AN EXPERIMENTAL INVESTIGATION OF TURBULENT BOUNDARY LAYER FLOW OVER SURFACE-MOUNTED CIRCULAR CAVITIES

(Spine Title: Turbulent Boundary Layer Flow over Circular Cavities)

(Thesis Format: Monograph)

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Engineering Science

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London, Ontario, Canada

November, 2005

ABSTRACT

The present work is an experimental investigation of turbulent boundary layer flow over surface mounted cavities of circular planform. Experiments were designed to develop a further understanding of the flows along cavity surfaces and their relationship to flows in the cavity wake. The link between the cavity surface flows and their corresponding acoustics is also sought along with an understanding for why flow asymmetry is noted at some configurations but not others. Velocity measurements acquired in the cavity wake using the hot-wire anemometry technique and surface pressure measurements collected at the cavity surfaces have extended previous knowledge of the link between the flow along cavity surfaces and the flow in the cavity wake. A frequency analysis of these time series data has revealed depth mode oscillations for deeper cavities along with possible evidence for cavity feedback resonance occurring at $h/D \approx 0.5$ not observed at other depths. It is suggested that this resonance may be a cause of the high level of flow asymmetry and cavity induced drag observed for this configuration. An experiment designed to apply controlled disturbances to the cavity flow for $h/D = 0.47$ has uncovered a reliable method for causing the asymmetric flow to be switched about the cavity stream-wise axis. Good agreement was found between the results of the present experiment and those previous, where they have existed.

Keywords: Cavity, circular, turbulent flow, boundary layer, hot-wire, wake flow, pressure measurements, microphone, wind tunnel, velocity profile, trailing vortex, oscillation, feedback resonance, depth mode, asymmetry, flow switch.

CO-AUTHORSHIP

This thesis was written under the supervision of my thesis advisor Dr. Eric Savory. The supervisor's role was to edit and provide comments on the work throughout the progress of the project.

DEDICATION

To my wife *Christen* for her patience, love and invaluable perspective.

ACKNOWLEDGEMENTS

Many people have been invaluable resources allowing the completion of this work. First of all, Prof. Eric Savory has provided incredibly detailed comments and advice based on wisdom and experience at all stages of this project. His support, even at the most difficult stages of the project, has been greatly appreciated.

Thank you to the people at the Boundary Layer Wind Tunnel Laboratory for allowing the use of the wind tunnel and other equipment for experiments, and to lab technician Stan Norman for his continued help.

Thank you to Prof. Gregory Kopp, for the use of his two-component hot-wire probe and for his help with this apparatus.

Thank you to the University Machine Shop for their advice and expertise in the manufacturing of the experimental models.

Thank you to the Engineering Electronics Shop for their patience and expertise when dealing with my many questions.

I would also like to thank the AFM Research Group for their constructive comments and physical help in the laboratory, especially M.E.Sc. candidates Tom Hering and Rita Patel.

Finally, I would like to thank the members of the examining board, in advance for their, patience and consideration in the reading of this thesis.

LIST OF SYMBOLS AND ABBREVIATIONS

ΔC_D	Incremental drag coefficient due to cavity presence
A	Dimensionless drag parameter (function of h/D)
A_n	Label for surface flow diagram attachment point
B	Dimensionless drag parameter (fuction of M)
BL	Boundary Layer
c	Speed of sound
C_n	Label for surface flow diagram circulation region
c_f	Local skin friction coefficient
Cp	Pressure coefficient ($Cp = \frac{\overline{p} - p_s}{q_0}$)
D	Cavity diameter
DAQ	Data Acquisition
δ	Boundary Layer thickness (based on $U = 0.99U_0$)
f	Frequency of oscillation
γ	Vortex sound pulse lag-time factor
h	Cavity depth
κ	Ratio of vortex convection velocity to free-stream velocity
l	Cavity stream-wise length
m	Oscillation mode number (integer)
M	Mach number
N	Mode number (positive integer)
ν	Kinematic viscosity
$\overline{p}$	Mean of measured pressure

p_s	Static pressure
PSD	Power Spectral Density
q_0	Free-stream dynamic pressure ($q_0 = 1/2\rho_a {U_0}^2$)
r	radial co-ordinate (origin at cavity centre)
ρ_a	Density of air
Re_D	Reynolds' number based on cavity diameter ($U_0 D/\nu$)
RMS	Root-mean-square (e.g. $\sqrt{\overline{u^2}}$)
τ	Wall shear stress
τ'	Shear stress across cavity mouth
θ	Angular co-ordinate centred at cavity centre
u	Fluctuating component of stream-wise velocity
U_0	Free-stream velocity
u_*	Friction velocity
$\overline{U}$	Stream-wise mean velocity
v	Fluctuating component of vertical velocity
V_n	Label for surface flow diagram focal node (vortex)
w	Fluctuating component of span-wise velocity
x	Stream-wise length co-ordinate (origin at cavity centre)
x_t	Stream-wise length co-ordinate (origin at working section entrance)
y	Vertical length co-ordinate (origin at cavity centre)
z	Lateral (span-wise) co-ordinate (origin at cavity centre)

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