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An Investigation of Dynamic of Ordered Structure in Excited Jet using PIV - based phase-averaging technique.

Experimental searching of ordered structures within turbulent jets are carried out during last 50 years [1-5]. In the classic picture from work of Brown & Roshko [2] the two-dimensional instability wave structure in plane turbulent mixing region of gases of different density is clearly seen. Within the axisymmetric turbulent jets the flow, as a rule, is chaotic and instability waves are masked with small scale turbulence. However the ordered structures become most pronouncedly seen under excitation of axisymmetric jet by harmonic sound (e.g. [3]). In the works [4-7] the theoretical base of role of instability waves in jet mixing processes and jet noise are presented.

One of the ways to extract the ordered part from chaotic processes is technique of phase conditional averaging. In the previous work of authors ([8]) PIV- based phase-averaging technique was developed for searching the instability waves in non-excited jets. In presented work this technique was applied to the investigation of dynamic of ordered structure in axisymmetric free jet with excitation by external harmonic acoustic waves.

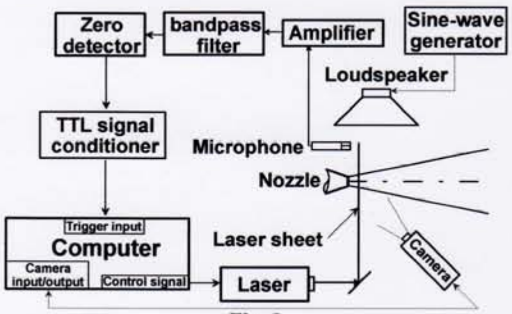

Fig. 1.

The scheme of PIV phase-averaging measurements is shown in the fig.1. The jet issuing from standard Dantec calibration nozzle of diameter *(d)* 12mm was excited by loudspeaker located from the side of a nozzle. Most of experiments was conducted for jet velocity U_0=80 m/s (Reynolds number is about 0.8×10^5). The frequencies of excitation were equal 2.5, 3.4 and 4kHz which corresponded to Strouhal number Sh=fd/U_0=0.375-0.6. The ¼" GRASS microphone (Fig. 1) placed between loudspeaker and nozzle was used for control of excitation level and as source of a reference signal for phase conditional averaging. The typical amplitude of excitation was 120dB (20Pa). The standard particle image velocimeter (PIV) "La Vision" was used with standard software. The light sheet was produced by twin-impulse NdYAG laser. Two digital cameras with high sensitivity were used to obtain instantaneous picture of the flow. The particles-markers were generated by "La Vision" seeder. The time history of pressure signal from microphone was used as reference signal. This signal was passed through band-pass filter to zero detector. After each jump in sign from negative to positive the TTL builder generated impulse. The laser flash was delayed respectively TTL pulse to provide the different phase of synchronization between microphone signal flow-field picture. In the experiments the time delay of TTS signal was consequently increased with a step equal 1/12 of sound excitation period up to full cycle. For each value of time delay the synchronized flow-field was averaged as usual by 400 pictures. Measurements were made as in longitudinal and in transverse sections of a jet.

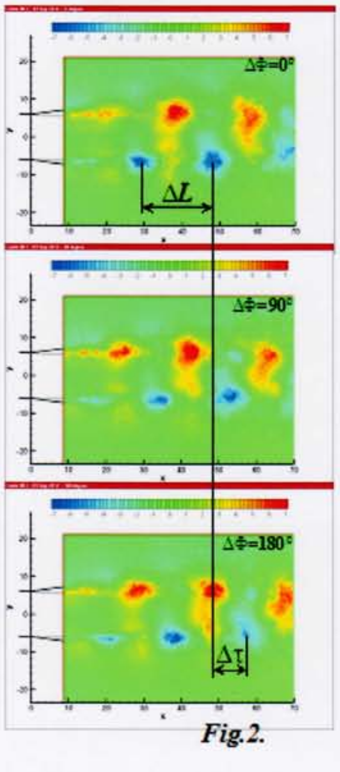

Fig.2.

