SYNTHETIC JET ACTUATION AT THE RESONANCE FREQUENCY

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<u>Summary</u> An air round jet was generated by a zero–net–mass–flux actuator. A satisfactory jet synthesis was confirmed experimentally by smoke visualization and hot-wire anemometry. The choice of suitable operating frequency was found near the resonance by means of theoretical as well as experimental approach. In the far field, the streamwise decay of the time-mean velocity is comparable with a conventional (steady) jet.

INTRODUCTION

Synthetic jets are generated by an oscillating force which pushes and pulls a fluid through an orifice (or nozzle) from a cavity [1]. The synthetic jets have many perspective applications such as control of primary flows [1, 2] and a valuable alternative for cooling applications [3].

The synthetic jets are characterized by two length scales: The length scale of the output orifice (diameter D), and the "stroke length" L_O [1]; another name is the "equivalent extruded (fluid) column length", [2]; the L_O is defined by integration of the the orifice velocity over the extrusion (discharge) stroke [1]. The Strouhal number is an only slightly modified ratio of the length scales D and L_O: e.g., at harmonic actuation $St = (1/\pi) f D/U_O = (1/\pi) D/L_O$ [2], where f is frequency, U_O is the time–mean orifice velocity during the extrusion stroke, i.e. $U_O = L_O/T$, and T is the time period, i.e. $T = 1/f$. There are many possible definitions of the Reynolds number, one of them sounds as $Re = U_O D/\nu$, [1].

RESULTS AND DISCUSSIONS

The present actuator consists of a sealed cavity, which is equipped with an actuating pair of diaphragms $D_D = 66.5$ mm in diameter, and with an emitting orifice $D = 8.0$ mm in diameter. The jet is oriented vertically upwards, a sinusoidal current feeds the actuator. An initiation step of the experiments was made by flow visualization by the smoke–wire technique. Further, the velocity distribution was measured by a hot–wire anemometer (DANTEC: CTA Bridge 56C17, Mean Value Unit 56N22, StreamLine 90N10 Frame, and CA-1000) in the constant temperature mode.

Analysis: resonance frequency of the actuator

From the point of view of energy transformation, the potential energy of the pair of diaphragms is transformed into the kinetic energy of fluid during each period. The oscillating diaphragms are assumed as harmonic motion, and the relationship between the velocities of the actuating diaphragms and the flow in the orifice satisfied the continuity equation (incompressible flow). In the top/bottom dead centers of the diaphragms, the kinetic energy of fluid is zero and the potential energy is maximum. On the other hand, in the neutral position of the diaphragms, the kinetic energy is maximum. The potential energy of the diaphragms can be written as for linear springs, and the resonance frequency can be derived as

$$f = \left(\frac{1}{2\pi}\right)\left(\frac{D}{D_D}\right)\sqrt{\frac{K_P}{2\rho L_e}} \cdot \qquad (1)$$

where K_P is the diaphragm (spring) constant (it was evaluated by an auxiliary experiment), ρ is fluid (air) density, and L_e is the "fluid column length" which captures the kinetic energy. For the present geometry, Eq. (1) gives $f = 78.5$ Hz. The "*nominal operating frequency*" has been refined according to the experimental results as $f = 75.0$ Hz.

Experimental results: Flow visualization and hot-wire measurement

Fig. 1 presents the visualization of the typical synthetic jet obtained using multiple exposures at low frequency actuation (30Hz) during 1 s, (it means, 30 superimposed frames were exposed). Fig. 1 shows the so–called "short L_O" (or "high St") synthetic jet, which was generated at $L_O/D = 3.2$, i.e. $St = 0.10$, and $Re = 400$, i.e. $U_O = 0.78$ m/s.
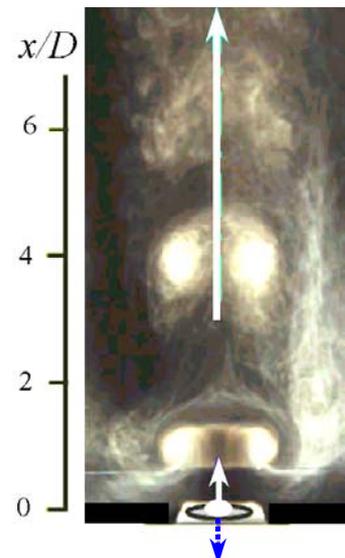

Fig. 1
Synthetic jet visualization,
$f = 30$ Hz, $L_O/D = 3.2$.

