5th Edition

INTRODUCTION TO Fluid Mechanics

YOUNG | MUNSON | OKIISHI | HUEBSCH

SI Version

Fifth Edition

Introduction to Fluid Mechanics

International Student Version

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■ **TABLE 1.2**

Conversion Factors from BG Units to SI Units[a]

	To convert from	to	Multiply by
Acceleration	ft/s^2	m/s^2	3.048 E − 1
Area	ft^2	m^2	9.290 E − 2
Density	$slugs/ft^3$	kg/m^3	5.154 E + 2
Energy	Btu	J	1.055 E + 3
	ft·lb	J	1.356
Force	lb	N	4.448
Length	ft	m	3.048 E − 1
	in.	m	2.540 E − 2
	mile	m	1.609 E + 3
Mass	slug	kg	1.459 E + 1
Power	ft·lb/s	W	1.356
	hp	W	7.457 E + 2
Pressure	in. Hg (60 °F)	N/m^2	3.377 E + 3
	lb/ft^2 (psf)	N/m^2	4.788 E + 1
	$lb/in.^2$ (psi)	N/m^2	6.895 E + 3
Specific weight	lb/ft^3	N/m^3	1.571 E + 2
Temperature	°F	°C	$T_C = (5/9)(T_F - 32°)$
	°R	K	5.556 E − 1
Velocity	ft/s	m/s	3.048 E − 1
	mi/hr (mph)	m/s	4.470 E − 1
Viscosity (dynamic)	$lb \cdot s/ft^2$	$N \cdot s/m^2$	4.788 E + 1
Viscosity (kinematic)	ft^2/s	m^2/s	9.290 E − 2
Volume flowrate	ft^3/s	m^3/s	2.832 E − 2
	gal/min (gpm)	m^3/s	6.309 E − 5

[a]If more than four-place accuracy is desired, refer to Appendix E.

■ TABLE 1.3

Conversion Factors from SI Units to BG Units[a]

	To convert from	to	Multiply by
Acceleration	m/s^2	ft/s^2	3.281
Area	m^2	ft^2	1.076 E + 1
Density	kg/m^3	$slugs/ft^3$	1.940 E − 3
Energy	J	Btu	9.478 E − 4
	J	ft·lb	7.376 E − 1
Force	N	lb	2.248 E − 1
Length	m	ft	3.281
	m	in.	3.937 E + 1
	m	mile	6.214 E − 4
Mass	kg	slug	6.852 E − 2
Power	W	ft·lb/s	7.376 E − 1
	W	hp	1.341 E − 3
Pressure	N/m^2	in. Hg (60 °F)	2.961 E − 4
	N/m^2	lb/ft^2 (psf)	2.089 E − 2
	N/m^2	$lb/in.^2$ (psi)	1.450 E − 4
Specific weight	N/m^3	lb/ft^3	6.366 E − 3
Temperature	°C	°F	$T_F = 1.8\ T_C + 32°$
	K	°R	1.800
Velocity	m/s	ft/s	3.281
	m/s	mi/hr (mph)	2.237
Viscosity (dynamic)	$N \cdot s/m^2$	$lb \cdot s/ft^2$	2.089 E − 2
Viscosity (kinematic)	m^2/s	ft^2/s	1.076 E + 1
Volume flowrate	m^3/s	ft^3/s	3.531 E + 1
	m^3/s	gal/min (gpm)	1.585 E + 4

[a]If more than four-place accuracy is desired, refer to Appendix E.

About the Authors

Donald F. Young, Anson Marston Distinguished Professor Emeritus in Engineering, is a faculty member in the Department of Aerospace Engineering and Engineering Mechanics at Iowa State University. Dr. Young received his B.S. degree in mechanical engineering, his M.S. and Ph.D. degrees in theoretical and applied mechanics from Iowa State, and has taught both undergraduate and graduate courses in fluid mechanics for many years. In addition to being named a Distinguished Professor in the College of Engineering, Dr. Young has also received the Standard Oil Foundation Outstanding Teacher Award and the Iowa State University Alumni Association Faculty Citation. He has been engaged in fluid mechanics research for more than 45 years, with special interests in similitude and modeling and the interdisciplinary field of biomedical fluid mechanics. Dr. Young has contributed to many technical publications and is the author or coauthor of two textbooks on applied mechanics. He is a Fellow of the American Society of Mechanical Engineers.

Bruce R. Munson, Professor Emeritus of Engineering Mechanics, has been a faculty member at Iowa State University since 1974. He received his B.S. and M.S. degrees from Purdue University and his Ph.D. degree from the Aerospace Engineering and Mechanics Department of the University of Minnesota in 1970.

From 1970 to 1974, Dr. Munson was on the mechanical engineering faculty of Duke University. From 1964 to 1966, he worked as an engineer in the jet engine fuel control department of Bendix Aerospace Corporation, South Bend, Indiana.

Dr. Munson's main professional activity has been in the area of fluid mechanics education and research. He has been responsible for the development of many fluid mechanics courses for studies in civil engineering, mechanical engineering, engineering science, and agricultural engineering and is the recipient of an Iowa State University Superior Engineering Teacher Award and the Iowa State University Alumni Association Faculty Citation.

