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EXPERIMENTAL INVESTIGATION OF SUBSONIC COAXIAL JETS

by

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SUMMARY

Investigation was made within the first seven diameters (diameter of the primary jet) downstream of subsonic coaxial jets. The velocity ratio, secondary jet to primary jet, is 0.5.

Hot wire and microphone spectra inside the jets yield two pronounced peaks, suggesting the existence of two types of noise sources at different frequencies. The noise sources are due to the two different mixing regions in the merging region of the jets, where the mixing of the two jet streams occurs. The locations of these dominant noise sources are also estimated.

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GLOSSARY

D	Diameter (outside) of secondary or annular nozzle
d	Diameter of primary or main nozzle
<u>f</u>	Frequency
U	Mean jet velocity in axial direction
u	Fluctuating component of axial velocity
x	Axial distance from nozzle exit section
y	Radial distance from primary nozzle centre-line

SUBSCRIPTS

i	Primary or main jet
o	Secondary or annular jet

INTRODUCTION

Homogeneous coaxial jets have been investigated by a number of workers (1, 2, 3). The investigation covered coaxial jets of different exit velocity, velocity ratio, nozzle diameter and area ratio. However, their main attention was on the mean velocity components such as the mean velocity distribution, and the mean profiles of the jets. From the results the inner potential core length and similarity of the velocity profiles of the primary jet and beyond six diameters downstream was observed (3).

Far field noise measurements have also been obtained (3, 4). For constant thrust attenuation of sound pressure level was observed for velocity ratio, secondary to primary, greater than zero. In other words sound pressure level generated by coaxial jets was always lower than single jet. The pressure spectrum in the far field yields a broad peak which was basically similar to the one observed in single jet.

The present work was undertaken to determine the flow characteristics within the first seven diameters, diameter of the primary nozzle, downstream of nozzle exits. Both the mean and fluctuating components of velocity inside the two potential cores and the two corresponding mixing regions, or shear regions, were obtained and presented. Noise sources from the two mixing regions are isolated and their dominance is also considered.

EXPERIMENTAL ARRANGEMENT

The experiments were carried out within coaxial air jets which mix externally. The central nozzle which generated the primary jet has a diameter of 2 cm. The area contraction ratio of this nozzle was 13:1. The outer or secondary jet was produced by an annular nozzle which has an outside diameter of 4 cm. The corresponding area contraction ratio was 8:1. However, the area ratio of the secondary to primary nozzles was 2.67. The Reynolds number was about 10^5. The mean exit velocity of the primary jet was 60 m/s. The velocity ratio of the secondary to primary jet was 0.5.

Because the present investigation was concerned with the conditions immediately downstream of the nozzle exits, the elimination of the inherited fluctuations to an acceptable value was important. Thus, two types of silencers were installed upstream of each nozzle. The turbulence intensity was reduced to 0.4 and 0.7 per cent of the mean exit velocity for the inner and outer nozzle respectively. The inherited overall background sound pressure level of both nozzles was 100 dB.

The hot wire anemometer used was a constant temperature type with linearised output (5). The wire has a diameter of 5×10^{-6} m and a length of 2 mm. The operating resistance was 15 ohms. The microphone used was the Brüel and Kjaer 1/8 in. diameter condenser type and the corresponding nose cone was adopted in the sound pressure measurements inside the jets. The suitability of using condenser microphone in measuring fluctuating pressure in a turbulent jet has been discussed (6). The 6% bandwidth spectra of both the velocity and sound pressure fluctuations were obtained with a Brüel and Kjaer frequency analyser and level recorder.

