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와이어 장치를 이용한 초음속 제트소음의 제어

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Control of the Supersonic Jet Noise Using a Wire Device

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Abstract

The present study describes an experimental work to reduce supersonic jet noise using a control wire device that is placed into the supersonic jet stream. The jet pressure ratio is varied to obtain the supersonic jets which are operated in a wide range of over-expanded to moderately under-expanded conditions. The wire device is composed of long cylinders with a very small diameter. X-type wire device is applied to control the supersonic jet noise, and its location is varied to investigate the effect of the control wire device on supersonic jet noise. A high-quality Schlieren optical system is used to visualize the flow field of supersonic jet with and without the control wire device. Acoustic measurement is performed to obtain the overall sound pressure level and noise spectra. The results obtained show that the present wire device destroys the shock-cell structures, reduces the shock strength, and consequently leading to a substantial suppression of supersonic jet noise.

Key Words : Supersonic Jet(초음속 제트), Noise Control(소음제어), Screech Tone(스크리치 톤), Shock Wave(충격파), Wire Device(와이어 장치), Supersonic Nozzle(초음속 노즐)

1. Introduction

Supersonic jets have long been used in many diverse fields of engineering applications such as supersonic aircraft, jet propulsion thrust vectoring, fuel injector for supersonic combustion, soot blower device, thermal spray device, etc.(1-2). It has been well known that the time-mean structure of supersonic jet is determined by jet pressure ratio and nozzle configuration. A considerable deal of researches has been made to understand the noise generation in supersonic jet and to obtain the noise control techniques appropriate to suppress the jet noise. Recently, the supersonic jet noise is being a very important issue to be resolved from the practical point of view of performance of fluidic device as well as environmental noise problem (3).

In general, it is known that supersonic jet noise consists of three major components(4) : the turbulent mixing noise, the broadband shock-associated noise, and the screech tones. Of the major components consisting of the supersonic jet noise, the screech tone has a strong directivity and high intensity, and thus, it can cause structural fatigue failure of fluid devices(5).

A great deal of experimental studies has been performed to reduce the supersonic jet noise. Most of the previous studies were mainly concentrated on modification of the shear layer generated at the nozzle exit, and thus leading to reduction. Tabs, grooves, asymmetric nozzles, porous plug, etc. have been used in these control techniques, which have been successful in the supersonic jet noise suppression(6-7). However, these methods are subjects to a large amount of the total

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pressure loss or the jet thrust penalty(8).

In the present study, a new control technique of the supersonic jet noise is investigated using a control wire device, which has a simple structure and is easy to implement. The objective of the present study is to experimentally investigate the control effectiveness of the wire device on the structures and acoustic fields of supersonic jet, and to get insight into physical mechanism related to the jet noise reduction. The present experimental results show that the control wire device is useful for the practical applications with regard to the jet noise suppressions.

2. Experimental Facilities

Experiment has been performed in an anechoic test room that is schematically shown in Fig.1. According to some preliminary acoustic tests, the present room is anechoic for all of frequency components above approximately 120Hz and has the background noise of about 1dB. Compressed dry air is supplied to the plenum chamber, in which a honeycomb system reduces flow turbulence. A convergent-divergent nozzle with a design Mach number of 2.0 is installed on the end wall of the plenum chamber. The pressure inside the plenum chamber is controlled by a pressure regulator valve which is located upstream of the plenum chamber. In the present study, the jet pressure ratio, NPR($=p_0/p_b$) is defined as the ratio of the pressure(p_0) inside the plenum chamber to atmospheric pressure(p_b), and it is varied between 2.0 and 18.0.