He has authored and coauthored many theoretical and experimental technical papers on hydrodynamic stability, low Reynolds number flow, secondary flow, and the applications of viscous incompressible flow. He is a member of the American Society of Mechanical Engineers (ASME), the American Physical Society, and the American Society for Engineering Education.

Theodore H. Okiishi, Associate Dean of Engineering and past Chair of Mechanical Engineering at Iowa State University, has taught fluid mechanics courses there since 1967. He received his undergraduate and graduate degrees at Iowa State.

From 1965 to 1967, Dr. Okiishi served as a U.S. Army officer with duty assignments at the National Aeronautics and Space Administration Lewis Research Center, Cleveland, Ohio, where he participated in rocket nozzle heat transfer research, and at the Combined Intelligence Center, Saigon, Republic of South Vietnam, where he studied seasonal river flooding problems.

Professor Okiishi is active in research on turbomachinery fluid dynamics. He and his graduate students and other colleagues have written a number of journal articles based on their studies. Some of these projects have involved significant collaboration with government and industrial laboratory researchers with one technical paper winning the ASME Melville Medal.

Dr. Okiishi has received several awards for teaching. He has developed undergraduate and graduate courses in classical fluid dynamics as well as the fluid dynamics of turbomachines.

He is a licensed professional engineer. His technical society activities include having been chair of the board of directors of the ASME International Gas Turbine Institute. He is a fellow member of the ASME and the technical editor of the *Journal of Turbomachinery.*

Wade W. Huebsch has been a faculty member in the Department of Mechanical and Aerospace Engineering at West Virginia University (WVU) since 2001. He received his B.S. degree in aerospace engineering from San Jose State University where he played college baseball. He received his M.S. degree in mechanical engineering and his Ph.D. in aerospace engineering from Iowa State University in 2000.

Dr. Huebsch specializes in computational fluid dynamics research and has authored multiple journal articles in the areas of aircraft icing, roughness-induced flow phenomena, and boundary layer flow control. He has taught both undergraduate and graduate courses in fluid mechanics and has developed a new undergraduate course in computational fluid dynamics. He has received multiple teaching awards such as Outstanding Teacher and Teacher of the Year from the College of Engineering and Mineral Resources at WVU as well as the Ralph R. Teetor Educational Award from Society of Automotive Engineers. He was also named as the Young Researcher of the Year from WVU. He is a member of the American Institute of Aeronautics and Astronautics, the Sigma Xi research society, the SAE, and the American Society of Engineering Education.

Preface

Introduction to Fluid Mechanics, Fifth Edition, is an abridged version of a more comprehensive treatment found in *Fundamentals of Fluid Mechanics* by Munson, Young, Okiishi, and Huebsch. Although this latter work continues to be successfully received by students and colleagues, it is a large volume containing much more material than can be covered in a typical one-semester undergraduate fluid mechanics course. A consideration of the numerous fluid mechanics texts that have been written during the past several decades reveals that there is a definite trend toward larger and larger books. This trend is understandable because the knowledge base in fluid mechanics has increased, along with the desire to include a broader scope of topics in an undergraduate course. Unfortunately, one of the dangers in this trend is that these large books can become intimidating to students who may have difficulty, in a beginning course, focusing on basic principles without getting lost in peripheral material. It is with this background in mind that the authors felt that a shorter but comprehensive text, covering the basic concepts and principles of fluid mechanics in a modern style, was needed. In this abridged version there is still more than ample material for a one-semester undergraduate fluid mechanics course. We have made every effort to retain the principal features of the original book while presenting the essential material in a more concise and focused manner that will be helpful to the beginning student.

This fifth edition has been prepared by the authors after several years of using the previous editions for an introductory course in fluid mechanics. Based on this experience, along with suggestions from reviewers, colleagues, and students, we have made a number of changes and additions in this new edition.

New to This Edition

In addition to the continual effort of updating the scope of the material presented and improving the presentation of all of the material, the following items are new to this edition.

With the widespread use of new technologies involving the web, DVDs, digital cameras, and the like, there are increasing use and appreciation of the variety of visual tools available for learning. After all, fluid mechanics can be a very visual topic. This fact has been addressed in the new edition by the inclusion of numerous new illustrations, graphs, photographs, and videos.

Illustrations: The book contains 148 ***new*** illustrations and graphs, bringing the total number to 890. These illustrations range from simple ones that help illustrate a basic concept or equation to more complex ones that illustrate practical applications of fluid mechanics in our everyday lives.

Photographs: The book contains 224 ***new*** photographs, bringing the total number to 240. Some photos involve situations that are so common to us that we probably never stop to realize how fluids are involved in them. Others involve new and novel situations that are still baffling to us. The photos are also used to help the reader better understand the basic concepts and examples discussed.

Videos: The video library for the book has been significantly enhanced by the addition of 76 ***new*** videos directly related to the text material, bringing the total number to 152. They illustrate many of the interesting and practical applications of real-world fluid phenomena. In addition to being located at the appropriate places within the text, they are all listed, each with an appropriate thumbnail photo, in a ***new*** video index. In the electronic version of the book, the videos can be selected directly from this index.

