ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

PERFORMANCE EVALUATION OF SPHERICAL REFLECTOR IN SUPPRESSING SUPERSONIC JET NOISE

Md. Tawhidul Islam Khan, Kunisato Seto and Kenbu Teramoto
Department of Mechanical Engineering, Saga University, 1 Honjo-machi, Saga 840-8502, Japan.
b0835@cc.saga-u.ac.jp

Abstract

Jet screech is the most remarkable aerodynamic noise which is caused by acoustic feedback loops and capable of causing structural failure. There were many efforts to suppress this screech component; however, most of them used a stuff that protruded into jet flow which reduced the thrust and finally decreased the overall efficiency. In the present study, investigations have been carried out to evaluate the performance of the new control technique of jet screech placing a spherical reflector at the nozzle exit. The reflector at the nozzle exit controlled the location of the sound image source as well as minimized the sound pressure at the nozzle exit and finally decreased the screech tone. It has been indicated that the new technique suppressed the broadband noise also. Furthermore the spherical reflector was very much effective in reducing overall sound pressure in the upstream region of the nozzle exit. Hence, proposed technique protects the upstream noise propagation and may be promising countermeasure to protect the fuselage of an aircraft from acoustic fatigue by incorporating it into a streamline form. In the present paper the performance of the proposed technique was examined acoustically as well as aerodynamically.

INTRODUCTION

The interaction of the shock cells pattern with the large-scale structure in the shear layer causes the radiation of two additional noise components from an underexpanded jet: screech tones, and broadband shock-associated noise [8]. The jet screech is of particular interest because of not only the general noise-reduction but also the acoustical fatigue of the structure [7]. The feedback loop leading to distinct screech tones is sensitive to small changes in the system conditions, and its explanation is to date mostly based on experimental observations [9]. A detailed observation of the feedback loop, the sound generation process and the receptivity issue was done by Panda [6]. He found that the feedback loop apparently chose the new length scale represented by the standing wavelength instead of the average shock spacing in selecting the screech frequency. The noise level of jet engines, particularly during the takeoff and the climb is often a concern for the people living near to the airport. It is well known that the intensity of screech tone decreases with the increase of the jet temperature when the jet Mach number is low [3]. However, the intended high-speed civil transport program calls the attention again for the noise reduction [1]. One of the most frustrating aspects of the research of supersonic jet noise is the inability to predict the intensity of screech tones. The difficulties appear to lie both in the extreme sensitivity of the screech tones to the surrounding environment and in the inherent need to deal with the nonlinearities of the feedback loop when trying to determine the screech amplitude. Thus, from the practical point of view, jet noise reduction is probably an important challenge at present.

A non-intrusive screech suppression technique using a turbulent jet issuing from a small tube with various exit alternations and various flat reflectors was studied by Norum [5] and the results provided good documentation of screech behavior under a variety of conditions. Nagel *et al* [4] proposed a method of reducing jet screech by placing a flat surface at a quarter distance of screech wavelength in the upstream of the nozzle exit. This arrangement prevented the acoustical excitation of the shear layer at the nozzle exit and cancelled the jet screech. However, to set up the reflector at the exact position for canceling jet screech seemed difficult and degraded its performance due to an effect of scattering.

A new technique of controlling jet screech with a spherical reflector had been proposed by the present authors where the reflector (150 mm diameter) was placed at the nozzle exit [2]. The theoretical and the experimental results showed that the jet screech was cancelled well as the reflector reduced the activities of receptivity process at the nozzle exit and destroyed the feedback loop and finally suppressed a screech tone. In the present study, the changes in the shock structure due to the use of a spherical reflector were analyzed by the Schlieren visualization apparatus along with a high-speed video camera and the thrust performances of the spherical reflectors was measured in a vertical wind tunnel as an extension of the previous works.

EXPERIMENTAL PROCEDURES

A cold and dry jet was generated by utilizing an air compressor, an air-cooling separator, an air dryer and an oil mist filter which was passed through a straight tube of exit (often referred in the present paper as the nozzle exit) diameter, 10 mm (D). The straight tube was attached to a convergent nozzle of 9 degrees in semi-vertex angle. A control valve was placed outside the testing chamber by which the jet pressure was correctly controlled. Experiments were carried out in an anechoic chamber and its internal dimensions were 6.0 x 4.35 x 2.18 m. Acoustic signals were measured with a condenser microphone of 6.35 mm in diameter (Brüel & Kjaer, Denmark) when the microphone was traversed along a measuring path of 60D radial distance from the center of the nozzle exit. The angular position of the microphone (θ) was measured from the direction of jet flow. Acoustic signals that were taken from the microphone were analyzed with the help of a signal amplifier, an 8-channel signal analyzer and WCA MSA software of A&D Co. Ltd., Japan (Copyright©2000 A&D Company, Ltd.). A schematic view of the experimental apparatus is seen in Fig. 1 where a portion of anechoic chamber is shown.

