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COMPUTATIONAL FLUID DYNAMICS AND COMPUTATIONAL AEROACOUSTICS FOR AIRCRAFT NOISE ESTIMATION

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References
[1] Lesieur, M. and Metais, O.: New trends in large-eddy simulations of turbulence, Ann. Rev. Fluid Mech., 28 (1996) p. 45--82
[2] Curle, N.: The influence of solid boundaries upon aerodynamic sound. Proc. Roy. Soc., London, A231 (1955) p. 505–514

INTRODUCTION

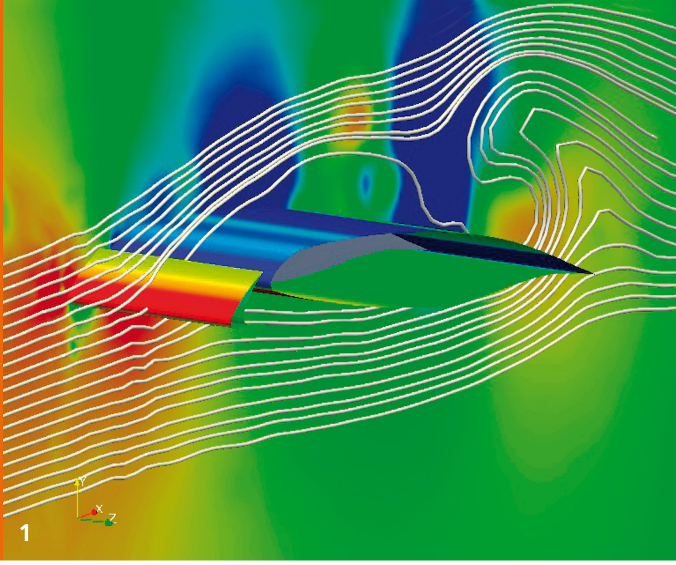
A new method for estimating aeroacoustic noise has been introduced to the Fraunhofer Institute for Building Physics IBP. It is a simulation study based on computational fluid dynamics (CFD) and computational aeroacoustics (CAA). CFD is a tool to simulate a flow numerically. Aeroacoustics is a sub-field of acoustics in which sound generated from a turbulent flow is studied. In CAA, such noise is computed numerically.

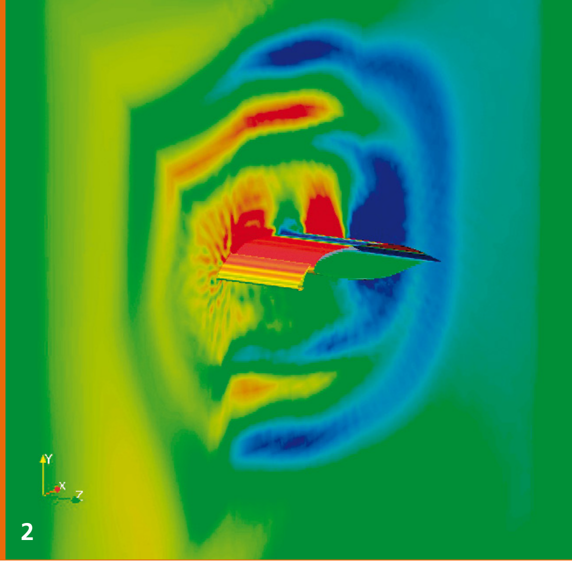
Due to recent development of low-noise aircraft engines, airframe noise has now become comparable to that from engines at landing phase. One major cause of airframe noise is a wing and high lift devices attached to it. This short report summarizes a way to estimate aeroacoustic noise from a wing.

FLOW SIMULATION

The incompressible Navier-Stokes equations were solved by assuming that the flow velocity is sufficiently smaller than the sound velocity. Large eddy simulation (LES) [1] was adopted here as a turbulence model. This is for correctly estimating the effect of small eddies that cannot be captured with a simulation mesh. The wing used in this analysis has a slat deployed in front of the main wing. The chord length, i. e., the length between the leading edge of the slat and the trailing edge of the main wing is 3.3 m. The flow was assumed to be two-dimensional. The velocity of the flow away from the wing was set to 50 m/s. The wing was tilted by ten degree to the direction of the flow. Fig. 1 (on next page) shows a simulation result, where a flow is represented by stream lines and pressure is denoted in color. Red and blue indicate high and low pressure, respectively.