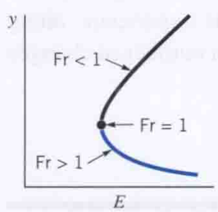
Examples: The book contains several ***new*** example problems that involve various fluid flow fundamentals. These examples also incorporate PtD (Prevention through Design) discussion material. The PtD project, under the direction of the National Institute for Occupational Safety and Health, involves, in part, the use of textbooks to encourage the proper design and use of workday equipment and material so as to reduce accidents and injuries in the workplace.

List of equations: Each chapter ends with a ***new*** summary of the most important equations in the chapter.

Problems: The book contains approximately 273 ***new*** homework problems, bringing the total number to 919. The print version of the book contains all the even-numbered problems; all the problems (even and odd numbered) are contained on the book's web site, www.wiley.com/go/global/young. There are several ***new*** problems in which the student is asked to find a photograph or image of a particular flow situation and write a paragraph describing it. In addition, each chapter contains ***new*** Lifelong Learning Problems (i.e., one aspect of the lifelong learning as interpreted by the authors) that ask the student to obtain information about a given new flow concept and to write about it.

Key Features

Illustrations, Photographs, and Videos



Fluid mechanics has always been a "visual" subject—much can be learned by viewing various aspects of fluid flow. In this new edition we have made several changes to reflect the fact that with new advances in technology, this visual component is becoming easier to incorporate into the learning environment, for both access and delivery, and is an important component to the learning of fluid mechanics. Thus, approximately 372 ***new*** photographs and illustrations have been added to the book. Some of these are within the text material; some are used to enhance the example problems; and some are included as marginal figures of the type shown in the left margin to more clearly illustrate various points discussed in the text. In addition, 76 ***new*** video segments have been added, bringing the total number of video segments to 152. These video segments illustrate many interesting and practical applications of real-world fluid phenomena. Many involve ***new*** CFD (computational fluid dynamics) material. Each video segment is identified at the appropriate location in the text material by a video icon and thumbnail photograph of the type shown in the left margin. Each video segment has a separate associated text description of what is shown in the video. There are many homework problems that are directly related to the topics in the videos.

V1.5 Floating razor blade

Examples

One of our aims is to represent fluid mechanics as it really is—an exciting and useful discipline. To this end, we include analyses of numerous everyday examples of fluid-flow phenomena to which students and faculty can easily relate. In the fifth edition 163 examples are presented that provide detailed solutions to a variety of problems. Several of the examples are new to this edition. Many of the examples have been extended to illustrate what happens if one or more of the parameters is changed. This gives the user a better feel for some of the basic principles involved. In addition, many of the examples contain *new* photographs of the actual device or item involved in the example. Also, all the examples are outlined and carried out with the problem-solving methodology of "Given, Find, Solution, and Comment" as discussed in the "Note to User" before Example 1.1. This edition contains several *new* example problems that incorporate PtD (Prevention through Design) discussion material as indicated on the previous page.

Fluids in the News

A set of 63 short "Fluids in the News" stories that reflect some of the latest important and novel ways that fluid mechanics affects our lives is provided. Many of these problems have homework problems associated with them.

Homework Problems

A set of 919 homework problems is provided. This represents an increase of approximately 42% more problems than in the previous edition. The even-numbered problems are in the print version of the book; all of the problems (even and odd) are at the book's web site, www.wiley.com/go/global/young. These problems stress the practical application of principles. The problems are grouped and identified according to topic. An effort has been made to include several easier problems at the start of each group. The following types of problems are included:

1) "Standard" problems
2) Computer problems
3) Discussion problems
4) Supply-your-own-data problems
5) Review problems with solutions
6) Problems based on the "Fluids in the News" topics
7) Problems based on the fluid videos
8) Excel-based lab problems
9) *New* "Lifelong Learning" problems
10) Problems that require the user to obtain a photograph or image of a given flow situation and write a brief paragraph to describe it
11) Simple CFD problems to be solved using FlowLab
12) Fundamental of Engineering (FE) exam questions available on book web site

Lab Problems—There are 30 extended, laboratory-type problems that involve actual experimental data for simple experiments of the type that are often found in the laboratory portion of many introductory fluid mechanics courses. The data for these problems are provided in Excel format.

Lifelong Learning Problems—There are 33 *new* lifelong learning problems that involve obtaining additional information about various new state-of-the-art fluid mechanics topics and writing a brief report about this material.

Review Problems—There is a set of 186 review problems covering most of the main topics in the book. Complete, detailed solutions to these problems can be found in the *Student Solutions Manual* (www.wiley.com/go/global/young).

Well-Paced Concept and Problem-Solving Development

Since this is an introductory text, we have designed the presentation of material to allow for the gradual development of student confidence in fluid problem solving. Each important concept or notion is considered in terms of simple and easy-to-understand circumstances before more complicated features are introduced.

Several brief components have been added to each chapter to help the user obtain the "big picture" idea of what key knowledge is to be gained from the chapter. A brief Learning Objectives section is provided at the beginning of each chapter. It is helpful to read through this list prior to reading the chapter to gain a preview of the main concepts presented. Upon completion of the chapter, it is beneficial to look back at the original learning objectives to ensure that a satisfactory level of understanding has been acquired for each item. Additional reinforcement of these learning objectives is provided in the form of a Chapter Summary and Study Guide at the end of each chapter. In this section a brief summary of the key concepts and principles introduced in the chapter is included along with a listing of important terms with which the student should be familiar. These terms are highlighted in the text. A ***new*** list of the main equations in the chapter is included in the chapter summary.

