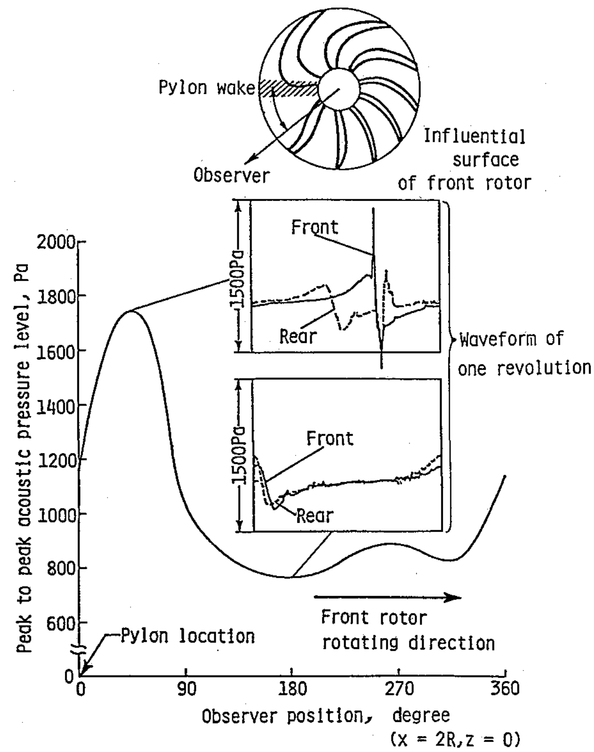

Fig. 3 Pylon influence on the azimuthwise directivity of pusher CRP.

using the prescribed pylon wake model. The peak-to-peak acoustic pressure obtained from the waveform calculation for one revolution changes with observer azimuthal position relative to the pylon location. Again, the coincidence of wake trajectory and the influential surface explains the large peak in the acoustic waveform.

The pylon wake interaction noise radiates most strongly toward the angle between 0 and 90 deg from the pylon direction, depending on the distance of the observer from the rotor. The observer in the cabin below the pylon hears a lower (higher) noise level when the propeller washes up (down) at the fuselage side, as does the observer on the ground. Therefore, the pylon wake noise can be controlled by the direction of rotation of the front propeller.

References

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