EIGHTH EDITION

# Fluid Mechanics

FOX | McDONALD | PRITCHARD

## SI Version

# FLUID MECHANICS

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*Table G.1*

**SI Units and Prefixes[a]**

| SI Units | Quantity | Unit | SI Symbol | Formula |
|---|---|---|---|---|
| SI base units: | Length | meter | m | — |
| | Mass | kilogram | kg | — |
| | Time | second | s | — |
| | Temperature | kelvin | K | — |
| SI supplementary unit: | Plane angle | radian | rad | — |
| SI derived units: | Energy | joule | J | N · m |
| | Force | newton | N | kg · m/s$^2$ |
| | Power | watt | W | J/s |
| | Pressure | pascal | Pa | N/m$^2$ |
| | Work | joule | J | N · m |

| SI prefixes | Multiplication Factor | Prefix | SI Symbol |
|---|---|---|---|
| | 1 000 000 000 000 = $10^{12}$ | tera | T |
| | 1 000 000 000 = $10^{9}$ | giga | G |
| | 1 000 000 = $10^{6}$ | mega | M |
| | 1 000 = $10^{3}$ | kilo | k |
| | 0.01 = $10^{-2}$ | centi[b] | c |
| | 0.001 = $10^{-3}$ | milli | m |
| | 0.000 001 = $10^{-6}$ | micro | $\mu$ |
| | 0.000 000 001 = $10^{-9}$ | nano | n |
| | 0.000 000 000 001 = $10^{-12}$ | pico | p |

[a]Source: ASTM Standard for Metric Practice E 380-97, 1997.

[b]To be avoided where possible.

*Table G.2*

**Conversion Factors and Definitions**

| Fundamental Dimension | English Unit | Exact SI Value | Approximate SI Value |
|---|---|---|---|
| Length | 1 in. | 0.0254 m | — |
| Mass | 1 lbm | 0.453 592 37 kg | 0.454 kg |
| Temperature | 1°F | 5/9 K | — |

**Definitions:**

| | |
|---|---|
| Acceleration of gravity: | $g = 9.8066$ m/s$^2$ (= 32.174 ft/s$^2$) |
| Energy: | Btu (British thermal unit) ≡ amount of energy required to raise the temperature of 1 lbm of water 1°F (1 Btu = 778.2 ft · lbf) |
| | kilocalorie ≡ amount of energy required to raise the temperature of 1 kg of water 1 K(1 kcal = 4187 J) |
| Length: | 1 mile = 5280 ft; 1 nautical mile = 6076.1 ft = 1852 m (exact) |
| Power: | 1 horsepower ≡ 550 ft · lbf/s |
| Pressure: | 1 bar ≡ $10^5$ Pa |
| Temperature: | degree Fahrenheit, $T_F = \frac{9}{5}T_C + 32$ (where $T_C$ is degrees Celsius) |
| | degree Rankine, $T_R = T_F + 459.67$ |
| | Kelvin, $T_K = T_C + 273.15$ (exact) |
| Viscosity: | 1 Poise ≡ 0.1 kg/(m · s) |
| | 1 Stoke ≡ 0.0001 m$^2$/s |
| Volume: | 1 gal ≡ 231 in.$^3$ (1 ft$^3$ = 7.48 gal) |

