JET SCREECH AND ITS SOURCE IDENTIFICATION BY SOUND INTENSITY ANALYSIS

Md. Tawhidul Islam Khan* & Kunisato Seto
Department of Mechanical Engineering, Saga University, Saga 840-8502, Japan

Abstract Jet screech or screech component of supersonic jet has been considered to be generated by an acoustic feedback loop between a nozzle lip and of a shock wave. Noise radiation to the upstream direction from an under expanded supersonic jet is dominated by jet screech which is a high amplitude tone. A two-dimensional sound intensity technique has been used to create a map of screech components in frequency domain and provides sound level and direction directly for each frequency of interest. This measuring system has quantified the sound power generated by any of a number of source systems operating simultaneously within a region of shock structure. Sound intensity vectors indicate the source location of jet screech as well as other jet noise components.

Keywords: Jet screech, Screech source, Sound intensity technique.

INTRODUCTION

The acoustic emission from a supersonic jet generally has a frequency spectrum that contains powerful discrete tones that have been called screech [Powell, 1953]. The generation of this screech component depends on an acoustic feedback loop [Powell, 1953, Tam, 1988]. Two criteria were developed that govern the existence of sustained oscillations of the feedback loop. A phase relationship concerned the wavelengths involved and the geometrical size of the feedback loop. An amplitude criterion concerned the gain around the feedback circuit; this involved the amplification of the sinuous disturbance of the jet and also the effectiveness by which the stationary sources radiated back to the nozzle [Powell et al, 1992].

Acoustic measurements have to be taken in the geometric near field, where the source region is large. Researchers have used several methods for identifying noise source locations with varying degrees of success. Many methods require large number of microphones and complex post-processing [Jaeger and Allen, 1993]. Sound intensity method has been used to measure the acoustic power in frequency domain for different sound sources [Karen et al., 1988, Jaeger and Allen, 1993, Ohta and Seto, 1997]. Maximum of them (Ohta and Seto, 1997; analyzed downstream screech components only) used this technique for analyzing the sound source of sonic or sub sonic levels. In the present work, this technique has been applied to identify the source region as well as to verify the other properties of screech tone. The analysis has been conducted in experiment basis inside a semi-anechoic chamber.

*Email: 00ts11@edu.cc.saga-u.ac.jp

SOUND INTENSITY THEORY

Sound intensity technique is equivalent to the time-averaged product of the acoustic pressure, P and the acoustic particle velocity, V at the point of measurement as follows:

$$I = \overline{P}.\overline{V} \qquad (1)$$

where, I indicates the intensity. Acoustic pressure can be measured directly by a pressure microphone but particle velocity is measured indirectly by two phase-matched microphone separated by a known distance as shown in following equation:

$$V_n = \frac{1}{\rho}\int \frac{P_2 - P_1}{\Delta d} \qquad (2)$$

where, V_n is the particle velocity in n direction, ρ is the air density, P_2, P_1 are the instantaneous acoustic pressures measured at each microphone and Δd is the distance between the acoustic centers.

The acoustic signals where long averaging times are possible, the mean active intensity can be obtained in the frequency domain at the specific frequency, f using:

$$I_n(f) = \frac{\mathrm{Im}\{G_{p_1 p_2}(f)\}}{2\pi f \rho \Delta d} \qquad (3)$$

where, $\mathrm{Im}\{G_{p1p2}\}$ is the imaginary portion of the complex cross spectrum, $G_{p1p2}(f)$ between microphone signals, p_1 and p_2 [Jaeger and Allen, 1993]. The imaginary portion of the cross-spectrum contains the phase difference between the signals measured by two microphones. Sound intensity level (IL) is generally presented in a logarithmic form in the same manner as sound pressure level (SPL) as follows:

$$IL = 10\log_{10}\left[\frac{I}{I_0}\right] \quad (4)$$

where, I_0 indicates the reference intensity as $I_0=10^{-12}\ W/m^2$.

EXPERIMENT

A semi-anechoic chamber of 3.5x3x2m internal dimensions has been used to perform the present experiment. A two-stage convergent nozzle of 20mm in exit diameter (D) and total 13 degree in convergence has been used to generate an under-expanded supersonic jet. Air compressor, air cooling separator, air dryer, oil mist filter have also been used to maintain the dry unheated jet flow. One pair of pressure type condenser microphone (B&K) of 6.35mm (1/4 inch.) in size has bee mounted on a digitally controlled traversing device, which can rotate about the jet exit plane. Pressure ratio (the ratio of jet pressure to the ambient pressure) has been set to 2.5 where the corresponding Mach number is 1.22. Measurements have been conducted to the x-axis (parallel to jet axis) and y-axis (perpendicular to jet axis) with an interval of 1.75D between two measuring points. In x-axis data has been taken from –9D to 20.75D when nozzle exit plane is considered as zero position. Similarly in y-axis, data has been taken from 7D to 19.25D away from the jet axis. Visualization of shock containing jet plume has been analyzed by Schlieren technique. Sound spectra have been analyzed by a WCAMSA 8-channel signal analyzer (A&D).