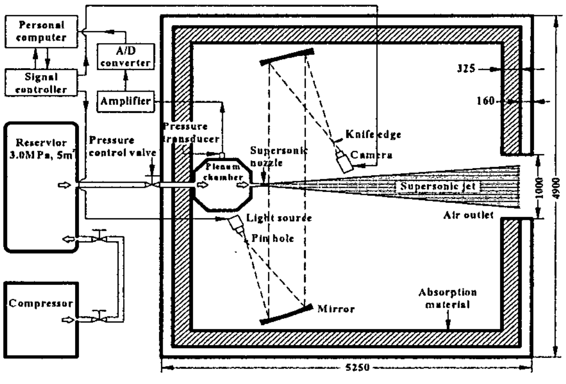


Fig.1 Experimental facility

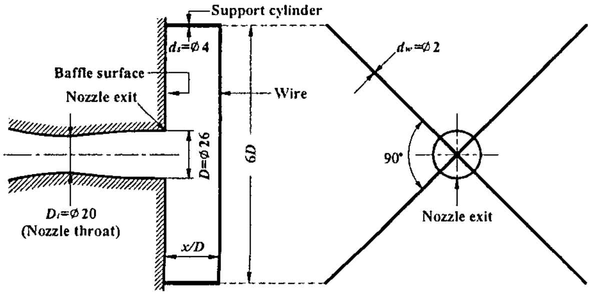


Fig.2 Arrangement of control wire device

A high-quality Schlieren optical system is employed to visualize the qualitative structures of supersonic jet. Acoustic measurements are made using a condenser microphone with a diameter 6.0*mm*, which is located at 98° and radius 38*D* away from the exit of nozzle.

The control wire device is illustrated in Fig.2. It is placed perpendicularly to the supersonic jet stream. The X-type wire device is composed of two long stainless cylinders with an extremely small diameter (d_w=2*mm*) which are crossed by an angle of 90°. Four ends of the wires are supported to four rigid cylinders which are tightly bolted onto the baffle plate installed at the nozzle exit. The location (x/D) of the wire device is varied.

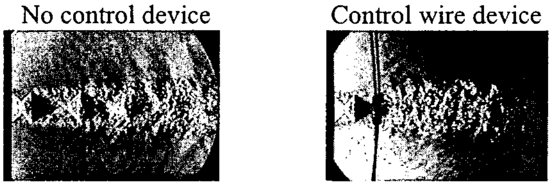
3. Results and Discussion

3.1 Effect of a wire device on the jet structure

Figure 3 shows the Schlieren pictures of supersonic jets with and without the X-type wire device, wire the location of the wire device is at x/D=1.0, and M_j is the fully expanded jet Mach number as given in Eq.(1),

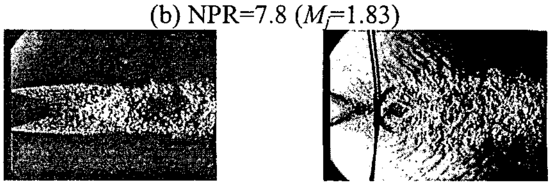
$$M_j = \left[2/(\gamma-1)\left\{(p_0/p_b)^{(\gamma-1)/\gamma}-1\right\}\right]^{1/2} \qquad (1)$$

where γ is the ratio of specific heats. Over-expanded jets are obtained for the pressure ratios less than NPR=7.8. For over-expanded-jet without the control wire device at NPR=4.0, oblique shock waves are generated inside the nozzle, and these are reflected from the jet axis, forming a Mach disk. The reflected shocks reflect again at the jet boundary, consequently leading to the repeated shock-cell structure. When the control wire device is placed at x/D=1.0, as also shown in Fig.3(a), the shock-cell structure just downstream of it is nearly broken, leading to strong instability waves which propagates both upstream and downstream. It seems that the control wire device increases somewhat the jet spreading rate due to the increased turbulence in the presence of the wire device.



(a) NPR=4.0 (M_j=1.56)

(b) NPR=7.8 (M_j=1.83)

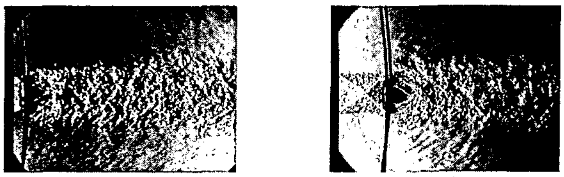


(c) NPR=12.0 (M_j=2.27)

Fig.3 Schlieren pictures of supersonic jets (x/D=1.0)

At NPR=7.8, the jet is correctly expansion at the nozzle exit, and then the pressure at the exit of nozzle is nearly matched to the ambient back pressure. In this case, the jet boundary is nearly parallel to the jet axis. The weak oblique shock waves observed at the exit of nozzle are due to the boundary layer effect. At the pressure ratios higher than NPR=7.8, the jets are under-expanded, as shown in Fig.3(c). The jet boundary is expanded due to expansion waves which are generated at the exit of nozzle. From the visualization pictures of Fig.3(b) and (c), it is observed that the control wire device increases the jet spreading rate.