Counter-rotating vortex pairs are formed at the nozzle exit, and they are distinguishable during their upward motion from the nozzle. According to Fig. 1, the streamwise distances from the nozzle to the first and second vortex pairs are approximately 1 D and 4 D, thus the average pitch of the train of individual vortex pairs is approximately $\Delta x_V = 3\,D$. This Δx_V– value is rather well comparable with the "equivalent extruded column length" $L_O = 3.2\,D$.

Fig. 2 shows results of hot-wire measurements of the "long L_O" (or "low St") synthetic jet, which was generated at the "*nominal operating point*": $f = 75$ Hz, $L_O/D = 14.3$, i.e., $St = 0.022$, and $Re = 4400$, i.e., $U_O = 8.7$ m/s. Fig. 2 shows the centerline velocities during the actuating cycle namely the phase averaged velocity; U is the time–mean velocity and U_f is the periodic component. This plotting demonstrates a

Fig. 2 Phase averaged centerline velocity.

formation of the pulsatile jet when fluid "puff" travels downstream, thus the velocity amplitude moves downstream, and the velocity oscillations gradually diminish. The time–mean velocity U along the centerline is plotted as well. The maximum velocity in the orifice is approximately $3.05U_O$. Behind the orifice, the maximum velocity increases slightly at first, mainly because of the velocity profile formation there; the highest value is nearly $3.5U_O$ at $x = 2.5\,D$. From $x/D = 3.75$, the maximum velocity starts to decrease. In fact, a periodic character of the jet is clearly distinguishable approximately up to $x/D_O = 20$. Further downstream, the initially pulsatile jet remains a conventional (steady) fluid jet with a constant monotonically decreasing streamwise velocity. The streamwise decay of the centerline time-mean velocity of the investigated (originally pulsatile) jet was evaluated as $U \sim x^{-1.04}$. It is very close to the well known proportionality $U \sim x^{-1.0}$ of conventional axisymmetric fully developed turbulent jets.
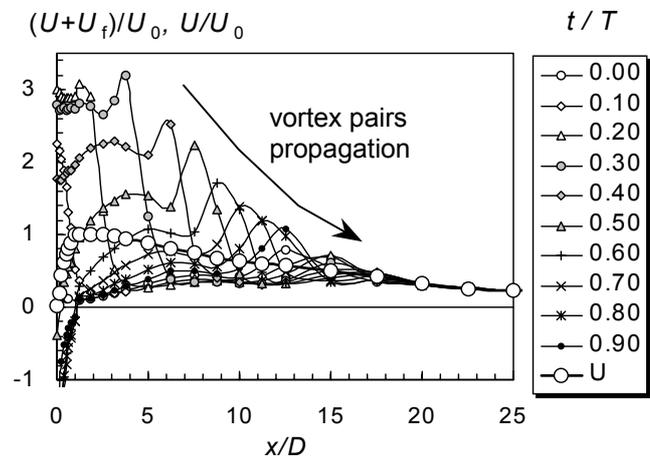
CONCLUSION

A round air jet was generated (synthesized) by means of a zero–net–mass–flux actuator from a train of counter-rotating vortex pairs. The choice of suitable operating frequency was found by means of both theoretical as well as experimental approach: The resonance frequency of the actuator was derived theoretically. In addition, the hot-wire measurement revealed a relationship between the time-mean velocity and the driving frequency. The chosen *"nominal operating frequency", f* = 75.0 Hz, agrees very well with both the theoretical and experimental results.

The expected function of the actuator has been tested experimentally by smoke visualization (using phase–locked multi–expositions) and hot-wire anemometry. The hot-wire data were processed using the phase-averaged technique, and the velocity was decomposed into the time–mean velocity, periodic and fluctuation components. The experiments have confirmed a satisfactory function of the "fluid jet synthesis". Two typical synthetic jets have been presented here, namely the "long–" and "short– extruded columns L_O" cases. The maxima of the centerline local and the time–mean velocities reached approximately 27 m/s and 8.7 m/s, respectively; it was occurred at the *"nominal operating point"* which produces the "long L_O" synthetic jet. The maximum Reynolds number was $Re = 4400$.

The synthetic jet is formed by travelling of fluid "puffs" downstream, thus the velocity amplitude moves downstream and the periodic component of the velocity gradually diminishes. The investigated, originally pulsatile jet resembles a conventional (steady) jet for the axial distance greater than 20 diameters from the orifice, where the streamwise decay of the centerline time-mean velocity was evaluated as $U \sim x^{-1.04}$.

References
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