

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/275025575>

# Advanced Mathematics for Engineering and Applied Sciences

Book · February 2015

---

CITATIONS

0

READS

6,240

1 author:



William W. Guo

Central Queensland University

120 PUBLICATIONS 460 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Modelling for Geophysics and Earth Sciences [View project](#)



Dynamic E-Learning Systems Development [View project](#)

WILLIAM W. GUO

**ADVANCED  
MATHEMATICS FOR  
ENGINEERING AND  
APPLIED SCIENCES**

SECOND EDITION

ALWAYS LEARNING

PEARSON

# **Advanced Mathematics for Engineering and Applied Sciences**

**Second Edition**

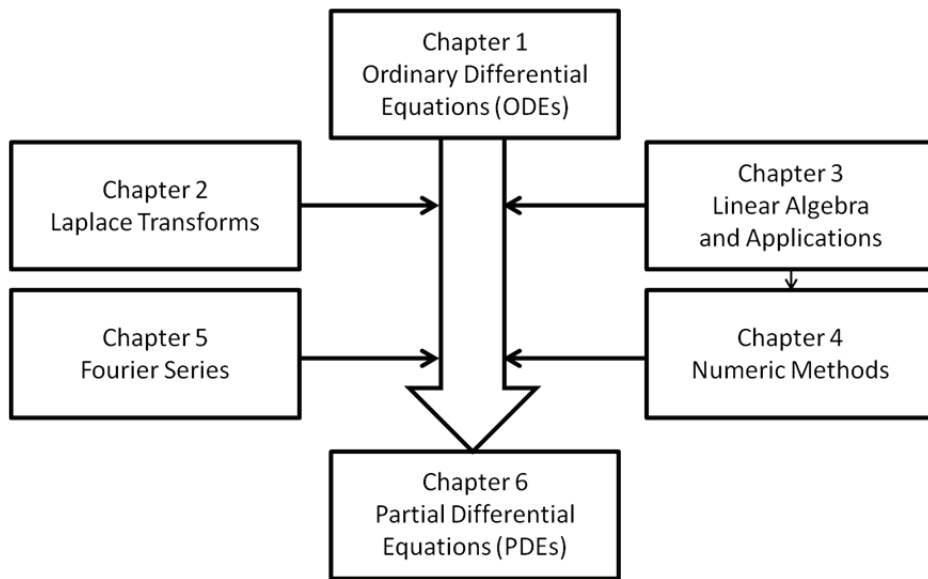
William W. Guo  
Central Queensland University Australia

# Preface

This book has been written as a designated textbook for university students studying engineering and some areas of applied sciences to continue knowledge building in mathematics after successfully completing a course in elementary calculus. Such an advanced mathematics course needs to cover a wide range of topics of applied mathematics for solving practical problems. For engineering students in US universities, the typical scheme of a comprehensive delivery of such an advanced mathematics course takes four consecutive semesters with at least 4 contact hours per week. Some good textbooks in advanced mathematics used in US universities are also popular in Australian universities for students studying engineering and some areas of applied sciences.

However, the advanced mathematics course in many Australian universities is taught over one semester. Choosing about a quarter of the contents from any US textbook in advanced mathematics for Australian students is always a difficult task in terms of maintaining the continuity and coherence among the chosen topics taught over a single semester. Recently I had direct experience in teaching two large groups of students in engineering mathematics at different levels. The feedback from many students revealed that they were dissatisfied with the discontinuity and incoherence among the chosen topics from the US-oriented textbook. Being a data processing scientist for 30 years of my career whose professional and research activities have been directly or indirectly associated with many areas of advanced mathematics, I took a similar view.

This book is designed to be delivered over one semester of 12–13 teaching weeks with at least 4 contact hours per week. As many scientific and engineering problems are associated with solving ordinary differential equations (ODEs) at an intermediate level and solving partial differential equations (PDEs) at an advanced level, the six chapters in this book together lead students from solving ODEs using various techniques to solving simple PDEs with knowledge and skills gained from the first five chapters. This logic flow is shown in the following diagram.