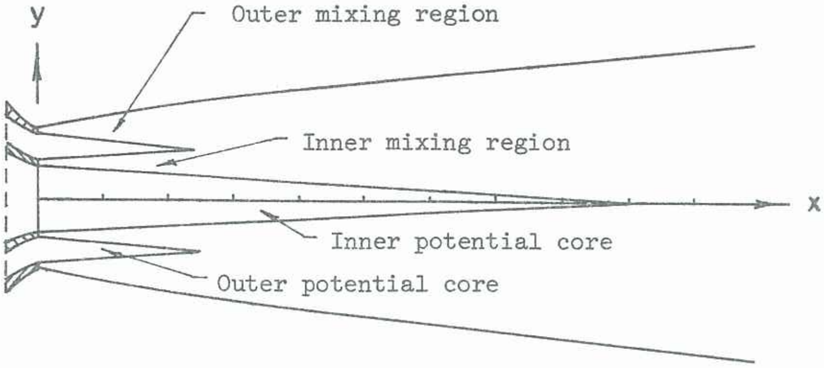


Fig. 1 Profile of the coaxial jets

RESULTS

Basically the merging region of coaxial jets has two potential cores which are surrounded by two mixing regions (Fig. 1). Because the mean exit velocity of the annular or secondary jet is lower than the central or primary jet, a velocity ratio of 0.5, the primary potential core is much longer (1, 2, 3). The core length is 8.81 of the diameter of primary nozzle. Compared with single jet the ratio of the core lengths is 1.89.

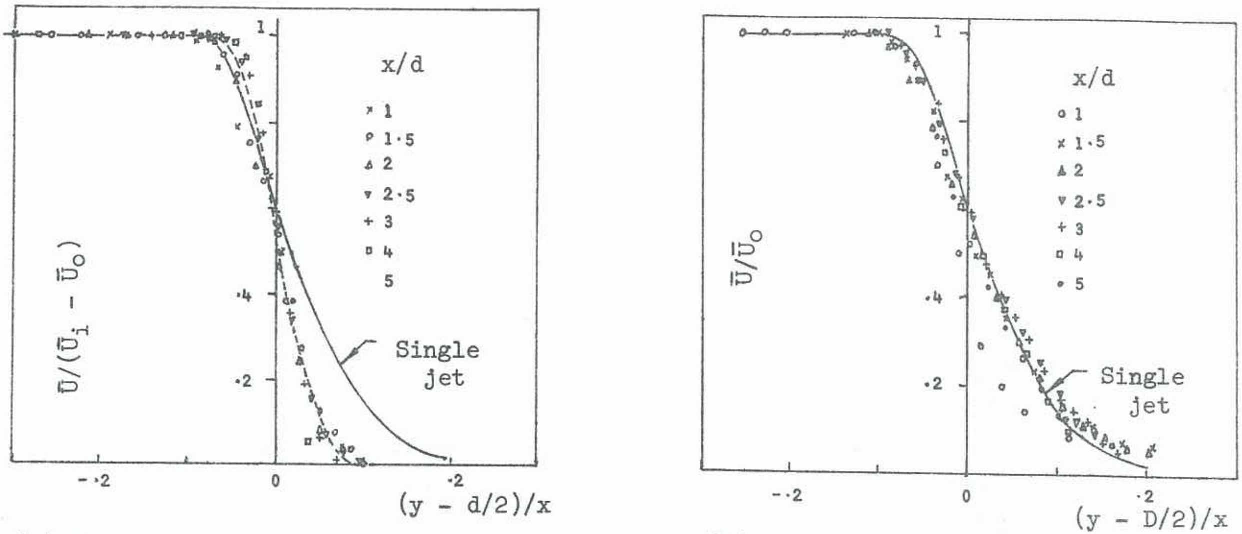
Except for the position $x/d \leqslant 1.0$, similarity of the mean velocity ratio in the two mixing regions is obtained (Fig. 2a and 2b). The respective diameter for the two jets, d and D, is used for the non-dimensional radial distance. Correspondingly, the mean velocity in the two potential cores, $\bar{U}_i - \bar{U}_o$ and $\bar{U}_o$, is used for the non-dimensional velocity. The similarity curve of the mean velocity of a single jet is also shown on Fig. 2. As far as the outer mixing region is concerned, the similarity roughly agrees with single jet (Fig. 2a). Minor differences occur at the radial position of -0.05 and 0.1. At the former position the coaxial jet has slightly lower velocity while at the latter position slightly higher.

