The Interaction between Synthetic Jet and Adverse Pressure Gradient Boundary Layer Flows

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Chapter 1 Introduction

Chapter 2 Experimental Arrangement

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Nomenclature

C_p	static pressure coefficient
d	membrane diameter (mm)
d_c	cavity diameter (mm)
d_o	orifice diameter (mm)
E	output voltage (V)
f	oscillation frequency (Hz)
H	shape factor, defined as $H = \delta^* / \theta$
h_c	cavity height (mm)
h_o	orifice height (mm)
p	dynamic pressure ($N \cdot m^{-2}$)
Re	Reynolds number
t	time (sec)
U_∞	free-stream velocity (ms^{-1})
u	mean component of velocity (ms^{-1})
u'	root-mean-square component of velocity (ms^{-1})

u_c	mean component of jet velocity on the centreline (ms^{-1})
u'_c	root-mean-square component of jet velocity on the centreline (ms^{-1})
x	distance in streamline direction (mm)
y	normal distance from plate surface (mm)
δ	distance from the surface at which the local velocity is 0.99 U_∞ (mm)
δ^*	displacement thickness (mm)
θ	momentum thickness (mm)
μ	coefficient of viscosity = 1.78×10^{-5} $kgm^{-1}\cdot sec^{-1}$
ρ	fluid density ($kg\cdot m^{-3}$)
Ω	resistance, ohm

Abstract

This research project aims to investigate the interaction between the synthetic jets and the separating flow in a boundary layer under adverse pressure gradient conditions. The thesis provides an understanding of how the jets work to modify the boundary layer flow structure and information for designing synthetic jet actuators.

To develop an understanding of the actuator operation, three actuators were first tested with variable frequencies and voltages under conditions of no cross-flow. At a fixed y/d_0 location, the relationships between the jet velocity and the forcing frequency and between the jet velocity and the forcing voltage were examined. It was found that the jet velocity increased with the increase of forcing voltage, whilst several peaks were observed in the jet velocity distributions with frequency. Furthermore, it was demonstrated that the peak velocity could occur at different locations relative to the actuator orifice, depending on the forcing frequency.

Experimental investigation to the effectiveness of the synthetic jet actuators were performed in a wind tunnel and measurements were taken in a boundary layer

under adverse pressure. Experimental results demonstrated that the boundary layer flow separation was effectively resisted by the synthetic jet actuation. The results also showed that the control effectiveness of synthetic jets might be more strongly affected by the forcing frequency than the forcing voltage, depending on the particular actuator characteristics. The results also indicated that synthetic jets might play dual roles; in resisting separation by increasing momentum near the wall and amplifying the natural frequencies in the flow.

The effectiveness of multiple jets in boundary layer separation control was investigated experimentally. When the actuators were operated individually, it was found that the performance of the actuator in the absence of cross-flow played a major role in determining the control effectiveness. For the same forcing frequency and forcing voltage, the effect of flow control was determined by locations of actuator. For multiple actuators, the control effect was increased relative to the interaction of individually operated actuator. Actuators located at different positions had their different 'most effective' forcing frequency. The results seem to indicate that the expected effect of flow control can be accomplished by varying forcing frequencies and voltages, but it may also be achieved by using different combined actuators. Generally, in combined actuators cases, the separation was controlled, with more effectiveness than individually operated actuators. In all cases, the boundary layer seems to approach the same downstream state, which indicates that both single and multiple actuators may have limited control effectiveness under the experimental conditions for present study for the cases considered.