REDUCTION OF AERODYNAMIC NOISE INDUCED BY FLOW OVER A CAVITY

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Summary An experimental study to develop effective methods to reduce the aerodynamic noise induced by a turbulent flow over a cavity at low Mach numbers is carried out. It is shown that noise reduction can be achieved by both an active flow control method using piezo-ceramic devices and a passive control method inserting a thin plate into the cavity.

INTRODUCTION & EXPERIMENTAL SETUP

The generation of aerodynamic sound at a cavity is a well known phenomenon which can be found in places such as buildings, automobiles with an open sunroof and landing gears on an aircraft. This aerodynamics noise becomes more intense as the velocity of the flow increases, which is currently the limiting factor for the maximum velocity of the high-speed train in Japan. In the process of generation of the cavity noise, a self-sustained mechanism namely the "feedback loop" plays a dominant role. When the cavity is exposed to a flow, the separating boundary layer becomes a free shear layer and rolls-up into series of vortices which repeatedly hit the downstream edge. The periodical pressure-fluctuation travels upstream and affects the shear layer at its origin through the receptivity process, forming a feedback loop. As a result of this feedback loop, the aerodynamic noise from a cavity tends to be a large amplitude single tone. This paper describes the results of series of experiments aimed at developing an efficient method to reduce the aerodynamic noise generated at a cavity when the approaching boundary layer flow is turbulent and is at low Mach numbers.

The experiments were conducted using a low-turbulence wind tunnel of the Institute of Fluid Science (IFS) in Tohoku University, and a large-scale, low-noise wind tunnel of the Railway Technical Research Institute (RTRI). In each case, the test-piece was horizontally mounted in the open-type test section as shown in Figs. 1 and 2. For the IFS experiment, the upstream turbulent boundary layer was created by a combination of a strip of rough surface and a trip wire. In each case, a resonator, long in the streamwise direction, was used to simulate a deep cavity environment. When the boundary layer is turbulent and the Mach number of the flow is small, as in this case, loud peaky noise is not induced by a shallow cavity. So only the deep cavity case becomes important. The naturally dominant frequency of the cavity noise was 523 Hz for IFS (30 [m/s]), and 90 Hz for ITRI (60 m/s). In each case, the operating frequency of the actuators was set to the frequency. The thickness of the approaching turbulent boundary layer was 11mm for the IFS experiment, and 100 mm for RTRI.

In the active control experiment, an array of "bi-morph type" piezo-ceramic actuators attached vertically along the upstream-end vertical wall of the cavity was used. Eight pieces of the actuators were attached side-by-side along the spanwise direction (Fig.1). The idea is move the upstream edge where the receptivity to disturbance is most sensitive. Each "bi-morph type" actuator makes a bending motion, making its top edge to move back an forth in the direction parallel to the freestream. The amplitude of the fluctuation that can be introduced by the actuator is not sufficient to alter the frequency of the tone noise when the flow is turbulent, however the purpose of the control is only to change the phase of the velocity fluctuation along the spanwise direction. In the passive control experiment, a small thin flat plate was inserted vertically into the cavity. The basic idea is to alter the mechanism which the shear layer rolls-up into a series of vortices. Its noise reducing effect was investigated, changing the size and position of the small plate. A single hot-wire and a condenser microphone were used to measure the velocity and the sound, respectively.

