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Signal Waveshape influence on the Impinging Synthetic Jets Flow Field and Heat Transfer

by G. Paolillo*, C.S Greco*, T. Astarita* and G. Cardone*

* University of Naples 'Federico II', 80125, Via Claudio, 21, Naples, Italy, *carlosalvatore.greco@unina.it*

Abstract

Synthetic jets are jets generated by the periodic oscillation of an actuator, such as a loudspeaker, a piezoelectric membrane or a piston inside a cavity provided with an orifice or a nozzle. The fluid dynamic characteristics of the impinging synthetic jet flow field and the related heat transfer performances are strongly influenced by the waveshape of the electric signal driving the actuator. Therefore, two different classes of waveshapes have been considered: those obtained by varying the suction duty cycle factor k and those obtained as Fourier series at a specified fundamental frequency.

1. Introduction

Synthetic Jets (SJs) have recently gained a huge spotlight due to their advantageous features like the absence of a fluid reservoir, their reduced dimensions and the low complexity and costs.

SJs are entirely generated from the surrounding environment, in which the device is embedded. The device is generally made up of a cavity with a hole on one side and an oscillating membrane on the other one. The diaphragm's function is to produce time-periodic oscillations of the volume inside the cavity, which themselves turn into pressure oscillations. In this way, the pressure oscillations cause the fluid moving alternatively and this movement is then characterized by ejection and suction phases (see figure 1 - left).

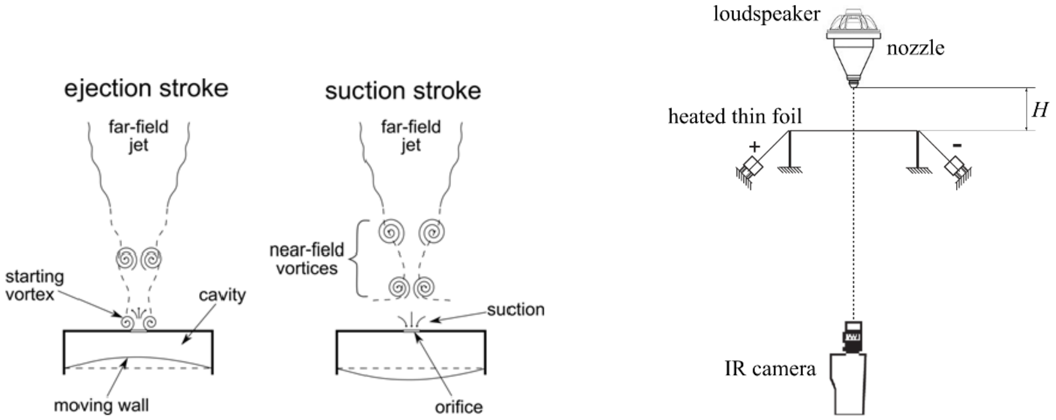

Fig. 1. *Synthetic jet ejection and suction phases (left), Sketch of the thermal experimental apparatus (right)*

SJs represent an innovative technology with promising features principally in the fields of flow control and electronics cooling. The behavior of a synthetic jet is governed by two non-dimensional parameters: the Reynolds number $Re = U_0 D/\nu$ and the Strouhal number $St = fD/U_0$ where U_0 is a characteristic velocity (generally correlated to the mass flow rate in the ejection phase), D is the exit diameter, ν the kinematic viscosity of air and f the operating frequency.

In the impinging configuration, important for the heat transfer applications, another governing parameter is the dimensionless nozzle-to-plate distance H/D, where H is the nozzle-to-plate distance.

Several studies have investigated the effects of Re, St and H/D on both the flow field and the related heat transfer behaviour of impinging synthetic jets [1,2]. Generally, a sinusoidal electrical signal is supplied to the actuator, which results in a sinusoidal pressure and exit velocity; in this case, St is sufficient to describe the morphology of the jet (along with the other governing parameters). However, when a different electric signal is provided to the actuator, a different behaviour of the flow during the ejection and suction phases is expected.

In the literature, very few works have investigated this effect and they have mainly analysed the influence of a sinusoidal signal with different suction duty cycle factor k, where k is defined as the temporal ratio between the suction phase and the ejection phase. In the present work, focus is given on a different point, specifically on the influence of the driving signal waveshape on the performance of impinging synthetic jets.