Based on good practices shared by other authors, my own experiences as an engineering student in the past, and then as a data processing scientist, this book has been written with the following general features:

- A cohesive logical flow that streamlines relevant topics together from solving ODEs to solving PDEs;
- A close connection between mathematical knowledge gained from completing previous math courses to the new topics in this book;
- A gradual increase in the level of difficulty with a smoother transition between two different themes in the same chapter and between two different chapters;
- Loose coupling among the middle chapters (Chapters 2–5) so that the chapters can be delivered almost independently;
- Providing many simple examples to make the book teachable for instructors and understandable for students through self learning;
- Providing real life applications of advanced mathematics in science and engineering.

For a semester-long course, some advanced topics in engineering mathematics, such as 2D/3D Fourier series and Fourier transforms, Bessel functions and Legendre functions, and computer-aided workshops, such as practicing numeric computation using *Matlab* or *Mathematica*, cannot be covered in 12 teaching weeks. Ideally these should be delivered in another subsequent mathematics course.

I am grateful to many engineering students at Central Queensland University who studied engineering mathematics courses in the 2013 academic year. It is the students' strong desire to learn mathematics, their active engagement with the teaching and learning processes, their earnest effort on both individual and group assignments, and their trust in my ability to assist them in achieving the best possible learning outcomes that inspired me to write this designated textbook in advanced mathematics for Australian engineering and science students. Their every endeavour deserves our special attention and full support as educators. Feedback, comments and suggestions on this first edition from students and other readers are most welcome and much appreciated. Special thanks go to the Customs Team at Pearson Australia for their great assistance to make the book published and available in a very short period of time.

Proof reading was done during the Christmas and New Year period by Harry, my son who has recently graduated with a Bachelor of Laws and a Bachelor of Commence from The University of Western Australia. His knowledge in laws offered little help in a mathematical context, but his advice brought changes to my writing style from 'scientific writing' for scientists towards 'plain writing' for junior undergraduate students. His criticism of my frequent use of long and complex sentences led to the significant reduction of such sentences in the final version. This book was written mostly on weekends and holidays during the past six months. I am deeply grateful to my wife Anna for her whole-hearted support throughout the entire journey.

William Guo  
January 2014

# A Note for Second Edition

It was a great success in improving student learning outcomes and experience by adopting the first edition of this textbook for the second-year engineering students in Semester 1 of 2014 at Central Queensland University Australia. The overwhelming positive feedback from so many students made this course “2014 CQUniversity Student Voice Commendation”. This honour is also a reflection of the tremendous effort on achieving quality teaching made by the teaching team during the semester.

Many students and colleagues have helped find out numerous typos in mathematical formulas, texts, tables, and diagrams since the book was released in February 2014. These found typos have been corrected in this new edition. According to the feedback from students through various communications, students like the structure, coverage of contents, and extensive use of worked examples throughout the text. As a result, this new edition keeps these aspects unchanged.

A number of students suggested leaving more spare spaces in the book so that students can take important notes nearby the key concepts or examples during a lecture, a tutorial, or even watching the recorded videos. Other students suggested using a colour scheme to better differentiate different (sub)sections and themes that were presented in the first edition using a simple black-white scheme. These two suggestions have been partly adopted in this new edition by both using dividing lines before or after a (sub)section/theme or an example and providing a spare space immediately after a (sub)section/theme or an example wherever possible. To keep the price of the book low, a grey scheme for (sub)headlines and dividing lines is used, instead of a colour scheme.

Two Appendixes are also included in this new edition to provide students with references to differentiations and integrations respectively.

Many students also expressed an interest in studying another mathematical course/unit after completing this one. It would be much better to have another elective mathematical course/unit for the students to keep advancing mathematical knowledge and problem solving skills in various engineering applications. This can only happen by the time when electives are made available in a new engineering curriculum. A few students suggested me writing a new mathematical textbook tailored to our first-year engineering students, just like this tailored book for our second-year students. This is certainly a great suggestion but also means a huge commitment. We might be able to make this happen in the future driven by our “can-do” approach.