System of Units

This text uses the International System of Units throughout.

Topical Organization

In the first four chapters the student is made aware of some fundamental aspects of fluid motion, including important fluid properties, regimes of flow, pressure variations in fluids at rest and in motion, fluid kinematics, and methods of flow description and analysis. The Bernoulli equation is introduced in Chapter 3 to draw attention, early on, to some of the interesting effects of fluid motion on the distribution of pressure in a flow field. We believe that this timely consideration of elementary fluid dynamics increases student enthusiasm for the more complicated material that follows. In Chapter 4 we convey the essential elements of kinematics, including Eulerian and Lagrangian mathematical descriptions of flow phenomena, and indicate the vital relationship between the two views. For teachers who wish to consider kinematics in detail before the material on elementary fluid dynamics, Chapters 3 and 4 can be interchanged without loss of continuity.

Chapters 5, 6, and 7 expand on the basic analysis methods generally used to solve or to begin solving fluid mechanics problems. Emphasis is placed on understanding how flow phenomena are described mathematically and on when and how to use infinitesimal and finite control volumes. The effects of fluid friction on pressure and velocity distributions are also considered in some detail. A formal course in thermodynamics is not required to understand the various portions of the text that consider some elementary aspects of the thermodynamics of fluid flow. Chapter 7 features the advantages of using dimensional analysis and similitude for organizing test data and for planning experiments and the basic techniques involved.

Owing to the growing importance of computational fluid dynamics (CFD) in engineering design and analysis, material on this subject is included in Appendix A. This material may be omitted without any loss of continuity to the rest of the text. This introductory CFD overview includes examples and problems of various interesting flow situations that are to be solved using FlowLab software.

Chapters 8 through 11 offer students opportunities for the further application of the principles learned early in the text. Also, where appropriate, additional important notions such as boundary layers, transition from laminar to turbulent flow, turbulence modeling, and flow separation are introduced. Practical concerns such as pipe flow, open-channel flow, flow measurement, drag and lift, and the fluid mechanics fundamentals associated with turbomachines are included.

Students who study this text and who solve a representative set of the exercises provided should acquire a useful knowledge of the fundamentals of fluid mechanics. Faculty who use this text are provided with numerous topics to select from in order to meet the objectives of their own courses. More material is included than can be reasonably covered in one term. All are reminded of the fine collection of supplementary material. We have cited throughout the text various articles and books that are available for enrichment.

Student and Instructor Resources

Student Companion Site—The student section of the book web site at www.wiley.com/go/global/young contains the assets that follow. Access is free of charge with the registration code included in the front of every new book.

Video Library
Review Problems with Answers
Lab Problems
Comprehensive Table of Conversion Factors
CFD-Driven Cavity Example
FlowLab Tutorial and User's Guide
FlowLab Problems

Instructor Companion Site—The instructor section of the book web site at www.wiley.com/go/global/young contains the assets in the Student Companion Site, as well as the following, which are available only to professors who adopt this book for classroom use:

- Instructor Solutions Manual, containing complete, detailed solutions to all of the problems in the text.
- Figures from the text, appropriate for use in lecture slides.

These instructor materials are password-protected. Visit the Instructor Companion Site to register for a password.

FlowLab®—In cooperation with Wiley, Ansys Inc. is offering to instructors who adopt this text the option to have FlowLab software installed in their department lab free of charge. (This offer is available in the Americas only; fees vary by geographic region outside the Americas.) FlowLab is a CFD package that allows students to solve fluid dynamics problems without requiring a long training period. This software introduces CFD technology to undergraduates and uses CFD to excite students about fluid dynamics and learning more about transport phenomena of all kinds. To learn more about FlowLab and request installation in your department, visit the Instructor Companion Site at www.wiley.com/go/global/young.

Acknowledgments

We wish to express our gratitude to the many persons who provided suggestions for this and previous editions through reviews and surveys. In addition, we wish to express our appreciation to the many persons who supplied the photographs and videos used throughout the text. A special thanks to Chris Griffin and Richard Rinehart for helping us incorporate the new PtD (Prevention through Design) material in this edition. Finally, we thank our families for their continued encouragement during the writing of this fifth edition.

Working with students over the years has taught us much about fluid mechanics education. We have tried in earnest to draw from this experience for the benefit of users of this book. Obviously we are still learning, and we welcome any suggestions and comments from you.

Bruce R. Munson
Donald F. Young
Theodore H. Okiishi
Wade W. Huebsch

Featured in This Book

FLUIDS IN THE NEWS

Throughout the book are many brief news stories involving current, sometimes novel, applications of fluid phenomena. Many of these stories have homework problems associated with them.

Fluids in the News

Incorrect raindrop shape The incorrect representation that raindrops are teardrop shaped is found nearly everywhere—from children's books to weather maps on the Weather Channel. About the only time raindrops possess the typical teardrop shape is when they run down a windowpane. The actual shape of a falling raindrop is a function of the size of the drop and results from a balance between surface tension forces and the air pressure exerted on the falling drop. Small drops with a radius less than about 0.5 mm have a spherical shape because the surface tension effect (which is inversely proportional to drop size) wins over the increased pressure, $\rho V_0^2/2$, caused by the motion of the drop and exerted on its bottom. With increasing size, the drops fall faster and the increased pressure causes the drops to flatten. A 2-mm drop, for example, is flattened into a hamburger bun shape. Slightly larger drops are actually concave on the bottom. When the radius is greater than about 4 mm, the depression of the bottom increases and the drop takes on the form of an inverted bag with an annular ring of water around its base. This ring finally breaks up into smaller drops. (See Problem 3.22.)

