



UNIVERSITI PUTRA MALAYSIA

**NUMERICAL STUDY OF TWO-DIMENSIONAL STEADY
INCOMPRESSIBLE LAMINAR FLOW OVER A BACKWARD-FACING
STEP AT MODERATE REYNOLDS NUMBER**

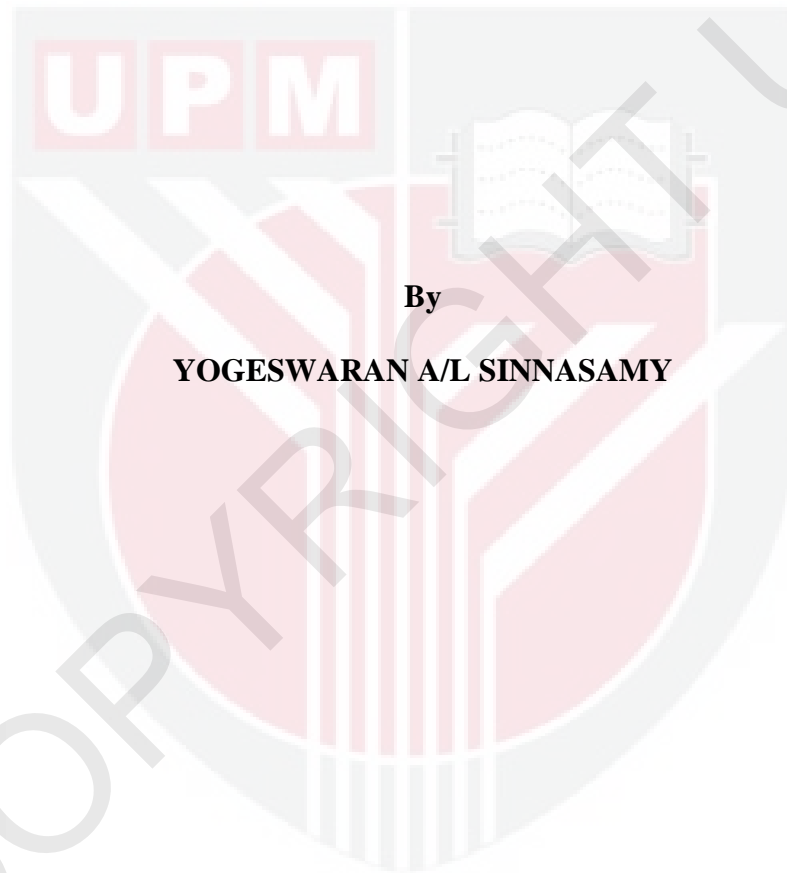
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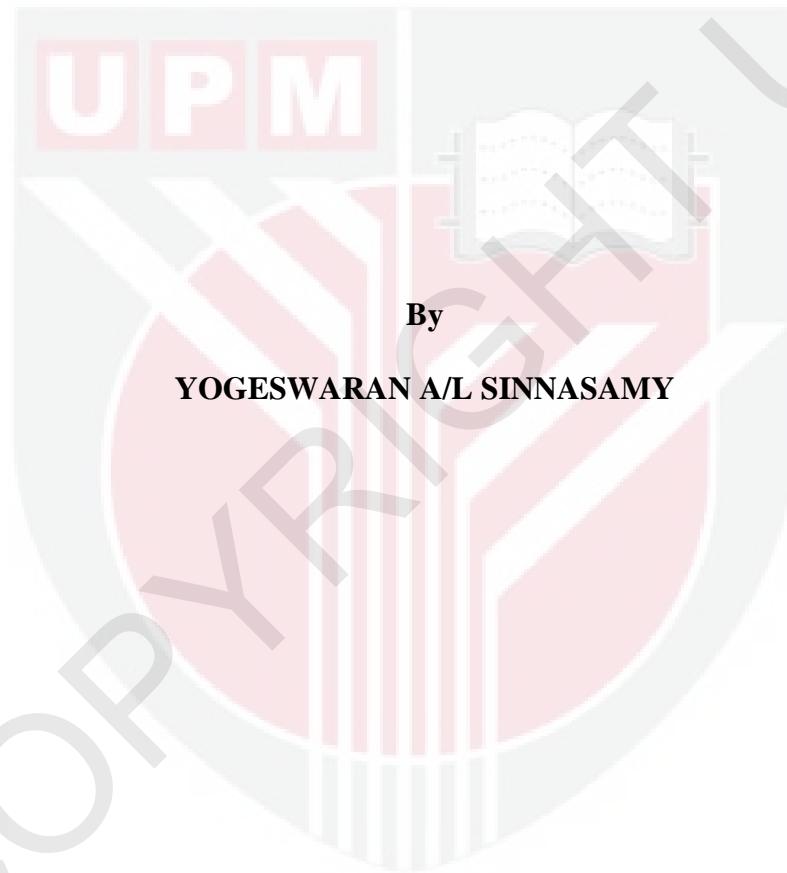
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By