A spherical reflector of 24D in diameter, D_R (radius, $R_R = 4.8\lambda$, where λ indicates the fundamental screech wave length) was placed at the nozzle exit for suppressing screech tones. Thus the effective radius of the reflecting surface of the reflector was the radius of the reflector minus the radius of the tube or jet. The reflector was placed at the nozzle exit with a traversing stand. A slit window was opened at the surface of the reflector for visualizing the shock structure. A close view of the reflector along with the slit window is shown in Fig. 2. The Schlieren apparatus along with a high-speed video camera of segment film 9000 pps and the segment film size 256 x 256 pixels was used. A vertical wind tunnel was used for measuring the thrust of spherical reflector directly.

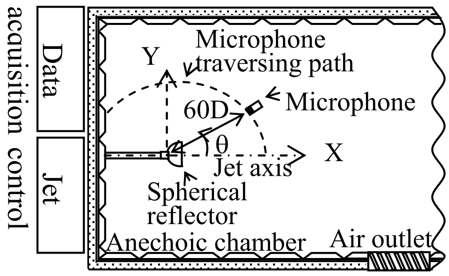


Figure 1 - Schematic view of the experimental apparatus

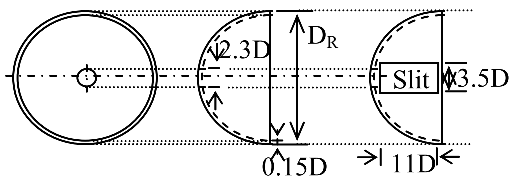


Figure 2 - Schematic of spherical reflector with slit window

EXPERIMENTAL RESULTS AND DISCUSSION

Screech reduction with spherical reflector

An underexpanded supersonic jet of pressure ratio (ratio of the jet pressure to the ambient pressure) of 3.2 and the corresponding jet Mach number 1.4 was generated to examine the cancellation technique of jet screech with a spherical reflector. For that purpose a spherical reflector of 24D in diameter was placed at the nozzle exit. Acoustic measurements were taken in the upstream direction, θ = 120º; normal direction, θ = 90º; as well as downstream direction, θ = 30º.

The result of jet screech cancellation when the measurement was done in the upstream direction by placing a spherical reflector at the nozzle exit is shown in Fig. 3. The fundamental screech component was generated at the frequency of 13.6 kHz which is shown in the spectrum (Fig. 3) of jet noise. A harmonic component of jet screech that was generated at the frequency of 27.2 kHz is seen also in the same acoustic spectrum. The placement of the spherical reflector (24D in diameter) at the nozzle exit cancelled both the components of jet screech as shown in Fig. 3. A substantial amount of broadband noise was also reduced by using the reflector as shown in the figure. Similarly the suppressions of screech components in the normal and in the downstream directions are shown in Figs. 4 and 5. In both cases, the reflector was placed at the nozzle exit. The harmonic component was dominating the noise spectrum in the measurement of the normal direction. However, both the fundamental and the harmonic components of jet screech were cancelled by the reflector. Broadband noise components were also reduced remarkably in the normal direction.

The acoustic spectrum measured in the downstream direction also contained the fundamental screech component with small amplitude at the frequency of 13.6 kHz. It is shown in Fig. 5, however, that there was no any screech component in the acoustic spectrum when a spherical reflector was placed at the nozzle exit for canceling jet screech. In that case there was no any acoustical shielding effect due to the reflector in the measurement of downstream direction. Noise propagating to the upstream direction was reflected toward downstream direction by the reflector and increased the noise level. Although, there were some increments of broadband noise level at high frequency components in the measurements of downstream direction, however, those were negligible compared to the decreases of overall noise levels in the upstream and in the normal directions.