CHAPTER SUMMARY AND STUDY GUIDE

At the end of each chapter is a brief summary of key concepts and principles introduced in the chapter along with key terms involved and a list of important equations.

4.5 Chapter Summary and Study Guide

field representation
velocity field
Eulerian method
Lagrangian method
one-, two-, and three-dimensional flow
steady and unsteady flow
streamline
streakline
pathline
acceleration field
material derivative
local acceleration
convective acceleration
system
control volume
Reynolds transport theorem

This chapter considered several fundamental concepts of fluid kinematics. That is, various aspects of fluid motion are discussed without regard to the forces needed to produce this motion. The concepts of a field representation of a flow and the Eulerian and Lagrangian approaches to describing a flow are introduced, as are the concepts of velocity and acceleration fields.

The properties of one-, two-, or three-dimensional flows and steady or unsteady flows are introduced along with the concepts of streamlines, streaklines, and pathlines. Streamlines, which are lines tangent to the velocity field, are identical to streaklines and pathlines if the flow is steady. For unsteady flows, they need not be identical.

As a fluid particle moves about, its properties (i.e., velocity, density, temperature) may change. The rate of change of these properties can be obtained by using the material derivative, which involves both unsteady effects (time rate of change at a fixed location) and convective effects (time rate of change due to the motion of the particle from one location to another).

The concepts of a control volume and a system are introduced, and the Reynolds transport theorem is developed. By using these ideas, the analysis of flows can be carried out using a control volume (a fixed volume through which the fluid flows), whereas the governing principles are stated in terms of a system (a flowing portion of fluid).

The following checklist provides a study guide for this chapter. When your study of the entire chapter and end-of-chapter exercises has been completed you should be able to

- write out the meanings of the terms listed here in the margin and understand each of the related concepts. These terms are particularly important and are set in color and bold type in the text.
- understand the concept of the field representation of a flow and the difference between Eulerian and Lagrangian methods of describing a flow.

BOXED EQUATIONS

Important equations are boxed to help the user identify them.

MARGINAL FIGURES

A set of simple figures and photographs in the margins is provided to help the students visualize concepts being described.

3.6 Examples of Use of the Bernoulli Equation

Between any two points, (1) and (2), on a streamline in steady, inviscid, incompressible flow the Bernoulli equation (Eq. 3.6) can be applied in the form

$$p_1 + \tfrac{1}{2}\rho V_1^2 + \gamma z_1 = p_2 + \tfrac{1}{2}\rho V_2^2 + \gamma z_2 \qquad (3.14)$$

The use of this equation is discussed in this section.

3.6.1 Free Jets

Consider flow of a liquid from a large reservoir as is shown in Fig. 3.7 or from a coffee urn as indicated by the figure in the margin. A jet of liquid of diameter d flows from the nozzle with

FLUID VIDEOS

A set of videos illustrating interesting and practical applications of fluid phenomena is provided on the book web site. An icon in the margin identifies each video. Many homework problems are tied to the videos.

4.1 The Velocity Field

V4.3 Cylinder-velocity vectors

The infinitesimal particles of a fluid are tightly packed together (as is implied by the continuum assumption). Thus, at a given instant in time, a description of any fluid property (such as density, pressure, velocity, and acceleration) may be given as a function of the fluid's location. This representation of fluid parameters as functions of the spatial coordinates is termed a ***field representation*** of the flow. Of course, the specific field representation may be different at different times, so that to describe a fluid flow we must determine the various parameters not only as a function of the spatial coordinates (x, y, z, for example) but also as a function of time, t.

One of the most important fluid variables is the ***velocity field,***

$$\mathbf{V} = u(x, y, z, t)\hat{\mathbf{i}} + v(x, y, z, t)\hat{\mathbf{j}} + w(x, y, z, t)\hat{\mathbf{k}}$$

where u, v, and w are the x, y, and z components of the velocity vector. By definition, the velocity of a particle is the time rate of change of the position vector for that particle. As is illustrated in Fig. 4.1, the position of particle A relative to the coordinate system is given by its *position vector,* $\mathbf{r}_A$, which (if the particle is moving) is a function of time. The time derivative of this position gives the *velocity* of the particle, $d\mathbf{r}_A/dt = \mathbf{V}_A$.

EXAMPLE 3.6 Pitot-Static Tube

GIVEN An airplane flies 300 km/h at an elevation of 3000 m in a standard atmosphere as shown in Fig. E3.6*a*.

FIND Determine the pressure at point (1) far ahead of the airplane, the pressure at the stagnation point on the nose of the airplane, point (2), and the pressure difference indicated by a Pitot-static probe attached to the fuselage.

■ FIGURE E3.6*a* **(Photo courtesy of Hawker Beechcraft.)**

SOLUTION

From Table C.1 we find that the static pressure at the altitude given is

$$p_1 = 7.012 \times 10^4 \text{ N/m}^2 \text{ (abs)} \qquad \textbf{(Ans)}$$

Also the density is $\rho = 0.9093 \text{ kg/m}^3$.