Two main effects are observed at the wing due to the flow: drag and lift. High pressure contributing to drag occurs at the front of the slat, because the air is stagnant there. Lift is generated due to the fact that pressure is low on the upper surface of the wing, while it is moderate and high on the lower surface. This is because flow velocity is larger above the wing than below it. After the flow along the upper surface passes the front part of the wing, it then leaves the surface (flow separation) and becomes





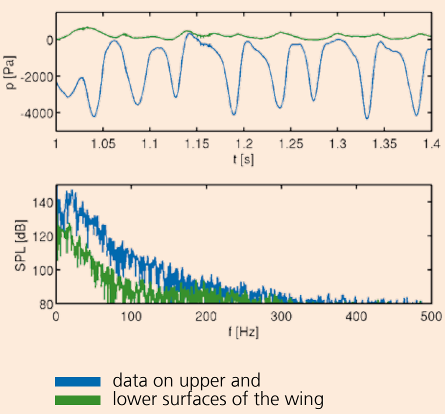
1 *Simulated flow and pressure around a wing with a slat. A flow is represented by stream lines. Pressure is denoted in color. Red and blue indicate high and low pressure, respectively.*

2 *Pressure wave radiating from the wing.*

turbulent. Eddies can be observed in the wake. These result in unsteady pressure and give rise to a noise source.

To investigate the characteristics of the noise source more deeply, the pressure at two points, one on the upper and the other on the lower surfaces, is analyzed. In Fig. 3, the waveforms and spectra of the pressure on the upper and lower surfaces are plotted in blue and green, respectively. The average of the pressure is smaller on the upper surface than on the lower surface. This difference corresponds to lift. The pressure fluctuation amplitude is larger on the upper surface than on the lower surface. This is because of the turbulent flow generated due to the flow separation above the upper surface. The frequency of the fluctuation is about 25 Hz. The spectrum of the pressure on the upper surface has a broad peak at this frequency.

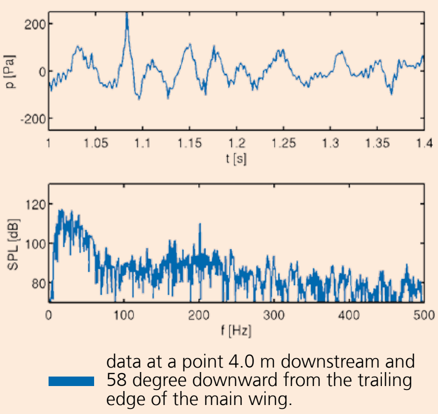
Fig. 3 Time histories of pressure fluctuation and resulting sound pressure levels versus frequency



ACOUSTIC SIMULATION

Acoustic radiation was calculated by solving the wave equations with fluctuating pressure on the wing surface as a noise source [2], which was obtained in the flow simulation. To realize a free field condition, a perfectly matched layer (PML) was arranged at the boundary of the calculation domain. This layer absorbs the wave radiating from the wing and does not reflect it back to the calculation domain. A snapshot of the sound pressure wave radiating from the wing is shown in Fig. 2, where high and low pressure is represented in red and blue. The radiation pattern is to some extent like that of the dipole radiation. The phases of the waves radiating towards the upper and lower directions are opposite to each other. This is, however, not obvious because the wing shape is not symmetric.

Fig. 4 Estimated noise waveform and spectrum



Sound pressure was monitored at a point 4.0 m downstream and 58 degree downward from the trailing edge of the main wing. The waveform and spectrum are plotted in Fig. 4. We find that this estimated noise has large components in the low frequency region, which is about 20 to 40 Hz. It also has perceptible components in the middle frequency region that is about 150 to 250 Hz.

SUMMARY

The paper presented a numerical method of how aeroacoustic noise from a wing is estimated. In a CFD simulation, an unsteady flow was first simulated to find pressure fluctuations on the wing surface. With a CAA simulation, noise was then estimated by solving the wave equation with the fluctuating pressure as a source. It was found that the estimated noise has large components in the low frequency region and perceptible components in the middle frequency region.