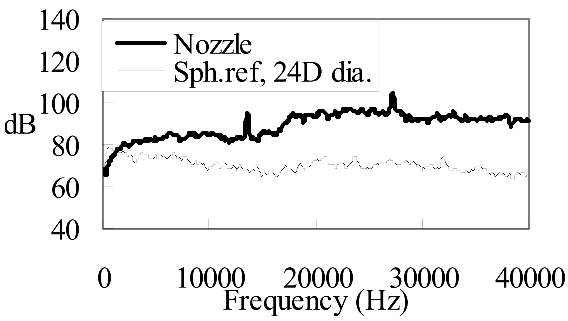


Figure 3 – Spectrum of noise control with reflector.θ=120º, Mach number=1.4

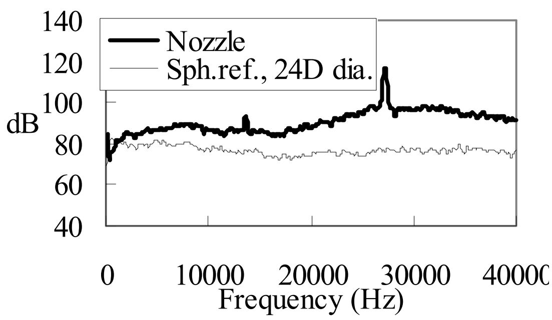


Figure 4 – Spectrum of noise control with reflector. θ=90º, Mach number=1.4

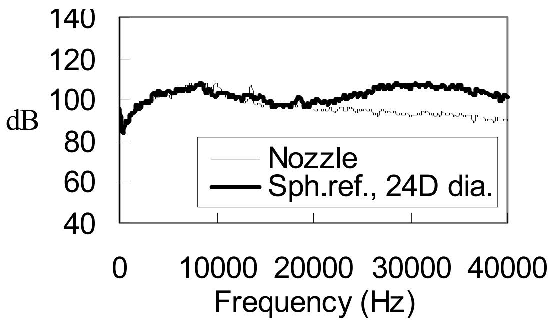
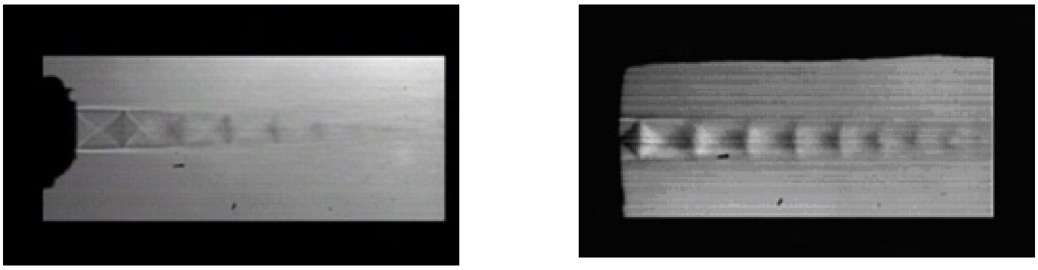


Figure 5 – Spectrum of noise control with reflector. θ=30º, Mach number=1.4

Observation of Shock Structure

It was interesting to observe the flow characteristics when the jet screech was cancelled with a spherical reflector. For that purpose, the flow was observed by the Schlieren visualization apparatus along with a high speed video camera. A slit window was opened in the reflector for visualizing the jet properly. The comparison of the jets with and without a reflector is shown in Fig. 6. In the flow ejected from a baseline tube (nozzle flow) without any reflector, only 6 shock cells were visible and fluctuating flow behaviors were observed at the downstream. On the other hand, in the flow with a spherical reflector, more than 9 shock cells were visible and the flow was stable up to the downstream. However, the shock cell spacing did not change remarkably as shown in Fig. 6 (b). The modification of the shock structure may be caused by the influence of the reflected sound wave.



(a) *(b)*

Figure 6 – Schlieren photograph of (a) nozzle without reflector, (b) nozzle with reflector at the nozzle exit. Mach number=1.4

Observation of Thrust Condition

The condition of thrust due to the attachment of the spherical reflector at the nozzle exit was evaluated in the present study. To investigate the performance of the thrust measuring device (vertical wind tunnel) a theoretical result was calculated from the following jet momentum equation as follows:

$$F = \dot{M} V_j + (P_j - P_0) A \quad (1)$$

where, $\dot{M}$, V_j, P_j, P_0 and A are mass flux, exit velocity, static pressure at the nozzle exit, atmospheric pressure and the area of nozzle exit respectively. A convergent nozzle of 30º in the convergence angle was used in the calculation as well as in the experiment instead of the baseline tube. The result is shown in Fig. 7. The comparison concerning the nozzle shows the close relation between the theoretical and the experimental result. The results of thrust of the baseline tube (base tube) without and with the spherical reflector at the tube exit were plotted against jet pressure ratio as shown in Fig. 8. It is found from the figure that the thrust loss due to the noise control with the spherical reflector is negligible.

