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# Experimental investigations on cavity-actuated under-expanded supersonic oscillating jet

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**Abstract** As one type of potential flow control actuators, cavity-actuated supersonic jet oscillators, which consist of a 2-D convergent nozzle and two face to face cavities, need to be investigated deeply to get the knowledge of their oscillating feature and underlying mechanism. Wind tunnel testing are conducted under different back pressures in a vacuum-type wind tunnel for two supersonic jet oscillators, to obtain their characteristics and the conditions for jet oscillating. The experimental results show that the continuous, nearly symmetric or asymmetric flipping between the two cavities appears over certain nozzle pressure ratio (NPR) range for both oscillators according to schlieren visualizations. Compared to the free jet, the oscillating jet with large exit achieves larger mixing; the oscillating jet with small exit has less mixing, based on the analysis of jet axial peak velocity and the entrainment. The cross-junction mode for estimating the resonance frequency in a pipe with two closed side branches is modified and obtained comparable estimations of the frequency of jet flipping with experimental data, but further investigations are needed to discover the underlying mechanism for the jet flipping.


## 1. Introduction

Fluidic oscillators, which produce an oscillating jet (sweeping or pulsing jet) at high frequency, are attracting increased attention in recent years due to their application potentials as flow control actuators.[1] The attractive features of fluidic oscillators for flow control are their characteristics of unsteady blowing, wide range of operating frequency and the distributed nature of momentum addition. The innovative application of fluidic oscillators to flow control problems includes separation control, jet thrust vectoring, cavity tone suppression, etc.[2,3]

One characteristic of all fluidic oscillators is that there must be some type of feedback mechanism to drive the oscillations. Based on the difference of the feedback mechanism, at least four types of fluidic oscillators have been invented so far, i.e., wall attachment, jet interaction, cavity resonating and vortex oscillator.[2] The wall attachment and jet interaction oscillators receive more investigations in recent years, and the details on these two oscillators have been summarized in the two latest review papers.[2,3] Hence, these two oscillators will be introduced briefly here, and cavity resonating oscillators will be described in detail since it is research object of this paper.

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In the wall attachment oscillator, a jet of fluid exiting from the nozzle attaches to the right-side surface in the cavity due to the "wall attachment" effect (see Fig. 1(a)), commonly known as the "Coanda" effect. The feedback channel transmits a pressure pulse (or actual flow) generated by the jet attachment on this side of the wall back to the point of the jet separation in the nozzle, thus deflecting the jet to the left-hand side as shown in Fig. 1(b). The cycle is repeated thus producing an oscillating jet at the exit of the device. Wall attachment oscillator has been demonstrated widely for flow control application, e.g., flow separation control,[4–8] noise suppression,[9] jet thrust vectoring[10] and jet mixing enhancement.[10,11]

Jet interaction oscillator is based on the inherent fluid dynamic instabilities. The two jets impinge (see Fig. 2) at each other and by proper design of the cavity, the impingement becomes unstable and an oscillatory jet flow is generated at the output.

The cavity resonating oscillator was developed as one type of temperature sensor around the 1970s.[12] One typical design is shown in Fig. 3.[13] In Fig. 3, $H$ denotes the total depth of two cavities, $L$ denotes the cavity length and $H_e$ denotes exhaust throat height. As a fluid jet issues from the inlet nozzle and impinges on a wedge, it is subjected to an oscillation transversely to the jet issuing direction. This oscillation has traditionally been called edge tone oscillation.[14] The edge tone oscillation is caused by inherent shear layer instabilities, vortex shedding and acoustic feedback characteristics of the jet-edge configuration and is dependent upon the jet velocity and distance between the nozzle exit to the wedge.

The cavity in which the fluid runs from the inlet nozzle to the discharge exhaust has a characteristic or resonant frequency (Eigen frequency). Carter[12] pointed out that the cavity Eigen frequency is excited by the edge tone oscillations beginning at an input pressure corresponding to the threshold point. No distinct oscillation is produced until the input pressure reaches the threshold value. At this value the frequencies of oscillation produced by the flow impinging on the edges at the exhaust begin to match the cavity Eigen frequencies.

Most of the recent researches on fluidic oscillators, focused on their operation of the subsonic flow. The wall attachment oscillator, which has been received more attention, is not clarified yet for its operation in the supersonic speed. The several researches on cavity resonating oscillator in the 1970s were also limited in its subsonic operation.

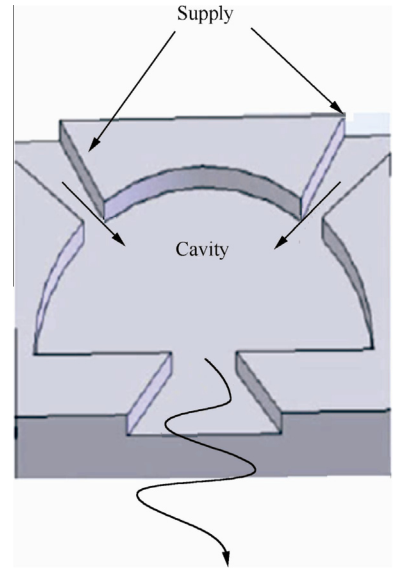


**Fig. 2** Jet interaction fluidic oscillator (reproduced from Ref. [3]).

This paper will focus on the characteristics of the cavity resonating oscillators with a supersonic under-expanded jet to produce a sweeping flow. The operation limit, oscillating course and mixing characteristics of the oscillating jets were studied experimentally.

## 2. Oscillator geometry

The oscillator geometry is similar to Fig. 3 from Carter's design and convergent nozzle is also employed in this work, but the wedge downstream the exit is removed. The oscillator (see Fig. 4) has a nozzle throat height of 5 mm and then there are two face-to-face cavities with a length–depth ratio of 2.04 and a rectangular divergent exhaust after the cavity. The divergent exhaust has a divergence angle of 60° and a throat which is much larger than the nozzle exit, which results in the smaller rear wall height of two cavities than the front walls.

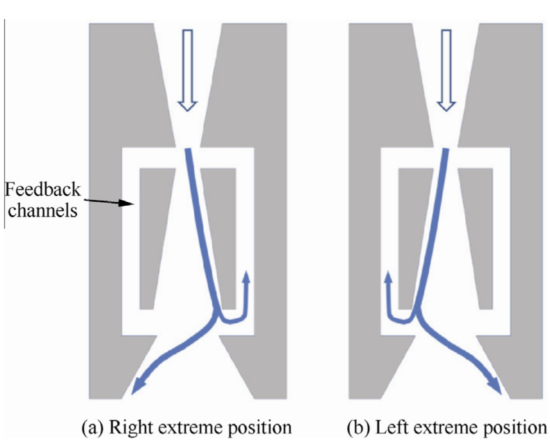


**Fig. 1** Typical wall attachment oscillator (redraw based on Ref. [3]).

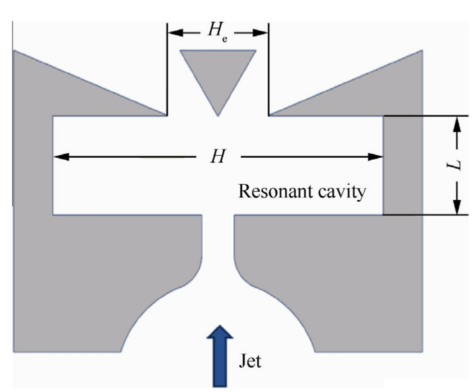


**Fig. 3** Cavity resonating oscillators.[13]