Typical phase-averaged pictures of transversal (vertical) velocity (V_y) are shown in the fig. 2 for exciting frequency 2.5kHz. The high ordered large-scale structures are distinctly seen in the averaged flow-field of a jet. It can be associated with instability waves propagated in the mixing layer of a jet [1-7]. The phase shift between pictures in the fig. 2 is ΔΦ=90°. The value L characterizes the longitudinal size of the vortexes, Δτ - convection velocity of the ordered structure. Experimental results show that convection velocity of the vortexes U_c≈49m/s≈0.61U_0. As longitudinal size of the vortexes is about 20mm (see fig.2) than characteristic Strouhal number (Sh_L=fL/U_c), defined by its velocity is equal 1. The analogous results were obtained for different frequencies of excitation f = 3.4 kHz and f = 4 kHz.

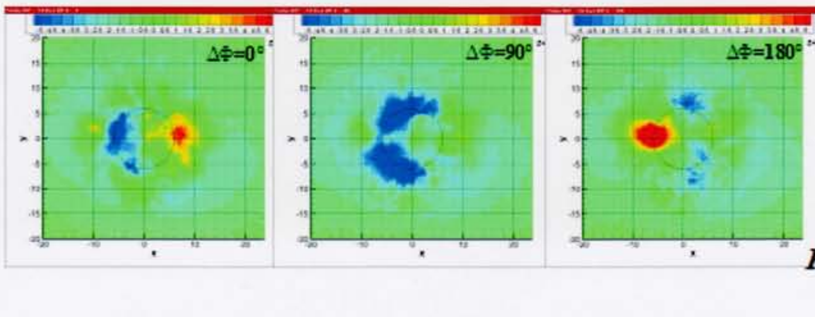

Fig.3.

In the fig. 3 the distributions of phase averaged radial velocities are shown in transversal section X=40mm for exciting frequency 4kHz. (Here – X –distance from nozzle exit.) The blue color corresponds to flow direction into jet, red – out. It can be seen that phase averaged flow field is not axisymmetrical. It is connected with non-symmetrical position of loudspeaker (left with respect of pictures in fig.3) so we can mark that induced instability waves have brightly expressed 3-D structure in our case.

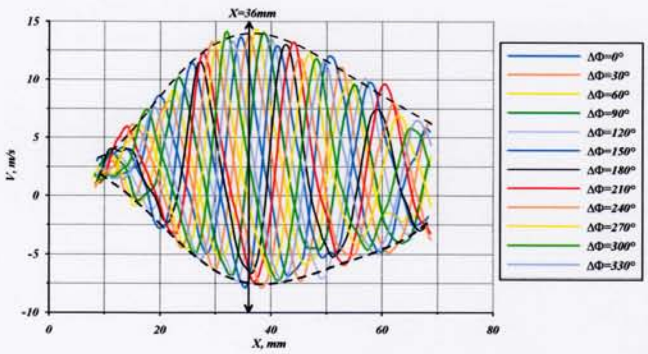

Fig.4

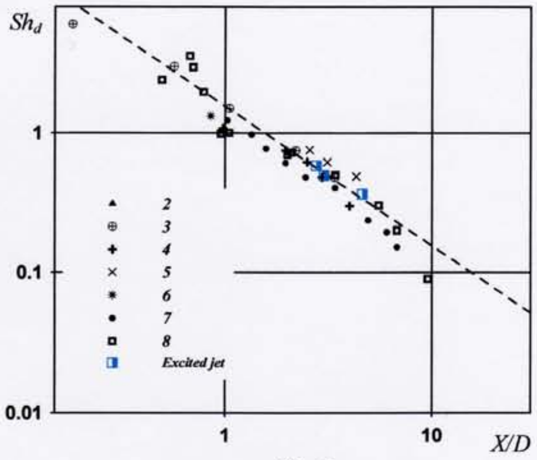

Fig.5

The phase averaged longitudinal distributions of transversal velocities along line extended nozzle edge are plotted in the fig.4. The different colors are corresponded to different phase shift between microphone signal and laser flash. Here the excitation frequency is 3.4kHz.The envelope curves are shown by dashed line. One can see that intensity of induced vortex (instability wave) of certain frequency (vortex size) in the beginning of mixing layer grows, then gain its maximum and then fade away along the X – axis. The analogous behavior of intensity of instability waves was obtained for other excitation frequencies.

The position of maximum of intensity of phase averaged radial velocity (axial maximum of induced instability wave) was associated with known dependence of characteristic frequency of noise source location on distance from nozzle tip (e.g. [9]). The corresponded results are shown in the fig. 4. Obtained data are found in a very good agreement with known data on jet source localization. This is pointed out on interconnections between dynamic of ordered structures within jet and jet noise radiation.

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