For three jet cases of over-, correctly-, and under-expanded conditions, the effect of the location of the control wire device is shown in Figs.4 to 6. It is found that the location of the wire device plays a significant role on the shock-cell structures and the jet spreading rate. At x/D=0.2, the X-type wire device destroys almost completely the shock-cell structure downstream of it. When the wire device is located at a distance of several times the shock-cell spacing, the jet structure upstream of it does not change in the presence of the control wire device. It is also interesting to note that the location of the control wire device significantly affects the instability waves. Additional instability waves are produced by the complicated interactions between the convective turbulent structures and the wire device.


(a) x/D=0.2 (b) x/D=1.0

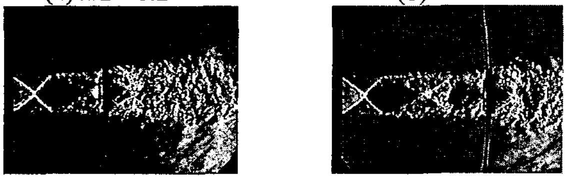
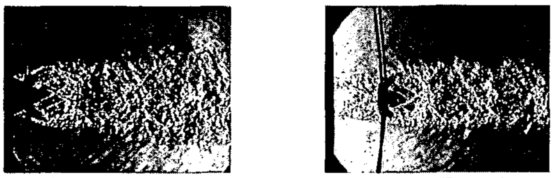

(c) x/D=2.0 (d) x/D=3.0

Fig.4 Over-expanded jets with the control wire device (NPR=5.0)


(a) x/D=0.2 (b) x/D=1.0

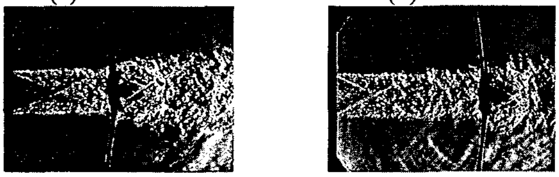
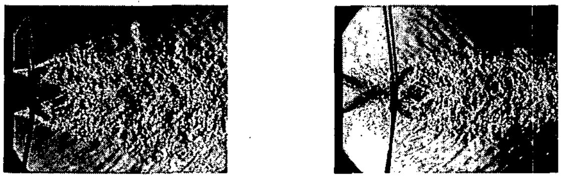

(c) x/D=2.0 (d) x/D=3.0

Fig.5 Correctly-expanded jets with the control wire device (NPR=7.8)


(a) x/D=0.2 (b) x/D=1.0

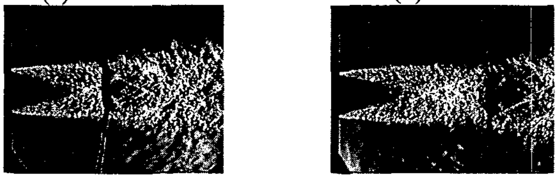

(c) x/D=2.0 (d) x/D=3.0

Fig.6 Under-expanded jets with the control wire device (NPR=12.0)

3.2 Acoustic measurement results

Figure 7 shows the noise spectra of typical over-expanded jet with and without the control wire device, where NPR=5.0, and x/D is the streamwise location of the wire device. For no wire device it is observed that there are three discrete peaks, called the screech tone, in the spectra, in which are the fundamental frequency and its harmonics. It is interesting to note that the control wire device eliminates the screech tone and considerably suppresses the broadband shock-associated noises as well, when it is located upstream of x/D=2.0. However, for the control wire device located at x/D=3.0 and 6.0, the discrete tones appear again, but its frequency seems to be changed, depending on the location of the control wire device. Moreover, in the frequency range below 10kHz, the sound pressure level associated with the broadband shock-associated noises increases in the presence of the control wire device (see Fig.7e). It is, thus, believed that the present control wire device is effective in suppressing the screech tones and the broadband shock-associated noises in over-expanded jet, provided that the wire device is located upstream of x/D=3.0. This indicates that the present control method is practically easy to implement since there is enough margin in the location of the wire device to control the supersonic jet noise.