If the flow is steady, inviscid, and incompressible and elevation changes are neglected, Eq. 3.6 becomes

$$p_2 = p_1 + \frac{\rho V_1^2}{2}$$

With $V_1 = 300$ km/h $= 83$ m/s and $V_2 = 0$ (since the coordinate system is fixed to the airplane) we obtain

$$p_2 = 7.012 \times 10^4 \text{ N/m}^2 + (0.9093 \text{ kg/m}^3)(83 \text{ m/s})^2/2$$
$$= (7.012 \times 10^4 + 3132) \text{ N/m}^2 \text{ (abs)}$$

Hence, in terms of gage pressure

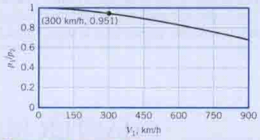
$$p_2 = 3132 \text{ N/m}^2 \qquad \textbf{(Ans)}$$

Thus, the pressure difference indicated by the Pitot-static tube is

$$p_2 - p_1 = \frac{\rho V_1^2}{2} = 3132 \text{ N/m}^2 \qquad \textbf{(Ans)}$$

COMMENTS Note that it is very easy to obtain incorrect results by using improper units. Recall that $(\text{kg/m}^3)(\text{m}^2/\text{s}^2) = (\text{kg} \cdot \text{m/s}^2)/(\text{m}^2) = \text{N/m}^2$.

It was assumed that the flow is incompressible—the density remains constant from (1) to (2). However, because $\rho = p/RT$, a change in pressure (or temperature) will cause a change in density. For this relatively low speed, the ratio of the absolute pressures is nearly unity [i.e., $p_1/p_2 = (7.012 \times 10^4 \text{ N/m}^2)/(7.012 \times 10^4 + 3132) \text{ N/m}^2 = 0.95$L] so that the density change is negligible. However, by repeating the calculations for various values of the speed, V_1, the results shown in Fig. E3.6*b* are obtained. Clearly at the 750 to 900 kmph speeds normally flown by commercial airliners, the pressure ratio is such that density changes are important. In such situations it is necessary to use compressible flow concepts to obtain accurate results.



■ FIGURE E3.6*b*

EXAMPLE PROBLEMS

A set of example problems provides the student detailed solutions and comments for interesting, real-world situations.

CHAPTER EQUATIONS

At the end of each chapter is a summary of the most important equations.

Equation for streamlines	$\frac{dy}{dx} = \frac{v}{u}$	(4.1)
Acceleration	$\mathbf{a} = \frac{\partial \mathbf{V}}{\partial t} + u\frac{\partial \mathbf{V}}{\partial x} + v\frac{\partial \mathbf{V}}{\partial y} + w\frac{\partial \mathbf{V}}{\partial z}$	(4.3)
Material derivative	$\frac{D(\;)}{Dt} = \frac{\partial(\;)}{\partial t} + (\mathbf{V} \cdot \nabla)(\;)$	(4.6)
Streamwise and normal components of acceleration	$a_s = V\frac{\partial V}{\partial s}, \quad a_n = \frac{V^2}{\mathcal{R}}$	(4.7)
Reynolds transport theorem	$\frac{DB_{sys}}{Dt} = \frac{\partial B_{cv}}{\partial t} + \sum \rho_{out} A_{out} V_{out} b_{out} - \sum \rho_{in} A_{in} V_{in} b_{in}$	(4.14)

References

1. Goldstein, R. J., *Fluid Mechanics Measurements*, Hemisphere, New York, 1983.
2. Homsy, G. M., et al., *Multimedia Fluid Mechanics*, CD-ROM, Second Edition, Cambridge University Press, New York, 2008.
3. Magarvey, R. H., and MacLatchy, C. S., The Formation and Structure of Vortex Rings, *Canadian Journal of Physics*, Vol. 42, 1964.

REVIEW PROBLEMS

On the book web site are nearly 200 Review Problems covering most of the main topics in the book. Complete, detailed solutions to these problems are found in the supplement *Student Solutions Manual*.

Review Problems

Go to Appendix G for a set of review problems with answers. Detailed solutions can be found in *Student Solutions Manual* (www.wiley.com/go/global/young).

Problems

Note: Unless otherwise indicated use the values of fluid properties found in the tables on the inside of the front cover. Problems designated with an (*) are intended to be solved with the aid of a programmable calculator or a computer. Problems designated with a (†) are "open-ended" problems and require critical thinking in that to work them one must make various assumptions and provide the necessary data. There is not a unique answer to these problems.

The even-numbered problems are included in the hard copy version of the book, and the answers to these even-numbered problems are listed at the end of the book. Odd-numbered problems are provided in Appendix L on the book's web site, www.wiley.com/go/global/young. The lab-type problems, FE problems, FlowLab problems, and the videos that accompany problems can also be accessed on these web sites.

Section 4.1 The Velocity Field

4.2 The components of a velocity field are given by $u = x + y$, $v = xy^3 + 16$, and $w = 0$. Determine the location of any stagnation points ($V = 0$) in the flow field.

