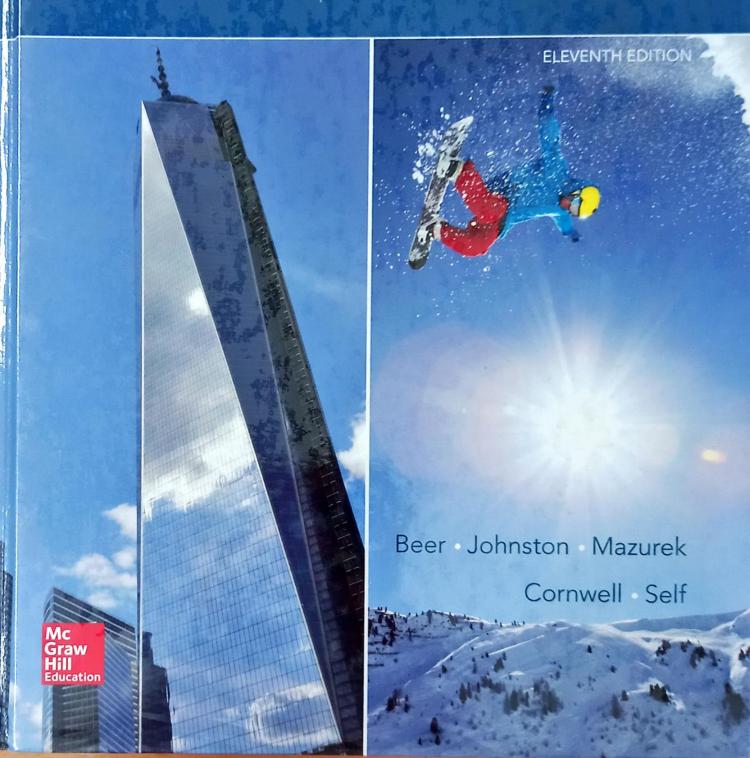
### **VECTOR MECHANICS for ENGINEERS**

# STATICS DYNAMICS



**Eleventh Edition** 

## Vector Mechanics For Engineers

### Statics and Dynamics

#### Ferdinand P. Beer

Late of Lehigh University

#### E. Russell Johnston, Jr.

Late of University of Connecticut

#### **David F. Mazurek**

U.S. Coast Guard Academy

#### Phillip J. Cornwell

Rose-Hulman Institute of Technology

#### **Brian P. Self**

California Polytechnic State University—San Luis Obispo





B

.

### VECTOR MECHANICS FOR ENGINEERS: STATICS AND DYNAMICS, ELEVENTH EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121. Copyright © 2016 by McGraw-Hill Education. All rights reserved. Printed in the United States of America. Previous editions © 2013, 2010, and 2007. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw-Hill Education, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

234567890 DOW/DOW 109876

ISBN 978-0-07-339824-2 MHID 0-07-339824-1

Managing Director: Thomas Timp

Global Brand Manager: Raghothaman Srinivasan

Director of Development: Rose Koos Product Developer: Robin Reed Brand Manager: Thomas Scaife, Ph.D. Digital Product Analyst: Dan Wallace

Editorial Coordinator: Samantha Donisi-Hamm

Marketing Manager: Nick McFadden LearnSmart Product Developer: Joan Weber Content Production Manager: Linda Avenarius

Content Project Managers: Jolynn Kilburg and Lora Neyens

Buyer. Laura Fuller

Designer: Matthew Backhaus

Content Licensing Specialist (Image): Carrie Burger

Typeface: 10/12 Times LT Std Printer: R. R. Donnelley

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

#### Library of Congress Cataloging-in-Publication Data

Beer, Ferdinand P. (Ferdinand Pierre), 1915-2003.

Vector mechanics for engineers. Statics and dynamics / Ferdinand P. Beer, Late of Lehigh University, E. Russell Johnston, Jr., Late of University of Connecticut, David F. Mazurek, U.S. Coast Guard Academy, Phillip J. Cornwell, Rose-Hulman Institute of Technology; with the collaboration of Brian P. Self, California Polytechnic State University, San Luis Obispo.—Eleventh edition.

pages cm

Includes index.

