UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

OPTIMIZATION OF SYNTHETIC JET ACTUATOR LOCATION FOR AERODYNAMIC DRAG REDUCTION OF BACKWARD-FACING STEP

Teo Yong Soon

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OPTIMIZATION OF SYNTHETIC JET ACTUATOR LOCATION FOR AERODYNAMIC DRAG REDUCTION OF BAKWARD-FACING STEP

TEO YONG SOON

A thesis submitted
in fulfillment of the requirements for the Bachelor of Mechanical Engineering (Hons)

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DECLARATION

I declare that this thesis entitled "Optimization of Synthetic Jet Actuator Location for Aerodynamic Drag Reduction of Backward-facing Step" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

DEDICATION

To my beloved mother and father

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Bachelor of Mechanical Engineering (Hons).

Signature :………………...

Supervisor Name :……………………….....................................

Date :……………………..

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ABSTRACT

Active flow control is one of the aerodynamics flow control techniques that used to improve aerodynamics properties such as drag reduction, lift augmentation, noise mitigation and mixing enhancement by manipulating the boundary layer of the fluid flow. Synthetic jet actuator (SJA) is an active flow control device that used to manipulate the boundary layer by synthetic jet pulse producing by a vibrating membrane through a small orifice in order to improve the aerodynamics properties. The purpose of this study was to find an ideal location to locate the SJA in the backward-facing step and study the effect on the aerodynamic drag of the bluff body at different jet locations. The first simulation was performed on the SJA model in order to adopt an appropriate method to locate it in the backward-facing step. After that, a simulation was done on the backward-facing step without SJA (uncontrolled flow) in order to get the separation point for the simulation on the backward-facing step with SJA (controlled flow). A series of simulation was done on the controlled flow case in which the SJA located at separation point (0.75h), before separation point (0.25h), after separation point (1.25h) and SJA arrays at both separation and reattachment point (0.75h and 2.0825h). The study found out that the SJA arrays located at both separation point and reattachment point had the highest drag reduction of 26.05% while the single SJA located before separation point had the lowest drag reduction of only 0.84%. It was concluded that the best location to locate the SJA was at both separation and reattachment point.

ABSTRAK

Kawalan aliran aktif adalah salah satu kawalan aliran aerodinamik yang digunakan untuk menambah baik ciri-ciri aerodinamik seperti pengurangan seretan aerodinamik, peningkatan lif aerodinamik, pengurangan hingar dan peningkatan pencampuran dengan memanipulasi lapisan sempadan aliran bendalir. Aktuator jet sintetik (AJS) adalah satu alat kawalan aliran aerodinamik yang digunakan untuk memanipulasi lapisan sempadan dengan denyut jet sintetik yang dihasilkan oleh satu lapisan bergetaran melalui satu orifis yang kecil untuk menambah baik ciri-ciri aerodinamik. Tujuan kajian ini adalah untuk mencari lokasi yang ideal untuk melokasi AJS dalam domain aliran silang dan mengaji kesan pada seretan aerodinamik tubuh tebal dekat lokasi jet yang berbeza. Simulasi yang pertama adalah dilakukan pada modal AJS untuk mengadaptasi satu kaedah yang sesuai untuk melokasi AJS dalam domain aliran silang. Kemudian, simulasi telah dilakukan pada domain aliran silang tanpa AJS (aliran tidak terkawal) untuk mendapati titik pemisahan untuk simulasi pada domain aliran silang yang mempunyai AJS (aliran terkawal). Satu siri simulasi telah dilakukan pada kes aliran terkawal di mana AJS terletak pada titik pemisahan (0.75h), sebelum titik pemisahan (0.25h), selepas titik pemisahan (1.25h) dan susunan AJS yang terletak pada kedua-dua titik pemisahan dan titik pelekatan semula (0.75h and 2.0825h). Kajian ini mendapati bahawa susunan AJS yang terletak di kedua-dua titik pemisahan dan titik pelekatan semula mempunyai pengurangan seretan aerodinamik tertinggi sebanyak 26.05% manakala AJS tunggal yang terletak sebelum titik pemisahan mempunyai pengurangan seretan aerodinamik yang paling rendah iaitu hanya 0.84%. Kesimpulannya, lokasi terbaik untuk meletak AJS adalah pada kedua-dua titik pemisahan dan titik pelekatan semula.