RESULTS & DISCUSSION

Fig. 3 shows how the peak height of the dominant frequency component of sound spectrum changes against the voltage supplied to the actuators. Four operation modes were tested: 1) Single-phase - all eight pieces were driven by the same signal, 2) Mode 4 - each group of four pieces were supplied with the same-phase signal, 3) Mode 2 - a couple of two pieces moved together, 4) Mode 1 - each neighbouring piece was manipulated 180 degrees out of phase. It is apparent from Fig.3 that the sound level is suppressed, regardless of the modes, compared to the without-control case. In particular, the maximum value of noise reduction in mode 1 reaches approximately 30dB. Fig.4 shows the contour map of streamwise velocity fluctuation in the *xz*-plane for each mode when the manipulating voltage is 70V. It can be found

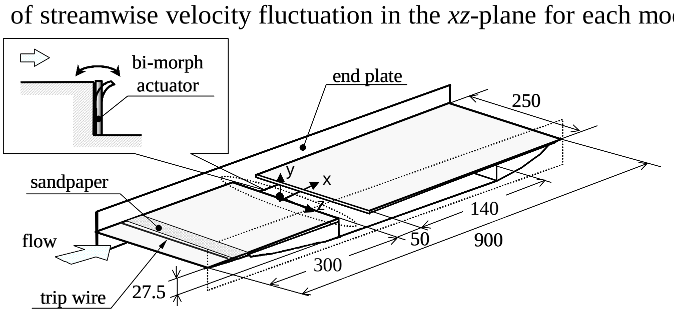

Fig.1 The model with a cavity (IFS)

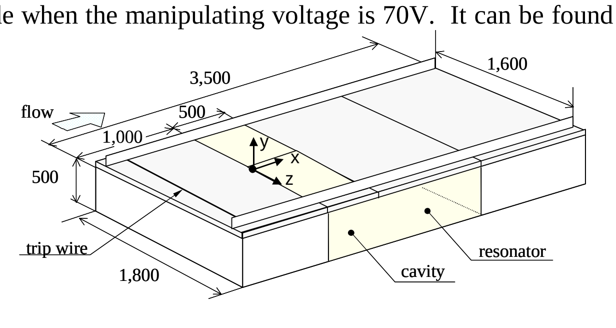

Fig.2 The model with a cavity (RTRI)

that the velocity fluctuation pattern changes sharply at several spanwise locations, which coincide with the boundary of the two actuator pieces that are manipulated 180 degrees out of phase. The results indicate that the active flow field control is successful. And it can be assumed that because the sound waves generated at neighbouring locations were 180 degrees out of phase, the sound waves cancelled each other resulting in the suppression of the peak noise.
The results of the passive control experiment are shown in Fig. 5. The abscissa is the x location of the plate, which corresponds to the distance between the upstream wall of the cavity and the plate. The upper tip of the plate is levelled with the upstream plate surface (y = 0). In the figure, it can be found that the noise suppressing effect becomes more obvious at around x = 15 and near the trailing edge of the cavity. The effect increases with the increase in the vertical length of the plate while it is between 2 and 8 mm. The noise reduction greater than the active control is achieved.
The results of the large wind-tunnel experiment shown in Fig. 6 show the same tendency. However, the noise suppression is not as effective as for the small wind tunnel experiments. When the vertical length of the plate is 30mm, an increase in noise can be found. This may be due to the oscillation of the test pieces itself. Fig. 7 shows the FFT spectra of the sound with and without control. It can be found that when the plate is placed near the leading edge (x = 100 [mm]), not only the peak of the cavity noise around 90 Hz but the energy levels of all frequencies decrease. On the other hand, for the case of x = 450 [mm], the peak noise decrease, but the sound energy levels of some frequency ranges increase instead. This tendency was not observed in the small wind-tunnel experiments.

CONCLUSIONS

Using both methods, the active and the passive flow control, cavity noise suppression experiments were carried out with some promising results. It was found that the "bi-morph type" piezo-ceramic actuators were capable of modifying the phase of the oscillatory flow fluctuation leading to noise suppression. This technique has a possibility to be applied in various flow controlling situations. It was also found that for noise suppression, the passive method to simply insert a thin flat plate into the cavity could be more effective. However, by comparing the experimental results from the two different sized facilities, it was found that the sound suppressing efficiency depends on the scale of the flow field. More research is needed, in order to clarify the reason.