ISBN 978-0-07-339824-2

 Statics. 2. Dynamics. I. Johnston, E. Russell (Elwood Russell), 1925–2010. II. Mazurek, David F. (David Francis) III. Title. IV. Title: Statics and dynamics. TA350.B3552 2016

IA350.B3552 2010

620.1'054-dc23

2014041301

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw-Hill Education, and McGraw-Hill Education does not guarantee the accuracy of the information presented at these sites.

www.mhhe.com

00077906

10

沙

15

23

10

100

13

### **Brief Contents**

- 1 Introduction 1
- 2 Statics of Particles 15
- 3 Rigid Bodies: Equivalent Systems of Forces 82
- 4 Equilibrium of Rigid Bodies 169
- 5 Distributed Forces: Centroids and Centers of Gravity 230
- 6 Analysis of Structures 297
- 7 Internal Forces and Moments 367
- 8 Friction 429
- 9 Distributed Forces: Moments of Inertia 485
- 10 Method of Virtual Work 573
- 11 Kinematics of Particles 615
- 12 Kinetics of Particles: Newton's Second Law 718
- 13 Kinetics of Particles: Energy and Momentum Methods 795
- 14 Systems of Particles 915
- 15 Kinematics of Rigid Bodies 977
- 16 Plane Motion of Rigid Bodies: Forces and Accelerations 1107
- 17 Plane Motion of Rigid Bodies: Energy and Momentum Methods 1181
- 18 Kinetics of Rigid Bodies in Three Dimensions 1264
- 19 Mechanical Vibrations 1332

Appendix: Fundamentals of Engineering Examination A1

Answers to Problems AN1

Photo Credits C1

Index 11

### Contents

Preface xi
Guided Tour xv
Digital Resources xviii
Acknowledgments xx
List of Symbols xxi

### 1 Introduction 1

- 1.1 What is Mechanics? 2
- 1.2 Fundamental Concepts and Principles 3
- 1.3 Systems of Units 5
- 1.4 Converting between Two Systems of Units 10
- 1.5 Method of Solving Problems 12
- 1.6 Numerical Accuracy 14

### Statics of Particles 15

- 2.1 Addition of Planar Forces 16
- 2.2 Adding Forces by Components 29
- 2.3 Forces and Equilibrium in a Plane 39
- 2.4 Adding Forces in Space 52
- 2.5 Forces and Equilibrium in Space 66

Review and Summary 75 Review Problems 79

### 3 Rigid Bodies: Equivalent Systems of Forces 82

- 3.1 Forces and Moments 84
- 3.2 Moment of a Force about an Axis 105
- 3.3 Couples and Force-Couple Systems 120
- 3.4 Simplifying Systems of Forces 136

Review and Summary 161 Review Problems 166

4	Equilibrium	of	Rigid	Bodies	169
---	-------------	----	-------	--------	-----

- 4.1 Equilibrium in Two Dimensions 172
- 4.2 Two Special Cases 195
- 4.3 Equilibrium in Three Dimensions 204

Review and Summary 225

Review Problems 227

### 5 Distributed Forces: Centroids and Centers of Gravity 230

- 5.1 Planar Centers of Gravity and Centroids 232
- 5.2 Further Considerations of Centroids 249
- 5.3 Additional Applications of Centroids 262
- 5.4 Centers of Gravity and Centroids of Volumes 273

Review and Summary 291

Review Problems 295

### 6 Analysis of Structures 297

- 6.1 Analysis of Trusses 299
- 6.2 Other Truss Analyses 317
- 6.3 Frames 330
- 6.4 Machines 348

Review and Summary 361

Review Problems 364

### 7 Internal Forces and Moments 367

- 7.1 Internal Forces in Members 368
- 7.2 Beams 378
- 7.3 Relations Among Load, Shear, and Bending Moment 391
- \*7.4 Cables 403
- \*7.5 Catenary Cables 416

Review and Summary 424

Review Problems 427

### S Friction 429

- 8.1 The Laws of Dry Friction 431
- 8.2 Wedges and Screws 450
- \*8.3 Friction on Axles, Disks, and Wheels 459
- 8.4 Belt Friction 469

Review and Summary 479

Review Problems 482

### 9 Distributed Forces: Moments of Inertia 485

- 9.1 Moments of Inertia of Areas 487
- 9.2 Parallel-Axis Theorem and Composite Areas 498
- \*9.3 Transformation of Moments of Inertia 513
- \*9.4 Mohr's Circle for Moments of Inertia 523
- 9.5 Mass Moments of Inertia 529
- \*9.6 Additional Concepts of Mass Moments of Inertia 549

Review and Summary 564

Review Problems 570

### 10 Method of Virtual Work 573

- \*10.1 The Basic Method 574
- \*10.2 Work, Potential Energy, and Stability 595

Review and Summary 609

Review Problems 612

### 11 Kinematics of Particles 615

- 11.1 Rectilinear Motion of Particles 617
- 11.2 Special Cases and Relative Motion 635
- \*11.3 Graphical Solutions 652
- 11.4 Curvilinear Motion of Particles 663
- 11.5 Non-Rectangular Components 690

Review and Summary 711

Review Problems 715

<sup>\*</sup>Advanced or specialty topics

### 12 Kinetics of Particles: Newton's Second Law 718

- 12.1 Newton's Second Law and Linear Momentum 720
- 12.2 Angular Momentum and Orbital Motion 763
- \*12.3 Applications of Central-Force Motion 774