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LIST OF ABBREVIATIONS

AFC	Active Flow Control
SJA	Synthetic Jet Actuator
ZNMF	Zero-Net Mass-Flux
RANS	Reynolds-Average Navier-Stokes
URANS	Unsteady Reynolds-Average Navier-Stokes
SST	Shear Stress Transport
AOA	Angle of Attack
PIV	Particle Image Velocimetry
FDM	Finite Difference Method
FEM	Finite Element Method
FVM	Finite Volume Method
CFD	Computational Fluid Dynamics
UDF	User-Defined Function

LIST OF SYMBOLS

Ma	Mach Number
Re	Reynolds Number
c	Chord Length
α	Angle of Attack
f_J	Forcing Frequency
f_{SEP}	Separation Bubble Frequency
f_{SL}	Shear Layer Frequency
x_{SEP}	Separation Location
L_{SEP}	Separation Bubble Length
$\triangle L_{SEP}$	Separation Bubble Length Increment
H_{SEP}	Separation Bubble Height
ρ	Density
v	Velocity
F_D	Drag Force
A	Frontal Area
C_D	Drag Coefficient
$\triangle C_D$	Drag Coefficient Increment
C_L	Lift Coefficient
$\triangle C_L$	Lift Coefficient Increment
x_i	Location in x-direction
x_j	Location in y-direction
x_s	Separation Point Location in x-direction
x_r	Reattachment Point Location in x-direction
F_i	Force in x-direction
F_{DP}	Pressure Drag Force
F_{DV}	Viscous Drag Force
F_{LP}	Pressure Lift Force
F_{LV}	Viscous Lift Force
v_i	Velocity in x-direction
v_j	Velocity in y-direction
v_{SJA}	Synthetic Jet Velocity
v_{max}	Maximum Jet Velocity
μ	Kinematics Viscosity
h	Step height

$z_{cavity\ wall}$	Cavity wall Location in z-direction
A	Amplitude
f	Frequency
t	Time
D_o	Orifice Width
N	Number of Time Step

CHAPTER 1

INTRODUCTION

1.1 Background

Aerodynamics flow control technique has been widely researched and developed in order to improve the aerodynamics properties in several sectors. Among the aerodynamics flow control techniques, active flow control (AFC) is one of the types of aerodynamics flow control techniques which are usually used in manipulating the boundary layer to improve aerodynamics properties in various applications. Those applications consist of drag reduction, lift augmentation, noise mitigation and mixing enhancement. In the active flow control device, momentum or energy is always added to the flow in a regulated manner in order to help in the control of the fluid flow. In the past decades, plenty of researches showed that active flow controls technique has provided solution for the problem faced by the aerodynamic transport applications and electronic cooling applications. Active flow control technique device such as synthetic jet actuator had helped to reduce aerodynamics drag of the vehicle for about 15.83% in suction and 14.38% in blowing (Harinaldi et al. 2011). Besides that, an appropriate combination of jet arrays in active flow control technique had increase both lift coefficient and drag coefficient of the passenger van by 100% and 26.5% respectively (Zhao G. et al. 2014). For active flow control devices in electronic cooling applications, larger hydraulic diameter and smaller aspect ratio orifices had a best result in the heat transfer (Lee et al. 2016).