**Useful Conversion Factors:**

| | | | |
|---|---|---|---|
| Length: | 1 ft = 0.3048 m | Power: | 1 hp = 745.7 W |
| | 1 in. = 25.4 mm | | 1 ft · lbf/s = 1.356 W |
| Mass: | 1 lbm = 0.4536 kg | | 1 Btu/hr = 0.2931 W |
| | 1 slug = 14.59 kg | Area | 1 ft$^2$ = 0.0929 m$^2$ |
| Force: | 1 lbf = 4.448 N | | 1 acre = 4047 m$^2$ |
| | 1 kgf = 9.807 N | Volume: | 1 ft$^3$ = 0.02832 m$^3$ |
| Velocity: | 1 ft/s = 0.3048 m/s | | 1 gal (US) = 0.003785 m$^3$ |
| | 1 ft/s = 15/22 mph | | 1 gal (US) = 3.785 L |
| | 1 mph = 0.447 m/s | Volume flow rate: | 1 ft$^3$/s = 0.02832 m$^3$/s |
| Pressure: | 1 psi = 6.895 kPa | | 1 gpm = $6.309 \times 10^{-5}$ m$^3$/s |
| | 1 lbf/ft$^2$ = 47.88 Pa | Viscosity (dynamic) | 1 lbf · s/ft$^2$ = 47.88 N · s/m$^2$ |
| | 1 atm = 101.3 kPa | | 1 g/(cm · s) = 0.1 N · s/m$^2$ |
| | 1 atm = 14.7 psi | | 1 Poise = 0.1 N · s/m$^2$ |
| | 1 in. Hg = 3.386 kPa | Viscosity (kinematic) | 1 ft$^2$/s = 0.0929 m$^2$/s |
| | 1 mm Hg = 133.3 Pa | | 1 Stoke = 0.0001 m$^2$/s |
| Energy: | 1 Btu = 1.055 kJ | | |
| | 1 ft · lbf = 1.356 J | | |
| | 1 cal = 4.187 J | | |

# Preface

## Introduction

This text was written for an introductory course in fluid mechanics. Our approach to the subject, as in all previous editions, emphasizes the physical concepts of fluid mechanics and methods of analysis that begin from basic principles. The primary objective of this text is to help users develop an orderly approach to problem solving. Thus we always start from governing equations, state assumptions clearly, and try to relate mathematical results to corresponding physical behavior. We continue to emphasize the use of control volumes to maintain a practical problem-solving approach that is also theoretically inclusive.

## Proven Problem-Solving Methodology

The Fox-McDonald-Pritchard solution methodology used in this text is illustrated in numerous Examples in each chapter. Solutions presented in the Examples have been prepared to illustrate good solution technique and to explain difficult points of theory. Examples are set apart in format from the text so that they are easy to identify and follow. Additional important information about the text and our procedures is given in the "Note to Student" in Section 1.1 of the printed text. We urge you to study this section carefully and to integrate the suggested procedures into your problem-solving and results-presentation approaches.

## Goals and Advantages of Using This Text

Complete explanations presented in the text, together with numerous detailed Examples, make this book understandable for students, freeing the instructor to depart from conventional lecture teaching methods. Classroom time can be used to bring in outside material, expand on special topics (such as non-Newtonian flow, boundary-layer flow, lift and drag, or experimental methods), solve example problems, or explain difficult points of assigned homework problems. In addition, the 51 Example *Excel* workbooks are useful for presenting a variety of fluid mechanics phenomena, especially the effects produced when varying input parameters. Thus each class period can be used in the manner most appropriate to meet student needs.

When students finish the fluid mechanics course, we expect them to be able to apply the governing equations to a variety of problems, including those they have not encountered previously. We particularly emphasize physical concepts throughout to help students model the variety of phenomena that occur in real fluid flow situations. Although we collect, for convenience, useful equations at the end of most chapters, we stress that our philosophy is to minimize the use of so-called magic formulas and emphasize the systematic and fundamental approach to problem solving. By following this format, we believe students develop confidence in their ability to apply the material and to find that they can reason out solutions to rather challenging problems.

The book is well suited for independent study by students or practicing engineers. Its readability and clear examples help build confidence. Answer to Selected Problems are included, so students may check their own work.

## Topical Coverage

The material has been selected carefully to include a broad range of topics suitable for a one- or two-semester course at the junior or senior level. We assume a background in rigid-body dynamics and mathematics through differential equations. A background in thermodynamics is desirable for studying compressible flow.

More advanced material, not typically covered in a first course, has been moved to the Web site (these sections are identified in the Table of Contents as being on the Web site). Advanced material is available to interested users of the book; available online, it does not interrupt the topic flow of the printed text.