YOGESWARAN A/L SINNASAMY

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

May 2012

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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May 2012

Chairman: Abdul Aziz bin Jaafar, PhD

Faculty: Engineering

This thesis describes the application of computational techniques to numerically investigate the 2D steady incompressible laminar flow over a backward-facing step moderate range of Reynolds number. This study comprises two parts; the influence of under relaxation factors (URFs) on convergence characteristics of solution for the transport equation and velocities (x - and z - directions) for the URFs values between 0.05 and 1.0 was examined. In the first part of study, a model of sudden expansion channel was constructed and simulations were performed by using PHOENICS; a Computational Fluid Dynamics (CFD) software. The values of error percentage of pressure and velocities variables of 430 simulations have been tabulated. Based on these values, graphical technique was applied to determine the best combinations of URFs for momentum and pressure correction equations have been conducted by concentrating on convergence criteria less than 1×10^{-6} and the assessment of interpolation solution for convective and diffusive terms in the transport equation. We found that for u_p between 0.1 and 1.0, the best combined URFs for velocities is

between 0.1 to 0.5 to achieve lower err (p) within shorter time period. Meanwhile, to achieve lower err (w) during the computation, the URFs are between 0.6 and 0.8. We also found that the recommended values of u_p to achieve lower err (u) during the computation are between 0.6 and 1.0. In this second part of study, a model of sudden expansion channel based on Erturk (2008) has been constructed. The streamlines-contours of each simulation have been plotted and main recirculation complex have been identified. The locations of the separation and reattachment points in the main reattachment zone and other recirculation zones on the bottom and upper surfaces of the sudden expansion channel were quantitatively determined. For range of Reynolds numbers between 100 and 3000, HYBRID and UPWIND schemes have been used and 60 simulations were performed. At lower range of Reynolds number between 100 and 500, 12 nonlinear schemes based on QUICK, FROMM and CUS scheme used to perform simulation and the streamlines of each simulation have been plotted and their main reattachment zone and other separation and reattachment zones were compared. The schemes used in this second part of study are SMART, HQUICK, UMIST, CHARM, VAN1, VAN2, OSPRE, VANALB, SUPBEE, MINMOD, KOREN and HCUS. It was found that the length of main reattachment zone is increasing when the Reynolds number is increased gradually from 100 to 1200. For beyond of $Re = 1200$, the flow exhibits more complex flow structure.

Abstraktesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagaimemenuhi sebahagian keperluan untuk ijazah Master Sains

**KAJIAN BERANGKA PEMBELAJARAN KE ATAS ALIRAN DUA
DIMENSI NYAH MAMPAT DAN MANTAP DALAM ALUR
PENGEMBANGAN MENDADAK PADA JULAT NILAI NOMBOR
REYNOLDS YANG SEDERHANA**

Oleh

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Pengerusi: Abdul Aziz Bin Jaafar, PhD

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Thesis ini menerangkan aplikasi teknik simulasi bagi kajian berangka yang melibatkan aliran 2D nyahmampat dan mantap ke atas tangam menghadap ke belakang pada julat nombor Reynolds yang sederhana. Kajian ini terbahagi kepada dua bahagian, iaitu pengaruh bawah faktor pengenduran ke atas ciri-ciri penumpuan bagi persamaan-persamaan yang melibatkan halaju pada arah x dan z bagi julat bawah faktor pengenduran di antara 0.05 dan 1.0. Dalam bahagian pertama kajian ini, sebuah model alur pengembangan mendadak diciptakan dalam simulasi dijalankan dengan menggunakan perisian PHOENICS Computational Fluid Dynamics. Nilai-nilai ralat bagi tekanan dan halaju yang diperolehi daripada kesemua 430 simulasi telah direkodkan. Berdasarkan pada graf-graf yang dihasilkan dengan menggunakan data-data yang diperolehi melalui simulasi-simulasi ini bagi persamaan momentum dan tekanan telah dikenalpasti yang mempunyai ciri penumpuan yang kurang daripada

