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Forced-oscillation control of sound radiated from the flow around a cascade of flat plates

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ABSTRACT

At specific velocities, intense tonal sound can be radiated from the flow around cascaded flat plates. This sound arises from the coupled phenomena of vortex shedding and acoustic resonance. To suppress such noise, we actively control the vortex shedding and acoustic radiation by oscillating the edges of every second plate in the cascade. The objective of this investigation was to clarify the effects and mechanism of noise reduction under this control. To understand how the amplitude and frequency of the oscillations influence the controlled flow and acoustic fields around the flat-plate cascade, we conducted direct aeroacoustic simulations using the volume penalization method. The sound pressure level at the resonance frequency was decreased by oscillating the plates at a dimensionless amplitude of 0.15. The pressure reduction failed at oscillation frequencies close to the resonance frequency, because the acoustic resonance occurs at the oscillation frequency. In the audible range of oscillation frequencies (0–20 kHz), the audible overall sound pressure level was not able to be reduced. In contrast, at oscillation frequencies beyond the audible range, both the tonal sound pressure level at the resonance frequency and the audible overall level were decreased. Consequently, the noise radiated from a cascade of plates can be reduced by forced oscillations at a frequency above the audible range. Moreover, we offset the phase of the oscillations between two plates and observed the effect on the acoustic field. At a one-quarter phase offset, the sound pressure level at the oscillation frequency exhibited a vertical asymmetrical directivity.

1. Introduction

Intense aerodynamic noise with an acoustic feedback loop often radiates from the flow around a cascade of flat plates (see Fig. 1). Cascaded flat-plate configurations exist in many industrial products, such as the front grills of automobiles and the louvers of high-rise buildings. This high-intensity noise is particularly annoying and causes discomfort to many people. To establish methods of suppressing this noise, we must clarify the acoustic radiation mechanism.

Parker [1] measured the sound pressure levels of the flows around a cascade of flat plates, and clarified that the sound pressure level intensifies at a specific velocity. They linked this phenomenon to coupling between the vortex shedding in the wakes and the acoustic resonance between the plates. Yokoyama et al. [2] also simulated the flow and acoustic field around a flat-plate cascade and predicted the phase-averaged flow fields around the plates. The vortices shed from neighboring plates were synchronised in an anti-phase mode, reinforcing the acoustic resonance.

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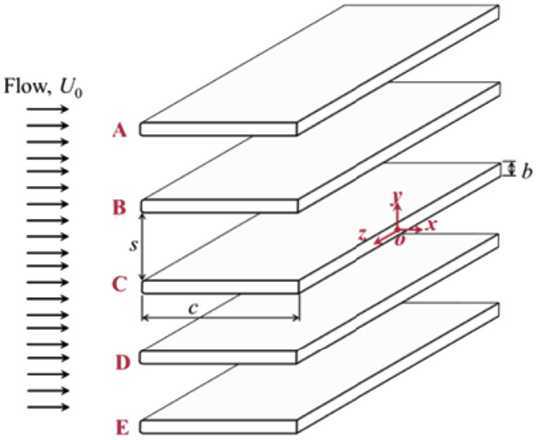

Fig. 1. Configuration of the flow around a cascade of flat plates.

Although these studies have elucidated the mechanism of sound generation accompanying acoustic resonance, a method for controlling and reducing the aerodynamic noise is not yet clarified. Therefore, this study discusses a method that decreases the aerodynamic noise by controlling the vortex shedding from the cascaded plates.

The wake and vortex shedding behind bluff bodies can be controlled by various techniques, including surface roughness [3], rotary oscillation [4] and an electrical method using plasma actuators [5]. These methods are classified into two groups: passive controls and active controls. Passive control requires no external energy source, but lacks design properties and provides limited reduction effects. Active control not only resolves these problems, but also enables feedback-loop control [6].

In the present paper, the tonal noise from the flow around a cascade of flat plates is suppressed by actively controlling the vortex shedding and acoustic radiation. The control is exerted by oscillating the downstream edges of the plates. To clarify the control effects on the flow and acoustic fields around the cascaded plates, we directly compute the flow and acoustic fields by the compressible Navier-Stokes equations and the volume penalization (VP) method [7,8], which is an immersed boundary method [9]. The VP method also predicts the flows and acoustic fields around complex geometries and moving objects such as oscillating plates.

To validate the present computational methods composed of the volume penalization method, the predicted sound field around the laminar flow of an oscillating square cylinder was compared with that described in Komatsu et al. [10], who applied the body-fitted coordinate (BFC) method. The same methods were applied to the prediction of the flows of the flat plates with a relatively high Reynolds number, where the flow in the wake becomes turbulent [2]. It is difficult to perform the experiments corresponding to the present computations for the flows around oscillating plates due to the lack of the appropriate actuators. Regarding the prediction of the turbulent flow in the wake, the predicted flow and sound around the rigid flat plates by using the same finite difference schemes with the present simulation and a BFC method have been validated by the comparison with the measured results [2]. Also, the predicted results with the VP method for stationary plates are presented with the measured data in this paper.

Section 2 explains the flow configurations, the control methods and the computational methodologies, and Section 3 validates the computational methodologies in comparison studies. The control effects on the flow and acoustic fields around the flat-plate cascade are discussed in Section 4.

2. Computational methodologies

2.1. Flow configurations

2.1.1. Flow around an oscillating square cylinder

Fig. 2 shows the configuration of an oscillating square cylinder in a cross-flow. The Reynolds number is $\mathrm{Re}_D \equiv \rho_0 U_0 D/\mu_0 = 100$, where ρ_0, U_0, μ_0 and D are the free-stream density, velocity, viscosity coefficient and the side the cylinder length, respectively. The free-stream Mach number is $M \equiv U_0/a_0 = 0.2$, where a_0 is the free-stream sound speed. The dimensionless amplitude and frequency of the sinusoidal oscillations are $A/D = 0.2$, and $\mathrm{St_v} \equiv f_\mathrm{v} D/U_0 = \{0.14, 1.0\}$, respectively, where A is the maximum tip deflection and f_v is the forced-oscillation frequency.

2.1.2. Flow around a cascade of flat plates

The flow and acoustic fields around a cascade of five flat plates were investigated as shown in Fig. 3. The computational parameters are listed in Table 1. The plate thickness b is 2 mm, and the aspect ratio c/b is 15.0. The separation to thickness ratio s/b of the flat-plate cascade is 6.0.