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REDUCTION OF NOISE RADIATED FROM SUPERSONIC JET BY USING CAVITY

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ABSTRACT

It is well known that the supersonic jets radiated broad band noise as well as very strong sound waves called screech tone. Powell showed that the screech tone is generated by a feedback loop consisting of the downstream-convecting coherent vortical structure surrounding the jet and upstream-propagating sound waves in the ambient. In recent years, the reduction of noise radiated from supersonic jet becomes very important theme in connection with the development of the supersonic passenger airplane of next generation. In this experimental study, the possibility of the reduction of very strong screech tone by using a circular cavity placed concentrically inside the circular nozzle was examined. The diameter of nozzle was 10mm and the depth of cavity was 2mm. The variations of the frequency and the sound pressure levels of the screech and cavity tones were measured by changing the pressure ratio of the jet and the length of cavity. From this experimental study, it is observed that in some cases, the sound pressure levels of screech and cavity tones become lower than that of the screech tone radiated from supersonic free jet by 20dB or so for wide range of the pressure ratio of the jet. It is also found from the optical and acoustical observations that in almost cases the oscillation modes of jets are axisymmetric.

1 - INTRODUCTION

The supersonic free jets radiate broadband noise and very strong sound wave called screech tone simultaneously. According to Powell [1], this sound wave is generated by the feedback loop consisting of the downstream-convecting coherent vortical structures around the jet and the upstream-propagating sound waves in the ambient. It is also known that the very strong sound wave called cavity tone is generated by the resonance phenomenon occurred in the high-speed jets flowing over the cavity Rockwelland [3] and Tam [4]. In recent years, reduction of noise radiated from the supersonic jet becomes very important theme in connection with the development of the supersonic passenger airplane of next generation. In the present experiment, a circular cavity was placed concentrically inside the nozzle and the acoustical characteristics of the screech and cavity tones radiated from the supersonic jet was investigated. From this experiment, it is found that remarkable reduction of the screech tone was achieved.

2 - EXPERIMENTAL APPARATUS

The schematic view of the nozzle configuration used in this experiment is shown in Fig. 1. The air jet was exhausted from a circular nozzle. The diameter D of the nozzle exit is 10 mm. The cavity was placed at 2 mm upstream of the nozzle exit. The lengths L of the cavity were 12, 16, and 20 mm. The diameter a of the cavity was fixed to 14 mm. Therefore, the depth of the circular cavity was 2 mm.

All the experiments were carried out within an anechoic chamber. First, the power spectra of the sounds radiated from supersonic jets were measured by using a microphone B&K type-4191 placed at the near sound field at various pressure ratios R of the jets. From these power spectra, the frequency change and the change of the SPL of the screech and cavity tones with the pressure ratio R of the jets were obtained.

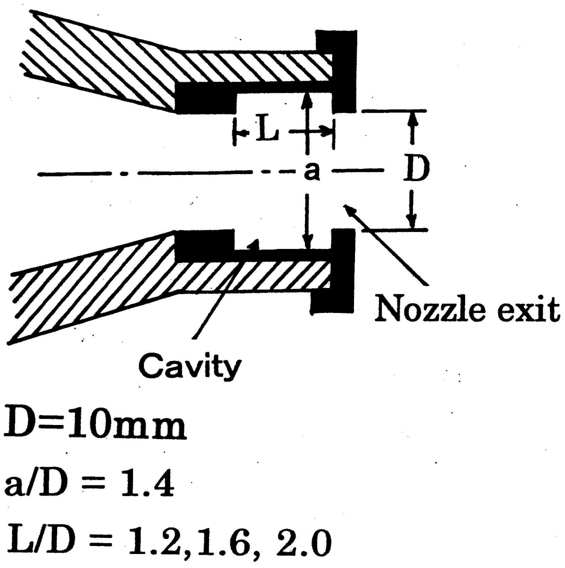

Figure 1: Nozzle configuration.