The similarity curve of the inner mixing region has smaller spread than the outer layer (Fig. 2b). Thus, the region occupies much smaller radial distance. Compared with single jet, slightly larger velocity ratio is found at the radial position nearer to the inner potential core but lower with further distance away from the inner core. This deviates from the characteristics of single jet.

Even though there are a bit of scatters for the inner region, similarity of the turbulence intensities of the two mixing layers is obtained (Fig. 3a and 3b). The maximum intensity level of the inner and outer regions is about the same, roughly at 14%. Both maxima are situated at the non-dimensional radial position of zero. This corresponds to the value of single jet.

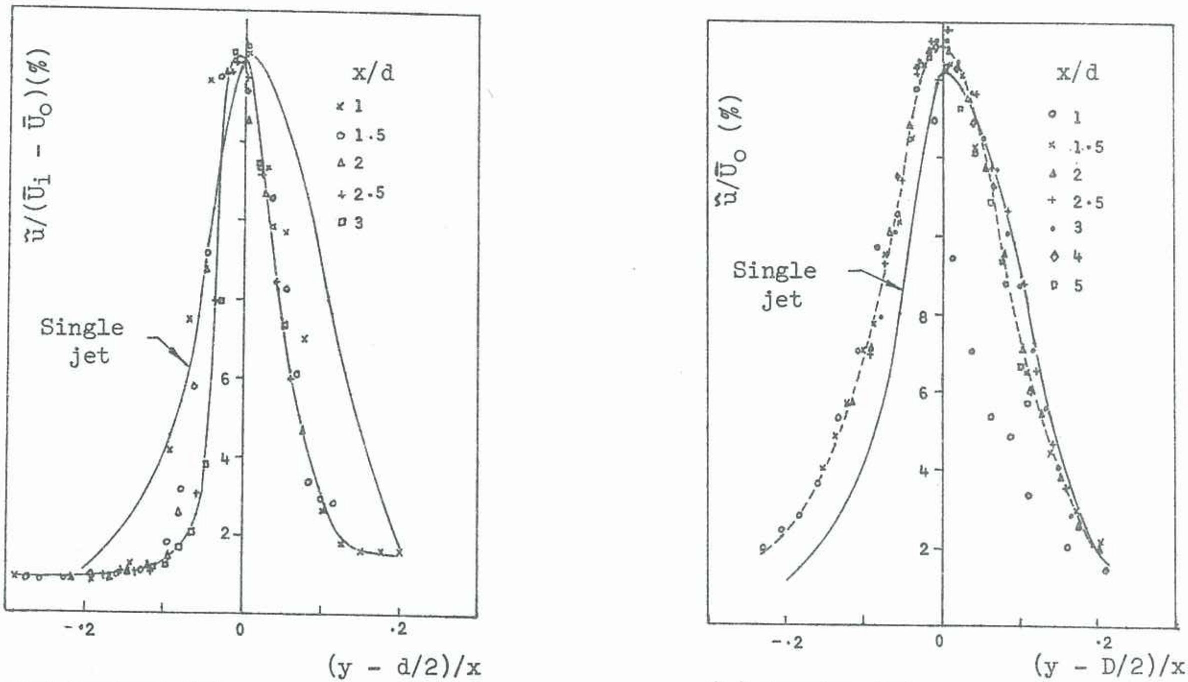
The spread of the intensity curves of the two regions follows the same pattern as the ones of the mean velocity. The outer region corresponds fairly well to the single jet results with a wider spread. The inner region has a narrower spread but the similarity is not as good.

