Acoustic Radiation from Vortex Pairing in Subsonic Mixing Layer Forced by Inflow Instability Waves with different Phases

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Summary The goal of this paper is to investigate the acoustic field generated by vortex pairing in a two-dimensional subsonic mixing layer. Direct numerical simulation (DNS) of the Navier-Stokes equations are used to compute the flow fields which excited by inflow instability waves with different phases. The Kirchhoff method is also applied to obtain far-filed noise using the near-field data of the DNS. It is shown that the position of the second votex pairing is delaying as the sencond subharmonic phase increased. The characteristic of acoustic radiation from vortex pairing is also changed because of the inflow forcing phase shift, which is shown on the comparison of the sound pressure level (SPL) along a far field line. The dominant acoustic mode is also analyzed to specify the directivity of the acoustic field vividly. This result may be useful to the noise control in the free shear flow.

MANUSCRIPT PREPARATION

Direct numerical simulation (DNS) of the unsteady compressible Navier-Stokes equations is used to computed the near field and a portion of the acoustic field of a mixing layer. To accurately resolved the subsonic flow and its generated acoustic field, sixth stages second-order Runge-Kutta time marching and seven point fourth-order DRP (Dispersion-Relation-Preserving) finite difference schemes are used[1,2]. Tam's radiation boundary conditions are used at each computational boundaries[2]. The sponge region technique is adopted to aviod acoustic reflecting at the outflow boundary, which is shown in fig.1 and fig2(the right region of the dash line)[3]. The present numerical scheme has been validated in many works[1,3,4].

To get better control of the roll-up and votex pairing processes, the mixing layer is forced in the most unstable frequency. A small amplitude excitation is applied to the inflow velocity, the disturbed velocity formula is

$$u_1'(0, x_2^{\text{inflexion}}, t) = a_0 \cdot \sin(2\pi f_0 t) + a_1 \cdot \sin[2\pi(f_0/2)t] + a_2 \cdot \sin[2\pi(f_0/4)t + \varphi]$$

a_0=0.0005, and a_1= a_2=a_0/2 are the amplitudes related to the harmonic frequencies f_0 and $f_0/2$, $f_0/4$. The f_0 excites instability waves that are convected by the flow rolling-up into vortices and $f_0/2$, $f_0/4$ induces the vortex first, second paring process, φ is the phase shift between these frequencies. This paper is focused on the influence of the phase shift , and three $\varphi = 0, \pi/2, \pi$ are choosed related to the flow cases in fig.1.

The 2-D frequency domain form of Kirchhoff formulation, including the effect of a mean flow in the observation region (fig.2) is used, and can be written as

$$p'(\mathbf{x},\omega) = \frac{i\beta}{4}\int\left\{\frac{\partial p(\mathbf{y},\omega)}{\partial n_\beta} H_0^{(2)}\left(\frac{k}{\beta^2} r_\beta\right) + \frac{k}{\beta^2} p(\mathbf{y},\omega)\left[\frac{\partial r_\beta}{\partial n_\beta} H_1^{(2)}\left(\frac{k}{\beta^2} r_\beta\right) - iM\frac{\partial y_1}{\partial n_\beta} H_0^{(2)}\left(\frac{k}{\beta^2} r_\beta\right)\right] \times \exp\left(i\frac{Mk(x_1 - y_1)}{\beta^2}\right)\right\} d\Sigma_\beta$$

$p'(\mathbf{x},\omega)$ is eigen pressure of the source point. The source points is located at the Kirchhoff control surface, like the gray piont in fig.2. More detail can be refer to the reference [4].

The votex pairing with different phase

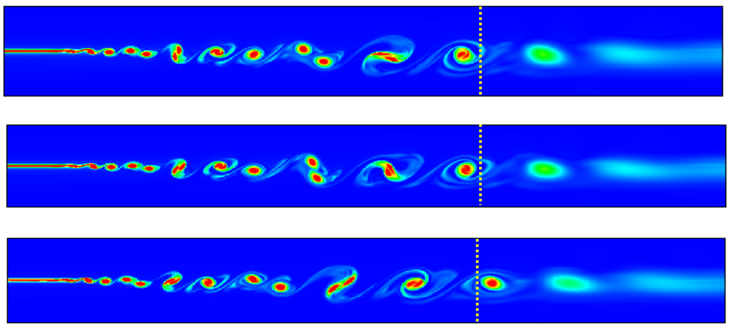
(a)
(b)
(c)

Fig.1 Votex pairing with different forcing phases. (a) $\varphi = 0$;(b) $\varphi = \pi/2$ (c) $\varphi = \pi$

Fig. 1 shows the vortex pairing with $\varphi = 0$ and $\varphi = \pi/2$, $\varphi = \pi$ in the second subharmonic frequency after about 38 second votex pairing periods. It can be found that the position of the first votex pairing is almost same in these cases, but the position of the second votex pairing is delaying as the sencond subharmonic phase increased. After pairings, the votex moves into sponge region, and be dissipated to suppress the acoustic reflecting in the outflow boundary.