2. Experimental Setup

Planar Particle Image Velocimetry (PIV) and heat transfer measurements are carried out. The PIV measurements are performed by using a low-speed laser Evergreen and an ANDOR ZYLA 5.5 mega-pixel camera. The seeding employed is olive oil. As regard the heat transfer measurements, they are performed by using infrared thermography coupled with the heated thin foil heat flux sensor.

The impinging synthetic jet is generated by an actuator made of a loudspeaker mounted at the side of a cavity delimited on the other side by a convergent nozzle. The input signal is generated by a signal generator Digilent Analog Discovery and it is amplified by a Hi-Fi amplifier (Kenwood KAC-6405). The convergent nozzle has an exit diameter of 10 mm and contraction ratio of 56:1.

The impingement plate consists of a rectangular 262×200 mm constantan foil with a thickness of 50 μm. The foil is steadily and uniformly heated by Joule effect and cooled from the upper side by the synthetic air jet impinging on it. The Joule heating is obtained by applying a steady voltage difference to the edges of the foil, by using a stabilized DC power supply. The lower side of the foil is coated by black paint with high emissivity and imaged by an IR camera. In the present tests, a FLIR™ T650sc with a resolution of 640 x 480 pixels is used (see figure 1 right). A local steady energy balance is applied to the foil to measure the convective heat transfer coefficients.

3. Results

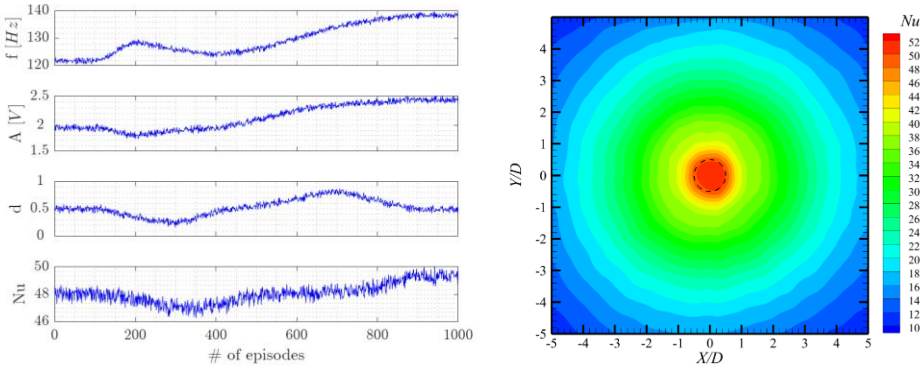

Fig. 3. *Results of the optimization for the waveshape with duty cycle (left) and Nusselt number distribution for the case at actuation frequency of 120 Hz, electrical signal amplitude of 2.5 V and duty cycle with d=0.5 (right).*

A preliminary investigation has been performed to assess whether the electric signal waveshape can provide a heat transfer enhancement. In particular, two different shapes of the supplied electric signal have been tested: those obtained by varying the duty cycle k and those obtained as Fourier series at a chosen fundamental frequency. The waveshape governing parameters, such as wave frequency, amplitude and duty cycle k or the Fourier series coefficients, are chosen through a machine-learning algorithm in order to maximize the Nusselt number $Nu = hD/k$ (with k being the air thermal conductivity), obtained by averaging the values inside the region delimited by the dashed black line depicted in figure 3 (right).

The obtained results show that the heat transfer distribution is affected by the waveshape of the electrical signal and, in particular, that optimal heat transfer is always obtained with purely sinusoidal driving signal.

Such a result is shown in figure 3 (left), where the variations of the frequency, amplitude and the parameter d (defined as $d = 1/(1+k)$) along with the variation of Nu across the iterations of the optimization process are reported. It is possible to observe that the parameter d tends to 0.5 which corresponds to the case of a purely sinusoidal signal.

4. Conclusions

The effects of the waveshape of the electrical signal on the heat transfer performances and the related flow field have been investigated through PIV and IR Thermography measurements. Two different classes of waveshape have been tested: the duty cycle k and those obtained as Fourier series at a chosen fundamental frequency. The governing parameters of these waveshapes have been optimized by using machine-learning approach. The waveshape that maximizes the heat transfer is found to be the purely sinusoidal shape.

REFERENCES

[1] Greco C. S., Ianiro A., Cardone G., “Time and phase average heat transfer in single and twin circular synthetic impinging air jets". International Journal of Heat and Mass Transfer, vol. 73, pp. 776-788, 2014.

[2] Greco C. S., Cardone G., Soria J., "On the behaviour of impinging zero-net-mass-flux jets". Journal of Fluid Mechanics, vol. 810, pp. 25-59, 2017.