The above similarities occur only within the first four to five diameters downstream (x/d). Beyond this distance the mixing of the two layers occurs and similarity would not be obtained till x/d = 7 (3). This agrees with the single jet results of other workers that similarity obtained within the first five diameters and after seven or eight diameters downstream (5, 7, 8). No similarity is obtained within the transition region between five to eight diameters.



(a) Central Jet (b) Annular Jet

Fig. 2 Non-dimensional plot of mean velocity ratio



(a) Central Jet (b) Annular Jet

Fig. 3 Non-dimensional plot of turbulence intensity level

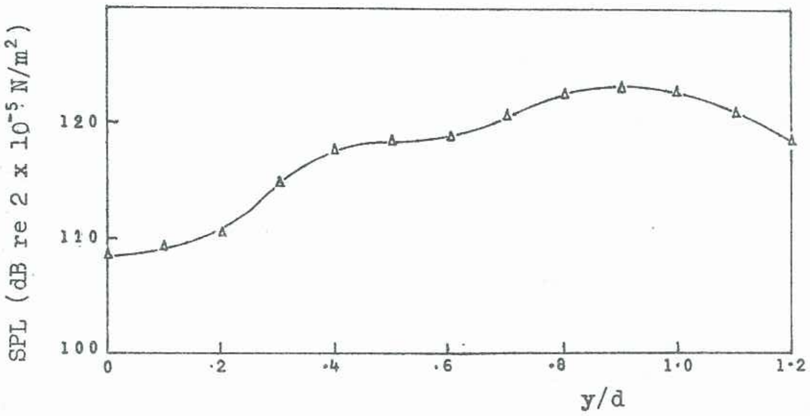


Fig. 4 Radial distribution of sound pressure level. x/d = 2.

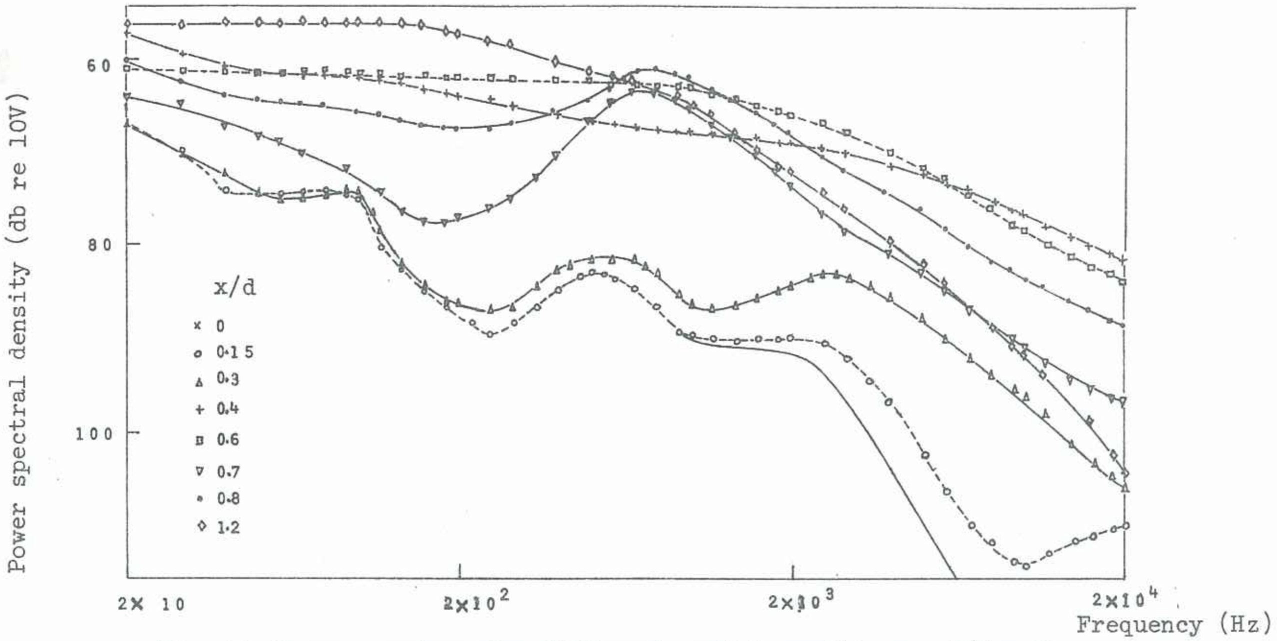


Fig. 5 Power spectrum for different radial positions. X/d = 2.