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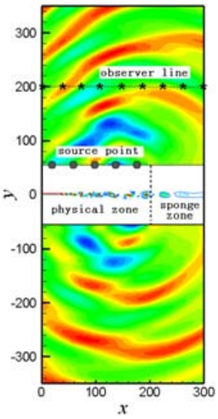
Acoustic radiation from vortex pairing

Fig.2 shows the acoustic field related to the case of Fig.1 (a), which extrapolated by the frequecy domain Kirchhoff methods. Extracting five points (gray circle) at the control surface, the analysis of their eigen pressure (Fouier transform) is shown in Fig.3. It is found that the acoustic eigen pressure is excellent coincident with the inflow excited instablity waves, which is also equaled to $\omega_0, \omega_0/2, \omega_0/4$.



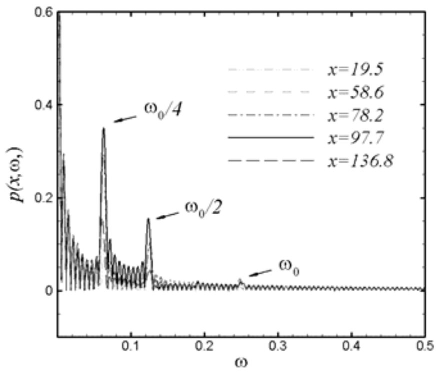


Fig.2 Sound radiation from vortex pairing.   Fig.3 The eigen pressure $\hat{p}$ of sources piont related to circle frequencies ω

The SPL at far-field line (* line at Fig.2) is compared in Fig.4. From this figure we can find the $\varphi = \pi/2$ phase forcing lead the intensity of sound radiation forth is lower, but intensive at the back. This result is confirmed by the dominant acoustic mode analysis in the Fig.5. Fig.5 extracted the $\omega_0/4$ acoustic mode using the Kirchhoff method, shows the directivity of the dominant sound wave clearly. Matched with the Fig.4, the $\varphi = \pi/2$ case sound wave radiated back ,different with the others.

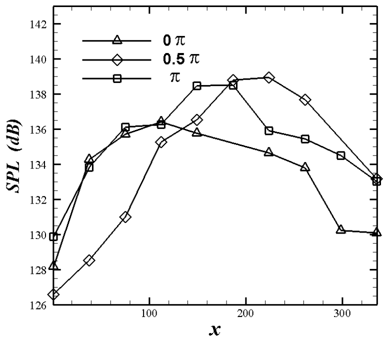
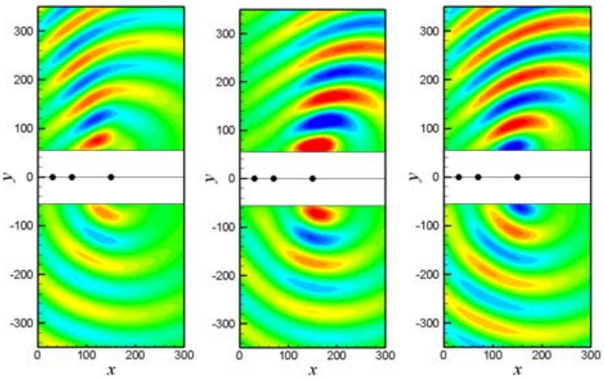


Fig.4 the sound pressure level (SPL) along far field line in three cases



(a)0   (b) $\pi/2$ (c) π

Fig.5 The dominant acoustic wave.

CONCLUSIONS

The acoustic field generated by vortex pairing in a two-dimensional subsonic mixing layer is investigated in this paper. Serveral computational aeracoustic techniques have been used. Though the parameter analysis, it is found that different phase may lead the large change of the directivity of the acoustic field, this may be useful to the noise control in the free shear flow.

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