4.4 A flow can be visualized by plotting the velocity field as velocity vectors at representative locations in the flow as shown in **Video V4.2** and Fig. E4.1. Consider the velocity field given in polar coordinates by $v_r = -10/r$ and $v_\theta = 10/r$. This flow

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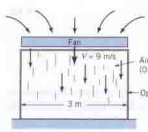
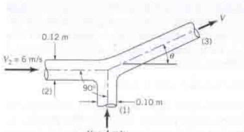


■ FIGURE P5.92

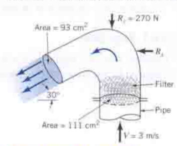
Section 5.3 The Energy and Linear Momentum Equations

5.94 Two water jets collide and form one homogeneous jet as shown in Fig. P5.94. **(a)** Determine the speed, V, and direction, θ, of the combined jet. **(b)** Determine the loss for a fluid particle flowing from (1) to (3), from (2) to (3). Gravity is negligible.



■ FIGURE P5.94

5.96 Water flows steadily in a pipe and exits as a free jet through an end cap that contains a filter as shown in Fig. P5.96. The flow is in a horizontal plane. The axial component, R_y, of the anchoring force needed to keep the end cap stationary is 270 N. Determine the head loss for the flow through the end cap.



■ FIGURE P5.96

■ **Lab Problems**

5.98 This problem involves the force that a jet of air exerts on a flat plate as the air is deflected by the plate. To proceed with this problem, go to the book's web site, www.wiley.com/go/global/young.

5.100 This problem involves the force that a jet of water exerts on a vane when the vane turns the jet through a given angle. To proceed with this problem, go to the book's web site, www.wiley.com/go/global/young.

■ **Lifelong Learning Problems**

5.102 What are typical efficiencies associated with swimming and how can they be improved?

5.104 Discuss the main causes of loss of available energy in a turbo-pump and how they can be minimized. What are typical turbo-pump efficiencies?

■ **FE Exam Problems**

Sample FE (Fundamentals of Engineering) exam questions for fluid mechanics are provided on the book's web site, www.wiley.com/go/global/young.

LAB PROBLEMS

On the book web site is a set of lab problems in Excel format involving actual data for experiments of the type found in many introductory fluid mechanics labs.

STUDENT SOLUTIONS MANUAL

The *Student Solutions Manual* for *Introduction to Fluid Mechanics* is available online at www.wiley.com/go/global/young and contains detailed solutions to the Review Problems.

PROBLEMS

A generous set of homework problems at the end of each chapter stresses the practical applications of fluid mechanics principles. This set contains 919 homework problems.

$\Delta p = 4\sigma/D$ greater than the surrounding pressure, where σ is the surface tension.

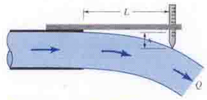
3.24 When an airplane is flying 322 km/hr at 2000 m altitude in a standard atmosphere, the air velocity at a certain point on the wing is 439 km/hr relative to the airplane. What suction pressure is developed on the wing at that point? What is the pressure at the leading edge (a stagnation point) of the wing?

Section 3.6.1 Free Jets

3.26 Water flows through a hole in the bottom of a large, open tank with a speed of 12 m/s. Determine the depth of water in the tank. Viscous effects are negligible.

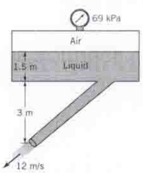
3.28 (See Fluids in the News article titled "Armed with a water jet for hunting," Section 3.4.) Determine the pressure needed in the gills of an archerfish if it can shoot a jet of water 1 m vertically upward. Assume steady, inviscid flow.

3.30 Water flowing from a pipe or a tank is acted upon by gravity and follows a curved trajectory as shown in Fig. P3.30 and **Videos V3.9** and **V4.7.** A simple flowmeter can be constructed as shown in Fig P3.30. A point gage mounted a distance L from the end of the horizontal pipe is adjusted to indicate that the top of the water stream is distance x below the outlet of the pipe. Show that the flowrate from this pipe of diameter D is given by $Q = \pi D^2 L\, g^{1/2}/(2^{5/2}\, x^{1/2})$.



■ FIGURE P3.30

3.32 An inviscid, incompressible liquid flows steadily from the large pressurized tank shown in Fig. P3.32. The velocity at the exit is 12 m/s. Determine the specific gravity of the liquid in the tank.

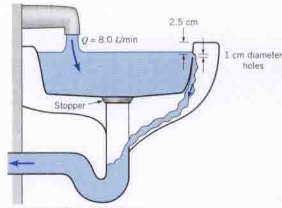


■ FIGURE P3.32

Section 3.6.2 Confined Flows (also see Lab Problems 3.84 and 3.86)

3.34 Obtain a photograph/image of a situation that involves a confined flow for which the Bernoulli and continuity equations are important. Print this photo and write a brief paragraph that describes the situation involved.

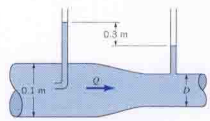
3.36 Water flows into the sink shown in Fig. P3.36 and **Video V5.1** at a rate of 8.0 L/min. If the drain is closed, the water will eventually flow through the overflow drain holes rather than over the edge of the sink. How many drain holes of diameter 1 cm are needed to ensure that the water does not overflow the sink? Neglect viscous effects.



