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MODELING AND MEASUREMENT OF SOUND INTENSITY OF JET SCREECH

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1. INTRODUCTION

An underexpanded jet issued from a convergent nozzle generates a high frequency noise that is called jet screech. The present paper shows the measurement of the sound source region by using sound intensity technique. In the present experiment, the pressure ratio was kept constant and the sound intensity distribution of a frequency component was investigated. Furthermore, we applied a sound propagation model to the obtained sound source region. Then, reproduced the sound intensity distribution and compared it with measured one. A reasonable agreement was obtained. Without a directivity model, predicted result did not agree with the measurements. We have carried out detailed measurements of sound intensity field around the noise source region and have obtained the distribution of intersection points of sound intensity vectors and the jet axis which may be considered as sources of a jet noise. Thus We have looked into the feature of the distribution of plausible noise source.

2. EXPERIMENTAL

Apparatus.
A sound intensity profile was obtained by using a pair of sound intensity microphone, 1/4-in. in size (Rion UC-541), mounted on a digitally controlled traversing device. The schematic view along with other experimental apparatus is shown in Fig.1. A convergent nozzle, 20mm in diameter(d) and 15deg in convergence angle was used to generate an underexpanded jet issued into a semi-anechoic chamber of about 3.5x3x2m. The pressure ratio (the ratio of jet pressure to the ambient) was set to 2.5. The Mach number of the jet was 1.22 and a probable jet screech of a discrete frequency about 10kHz appeared in the present case. In the experiment, we have studied the directivity and the distribution of sound intensity in a far field as well as in a near field. The directivity has been investigated along a semi-circle of 500mm in radius with a center placed at the nozzle exit. The angle of direction ranged from 20 to 90 deg at an interval of 5 deg. Measuring region of far-field and near-field of sound intensity was shown in Fig.2. The measuring points in the far field ranged from 20 to 700mm at an interval of 40mm in x-axis and 200 to 600mm at an interval of 50mm in y-axis, while in the near field, meas.HE

urement was carried out along a line L0 parallel to and 100mm off the jet axis (Fig.2) at an interval of 5mm ranged from 20 to 250mm from the exit plane. Sound intensity has been obtained by using FFT analysis and a cross spectrum method. In order to investigate the decaying characteristics of a sound of a particular frequency, a loud speaker of 20mm in diameter was utilized.

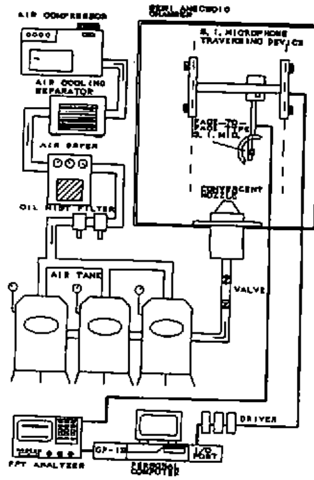

Fig.1 Schematic view of the experimental apparatus

3.SHOCK-VORTEX INTERACTION MODEL

We have studied the mechanism of jet screech according to the model proposed by E.J.Kerschen and A.B.Cain. Let us call the model as shock-vortex interaction (SVI) model [1]. This model is based on continuity, Euler and Energy equations which were analyzed by a perturbation method.The directivity function g_+ is given as follows.

$$g_+(r,\theta) \sim \frac{\sqrt{M_+}}{\sqrt{2\pi}} D_+(-M_+ cos\theta) sin\theta \frac{e^{i(M_+ r - \frac{\pi}{4})}}{\sqrt{r}} + O(r^{-\frac{3}{2}}) \tag{1}$$

$$r = \sqrt{x^2 + y^2},\ \theta = tan^{-1}\left(\frac{y}{x}\right)$$

,where M_+, θ, x and y stand for Mach number, observation angle, and a coordinate along and normal to jet axis respectively. D_+ means a function [1]. For examining the results of directivity, we also compared it with a model by A.Powell[2].

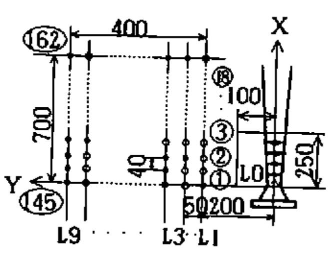

Fig.2 Schematic view of the measured region

4.ANALYTICAL AND EXPERIMENTAL RESULTS

Directivity

In the present paper, we have treated with the case of pressure ratio 2.5 (Mach number 1.22). The spectrum of a jet screech of the present experiment contains discrete tones of 10 and 8kHz in addition to the broad band turbulence noise. The discrete tones were probably caused by jet screech. Here in the present paper, we restricted ourselves to the case of the 10kHz tone. The reason for the limitation is, first, the limited space of the paper and ,second, the component is most conspicuous. In downstream region, measured maximum directivity was observed at 28 deg from the jet axis which agreed to the prediction using SVI model by Kerschen and Cain.

Sound Intensity Distribution in near-field

For each frequency component, we investigated the mechanism of aerodynamic noise generation by using intensity vector measured on the line L0 and Schlieren photograph. Fig.3 shows the intensity vector measured by using 1/3 octave band width centered at 10kHz along with an equally scaled Schlieren photograph. The band width may contain a screech component. A wavy distribution of sound intensity corresponds to shock cell structure of the underexpanded jet shown in the lower photograph of Fig.3. Especially the first shock cell (the closest to the nozzle exit) seems to radiate the strongest intensity. On the other hand, in more downstream region than 7d(exit diameter), the intensity decreased monotonically as it went downstream.