All the signal outputs from the microphones were analyzed on an Ono Sokki type CF-5210 FFT spectrum analyzer. The pressure ratios R (=P_o/P, where P_o is the stagnation pressure and P the ambient pressure) of the jets were changed in the range about 2.0∼6.3. A conventional single pass schlieren system was used with a spark light source to visualize the floe field and near sound field.

3 - EXPERIMENTAL RESULTS

3.1 - Frequency characteristics

First, the frequency characteristics of the screech and cavity tones emitted from the circular jet was measured at various pressure ratios R of the jets and the results are shown in Fig. 2. In these figures, the solid circles indicate the frequencies of the dominant tones, defined here as those that exceed the local broad band noise by at least 10 dB. The open circles mark the secondary tones that exceed the broadband noise by 5-10 dB.

As can be seen in Fig. 2a, only the screech tones labeled with capital letter S are radiated from the supersonic free jet. It is observed that the steady decrease of the screech frequency with increasing the pressure ratio is interrupted by three frequency jumps. In the case of the jet issuing from the nozzle with cavity, both screech and cavity tones labeled with capital letters S and C are radiated as shown in Figs. 2b-d. In these figures, it is observed that the frequencies of the cavity tones are kept at constant whatever the pressure ratio R of the jet is changed, and the screech tones with the frequency higher than the fundamental frequency of the cavity tone is reduced efficiently.

3.2 - Sound pressure levels

Next, in Figs. 3, 4 and 5, the sound pressure levels (SPL) of the screech and the cavity tones radiated from the jets exhausting from the nozzle with cavity was compared with that of the screech tone radiated from the supersonic free jet. In this figure, the open circles indicate the SPL of the screech tone radiated from the free jet and the solid circles represent the SPL of the screech tone and cavity tone emitted from the jet exhausted from the nozzle with cavity.

Figure 3 shows the results for the cavity length of L/D = 1.2. From these figures, it is observed that the SPL of the screech tone radiated from the jet issuing from the nozzle with cavity becomes lower than that of the screech tone radiated from the free jet by about 20 to 30 dB in the pressure ratio range $3<R<5$ (Fig. 3a) and the SPL of the cavity tone with the frequency of 6.8 kHz also becomes lower than that of the screech tone radiated from the free jet by about 20 to 30 dB in the same pressure ratio range (Fig. 3b). The SPL of the cavity tone with the frequency of 13.6 kHz becomes lower than that radiated from free jet by about 0 to 20 dB in the pressure ratio range about $3<R<5$ (Fig. 3c).

Figure 4 shows the experimental results for the cavity length of L/D = 1.6. From these figures it is observed that the SPL of the screech tone radiated from the jet issuing from the nozzle with cavity be comes lower than that of the screech tone radiated from the free jet by about 15 to 30 dB in the pressure

