AERODYNAMIC NOISE SIMULATION OF PROPELLER FAN BY LARGE EDDY SIMULATION

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Background

Want to increase

- Cooling performance
- Flow quantity

Fig. 1 Our products using propeller fans

Fig. 2 Noise increase
Problems

flow direction

greatly protrude

side view

bell mouth

(by now)

"Rules of thumb"

most suitable design parameter

need

- clarify the noise source
- understand the mechanism of noise generation

get transient flow information

need

LES

(used in small pressure head)

Fig.3 Half-open type propeller fan
Past Research Examples (RANS)

RANS (Reynolds Averaged Navier-Stokes Simulation)


Fig. 2: Acoustic test chamber of DC R&T in Stuttgart with fan test rig and microphones.

Fig. 3: Serial E-Class engine cooling fan ("W210 fan").

Fig. 4: Symmetrically spaced test fan ("symmetric fan").

- No direct information of unsteady flow
- RANS ability to explain the phenomenon of unsteady flow is limited

Further more
Past Research Examples (LES)

Miyazawa et al. 2005 (C. Kato Laboratory, University of Tokyo)

- Good agreement in low freq.
- Overestimate in high freq.

Yamade et al. 2006 (C. Kato Laboratory, University of Tokyo)

- Same grid resolution
- Turbulent boundary layer

Ducted axial-flow fan (HITACHI)

Streamwise vorticies

Sound prediction has not yet been achieved
Objectives

1. Predict aerodynamic noise by LES
2. Discuss the three-dimensional flow structures that primary influence aerodynamic noise generation

our further goals

• predict broadband spectrum quickly and accurately
• test without prototyping (reducing cost)
• develop lower-noise new shape fans
Test Propeller Fan

specifications of propeller fan

- designed flow rate: 30[m3/min]
- density of air: 1.205[kg/m3]
- number of revolutions: 800[r/m]
- tip speed: 16.755[m/s]

Fig. 4 Meridional shape
Calculation Method

Grid
- consisted of three parts (overset)
- inlet & pressure boundary
- Non-Reflective Boundary Condition
  (prevent unphysical P fluctuations)

Code
- streamline-upwind finite element method
- Standard & dynamic smagorinsky modes
- 2nd order in both time and space
- Fractional step for pressure equation
- low Mach-number assumption (M=0.1, 0.2)
- Curle’s equation
- LES code name: "Front Flow/Blue"

Fig. 5 Computational grid
Experimental Apparatus

![Diagram of experimental apparatus]

**Fig. 6 Aerodynamic noise measurement**

(pressure rise, aerodynamic noise were measured to compare the validity)

**Fig. 7 wake flow measurement**

(ensemble averaged velocity field)

(The technology that Kuroumaru developed in 1982)
Static Pressure Rise

Fig. 8 Result of static pressure rise

Overall agreement is satisfactory.
Instantaneous Flow Field

Fig. 9 Instantaneous velocity field by LES
Averaged Flow Field

- not clear: weak
- tip vortex: strong
- wake qualitatively predicted
- wake

Discrepancy may have insufficient resolution of the grid

Fig. 10 Comparison of time averaged flow field
Wake Flow 1.

(a) Magnitude of Velocity Vector

Different quantitatively caught qualitatively

(b) Radial Component

good agreement

Fig.11 Comparison of velocity component
Wake Flow 2.

(c) Tangential Component

(d) Axial Component

Fig. 11 Comparison of velocity component
Tip Vortex

**Fig. 12 Velocity field computed by LES**
Aerodynamic Noise

Effects of Sub Grid Scale models

Effects of Mach-Number, M

Fig.13 Comparison of sound pressure levels
Conclusion

1. LES calculation showed 15% smaller static pressure rise than the measurement at the designed flow rate.

2. Flow field characteristics qualitatively agreed with the measurement in the wake.

3. As for the tip vortex, the LES calculation didn’t show it as clearly as in the measurements.

4. The tip vortex generated on the blade surface is stable, but it cannot be seen clearly when it arrived to the downstream blade in LES.

5. The sound frequency of NZ, 2NZ, 3NZ were quantitatively predicted. The 3NZ sound pressure level is almost corresponded to the measurement value.

6. In the effects of Mach-number M, it doesn’t show any appreciable difference in the predicted sound pressure except for high frequency.
Thank you very much