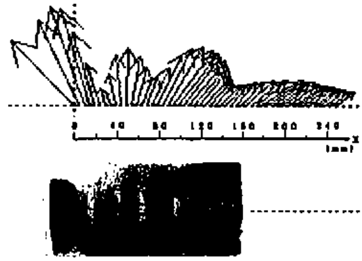

Fig.3 Near field distribution of sound intensity rays(Screech)

Far-field Intensity Distribution and estimation of sound source region

In the far-field, sound intensity near the nozzle exit plane was more diminished as the measuring point went farther from the jet axis and a maximum directivity in the downstream region is same to one predicted by SVI model as is shown in Fig.4. Fig.5 shows the intersection points between the jet axis and backward extrapolated sound intensity vectors which may be considered as the locations of sound sources. The abscissa stands for the distance from the nozzle exit divided by its diameter. The ordinate means the number of measuring point defined as shown in Fig.2. Each parallel line to the jet axis has 18 measuring points numbered in numerical order. So the closest to the jet axis has points numbered 1 to 18 and the next line has points numbered 19 to 36. The total number is 162. As is shown in the figure, all those points distributed within the region up to 10d from the nozzle exit which means the sources of the jet screech in case of pressure ratio 2.5 (Mach number 1.22) were located within 0 to 10d from the exit. The region covered the shock cell structure of the underexpanded jet shown in Fig 3. Here in Fig.5, the experimental values are marked with an open square. Those marked with a solid circle are predicted one. The details of the prediction is described in the following section.

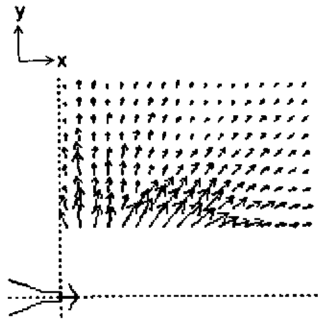

Fig.4 Measured far field distribution of sound intensity rays

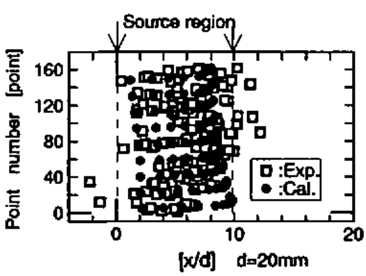

Fig.5 Distribution of source region (Screech)

Propagation Model of Jet Screech

Applying SVI model to the noise source region mentioned above, we obtained a model of the propagation of acoustic energy. Here we have assumed the sound intensity distribution obtained in the near-field as the noise source distribution on the jet axis and predicted that in the far-field. The intensity distribution in the near-field was that of Fig.3. The magnitude distribution of the intensity has been represented by the curve given in Fig. 6. As far as 5d, it was observed to correspond to the interval of shock cells. We approximated the upstream and the downstream part of the curve with 11th and 6th order equation respectively. Then, we predicted the sound intensity distribution in the far-field by locating the sound source with 0.5d interval. The predicted sound intensity distribution is shown in Fig.7. By comparing it with the experimental one shown in Fig.4, we may say that a considerable agreement has been obtained. Furthermore, we have reproduced the source region by extending the predicted sound intensity backwards to intersect with the jet axis. The predicted points are depicted by solid circles in Fig. 5. Except near the jet axis, a rather good agreement was obtained.

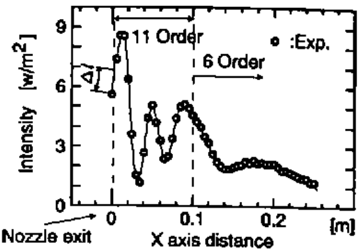

Fig.6 Interpolation curve of source strength

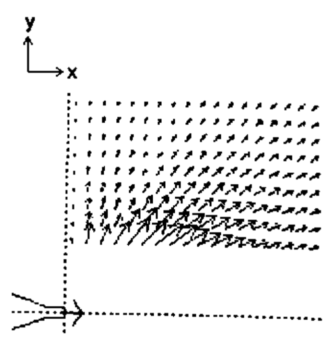

Fig.7 Calculated far field distribution of sound intensity rays (Using an interpolation curve)

5.CONCLUSIONS

Analyzing jet screech from a nozzle of 20mm in diameter under the condition of pressure ratio 2.5 (Mach number 1.22), we have obtained the following conclusions.

1) Experimentally we have confirmed that the sound sources ranged within 10d from nozzle exit. The region included all the shock cell structure of the jet.

2) Prediction of far-field sound intensity distribution has been carried out successfully by applying SVI model to the sound source region.

3) From the measurement of sound intensity in the near-field and schlieren photograph, the distribution of acoustic energy has been confirmed to correspond to the location of shock cells and shape like a wave with the amplitude changing sinusoidally. Hence, the fact that the shock cell is the main source of jet screech has been confirmed also from the aspect of acoustic energy distribution.

References

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[3]A.Powell,J.Acoust.Soc.Am.,83,2(1988).

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