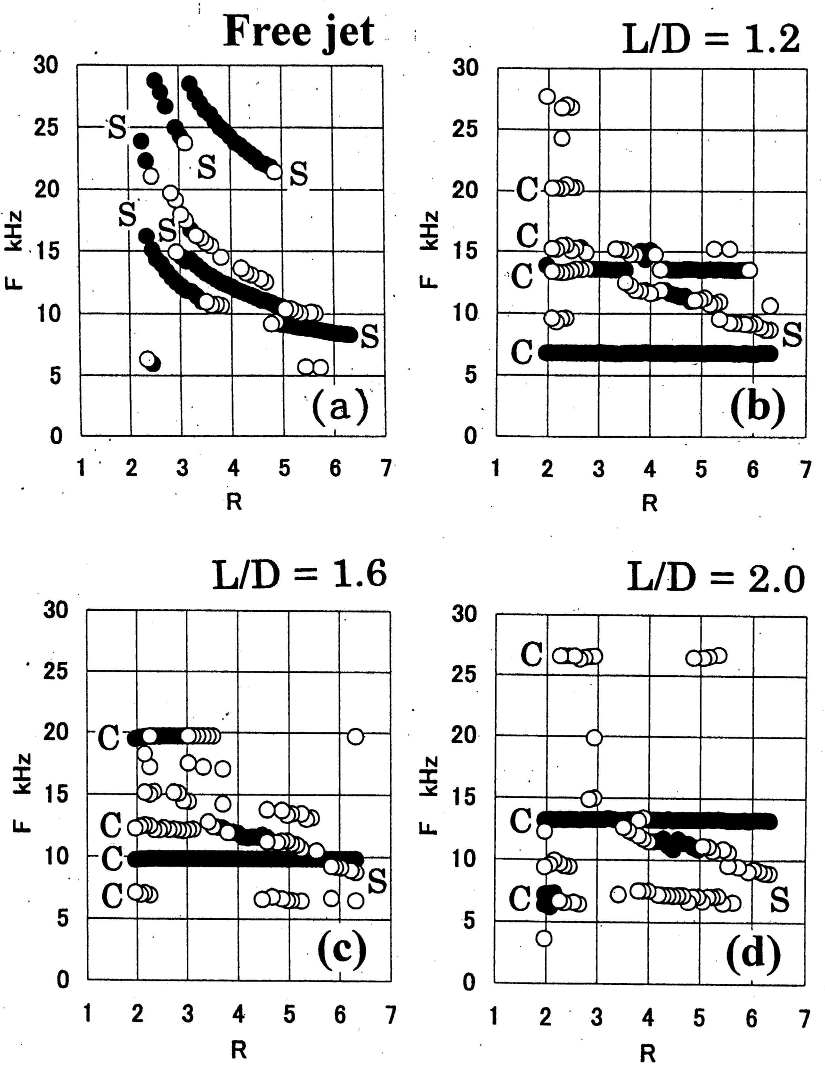

Figure 2: Frequencies of screech and cavity tones.

ratio range 3<R<5 (Fig. 4a) and the SPL of the cavity tone becomes lower than that of the screech tone radiated from the free jet by about 15 to 20 dB in the same pressure ratio range (Fig. 4).
Figure 5 demonstrates the results for the cavity length of L/D=1.6. From Fig. 5a, it is observed that the SPL of the screech tone becomes lower than that of the screech tone emitted by the free jet by about 20 to 30 dB in the pressure ratio range 3<R<5. The SPL of the cavity tone becomes lower than that of the screech tone radiated from the free jet by about 0 to 20 dB in the same pressure ratio range (Fig. 5b).
From these results, it is observed that the effect of the reduction of the screech tone is almost the same for these three lengths of cavities. Therefore, the superiority of the net reduction of the noise depends on the SPL of the cavity tone. The SPL of the cavity tone radiated from the cavity with the length of L/D = 1.6 shows the lowest one in the same pressure ratio range of 3<R<5. Thus, it is confirmed that the cavity with the length of L/D = 1.6 is superior one among these three cavity with different lengths to reduce the noise radiated from the supersonic jets.

3.3 - Optical observation

Figure 6 shows the schlieren instantaneous photographs of the jets and near sound fields taken at a pressure ratio R = 3.90. Figure 6a shows the free jet and Fig. 6b-d show the jets exhausted from the nozzle with cavity whose lengths are 1.2, 1.6, and 2.0, respectively. From these photographs, it is clearly seen that very strong screech tone shown in Fig. 6a is reduced completely as shown in Fig. 6b-d.

4 - CONCLUSION

In this experimental study, the acoustical characteristics of screech and cavity tones were measured in