Material in the printed text has been organized into broad topic areas:

- Introductory concepts, scope of fluid mechanics, and fluid statics (Chapters 1, 2, and 3)
- Development and application of control volume forms of basic equations (Chapter 4)
- Development and application of differential forms of basic equations (Chapters 5 and 6)
- Dimensional analysis and correlation of experimental data (Chapter 7)
- Applications for internal viscous incompressible flows (Chapter 8)
- Applications for external viscous incompressible flows (Chapter 9)
- Analysis of fluid machinery and system applications (Chapter 10)
- Analysis and applications of open-channel flows (Chapter 11)
- Analysis and applications of one- and two-dimensional compressible flows (Chapters 12 and 13)

Chapter 4 deals with analysis using both finite and differential control volumes. The Bernoulli equation is derived (in an optional subsection of Section 4.4) as an example application of the basic equations to a differential control volume. Being able to use the Bernoulli equation in Chapter 4 allows us to include more challenging problems dealing with the momentum equation for finite control volumes.

Another derivation of the Bernoulli equation is presented in Chapter 6, where it is obtained by integrating Euler's equation along a streamline. If an instructor chooses to delay introducing the Bernoulli equation, the challenging problems from Chapter 4 may be assigned during study of Chapter 6.

## Text Features

This edition incorporates a number of useful features:

- *Examples*: Fifty-one of the Examples include *Excel* workbooks, available online at the text Web site, making them useful for what-if analyses by students or by the instructor during class.
- *Case Studies*: Every chapter begins with a *Case Studies in Energy and the Environment*, each describing an interesting application of fluid mechanics in the area of renewable energy or of improving machine efficiencies. We have also retained from the previous edition chapter-specific *Case Studies*, which are now located at the end of chapters. These explore unusual or intriguing applications of fluid mechanics in a number of areas.
- *Chapter Summary and Useful Equations*: At the end of most chapters we collect for the student's convenience the most used or most significant equations of the chapter. Although this is a convenience, we cannot stress enough the need for the student to ensure an understanding of the derivation and limitations of each equation before its use!
- *Design Problems*: Where appropriate, we have provided open-ended design problems in place of traditional laboratory experiments. For those who do not have complete laboratory facilities, students could be assigned to work in teams to solve these problems. Design problems encourage students to spend more time exploring applications of fluid mechanics principles to the design of devices and systems. As in the previous edition, design problems are included with the end-of-chapter problems
- *Open-Ended Problems*: We have included many open-ended problems. Some are thought-provoking questions intended to test understanding of fundamental concepts, and some require creative thought, synthesis, and/or narrative discussion. We hope these problems will help instructors to encourage their students to think and work in more dynamic ways, as well as to inspire each instructor to develop and use more open-ended problems.
- *End-of-Chapter Problems*: Problems in each chapter are arranged by topic, and within each topic they generally increase in complexity or difficulty. This makes it easy for the instructor to assign homework problems at the appropriate difficulty level for each section of the book. For convenience, problems are now grouped according to the chapter section headings.

## New to This Edition

This edition incorporates a number of significant changes:

- *Case Studies in Energy and the Environment*: At the beginning of each chapter is a new case study. With these case studies we hope to provide a survey of the most interesting and novel applications of fluid mechanics with the goal of generating increasing amounts of the world's energy needs from renewable sources. The case studies are not chapter specific; that is, each one is not necessarily based on the material of the chapter in which it is presented. Instead, we hope these new case studies will serve as a stimulating narrative on the field of renewable energy for

CLASSIC VIDEO

*Classics!*

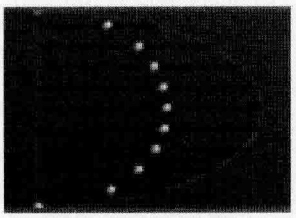
the reader and that they will provide material for classroom discussion. The case studies from the previous edition have been retained and relocated to the ends of chapters.