Synthetic jet actuator (SJA), also can be called as Zero-Net Mass-Flux (ZNMF) actuator is a device that uses in active flow control technique by using synthetic jet produces by a vibrating membrane through an orifice. In fluid dynamics, synthetic jet flow is a type of jet flow which is usually created by an actuator with one or two vibrating diaphragm where the stream of one fluid mixes with the surrounding medium (Kurowski et al. 2015). In flow control applications, SJA is use to create a formation of vortex ring pair in order to impart momentum on the boundary layer of the flow. The performance of the synthetic jet usually depends on either the parameter of the actuator or the properties of the fluid. The various parameters of the actuator that influence the performance of the synthetic jet are normally diaphragm vibration properties, cavity dimensions, cavity shape, orifice dimensions and orifice shape. According to the research of the past decades, the performance of the synthetic jet is based on the velocity of the synthetic jet, vorticity and pressure contours produce by the synthetic jet. In active flow control, the cavity shapes of the actuator did not have large impact on the performance of the synthetic jet (Feero et al. 2015). Besides that, for different actuator's parameters, different excitation frequency of the diaphragm will have difference performance (Lv Yuan-wei et al. 2014). This study shows that the performance of the synthetic jet can be achieves by finding the optimal design for each parameter and the suitable excitation frequency for the actuator. Moreover, by using double vibrating diaphragm and higher vibrating amplitude, the results showed massive increasing in the jet velocity with the same membrane and cavity resonant frequency (Kurowski et al. 2015).

A bluff body in fluid mechanics can be defined as a body that the drag force experience by the body is dominant by pressure drag due to the shape of the body which has separated flow over a substantial part of its surface. A bluff body flow involve in interaction of 3 shear layers which will influence the aerodynamics properties which are boundary layer, separating free shear layer and the wake. In the aerodynamics of bluff body, the aerodynamics properties improvements that will usually be consider are the aerodynamic drag reduction, lift enhancement, vibration and noise reduction. In order to achieve those improvements, it is important to control the wake and the dynamics of vortex formations which acts as the source of fluid forces of the bluff body (Efstathios Konstantinidis et al. 2016). Those controls can be done by using passive or active flow control techniques.

1.2 Problem Statement

Aerodynamic properties such as aerodynamic drags of the bluff body such as building and transportation acts as an importance factors in reducing power consumption and higher height construction probability. Therefore, the active flow control device such as synthetic jet actuator was introduced to help in the reducing the aerodynamic drag of the bluff body. In order to achieve a better drag reduction of the bluff body, it is necessary to study the ideal location to locate the synthetic jet actuator.

1.3 Objective

The objectives of this final year project are as follows:

1. To find an optimal design on the location of the synthetic jet actuator in the backward-facing step.
2. To study the effect of the synthetic jet actuator position in the backward-facing step on the aerodynamic drag of the bluff body.

1.4 Scope of Project

The scopes of this final year project are:

1. Only the effect of the synthetic jet actuator's location on the aerodynamic drag in the backward-facing step will be study in this report.
2. Turbulence flow will be simulated inside the backward-facing step.
3. The analysis of the performance of the synthetic jet and aerodynamic drag of the bluff body will be conduct by using simulation by ANSYS-Computational Fluid Dynamic (CFD) software in this report.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Active flow devices have a high potential to use in jet's thrust vectoring, mixing enhancement, heat transfer, drag reduction and separation in flow regimes reduction (Saambavi et al. 2014). A general synthetic jet actuator (SJA) (Fig. 2.1) is one of the types of active flow control device that contains of a cavity with an oscillating diaphragm and a small orifice (Zhou et al. 2010). There were also some different kinds of orientation of diaphragm of the synthetic jet actuator such as double diaphragm parallel to the orifice exit (Fig. 2.2(b)) (Kurowski et al. 2015) and single diaphragm parallel to the orifice exit (Fig. 2.2(a)) (Xiong et al. 2013). The generation of the synthetic jet was caused by the volume change in the cavity due to the fluctuation of the oscillating diaphragm. During the suction stroke, the diaphragm of the SJA will move downwards and causes the fluid from the surrounding medium to enter the cavity. During blowing stroke, the diaphragm of the SJA will move upwards, causing the fluid inside the cavity push out from the cavity through the small orifice in the form of a jet. When the fluid pass through the orifice during both suction and blowing stroke, a shear layer will form which causing a rolling vortex ring formed at the orifice (Zhou et al. 2010). The formation of synthetic jet is governed by some of the parameters such as actuator diaphragm parameters, actuator geometry parameters and the fluid domain parameters (Fig. 2.3). Besides than the actuator and fluid parameters, the synthetic jet can also be characterised by the non-dimensional parameters such as Reynolds number, Strouhal number, Stokes number and stroke ratio (Murugan et al. 2016).