1×10^{-6} dan penilaian keatas penyelesaian faktor-faktor konveksi dan difusi di dalam persamaan pengangkutan. Dalam bagian kedua ini, model alur pengembangan mendadak yang dihasilkan oleh Erturk (2008) telah dijadikan sebagai panduan untuk menghasilkan model dalam bagian ini. Garisan-garisan jet aliran bagi setiap simulasi telah diplotkan dan kawasan pusaran utama dikenal pasti bagi setiap plot yang dihasilkan. Kedudukan bagi titik-titik perpisah dan percantuman semula dalam kawasan pusaran utama dan lain-lain pusaran pada permukaan bawah dan atas permukaan-permukaan alur pengembangan mendadak ditentukan. Bagi julat nombor Reynolds yang di antara 100 dan 3000, sebanyak 60 simulasi telah dijalankan dengan menggunakan skema-skema HYBRID dan UPWIND. Bagi julat nombor Reynolds yang di antara 100 dan 500, skema-skema yang berasaskan QUICK, FROMM dan CUS telah digunakan. Untuk julat nombor Reynolds yang kecil ini, sebanyak 12 yang bersifat bukan linear telah digunakan. Bagi julat nombor Reynolds yang kecil iaitu di antara 100 dan 500, sebanyak 70 simulasi telah dijalankan dengan menggunakan skema-skema yang berikut; SMART, HQUICK, UMIST, CHARM, VAN1, VAN2, OSPRE, VANALB, SUPBEE, MINMOD, KOREN dan HCUS. Garisan-garisan jet aliran bagi setiap simulasi telah diplotkan dan kawasan percantuman utama dan kawasan-kawasan pusaran yang lain telah dibandingkan. Bagi setiap peningkatan bagi nombor Reynolds bermula daripada 100 sehingga 1200, didapati panjang bagi kawasan pusaran utama meningkat. Bagi nombor-nombor Reynolds yang lebih daripada 1200, didapati kawasan pusaran dan garisan-garisan jet aliran menunjukkan suatu situasi yang kompleks.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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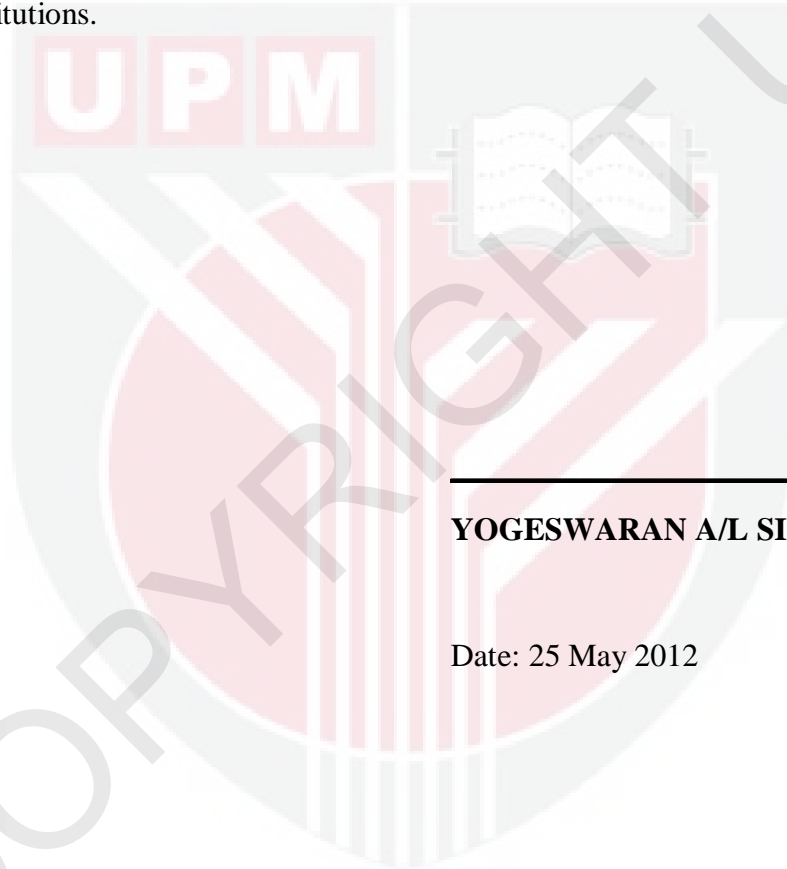
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DECLARATION

I declare that the thesis is my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously and currently is not submitted for any other degree at Universiti Putra Malaysia or other institutions.