RESULTS AND DISCUSSION

Sound spectrum showing jet screech

Sound spectrum showing the screech component is found in Fig. 1. In this figure the screech component is found at a frequency of 10.2 kHz when a hysteresis lobe is found at 8 kHz. This is caused due to unknown effects though some mode dependant features are explained by Powell et al. [1992]. An interest is found that this discrete tone is more remarkable at the upstream boundary. Other harmonics are also shown with the broadband spectrum. A pronounced dip in the level of the broadband noise spectrum on the lower frequency side of the discrete tone is found.

Sound energy emission from shock containing jet

Shock containing jet is analyzed by Schlieren visualization technique. Fig. 2 shows the shock associated jet along with ambient sound intensity spectra. The roughly periodic structure characteristic of undisturbed chocked jet is prominent in the Schlieren picture. The first two cells are clearly defined but further downstream the cells become less and less distinct as the flow becomes dominated by large disturbances and turbulences. Moreover, the shock spacing decreases with downstream distance though it increases with increasing pressure ratio.

Sound emission due to this shock associated jet are also shown in Fig. 2. Sound intensity vectors at 10kHz frequency are shown. It has a wavy emission and seems to come from the shock containing jet. It contains screech components as shown in Fig. 1, which show strong emission to the upstream than downstream.

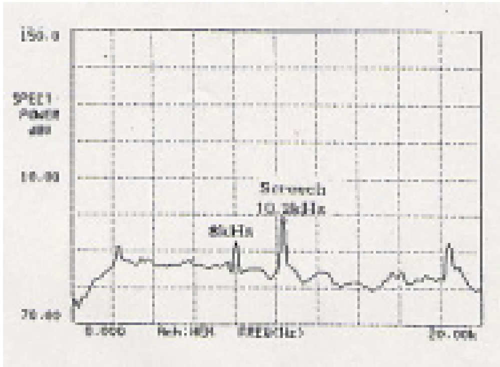

Fig. 1 Sound intensity diagram showing jet screech.

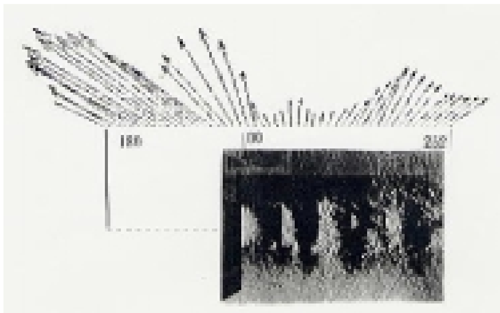

Fig. 2 Sound energy emissions from shock containing jet. Mach number 1.22, frequency 10kHz.

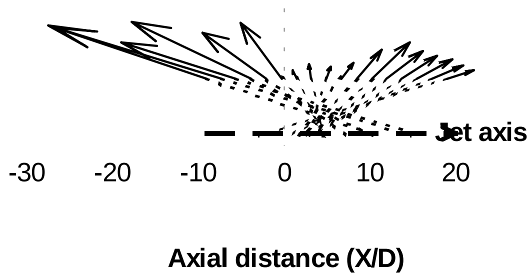

Fig. 3 Sound intensity ray of frequency 10kHz and jet Mach number, 1.22. Intensity vectors are coming from shock region of jet plume. Strong radiation to upstream.

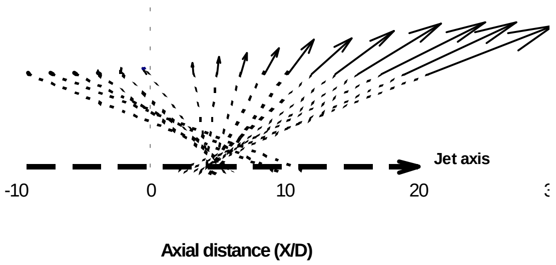

Fig. 4 Sound intensity ray of frequency, 5kHz and jet Mach number, 1.22. Intensity vectors are coming from shock region of jet plume. Strong radiation to downstream.

Sound intensity for screech source analysis

A map of the radiation field of the jet emerges by drawing the resultant intensity vectors at each of the probe positions. The intensity measured at near field (8.75D). The sound intensity vectors can be extended back along their respective directions as shown in Fig. 3 and Fig. 4 to explore their sources. The method does not necessarily indicate where the exact source of sound is, but only where the apparent location of the noise source is as seen from the probe location. Sound intensity can measure the sound level and directions directly for each frequency of interest. For example, if the intensity of two monopole sources, separated by a distance, were measured at a distance comparable to that distance, the apparent source location given by the intensity probe would lie between the two monopoles [Jaeger and Allen, 1993]. In the same fashion, the intensity measurements of the jet plume produce resultant intensity vectors, which give information about the apparent noise source. Near field effects and other nonlinear and non-stationary effects of the jet plume may mask the actual location of noise emanating from the plume. Still the results shown in Figs. 2, 3 and 4 are quite reasonable to accept the technique for selecting the apparent sources of these jet noise components. Moreover, considering monopole sources during near field measurements sometimes may arise haziness in jet noise concept.