My sincere appreciation goes to my students and colleagues at Central Queensland University for their encouragement and support all the time. This new version was done mostly on weekends in the past ten months. Once again I am very grateful to my wife Anna for her whole-hearted support throughout seemingly an endless journey.

Professor William Guo  
School of Engineering & Technology  
Central Queensland University Australia  
December 2014

# Table of Contents

Preface.....	i
Chapter 1 Ordinary Differential Equations.....	1
1.1 Essentials of ordinary differential equations.....	1
1.1.1 Concepts of ordinary differential equations (ODEs).....	1
1.1.2 Classification of ODEs.....	5
1.2 Direct integration & separation of variables.....	8
1.2.1 Direct integration.....	8
1.2.2 Separation of variables.....	11
1.2.3 Exact differential equations.....	14
1.3 First-order linear ODEs.....	18
1.3.1 Solving first-order linear ODEs by integrating factors.....	18
1.3.2 The structure of general solutions of linear ODEs.....	22
1.3.3 Bernoulli equations.....	25
1.4 Second-order linear ODEs.....	29
1.4.1 The structure of general solutions to second-order linear ODEs.....	29
1.4.2 Second-order constant-coefficient homogeneous linear ODEs.....	31
1.4.3 Second-order constant-coefficient inhomogeneous linear ODEs.....	35
1.5 Euler equations and systems of ODEs.....	43
1.5.1 Euler equations.....	43
1.5.2 Systems of ODEs.....	45
1.6 Applications of ODEs.....	49
1.6.1 Procedure of modelling and simulation.....	49
1.6.2 Applications of ODEs.....	50
Chapter 2 Laplace Transforms.....	67
2.1 Fundamentals of Laplace transforms.....	67
2.1.1 The concept of Laplace transforms.....	67
2.1.2 Laplace transforms of common functions.....	69

2.1.3 Properties of Laplace transforms .....	70
2.2 Inverse Laplace transforms .....	81
2.2.1 The concept of inverse Laplace transforms .....	81
2.2.2 Solving inverse Laplace transforms using partial fractions .....	82
2.3 The convolution theorem .....	85
2.3.1 The concept of convolution.....	85
2.3.2 The convolution theorem .....	86
2.4 Applications of Laplace transforms .....	91
2.4.1 Solving ODEs by Laplace transforms.....	91
2.4.2 Solving systems of ODEs by Laplace transforms.....	95
2.4.3* Transfer functions of linear systems .....	97
Chapter 3 Linear Algebra and Applications .....	101
3.1 Review of linear algebra .....	101
3.1.1 Fundamentals of matrices and vectors.....	101
3.1.2 Basic operations of matrices and vectors.....	104
3.1.3 Determinants and basic operations .....	110
3.1.4 The inverse of a matrix .....	116
3.2 Solving linear systems of equations.....	124
3.2.1 Linear systems, coefficient matrices, and augmented matrices .....	124
3.2.2 General properties of linear systems of equations .....	126
3.2.3 Solving linear systems by Cramer's rule .....	127
3.2.4 Solving linear systems by Gauss elimination .....	130
3.2.5 Solving linear systems using the inverse of a matrix.....	134
3.2.6 Solving linear systems by Gauss-Jordan elimination .....	138
3.3 Eigenvalues and eigenvectors .....	144
3.3.1 Eigenvalues .....	144
3.3.2 Eigenvectors.....	147
3.4 Applications of linear algebra .....	152
3.4.1 Solving engineering and science problems by matrix operations.....	152