Review and Summary 788 Review Problems 792

### Kinetics of Particles: Energy and Momentum Methods 795

- 13.1 Work and Energy 797
- 13.2 Conservation of Energy 827
- 13.3 Impulse and Momentum 855
- 13.4 Impacts 877

Review and Summary 905 Review Problems 911

### 14 Systems of Particles 915

- 14.1 Applying Newton's Second Law and Momentum Principles to Systems of Particles 917
- 14.2 Energy and Momentum Methods for a System of Particles 936
- \*14.3 Variable Systems of Particles 950

Review and Summary 970 Review Problems 974

### 15 Kinematics of Rigid Bodies 977

- 15.1 Translation and Fixed Axis Rotation 980
- 15.2 General Plane Motion: Velocity 997
- 15.3 Instantaneous Center of Rotation 1015
- 15.4 General Plane Motion: Acceleration 1029
- 15.5 Analyzing Motion with Respect to a Rotating Frame 1048
- \*15.6 Motion of a Rigid Body in Space 1065
- \*15.7 Motion Relative to a Moving Reference Frame 1082

Review and Summary 1097 Review Problems 1104

16	Plane Motion of Rigid Bodies: Forces and Accelerations 1107			
16.1 Kinetics of a Rigid Body 1109 16.2 Constrained Plane Motion 1144 Review and Summary 1085 Review Problems 1087				
7	Plane Motion of Rigid Bodies: Energy and Momentum Methods 1181			
1 2 3	Energy Methods for a Rigid Body 1183  Momentum Methods for a Rigid Body 1211  Eccentric Impact 1234			
	Review and Summary 1256 Review Problems 1260			
3	Kinetics of Rigid Bodies in Three Dimensions 1264			
2	Energy and Momentum of a Rigid Body 1266  Motion of a Rigid Body in Three Dimensions 1285  Motion of a Gyroscope 1305			
	Review and Summary 1323 Review Problems 1328			
)	Mechanical Vibrations 1332			
	Vibrations without Damping 1334 Free Vibrations of Rigid Bodies 1350 Applying the Principle of Conservation of Energy 1364 Forced Vibrations 1375 Damped Vibrations 1389			
5	Damped Vibrations 1389 Review and Summary 1403 Review Problems 1408			
swer	ix: Fundamentals of Engineering Examination A1 s to Problems AN1			

Index I1

first course in mechanics should develop a student's ability to analyze and solve problems using well-understood basic principles applied in a simple, logical manner. The emphasis of the 11th edition of Vector Mechanics continues this tradition and focuses on the correct understanding of the principles of mechanics and on their application to the solving of engineering problems. New to this edition, the text employs the SMART Problem-Solving Methodology in all Sample Problems. The SMART approach is used to consistently promote a systematic approach to solving engineering problems—Strategy, Modeling, Analysis, and Reflect & Think. The presentation and methodology is intended to support students applying this approach in all assigned problems. To further support student learning, practical applications are introduced early, new concepts are introduced simply, and fundamental principles are placed in simple contexts.

Students are given extensive practice through Sample Problems, special sections entitled Solving Problems on Your Own, and extensive homework problem sets.

### **connect**

McGraw-Hill Connect® Engineering provides online presentation, assignment, and assessment solutions. It connects **IENGINEERING** your students with the tools and resources they'll need to achieve success. With Connect Engineering you can deliver assignments, quizzes, and tests online. A robust set of questions and activities are presented and aligned with the textbook's learning outcomes. As an instructor, you can edit existing questions and author entirely new problems. Integrate grade reports easily with Learning Management Systems (LMS), such as WebCT and Blackboard—and much more. Connect Engineering also provides students with 24/7 online access to a media-rich eBook, allowing seamless integration of text, media, and assessments.

To learn more, visit connect.mheducation.com

EARNSMART® McGraw-Hill LearnSmart® is available as an integrated feature of Connect. It is an adaptive learning system designed to help students learn faster, study more efficiently, and retain more knowledge for greater success. LearnSmart assesses a student's knowledge of course content through a series of adaptive questions. It pinpoints concepts the student does not understand and maps out a personalized study plan for success. This innovative study tool also has features that allow instructors to see exactly what students have accomplished and a built-in assessment tool for graded assignments.

**SmartBook®** is the first and only adaptive reading experience available for the higher education market. Powered by an intelligent diagnostic and adaptive engine, SmartBook facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments. As the student reads, the reading material constantly adapts to ensure the student is focused on the content he or she needs the most to close any knowledge gaps.

> Visit the following site for a demonstration of LearnSmart or SmartBook: www.learnsmartadvantage.com