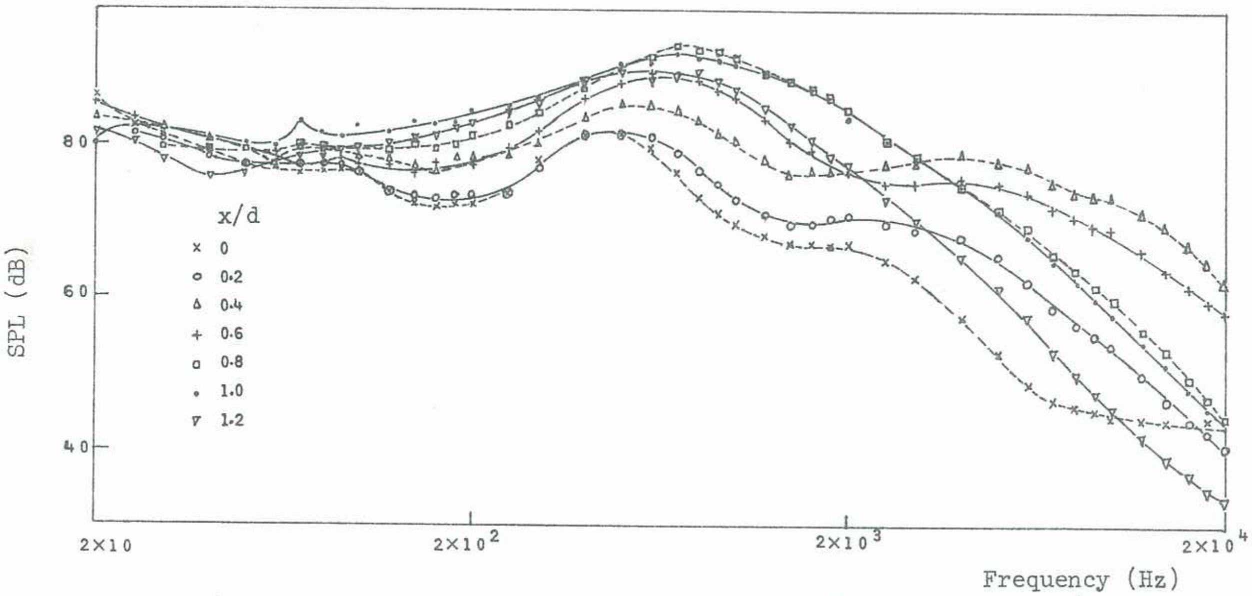


Fig. 6 Sound pressure spectrum for different raidal positions. x/d = 2.