■ FIGURE P3.36

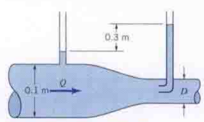
3.38 Air flows steadily through a horizontal 10 cm diameter pipe and exits into the atmosphere through a 7.0 cm diameter nozzle. The velocity at the nozzle exit is 46 m/s. Determine the pressure in the pipe if viscous effects are negligible.

3.40 Water flows through the pipe contraction shown in Fig. P3.40. For the given 0.2-m difference in the manometer level, determine the flowrate as a function of the diameter of the small pipe, D.

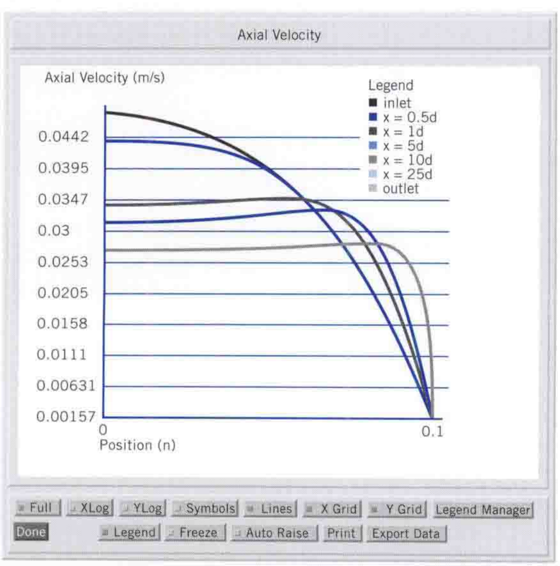


■ FIGURE P3.40

3.42 Water flows through the pipe contraction shown in Fig. P3.42. For the given 0.2-m difference in the manometer level, determine the flowrate as a function of the diameter of the small pipe, D.



■ FIGURE P3.42

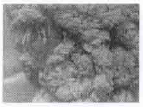


CFD AND FlowLab

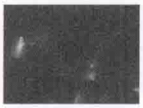
For those who wish to become familiar with the basic concepts of computational fluid dynamics, an overview to CFD is provided in Appendices A and I. In addition, the use of FlowLab software to solve interesting flow problems is described in Appendices J and K.

Index of Fluids Phenomena Videos

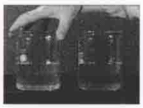
Available on www.wiley.com/college/young. In the ebook, these videos can be accessed by clicking on the video thumbnails shown below. Use the registration code included with this new text to access the videos.



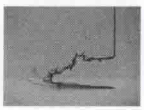
V1.1 Mt. St. Helens Eruption



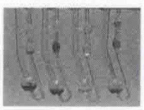
V1.2 *E. coli* swimming



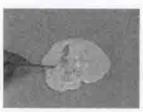
V1.3 Viscous fluids



V1.4 No-slip condition



V1.5 Capillary tube viscometer

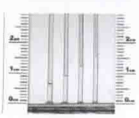


V1.6 Non-Newtonian behavior

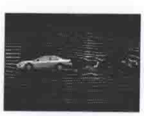
V1.7 Water balloon

V1.8 As fast as a speeding bullet

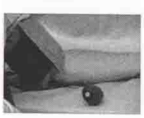
V1.9 Floating razor blade



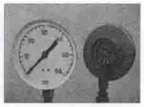
V1.10 Capillary rise



V2.1 Pressure on a car



V2.2 Blood pressure measurement



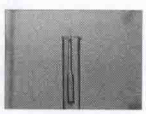
V2.3 Bourdon gage

V2.4 Hoover dam

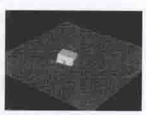
V2.5 Pop bottle

V2.6 Atmospheric buoyancy

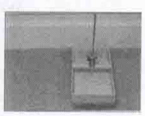
V2.7 Cartesian Diver



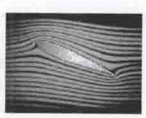
V2.8 Hydrometer



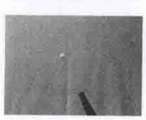
V2.9 Stability of a floating cube



V2.10 Stability of a model barge

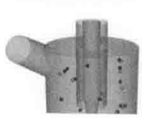


V3.1 Streamlines past an airfoil



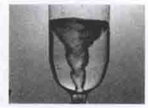
V3.2 Balancing ball

V3.3 Flow past a biker

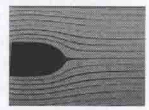


V3.4 Hydrocyclone separator

V3.5 Aircraft wing tip vortex

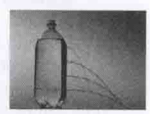


V3.6 Free vortex

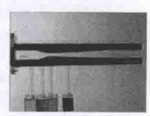


V3.7 Stagnation point flow

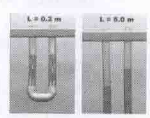
V3.8 Airspeed indicator



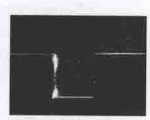
V3.9 Flow from a tank



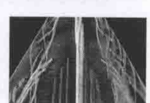
V3.10 Venturi channel



V3.11 Oscillations in a U-tube



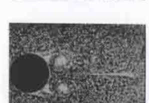
V3.12 Flow over a cavity



V4.1 Streaklines

V4.2 Velocity field

V4.3 Cylinder-velocity vectors



V4.4 Follow the particles (experiment)