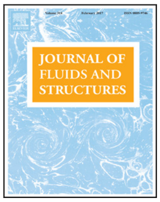
Journal of Fluids and Structures 81 (2018) 466–478

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs



Synthetic jet Reynolds number based on reaction force measurement

Paweł Gil

Rzeszow University of Technology, The Faculty of Mechanical Engineering and Aeronautics, al. Powstańców Warszawy 12, Rzeszów, 35-959, Poland

HIGHLIGHTS

- New method for synthetic jet Reynolds number calculating has been presented.
- A method for determining the Reynolds number for multi-orifices has been proposed.
- New method for synthetic jet existence detection has been presented.

ARTICLE INFO

Article history:
Received 27 December 2017
Received in revised form 12 May 2018
Accepted 24 May 2018

Keywords:
Synthetic jet
Zero-net-mass-flux
Reynolds number
Reaction force
Multi-orifices

ABSTRACT

The paper presents a new method for calculating Reynolds number and dimensionless stroke length based on synthetic jet actuator reaction force measurement. The new method was validated for axisymmetric synthetic jet and classical Reynolds number from about 2000 to 25000 and dimensionless stroke length from 0.5 to about 100, obtaining the coefficient of determination $R^2 = 0.90$ for Reynolds number and $R^2 = 0.94$ for dimensionless stroke length. New method is simple, time and cost effective, allows measuring the Reynolds number for orifices of any shape and multi orifices configuration.

1. Introduction

A zero-net-mass-flux (ZNMF) or synthetic jet actuator (SJA) in common cases consists of a vibrating diaphragm and cavity that contains an orifice. This actuator can be for example a loudspeaker (Gil and Strzelczyk, 2016; Chaudhari et al., 2009), piezoelectric diaphragm (Gallas et al., 2003) or a mechanical piston (Liu and Hong, 2017). There are also other devices that produce a synthetic jet, for example no-moving-part hybrid-synthetic jet actuator (Tesař et al., 2006) or plasma synthetic jet actuator (Santhanakrishnan and Jacob, 2007; Wang et al., 2013).

The device is called ZNMF because the integration of the mass flow rate across the orifice over an integer number of cycles is equal to zero. Although there is no net mass transfer to ambient fluid, the ZNMF device has an interesting property of causing a finite amount of momentum transfer and thus reaction force generation (Trávníček et al., 2008).

It has been many years since synthetic jet actuators was used for active flow control (Glezer and Amitay, 2002; Cattafesta and Sheplak, 2011), lift control (Smith et al., 1998; Amitay et al., 2001; Torres et al., 2016), mixing enhancement (Wang and Menon, 2001; Xia and Zhong, 2017; Eri et al., 2016), propulsion (Thomas et al., 2005; Marchitto et al., 2017; Geng et al., 2016, 2018) and heat transfer enhancement (Chaudhari et al., 2010; Valiorgue et al., 2009; Arik, 2008; Gillespie et al., 2006). It is widely known that pulsating jets, such as a synthetic jet, clearly describe two dimensionless numbers: Reynolds and

---

E-mail address: gilpawel@prz.edu.pl.

https://doi.org/10.1016/j.jfluidstructs.2018.05.011
0889-9746/© 2018 Elsevier Ltd. All rights reserved.

Nomenclature

A	Orifice area, m^2
d	Orifice diameter, mm
E	RMS voltage, V
F_f	Measured time-average reaction force, mN (10^{-3}N)
F_u	Calculated time-average reaction force from velocity, mN (10^{-3}N)
f	Excitation frequency, Hz
H	Depth of cavity, mm
l	Characteristic length, m
L_u	Stroke length calculated from velocity, m
$L_{0\mathrm{u}}$	Dimensionless stroke length calculated from velocity
L_f	Stroke length calculated from reaction force, m
$L_{0\mathrm{f}}$	Dimensionless stroke length calculated from reaction force
r	Radial distance, mm
Re_u	Reynolds number calculated from velocity
H	Depth of cavity, mm
Re_f	Reynolds number calculated from reaction force
St	Stokes number
Sr	Strouhal number
t	Orifice thickness, mm
T	Oscillation period, s
x	Axial distance, mm
u	Instantaneous velocity, m/s
U	Characteristic velocity, m/s
U_0	Time and spatial averaged momentum velocity, m/s

Greek symbols

ν	Kinematic viscosity, m^2/s
ρ	Density of air, kg/m^3
τ	Time, s
Φ	Phase, °

Index

c	Centerline ($r = 0$)

Abbreviations

SJA	Synthetic jet actuator

Strouhal numbers. The governing parameters for a synthetic jet based on a simple "slug-velocity-profile" model include a Reynolds number and dimensionless stroke length based on the characteristic velocity scale (Holman et al., 2005; Smith and Glezer, 1998). In the first publications concerning synthetic jet, centerline velocity during the ejection portion of the cycle was used (Glezer and Amitay, 2002; Smith and Glezer, 1998). Smith and Swift (2001) argued that because the spatial velocity profile can deviate significantly from the assumed slug shape, the centerline velocity profile is more generally defined as the spatial-averaged velocity at the exit. Holman et al. (2005) suggested that a synthetic jet Reynolds number can be defined in terms of the time and spatial averaged exit velocity during the expulsion stroke. So far, the definition proposed by Holman et al. (2005) is the most commonly used and accurate but also the most complicated. The measurement of characteristic velocity becomes the most problematic. First of all, the velocity only during the ejection stroke has to be measured. Secondly, the instantaneous velocity has to be integrated. In the case of orifice/slot with complex shapes it is very difficult to achieve spatial averaging. Moreover, SJA with multi-orifices is increasingly studied (Chaudhari et al., 2011; Mangate and Chaudhari, 2016). In the case of multi-orifices with different shapes the measurements of Reynolds number and dimensionless stroke length become great problem.

According to the described problems, the paper presents a new effective method to determine the Reynolds number and dimensionless stroke length. This method is based on the measurement of the synthetic jet actuator reaction force. The method has been known for a long time, but has not been applied to a synthetic jet yet. The new method was validated for axisymmetric synthetic jet. The advantages and disadvantages of the new method in relation to current methods have been presented.