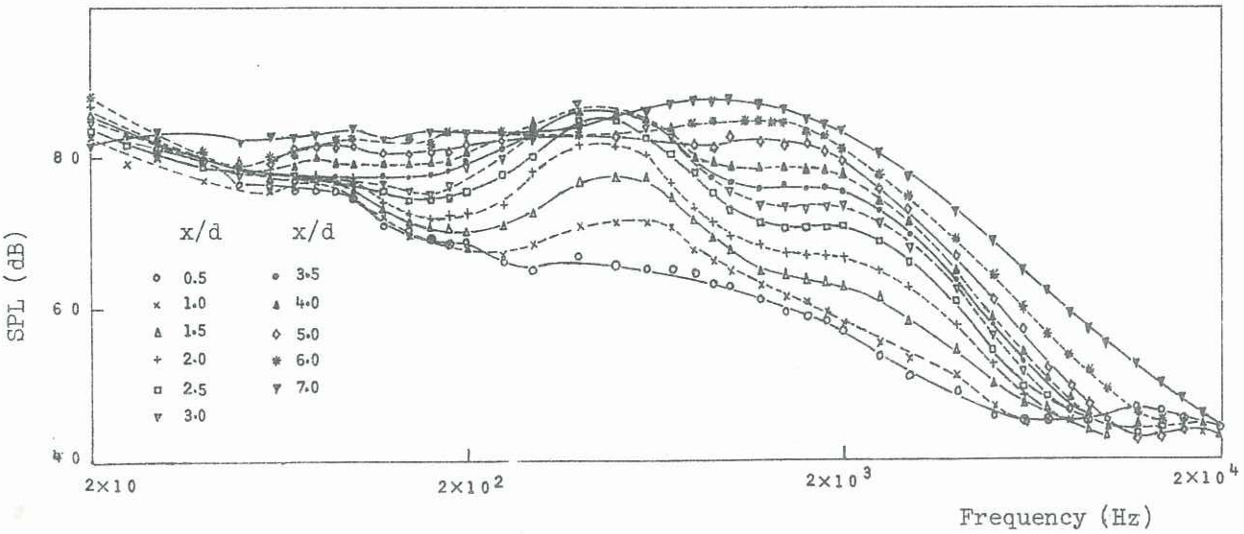


Fig. 7 Sound pressure spectrum for different axial positions. y/d = 0.

The radial distribution of power spectra of the velocity fluctuations obtained by hot wire is shown on Fig. 4. The axial position is x/d = 2. At the radial positions of y/d = 0.6 and 1.2, that is, near the maximum intensity within the two mixing regions, constant spectral density level with frequency, till the cut-off frequency, is observed. This constant behaviour is the same as the one observed in the mixing region of the single jet (5, 7, 8). In addition, the level of the constant spectral density of the outer mixing region is higher than the one in the inner region. However, for components higher than 1 kHz the spectral level of the outer mixing region is lower than the inner one. This means that lower frequency components are dominant in the outer region and the higher frequency components are dominant in the inner region. The dominance of the different frequency components can also be seen from the cut-off frequency of the two regions, 160 Hz for outer region and 1 kHz for inner region.

In the inner potential core, y/d ⩽ 0.3, two peaks on the spectra are shown on Fig. 4. One is at the frequency of 500 to 600 Hz, while the other at about 2.5 kHz. The spectra obtained in the outer potential core, 0.7 ⩽ y/d ⩽ 0.8, show only a single peak at 700 to 800 Hz. The frequency of this peak is slightly higher than the low frequency one observed in the inner core. This close similarity in peak frequency between the two suggests the same type of noise sources is responsible for the low frequency peaks observed in the two potential cores.

The overall sound pressure levels obtained with the 1/8 in. microphone are shown on Fig. 5. Because the size of the microphone is comparable with the size of the coaxial jet, care has to be taken for the interpretation. However, the radial distribution of the overall pressure levels at x/d = 2 shows two peaks. The inner peak occurs at the radial position of y/d = 0.45 and the outer one at y/d = 0.9. Referring to Fig. 1, the two radial positions fall within the two mixing regions. In addition, the peaks do not fall on the two locations where the maximum intensity occurs, non-dimensional radial positions equal to zero. Rather they are nearer to the inner boundaries with the potential cores. These locations are in general agreement with the estimation of the positions of sources in a single jet by the author (9). Also the radial distribution of the overall pressure indicates that the peak level inside the outer mixing region is higher than the one inside the inner mixing region. This suggests that at this velocity ratio the noise produced by the outer region is more dominant.

