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Fluid Mechanics

Fourth Edition

Frank M. White
University of Rhode Island

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About the Author

Frank M. White is Professor of Mechanical and Ocean Engineering at the University of Rhode Island. He studied at Georgia Tech and M.I.T. In 1966 he helped found, at URI, the first department of ocean engineering in the country. Known primarily as a teacher and writer, he has received eight teaching awards and has written four textbooks on fluid mechanics and heat transfer.

During 1979–1990 he was editor-in-chief of the *ASME Journal of Fluids Engineering* and then served from 1991 to 1997 as chairman of the ASME Board of Editors and of the Publications Committee. He is a Fellow of ASME and in 1991 received the ASME Fluids Engineering Award. He lives with his wife, Jeanne, in Narragansett, Rhode Island.

To Jeanne

Preface

General Approach

The fourth edition of this textbook sees some additions and deletions but no philosophical change. The basic outline of eleven chapters and five appendices remains the same. The triad of integral, differential, and experimental approaches is retained and is approached in that order of presentation. The book is intended for an undergraduate course in fluid mechanics, and there is plenty of material for a full year of instruction. The author covers the first six chapters and part of Chapter 7 in the introductory semester. The more specialized and applied topics from Chapters 7 to 11 are then covered at our university in a second semester. The informal, student-oriented style is retained and, if it succeeds, has the flavor of an interactive lecture by the author.

Learning Tools

Approximately 30 percent of the problem exercises, and some fully worked examples, have been changed or are new. The total number of problem exercises has increased to more than 1500 in this fourth edition. The focus of the new problems is on practical and realistic fluids engineering experiences. Problems are grouped according to topic, and some are labeled either with an asterisk (especially challenging) or a computer-disk icon (where computer solution is recommended). A number of new photographs and figures have been added, especially to illustrate new design applications and new instruments.

Professor John Cimbala, of Pennsylvania State University, contributed many of the new problems. He had the great idea of setting *comprehensive problems* at the end of each chapter, covering a broad range of concepts, often from several different chapters. These comprehensive problems grow and recur throughout the book as new concepts arise. Six more open-ended design projects have been added, making 15 projects in all. The projects allow the student to set sizes and parameters and achieve good design with more than one approach.

An entirely new addition is a set of 95 multiple-choice problems suitable for preparing for the Fundamentals of Engineering (FE) Examination. These FE problems come at the end of Chapters 1 to 10. Meant as a realistic practice for the actual FE Exam, they are engineering problems with five suggested answers, all of them plausible, but only one of them correct.

New to this book, and to any fluid mechanics textbook, is a special appendix, Appendix E, Introduction to the Engineering Equation Solver (EES), which is keyed to many examples and problems throughout the book. The author finds EES to be an extremely attractive tool for applied engineering problems. Not only does it solve arbitrarily complex systems of equations, written in any order or form, but also it has built-in property evaluations (density, viscosity, enthalpy, entropy, etc.), linear and nonlinear regression, and easily formatted parameter studies and publication-quality plotting. The author is indebted to Professors Sanford Klein and William Beckman, of the University of Wisconsin, for invaluable and continuous help in preparing this EES material. The book is now available with or without an EES problems disk. The EES engine is available to adopters of the text with the problems disk.

Another welcome addition, especially for students, is Answers to Selected Problems. Over 600 answers are provided, or about 43 percent of all the regular problem assignments. Thus a compromise is struck between sometimes having a specific numerical goal and sometimes directly applying yourself and hoping for the best result.

Content Changes

There are revisions in every chapter. Chapter 1—which is purely introductory and could be assigned as reading—has been toned down from earlier editions. For example, the discussion of the fluid acceleration vector has been moved entirely to Chapter 4. Four brief new sections have been added: (1) the uncertainty of engineering data, (2) the use of EES, (3) the FE Examination, and (4) recommended problem-solving techniques.

