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Effects of acoustic excitation at resonance Strouhal numbers on characteristics of an elevated transverse jet

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ABSTRACT

The effects of acoustic excitation on the flow behavior, penetration, and spread of the stack-issued and wall-issued transverse jets were studied experimentally. The jet flow was periodically excited by a loudspeaker that was driven with a square wave at resonance Strouhal numbers. The pulsed transverse jet was characterized by jet Reynolds number 2000. Streak pictures of the smoke flow patterns illuminated by the laser-light sheet in the median plane were recorded with a high-speed digital camera to illustrate the evolution process of the characteristic flow behavior within one excitation cycle. The binary edge-detection technique was used to determine penetration height and spread width. The tracer-gas concentration measurement provided jet dispersion information. The evolution processes of both the stack-issued and wall-issued transverse jets were characterized by a leading vortex ring and swing motion of the jet column near the jet exit as the jets were forced at resonance Strouhal numbers. A leading vortex ring appeared near the jet exit during the leading phase of excitation cycle and evolved subsequently to puffs of jet fluids in the upwind shear layer of the deflected jet. The swinging motion of the near-tube tip jet column induced up/down oscillation of the deflected jet. The excited stack-issued transverse jet exhibited significantly larger penetration height and spread width than the excited wall-issued transverse jet. The tracer-gas detection experiment results showed that the excited transverse jet disperses significantly faster and wider than the non-excited transverse jet. Pulsating the transverse jet at low resonance Strouhal numbers produced higher mixing and dispersion effects than pulsating the transverse jet at high resonance Strouhal numbers.

1. Introduction

The study of jet in crossflow is important for its various practical engineering applications such as combustion, injection cooling, industrial mixing, and pollution transport. Depending on the jet configurations, the studies of jet-in-crossflow are conventionally classified into two categories: one is wall-issued transverse jet [1–4], and the other is stack-issued transverse jet [5–7]. The wall-issued transverse jet is characterized by three-dimensional flows, which are subject to the interactions between the jet, jet-wake, and wall boundary-layer. The flow structures in the stack-issued transverse jet are subject to the interactions between the jet, jet-wake, and stack-wake. The common feature in the time-averaged flow structure of the wall-issued and the stack-issued transverse jets is the counter-rotating vortex pair associated with the jet cross section that appears in the far field. However, the characteristics of the flow field, the coherent structure along the upwind shear layer of the deflected jet, the trajectory of the deflected jet, and the wake properties of these two cases present prominent differences.

During the past two decades, it has been found that the mixing process of the wall-issued transverse jet can be improved by pulsating the jet flow. Several methods, for example, acoustic excitation, piezoelectric actuator, and solenoid valve, have been employed to pulsate the jet velocity. Recent investigations [8–16] revealed that temporally varying the jet velocity allows jet penetration and spread to increase at specific excitation conditions. Vermeulen et al. [8] showed that acoustically forcing a jet in crossflow produces significant increase in jet spread, penetration, and mixing and a decrease in mixing length. Turbulence and penetration data showed that the responses of spread and penetration appeared to be optimum at a Strouhal number of about 0.22. Gogineni et al. [9] used piezoelectric actuators mounted on the interior walls of a square jet to modulate an air jet in crossflow. They found that manipulation of the upstream and downstream segments of the jet shear layer leads to an increase in the jet penetration into the crossflow and to substantial mixing enhancement. A solenoid valve operated by a square wave signal of variable frequency, injection time, and duty cycle was used to pulse

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