- *Demonstration Videos*: The "classic" NCFMF videos (approximately 20 minutes each, with Professor Ascher Shapiro of MIT, a pioneer in the field of biomedical engineering and a leader in fluid mechanics research and education, explaining and demonstrating fluid mechanics concepts) referenced in the previous edition have all been retained and supplemented with additional new brief videos (approximately 30 seconds to 2 minutes each) from a variety of sources.

  Both the classic and new videos are intended to provide visual aids for many of the concepts covered in the text, and are available at www.wiley.com/go/global/fox.

VIDEO

*New Videos!*



- *CFD*: The section on basic concepts of computational fluid dynamics in Chapter 5 now includes material on using the spreadsheet for numerical analysis of simple one- and two-dimensional flows; it includes an introduction to the Euler method.
- *Fluid Machinery*: Chapter 10 has been restructured, presenting material for pumps and fans first, followed by a section on hydraulic turbines. Propellers and wind turbines are now presented together. The section on wind turbines now includes the analysis of vertical axis wind turbines (VAWTs) in additional depth. A section on compressible flow machines has also been added to familiarize students with the differences in evaluating performance of compressible versus incompressible flow machines. The data in Appendix D on pumps and fans has been updated to reflect new products and new means of presenting data.
- *Open-Channel Flow*: In this edition we have completely rewritten the material on open-channel flows. An innovation of this new material compared to similar texts is that we have treated "local" effects, including the hydraulic jump before considering uniform and gradually varying flows. This material provides a sufficient background on the topic for mechanical engineers and serves as an introduction for civil engineers.
- *Compressible Flow*: The material in Chapter 13 has been restructured so that normal shocks are discussed before Fanno and Rayleigh flows. This was done because many college fluid mechanics curriculums cover normal shocks but not Fanno or Rayleigh flows.
- *New Homework Problems*: The eighth edition includes 1705 end-of-chapter problems. Many problems have been combined and contain multiple parts. Most have been structured so that all parts need not be assigned at once, and almost 25 percent of subparts have been designed to explore what-if questions. New or modified for this edition are some 518 problems, some created by a panel of instructors and subject matter experts. End-of-chapter homework problems are now grouped according to text sections.

## Resources for Instructors

The following resources are available to instructors who adopt this text. Visit the Web site at www.wiley.com/go/global/fox to register for a password.

- *Solutions Manual for Instructors*: The solutions manual for this edition contains a complete, detailed solution for all homework problems. Each solution is prepared in the same systematic way as the Example solutions in the printed text. Each solution begins from governing equations, clearly states assumptions, reduces governing equations to computing equations, obtains an algebraic result, and finally substitutes numerical values to calculate a quantitative answer. Solutions may be reproduced for classroom or library use, eliminating the labor of problem solving for the instructor who adopts the text.

The *Solutions Manual* is available online after the text is adopted. Visit the instructor section of the text's Web site at www.wiley.com/go/global/fox to request access to the password-protected online *Solutions Manual*.

- *Problem Key*: A list of all problems that are renumbered from the seventh edition of this title, to the eighth edition. There is no change to the actual solution to each of these problems.
- *PowerPoint Lecture Slides*: Lecture slides have been developed by Philip Pritchard, outlining the concepts in the book, and including appropriate illustrations and equations.
- *Image Gallery*: Illustrations from the text in a format appropriate to include in lecture presentations.

## Additional Resources

- *A Brief Review of Microsoft Excel*: Prepared by Philip Pritchard and included on the book Web site as Appendix H, this resource will coach students in setting up and solving fluid mechanics problems using *Excel* spreadsheets. Visit www.wiley.com/go/global/fox to access it.
- *Excel Files*: These *Excel* Files and add-ins are for use with specific Examples from the text.
- *Additional Text Topics*: PDF files for these topics/sections are available only on the Web site. These topics are highlighted in the text's table of contents and in the chapters as being available on the Web site.
- *Answers to Selected Problems*: Answers to odd-numbered problems are listed at the end of the book as a useful aid for student self-study.
- *Videos*: Many worthwhile videos are available on the book Web site to demonstrate and clarify the basic principles of fluid mechanics. When it is appropriate to view these videos to aid in understanding concepts or phenomena, an icon appears in the margin of the printed text; the Web site provides links to both classic and new videos, and these are also listed in Appendix C.