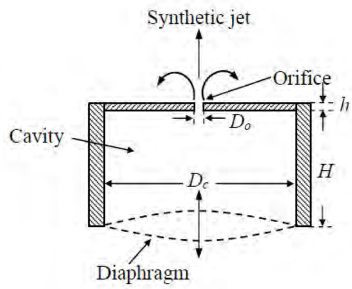
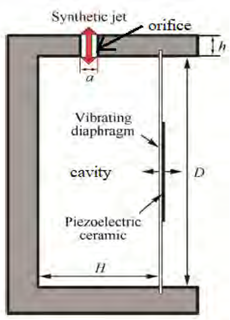


Figure 2.1: Schematic of general Synthetic Jet Actuator (Source: Zhou et al. 2015)

(a)



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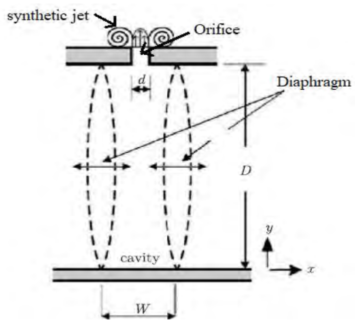

Figure 2.2: Schematic of Synthetic Jet Actuators with (a) single diaphragm (Source: Xiong et al. 2010) and (b) double diaphragm (Source: Kurowski et al. 2015).

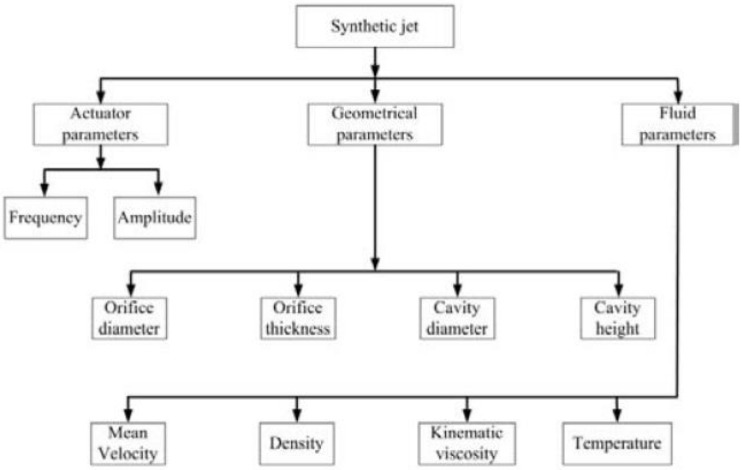

Figure 2.3: Synthetic jet formation parameters (Source: Murugan et al. 2016)

2.2 Synthetic Jet Actuator in Backward-facing Step

Many recent studies and researches had conducted the effect of the different in the location of the synthetic jet actuator in the backward-facing step. In the study done on the effect of the synthetic jet control on the separation, the simulation conducted by using unsteady coupled turbulence k-ω SST Reynolds-Averaged Navier-Stokes (URANS) equations with subsonic stream flow of Ma = 0.4 on the OA213 rotor airfoil. The oscillating diaphragm motion of the SJA on the airfoil was replaced with a sinusoidal velocity boundary condition with orifice width of 1%c, oscillatory frequency and momentum of 1.0 and 0.0007 respectively. In the simulation for the analysis of jet locations at 5%c, 15%c, 30%c, 45%c and 60%c, the results showed that at small AOA and high AOA, placing the SJA at 15%c and 5%c has the best effect on lift increment respectively. Besides, they also study the combination of jet array on the effect of the lift increment and the results showed that the jet arrays have a better effect on the lift increment compared to single jet where the lift increment and drag reduction could be