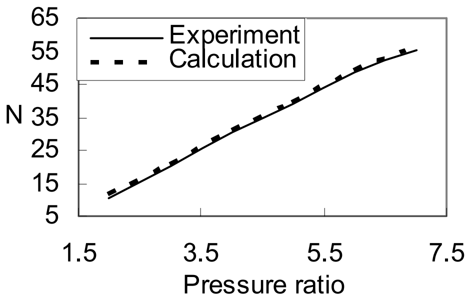


Figure 7 – Thrust analysis of nozzle flow

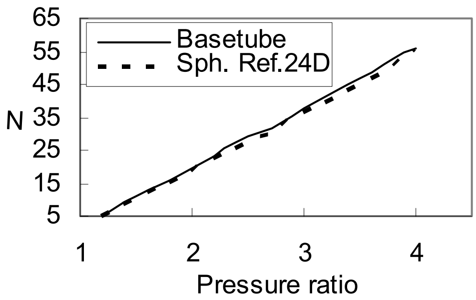


Figure 7 – Thrust loss analysis of the spherical reflector (24D dia.)

Discussion

A spherical reflector of 24D in diameter was used in the present work to investigate the performance of the proposed noise suppression technique. Particularly, to investigate the modifications in the shock structures of the jet as well as in the thrust by using the spherical reflector at the nozzle exit were the main objectives of the present work. Therefore, the spherical reflector (24D in diameter) capable of visualizing almost all shock structures through its slit windows was constructed and used for the optical observation. At the same time the performance of jet screech as well as broadband noise suppression was checked also with the reflector. Although, it seems to have some criticisms as the broadband noise level increased by using the reflector at the measurement in the downstream direction, from figures mentioned above, however, it is understandable that the amount of noise level that was suppressed in the upstream direction was greater than that was augmented in the downstream direction. Therefore, it is considered that the proposed mechanism of screech suppression might have some influence in the suppression of the broadband noise as well. Moreover, the modification of the jet structure that was observed in the present research may have also reduced the broadband noise component.

CONCLUSIONS

A successful suppression of supersonic jet noise was possible by placing a spherical reflector at the nozzle exit. The placement of the spherical reflector at the nozzle exit suppressed not only the jet screech noise but also reduced the broadband noise substantially. The placement of the spherical reflector at the nozzle exit did not alter the shock cell spacing but made the shock cell structure more stable. Thrust loss of the proposed noise control mechanism was also substantially low.

REFERENCES

[1] Anderson, B. A., Wygnanski, I. J. and Gutmark, E. J. Noise Reduction by Interaction of Flexible Filaments with an Underexpanded Supersonic Jet, AIAA paper 99-0080, (1999).

[2] Khan, M. T. I., Seto, K., Xu, Z. and Ohta, H. An Approach to Noise Reduction of a Supersonic Jet with a Spherical Reflector, *J. Acoust. Sci. & Tech.*, **25** (2), 136-143, (2004).

[3] Massey, K., Ahuja, K. K., Jones, R III and Tam, C. K. W. Screech Tones of Supersonic Heated Free Jets, AIAA paper 94-0141, (1994).

[4] Nagel, R. T. Denham, J. W. and Papathanasiou, A. G. Supersonic Jet Screech Tone Cancellation, *AIAA Journal*, **21** (11), 1541-1545 (1983).

[5] Norum, T. D. Screech Suppression in Supersonic Jets, *AIAA Journal*, **21** (2), 235-240, (1983).

[6] Panda, J. An Experimental Investigation of Screech Noise Generation, *Journal of Fluid Mech.*, **378**, 71-96, (1999).

[7] Seiner, J. M., Manning, J. C. and Ponton, M. K. Model and Full Scale Study of Twin Supersonic Plume Resonance, AIAA paper 87-0244, (1987).

[8] Tam, C. K. W. and Chen, P. Turbulent Mixing Noise from Supersonic Jets, *AIAA Journal*, **32** (9), 1774-1780 (1994).

[9] Tam, C. K. W. Supersonic Jet Noise, *Annu. Rev. Fluid Mechanics*, **27**, 17-43, (1995).