In Fig. 3 and Fig. 4, the intensity rays appear to coalesce each other on and near the jet plume. This characteristic is attributed to the fact that the noise sources for a particular frequency are distributed over a finite region within the plume. The dominant screech components at the upstream for 10kHz are shown in Fig. 3 when the broadband noise along with other components at 5kHz is shown in Fig. 4 as dominated component. The intersection between jet axis and its vertical ray with other ray vectors suggests where the apparent source is located; and the distance measured from the jet exit point on the jet axis reveal the related physical size of the source. From Fig. 3 it has been found that the dominant source region is spread over a region of 3.0 to 7.5 jet diameter from exit point towards jet axis and 0.5 to 4.5 jet diameter towards the vertical of jet axis. Similarly, from Fig. 4 source region is found to spread over 4.25 to 5.5 jet diameter towards jet axis and -0.25 to 1.0 jet diameter towards vertical of jet axis. Though, in all cases some interaction effects are clear, particularly in screech case, near nozzle exit region. In both cases, it is found shock regions are combined with in their source spread regions, which are, also satisfies with Fig. 2. Moreover, it is observed that screech components are spread over a wider region in the plume. It is thought, this may happen due to the nonlinear features and formatting characteristics of screech components.

Another characteristic to explore is the peak radiation direction of jet screech and other jet noise components as a function of frequency and radiation distance. Fig. 5 and Fig 6 show these directivity characteristics of sound intensity radiation at frequencies 10kHz and 5kHz respectively for a finite radiation range. The directivity of each sound component is calculated from the intensity spectra. In these figures, it is found that upstream radiation is stronger than that of downstream during screech tone, but when screech component is absent, downstream radiation is stronger than that of upstream. The peak radiation of screech component is found to distribute within 20 to 40 degrees. The radiation of screech component at upstream is faster than downstream radiation with the increases of radiation distance, which is also shown in Fig. 7.

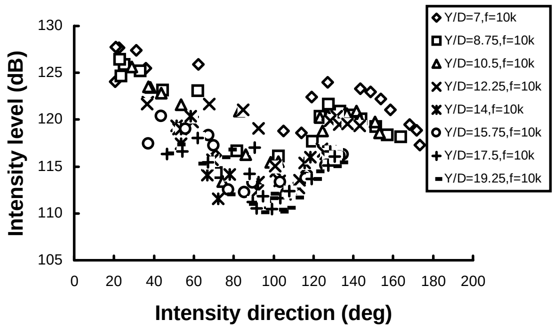

Fig. 5 Sound intensity level verses sound intensity direction for variation of distance at frequency, 10kHz.

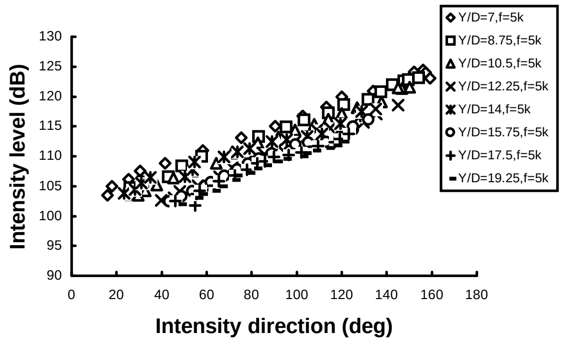

Fig. 6 Sound intensity level verses sound intensity direction for variation of distance at frequency, 5kHz.

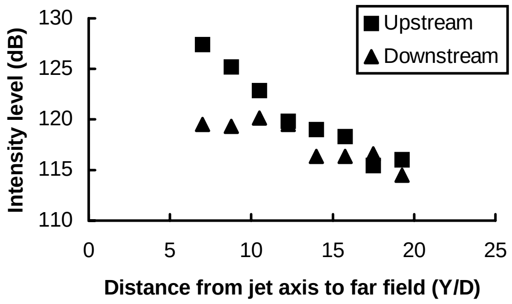

Fig. 7 Sound intensity radiation pattern of jet screech in upstream and downstream with the change of radiation distance (vertical to jet axis).

CONCLUSIONS

Strong and discrete sound known as jet screech is developed from a shock associated supersonic jet. The fundamental component is found to develop here at 10kHz.

Two-dimensional sound intensity mapping is able to show the apparent sizes and locations of jet screech and other jet noise sources.

Directivities and radiation patterns of jet screech are also possible to show by sound intensity analysis.

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