Influence of Oscillation Characteristics on Synthetic Jet Structure


*Konosuke Sasaki, Tokyo City University
Koichi Nishibe, Tokyo City University
Tamio Fujiwara, Tokyo City University
Hiroshi Ohue, Tokyo City University
Kotaro Sato, Kogakuin University

Introduction

✓ Continuous Jet
Useful for flow control

Disadvantage
It’s difficult to design a downsized as the entire system

✓ Synthetic Jet

❖ To form a time-averaged jet downstream by blowing / suction
❖ No time-averaged flow and velocity at a slot
❖ Generated by a compact actuator (e.g. piezoelectric actuator, speaker-driven actuator)

Visualization of synthetic Jet (speaker-driven)

Adequate to apply instead of continuous jet
Motivation

Synthetic Jet

Reported to date

- Fundamental flow characteristics (Amity, Holman, etc.)
- Application to control flow separation (Duvigneau, Tensi, etc.)

Important research issues

- The generated momentum is small
- A synthetic jet actuator using bubble motion produced by electric discharge (Nishibe)

However,

- The discussion about the effect of the nonlinear oscillation on the jet structure is still insufficient

 Purpose of the present study

Clarify the effect of the relationship between the nondimensional stroke $L_0$ and the length of the pause ($u = 0$) on the generated flow from experiments & numerical simulations

Experimental setup

Speaker-driven synthetic jet actuator

- Inputted signal
- Wave with downtime
- Sinusoidal wave

Magnified view of slot

Aspect ratio $h/b_0 = 20$

Measurements for the jet velocities

Measurements of the jet velocities

I-type hotwire anemometer
**Numerical simulation**

**Assumptions**

**Code:**
Commercially computer code
SC/Tetra (Software Cradle., Ltd)

**Adapted:**
Two-dimensional incompressible viscous flow
Turbulent model: $k$-$\varepsilon$ model
Symmetry Grid points: 260,000

**Boundary condition**

- **Inlet:**
  Time varying velocity condition
- **Outlet:** Static pressure $P_s = 0$
- **Wall:** No slip
- **Lateral side:** Uniform velocity at $H = 320$ $b_0$ as the infinite boundary condition

**Key symbols, for the nondimensional numbers**

- **Nondimensional stroke, $L_0$**
  \[
  L_0 = \frac{l_0}{b_0}
  \]
  \[
  l_0 = \int_0^T u_0(t)dt = \int_0^T u_{sa}\sin2\pi ft dt
  \]
  (Holman et al, 2005)
  where $l_0$: length of the fluid body that is blown out in period of the oscillation
  $T$: period of the oscillation
  $u_0$: centerline velocity at the exit

- **Reynolds number, $Re$**
  \[
  Re = \frac{U_0 b_0}{v}
  \]
  where $U_0$: Characteristic velocity $U_0 = \frac{l_0}{T} = \frac{U_{sa}}{\pi}$

$\rho$: Density
$\mu$: Dynamic viscosity
$\nu$: Kinematic viscosity
$\kappa$: Kinematic temperature
$\varepsilon$: Temperature
$\theta$: Temperature
$\beta$: Temperature
$\gamma$: Temperature
Key symbols, Definition of $T^*$

Definition of $T^*$

$$T^* = \frac{T_b}{T_d} = \frac{T_d - T_p}{T_d}$$

where $T_b$: driving cycle period of the actuator

$T_d$: cycle period of the oscillation

$T_p$: downtime (pause time)

$$U_{b0} = \frac{U_{sab} T^*}{\pi} \text{ where } U_{b0} = U_0$$

$U_{sae} = U_{sab} T^*$

$U_{sab}$ is adjusted to equalize bellow values for compare the synthetic jet among $T^* = 1.0, 0.2$

- Nondimensional stroke, $L_0 = 30, 90$
- Characteristic velocity, $U_0 = 2.4$
- Reynolds number, $Re = 800$

Results & Discussion, velocity waveform

Blowing Suction

$T^* = 1.0$

Measurements point ($x/b_0 = 0.4$)

Blowing Suction

$T^* = 0.2$

Velocity waveform variation along the centerline of the jet from hot-wire anemometer and the numerical simulation ($U_0 = 2.4$, $Re = 800$, $L_0 = 90$, $x/b_0 = 0.4$, $T_d = t/T_d$)

- Experiment results are including rebound effect
- Numerical simulation conducts without rebound motion

Copyright © Fluid Eng. Lab., Tokyo City University, All Rights Reserved.
Results & Discussion, jet flow pattern (Velocity vectors)

Behavior of the synthetic jet for one cycle from the numerical simulation ($U_0=2.4$, $Re = 800$)

Results & Discussion, the variation in the vortex pair centers

The variation in the vortex pair centers ($Re = 800$, $y=0$, $\tau_d = t/T_d$)

The traveling speed of vortex pair depends on $L_0$ and $T^*$, but in downstream, it depends on only $L_0$
Results & Discussion, the nondimensional turbulence intensity

![Graph showing variation in streamwise RMS values along the centerline (Re = 800, y=0).](image)

Variation in the streamwise RMS values along the centerline (Re = 800, y=0).

\[
RMS = \frac{1}{n} \sum_{k=1}^{n} |u_k - u_m|
\]

Results & Discussion, profile of the streamwise time mean

![Graph showing profile of the streamwise time mean velocities along the centerline under the equivalent U0 (Re=800, y=0).](image)

Profile of the streamwise time mean velocities along the centerline under the equivalent U0 (Re=800, y=0)

\[
U_m = \frac{1}{T_d} \int_0^{\frac{T_d}{2}} u_s a^2 \sin^2 \omega dt
d\]

\[
= \frac{U_s a}{2} \sqrt{T^*}
\]
Results & Discussion, profile of the streamwise time mean velocities along the centerline under the equivalent \( U_0 \) (Re=800, y=0)

Profile of the streamwise time mean velocities along the centerline under the equivalent inputted momentum \( U_m \) (Re=800, y=0)

The effect on flow field of \( L_0 \) and \( T^* \) limited near the slot area. But the trend to be quasi continuous jet can vary by \( L_0 \) and \( T^* \)

Conclusion

Effect of the differences of the oscillation waveform on jet structure along the centerline was clarified by conducting the experimental and numerical simulations under the equivalent to Reynolds numbers

Numerical oscillation (with downtime, \( T^* < 1.0 \))

- The speed of vortex pair
- The profile of the turbulent intercity
- The profile of time mean velocity

Effect of \( L_0 \)

Same trend in case of simulation (\( T^* = 1.0 \))

Effect of \( T^* \)

- It is similar to the effect of \( L_0 \)
- Impact of the difference of imputed momentum

For evaluation of the flow characteristic of the synthetic jets generated by various oscillation, It may be better to set the same momentum basis characteristic velocity \( U_m \)