YOGESWARAN A/L SINNASAMY

Date: 25 May 2012

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xix
CHAPTER	
1 INTRODUCTION	
1.1 Introduction	1
1.2 Schematic Diagram of BFS Flow Structure	2
1.3 Problem Statement and Research Methodologies	3
1.4 Aim and Objective of the Study	4
1.5 Layout of the Thesis	4
1.6 Contribution of Work	5
2 LITERATURE REVIEW	
2.1 Introduction	8
2.2 Description on Experimental Techniques	9
2.2.1 Laser-Doppler Anemometer (LDA)	9
2.2.2 Multi-element Hot-film Sensor (MHFS)	11
2.2.3 Electro-diffusion Principle Technique	12
2.2.4 Laser-Doppler Velocimeter (LDV)	13
2.2.5 Particle Image Velocimetry (PIV)	14
2.3 Numerical Investigations of BFS Flow	15
2.3.1 Numerical Investigations Based on BFS Models with <i>ER</i> Value Between 1.0 and 1.5	15
2.3.2 Numerical Investigations Based on BFS Models with <i>ER</i> Value Between 1.94 and 2.0	20
2.3.3 Numerical Investigations Based on BFS Models with <i>ER</i> Value Between 2.02 and 3.0	30
2.4 The Influence of Under Relaxation Factors on	34

Convergence Behavior

3.	RESEARCH METHODOLOGY	
3.1	Introduction	64
3.2	BFS Flow Model	65
3.2.1	BFS With $ER = 4.0$	65
3.2.2	BFS With $ER = 2.0$	66
3.3	Numerical Methods	66
3.3.1	Governing Equations of Motion	66
3.3.2	Solution Procedure of the SIMPLE Algorithm	72
3.3.3	Boundary Conditions	76
3.3.4	Computational Grid	76
3.4	Data Organization and Analysis	77
3.4.1	Test Cases	77
3.4.2	Schemes for Convection Discretization in PHOENICS	79
3.4.3	Convergence History	79
3.4.4	Grid Independent Study	79
3.4.5	Manipulation of Under-relaxation Factors	80
3.5	Summary	81
4.	RESULTS AND DISCUSSION	
4.1	Introduction	91
4.2	Validation of the Computational Approach	91
4.3	Assessment on Error Percentage of Pressure and Velocities	92
4.3.1	The Effect of u_p on the Trending of $err(p)$	94
4.3.2	The Effect of u_p on the Trending of $err(u)$	95
4.3.3	The Effect of u_p on the Trending of $err(w)$	96
4.4	Numerical Schemes	97
4.4.1	Linear Higher-Order Schemes	97
4.4.2	Non-linear Schemes Based on QUICK	98
4.4.3	Non-linear Schemes Based on FROMM	99
4.4.4	Non-linear Schemes Based on CUS	99
4.5	Reattachment Length (RL)	100
4.5.1	RL Obtained in Our Study Based on HY and UP Schemes for $100 \leq Re \leq 3000$	101
4.5.2	RL Obtained in Our Study on Non-linear Schemes Based on QUICK for $100 \leq Re \leq 500$	103
4.5.3	RL Obtained in Our Study on Non-linear Schemes Based on FROMM for $100 \leq Re \leq 500$	103

	4.5.4	RL Obtained in Our Study on Non-linear Schemes Based on CUS for $100 \leq Re \leq 500$	104
4.6		Comparison between Our Data of RL Based on HY Scheme with Experimental Data Available in the Literature	104
	4.6.1	Denham and Patrick	104
	4.6.2	Armaly	105
4.7		Comparison between Our Data of RL Based on HY Scheme with Computational Data Available in the Literature	106
	4.7.1	Lee and Mateescu	106
	4.7.2	Erturk	107
5.		CONCLUSION AND RECOMMENDATIONS	
	5.1	Introduction	125
	5.2	Conclusion	125
	5.3	Recommendation for future works	127
		REFERENCES	129
		APPENDICES	132
		BIODATA OF THE STUDENT	154