Chapter 2 has an improved discussion of the stability of floating bodies, with a fully derived formula for computing the metacentric height. Coverage is confined to static fluids and rigid-body motions. An improved section on pressure measurement discusses modern microsensors, such as the fused-quartz bourdon tube, micromachined silicon capacitive and piezoelectric sensors, and tiny (2 mm long) silicon resonant-frequency devices.

Chapter 3 tightens up the energy equation discussion and retains the plan that Bernoulli's equation comes *last,* after control-volume mass, linear momentum, angular momentum, and energy studies. Although some texts begin with an entire chapter on the Bernoulli equation, this author tries to stress that it is a dangerously restricted relation which is often misused by both students and graduate engineers.

In Chapter 4 a few inviscid and viscous flow examples have been added to the basic partial differential equations of fluid mechanics. More extensive discussion continues in Chapter 8.

Chapter 5 is more successful when one selects scaling variables before using the pi theorem. Nevertheless, students still complain that the problems are too ambiguous and lead to too many different parameter groups. Several problem assignments now contain a few hints about selecting the repeating variables to arrive at traditional pi groups.

In Chapter 6, the "alternate forms of the Moody chart" have been resurrected as problem assignments. Meanwhile, the three basic pipe-flow problems—pressure drop, flow rate, and pipe sizing—can easily be handled by the EES software, and examples are given. Some newer flowmeter descriptions have been added for further enrichment. Chapter 7 has added some new data on drag and resistance of various bodies, notably biological systems which adapt to the flow of wind and water.

Chapter 8 picks up from the sample plane potential flows of Section 4.10 and plunges right into inviscid-flow analysis, especially aerodynamics. The discussion of numerical methods, or computational fluid dynamics (CFD), both inviscid and viscous, steady and unsteady, has been greatly expanded. Chapter 9, with its myriad complex algebraic equations, illustrates the type of examples and problem assignments which can be solved more easily using EES. A new section has been added about the suborbital X-33 and VentureStar vehicles.

In the discussion of open-channel flow, Chapter 10, we have further attempted to make the material more attractive to civil engineers by adding real-world comprehensive problems and design projects from the author's experience with hydropower projects. More emphasis is placed on the use of friction factors rather than on the Manning roughness parameter. Chapter 11, on turbomachinery, has added new material on compressors and the delivery of gases. Some additional fluid properties and formulas have been included in the appendices, which are otherwise much the same.

Supplements

The all new **Instructor's Resource CD** contains a PowerPoint presentation of key text figures as well as additional helpful teaching tools. The list of films and videos, formerly App. C, is now omitted and relegated to the **Instructor's Resource CD.**

The **Solutions Manual** provides complete and detailed solutions, including problem statements and artwork, to the end-of-chapter problems. It may be photocopied for posting or preparing transparencies for the classroom.

EES Software

The Engineering Equation Solver (EES) was developed by Sandy Klein and Bill Beckman, both of the University of Wisconsin—Madison. A combination of equation-solving capability and engineering property data makes EES an extremely powerful tool for your students. EES (pronounced "ease") enables students to solve problems, especially design problems, and to ask "what if" questions. EES can do optimization, parametric analysis, linear and nonlinear regression, and provide publication-quality plotting capability. Simple to master, this software allows you to enter equations in any form and in any order. It automatically rearranges the equations to solve them in the most efficient manner.

EES is particularly useful for fluid mechanics problems since much of the property data needed for solving problems in these areas are provided in the program. Air tables are built-in, as are psychometric functions and Joint Army Navy Air Force (JANAF) table data for many common gases. Transport properties are also provided for all substances. EES allows the user to enter property data or functional relationships written in Pascal, C, C++, or Fortran. The EES engine is available free to qualified adopters via a password-protected website, to those who adopt the text with the problems disk. The program is updated every semester.

The EES software problems disk provides examples of typical problems in this text. Problems solved are denoted in the text with a disk symbol. Each fully documented solution is actually an EES program that is run using the EES engine. Each program provides detailed comments and on-line help. These programs illustrate the use of EES and help the student master the important concepts without the calculational burden that has been previously required.

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