References

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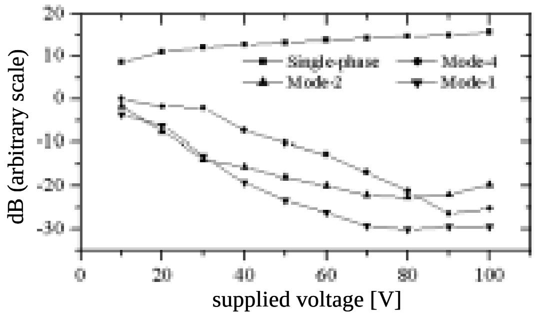
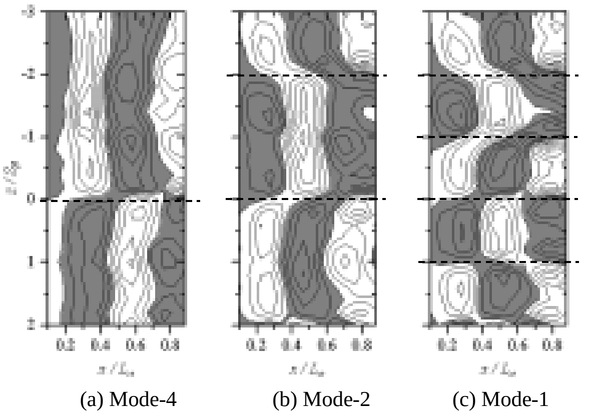


Fig. 3 Noise suppression effect of bimorph actuators (IFS)


(a) Mode-4 (b) Mode-2 (c) Mode-1
Fig.4 Contour maps of streamwise velocity fluctuations in xz-plane at y = 0 and supplied voltage = 70 V (IFS)

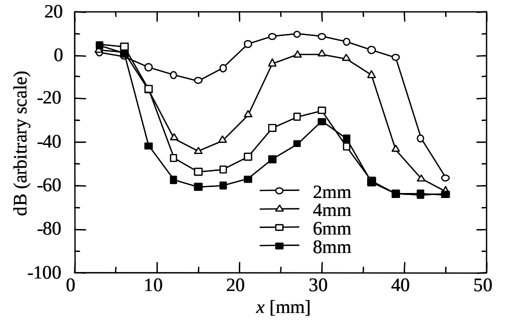


Fig.5 Variation of peak level with plates of different vertical lengths and x locations (IFS)

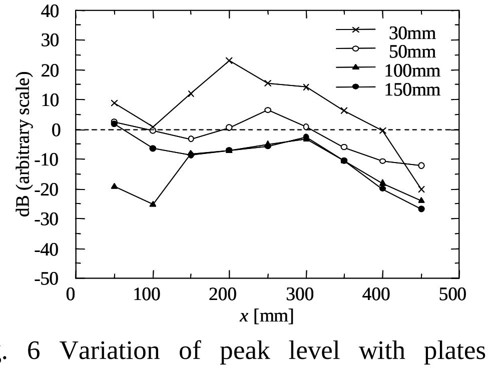


Fig. 6 Variation of peak level with plates of different vertical lengths and x locations (RTRI)

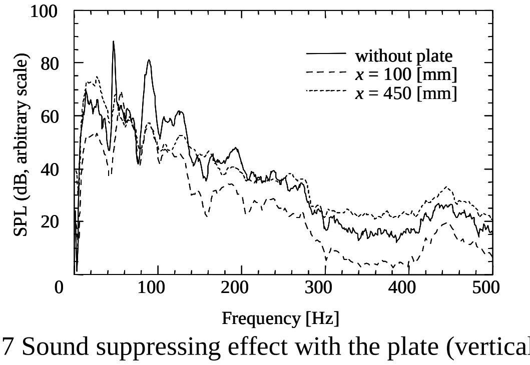


Fig.7 Sound suppressing effect with the plate (vertical length = 100 [mm]) at x = 100 and 450 mm (RTRI)

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