The sound pressure spectra obtained at the same positions are shown on Fig. 6. Basically, the spectra are similar to ones obtained by hot wire (Fig. 4). In the inner potential cone, y/d ⩽ 0.3, the two peaks are found. Their peak frequencies are around 500 Hz and 2.5 kHz. Between the two, the lower frequency peak has higher level than the higher frequency one. This peak level increases as the radial distance increases and attains its maximum level at about y/d = 0.8. This position agrees with the position shown on Fig. 5.

The occurrence of this low frequency peak across the jet and the occurrence of its maximum in the outer region suggest that the low frequency peak is due to the noise sources generated in the outer mixing region. The high level observed points to the fact that these noise sources are the dominant ones in the coaxial jets.

The high frequency peak on the sound pressure spectra is mainly found for y/d ⩽ 0.6. Beyond this radial position, the peak disappears. In actual fact this is the radial position where the inner mixing region ends (Fig. 1). Thus, it is a clear indication that the high frequency peak is due to the noise sources generated in the inner mixing region.

The maximum of the peak level of this high frequency peak occurs at about y/d = 0.4 (Fig. 6). This is at the same position observed on Fig. 5 and supports the above discussion on the location of noise sources.

From the observed positions of the maximum sound pressure levels within the two mixing regions and the findings of a single jet of the author (9), it seems that the dominant noise sources generated in the mixing region of a jet are located in the region adjacent to its respective potential core boundary. They are not situated at the region where the maximum intensity level occurs.

Comparison of the spectra obtained by hot wire and microphone (Fig. 4 and 6) yields the effect of local turbulence on hot wire signals. With the pressure of strong local turbulence, such as in the two mixing regions, even the dominant low frequency peak is sometimes masked. The resultant shape of the spectra is the one observed for turbulence, that is, constant level till cut-off frequency. However, at y/d = 0.8 the hot wire spectra does show the maximum of the dominant peak, indicating that at this particular position.the noise sources are more dominant than the local turbulence.

Axial distribution of the sound pressure spectra at the axis of the coaxial jets ($y/d = 0$) are shown on Fig. 7. The effect of the two types of noise sources is clearly shown. Within the first four diameters downstream, $x/d \leqslant 4$, both types are found. The field due to the low frequency ones is always more dominant than the high frequency ones. Further, increase in level of the former field is higher than the latter one. This agrees with the results obtained above.

Fig. 7 further yields the fact that the low frequency peak reaches its maximum pressure level at the position of $x/d = 3$. Any increase in axial distance downstream does not increase its peak value. This constant maximum level at $x/d = 3$ suggests that the development of the noise sources in the outer mixing region is completed within the first three to four diameters downstream. For the inner noise sources continuous increase in level further downstream indicates incomplete development of the noise sources in the inner mixing region, even after $x/d = 5$.

From five diameters downstream both peaks are replaced by a broad single peak. The peak frequency of which is around 1 kHz, between the frequencies of the former two. This suggests mixing of the two types of noise sources within these two diameters, $5 \leqslant x/d \leqslant 7$.

The disappearance of the peak generated by the outer mixing region in this distance and the incomplete development of the inner noise sources indicate the loss of dominance of the outer noise sources. This broad single peak may be mainly due to the noise sources further developed in the inner layer, though at lower frequencies. Further detailed investigation will be required to look at this mixing region.

CONCLUSIONS

This study of the merging region of coaxial jets has shown within the first five diameters similarities are found for the mean velocity and turbulence intensity level of the two mixing regions. It has also isolated noise sources which are generated within these two regions. For this particular velocity ratio the low frequency ones are due to the noise sources in the outer mixing region and they are more dominant ones within the first four diameters downstream of the nozzle exits.

The inner mixing region, however, is responsible for the noise sources at the high frequency regime and they need longer distance downstream to be developed. There is an indication that the late developed noise sources may be responsible for the behaviour of the coaxial jets further than the merging region.

The noise sources within the two mixing regions seem to concentrate in the regions adjacent to its respective potential core boundaries but not at the regions of maximum turbulence intensity.

ACKNOWLEDGEMENT

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