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- Concept Question Assignments: Questions developed by Jay Martin and John Mitchell of the University of Wisconsin-Madison to assess students' conceptual understanding of fluid mechanics.

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# *Acknowledgments*

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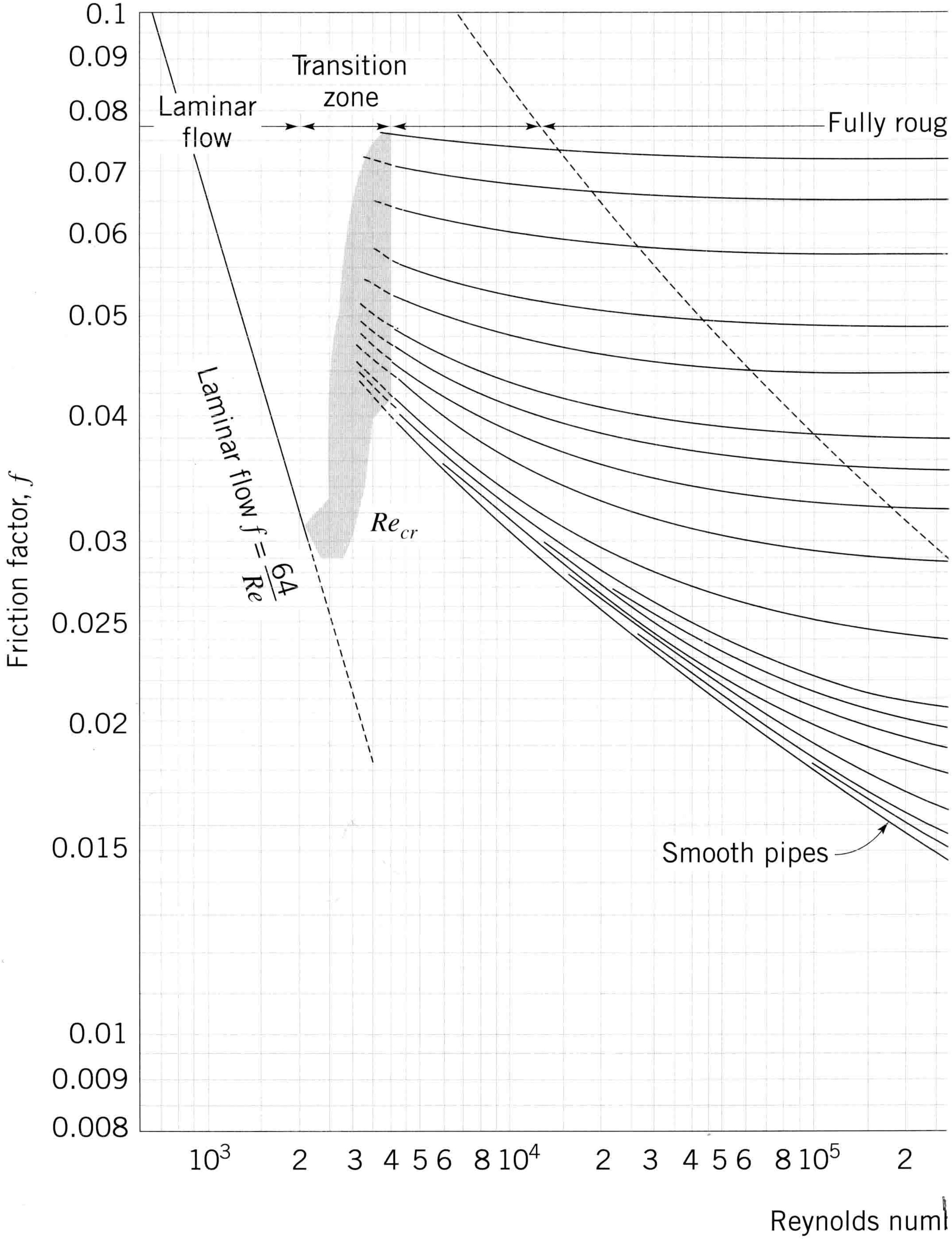
We look forward to continued interactions with these and other colleagues who use the book.