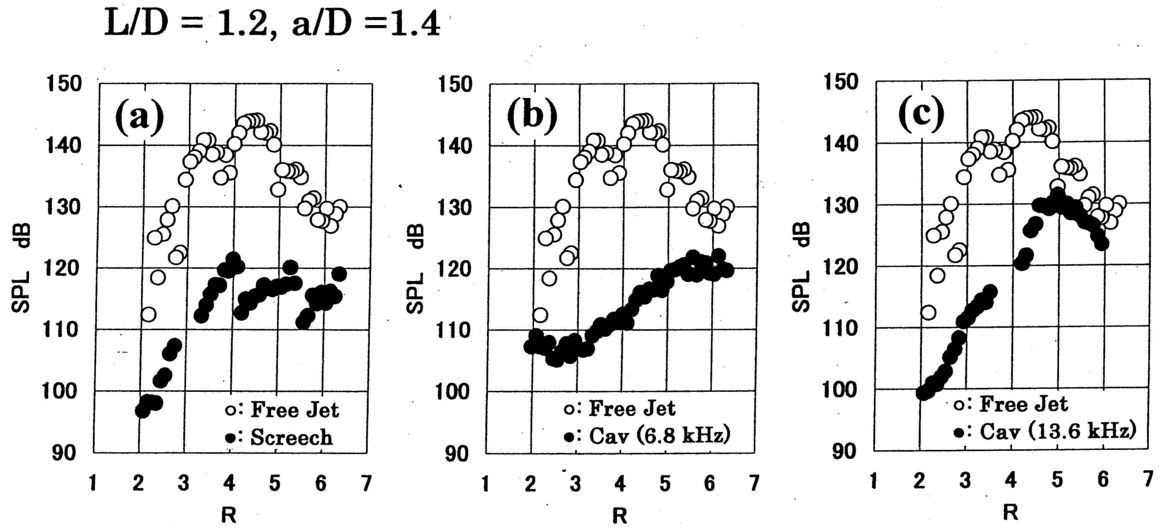

Figure 3: Change of SPL of screech and cavity toneswith pressure ratio of jets.

the near sound field by changing the pressure ratio R of the jet and the length L/D of the cavity. From this experimental study, it is observed that when the circular cavity was placed concentrically inside the circular nozzle, the sound pressure levels SPL of the screech and cavity tones become lower than that of the screech tone radiated from the free jet by about 30 dB and 20 dB at most, respectively, in the pressure ratio range 3<R<5.

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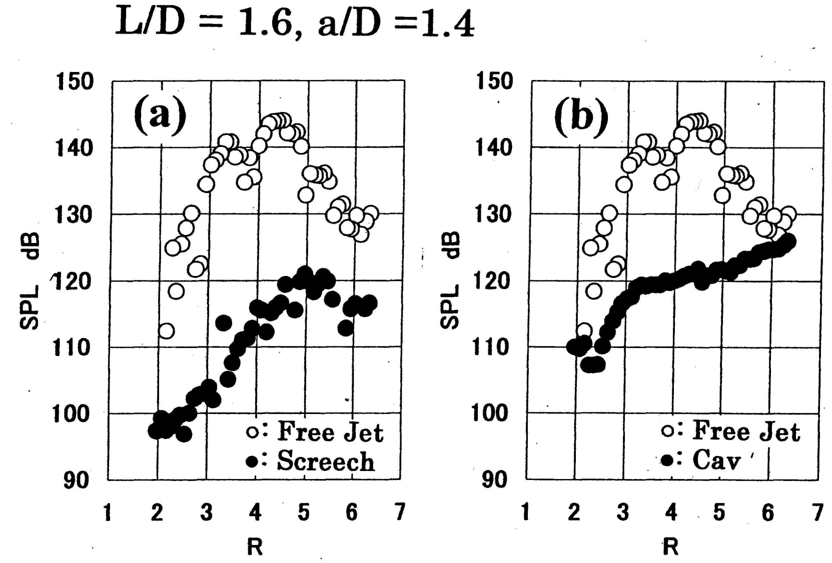


Figure 4: Change of SPL of screech and cavity toneswith pressure ratio of jets.