3.4.2 Solving ODEs by eigenvalues and eigenvectors.....	160
Chapter 4 Numeric Methods .....	173
4.1 Introduction to numeric methods .....	173
4.1.1 The general procedure of numeric computation .....	173
4.1.2 Errors in numeric computation.....	174
4.1.3 Concepts of some numeric methods.....	175
4.2 Interpolation .....	179
4.2.1 Lagrange interpolations.....	179
4.2.2 Newton's divided difference interpolations .....	184
4.2.3 Cubic spline interpolations.....	188
4.3 Curve fitting by the least squares method .....	194
4.3.1 Concepts of curve fitting and the least squares method.....	194
4.3.2 Linear regression .....	195
4.3.3 Quadratic fitting .....	199
4.4 Numeric methods for solving ODEs.....	203
4.4.1 Euler methods.....	203
4.4.2 Runge-Kutta methods.....	207
*4.4.3 Numeric methods for systems of ODEs and higher-order ODEs .....	210
Chapter 5 Fourier Series.....	215
5.1 The concepts of Fourier series .....	215
5.2 Fourier sine and cosine series.....	224
5.2.1 Fourier series of even and odd functions .....	224
5.2.2 Half-range expansion .....	228
5.3 Fourier series of functions with any period.....	233
5.3.1 Fourier series of functions with period $p = 2L$ .....	233
5.3.2 Parseval's theorem .....	238
*5.3.3 Complex notation of Fourier series.....	239
5.4 Applications of Fourier series .....	242
5.4.1 Component analysis of periodic functions with Parseval's theorem .....	242

5.4.2 Solving ODEs using Fourier series.....	244
* 5.4.3 Principles of time-domain signal filtering by Fourier series .....	246
Chapter 6 Partial Differential Equations.....	253
6.1 Essentials of partial differential equations.....	253
6.1.1 Basic concepts of partial differential equations (PDEs) .....	253
6.1.2 Solutions of PDEs .....	254
6.2 Solving simple PDEs .....	259
General References .....	271
Appendix A: Differentiation .....	273
Appendix B: Integration.....	275

# General References

- [1] Birkhoff, G., and Rota, G. C. Ordinary Differential Equations, 4<sup>th</sup> Edition, USA, 1989.
- [2] Croft, A., and Davison, R. Mathematics for Engineers, 3<sup>rd</sup> Edition, Pearson, England, 2010.
- [3] Croft, A., Davison, R., Hargreaves, M., and Flint, J. Engineering Mathematics, 4<sup>th</sup> Edition, Pearson, England, 2013.
- [4] Gillett, P. Calculus and Analytic Geometry, D.C. Heath and Company, USA, 1981.
- [5] Guo, W.W. Magnetic petrophysics and density investigations of the Hamersley Province, Western Australia: implications for magnetic and gravity interpretation, The University of Western Australia, Perth, 1999.
- [6] Guo, W.W. and Xue, H. An incorporative statistic and neural approach for crop yield modelling and forecasting, *Neural Computing & Applications*, 2, 109–117, 2012.
- [7] Guo, W.W. A novel application of neural networks for instant iron-ore grade estimation, *Expert Systems with Applications*, 37, 8729–8735, 2010.
- [8] Guo, W.W., Li, M.M., Whymark, G. and Li, Z.X. Mutual complement between statistical and neural network approaches for rock magnetism data analysis, *Expert Systems with Applications*, 36, 9678–9682, 2009.
- [9] Hao, Z., Xie, G., Fang, W., Wang, G. Linear Algebra, 3<sup>rd</sup> Edition, Higher Education Press, Beijing, 2008.
- [10] Johnson, R., and Bhattacharyya, G. K. Statistics: Principles and Methods, 3<sup>rd</sup> Edition, Wiley, UAS, 1996.
- [11] Kreyszig, E. Advanced Engineering Mathematics, 10<sup>th</sup> Edition, Wiley, UAS, 2011.
- [12] Proakis, J. G., and Manolakis, D. G. Digital Signal Processing, 3<sup>rd</sup> Edition, Prentice Hall, USA, 1996.
- [13] Weiers, R. M. Introduction to Business Statistics, Duxbury, 2002.
- [14] Xue, L. Numeric Methods, Electronics Industry Press, Beijing, 2007.
- [15] Zauderer, E. Partial Differential Equations of Applied Mathematics, 3<sup>rd</sup> Edition, Wiley, USA, 2006.
- [16] Zhang, Y. Integral Transforms, 4<sup>th</sup> Edition, Higher Education Press, Beijing, 2003.
- [17] Zwillinger, D. Handbook of Differential Equations, 3<sup>rd</sup> Edition, Academic Press, USA, 1998.