Professor Pritchard appreciates the unstinting support of his wife, Penelope, who is keenly aware of all the hours that went into the effort of preparing this edition.

We welcome suggestions and/or criticisms from interested users of this book.

Philip J. Pritchard
August 2010



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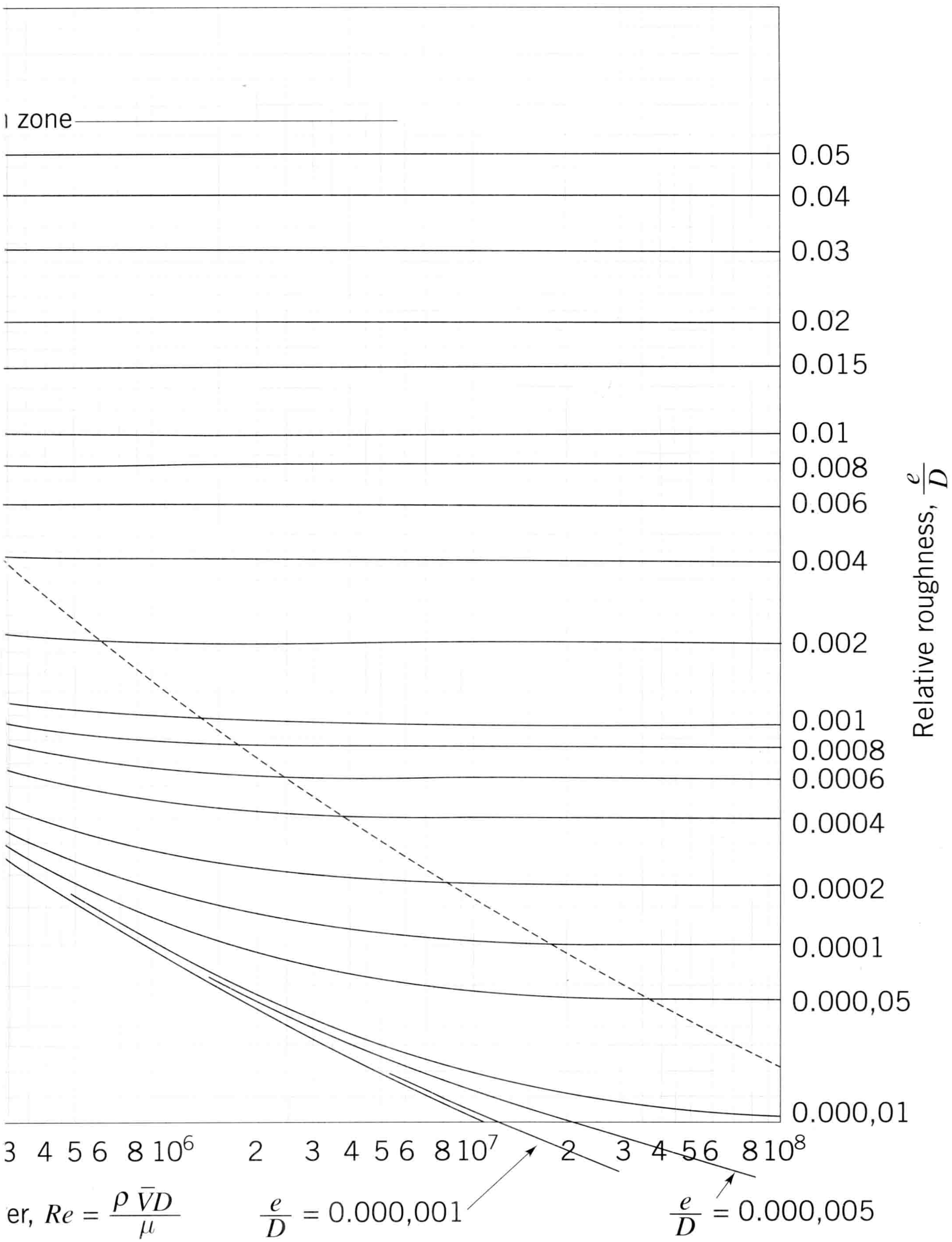