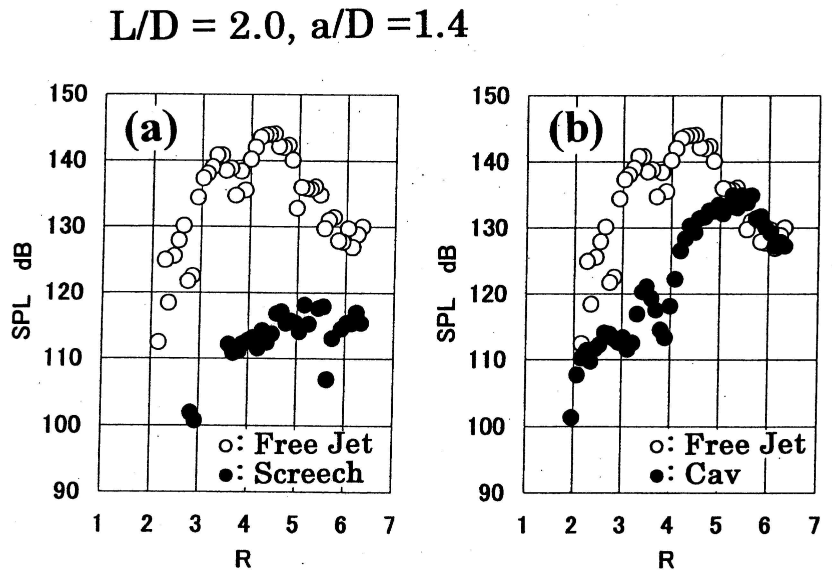
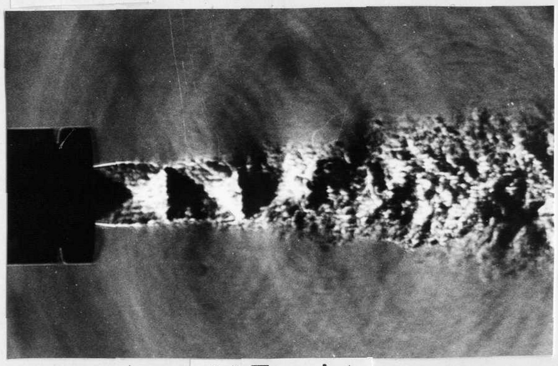
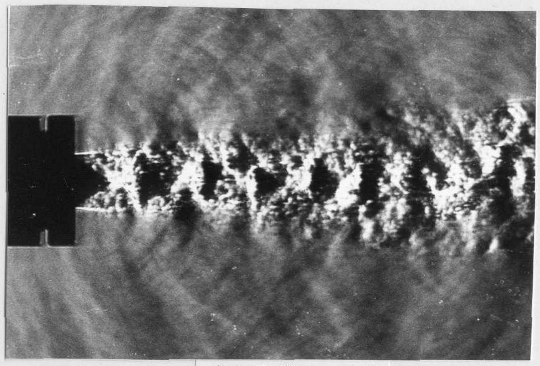
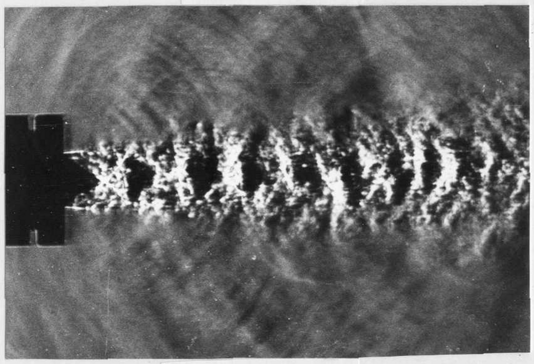
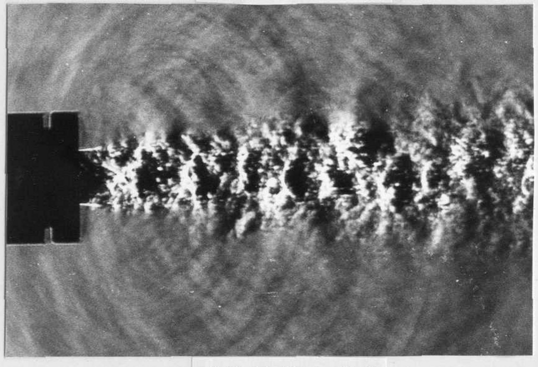


Figure 5: Change of SPL of screech and cavity tones with pressure ratio of jets.

R = 3.90

(a) Free jet (b) L/D = 1.2

(c) L/D = 1.6 (d) L/D = 2.0

Fig. 6 Photographs of jets.

Figure 6: Photographs of jets.