Figure 8 shows the control effect of the X-type wire device on the fundamental screech tone amplitude. In the case of no control device, the fundamental screech tone amplitude has respective peak values for both the over-expanded and under-expanded jets, while there is no screech tone for correctly-expanded jet. It is found that for the location of the wire device at $x/D \leqq 3.0$, the screech tone amplitude is remarkably decreased, compared with the case of no control device. It is noted here that for the location of the wire device at x/D=0.2, the screech tones were completely vanished. However, as the wire device is moved downstream, the screech tone amplitude increases. For x/D=6.0, the screech tone amplitude is much higher than that of no control device, in especial, in the over-expanded conditions, and it has some peak values at M_j=1.64, 1.88 and 2.09, respectively.

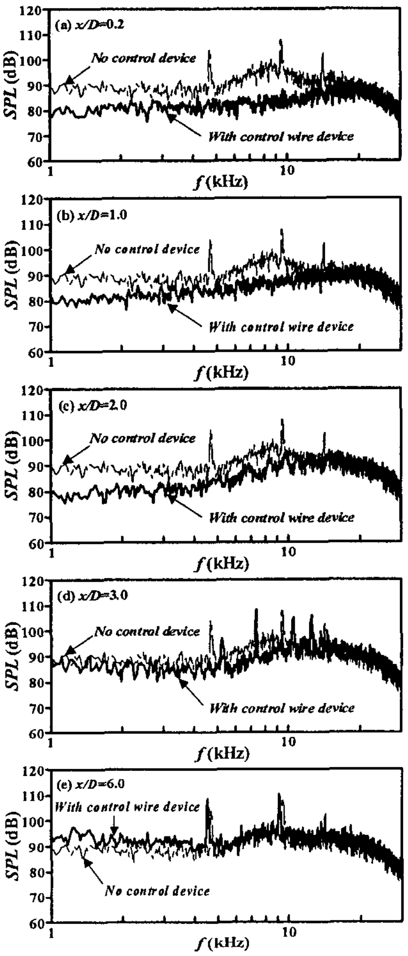


Fig.7 Noise spectra of over-expanded jets without and with the control wire device (NPR=5.0)

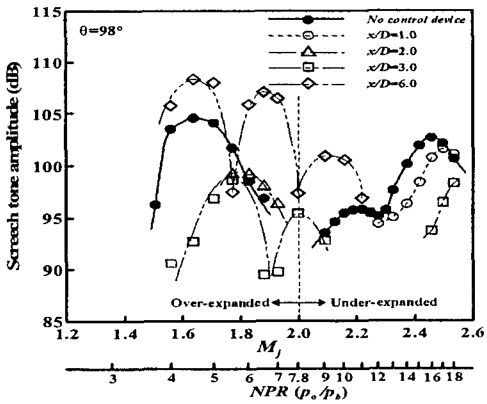


Fig.8 Fundamental screech tone amplitude vs M_j

The control effect of the wire device on the overall sound pressure level (OASPL) is presented in Fig.9. For no control device, the OASPL increases gradually with an increase in M_j, slightly decreasing at the vicinity of M_j=2.0, and then is kept nearly constant with a further increase in M_j. Similar qualitative tendency is also found in the cases with the control wire device. However, the OASPL in the over-expanded conditions is remarkably reduced by the control wire device, provided that the control wire device is located at x/D=0.2. The maximum reduction in the OASPL is about 11dB at M_j=1.56. As the location of the control wire device is moved downstream, the control effect becomes less.

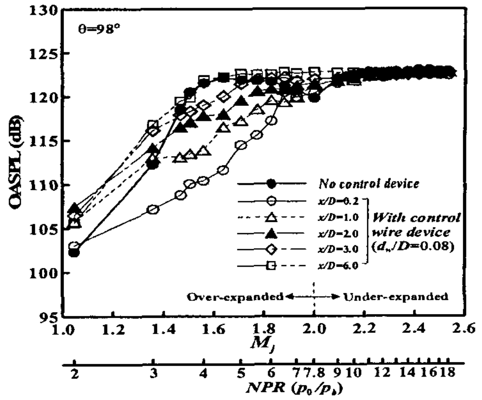


Fig.9 Variation of OASPL with M_j

4. Conclusion

The present wire device significantly affects the jet structure and acoustic field, depending on its location and the jet pressure ratio. By introducing the wire device to the jet stream, the shock-cell structure is destroyed and its strength is reduced, while the jet spreading rate downstream of the wire device somewhat increases. The present control wire device suppresses the screech tones and the broadband shock-associated noise as well as the overall sound pressure level, when its suitably placed at a location close to the exit of nozzle.

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