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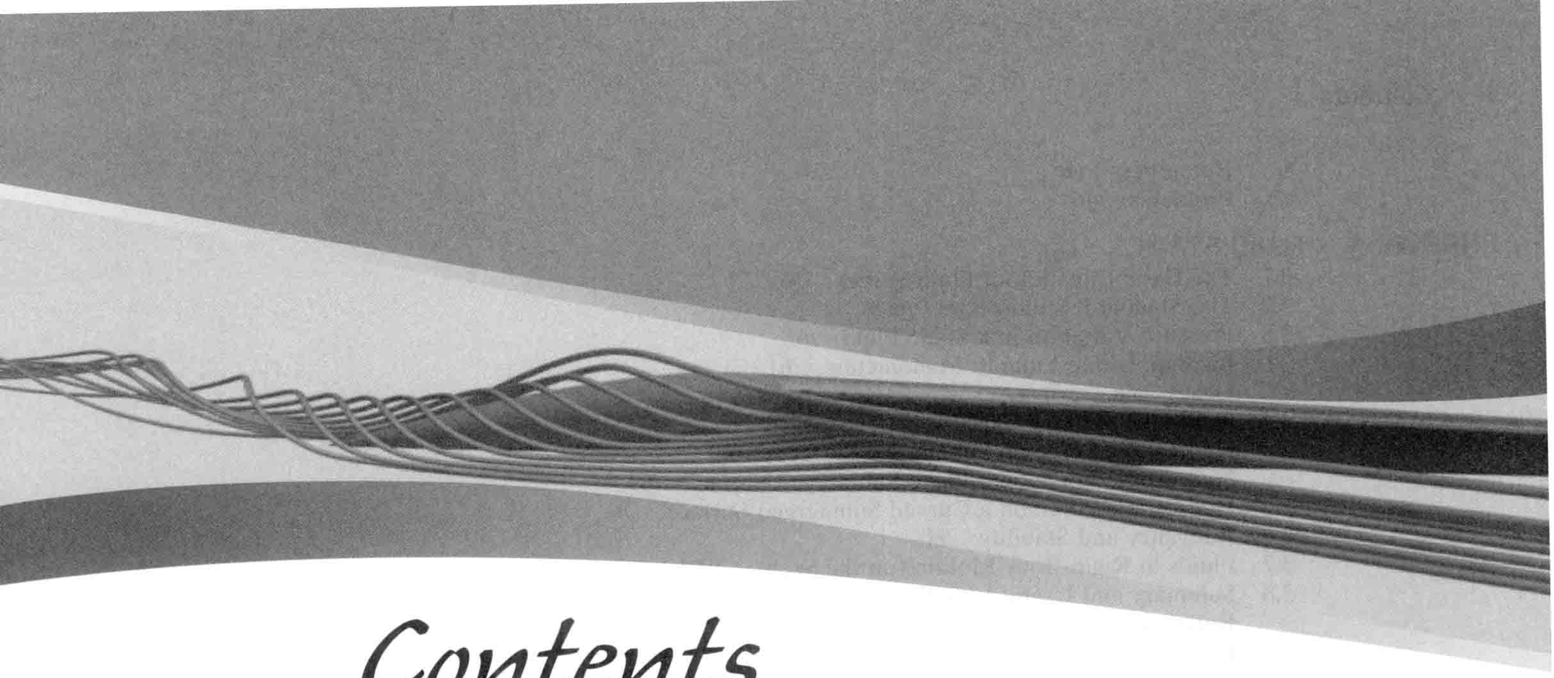

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