

**COMPRESSIBLE INVISCID FLOW:  
ONE-DIMENSIONAL  
HIGH-ORDER  
COMPACT METHOD  
USING EULER EQUATIONS APPROACH**

# COMPRESSIBLE INVISCID FLOW: ONE-DIMENSIONAL HIGH-ORDER COMPACT METHOD USING EULER EQUATIONS APPROACH

*Mahmod Abd Hakim Mohamad  
Yahaya Ramli  
Shahnor Basri  
Bambang Basuno  
Misbahul Muneer Abd Rahman*

  
Penerbit  
**UTHM**  
2018

© Penerbit UTHM  
First Published 2018

Copyright reserved. Reproduction of any articles, illustrations and content of this book in any form be it electronic, mechanical photocopy, recording or any other form without any prior written permission from The Publisher's Office of Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor is prohibited. Any negotiations are subjected to calculations of royalty and honorarium.

Perpustakaan Negara Malaysia Cataloguing—in—Publication Data

Mahmod Abd. Hakim Mohamad

COMPRESSIBLE INVISCID FLOW: ONE-DIMENSIONAL HIGH-ORDER COMPACT METHOD USING EULER EQUATIONS

APPROACH/ Mahmod Abd Hakim, Yahaya Ramli, Shahnor Basri, Bambang Basuno, Misbahul Muneer Abd Rahman.

ISBN 978-967-2183-17-4

1. Computational fluid dynamics. 2. Lagrange equations--Numerical solutions. 3. Differential equation--Data processing.

4. Government publications--Malaysia.

I. Yahya Ramli, Prof. Ir. II. Shahnor Basri, Prof. Dr. Ir.

III. Bambang Basuno. IV. Misbahul Muneer Abd. Rahman. Judul. 620.1064

Published by:  
Penerbit UTHM  
Universiti Tun Hussein Onn Malaysia  
86400 Parit Raja,  
Batu Pahat, Johor  
Tel: 07-453 8698/8529  
Fax: 07-453 6145

Website: <http://penerbit.uthm.edu.my>  
E-mail: [pt@uthm.edu.my](mailto:pt@uthm.edu.my)  
<http://e-bookstore.uthm.edu.my>

Penerbit UTHM is a member of  
Majlis Penerbitan Ilmiah Malaysia  
(MAPIM)

Printed by:  
PERCETAKAN IMPIAN SDN. BHD.  
No. 10, Jalan Bukit 8,  
Kawasan Perindustrian Miel,  
Bandar Baru Seri Alam,  
81750 Masai, Johor

---

# Dedicated

to

My beloved wife Hafsa,

Our daughters Sumaiyah, Najihah, Huzaifah & Usamah

All My Parents,

Hj. Mohamad and Hjh. Jawahil, Ir. Hj. Mohamed Makki and Hjh.  
Siti Rohani

For all their love, support, motivation and understanding

---

Mahmod Abd. Hakim Mohamad

# Table of Contents

<i>List of Nomenclature</i>	<i>xi</i>
<i>List of Abbreviations</i>	<i>xiii</i>
<i>Preface</i>	<i>xv</i>
<i>Acknowledgement</i>	<i>xvii</i>

## CHAPTER

### 1. INTRODUCTION

1.1 OVERVIEW	1
1.2 COMPUTATIONAL FLUID DYNAMICS	1
1.3 AUSM	2
1.4 APPROACH AND LIMITATION	2
1.5 LAYOUT OF THE BOOK	2
1.6 CONTRIBUTION OF INVESTIGATION	3

### 2. DEVELOPMENT OF HIGH-ORDER COMPACT SCHEMES

2.1 OVERVIEW	5
2.2 HIGH-ORDER COMPACT SCHEMES	5
2.3 UPWIND HIGH-ORDER COMPACT SCHEMES	8
2.4 HISTORICAL BACKGROUND OF AUSM SCHEME	9
2.5 FLUX SPLITTING TECHNIQUES	12
2.6 SUMMARY	14

### 3. NUMERICAL METHODS

3.1 OVERVIEW	15
3.2 EULER EQUATIONS	15
3.3 FINITE DIFFERENCE METHOD	16
3.3.1 Explicit method	18
3.3.2 Implicit method	19
3.3.3 Crank-Nicolson method	19
3.4 TRANSFORMATION OF EULER EQUATIONS	20
3.5 AN INTRODUCTION OF COMPACT DIFFERENCING	22
3.5.1 Simple example of compact difference approximation to the first derivative	22
3.5.2 Approximation to the second derivative	24
3.5.3 Compact upwind approximations to the first derivative	24